DEVELOPMENT OF A SOCIAL-ECOLOGICAL MONITORING FRAMEWORK TO IMPROVE RIVER HEALTH ASSESSMENT IN THE LOWER KOMATI RIVER

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A Thesis submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Doctor of Philosophy.

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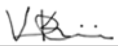
NOVEMBER 2021

DECLARATION OF PLAGIARISM

I declare this thesis is my own work and it is presented for the degree of Doctor of Philosophy at the University of the Witwatersrand, Johannesburg. It is not submitted for any other degree or professional qualification at any other learning institution.

(Candidate's Signature)



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ABSTRACT

Research attests that the degradation of rivers by multiple stressors is globally recognised as it impacts their ecological functions and supply of ecosystem services to society. However, most river health studies, emphasize ecological monitoring, with less attention on the social function of rivers and relationships between rivers and communities in their proximity. This is significant because river catchments are considered social-ecological systems and 20^{th}-century policies and definitions of river health put more emphasis on the social and ecological functions of the river. Thus this study sought to investigate how social-ecological dimensions: human and river interactions in the Lower Komati River, can be used to expand on and transform the way river health is understood and monitored by developing an integrated social-ecological framework for monitoring.

To come up with the integrated social-ecological framework, qualitative and quantitative approaches were used to explain and determine river health in the Lower Komati River. The quantitative approach was based on ecological assessments using fish and macroinvertebrates as ecological indicators. Fish and macroinvertebrates communities were sampled from six sites, between April 2018 and December 2019, and analyzed using FRAI; SASS and MIRAI respectively to assess river health. Multivariate statistical analysis determined potential drivers of the prevailing families' composition. The qualitative approach made use of community participatory mapping and key informant interviews to ascertain how river health is socially conceptualised by local communities, analyze relationships between the river and local communities and suggest how they can be used in river health monitoring.

Ecological assessments using fish and macroinvertebrate communities showed a decline in the Lower Komati's river health condition. The ecological categories, based on macroinvertebrates and fish communities, ranged from modified (D) to severely modified (E). The reference site which was historically established, based on its geographical position (most upstream), also showed that it is degraded. This presents a weakness of relying on the geographic position of reference sites to establish indicators and develop indices. In addition, the results show a lack of balance between the use and protection of the river. However, basing river health solely on ecological variables does not fully explain the root causes and social consequences of the lack of balance between use and protection. Thus, social analysis of river health based on use, relationship with the river, human experiences and contextual realities are equally necessary.

Social analysis of river health in the Lower Komati river showed that, as a result of use and experience, people have forged relationships with the river leading to place attachment and solastalgia. These concepts point to a connection or relationship between nature and society, to define what matters when identifying and monitoring river health. These two concepts emerged as useful to predict the river' health by community members who have resided near the river for more

than 10 years. The results also showed that changes in the state of the river's health and the political history of the catchment are interlinked. The waterscape concept drew attention to relations between social power and the rerouting of natural watercourses through constructed taps in the catchment. The research conceptualized that a shift in the way the river is perceived by communities led to a fragmented waterscape and biophysical transformation manifesting as increased solid waste and reduced flow. Therefore, monitoring should go beyond ecological conditions to also consider political and social-ecological relationships that influence the river's health. The research also recognized that there is constant transmission of knowledge between local communities through social learning. Knowledge transmission pathways were identified as opportunities to share locally congruent river health indicators to consider during monitoring.

Based on the ecological and social analysis, the results were interlinked to develop an integrated framework and expand the understanding of river health and improve assessment. Opportunities to interlink social and ecological dynamics in river health were identified in four areas, namely: (i) local communities' and scientific knowledge, (ii) participants' historical observation or experience and historical ecological reference data, (iii) communities' reference site framing and ecological results which show a compromise between naturalness and use, and (iv) threats to the river's ecological condition, use and social value of the river. Based on these points of convergence, a five-tier integrated river health monitoring framework was developed emphasizing what to monitor, why and where. The framework shows the importance of analyzing governance dynamics, understanding human and river relationships, active participation of stakeholders to develop social-ecological indicators, identification of social-ecological hotspots, and recognizing communities' local ecological knowledge as important traits for social-ecological river health assessment.

ACKNOWLEDGEMENTS

My greatest gratitude goes to God, for granting me the grace to succeed all the time.

I'm also indebted to the following individuals and institutions:
My supervisors; Professor Christopher Curtis, Professor Melanie Samson and Dr Gordon O'Brien for their guidance, constructive inputs and patience on repeated mistakes throughout the study.

The University of Mpumalanga for funding my studies and support, the Inkomati Usuthu Catchment Management Agency (IUCMA) for supporting the study and their staff who helped in different ways during the research. The Mpumalanga Tourism and Parks Agency (MTPA) for granting permission to conduct the study. I also benefitted immensely from Rivers of Life Programme' support during data collection with equipment and research assistants (Bayanda, Fortunate, Stacey and Colile). The study wouldn't have been possible without the inputs from different community members along the Lower Komati River, thank you to them for allowing me into their 'space'. I can never forget the passion and love they have for the river; I hope one day all their efforts as they diligently participate in the river's clean-up campaign pay off. To Marielle who edited my thesis, your input was valuable, thank you for rescuing me.

To my husband Gcina, for the support, taking care of our home and our little girl when I was swamped with work, sometimes spending days and nights with me reviewing and checking my references. To my friends, Dr Lucky Mnisi, Joanna Fatch and Dr Siphiwe Dlamini, with who I always bounced ideas, thank you for listening and always reminding me that 'I need to finish'. To my family, for the emotional support and late dad (my hype man), who unfortunately passed away at the inception of this research. Lastly, I appreciate all the sacrifices my parents made, to give us education, something they never had.

DEDICATION

To my little star ***Melo****: whose dazzling light makes everything brighter; may you be inspired to reach greater heights.*

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ACRONYMS LIST

ASPT	Average Score Per Taxon
CA	Cluster Analysis
CMA	Catchment Management Agency
CMS	Catchment Management Strategy
DWAF	Department of Water Affairs and Forestry
DWA	Department of Water Affairs
DWS	Department of Water and Sanitation
DPSIR	Driver-Pressure-State-Impact-Response
EC	Ecological Category
ES	Ecosystem Services
FRAI	Fish Response Assessment Index
FROC	Frequency-of-Occurrence
GCEE	Grassroots Communication and Environmental Education
GIS	Geographic Information System
ICEM	International Centre for Environmental Management
IUCMA	Inkomati-Usuthu Catchment Management Agency
MEA	Millennium Ecosystem Assessment
MIRAI	Macroinvertebrates Response Assessment Index
MTPA	Mpumalanga Tourism and Parks Agency
NAEHMP	National Aquatic Ecosystem Health Monitoring Programme
NGO	Non-Governmental Organisation
NPO	Non-Profit Organisation
NWRS	National Water Resource Strategy
PGIS	Participatory Geographic Information System
PESEIS	Present Ecological State Ecological Importance And Ecological Sensitivity
PCA	Principal Component Analysis
RDA	Redundancy Analysis
RHP	River Health Program
RQOs	Resource Quality Objectives
REMP	River Ecostatus Monitoring Programme
SES	Social-Ecological System
SASS	South African Scoring System
SASS5	South Africa Scoring System Version 5
TDS	Total Dissolved Solids
TL	Total Length
WWTWs	Waste Water Treatment Works

1. CHAPTER 1: INTRODUCTION

1.1 Introduction

Global freshwater ecosystems are collectively experiencing increased rates of degradation as a result of synergistic effects of multiple stressors (Wetzel, 1992), affecting biodiversity and irreplaceable ecological and social functions to nature and society. According to Vollmer et al. (2016), the degradation of freshwater ecosystems may lead to increased water insecurity and threats to biodiversity. Literature (Wichert & Rapport, 1998; Hepp *et al*. 2010; Ntshane & Gambiza, 2016) has identified population growth, increased water abstraction, decline in water quality, habitat transformation and climate change as the main threats to freshwater ecosystem biodiversity. Dudgeon *et al.* (2006); Balian *et al.* (2007) and the United Nations Environmental Programme (UNEP), (2017) describe numerous threatened globally significant freshwater ecosystems which are out of equilibrium from what is desired by humans and for ecological functioning.

According to Allan and Flecker (1993), there is increasing worldwide concern about the loss of ecosystem services, freshwater landscapes and biodiversity values. Darwall *et al. (*2011) highlight the importance of these freshwater systems for the protection of global biodiversity as they are home to 10% of global species (Balian *et al*., 2007) and are essential for human use. Thus, over the years, studies have focused on the monitoring and management of freshwaters, analysing the diverse and unique species in different habitats and ecosystems, including some of the most threatened species and ecosystems that are of greatest value to human communities (Chessman *et al.*, 2010; Russell, 2011; Tan & Beh, 2016; Tickner *et al.*, 2017; Amusan *et al.,* 2018; Rocha *et al.*, 2020). The protection and management of freshwater resources have even been prioritised in global and national programmes. The United Nations Sustainable Development Goals (SDGs) refers to the management of freshwater ecosystems through goal 6 target 6.3 which aspires to improve water quality by reducing pollution and target 6.6 to protect and restore water-related ecosystems. These SDG targets have indicators which have to be achieved at national level.

Literature in South Africa has shown that there is a continuous decline in the ecological state of South Africa's river ecosystems (Driver *et al.*, 2005; Soko & Gyedu-Ababio, 2015; Levin *et al.*, 2019; Madzivanzira *et al.*, 2020). According to the National Biodiversity Assessment of 2018, 64% of South Africa's river ecosystem types are threatened, 13% are well protected and 42% are not protected. The high percentage of threatened river ecosystems is mostly attributed to changes in hydrological regimes, pollution, habitat loss, biological invasions and climate change (Driver *et al.*, 2005). There has also been a wide research on the importance of monitoring freshwater ecosystems to maintain biodiversity. The central objective is to minimise negative human impacts on freshwater ecosystems. Ecologists and environmental practitioners have categorically called for improved science and effective application of efforts to minimise pollution (Sutherland, *et al., 2004*; McNie). According to Allan and Flecker (1993), there is increasing worldwide concern about the loss of ecosystem services, freshwater landscapes and biodiversity values. Darwall *et al. (*2011) highlight the importance of these freshwater systems for the protection of global biodiversity as they are home to 10% of global species (Balian *et al*., 2007) and are essential for human use. Thus, over the years, studies have focused on the monitoring and management of freshwaters, analysing the diverse and unique species in different habitats and ecosystems, including some of the most threatened species and ecosystems which are of greatest value to human communities (Chessman *et al.*, 2010; Russell, 2011; Tan & Beh, 2016; Tickner *et al.*, 2017; Amusan *et al.,* 2018; Rocha *et al.*, 2020). The protection and management of freshwater resources have even been prioritised in global and national programmes. The United Nations Sustainable Development Goals (SDGs) refers to the management of freshwater ecosystems through goal 6 target 6.3 which aspires to improve water quality by reducing pollution and target 6.6 to protect and restore water-related ecosystems. These SDG targets have indicators which have to be achieved at national level.

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International environmental agreements have acknowledged and incorporated varying values held by scientists and communities as important fundamentals that require pro-active deliberations and decision-making. Since the Rio Declaration on Environment and Development (1992), countries enacted legislation to apply ecological quality ideas as targets for environmental standards and to encourage the active involvement of society during implementation. According to Poff *et al.* (2016), the inclusion of society is important as a result of increasing recognition of the human dimension, where society's values must be maintained in the process of river management. These social values stress what is important to a local community, as well as what they require and want (O'Brien & Wolf, 2010). Ives and Kendal (2014) argue that social values coupled with ecological data are paramount to achieving socially acceptable and scientifically defendable environmental management outcomes. The social values portray different interests and priorities of different sectors of society in resources management (Nahuelhual *et al.,* 2016). Values have been used as key inputs in water resource management and are evidence of water resources used by societies (Mostert, 2018; Anderson *et al.*, 2019). However, the inclusion of social values is notably absent from water management efforts regarding the monitoring of river health in literature.

1.2 **Water-resource protection measures and river health monitoring in South Africa**

Over the years, there has been increasing concern about the development pressures associated with riverine landscapes. Kummu *et al.* (2012) state that more than 50% of the world's population live within three kilometres of a river. River ecosystems have been altered worldwide due to human activities which include pollution from industrial development, agriculture, water abstraction, the introduction of invasive species and alteration of riparian habitat (Malmqvist & Rundle, 2002; Baron *et al.,* 2002; Xenopoulos & Lodge, 2006; Fanaian *et al.*, 2015; Steward *et al.*, 2018; Li *et al.* 2020). The contamination of water resources with multiple stressors habitat degradation and non-indigenous species threaten aquatic ecosystem health by altering the composition of communities, biological diversity, ecological functioning and ability of ecosystems to provide ES (Mueller *et al.*, 2011; Tolkkinen *et al.*, 2016; Rocha *et al.*, 2020). The cited literature shows that these alterations pose a direct threat to aquatic ecosystems and associated endangered species for which these systems are known and human communities who depend on these ecosystems. As river ecosystems are undergoing rapid degradation and depletion, one activity that has attracted attention is the periodic monitoring of rivers to detect trends, threats and the condition of rivers.

Management and conservation actions that promote ecological monitoring of rivers have been initiated in South Africa. The River Health Programme (RHP), is a major initiative part of the National Aquatic Ecosystem Health Monitoring Programme (NAEHMP). According to Nomquphu et al. (2007), the RHP was initiated in 1994 to monitor, assess and report on the ecological status of rivers in South Africa. The programme was based on the biological condition of the river and the human activities affecting the river. Three years after establishing the RHP, the Department of Water Affairs and Forestry (DWAF) (1997) established the National Water Policy of 1997, which asserts that monitoring and assessment of water resources are critical for effective resource management and protection. Later, in 1998, South Africa's National Water Act (Act 36 of 1998), (hereafter NWA) was enacted, which prioritised the protection of water resources for their use, development, conservation and management. South Africa's NWA of (1998) and the Water Policy of (1997) reflects a holistic approach in the management of water resources in the country (DWA, 1998). This legislation advocates for a balance between the use of water resources for livelihoods and protecting the resources, whilst also promoting social equity, environmental sustainability and economic efficiency

(DWAF, 2004). The enactment of the NWA created a legal framework that embodies the principles of equity and sustainable use of water resources. The NWA also provides for monitoring and classification systems intended for the holistic protection of water resources.

Alongside the NWA and associated policies, measures have also been developed within the contexts of the National Water Resource Strategy (NWRS) to protect, monitor, develop and manage water resources (South Africa Department of Water and Forestry (DWAF), 2004). The NWRS was developed to ensure that national water resources are protected, used, developed, conserved, managed and controlled efficiently and sustainably whilst ensuring that South Africa's development priorities are achieved equitably (DWAF, 2004). Since the RHP was implemented in 1994, prior to the enactment of the NWA, according to UNEP (2017), the RHP did not fully address the cause and effect relationships for resources deterioration, as provided in the NWA. Thus to harmonise these two, the National Aquatic Ecosystem Health Monitoring Programme (NAEHMP) was established, which provided for the provisions as set out in the NWA, specifically the determination of ecological water requirements and resource quality objectives, which establish targets that must be met. The River Health Programme thus had to also evolve which led to the formation of the River Eco-Status Monitoring Programme (REMP) in 2016. The River Eco-Status Monitoring Programme (REMP) requires the use of multiple indices or tools to evaluate attributes of a river's health. These river health monitoring tools have been developed over time, to monitor the state of South African rivers (Roux, 2001; Kleynhans *et al.,* 2007; Taylor *et al.*, 2007; Thirion, 2007; Kleynhans and Louw 2008). REMP as an updated version of the assessment of river health considers the ecological status, based on the system drivers and biological responses (instream and riparian) with its foundation on the existing RHP tools. The programme's ecological classification is based on comparison and deviation from the expected natural condition of a river ecosystem (DWS, 2016). This requires the characterisation of the river's natural condition status to be compared to the present ecological conditions.

In addition, the NWRS advocates for the active participation of ordinary citizens in the management of water resources (DWA, 2013). The active participation is intended to ensure that the resource developments and their consequences are meaningful to the local population and broadens the responsibility for effective and sustainable water resource management. To foster active public participation in water resources management, CMAs (mentioned above) were established, to implement the NWA' mandate on local and regional scales and include all stakeholders in the process. The objective of a CMA is to enable the management of resources at a catchment scale with the support and participation of communities (Bourblanc & Blanchon, 2014). Most CMAs develop a Catchment Management Strategy (CMS) to guide the protection, use, development, management, conservation and control of water resources within their Water Management Area (DWAF, 2004). The CMS incorporates plans and principles that are in line with the National Water Act (Act 36 of 1998) and NWRS which relates to stakeholder participation, protection, use, development, conservation, management and control of water resources. The CMS also considers that the CMAs are mandated to constantly monitor and manage water resources within their jurisdiction.

According to Stuart-Hill and Meissner (2018), years after the proclamation of the NWA, only two CMAs are operational; Breede-Overberg and the Inkomati-Usuthu Catchment Management Agency (IUCMA). The IUCMA was the first fully operational CMA established in 2005, until 2010 when the Breede-Overberg was established (Meissner *et al*., 2017). The IUCMA manages the Inkomati Usuthu Management Area (Figure 1.1), which is a shared watercourse between Eswatini, Mozambique and South Africa.

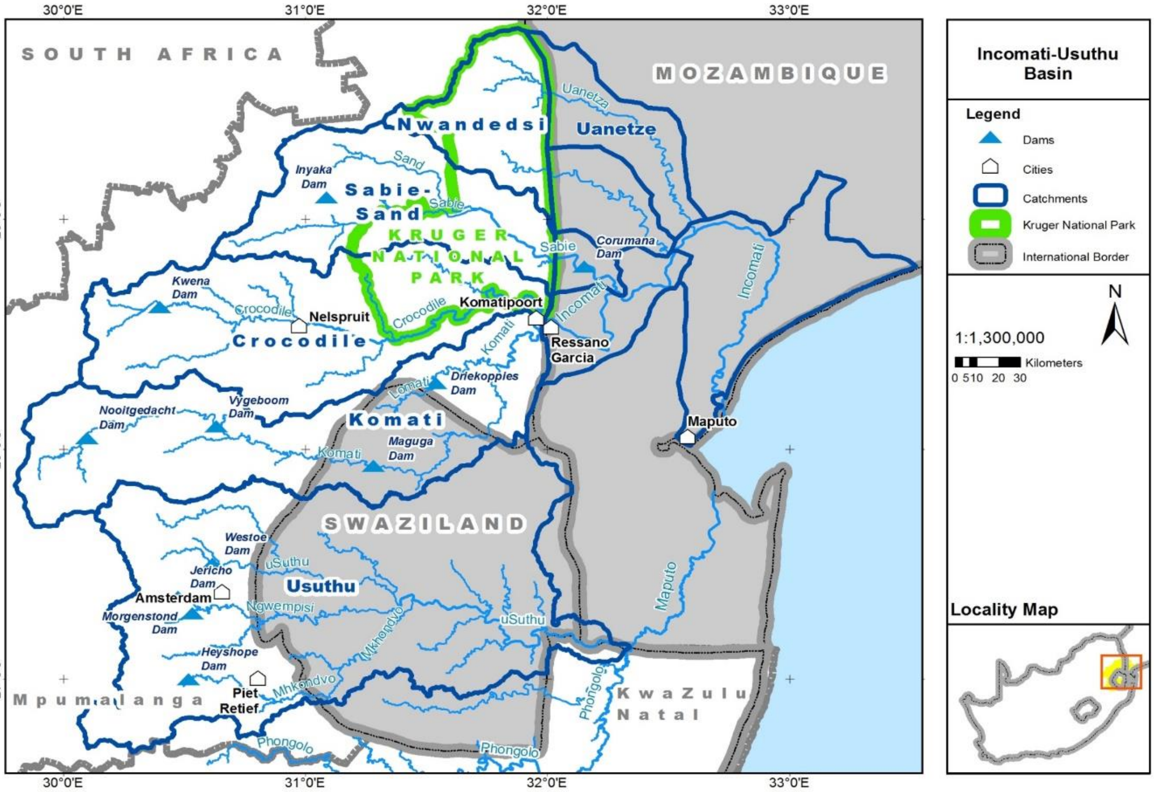

Figure 1.1 Map showing the Inkomati-Usuthu Water Management Area (Source: IUCMA, 2019)

The Inkomati-Usuthu Water Management Area includes the Sabie-Sand, Crocodile, Komati Rivers and Usuthu River which is part of the greater Pongola catchment. All of these rivers flow from South Africa in an easterly direction into Mozambique or Eswatini and then Mozambique (DWA, 2013) as shown in Figure 1.1. A transboundary agreement between South Africa, Eswatini and Mozambique has been established to co-govern and protect the shared water resource called the IncoMaputo Water Use Agreement. The Komati River contributes to the water requirement for Mozambique which makes it an important sub-catchment in the water management area to monitor.

Upon instituting the IUCMA, Anderson (2005) states that representation and participation of all stakeholders was a major concern, as these stakeholders were from different socio-economic backgrounds. The catchment management area stakeholders comprise of previously disadvantaged black communities and white commercial farming communities, conservation which complicated decision making and equitable stakeholder participation. Efforts have been made to improve stakeholder participation and decision making processes in the catchment by developing an adaptive and stakeholder-centred catchment approach to integrated water resources management and use of shared objectives to guide decision making (Rogers & Luton 2016). Despite the efforts to adopt the stakeholder-centred approach (and that the NWRS advocates for the active participation of stakeholders), the current river health monitoring framework does not provide an opportunity to actively consider stakeholders' input, decisions or demonstrate the stakeholder approach.

River health monitoring is based on a Decision Support Framework as shown in Figure 1.2, which helps resource managers to understand the causes and sources of the river's ecological condition. The framework in Figure 1.2 shows that river health is based on the river's ecological specifications as the decision support framework only considers the visual assessment of the habitat and biological responses of ecological indicators.

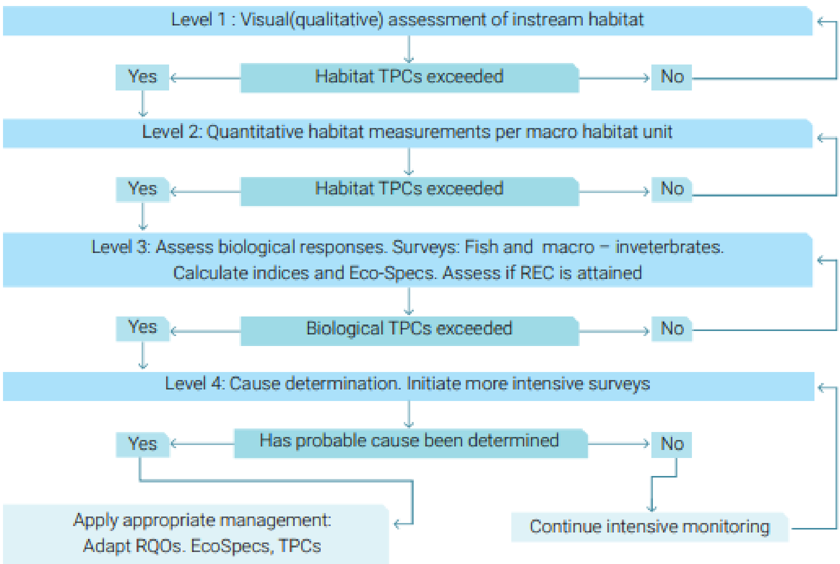

Figure 1.2 Decision Support Framework for river health monitoring (TPC = Threshold of Potential Concern, EcoSpecs = Ecological specifications, REC = Recommended Ecological Category, RQO = resource quality objectives) (United Nations Environment Programme, 2018)

1.2.1 River health monitoring in the Lower Komati River catchment; emerging challenges

Several river health and eco status studies have been conducted in the Inkomati Usuthu Catchment Management Area (Dlamini *et al.,* 2010; Roux & Selepe, 2013; van der Laan *et al.,* 2012). Results show that Lower Komati is degraded and of major concern as a result of a low Present Ecological Status compared to the other sub-catchments. Chibwe *et al.* (2012) explain that there is also water shortage in the Inkomati Water Management Area, generally experienced in the Komati and Crocodile Rivers (41 million and 149 million m^3/year, respectively). This suggests that pressure on water resources exists in the Inkomati Water Management Area not only on the health but also on the amount of water in the catchment. Reportedly, the Lower Komati River Catchment's poor ecological condition is a result of high nutrients (with associated benthic algal blooms) and faecal coliforms - a common feature affecting the use of the water resource (IUCMA, 2017). The IUCMA annual reports of 2016/2017 and 2018/2019 state that as a result of reported pollution and deteriorating river health, the Adopt-A-River and River Clean-up Campaigns were introduced, which involved communities and schools as part of RHP. The IUCMA co-opt communities as per the National Water Resources Strategy and CMS, which state that river health monitoring should be broadened to take an integrated water resource management approach that encourages community participation.

According to Griffin *et al.* (2014), based on the National Aquatic Ecosystem Health Monitoring Programme (NAEHMP) and more precisely, the RHP, the protection of water resources should be by people closest to the water resource. Through the citizen science programmes, communities periodically detect the environmental conditions, threats, changes and trends to river health to enhance and improve the environmental consciousness of the communities (Cele, 2015). According to Graham *et al.* (2006), citizen science in the RHPs was initiated for communities to learn and un-learn together, to achieve a deeper understanding of river health. The protocol for assessing the health of a river by the communities is through using the aquatic macroinvertebrates sampling method, simplified for non-scientists. Communities collected data using simple citizen science tools which include miniSASS, which uses classes of aquatic invertebrates to indicate river health status (Dickens & Graham, 2002). The tool uses invertebrates such as dragonflies, mayflies, crabs, shrimp, water snails, worms, damselflies, leeches, stoneflies and others to classify a river's health status (Peddie, 2008). The target groups for the programme are Non-Profit Organisations (NPOs), municipalities, unemployed women, youth, people living with disabilities, pensioners, school pupils, industries, catchment forums and water user associations that might not have much scientific knowledge (Cele, 2015). The aim is to motivate communities and other water users to 'protect' water resources and encourage learning and knowledge sharing as participants take part in the monitoring process. The IUCMA has conducted yearly citizen science and river cleaning campaigns since 2015, however, in 2020 due to Covid-19 regulations restrictions, the river cleaning campaigns were cancelled. The annual reports of the IUCMA (2017; 2018; 2019), indicate that there continues to be deterioration of water quality and declining river health in local rivers, despite the involvement of communities. It was envisaged that the participation of communities in the community-based monitoring practices would influence learning and sustainable utilisation of water resources in the catchment whilst improving water quality in their local rivers.

In the Lower Komati River catchment, local community groups have been involved in the monitoring of river health and clean up campaigns through the citizen science programme. The use of local communities in river health monitoring depicts social learning. Cundill and Rodela (2012:11) view social learning as taking place "through deliberate experimentation and reflective practice involving actions such as monitoring". It was envisaged that the voluntary participation of communities in river health monitoring would spread to others, to "influence and empower" communities towards addressing the declining state of water quality and health in rivers and build capacity to continually fight environmental problems (DWA, 2009). Corburn (2003) argues that during the citizen science approach, residents may use local knowledge to pressurise planners and decision-makers to act on the identified river health problems. However, the inclusion of local communities in the Adopt-A-River Programme does not explicitly depict social learning. In the current RHPs, the involvement of communities in the development of indicators to meet the requirements of stakeholders in the catchment is not clear, as communities use pre-determined scientific indicators. The indicators used in river health monitoring with communities do not consider the locally relevant indicators to measure river health. However, local input is identified as an important consideration when communities are involved in monitoring (Fraser *et al.,* 2006). Reed *et al.* (2010) argue that for social learning to take place in SESs, learning should take place through social interaction processes. Social learning by definition involves individuals and groups' collaborative learning processes through sustained interaction and deliberations between stakeholders (Leeuwis, 2002; Mostert *et al.,*2008; Wals, 2009; Reed *et al.*, 2010). This process is currently absent in river health monitoring involving local communities.

The Lower Komati River's local communities and water users' social knowledge about the river is not considered during river health monitoring, despite their residence around the catchment and the fact that they have used the local water resources for many years. During the monitoring process, rivers are graded based on ecological value (biodiversity) and management is based on the extent of resource exploitation perspectives, without considering the social dynamics in the catchment or water users' social knowledge. The Komati River Catchment was prioritised by the DWAF for a comprehensive reserve determination, as it is a hardworking and stressed river catchment (AfriDev, 2006). The social value of the Komati River catchment was determined in 2006. The Resource Quality Objectives and reserve determination process advocates for the full participation of stakeholders, thus stakeholders were involved in determining the catchment's vision and prioritising of resource units. According to Afridev (2006), the general knowledge of the area was discussed with various people with local knowledge and use of experts' information on key drivers, system operation, hydrology, tributary characteristics, habitat integrity, geomorphological characteristics, groundwater zonation and water quality zonation. However, the specific Socio-cultural Importance (SI) of the catchment's resource units was determined using a rapid assessment by experts. Despite the participation of local stakeholders in prioritising the resource units, the report (AfriDev, 2006) shows that the prioritisation process of rating the resource units was primarily based on experts opinions. Experts determined the importance of the catchment based on people's dependency on the river, use of riparian resources, subsistence fishing, use of the river for recreational purposes, as well as the cultural and aesthetic value depending on proximity to the river.

This process of resource unit prioritisation during the reserve determination in the Komati River, using the social value of the catchment does not portray full stakeholder participation as a central guiding principle. The determination of the catchment's resource units' Socio-cultural Importance (SI showed an expert-driven process with less deep insights on human experiences. Wilson and Perret (2010) explain that stakeholder centred approaches and participation in river management require deeper insights into the catchment. Walmsley *et al.* (2001) and Herrmann *et al.* (2016) also argue that residents have a good understanding of the structure and function of the rivers, thus they have accurate information about social characters that residents prefer and are familiar with in the river catchment, which can be found through active participation of the stakeholders. Therefore, one major contribution of this study is to use participatory mapping as a stakeholder approach that is local community-centred. The local communities used participatory mapping to determine what is important to them and to identify river health social indicators and sites that are locally relevant for the Lower Komati River. The main intention of using this approach is to identify important attributes for river health assessment based on community members' understanding of the area and all activities contributing to the river's health status. Participatory mapping was appropriate as it allowed participants to identify areas of social value and their important attributes, based on their experience, allowing for their full input.

Catchments have been recognised as complex social-ecological entities and authors who have studied such systems recognise social and ecological dynamics as fundamental in dealing with environmental changes (Dlamini, 2009; Cabello & Willaarts, 2015). Vollmer *et al.* (2018) explain that social-ecological entities like rivers have integrative and dynamic interactions. This can be partially explained by the several interactions (ecologically, physically, socially, and economically) that result in the need to describe a river holistically. However, studies in South African have not studied river health by understanding the river as an SES and the role of the relationships and interactions that influence or explain the river's health. Blue (2018) recognises the inseparability of physical and ecological attributes in river health and identifies holistic approaches as important in understanding river health. One can argue that the criteria which necessitate monitoring of catchments as social-ecological entities or in a holistic way are not met during the river health monitoring with communities in the Lower Komati. There is no consideration of the existing relationships and interaction of social and ecological components in the catchment during the monitoring process.

Therefore, this study attempts to understand the ecological and social components and subsystems that are present in the Lower Komati River and how these components have an influence and can be used to describe river health. The research is guided by the social-ecological and political ecology's 'waterscape' and 'socio-nature' theoretical concepts which consider that human and nature relationships lead to the formation of a 'hybrid' character of the landscape. The ecological condition and social dynamics (which include the social value) of the river, human and river relationships were evaluated, to explore how these can be integrated to improve river health monitoring and contribute to the theory of social-ecological systems (SESs). This was achieved a) by exploring social values of the river and analysis of how these may be used to derive community-relevant river health indicators, to better explain river health monitoring and b) understand how changes in river condition may affect the social values and delivery of water-related ES. The research explores the interaction between ecology and society in a river catchment and how this interaction might be used to better explain river health and improve assessment. This research led to an interdisciplinary social-ecological framework, for the analysis of the relationships between ecological and social values, applicable to a river as an SES. Such a framework is based on causal relationships between components of ecosystems and society through the use of ES and communities' knowledge.

One of the novel contributions of this research includes the interpretation of the ecological and social status of the Lower Komati River catchment and the link between these components to explain the system's river health in an integrated manner. A multi-dimensional methodology intended to analyse the ecological state of the river and how local communities and fishers along the Lower Komati River perceived and valued the river was followed. The research drew on the SES, political ecology and social learning theories when presenting the results, by unpacking and linking the ecological and social system in river health. The research took place in these general steps:

1) Characterisation of the river's ecological status using macroinvertebrates;
2) Determination of the present ecological state of the river using fish communities, their preferred physical habitat and potential stressors;
3) Identification of social values, existing human and nature relationships between the rivers and the users (communities) through a bottom-up inductive approach (participatory tools). The use of participatory tools is an important contribution to this research to elicit the knowledge, values and preferences of communities; and
4) Illustration of the incorporation of social and ecological elements of river health by developing an integrated river health assessment framework and identifying entry points for the developed framework;

1.3 **Problem Statement**

The NWA acknowledges the importance of protecting aquatic ecosystems to maintain a full suite of goods and services that human communities rely on for their livelihoods. According to Roux (1999), the RHP was initiated as a response to the need for more detailed information on the state of South Africa's rivers to protect them. Thus, during the initial implementation of the RHP, Roux (2001) states that there was an initiative to develop proper means of associating the technically oriented biomonitoring approaches (top-down) with community-based methods of conservation (bottom-up), to advance the RHP. The voluntary participation of citizens in monitoring water resources was thus established in South Africa (DWA, 2009). Griffin *et al.* (2014) argue that based on the RHP, the protection of water resources by people closest to them makes sense. The NWA also acknowledges the 'water and society' system links in rivers. Catchments have been recognised as complex social-ecological entities and authors who have studied such systems recognise local perceptions and relationships regarding ecological changes as fundamental in dealing with environmental changes (Dlamini, 2009; Cabello & Willaarts, 2015). Smith *et al.* (2016) argue that the relationship between rivers and the human population is through a social process in which human experience becomes valuable. All these studies acknowledge rivers as social-ecological units which acknowledge the river's social and ecological characteristics, composition and function.

However, despite all these acknowledgements of the linkages between rivers and society as well as social and ecological characteristics, little research has been done that recognises the social-ecological relationships and characteristics in river health monitoring in South Africa. The criteria which necessitate monitoring of catchments as social-ecological entities or in a holistic way are not met during river health monitoring with communities in the Lower Komati. The river health monitoring decision-making framework (Figure 1.2) does not explicitly integrate social and ecological indicators or acknowledge communities' knowledge and social values transparently. The current river health monitoring framework in South Africa only reflects the use of ecological indicators, methods and techniques, which exclude communities' contextual, social and cultural realities. Reed *et al.* (2008) advise that monitoring must be relevant to local people and methods used should allow full engagement of the local people to ensure effective and efficient implementation monitoring. Moreover, considering that the Lower Komati River is in proximity to local communities that are socially aware of the environment, there is a need for a river health assessment framework that will consider the communities' input and knowledge on river health and local realities. Parsons *et al.* (2016) emphasise that advancement in river ecosystem sustainability in the twenty-first century will require river assessment programmes that pay greater attention to the linkages between social knowledge and the condition of biophysical elements of river ecosystems. Therefore, this calls for more consideration of local communities' knowledge and the complexities between the biophysical environment and social dynamics and how these are linked to river health.

In the context of the need to improve the integration of the social and ecological attributes in river health assessment, this research attempts to develop an integrated framework of river health monitoring that explicitly includes connections between ecological and social elements of rivers by using the social value of the river as the link. To initiate the development of the integrated approach, the research analyses the cognitive basis of how people relate to their river ecosystem, their local knowledge, values and attitudes (Turner & Berkes 2006; Beratan, 2007; Larson *et al.* 2010; Lynam *et al.* 2012). This study focuses on social values as the most stable form of human cognition, as they can provide insight into people's differing viewpoints on how the environment changes and is experienced (Ives & Kendal 2014). Satterfield (2001) explains that values compared to attitudes are defendable, which makes them appropriate in environmental change studies. According to Brauman *et al.* (2007) and Tuvendal and lmqvist (2011), for environmental monitoring of slow-changing variables to make sense to local stakeholders, clear links to social value and their relationship to the river is necessary. Vollmer *et al.* (2018) note that indices that measure freshwater ecological health most often do not explicitly link the communities' social values and use of the river, whilst these are the main links between society and the ecological systems. To link society and ecological systems in water resources requires frameworks that incorporate multiple dimensions and dynamics that exist in the catchment cutting across hydrologic, biophysical and socioeconomic methodologies (Bunn *et al.*, 2010; Vollmer *et al.*, 2018). Therefore, in light of these studies' arguments, this research links social value and ecological river health conditions. This will be through interrogating what is valued by the different local communities and linking this to ecological indicators, to develop social-ecological indicators that are locally congruent. These will be used to expand the way river health is presented and analysed. The study findings are limited to the Lower Komati River case study boundaries in South Africa but the methodological process could be replicated elsewhere.

1.4 **Research question**

The main overarching research question for the study is: how can social and ecological attributes as well as human and river interactions in the Lower Komati River be used to transform how 'river health' is understood and assessed in South Africa? This question will be answered by combining qualitative and quantitative methods to combine social-ecological attributes of the river into a new framework for river health monitoring. To analyse the human and river relationships and interactions that exist, the SES, political ecology concepts and social learning theory will be used. The combined use of the different methods and approaches will assist in developing an integrated framework and show the interaction between ecological and social dimensions of river health.

To address the main question, the following secondary questions will be answered:

i. What is the present ecological health profile of the Lower Komati catchment system based on water quality, macroinvertebrates and fish communities as indicators?
ii. What are the controlling variables that act as drivers on the ecological river health profile of the Lower Komati?
iii. What are the various social-ecological (human-nature) relationships and local communities' shared social values that exist in the Lower Komati River?
iv. How would the existing relationships and shared social values in the Lower Komati River catchment help to improve river health monitoring?
v. What are the opportunities of integrating social and ecological systems to improve river health monitoring in the Lower Komati River?
vi. How can a suitable integrated river health monitoring framework that incorporates the social and ecological dynamics of the river be developed for the Lower Komati River?

1.5 **Aim and objectives**

This study attempts to characterise the social and ecological interactions that exist in the catchment and how these relationships may be used to improve the Lower Komati River's health assessment. This will be achieved through developing a new way of theorising and understanding river health so that the river's social value is made an equal priority to its ecological value in river health monitoring plans of the Lower Komati River catchment. Specifically, the objectives are to:

i. Determine the river health status of the Lower Komati by analysing changes in macroinvertebrate communities and water quality in the Lower Komati between 2018-2019;

ii. Assess the ecological state of the river using fish communities, their preferred physical habitat and potential stressors in the Lower Komati River;
iii. Identify social values and existing human and nature relationships between the Lower Komati River and the local human communities via a bottom-up inductive approach (participatory tools); and
iv. Illustrate the incorporation of social dynamics, social values and ecological indicators by developing an integrated river health assessment framework and identifying entry points for the developed framework.

1.6 **Research Rationale**

The study's contributions to science are theoretical and methodological but also practice-centred. The research considers the need to include the contextual relevance of indicators, communities' shared social values and human and river relationships as input to enhance understanding of river health monitoring. Shared social values are considered as outcomes from social interaction, open dialogue and social learning (Kenter *et al*., 2015). The social interaction and open dialogue will be through participatory mapping which will encourage engagement of communities in the spatial determination of areas of concern and in determining social values. The social values, relationships and local indicators will be merged with the existing ecological indicators in detecting and explaining trends, threats, changes and conditions of the river. It is hoped that the study will develop a framework of river health monitoring that is more contextually congruent as it considers social and ecological dimensions of river health monitoring in a 'hybrid' way.

Moreover, the research offers an opportunity for collaborative learning between water users and scientists. Tengö *et al*. (2014) and Nel *et al.* (2016) argue that the co-production of knowledge between stakeholders from diverse knowledge systems is an appropriate approach to building a vision and a knowledge system that is sustainable for the management of ecosystems. The research contends that this co-production can be achieved through the interfacing of local and ecological knowledge. Therefore, the study hopes to contribute to new knowledge through the development of social-ecological indicators and sampling sites that are based on social and ecological information and knowledge from local communities and scientists. The research encourages collaborative learning between the local communities and experts as it explores how social and ecological river health knowledge, indicators and monitoring points can be incorporated in integrated river health monitoring.

The thesis contributes to an integrated understanding of river health and current knowledge needs for comprehensive river health monitoring. This was through the formation of a social and ecological framework which contribute to discourses on the role of human and river relationships in water resources management. In the process of formulating the framework, locally relevant social-ecological indicators and sampling points for river health monitoring will be established. The framework and indicators have the potential to provide catchment decision-makers with a transparent decision-making framework that considers locally congruent river health indicators and sampling sites while connecting ecological health and human use of the river, which has not been adequately considered in South Africa's context. King and Brown (2010) and Finn and Jackson (2011) advocate that water resource planning and management should recognise the strongest link between humans and river resources, as human dependency on rivers has deep meaning. Finn and Jackson (2011) argue that given the contribution that rivers make to communities, aquatic habitats are highly valued. However, the social value that water users have on rivers tends to be overlooked in the scientific processes when developing river health monitoring tools. Thus, understanding the connection between local water users and rivers is essential to bringing an ecological and sustainable influence on river health monitoring required to improve the understanding of river health in the Komati River.

1.7 **Overview of chapters**

The following chapters present the different parts of the thesis. Each chapter's contents are discussed below in relation to achieving the study's aim.

Chapter 1: Introduction. The chapter highlights a summary of the research focus, problem statement, research aim, objectives and questions, as well as the significance of the study in contributing to new knowledge. The chapter further discusses the use of the social-ecological framework as the interface of ecological and social relations in river health monitoring and proposes the integration of the latter to the former.

Chapter 2: Literature review. This presents the contextual profile of the study concerning what is already known in the literature. Significant to this chapter is an in-depth overview of existing relationships between rivers and society which led to the need for river health monitoring and analysis of current river health monitoring trends and indicators. The chapter also characterises river catchments within the social-ecological framework. Lastly, the chapter discusses the social-ecological system, political ecology and social learning theories that are used to frame the study.

Chapter 3: Methodological procedures. The chapter presents mixed data collection methods used to address the research questions and objectives. Of major importance in this chapter is that the mixed methods are used to develop an integrated framework with the social and ecological elements of river health. The mixed qualitative and quantitative method approaches were important to expand the understanding of river health, complexity and history of the river catchment. More importantly, the use of the mixed-methods approach allowed the thesis to reflect on the complexity of relationships between humans and nature that are entrenched in the Lower Komati River. By so doing, the chapter also provides details about the study site, ecological sampling procedures and sampling points, the selection of research participants, the scope of the study and the selected research design. Finally, the chapter presents and discusses the validity of data concerning ethical considerations and the researcher's reflexivity.

Chapter 4: Use of macroinvertebrates as indicators of the ecological health of the Lower Komati. The chapter presents results from the ecological river health assessment of the Lower Komati River catchment using macroinvertebrates and water quality. Macroinvertebrate community structure data collected between 2017-2019 is used in the study. Two metrics or indices are used to analyse the macroinvertebrate communities, namely the South African Scoring System (SASS5) and Macroinvertebrate Response Assessment Index (MIRAI). Multivariate statistical analyses methods were used to determine the relationship between water quality and sampled macroinvertebrates. All methods establish the ecological state of the study area and macroinvertebrate community responses to environmental drivers. The multivariate statistics identify stressors which influence the macroinvertebrate community distributions. The stressors include elevated nitrate levels as a result of agricultural activities in the catchment and *E. coli*, which is detrimental to human health.

Chapter 5: Fish communities as ecological indicators of river health. The assessment of the ecological state of the river using fish communities, their preferred physical habitat and potential stressors in the Lower Komati River is discussed in this chapter. The Fish Response Assessment Index (FRAI) and multivariate statistical assessments are used to determine the responses of local fish communities to different driving ecosystem variables. Results show that fish communities respond to water quality, habitat and flow modifications as well as competition and possible predation of indigenous species by alien species. The fish communities of the Lower Komati River are influenced directly by water quality impacts, invasive species and indirectly due to habitat changes associated with flow impacts. Other stressors are flow-related from the dams, weirs, sand mining and agricultural activities within the study area.

Chapter 6: Human-river relationships and social dynamics in the Lower Komati River. This chapter presents results of how river health has been constructed in the Lower Komati as well as the relationships that exist between local communities and the river. The chapter also emphasises the role of the relationships and connections between communities and the Lower Komati River in simulating social values seen through feelings of solastalgia and place attachment (which has developed over the years within the local communities). The different connections between the Lower Komati River lead to the formation of mosaic values in the catchment. The thesis uses the waterscape and socio nature concepts to explain how the local communities have formed multiple indicators and describe observed changes in the river's health based on their relationship with the river.

The research also recognises that there is a connection between people's social values, fish and macroinvertebrates - which have been chosen as indicators in this study. This relationship comes as a result of people's reliance on fish for subsistence livelihoods; macroinvertebrates are also part of fish trophic interactions. The connection that exists between these three leads to the understanding that changes in any of them will cascade to changes in the others. Furthermore, the relationship between people and fish and other parts of the river through the provision of ecosystem services leads to the formation of values towards the different parts of the river and the constant transmission of knowledge between local communities. The transmission of knowledge supports social learning and is a reflection of the relationship between rivers and local communities. The transmission of knowledge is key to the development and sharing of locally relevant indicators of river health, as people share and learn from each other through interactions. Lastly, as a result of the relationship between the different parts of the river and the local communities, the research found that river health in the Lower Komati River is politically constructed. The political ecology approach is used to analyse how declining river health is a result of an interplay of politics in the catchment. Based on the multiple relationships that exist between people and the river, the research argues that river health is socially-ecologically constructed, thus it's monitoring also requires social and ecological approaches, which include scientific approaches, epistemic community participation and local knowledge recognition. Lastly, the research claims that river health is place-based and thus community participation and local ecological knowledge and place attachment become important attributes of encouraging the management of river health.

Chapter 7: Bringing it together: integrating social value for an integrated framework to assess river health. Building on the findings and analysis presented in Chapters 4, 5 and 6, this chapter presents the development of a comprehensive river health monitoring framework that integrates the social and ecological dynamics of the catchment. The chapter begins by providing a summary of the findings in these earlier chapters. Pockets/areas of potential integration between social and ecological dimensions of river health in the Lower Komati River are identified. This then leads to the development of an integrated river health monitoring framework. The integrative framework is based on five major steps. The framework firstly explains existing governance dynamics in the river catchment and how these can be improved to allow equal consideration of ecological and social knowledge. Secondly, it explains the social-ecological analysis of the different relationships formed by the river and human communities' interactions and how they may influence and explain the river's health. Place attachment and solastalgia are identified as major relationships that may be used to improve river health meaning and monitoring in the Lower Komati River. Thirdly, local congruent indicators that capture the social and ecological dynamics of the river are identified, emphasising the importance of local knowledge, social learning and how they may be used to improve river health monitoring. Fourthly, based on communities' social valuing of different parts of the river and observed ecological changes "social-ecological hot spots'' are identified as entry points for social-ecological river health monitoring. The last phase of the integrated river health framework is to monitor and determine the river's social-ecological health and probable root causes using communities' social value and ecological indicators, to understand the state of the river from an ecological and social point of view and come up with locally congruent management plans.

The developed framework adds to theoretical debates by emphasising that river health assessment should be characterised by social-ecological relations, indicators and monitoring sites co-designed and co-produced with local communities based on their local understanding. This research brings together SES analysis, political ecology and social learning theories to develop the framework. The integrated framework contributes to demonstrating socio-nature relationships within the Lower Komati catchment, identifying knowledge exchange and sharing facilitated through the participation of local communities in river health assessment. This process of developing the framework provides the foundation for collaborative solutions for river health by creating a platform that incorporates multiple ecological and social perspectives of river health. This has the potential to improve existing collaborations between the communities and the scientists and transform relationships between the local communities, water users, scientists and the IUCMA. The thesis also makes contributions to literature by theorising that history and politics are important in river health assessment, to explain the social-ecological change in river health, which has not been discussed in detail in previous literature.

Chapter 8: Summarising the key findings of the thesis, conclusions and the research contributions. The major conceptual dimensions produced in this study relate to the production of social values through the human-nature relationship, the role of history and politics and place attachment and solastalgia in river health. The major findings are that the river's ecological profile, communities' social values, political history dynamics, community social values, place attachment and solastalgia portray the connection between the Lower Komati River and local communities and improve river health understanding. As a result of these multiple disciplines and dimensions of river health that exist, an integrative conceptual framework was developed to capture all these conceptual dimensions. What makes the framework unique is that it allows the reframing of river health as a social-ecological concept, showing all the social-ecological pathways and relationships in the catchment that influence river health

Theoretical contributions of the study are centred on the improved understanding of river health. This thesis shows the formation of 'hybrid' social-ecological knowledge, indicators and sampling sites from social-ecological analyses of the river. This shows the involvement of communities in deciding what to measure and where, using a multidimensional methodology - a novel contribution of the study. The development of social-ecological indicators and sampling sites overcome the divide between ecological and social approaches in river health. The participatory research approach adopted by the study demonstrates the need for communities to be actively involved in all aspects of development, decision making and monitoring of river health. The active involvement of participants from the planning stage to the implementation stage is an improvement from current citizen science river health monitoring. The involvement of local communities in decision-making processes on what to monitor (indicators relevant to the communities) and where to monitor (through determining river health hotspots), opens avenues for knowledge exchange and sharing. The research shows different ways through which the communities share knowledge. Accounts from participants show that knowledge can be shared with other community members and be transferred between them.

2. CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter has three objectives. Firstly, to critically review the literature on the interrelationships between ecological and social attributes of rivers and conceptualise river catchments as Social-Ecological Systems (SESs). Secondly, to analyse literature on indices and approaches presently used in river health monitoring and critique them on their shortcomings to comprehensively integrate social and ecological attributes during monitoring. Useful literature on the theories and concepts used to guide the development of the integrated river health assessment framework is also discussed. Finally, the chapter concludes by analysing how each of the theoretical concepts used to analyse social-ecological relationships in the catchment complements each other and are useful for the development of the river health monitoring integrated framework.

2.2 Rivers and society

Different scholars have conceptualised society in different ways. According to Greenwald (1973), society was conceptualised by Durkheim in 1912 as a product created by different individuals' actions and wields a strong social force on those individuals. The conceptualisation was based on the idea that what makes a society is not just the existence of groups of individuals but the place occupied, movement and how they conceive themselves. These individuals are aware of each other's existence as beings, as well as their collective consciousness in society. Lee (2000) and Luhmann (2000) defined society not as a mere group of individuals but with communicative ability. The early scholars' definition of society shows that it is not just individuals but there is a network of social relationships and interrelation. These relationships and networks are society's driving force.

In the 1970s, two early scholars in sociology (Riley Dunlap & William Catton) called for a model shift, which brought nature into the sociological analysis (Goldman & Schurman, 2000). The scholars recognised nature not as a novel variable in sociology but as inseparable from society. To emphasise the inseparability of nature and society, Spaargaren (2000) explains that social practices, shape the interaction between society and nature on a routine basis. This shows that people exist in nature as agents of social relationships that exist within themselves and with nature (Stehr, 2015). Stehr's (2015) main assertion is that nature is socially constructed and deeply embedded within society. As a result of increasing environmental problems that threaten nature, there is now growing literature analysing the relationships between human societies and nature (Nisbet & Zelenski, 2013; Seymour, 2016). These studies seek to understand the role of the relationships in shaping the state of the environment. Based on the above conceptualisation of the relationships between society and nature, the thesis will identify and analyse river- and societal relationships and analyse their contribution to river health.

Rivers provide water, which is regarded as the world's most essential natural resource. However, rivers are also one of the most intensively modified ecosystems. Literature shows that due to the proximity of rivers and society, many river ecosystems are prone to human activity stressors, which render rivers, less efficient to provide goods and services (Rapport *et al.*, 1998; Pollard *et al.,* 2011). According to Ashmore (2015), society and river's relationships have resulted in complex SESs. Rivers are threatened by human activities, which alter their integrity and functions and may result in a biodiversity crisis (Elosegi *et al.,*2010; Elosegi *et al.*, 2017 & Singh & Saxena, 2018). Human communities have shaped the physical structure, spatial and temporal distribution of freshwater resources and function of the ecosystems in the environment (Ormerod *et al.*, 2010; Vörösmarty *et al*., 2010). When assessing the global threats to water and biodiversity, Vorosmarty *et al.* (2010) found that nearly 80% of the world's population is exposed to high levels of threats to water security. The authors, further state this is a result of increased water degradation of freshwater ecosystems and the services they provide. The study also shows that the rivers' integrity range is thereafter created, which ranges from pristine conditions to severe disturbance of the river ecosystem. Therefore, efforts to identify parts of the river that have been impaired and require protection have been initiated worldwide (Rivers-Moore *et al.,* 2007). Norris and Hawkins (2000) state that the protection, maintenance and restoration of 'healthy' rivers have become important to determine their integrity, which takes place through river health analysis.

2.3 River health meaning

Before one can debate the meaning of river health it is important to differentiate between river ecostatus, river integrity and river health. Different authors have used these concepts interchangeably whilst some have argued that they are too different to be interchangeable. Thus it is imperative that this thesis differentiates between these concepts and explain why "health" has been chosen over the other terms. Karr (1999) distinguishes aquatic ecosystem integrity from health and relates integrity to the natural processes, structure, dynamics, functions, which all support biota and are maintained with minimal human influence. The author further defines ecosystem health based on the system' ecological condition and its ability to sustainably supply goods and services required by humans. Peng *et al.* (2007) define ecosystem health based on the systems' vigour, organization, resilience, and ecosystem service functions to ensure the sustainability of human and socio-economic development. Integrity according to these authors is based on changes in biophysical conditions and set environmental criteria. Ecological status is described as the state of a water body, which is characterized and established through measuring the quality of ecological elements (Cancela *et al*., 2009). The Water Framework Directive (WFD) also described ecological status based on the state of ecological and biological indicators which include macroinvertebrates and fish fauna. The definitions of ecological status are mostly concerned about the biophysical quality elements of an ecosystem. From the definitions of the three elements, the main distinction is that ecosystem integrity is only concerned with the system's biophysical processes and structure, health is more concerned with ecological structure, functions and the provision of ecosystem services whilst ecostatus is more on the quality of the biophysical condition of an ecosystem. This shows that integrity and ecostatus only consider biophysical traits and their quality and ecological function whilst health considers biophysical and social traits of an ecosystem. Karr (1999) identified ecosystem health as having double meaning based on ecological vigour (ecological function) and ecosystem services supply (social function). This shows that ecosystem health is more comprehensive as it considers the two functions of a system. Based on these arguments, the thesis will consider the use of river health. This is mostly because the definition of river health is rooted in meeting the social and ecological functions of a system and the thesis looks at ways of integrating social and ecological traits of a river in assessing river health comprehensively. Odume and de Wet (2019) argue that health has gained acceptability amongst ecologists, policymakers, and resource managers and has been used widely to explain river' conditions, Although river health has been argued to consider social and ecological functions, it is important to also trace the genesis of river health meaning and how it is presently measured.

The meaning of river health, river assessment procedures and what is to be measured, has been subject to several scholarly debates with some authors considering it as an entirely ecological concept and some arguing that it has social and ecological traits (Karr, 1999; Norris & Thoms, 1999; Quigley *et al.,* 2001; Burnett *et al.*, 2006; Deng *et al.,* 2015). The literature shows that; river health meaning is complex due to the competing interests of multiple stakeholders. Over the years, the advancement of multiple river health definitions is all dependent on the authors' objectives and discipline. Ecologists have defined river health as a strictly biophysical and ecological concept. Norris and Thoms, (1999) associate river health with the diversity of species; that a healthy river has diverse species, which focus on the importance of biota and ecological values. Harris and Silveira (1999) and Norris and Thomas (1999) base the definition not only on species diversity but also on the physical, chemical and biological attributes of a river to match the natural condition at all scales. All these definitions are ecological interpretations of river health, with more emphasis on biota and ecosystems as the most important parts of river health.

With further understanding of the traits and functions of the rivers, the definition of river health expanded to include socio-economic variables. Authors advanced river health as not only ecologically-based but considered the complex notion that it is influenced by social, political and scientific elements. Suter (1993); Wicklum and Davies (1995) contend that river health based on biophysical properties is narrow, as it only considers one function of a river whilst river health is a 'value-laden concept', thus science alone may not suitably explain it. Karr (1999) reports that applying the value concept to explain the health of rivers is only logical as their management now includes social and biological variables. Odume and de Wet (2019) argue that the most used biophysical approach which considers the ecological component is insufficient as it does not consider the integrative nature of water management. Groenfeldt and Schmidt (2013) advocate for a holistic view of river health, where social and biological components should be assessed and evaluated to determine what is acceptable or not.

Meyer (1997) suggested the inclusion of social values in defining and protecting river health as rivers are rooted in ecology combined with human values. Regier (1993) and Rapport *et al.,* (1998) affirm that in defining any ecosystem's health it is crucial to also consider the human uses and amenities like goods and services derived from the system. Horwitz *et al.* (2001) support the 20th -century studies by arguing that the health of an ecosystem is more than just its biodiversity but its vigour, organisation (structure, components) and resilience. Thus, these authors conclude that the assessment of the 'health' of any ecosystem is incomplete without including all social and ecological functions. Human activities alter aquatic ecosystem integrity, resulting in the ecosystem being in a particular health condition. According to Odume and Wet (2019), science can provide evidence on the magnitude, frequency and state of changes in aquatic ecosystems, however, society determines acceptable alteration (Su *et al*., 2010). The judgement is based on whether the resultant ecosystem health condition is sustainable to either support the area's biophysical structure, function and processes or ability to supply ecosystem services.

In as much as the authors in the previous section highlighted that river health is associated with environmental and societal functions, Bennett (2002) expands and explains that the social function depends on the social background of the catchment. Vugteveen *et al.* (2006), Changming and Xiaoyan (2009) and Li *et al.* (2013) allude that river health considers the broader context of a river system which includes its societal function, sustenance of the main processes and providing services as per the system structure. All its social and natural functions can be balanced or compromised in terms of socio-economic and environmental values associated with the river (Li & Liu, 2009). Thus, river health is a reflection of catchment processes, which have consequences on the delivery of services provided by the river (Parker & Oates, 2016). Vugteveen *et al.* (2006) define river health based on how catchment processes have a direct influence on it, by considering ecosystem health and economic and social services systems in the catchment. The authors showed that the river's health is about the system's ability to deliver water-related ES, sustainably and equitably, at the catchment scale, thus linking the ecological and social function. The authors considered river health from a system perspective that encompasses ecological and social domains, on which ecosystem health is dependent. However, analysis shows that in as much as river health is considered from a system perspective, the study did not show how the river's ecological and social domains intersect considering the socio-nature of the catchment.

Comparing the earlier and latest studies, the latter shows that river health is an environmental problem with social and ecological dimensions and scales of analysis, whilst the earlier definitions narrowed it to only ecological species and did not consider the river's social function. These latest studies show that a river's health is based on how well it performs its social and natural functions and the competing interests of multiple stakeholders in river catchments. Considering the latest river health definitions and unique geographical nature of most South African catchments (which have local communities in proximity who rely heavily on the catchment), it is important to consider the ecological, societal and political dimensions of river health. Moreover, river catchments have been considered as SESs, thus it is important to consider the river health definition that shows the co-importance of multiple social and ecological functions. Thus, this research will theorise river health guided by what is important and valued in the river catchment by considering its locally relevant social and ecological functions. Odum and deWet (2019) argue that value judgement is important to define ecosystem health conditions, as it infuses all aspects of the use and protection of aquatic ecosystems.

The research draws inspiration from Palmer *et al.* (2005), who highlight that endpoints to river health are not universal but suggest a 'guiding image' be used to define valuable variables; for example, economic, ecological and in a state possible at the specific river catchment. This is affirmed by Li and Liu (2009), who state that the standards adopted for a healthy river are determined according to the requirements to maintain the river's functions in a balanced way. This means that river health in this research will be based on determining specific social and ecological endpoints and values in the Lower Komati River and work towards bringing them together to determine the river health condition.

2.4 River health assessment and monitoring indicators

River health assessment approaches and variables have been used to determine the level of river health. Assessing a river's health entails an in-depth understanding of the condition of the river-ecosystem, anthropogenic and natural stressors using indicators that best measure the river's health (Anwar Sadat *et al*., 2020). According to Orians and Policansky (2009), Jia and Chen (2013) and Singh and Saxena, (2018), authors offer different definitions of indicators. Smyth and Dumanski (1993) and Gallopín (1997) define indicators from an environmental point of view and state that these are traits that reflect an environmental position, changes and trends with set goals and targets. This is necessary to provide early warning information or anticipate future conditions and trends. Yli-Viikari (1999) explain that indicators refer to measured or observed properties, that predict or show anticipated results depending on the assessment. In principle, the reviewed literature shows that indicators are sensitive to changes over time. Therefore, a well-designed river health assessment should consist of indicators that are sensitive to any changes in the condition of the system.

Depending on the attributes measured, indicators may be qualitative or quantitative. Gallopin (1997) explains that qualitative indicators are collected through observations or descriptions, based on people's judgments, whilst quantitative indicators are measurable data such as numbers and ratios. Both qualitative or quantitative indicators can measure or detect change/trends directly or indirectly. Singh and Saxena (2018) explain that direct indicators indicate a change precisely, without considering related measures to describe them; for example, the number of fish recorded will be a direct indication of any change. However, indirect indicators demonstrate change where direct measurements are not practicable (Woolsey *et al*., 2007). This is mostly in cases where it is difficult to monitor or directly measure, thus a proxy indicator may be easier to monitor; for example, phosphorus indirectly measures (indicates) potential excessive plant growth.

Different studies advanced the use and choice of indicators in different river systems. Over the years, different river variables have been used as indicators to monitor river health and determine environmental changes, the effectiveness of management and as warning signals for future ecological shifts (Rapport *et al.*, 1998; Vugteveen *et al.,* 2006; Vollmer *et al.*, 2018). In most cases, indicators in river health monitoring focus attention on areas sensitive to environmental changes and management actions. The use of indicators during river health assessments assumes that their presence-absence signals changes in the system's health. Boulton (1999) explains that indicators can be used to identify a system's deviation from normal values, thus indicators chosen should be sensitive to such deviations. MacDonald and Niem (2004) argue that indicators can be used as early-warning signs of ecological problems and as a gauge for ecological resources patterns. Muñoz-Erickson *et al.,*(2007) recognise indicators as useful in detecting stressors in ecosystems and social conditions by combining large amounts of information. Not only are indicators used to determine deviations and threats, but they can also be used for management purposes. According to Rapport *et al.* (2013) and Poe *et al.* (2014), indicators assess ecosystem health in protected and managed ecosystems for environmental planning in both ecological integrity and societal goals. These indicators communicate and identify management goals and objectives for the ecosystem. This means that the selected indicators are based on their criteria for the development goal and intended use. Singh and Saxena (2018) emphasise that the most important thing in river health monitoring is the selection and measurement of the indicators, which reflect the purpose of the assessment goal. That means that how indicators are selected is vital to measuring the value of the information required. The selected indicators aid in providing specific information as per the intended objective of the assessment.

Several river health monitoring studies have used indicators to determine river health conditions. These studies have used different organisms as singular or coupled indicators which include; fish assemblages, macroinvertebrates, diatoms, protozoans and zooplankton (Gratwicke *et al.*, 2003; O'Brien *et al.*, 2016; Levin *et al.*, 2019; Krupa *et al*., 2020) to determine river health condition. These studies base this on the notion that the specific species are confined to specific parts of the river and if monitored over time can determine the river condition. However, Lindenmayer and Likens (2010) and Siddig *et al.* (2016) argue that a single indicator may not reflect the complexity of the environment and its selection may not reflect the river's overall health condition or characterise the entire system effectively. Thus, composite indicators which incorporate the multiple aspects of a chosen ecosystem have also been explored in numerous studies. Several authors (Maher et al., 1999; Quigley *et al*., 2001; Vugteveen *et al.*, 2006; Vollmer *et al.*, 2018) have used multiple indicators that range from different aspects of the physical and chemical habitat to the biological features of the inhabitants to determine river's health. These indicators offer a composite understanding of the river's condition which entails the assemblage structure of taxonomic groups and the physical and chemical habitat that determine the distribution of these groups. In that way, the river's health is comprehensively assessed.

River health studies conducted in different parts of the world have used ecological indicators and indices suitable for local conditions which have heightened the prioritization of biota and ecological structure of a river system (Simpson & Norris, 2000; Parsons *et al.*, 2002). However, according to Chambers and Messinger (2001), a few are rigorous and have been effectively used in different parts of the world to determine disturbances and river health of different rivers. The River Invertebrate Prediction and Classification System (RIVPACS) is one of the most frequently used river health assessment indices in Europe (Clarke *et al.* 2003). This index uses a rapid assessment method to predict the rivers' ecological health by comparing macroinvertebrates at pristine and present conditions (Herbst & Silldorff, 2006). RIVPACS relies on the existence of high-quality reference sites, with pristine conditions to compare with collected data. These pristine sites are selected on short river stretches within the study areas.

The Australian River Assessment System (AusRivAS) is another robust index, commonly used to determine the health of rivers in Australia (Parsons *et al.,* 2002). The AusRivAS system is based on comparing observed and expected aquatic biota assessed from designated reference sites (Simpson & Norris, 2000; Parsons *et al.,* 2002). AusRivAS was adapted from RIVPACS but configured for use in Australian rivers (Simpson & Norris, 2000). Both these indices use aquatic macro-invertebrate fauna to predict the aquatic state of a site. AusRivAS and RIVPACS indices have been criticised by Chessman (2021) for lack of quantified and geographically variable criteria to be used in other settings and describing river health without considering the riparian zone integrity and major point sources of pollution which might interfere with the river's health condition. Thus, these indices might not be suitable to determine the effect of pollutants or human activities on river health or its indicators. Secondly, although the mentioned river health monitoring indices have been extensively used, they rely on the knowledge and extensive site-specific reference conditions to effectively determine disturbances to the rivers. Thus these indices would not be suitable for direct use in South Africa as the availability of data (macroinvertebrates and fish species) may be unique per region. Thus, it will need to be configured to South Africa geographical setting to match the reference data for the region. Some taxa and species might not be available in South Africa for comparisons

Another commonly used index to determine river health is the Index of Biological Integrity (IBI) which uses several biological indicators including fish and macroinvertebrate communities and attributes from reference data, and comparing it to the sampled data (Paller, 2001; Selego, *et al.* 2012; Kim & An, 2015). Some studies used the IBI to quantify the biological conditions of fish and macroinvertebrate communities in different rivers in the United States. The studies were based on macroinvertebrates at a family level, fish species and guild metrics which were all used to indicate assemblage and ecological condition of water bodies. Kim and An (2015) reported that the main shortcoming of the IBI index is that it does not cover the physical habitat conditions and chemical pollution, whilst other studies (Zedková *et al.,* 2015; Ruaro *et al.,* 2016; Gál *et al.,* 2020) show that habitat and water quality attributes have a major influence on the biota assemblage. Thus the IBI index would not be suitable for river health studies, as South African studies have shown that human activities and habitat conditions are responsible for the state of biotic assemblages and river health (Odume & Mgaba, 2016; Dalu & Chauke, 2020). Thus an index that takes into consideration water quality and habitat conditions would be important.

Benthic diatoms have also been widely used as indicators to assess water quality in lotic ecosystems (Kahlert & Gottschalk, 2014; Moresco *et al.,*2015; Tan *et al*., 2017). However, these diatom-based indices are confined to countries where they were developed, as they only determine species in that geographic region. Waterbirds have also been used to determine long-term environmental change in freshwater ecosystems in different studies (Thapa & Saund, 2012; Kingsford *et al*., 2020) In these studies, historical waterbirds data is used to compare with collected data. The waterbirds are used as key indicators of freshwater ecosystem change as different groups reflect food availability (e.g. piscivores group is associated with fish). Using waterbirds as river health indicators is not widely adopted, since they require expert knowledge and experience and these birds have to be observed over a long period, thus cannot give immediate results which is often needed in river health assessments.

Table 2.1 Summary of global index and indicators for river health monitoring

Index	**Indicators**	**Purpose**	**Geographic area used**
Australian Rivers Assessment System (AUSRIVAS)	aquatic macroinvertebrates	predict the aquatic macroinvertebrate fauna expected to occur at a site in the absence of environmental stress and compares with expected aquatic biota from reference sites	Australia and configured for other specific geographic areas
River Invertebrate Prediction and Classification System (RIVPACS)	macroinvertebrates	predict the rivers' ecological health by comparing macroinvertebrate at pristine and present conditions	Europe
Index of Biological Integrity (IBI)	benthic macroinvertebrate and fish	quantify the biological conditions of fishes and macroinvertebrate communities	United States
Diatom Biological Index (IBD)	Benthic diatoms	based on 209 key species showing different pollution sensitivities	France
Trophic Diatom Index	Benthic diatoms	diatom composition is compared to historical composition	England & Wales
Waterbirds surveys	Waterbirds	key indicators of freshwater ecosystem change as different groups reflect food availability	Australia & Nepal

In South Africa, locally relevant river health monitoring programmes have been developed and they use several sets of ecological indicators as representative of the wider ecosystem health (Roux*, et al.,* 1999). Most of the river health monitoring studies have specifically used water quality, fauna and habitat condition components as biological indicators of ecosystem health, as shown in Table 2.2. The prevailing conditions of a river are assessed based on the biophysical variables used as indicators. Different studies have used riverine organisms as ecological indicators, ranging from fish assemblages to macroinvertebrates (Gratwicke *et al.*, 2003; de la Rey *et al.*, 2004; AfriDev, 2006; Holeck *et al.*, 2008; Dlamini *et al.*, 2010; Rivers-Moore, 2012; Agboola, *et al.,*2019). These ecological indicators are regarded as responders and are paired with drivers, for example, chemical and physical water quality variables, and riparian vegetation analyses to explain the state of the river (Friberg *et al.*, 2011; Levin *et al.,*2019). Such responses are taken as integrated indicators of the state of the biotic and abiotic variables representing stream health (Karr,1999; Bonada *et al.*, 2006). The use of integrated ecological indicators and drivers is based on the idea that biotic communities respond to changes in habitat and water quality due to anthropogenic disturbance.

Over the years, macroinvertebrates have been widely used as biological indicators (Day, 2000; Chessman *et al.,* 2010; Agboola, 2017; Dalu & Chauke, 2020; Koehnken *et al.,* 2020) as they are better established in lotic systems. Macroinvertebrates are most preferred because they are usually confined to parts of the river where physical and chemical conditions are suitable. This means that they can reflect any changes in river conditions. Kenney *et al.* (2009) highlight that this is because of their wide presence in most streams, they are fairly diverse, with relatively short lifespans and their differences in tolerance to pollutants and other aspects of water quality make them a preferred choice in river ecological health studies (Anwar Sadat *et al.,* 2020). Macroinvertebrates are suited for river quality assessment and copious data exists on family levels which are widely used in river and ecosystem health studies. The wide variety of data and studies from international and local studies using macroinvertebrates (Cooper *et al.,* 2006; Odume & Mgaba, 2016; Dalu & Chauke, 2020) makes them the most preferred indicators. Thus, their composition and abundance are mostly used to indicate the overall ecological state of the water resource, making their diversity a good measure of the health of ecosystems.

Riverine invertebrates have various habitat preferences and are predisposed to different disturbances (Cooper *et al.,* 2006; Chessman *et al.,* 2010; Rocha *et al.,* 2020). The macroinvertebrate assemblage present at any site is dependent on prevailing water quality, habitat change and seasonal variability (Gyedu-Ababio & van Wyk, 2004; Dlamini *et al.*, 2010; Gál *et al.*, 2020). According to Day (2000), it is important to evaluate how changes in habitat integrity might affect invertebrate distribution. Dale and Beyeler (2001) support the argument that habitat conditions can provide crucial information on the structure, function and composition of the ecosystems. Therefore, macroinvertebrate indices have been adopted for the analysis of habitat integrity in most comprehensive river health studies. These indices incorporate various characteristics of the chosen ecosystem, based on aquatic biota and habitat integrity as indicators of ecological conditions.

The South African Scoring System Version 5 (SASS5) and MIRAI for macroinvertebrates are two methods that have been widely used to determine river health in South Africa using macroinvertebrates as shown in Table 2.2. Macroinvertebrates are collected and identified to family level using the SASS5 method, to indicate water quality impairment and overall river health (Dickens and Graham, 2002). The SASS5 method describes the river's present health condition by enumerating all the collected families and determining their tolerance to environmental stressors. MIRAI uses data collected through SASS5 to explain a habitat-based, cause-and-effect foundation and interpret the deviation of the macroinvertebrate community structure from the reference state (Thirion, 2007; 2016). From the collected data, the river's health is determined by incorporating the ecological requirements of macroinvertebrate assemblages in each site and relating these to flow modifications, stream habitat structure, water quality modification, connectivity and seasonality. After considering these ecological requirements, MIRAI then classifies the river's ecological state based on a six-point scale, which ranges from 'A' (pristine) to 'F' (critically modified) (Agboola *et al.,* 2019).

Fish have been effectively used as indicators to determine aquatic ecosystem' well-being (Das *et al.*, 2013; Herman & Nejadhashem, 2015; Evans, 2017; Levin *et al.,* 2019). Fish are preferred indicators as they are functionally diverse and represent a variety of habitat use; they are also sensitive and respond differently to various environmental stressors (Wichert & Rapport, 1998; Levin *et al*.,2019). Jia and Chen (2013) state that fish species' most useful traits are that they live long, are mobile and can reflect integrated effects of stressors over longer spatial and temporal scales. Different fish communities found in different river reaches reflect the long-term health of a system and well-being of the reaches as they are resident in these reaches (Singh & Saxena, 2018). Various fish species (communities) have been used as indicators of ecosystem well-being and to identify environmental stressors in different river reaches (Kwak & Peterson, 2007). Their known preferred habitat and intolerances reflect the prevailing environmental conditions. As a result of their known and predictable responses to most anthropogenic disturbances (as well as their longevity), fish communities have been successfully used as indicators of ecosystem well-being (Gao *et al.*, 2010). Since the environmental requirements and life history of most fish species are well studied; therefore, the presence or absence of species can be easily interpreted.

In South Africa, the Fish Response Assessment Index (FRAI) is a widely used method, that assesses the ecological state of the country's aquatic ecosystems using freshwater fish assemblages (Kleynhans, 2007) as shown in Table 2.2. FRAI assesses the response of freshwater fish species through their occurrence to the condition of the habitat (Kleynhans, 2007). FRAI is based on fish sample data and habitat data recorded at that time and compared to historical data from assumed natural conditions. Fish communities are used to assess the well-being of an ecosystem and habitat variables (Kwak & Peterson, 2007; Evans, 2017; Levin *et al.,* 2019). To effectively use FRAI and evaluate the derived response of species metrics to habitat changes, knowledge of fish species and their ecological requirements is important (Kleynhans, 2007).

As already discussed, aquatic macroinvertebrates and fish' presence can be dependent on habitat conditions which include the riparian zones (Dlamini *et al.,* 2010; Gál *et al.,* 2020). Thus it is important to also measure the riparian zone's condition to explain available fish and macroinvertebrates' assemblages in river health studies. The Vegetation Response Assessment Index (VEGRAI) was developed in South Africa to assess the riparian vegetation condition (Kleynhans *et al.,* 2007). Kleynhans *et al*. (2007) explain that VEGRAI, in river health studies is used to determine features and characteristics of the river and its riparian areas. The VEGRAI is an index that uses different metrics to describe the ecological status of riparian vegetation. The VEGRAI index scores range from 0 (critically modified) to 100 (natural indigenous) (Kleynhans *et al*., 2007). According to Kleynhans *et al.* (2007), there are five levels of this index which increase in the level of detail required to execute them. The first level is a desktop method and the second level is a rapid method. Level one does not involve any fieldwork but is based on literature and the use of images whilst levels two and three are based on a basic assessment of the riparian condition. Level three riparian assessment is intended for use in River Health Programme (RHP). Leave four and five, are more advanced and require information not only about the species composition but also appropriate knowledge on the driver information to determine the impacts on the riparian vegetation (Kleynhans *et al*., 2007).

According to Kleynhans *et al.* (2007), during an assessment, the riparian habitat is divided into zones, with each zone assessed based on the extent and intensity of riparian vegetation modification, presence of, invasive alien or exotic plant species and changes in the vegetation functional groups. The state of the riparian vegetation zone is used as a complementary indicator. VEGRAI is used collaboratively with either fish or macroinvertebrates indicators (Fourie *et al.,* 2014; Agboola *et al.,* 2020) to determine the riparian zone's impact on the indicators and the river' overall biotic integrity or ecological status. This is mostly because according to Kleynhans *et al.* (2007) the riparian vegetation structure and function on instream habitat influences the availability of the biota (fish and macroinvertebrates).

2.5 Current river health monitoring trends critique

The previous section showed that the most commonly used indicators of river health in South Africa are riverine based. Most river health studies in South Africa have used these riverine indicators individually to describe freshwater systems' health (Odume & Mgaba, 2016; Agboola, 2017; Levin, *et al.,* 2019). However, the sole use of riverine organisms as indicators in river health assessment has been criticised in literature. Niemi and McDonald (2004) assert that the use of a single indicator lacks appropriate context, as a river system has multiple attributes and a single indicator might not capture, despite being interpreted in temporal and spatial variation. The main risk is that it cannot account for the effect of habitat on population size. Siddig *et al.* (2016) further explain that a single population rarely reflects the complexity of the natural environment and other biological interactions

Table 2.2 Tools and indicators commonly used in South African River Health Assessment study.

Tool/Indices	**Purpose**	**Indicators**
SASS	Based on the presence of riverine macroinvertebrate families, it reflects changes in water quality with implications for ecosystem health and integrity.	Riverine macroinvertebrate assemblage and their sensitivity level to stressors.
MIRAI	Aquatic macroinvertebrate assemblages reflect the prevailing flow regime, water quality and available habitat at a site in a river.	Riverine macroinvertebrates' responses to changes in habitat conditions from the reference condition.
Fish Response Integrity Index	Habitat-based, the cause-and-effect index that interprets deviation of a fish assemblage from the reference condition.	Fish community assemblage, compared to reference data and their response to different habitat metrics,
VEGRAI	Riparian vegetation is used to determine the influence of riparian vegetation structure and function on instream biota.	Riparian vegetation abundance, cover, recruitment, population structure and species composition are compared to reference conditions.

at the systems community level. The use of singular ecological indicators is also criticised by Brainwood *et al.* (2004), who explains that not all riverine taxonomic groups are similarly sensitive to disturbance. Different indicators show information on their diverse ecological function in the ecosystems, their interactions and environmental changes (Holt & Miller, 2010). Thus, it is important to consider various species of indicators that will consider the system as a community level and not be confined to a narrow range of conditions.

The second critique is the use of ecological indicators in South African river health assessment without considering the human or social dimension in selecting locally relevant and locally understood indicators. This is despite that, some literature from South Africa (Odume & de Wet, 2019; de Wet & Odume, 2019) argue that to achieve a reduction in ecological degradation and t improve understanding of ecosystem health, there needs to be a change from the use of conventional ecological assessments to more integrative, and holistic approaches which draw from diverse disciplines, with values and ethics as fundamental to such approaches. The authors further developed a Systemic-Relational Ethical Framework for aquatic ecosystem health research, which showed that value judgement is important in defining acceptable ecosystem health conditions. However, river health assessments in South Africa, are still solely dependent on ecological indicators to determine the river's health status, without considering water users' and communities' value judgement during monitoring.

Local publications as shown in Section 2.3 explained that most rivers health studies have paid attention to the ecological river health based on ecological indicators. River health definitions in different articles (Section 2.2 and 2.3) have acknowledged the human dimension of river health. However, not many research studies acknowledge indicators that highlight the importance of human dimensions and social value judgement in river health monitoring in South Africa. This is despite that according to Petrosillo & Zurlini (2016), humans are the most apparent ecological engineers as they change the environment. The physical environment and species are most affected by human use (Petrosillo & Zurlini, 2016). South African river health assessment indicators do not explicitly acknowledge the long histories of entanglement between people and landscapes The preceding paragraphs show that the commonly used indicators and methodologies in river monitoring programmes in South Africa are inclined to the biota coupled with biophysical elements of the river ecosystems.

In the 1990s, authors(Boulton, 1999; Norris & Thoms, 1999 criticised the ecological inclination of river health as less comprehensive. Ross *et al.* (1997) called for 'a postmodern ecology' which emphasises the complexity of natural systems and necessitate the inclusion of human attributes. Meyer (1997) conceptualised ecosystem health as social value-laden, with a model for the balance between ecological and human dimensions as key factors to maintaining river health. The author's major argument is that the human component is important as human actions are responsible for much of the environmental deterioration. According to Meyer (1997) the human and ecological dimensions modelling and conceptualisation assumes a balance between major human and ecological values which are important to maintaining the ecological health of a river and goods and services delivery. Thus, Norris and Thoms (1999) argue that indicators of river health should reflect all the river's variables, such as physical, chemical, biological, social and economic

Whilst there might be a lag in incorporating the social and ecological analysis considerations in river health assessment in South Africa, some countries have made attempts. In Australia, China and New Zealand, there has been an increase in studies that developed social indicators ranging from cultural, human well-being, human service demand and public satisfaction in river health assessments (Pinto *et al.*, 2012; Hiatt & Passalacqua, 2015; Harmsworth, *et al.,* 2016; Gratani *et al.,*2016; International Centre for Environmental Management [ICEM], 2018; Zuo *et al.*, 2020). According to Metcalfe and Riedlinger (2009), water management in Australia is increasingly recognising the need for studies to merge the biophysical condition of the environment with social consideration, such as local knowledge, cultural indicators and community input during river health monitoring. The authors conducted a social benchmarking study to produce a set of social indicators for river health that could be measured regularly. This was achieved by assessing the social conditions of communities to complement the assessment of the ecological and biophysical aspects of river health. Results from the study provided the Victoria catchment Management Area, with information to help them develop social and environmental priorities for river health management. The results also provided benchmarking data to assess changes in the social condition of river health over time in the three catchment areas sampled.

In another study from Australia, Pinto and Maheshwari (2015) determined the community' perspective on managing the health of the Hawkesbury-Nepean River system, a peri-urban river system. The study was necessitated by the notion that peri-urban rivers in Australia and other parts of the world have deteriorated over time, affecting the diversity of aquatic species and the social well-being of communities. The study took into consideration community perspectives in the assessment, as most studies had paid much attention to the diversity of aquatic species for river health assessment, neglecting communities' perceptions in understanding changing river conditions. Results revealed that the community used several visual indicators (for example, floating debris) to determine river health. These indicators were most common with communities with much interest in recreational and leisure activities with more proximity to rivers. The study concluded that if properly standardised, calibrated and investigated, these indicators may be potentially used as cost-effective monitoring tools.

In another study in Australia, Gratani *et al.* (2016) developed water monitoring indicators to express the indigenous Australian community's interests. The conservation of cultural and spiritual places, significant species abundance and richness coupled with trends in water quality riparian habitat and changes in river flows were taken into consideration when deriving the indicators. Results from the study revealed that for water management to make sense to local communities, a monitoring framework that the participating community can understand which support indigenous advocacy was suggested. The study produced a criteria and indicators framework that was grounded on environmental values and the worldview of the participants, which highlighted community values. The suggested framework considered community indicators as more meaningful and offered more social knowledge about the river which biological indicators alone could not do.

In Myanmar, the International Centre for Environmental Management (ICEM) (2018) developed and tested a river health method and tools framework which allowed government and communities to monitor the status of rivers based on the ES they value, through the Myanmar Healthy Rivers Initiative (MHRI). The study explored the ways that communities used and valued rivers and how these uses affect the health of the rivers and ecosystem benefits they provide to these communities. The study provided a framework that communities could use to monitor and manage rivers for their benefits, based on the authors' definition of river health: 'a river is healthy if it performs functions for the environment and can meet community needs at a catchment and community level'. The results of the study showed that communities and experts regard different areas of ecological and social importance in river health in terms of monitoring, prioritising (to reduce pressures) and improving conservation efforts.

In New Zealand, Harmsworth *et al. (2011)* and Gratani *et al.* (2016) linked traditional and western philosophies in river health monitoring. The authors investigated the link between cultural and scientific indicators of river and stream health in New Zealand by comparing monitoring approaches and results in different rivers. The overall goal was to introduce cultural methods and indicators adapted and refined to monitor river health. The studies' methodologies were based on the notion that indigenous people have different cultural values that reflect their background, needs and aspirations about the river. The cultural indicators provided knowledge, values and prescribe standards and offer guidelines necessary in river health monitoring, based on participants' experiences of using the river for cultural use. However, Gratani *et al.* (2016) criticised the epistemologies and methodologies of deriving the cultural indicators and compared them to scientific methodologies. The authors argued that community-led analysis is qualitative and subjective as the methods used were based on observations, experience and knowledge. Scientific monitoring was argued to be more objective as it is based on ecological peer-reviewed methods and equipment. Although there is criticism on the epistemological differences between the two approaches, the studies concluded that the approaches complement each other - which is a great benefit. The cultural indicators represented the whole vision about the environment whilst scientific indicators addressed specific methodologies suitable for the analysis.

Harmsworth, et al. (2016) incorporated cultural and scientific indicators in river health monitoring based on the Māori tribes' knowledge systems. The Māori tribes determined the river's health and ways to manage and protect freshwater resources based on their social values. This led to the adoption of a traditional concept in New Zealand's water policy framework. In as much as the study considered the community's inputs, however, it limited indigenous people's interests to cultural values and did not consider that the communities might have multiple values, uses and interests. Tickner *et al.* (2017) and Ekka *et al.* (2020) argue that river ecosystems provide multiple social and economic benefits and several processes that affect their health. Thus, the analysis of multiple physical and social structures and processes is necessary for holistic river ecosystem management and consideration of all social-ecological interactions.

Nandi *et al.* (2016) conducted a study in the Ganga River in India and found out that the cultural knowledge of the communities was neglected, which led to the non-cooperation of communities in efforts to improve the river's deteriorating condition. According to Meyer's (1997) and Nandi *et al.* (2016)'s proposed River Health Assessment (RHA) model, for river health management efforts to be successful, the conceptualisation of ecosystem health should incorporate ecological and human values that include ES. Nandi *et al.* (2016)'s RHA model incorporated culturally sensitive indicators, after recognising that only the ecological sensitivity of the Ganga River was studied, which was insufficient as the river has cultural relevance. The key features of the RHA model developed by Nandi *et al.,* (2016) are that a good balance between social, economic and ecological factors should be ensured and that human values are key to anthropogenic activities thus should be central to the model, to explain the socio-economic and ecological health of the river. The model further advocates for consideration and active participation of all stakeholders in the management of the river's health. The RHA model is anchored on the principle that people's relationship with the river is vital to any effort towards restoration and sustainable river health management (in India). The study concluded that any river health and restoration programmes associated with a culturally sensitive context such as Ganga River need to adopt an approach that creates inclusive spaces to bridge the gap between science and social well-being. The model results highlight how the river's transformation from pristine to a disturbed state can also indicate the changing perception of human values towards rivers and their cultural uses.

Although studies conducted in the countries outside of Africa considered human and ecological indicators in river health monitoring, however, these studies do not show and acknowledge the embeddedness and relationship of humans and ecology in river systems. The studies considered the human and ecology values in river health monitoring but, have not demonstrated how these two systems merge and how their relationships are related to river health. For example, the River Health Assessment (RHA) model developed by Nandi *et al.* (2016) does not show how human and ecological sensitivities in river health monitoring can be merged. McShane *et al.* (2011) state that explicit combined social and human value consideration in river health makes the planning process more realistic and inclusive to communities involved.

Vollmer *et al.* (2018) also developed the Freshwater Health Index (FHI) in the Dongjiang River Basin in southern China to highlight relationships between healthy freshwater ecosystems, their governance and the benefits they provide to human beings. The study proposed a set of indicators to monitor freshwater ecosystem health based on human and ecological prioritisation. The study addressed the multiple demands, uses of the river and the linkages between human beings, freshwater ecosystems and governance. However, one major weakness of the study is that the selection of indicators was determined by historical data or model results. The index does not show the role of water users (humans) in developing the indicators and the human's relationship to the river. The index followed a top-down approach of selecting indicators by relying on models and decision-makers in the catchment. Secondly, in as much as the aim of the RHA model developed by Nandi *et al.* (2016), was to improve the gaps between science and social knowledge, the article shows that stakeholders only participated in awareness-raising campaigns and not model planning. This shows weak inputs from stakeholders as the model's schematic representation does not show their active participation to provide information on how the model was established. The active participation understanding of people's relationship with the river was not prioritised. Gratani *et al.* (2016) argue that water monitoring that prioritises communities' values, should prioritise their knowledge and interests which also empowers them to negotiate greater involvement and solutions in water management.

Involvement and empowerment of communities are important to understand their relationship and views about river health. According to Nandi *et al.* (2016) and Jones *et al.* (2016), human values show human knowledge about the ecological integrity and resilience of the river. Blue (2018) recognises the inseparability of human and ecological attributes in river health and advocates for holistic approaches to understanding rivers. Therefore, one can pinpoint that since river health has intertwined ecological and human considerations; the selection of indicators should not be oversimplified by not acknowledging the relationship between ecological inputs and human inputs in decision making. This approach can bridge the gap between science and society and provide a holistic analysis of the river's health.

From the analysis of the studies, firstly one can draw that all the river health studies focused mostly on the traditional/cultural importance of the water resources. The studies do not consider the multiple uses of the river; stakeholders' relationship analysis was mostly streamlined to the cultural use of the river. This shows a narrow view as Tickner *et al.* (2017) explain that rivers have multiple benefits which should be co-managed. Furthermore, the reviewed studies which have researched cultural ES knowledge-based river health indicators have not shown how this knowledge system may corroborate with scientific knowledge to improve river health monitoring. Most of the social indicators and considerations in river health (some of which are referred to in Table 2.3) focus on their formulation based on cultural use without considering how they could be integrated with ecological indicators. The studies in Table 2.3 only show the formulation of the socio-cultural and ecological indicators separately using qualitative and quantitative epistemologies in each case, without finding ways to corroborate their relationships in use. However, geographers contend that rivers have inseparable social, physical and biological processes, which makes collaborative frameworks necessary (Emery *et al.,* 2013; Ashmore, 2015; Lave, 2016; Volenzo & Odiyo, 2018). Thus, it would be necessary to show the collaborative relationship between the social and ecological river health indicators which will result in the formulation of integrated indicators. Thus, this research will explore and demonstrate explicitly how these social and ecological considerations of river health are related and may be co-used to improve river health monitoring.

Secondly, all the river health studies that considered social and cultural indicators in river health did not explicitly analyse the different human and environmental relations in the river catchment, how these may lead to a unified understanding of river health and be used to improve understanding and monitoring of river health. Moffatt and Kohler (2008) explain that a unifying theory in environmental analysis requires a complex social-ecological system foundation that shows the different related relationships at different scales. Given the existence of thriving epistemic local communities involved in river health assessments in South Africa, understanding human-environment interactions through a social-ecological lens becomes important. Zimmerer and Bassett (2003) explain that social-ecological interactions provide a contextual background of current management challenges and existing relationships. Bourblanc and Blanchon (2019) explain that in South Africa, environmental issues are highly politicised with active mobilisation of community participation at the grassroots level and there is a tradition of linking environmental and political issues in South Africa. However, there are no explicit considerations of existing political considerations and relations that may influence river health, during monitoring and determining of river health indicators. Therefore, this study will determine existing human and nature relationships in the catchment and how a unified social-ecological understanding and monitoring of river health may be formed.

Thirdly, the pathways of knowledge sharing and engagement between communities during the development of river health indicators were also not considered. Some studies, as shown in Table 2.3, involved communities and water users in developing socially relevant indicators formed through group discussions, yet none of the studies explain the pathways of knowledge sharing between participants. Pahl-Wostl *et al.* (2007) and Reed *et al.* (2010) state that participatory monitoring programmes at the community level are allowed interactions and knowledge sharing that are all opportunities for social learning. The authors conceptualise that when people engage in groups, they learn from each other and share ideas and this benefits social learning. None of the river health studies reviewed attempted to review and understand social learning and the pathways which would improve the development of locally relevant indicators. During interactions, people share knowledge and learn from each other which leads to new solutions that benefit the wider SES (Pahl-Wostl & Hare, 2004; Cundill & Rodela, 2012). The studies reviewed do not explicitly show how human-environment relationships and social learning are formed in the catchment and how these may be used to improve understanding of river health as a social-ecological concept. Therefore, this study will develop an integrative river health monitoring framework that explicitly takes into consideration human and environmental relationships that exist and how community participation may lead to social learning which is useful to improve understanding and assessment of river health.

Table 2.3 Summary of case studies that showed the use of social and ecological indicators in river health monitoring in different countries

Authors and Country	**Method**	**Indicators**	**Legislation**	**New information**	**Critique**	**Lessons for consideration in this research**
Harmsworth, *et al*. (2011) New Zealand	Field assessment and interviews.	***Scientific:*** • Water quality (*E. coli*, turbidity); • Macroinvertebrates; • Community abundance. ***Cultural:*** • Wild foods; • Maori values, cultural sites.	Standards and guidelines for New Zealand streams, rivers that reflect societal needs and values.	Cultural river health index for river.	• No criteria to determine monitoring sites; • Other users not considered, only cultural value; • History and political processes of the area are not considered.	Users adjacent to rivers have various uses and they should be considered. Local communities have pre-existing indicators relevant to their setting.
(Luo *et al.*, 2018)China	Sampling and monitoring of physical and chemical, biological and habitat indicators. Human service demand: based	***Ecosystem integrity*** • Habitat condition; • Physical and chemical water quality status (total nitrogen and phosphorus, dissolved oxygen); • Biological indicators.	No ongoing river health assessment programs linked to river management policy.	New framework to assess river health with human service demand and river ecosystem integrity as indicators.	• Human satisfaction based on economic value, no consideration for non-monetary value satisfaction; • No consideration of the value of local knowledge.	Consideration of satisfaction of users in river health assessment monitoring.

	on the optimal value, determined based on the national optimal level.	***human service demand***: • Water resources development and utilisation rate; • Water ecological environment satisfaction; • Water consumption of GDP.				
Zuo *et al.,*(2020) China	Existing river health assessment results; expert consultation method through questionnaire.	**Biophysical** • Safe operation; physical structure and hydrologic processes; • Sustainable water supply, water availability and accessibility; • Ecological indicators, water quality and biota. **Public satisfaction:** • Residents' satisfaction;		The Happy River Index (HRI) that integrates ecological trends in river health and human well-being.	Most data were based on experts' opinion use of available data. The communities were not involved in the formulation of the indicators.	

		• Cultural and recreational value, water conservation level.				
Pinto & Maheshwari (2015) Australia	Questionnaires	**Water quality** • pH, turbidity and dissolved oxygen; Enterococci and Escherichia coli); **Ecological** • Phytoplankton community structure distribution and abundance; • Benthic-macroinvertebrate communities; • Community views on river health were influenced by individual's age and proximity to the river.	Indigenous people's interests are recognised in water policy. National Water policy; with environmental, cultural and social concerns. These concerns are positioned within a framework that relies on markets for water allocations.	• Understanding the meaning of river health from a community perspective • River health assessment framework showing competing interests, uses associated with peri-urban rivers.	Politics, power and decision-making processes are not taken into consideration. Specific indicators regarding community value and use were not considered, only ecological indicators were statistically considered.	Importance of recognising the meaning of river health from a social local context especially for communities that are water users.
Gratani *et al.*,(2016)	Interviews, participant	**Conservation status; cultural and spiritual**		Water monitoring framework	No demonstration of integration between	

Australia	observation during field trips, photographic documentation.	**places:** • Condition of burial sites; • Fish traps; • Healing places; • Birth places; • The abundance of culturally important species.		with an expression of the Indigenous Australian community's interests and vision for the rivers' management.	indigenous knowledge and ecological indicators in the framework. The study did not ascertain if the meaning of river health between scientists and communities was similar or related. Description of river health was based on the researcher's definition of "not looking sick".	
		• Good fishing spots, medicinal plant species presence and abundance.				
		Water quality • Sediment presence; • Presence of organisms that prefer good water quality.				
		Water quantity • Riverbed condition; • River flow.				
		• Ecological species				

		of cultural importance; • Species abundance and richness.				
ICEM (2018). Myanmar Healthy Rivers Initiative (MHRI)	Focus group workshops. Field community identification of river health. Participatory mapping. Village's Historical Profile.	**Community** • Fishing - number, size and diversity of endemic species; • Water – flow and water quality; • River and riverbank condition – location, depth, condition; • Significant events for example flooding.		Established new community monitoring sites and indicators with communities by linking ES and river conditions over time.	Did not consider social and cultural value indicators which were more qualitative. Consideration of communities was quantitative, for example, number, size and diversity of fish, condition of fish not considered. There is no clear integration of the community derived and scientific indicators in the new framework.	Determination of monitoring sites (hotspot) and community-relevant indicators. Importance of active participation of communities.

2.6 River catchment as Social-Ecological Systems (SES)

Ostrom (2009) developed the Social-Ecological Systems (SES) theory to explain the interaction between society and the natural system. The SES theory came about as a result of close interaction between society and natural systems (Petrosillo *et al*., 2015). Colding and Barthel (2019) explain that SES are systems where social, economic, ecological, cultural, political, technological and other components are strongly linked and nested across scales (Bouamrane *et al.,* 2016). These SESs show interconnection between human and nature co-evolving across spatial and temporal scales. SES is the main feature in analysing human and nature interactions which have also shown an ontological shift in understanding human-nature relationships (Young *et al.,* 2006). Ostrom (2009) argues that all resources liked by society are entrenched in complex SESs. Through the use of SES theory, researchers brought together the social and ecological systems to deal with research questions that address environmental crises.

Colding and Barthel (2019) traced the evolution of the SES discourse from its inception in the 1970s to 2009 when it was turned into a framework, to understand society and nature relationships. The authors explain that at its inception, the concept was to analyse the relationship between social-natural systems and generate insights on how to interpret feedbacks from these relationships. However, over the years some authors (Bassett *et al*., 2015; Petrosillo *et al.,* 2015 & Mathevet *et al.,* 2016) have used the term "socio-ecological" and "social-ecological" interchangeably. Berkes (2017a) argues against the use of socio-ecological and advocates for the consistent use of "social-ecological". The author argues that "social-ecological" emphasizes the equal importance of the social and ecological subsystems, whilst "socio-ecological" is modified and suggests a less equal status of the social subsystem, compared to the ecological which has maintained its full name. Therefore, since this thesis' main argument is that rivers have equal social-ecological functions and proposes a framework that equally considers these functions, the term "social-ecological" is used consistently throughout the thesis. This is to emphasize the equal importance of the social and ecological systems in river health assessments.

According to Ostrom (2009) in a Social-Ecological System (SES) there are subsystems such as a resource system (e.g. river), resource units (fish), users (people), and governance systems (institutions and rules that govern its management). Ostrom (2009) and Binder *et al.* (2013) explain that the SES foundation is based on theories of how the ecological and social systems should be treated in equal depth. All the units are said to interact with each other inseparably but produce outcomes at the SES level. Petrosillo *et al*. (2015) explain that SESs are an emphasis on 'human-in-nature' perspective as an integrated concept. This is because, SESs are composed of multiple subsystems and internal variables within these subsystems – namely the resource system, resource units, users, governance system and rules (Ostrom 2009). Petrosillo *et al.*(2015); Colding and Barthel (2019) state that the basic features of a social-ecological system model include, resources that are used by resource users; public infrastructure providers; public infrastructure; physical capital (such as any engineered works); and social capital (such as the rules used by those governing, managing and using the system; includes monitoring and enforcement of these rules). Colding and Barthel (2019) further argue that these subsystems interact in an interdependent manner which may affect and be affected by the larger socio-economic, political and ecological settings prevailing in which these variables are embedded. Schoon and Van Der Leeuw (2015) and Petrosillo *et al.* (2015) argue that in the SES theory, nature does not set the context in which social interactions happen, instead humans are considered as an integral part of the biophysical environment. Humans and nature co-exist, as humans are no longer regarded as external disturbances but rather part of nature. Therefore, an SES framework is considered as a whole, made of the human and nature subsystems and variables.

The SES variables and subsystems interaction and formed patterns of interactions are a reflection of the overall outcome of the system, in such a way that any changes in interactions may affect the system (Ostrom, 2007; Korpilo *et al.*, 2018). These subsystems are independent, however, they interact to produce results at the SES level which also affect these subsystems and the SES at large (Ostrom, 2009; Petrosillo *et al*., 2015; Liehr *et al.*, 2017). This shows that the SES concept goes beyond just acknowledging the human and nature relationship but also takes into consideration interactions, feedbacks and dependencies between social and ecological systems (Petrosillo *et al*., 2015; Virapongse *et al.*, 2016; Colding & Barthel, 2019). From these studies, one can deduce that the SES concept brings together different subsystems and offers a better understanding of the functions of each subsystem's sub-components.

Schoon and Van der Leeuw (2015) argue that this approach is against previous scientific perspectives which supported narrow, reductionist views over a more holistic understanding of problems. SESs focus on acknowledging the link between social and ecological systems, bringing trans-disciplinary methodologies into play. Levin *et al.* (2013) argue that the interconnectivity in SESs can be seen through patterns of use and resource demands. The patterns of use and demand at the end produce feedbacks that work within and between different levels (subsystems) on spatial and temporal scales. The interactions and feedbacks between the systems result in changes in the main social-ecological system and subsystems which may not be linear (Scheffer *et al.*, 2001). These non-linear changes may result in a reorganised system that might be beyond the critical thresholds of the original system.

Since the SES has its origin in the social sciences, some authors have argued that this has weakened its effectiveness for interdisciplinary and ability to explain the ecological complexities. Partelow (2018) explains that the framework places more emphasis on the institutional and anthropocentric lenses than on the analysis of natural resources. Epstein *et al*. (2013) argue that the social is drowning the ecological in the model. Vogt *et al.* (2015) support the argument by suggesting that there is a general absence of ecological considerations, thus the SES framework lacks meaningful interdisciplinary dialogue. As a result, Epstein *et al.* (2013) and Vogt *et al.* (2015)

proposed the introduction of ecological rules to be equally important as social, economic, and political rules in the SES framework. However, Partelow (2018) criticised the suggestion of adding ecological rules and emphasised that there has to be an epistemological congruence to justify it and be aligned to the existing rules and variables. The main argument was that if the framework's variable is modified outside of their influence on collective action, this will conflict with the basis of the model. Based on these arguments one can explain that whilst some authors' arguments for explicit specification of ecological variables are justified, there is also a need to ensure that the main basis of the model, of ensuring that nature does not set a context but rather a holistic and transdisciplinary approach, is maintained.

Despite the shortcomings of the SES framework as explained in the previous paragraph, it remains useful to explain natural resources like river catchments. According to Cabello and Willaarts (2015) and Dunham *et al.* (2018), river catchments appeal to SESs as they entail hydrological, ecological, institutional or socioeconomic components, as well as human and riverscape influences. Several studies (Cabello & Willaarts, 2015; Vollmer *et al.*, 2018; Dunham *et al.*, 2018) have looked at rivers as complex SESs to explain water use, demands, ecohydrology of a catchment and to characterise freshwater health. Vollmer *et al.* (2018) characterised freshwater health using the SES to explain the complex social-ecological problems of a catchment. Understanding rivers as SESs is important to explain human interactions that result in changes in the ecosystem (Anand *et al.*, 2010). The SES allows a better understanding of how human actions affect the river ecosystems, how changes in ecosystems may also affect human well-being and how people value the ecosystem (Townsend *et al.,* 2012). In light of this, there has been an increasing effort to study river catchments as complex SESs, where human and ecological systems are viewed as inextricably linked. Research shows that humans have a major influence in changing spatiotemporal distribution of freshwater resources (Vörösmarty *et al.*, 2010) structure and function (Ormerod *et al.*, 2010) as well as the physical form of rivers (Ashmore, 2015). The changes show the links and feedbacks of the relationship between human water use and the effects of these uses on the freshwater ecosystems as an SES and its subsystems. These links and feedback interactions shape the river catchment which leads to river catchments being conceptualised as SESs. Thus, this research will use the SES concept to centre and understand existing relationships between communities and the Lower Komati River and how these relationships may be used to better explain river health.

Understanding human and nature relationships and centring river health studies around the SES concept is important; Parsons *et al*. (2016) state that in practice, most catchment studies prioritize biophysical parameters to provide information about the ecological state of a river ecosystem and the social state of a river is ignored. Using a singular ecological view does not manifest interconnections among the physical, ecological and social components of the river catchment and explain the river's health comprehensively. Understanding changes in rivers through the SES concept leads to an understanding of the importance of the continued provision of benefits for people and maintaining the river's social value, which may enhance the river ecosystem' maintenance (Ives & Kendal, 2014). Tasca *et al.* (2020) argue that some water management interventions may fail as a result of inadequate integration and understanding between the social and ecological factors which reflects systems thinking. This calls for the strengthening of studies that look at a river as an SES, which considers the balance between ecological and social functions.

Despite the consideration of the SES as important in studying environmental systems and river catchments, it has been criticised for some ambiguity in its formulation. There have been some studies that have identified its shortcoming and proposed adjustment of the theory. For purposes of this research, three proposed adjustments of the SES that emerged in literature will be discussed. According to Ostrom (2009) and Stojanovic *et al.* (2016), SES's assumes that institutional design principles and community are homogeneous and do not explicitly interrogate how social units might be heterogeneous as their experience of the environment is not the same. The authors argue that the assumption that society's interests, expectations and experiences are the same is not the case in real life. Coté and Nightingale (2012) explained that communities as social units may hold different beliefs, values and experiences with resources in their immediate environment. Mathevet *et al.* (2016) explain that the SES does not adequately acknowledge the different values, interests and power of the different social actors and their roles in navigating social-ecological change. The communities' differences can be in different forms (for example gender ethnicity and age), which may influence how the environment is managed and experienced by different people and may manifest in the human and nature relationship. Welsh (2014) acknowledges that SES pays less attention to social diversity within social units and lacks interrogation of power relations within the system. Based on these arguments, the author called for a consideration of conceiving of society and its components as a system with multiple social units with their complexities. The consideration of society as a complex unit with different social units provides the SES as a platform for social learning (Fernandez-Gimenez *et al.,*2008) as the society's interests are different thus offering opportunities to learn from each other.

Secondly, Fabinyi, *et al*. (2014) argue that the SES focuses more on institutions, organised social units and nature as a physical unit and that humans are within the environment. The SES concept does not explicitly explore if a new unit or subsystem is formed from the interactions. Whilst the SES framework aims to enhance a cross-disciplinary building, it does not explicitly explain that when these social and ecological entities merge a new unit might be formed. Thus, Stojanovic *et al*. (2016) advocated for the strengthening of the theory to consider systems hybrid nature-culture spaces. This is mostly because society's different components e.g economics and culture are amenable to conceptualisation as units/ systems. Thus cultural-economics units can be the new cross-disciplinary hybrids formed.

Thirdly, Epstein *et al.* (2014) explain that power is not explicitly included in the SES framework, there are potential indicators of institutional power which include operational rules governing the system. Fabinyi *et al.* (2014) and Welsh (2014) highlight that the human and nature relationship explained by the SES concept is a value-laden exercise, which may be contested by groups with differential power. This demonstrates how different environmental issues are commonly understood and represented. Stojanovic *et al.* (2016) argue that the SES approaches show the construction of 'natural' or 'social,' and produce automatic interpretations of the relationship without combining the power relations or politics that might exist when a new entity is formed. Welsh (2014) highlights that power relations can influence people's openness to generate, absorb and process information about social-ecological change. Boelens *et al.* (2016) argue that society produces and reproduces their immediate environment through using, inhabiting and/or managing it according to their ideologies, knowledge and political power. There has been little consideration of power-centred approaches in the SES framework, thus Boelens *et al.* (2016) advocate for an expansion of the framework to explicitly incorporate power into analysis using the SES framework. The authors further theorised that power is central when there are social and ecological interactions and play a major role in social-ecological processes, decisions and outcomes. The authors' advocated for the consideration of power and formation of hybrids during social and ecological interactions as explained in the preceding paragraphs. Therefore, this thesis will use the political ecology's waterscape to explain power relations in the river catchment and how they might influence river health. This concept stresses how the geographical location, social-ecological relationships, politics and power relations that exist in the catchment may be linked to the Lower Komati River's health condition.

2.7 Position of Ecosystem Services in the Social-Ecological System framework

The publication of the Millennium Ecosystem Assessment (MEA) in 2005 led to the increased awareness of the importance of Ecosystem Services (ES) in social-ecological studies. Society and nature relationships are usually framed using ES as a link between the two (McAfee, 2012). ES are defined by Costanza *et al.* (1997), Nelson *et al.* (2009) and Jenkins *et al.* (2010) as a range of characteristics, goods and services generated by ecosystems that are of benefit to human well-being. This definition of ES shows that people derive 'benefits' from ecosystems. The MA classified ES into provisioning (food, freshwater, fuel); regulating (water purification, climate regulation); cultural (recreation, spirituality); and supporting services needed for the production of all other ES (nutrient cycling, soil formation). Supporting and regulating services are often combined as their functions and processes can be interdependent.

There have been different debates and criticisms of the ES concept. Schröter *et al.* (2014) have argued that defining ES by centring it on human benefits promotes the commodification of nature and exploits the human-nature relationship. McAfee (1999) and Prudham (2004) argue that promoting commoditisation for conservation and 'equitable sharing' of the benefits of nature may create spaces for capitalist accumulation. McCauley (2006), Haines-Young and Potschin (2010) and Nassl and Löffler (2015) criticise this approach of centering ES on use and demand to be more of a human-centric view. Political ecologists have also argued that the ES concept is anthropocentric and promotes the exploitation of nature (Fairhead *et al.,* 2012; Schröter *et al.*, 2014; Hoque *et al.,* 2017) as human well-being is at the centre of ecosystems management, which is a human-centric view.

This means that the approach puts humans at the centre and nature is simply there to provide - it does not show any human input. The authors explain that the ES concept shows the human-nature relationship as utility-oriented, which may alter the attitude and behaviour of society concerning nature.

Different scholars (Gómez-Baggethun *et al.*, 2010; Sullivan, 2011; Robertson, 2012; Kopnina, 2017) have also criticised the notion of centring ecosystems; that this may lead not only to the commodification of nature but create new sites for capital accumulation, especially for the affluent. Kosoy and Corbera (2010); Kopnina (2017) explain that this can result in new socio-economic hierarchies, leading to unequal power relations in accessing natural resources, as social actors are re-positioned. This may disadvantage poor local communities, as they are unlikely to benefit from the natural commodities at their disposal, as opposed to the rich. Robertson (2012) and Schröter *et al.* (2014) argue that this might turn people into consumers separated from nature, contradicting the human-nature relationship and neglecting societal demand and access. This conflict with human–nature relationships presents a gap for a holistic perspective of SES.

Some authors do not agree with the notion that the human and nature connection through ES may lead to the commodification of nature. Lele *et al.* (2013) argue that ecosystems do not simply generate the services but there is human input that ensures the ecosystem processes gain value. Even though ES have been recognised and valued in understanding the links between nature and society, the main issue is a lack of consensus on how to measure and quantify ES (Nassl, 2015; Opdam *et al.*, 2015; Boerema *et al.*, 2017). It may be challenging to determine the exact value of the benefits. Debates have been ongoing about whether it is possible and ethical to confer value to something that might be priceless (McCauley, 2006). Reyers *et al.*, (2012) argue that ecosystem services are often associated with instrumental value as they contribute services that improve human well-being. Arias-Arévalo *et al.* (2017) describe instrumental values as merely means to an end and are often measured in monetary terms but can also be non-monetary. Mok *et al.* (2021) argue that instrumental values quantify trade-offs and help reach consensus quickly among stakeholders, as it is often based on benefits and stipulated by a definite figure. However, Schröter *et al.* (2014) argue that valuing of ecosystems should go beyond instrumental value, as it only emphasizes humanity's dependence on nature and economic value. Some authors (Tallis & Lubchenco*,* 2014; Piccolo, 2017) argue that focusing on nature for human sake is not enough as protecting nature for its own sake (intrinsic value) is equally important regardless of the human perspective. Thus, Arias-Arévalo *et al.* (2017) advocate for pluralism when valuing ES, which is adopted in this thesis, that recognises intrinsic and instrumental values and are assigned to the features of the ecosystem by the people equally. Arias-Arévalo *et al.* (2017) argue that the pluralism and multiple values approach are crucial for the sustainable management of social-ecological systems. This is mostly because the ecosystem is valued for itself and its use by people. Thus for sustainable management of aquatic resources, there is a need for a balanced approach that considers valuing ES importance, for users and nature’s sake. This creates a balance between use and protection. This is supported by Ostrom (2009) who argues that the varied values placed on an ecosystem are crucial for the sustainable management of social-ecological systems. If the multiple values of the ecosystem are balanced, the management will also be balanced.

In as much as humans benefit from nature to harness services, there is also co-production as humans invest in labour and human-made capital. Humans fully rely on nature for their survival but they are also an integral part of the biosphere (Costanza *et al.*, 2017). As society becomes disconnected from nature, the ES concept has the potential to bridge the gap between consumers and ecosystems. It reconceptualises humanity's relationship with nature, by including reciprocal feedbacks (Schröter *et al.,* 2014). ES are a link between nature and society with humans embedded within nature. Humans are considered as part of nature like all other species, who 'use' the resources in the environment to survive and thrive. This shows that nature and humans co-exist and that it is not only humans that matter and benefit. Different models have been developed to operationalize the relationship between people and nature. The cascade model was developed by Haines-Young and Potschin (2010) to illustrate the pathway of ecosystem services from ecological structures, processes of human benefit to value generation as shown in Figure 2.1. The model helps to explain the relationships between people and nature by illustrating how benefits from ecosystem services lead to value generation.

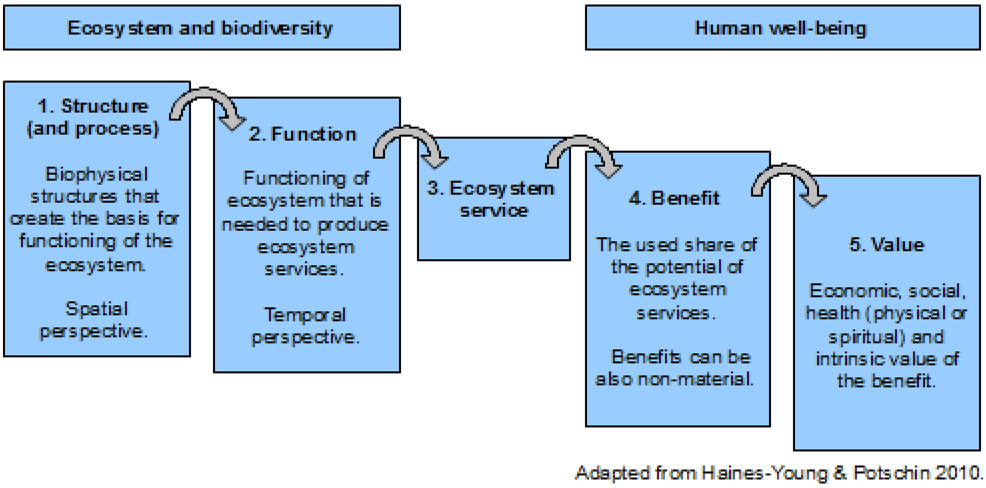

Figure 2.1 Illustration of the cascade model chain from start of biophysical structures to the creation of values (Haines-Young & Potschin 2010)

The model in Figure 2.1, shows that the ecosystem's biophysical structure has the potential to provide ES that benefits humans (Haines-Young & Potschin, 2010; Nassl & Löffler, 2015; Boerema *et al.*, 2017). This shows that biophysical ecosystem functions also have social benefits through ES benefits and these have an influence on human well-being. Human well-being considers, ecosystem services, which are humans' derived benefits that result in the creation of value that can be intrinsic or instrumental. Potschin-Young *et al.* (2018) suggest that the model also identifies the functional characteristics of ecosystems that bring out the services and benefits and values that they support.

The original cascade model's limitation was that it offers a linear relationship between processes, benefits and values of ecological structures, whilst in reality, articulating ES values is complex and cannot be captured in a linear model (Nassl & Löffler, 2015). According to (Spangenberg *et al.,*2014, the model neglected human 'input' as an essential part of the 'cascade process'. Thus, the ES cascade was revised by different authors (Oudenhoven *et al.,* 2012; Hernandez-Morcillo *et al.,* 2013 and Boerema *et al.*, 2017) to include the Driver-Pressure-State-Impact-Response (DPSIR) scheme. According to Van Oudenhoven *et al.* (2012), it is necessary to position the 'cascade' in a broader scheme within the SES and analyse human and nature relationships which take into consideration human pressure, drivers, impact and response of nature. Hernandez-Morcillo *et al.* (2013) argue that incorporating elements from the driving force-pressure-state-impact-response (DPSIR) is useful to identify all units of the SES from which functions, benefits and values come from. To achieve that, a full analysis of each ES in SESs is important and there is a need to consider the ecological and socio-economic network of relationships (de Groot *et al.*, 2010; Boerema *et al.*, 2017). Balvanera *et al.* (2012); Abson *et al.* (2014); Weber *et al.* (2017) and Grizzetti *et al.* (2019) argue that ES can be effectively used as a keystone for the integrative analysis of coupled SESs and show multiple interactions between human welfare and environmental management. The ecosystem relationship with services is complex and may change over time, as it largely depends on the continued flow and distribution of ES, which shows the complexity of SESs (McMichael *et al.*, 2005)

Müller & Burkhard (2012) and van Oudenhoven *et al.* (2012) argue that, as a result of complexity, connections, cause and effect relationships in human-environmental systems as they harness ES, there have been attempts to bring some order into these complicated systems structures through the Drivers, Pressures, State, Impact, Response (DPSIR) framework. The DPSIR framework shows causal links between the underlying factors promoting environmental change (drivers) which create 'pressure' on the system. This pressure then changes the 'state' of the system, causing 'impacts' on ecosystems and society. These impacts lead to a 'response' in the state of the ecosystem that has social and ecological characteristics (Nassl, 2015; Gebremedhin *et al.*, 2018). These responses are based on social consumption or production patterns in societies, which drive the production of certain pressures in ecosystems (Gebremedhin *et al.,* 2018). These pressures can be environmental inputs due to resource use and human activities. These pressures also change the state of the environmental systems, which might result in a change in the provision of ecosystem goods and services and the SES.

Studies have taken place to understand the social-ecological state of the ecosystem using the DPSIR model (Hohenthal, *et al.*, 2015; Gebremedhin *et al.,* 2018). Gebremedhin *et al.* (2018) used the DPSIR to better understand the causal dependencies between a broad set of human activities and their various effects on the lake ecosystem. The use of the framework helped describe the available knowledge and management needs in the catchment. Bowen and Riley (2003) used the framework to assess the current state of ecosystems and their changes over time, which shaped the future management and use of water ecosystems. Santos-Martín *et al.* (2013) analysed the complex relationships established between ecosystems and human systems in Spain through the use of the DPSIR framework. The framework was used to visualise the complex relationships between ecosystems and human systems from a holistic point of view. The authors analysed the intricate associations between the ecological and social components by using indicators of social and ecological processes to evaluate the direct and indirect effects of loss of biodiversity and ES on human well-being and the ecosystem in Spain. The indicators were based on biodiversity, land-use changes and socio-political ecology. Results illustrated the close relationships between biodiversity, ES, human well-being, drivers of change and political systems. Loss of biodiversity and the deterioration of certain ES flows were noted to be a result of numerous drivers (increased land use and political systems) acting synergistically. This offered a window of opportunity to rethink the conservation of ecosystems more holistically.

However, some research has criticised the use of the DPSIR in making management decisions. Gari *et al.* (2015) argue that the major problem with the DPSIR framework is that it does not explicitly create a space for ES in describing human interactions with ecosystems. Thus, a new model Ecosystem-Based-DPSR, (DPSER) was introduced which replaced impacts with ES and highlights human-nature interactions (Hohenthal *et al.,* 2015). The model highlights an ecosystem-based management approach, which captures a system-level understanding of how an ES approach considers a holistic representation of ecosystem and human interactions. Through the use of the DPSER model, the importance of ES, human actions and historical perspective to explain the state of a catchment is recognised (Hohenthal *et al.,* 2015). Thus, this research will take inspiration from Hohenthal *et al.'s* (2015) study to show the different human actions, connections and historical perspectives in the catchment and if they can be used to explain river health. The aim is that every potential driver of change in a river will be analysed on how it affects preceding networks of interactions in varying spatial and temporal scales based on the ecosystem approach as explained by Butler and Oluoch-Kosura (2006). Le Maitre *et al.* (2007) explain that ecosystem approach studies are based on the holistic relationship between people and rivers. This approach will be adopted in this study as it advances the understanding of the complex interrelationships between people and the environment, not as linear and straightforward but rather as complex, coupled with multiple interactions from human and nature relationships by centring and offering ES.

The ES-based approach to manage water resources and determine the relationship between multiple pressures and services of aquatic ecosystems has been widely used (Hohenthal *et al.*, 2015; Liehr *et al.*, 2017; Tickner *et al.*, 2017). The ES approach has been used to determine all the values provided by an ecosystem (Hearnshaw *et al.,* 2010). It has also been recommended and used in urban river restoration, as Everard and Moggridge (2012) demonstrated the value of the ES approach to establish an ecological and human focal point, reflecting the relationship between humans and rivers. The ecosystem approach has been used to explore the relationship between river health, ES and social benefits in rivers (Van Houtven *et al*, 2007; Vörösmarty *et al.*, 2010; Ekka *et al.*, 2020). ES show integrated outcomes of the interaction between social and ecological dimensions and reflect as emergent features of SESs (Reyers *et al.*, 2013; Huntsinger & Oviedo, 2014). Poff *et al.* (2016) argue that ES adequately shows the link between river health and human benefit, which has become necessary to ensure that freshwater ecosystems continue to provide services essential to human well-being, despite multiple pressures. For example, the supply of good water quality and adequate river flow is important to communities for the provision of clean, water which benefits human health. Tickner *et al.* (2017) suggest that different social benefits derived from rivers depend on river health. Parker and Oates (2016) argue that changes to river' health have implications for the services a river can provide and benefits society can derive. This is in agreement with Pollard *et al.* (2013), who state that ESs are linked to the ecological integrity and overall state of a catchment. This shows that social benefits derived from rivers are all dependent on good river health. Therefore, there is a need to show evidence of the relationship between river health and the people who depend on the ecosystem services. This requires the strengthening of the evidence base which links river health for ecological and social benefits.

Literature shows that the link between a rivers' social and ecological benefits requires a comprehensive understanding of the coupled and reciprocal relationship between humans and ecosystems through ES (Liu *et al.*, 2007; Carpenter *et al.*, 2009; Díaz *et al.*, 2015; Folke *et al.*, 2016). Pollard *et al.* (2013) recognise that ES have a major role in understating catchments as SESs, as the derived services support humans in multiple ways. ES represent integrated interaction between social and ecological factors and thus are a crucial feature in SESs (Reyers *et al.*, 2013; Huntsinger & Oviedo, 2014; Palomo *et al.* 2016). In an SES system such as a river catchment, there is an interaction between the resource users and the ecological system to generate ES (Ostrom, 2009). The ES show how nature supports human well-being by generating multiple benefits. Fisher *et al.* (2009) argue that the ES paradigm encourages people to examine the links between ecosystems and human well-being. Thus, for the comprehensive understanding of river health, it is important to understand the relationship between humans and the ecosystem using ES as an interconnector, to show factors that might help understand the nature and scale of ecosystem degradation.

2.8 Ethics and Ecosystem services ES

As discussed in section 2.2, human activities degrade ecosystems which results in the loss of ecosystem services and according to Millennium Ecosystem Assessment [MEA] (2005), most often the marginalised and rural populations are negatively affected as they directly rely on the ecosystem services for most of their needs. Moreover, de Wet and Odume (2019) argue that trajectories of pressure on aquatic ecosystems are influenced by social values held by humans on the ecosystem. This is illustrated by the fact that, people tend to protect areas they prioritise and may not protect areas they don't prioritise yet the same area may be important to other people. Based on these two assertions; the human use of river ecosystem services and the different values they hold, the fundamental issues of environmental justice and ethics arise. Jax *et al.* (2013) define ethics as the morality and accepted norms, values and informal rules within a social group that guide individual and collective behaviour. Ethics justify good or bad actions in society and call for responsible action in a society. Odume and de Wet (2019) developed a framework for ecosystem health management that recognised the importance of ethics for healthy ecosystems in South Africa. The research found that the ethical challenge in the deriving of ecosystem services from rivers is ensuring equal participation by all interested ecosystem users. In the South African context, this include; the historically privileged and the marginalised, women and men, urban dwellers and rural dwellers. As Manfredo *et al.* (2017) explain that ethics help to openly engage and discourage values not in conformity with the values of equity and sustainability. It is also important that ethical considerations are taken into account that no one value is promoted over other kinds of values. This is mostly to reconcile different principles and account for the different ecosystem service benefits and different value positions.

The reconciliation of values and ensuring equal consideration of values in this research is important since South Africa's past political dispensation (apartheid) resulted in a highly skewed use and benefits in the use of natural resources which include water. According to Ramasar (2014), resulted in distributive injustice of natural resources. According to Sievers-Glotzbach (2013) for distributive environmental justice to take place, it is required that environmental benefits and burdens be distributed fairly. Thus, a fundamental ethical challenge that faces resource managers, policy and decision-makers in South Africa, is the equitable use and allocation of resources and treating all values equally. According to Jax *et al.* (2013) determining if something is important or allocating it accordingly and fairly lies within the domain of ethics. This is important in South Africa, as the country's historical context (apartheid) had its own ethical imperative. Thus, there is a need to effect transformation towards social justice and equitable distribution of resources. Ramasar (2014) explains that South Africa's post-apartheid priorities include justice to access natural resources e.g. water. However, the authors argue that despite the efforts by the country's policies and legislation to balance, there will always be different needs and desires in society which might lead to inequitable distribution of resources. Thus, ethical considerations that take into account that multi values exist in river catchments and also give equal opportunities to marginalised groups and ensuring that all values are regarded is important.

Sivers-Glotzbach (2013) explains that ethics can be used to address injustices in the use and conservation of ecosystems. So, an ethical value-based system coupled with ethics consideration is important in this research which is within a South African context by ensuring that previously disadvantaged groups and marginalised groups' values are taken into consideration. This will be through giving a voice to every water user and allowing marginalised groups to equally participate in the study. This has been identified by Odume and de Wet (2019) as an important instrument to stimulate support for water resource protection by contextualising and linking relevant management options with local communities' values.

2.9 Formation of social values from human and nature interaction

Sections 2.2 and 2.6 show that water facilitates social interaction between people and the environment, where interpersonal and societal-environmental inter-relationships develop (Priscoli, 2004; Syme *et al.*, 2008). These relationships result in connections between the river, ES which offers multiple benefits to different groups in society. Thus, to better understand the relationship and connection between rivers and society, it is important to analyse how social value is formed. This section of the literature review explains how human and nature's interactions lead to the formation of social values and how these social values accrue in rivers as well as the potential to use social values in river health monitoring. Before the thesis can analyse the formation of social value from human and nature relationships, it is important to show how the meaning of 'value' and 'social value' is conceptualised in this research.

The term 'value' has different meanings depending on the context of its use. From a classical economic perspective 'value' has been used in market and non-market valuation techniques to explore how people trade and determine the price of goods and services (Freeman, 1996). Economics estimate the value (price) of things to exchange goods and services between people within a market (Spangenberg & Settele 2010). However, non-economists have explained value from their point of view, over the decades. Social science' early scholars (Oskamp, 1977; Rescher, 1982) in Willers and Staden (1998) described values as beliefs on which man acts by preference. Values' principles lie on the judgement of what is important (Groenfeldt & Schmidt, 2013). Rutgers (2012) described values as the most important and central elements in a person's system of attitudes and beliefs. People construct values, based on the social structure they interact with and recognise priorities and hierarchies, indicating coexistence and interactions (Stern *et al.,* 1995).

People's values form in early life stages and remain relatively stable through life (Stern *et al.,* 1995). In the early stages of life, children receive most of their knowledge from adults, which they eventually reconstruct with what they experienced as realities as they grow older to form values. Later in life, according to Dietz *et al.*(2005) and McIntyre *et al.* (2008) values and beliefs develop from interaction, communication and negotiation with others in the social structure - these shape a person's values and beliefs. Shared beliefs, behavioural standards and rules become the common and characteristic values of distinct social structures (McIntyre *et al.*2008 & Nilsson, 2014). de Wet and Odume (2019) argue that as a result of the socio-cultural, politically and economically diverse societies, people's needs, values and desires differ. The social, economic and cultural structures provide experiences, opportunities and constraints that help to identify an individual's values.

Seymour *et al.* (2010) explain that values from a natural resources management perspective bring together economics and social science definitions as current conditions of natural resources and how people make trade-offs are explained. People associate values with different relationships/interdependences between human beings and nature (de Wet and Odume (2019). Klamer (2003) argues that values based on what society holds close, as a collection of preferences and experiences are termed “social values”. The term “social value” has been used and described in different ways. In natural resources management, it has been used to refer to the societal importance given to a place that benefits people (such as individuals, communities, societies) through interaction with the environment (Seymour *et al.*, 2010; Díaz *et al.,* 2015; Kenter *et al.*, 2015; Jones *et al.*, 2016). Through the physical linkages existing between society and nature, a social interconnection is forged, leading to the formation of social values (Lackey, 2001). Bryan *et al.* (2011) and Kenter *et al.* (2015) explain that social values can be any kind of use or non-use benefits that people derive from ecosystems which cannot always be in monetary terms. Brown (2013) and Sherrouse *et al. (*2014) affirm that social values are not only non-monetary/non-market but also place-based, for example, can be spiritual, aesthetic and subsistence benefit of place. All these authors attribute social values based on human and nature relationships and benefits. Thus, since the study sought to investigate how human and nature interactions may be used to expand and transform the way river health is understood, the use of “social value” concept is adopted. The thesis will use social value throughout, assuming an anthropocentric view, which is based on non-monetary benefits forged from nature and people’s relationships.

The social values may be held individually or shared by a group (Fitton *et al.,* 2015). Individuals’ values are exclusive to them, based on their interpretations of nature and society experiences and knowledge whilst shared values are based on guiding principles and normative values shared by groups or communities (Kenter *et al.,* 2015). This means a group of people who have had similar experiences, working or living together, may develop shared values. Societies share values that reflect their context which is called ‘shared social values (Norton & Steinemann, 2001). These shared social values reflect the ambitions and objectives of the group. The shared social values can develop through social learning, where people share history and knowledge about common ambitions through open interaction and shared meaning (Webler *et al.,* 1995). Downton *et al.* (2005) and Ives and Kendal (2014) caution that in as much as they may share values, local communities are not single entities with similar experiences. Lackey (2001) argues that society is not a monument but has varying competing opinions on what is important and distinguished by societal aspirations and social value. According to Díaz *et al.* (2015), the resource and benefits of the environment work as guiding principles of behaviour. These local communities’ different experiences and values are measured in terms of their benefit to the users. Thus, to capture shared values it is also important to consider different experiences within the society.

Furthermore, according to Seymour *et al.* (2010) in natural resources management, social values’ have been used in diverse ways and there are two most common kinds; held and assigned values. Held values are explained as ideas or principles that people hold as important to them, which are generally highly abstract, generic and conceptual (Lockwood, 1999; McIntyre *et al*., 2008). These values have been identified as principles or ideas that are important to people such as notions of liberty (Lockwood, 1999). According to Seymour *et al.* (2010), held values are personal principles that are important to people as enduring beliefs that certain conduct is socially preferred based on notions of liberty and responsibility. As mentioned previously, held values are abstract, conceptual and work as guiding principles that individuals hold as very important. In natural resources management, these values have been commonly used from a psychological approach. They are seen as motivating and guiding principles. According to Stern *et al.* (1995) and Lockwood (1999), the held values are constructed from demographic and social characteristics, life experiences, institutional constraints which can be motivating and work as guiding principles. The different authors have focused on the held values to explain people's environmental beliefs, attitudes and decisions.

Stern *et al.* (1995) argue that held values are constructed from demographic, social characteristics, life experiences and institutional constraints and can be commonly divided into 'individual'; 'social'; and 'biocentric or ecocentric' orientations. According to Dietz *et al.* (2005) and Seymour *et al.* (2010) 'individual orientation' is most concerned with how people care about the environment and how it influences them personally, thus people make decisions about the environment based on personal interests. The 'social orientation' is more of an anthropocentric view as it extends to society (Dietz *et al.,*2005). Lastly, 'biocentricism', is based on people's concern for the environment and ecosystems which is more intrinsic (Dietz *et al*., 2005; Seymour *et al.*, 2010). This shows that values' orientation will differ depending on the interest of individuals and groups in society. Although the held values guide personal and society's actions, they do not focus on specific areas, they are more general. Seymour *et al.*, (2010) explain that it is in assigned values, that individuals attached focus or attach value to different places.

Assigned values are defined as the values that individuals attach to physical places, goods and services which are expressed in relation to specific natural places (Lockwood, 1999; Seymour *et al.*, 2010). Assigned values focus on a specific place and the value they hold compared with similar characteristics (Lockwood, 1999; Seymour *et al.*, 2010). Assigned values are mostly preferred to explain the relationship between society and specific sites (McIntyre *et al*., 2008). In natural resources management studies, assigned values are preferred as they offer to a better understanding of community values for specific natural places (McIntyre *et al.,* 2008; Seymour *et al.,* 2010). Studies (Curtis & Robertson, 2003; Brown & Raymond, 2007) show that people assign values to natural ecosystems based on benefits, relationships and experiences with the area. These studies showed that these assigned values are based on people's experiences with the areas' benefits. This means, assigned values are founded on the area's importance to society. Therefore, since river health assessment is place-based, this thesis will use people's assigned values on different parts of a river to explain river health. Assigned values are preferred as McIntyre *et al.* (2008) argue that assigned values are more specific to place attributes or phenomena.

Hicks *et al.* (2015) used assigned value typology in coral reef fishing communities by tying ES derived by the communities' to the prevailing values of the fishing areas. Study results showed that The people's values developed as a result of coral reef fishing and these values guided the development of effective conservation initiatives. Participants assigned similar values on the coral reef fishing area, however, their interpretation differed based on age and proximity to the areas. This shows that in as much as they are shared but their interpretation was diverse based on different social factors. The interpretation showed that people respond in different ways despite similar experiences (Camarinha-Matos & Macedo, 2010).

Values assigned to natural areas reflect a sense of connection to the natural resources and other themes of relevance to environmental attitudes. The assigned values may be helpful to examine the influence of external factors such as economic conditions and proximity to specific locations (McIntyre *et al*., 2008), in an area. This is mostly because assigned values are in relation to specific places. Thus, assigned value adds considerable dimensions to spatiality, which emphasises that humans always relate their values to the surroundings they interact with and transform (Bonnemaison, 2005). Hussain and Floss (2016) used assigned values to determine a river's importance to communities and found that, rivers' spatial focal points to the communities are within a given context characterised by uniqueness and aesthetic appearance. This determined how different parts of the river were valued. Hussain and Floss (2016) further explain that as the rivers travel over vast spatial distances their assigned social values by the communities differ. This shows that space and assigned value are rooted in experience as different parts of the environment have different significance and values to people as they are conceived and experienced differently. In essence, space seems to be inextricably interwoven with assigned values (Wilcock *et al.,* 2013) and are thus mostly taken into account when human-environment interactions are discussed.

Assigned values have been used by researchers and practitioners to categorise, measure and understand diverse human-environment relations and to inform environmental management (Ives & Kendal, 2014; Jones *et al.,* 2016;). Studies (Chan *et al.*, 2016; Nahuelhual *et al.*, 2016; Bogdan *et al.*, 2019) have been conducted to understand the relationship between assigned value and place which used mapping to identify priority areas for different natural resources management, protecting biodiversity and human well-being. Chan *et al.* (2006) mapped ES in the Central Coast eco-region of California, to ascertain if there was a spatial coincidence between those areas which were being targeted for conservation and those for sustaining ES. The study showed that understanding the relationship between local communities and the nature reserve as space was important in identifying and prioritising conservation efforts. The assigning of the values in these studies, showed commonalities and differences between the categories that people value and the different locations of these values e.g people place different values in places for multiple reasons.

According to Bogdan *et al.* (2019) and Brown *et al.* (2020), mapping is the most preferred method during assigned values study as it allows a better understanding of local contexts for stakeholders when prioritising and valuing an area. Crossman *et al.* (2012) and Brown (2013), conducted ES mapping exercises to provide spatial information on where ecosystem hotspots exist in landscapes which will assist in resource conservation and environmental management. The mapping process demonstrated a collaborative process, which brought people and their different views/interests together (Schröter *et al.*, 2014). According to Brown (2013), the mapping requires an intensive collection of detailed socioeconomic and biophysical data, leading to close collaboration. Thus, people's different worldviews about the resource are brought together during the process. In all these case studies, the mapping led to an intensive collection of detailed socioeconomic and biophysical data which led to a better understanding of the relationships between the people and the natural resource.

According to Schulz *et al.* (2017), assigned values may be connected to politics as the assigning of value is dependent on the power held by the people who value the resource in that space. Fishing legislation may be a result of fishing as a highly assigned value in a particular area by the people. So, assigning values shows how power relations are shaped between the resource and the people. This explains that assigned value may be connected to politics and power relations, in the sense that those valuing a resource for different reasons may hold different power in the society. Schulz *et al.* (2017) further argue that over time the assigned values may impact governance-related values. If a balance and ethics are not taken into consideration, policies and legislation can be developed around values assigned by those who hold more power.

In relation to natural resources, assigned values can be used as expressions of not only the importance and meanings of resources in certain places but also determining how people take care of the environment (Schulz *et al.*, 2017). Studies by Curtis and Robertson (2003) and Seymour *et al.* (2010) explored the relationship between assigned values and behaviour and concluded that assigned values are better predictors of environmental behaviours. According to Ahmed *et al*. (2020), assigned values have a major influence on people's attitudes and actions towards natural resources, and responsibility to their management. Thus understanding the assigned value, role and contexts of that resource in a community are important to understand people's behaviour towards that resource and its management. According to Seymour *et al.* (2010), to encourage pro-environmental behaviour, attention is focused on specific places as per assigned values. Thus, assigned values are more flexible than held values, which are relatively stable.

Assigned value allocated to places can be influenced by individuals' or societal feelings that interrelate nature and self, which then influences assigning (Schultz *et al.,* 2017). Thus, this research uses assigned values to explain river health from an individual and societal orientation. The thesis will also zoom in and pay more attention to assigned social values to explain changes in river health from specific areas and compare them. These assigned values will be used to predict river health changes using assigned values as Seymour *et al.* (2010) explain that assigned values are better predictors of changes. Although current studies have shown the use of assigned values in understanding values placed on natural resources and water resources, however, they do not show utility to determine trends, which is a necessity for monitoring water resources.

Based on the nature and use of assigned values, this thesis draws on Kenter *et al.* (2015)'s definition that when a value is assigned to an object or a place, it is a way of showing the importance or worth of that place relative to another and also guides its management. The assigned values are most preferred in this research since they are specific to an area than held values which are more conceptual. Moreover, assigned value ascribe to resources and places, based on multiple philosophies which include; environmental, ecological, economics and location (Schulz *et al.* (2017), taking an integrated view which is the basis of this research. This research is more interested in assigned values as assigning values to places relates to identifying individually valued objects (i.e. species, habitats) in that area, which is also relevant in river health assessment. Studies (Horlings, 2015; Brown *et al.,* 2020;) which have used assigned values in conservation have incorporated a system of 'weighting' based on a set criterion (e.g. level of threat, uniqueness and benefits). The weightings show that natural areas may be valued differently either for benefits or for their own sake which is an intrinsic reason (Kumar & Kumar 2008). The consideration of weighting based on nature for itself and people's benefits is a pathway followed by this thesis. Ives and Kendal (2014) show that people with an environmental orientation may value a park for biodiversity, while people with a social orientation may value the same park for its cleanliness, which portray an integrated value system, which this research is also portraying in river health assessment.

2.9.1 Social value of rivers

The previous section of this literature review shows that society remains important in understanding the spatial context, societal choices, values, structure and function of ecological systems. Cobb and Rixford (1998) argue that how people relate to water resources will differ among social groups (for example, age) and across different geographic extents (for example, distance from the river) and individual experiences (memories of experiences). These social values are imparted through exposure to individuals' experiences and society's cultural norms. Choices of values on a river may be driven by individuals, communities, societies or governments through a complex series of processes, interactions and experiences. Tickner *et al.* (2017) highlight that social values of water are associated with the unique use of each society, which influences the way water is managed. Thus, the way water is understood and managed, depends on the value people place on it. This section highlights how, the different experiences, of water use benefits, are realised and distributed across a river resulting in social value formation.

Cultural and spiritual value of water

Rivers exist in a natural habitat; this exerts influence on the socio-cultural system of the catchment. River systems are historically situated ecocultural systems, where a special bond exists between the people and water (Tempelhoff, 2008; Daniel *et al.,* 2021). According to Harmsworth *et al.* (2016), people use the river for cultural and spiritual rituals and regard the river as a source of life and a sacred place where ancestors reside. Cock (2018) describes the Kowie river as an ultimate life-sustaining resource when describing its cultural role. This has resulted in members of communities having great respect for the river and its role in their spiritual lives. Cultural values of water are part of society's history and everyday lives concerning the river. Cultural, traditional rituals, religious practices and beliefs associated with the river form an important part of the lives of people living in proximity to the river (Mboweni & De Crom, 2016; Nahuelhual *et al.*, 2016; Acabado & Martin, 2020). Hussain and Floss (2016) argue that rivers can be either natural entities that people adapt and react to or cultural and meaningful entities they experience and interpret in different ways. Since human beings live in societies and each society possesses a culture that may be passed freely from one generation to another through cultural diffusion (Kumar, 2017). Gunasena (2017) explains that these socio-cultural systems vary widely in their structure and organisation and this is attributed to differences in physical habitats and society's attitudes, values, ideals and beliefs. Cultural water values cannot be homogenised into one perspective, as they are regionally diverse and complex, although there are some commonalities and distinctions (Altman, 2008). Thus, a river's cultural value has multiple reference points due to the community's differing identities, relationships, behaviours or attitudes.

According to Bouguerra (2006), people attach different symbolic cultural meanings to rivers using different attributes. For example, water flow is an important attribute for the cultural use of a river. Oestigaard (2009) and Rinne (2001) describe a river as alive because of its flow movement which is suitable for giving life. The authors argue that the river's flow symbolises its virginity, purity and freshness. According to Gunasena (2017) and Anderson *et al.* (2019) water flow is a connector, giver of life and cultural purifier to counteract evil effects. Gunasena (2017) argues that as the river's water flows in unique patterns it cleans and purifies; giving life to everything that grows and destroying evil. The author further argues that river flow is an important value of a river, as this attribute signifies purity - physically and symbolically. Thus without the required water flow, the ability to cleanse is lost. Most cultural use of water recognises flow as an important attribute for the cultural role of freshwater resources (Altman, 2008; Tipa & Nelson, 2012). Therefore, the river flow gives water power and value, which is the life-giving power.

What is also of importance is that society places value on different areas of a river and the justification is based on the cultural significance of that area. According to Bernard (2003) and Mahlangu and Garutsa (2014), in most cultures, there are sacred places in rivers reserved for cultural practices. The author highlights that this practice is common to many indigenous groups in Africa, as the local communities believe that these areas are to be reserved. Mahlangu and Garutsa (2014) found that river pools were identified as sacred places as they were habitats for mermaids and used for cultural rituals, thus people were discouraged to use these areas in the river. These reserved sacred places in the river are not only for cultural rituals but also have ecological significance, to conserve important areas with endangered species (Wilson, 1993; Cock, 2018). This results in animal and plant species growing around these sacred areas being less disturbed than those in other parts of the river as people are discouraged to visit these areas in the river. The reserving of cultural places in rivers is explained by Mboweni and De Crom (2016) as a demonstration of human entanglement with nature with specific landscape features. These features can be identified as key areas of integration between people and the river.

Despite that the reviewed studies, show that society place value on water resources based on its cultural value, it might not be easy to measure this cultural value. Harmsworth *et al*. (2011) in trying to come up with cultural indicators for river health in New Zealand reported that the greatest challenge is that, culture evolves making consistent measurement impossible. Mostert (2018) and Anderson *et al*. (2019) explain that measuring cultural value may not be simple as culture is dynamic and may change over time and most of it is not documented. Thus, comparing past cultural and current data might be a problem. Harmsworth *et al.* (2011) identified shared learning of cultural norms as an important approach to ensure that, information is kept going within a group and to choose different measurement methods that encourage shared learning with the cultural groups. This can be fundamental in areas regarded as culturally significant.

Aesthetics values of water

Pflüger *et al.* (2010) describe the aesthetic quality of a river is to provide pleasing sensory experiences based on scenic beauty or visual amenities. Tallar and Suen (2017) established that intangible, sensorial and emotional aspects of landscape appreciation approaches are used to determine a river's aesthetic values. People's beliefs and aesthetic values and attitudes shape the degree of satisfaction about the river. This shows that its measurement is more qualitative and based on personal feelings. Studies show that there is an empirical relationship between rivers and scenic beauty, with the flow as a major determining factor in influencing river aesthetics (Corrigan *et al*, 2009; Pflüger *et al.,* 2010; Bark *et al.,* 2011; Mostert, 2018). The state of the river determines its appeal to the people and the kind of relationship that results. Pflüger *et al.* (2010) assessed the value of flow for aesthetics and noted that the river's aesthetic value was related to its flow. The study concluded that the natural state of river flow, coupled with the diversity of a river are important variables for its aesthetic quality which was important to residents. River flow levels and river's aesthetic quality were also assessed by Brown and Daniel (1991), who found that aesthetic quality (as indicated by scenic-beauty scores) increased with the increasing flow to a maximum. The association of the flow of a river with aesthetic levels of the river shows the relationship between natural and human environments. It is a demonstration that rivers rely on their physical characteristics to appeal as visual and aesthetical attributes, resulting in the formation of social value about the river.

Personal attachment

People recognise, value and interact with rivers in various ways, which may lead to attachment. Interaction and association that people built with a place led to attachment (Lin & Lockwood, 2014; (Brown *et al.*, 2015; Escalera-Reyes, 2020). According to Herrmann *et al.* (2016), place attachment develops through a social process of human experience and perceived characteristics of a location. Place attachment is influenced by physical, social and cultural factors, time, memories and experiences, place satisfaction and interaction (Hashim *et al.,* 2013). Viewing a river as a place of attachment emphasises the importance of human experience and social relationships between society and rivers. Ganzevoort and van den Born (2019) explain that attachment in rivers may develop as a result of human connections through use or experience with the physical river. This shows that attachment is a subjective quality that shows connections to place and social context (Hay, 1998). Attachment to a place differs per human experience and history, which leads to assigned social meanings of the physical area by people. How people assign the area will differ according to their experience and feelings. This means that place attachment develops as a social process but is rooted in the physical setting. The area's physical features, activities and meanings of the river are considered as the main constructs that lead to social valuing and attachment (Najafi & Kamal, 2012). This means that for attachment to take place, people should be satisfied and value the area's physical features.

Place attachment has been used in studies to understand people's attachment to rivers and subsequent river management as a result of the attachment (Agyeman et al., 2009; Jacobs & Buijs, 2011; Åberg & Tapsell, 2013). The main conclusion was that people are attached to different parts of the river they value which also influenced how it is managed. These exercises led to quantifiable attachment to different parts of the river understudy. Assigned values are more specific and focus on a specific place and the value can be used to compare different places or objects (Seymour *et al.*, 2010). According to Mulvaney *et al.* (2020) attachment to a place is a good indicator of value, which shows the social value of a physical area through emotional connection. The authors further state that the social value of the area portrayed by place attachment usually manifests through environmental protection responses, concern, intentions and behaviour. As a result, the place-based attachment approach is used in managing natural resources when working with local communities to understand their place-based values (Kainzinger *et al*., 2018 & Verbrugge *et al.*, 2019). Whitehead *et al.* (2014) combine social values of biodiversity to generate various conservation planning scenarios. This is useful to ensure the acceptability of environmental management actions as participants' mapped areas of social value.

To determine the relationship between place attachment and values people hold about an area, the Public Participation Geographic Information System (PPGIS) method is commonly used. This method involves stakeholders interacting with maps to show places they value and are attached to. Studies have recommended mapping to show attachment to space through landscape values as a natural resource management tool that identifies areas to be prioritised (Drenthen, 2013; Brown *et al.,* 2015; Brown *et al.,* 2020). Brown (2013) used place-based values to link the ecological traits of an area to the landscape history. In these studies, the common conclusion is that different participants associated place attachment with how people value the natural landscape or natural resource; which include; aesthetics, economic provision, recreation, biological diversity, spiritual, historic and cultural values of the different sites. People are linked to geographic areas with significant dimensions of the area. The attachment reflects the relationship between people and the environment. People's values for certain parts of the river led to the formation of strong attachments and the way it is managed.

Despite that literature has shown multiple social values of rivers (aesthetic value, cultural and spiritual value), managers are not well versed in techniques relating to social value analysis. Norton and Noonan (2007) argue that there is anxiety in considering social value in ecological management decisions amongst scientists. According to Ives and Kendal (2014), natural resources managers are not well versed in methods and literature related to assessing social values and incorporating them into ecological management decisions. The main contentious issue is that the definition of value has different interpretations and applications, which might not be viewed as 'scientific' enough during the development and use of ecological models. According to Brown and Reed (2012), the main contestation is that social values are subject to people's feelings and relationships with the resource. This has led to social value being overlooked because it is 'subjective' and thus difficult to quantitatively assess. However, Brown and Reed (2012) suggest that social values are useful to show how people engage with conservation and ecological issues and explain the connection between people and the environment.

According to Larson *et al.* (2013), a more comprehensive view can be achieved with social values, as scientific knowledge can be considered subjective and dependent on personal background and ideologies. Robbins (2003) suggests that this can be epitomised through the inclusion of local ecological knowledge. Literature shows that local knowledge has a great potential for monitoring, as it has been used to understand vegetation changes and disaster reduction (Verlinden & Dayot, 2005; Davis & Ruddle, 2010; Tomasini & Theilade, 2019). However, often local and indigenous knowledge can be difficult to reconcile with scientific methods because of its closeness with morals, beliefs and values (Gadgil *et al.,* 1993) and its basis on perceptual 'measurements' (Verlinden & Dayot, 2005). However, McIntyre *et al.* (2008); Tomasini and Theilade (2019); Williams *et al*. (2020) argue that indigenous peoples and communities have vast knowledge and values related to their environment, which will achieve long-term conservation goals and gain community commitment. These local communities are the ones that have to deal with decisions made to protect or manage their environment.

Research shows that major challenges exist in dialogue building related to epistemological differences between local ecological knowledge and scientific knowledge (Chalmers & Fabricius, 2007; Berkes, 2012; Bender *et al.*, 2014; Alexander *et al.*, 2019). Local knowledge has sometimes been considered irrational and scientific knowledge has been given a superior role due to its universal character. This shows an asymmetric dialogue between scientific and traditional knowledge. This may be a result of ontological differences in the two knowledge systems and the way it is generated. However, Agrwal (2002) considers the differences between scientific and local ecological knowledge and suggests a balance between the competing values. The balance is necessary as scientific information is mostly focused on what can be presently measured using pre-specified indicators without considering human experiences and other societal knowledge. Local knowledge considers people's experiences, social norms and social connections which can broadly influence an environments' prevailing conditions. Scientific information is based on specific information understudy. Thus, the use of both local and scientific knowledge create a balance through consideration of each knowledge system's traits creating a systematic view of the knowledge systems.

2.9.2 Potential of social values in river health monitoring

The previous research suggests the inclusion of social values in natural resources, river and water management but their potential in river health is not explored. Whitehead *et al.* (2014) and Mostert (2018) state that the potential use of social values is arguably one of the most important achievements in river management; however, their potential remains poorly exploited in river health assessment. Ives and Kendal (2014) identified five attributes that make values important in monitoring and management of ecological systems, namely that:

(i) values change over time;
(ii) values differ between groups of people;
(iii) multiple values can be assigned to the same places;
(iv) multiple pathways exist between values, attitudes and behaviours towards ecosystems; and
(v) values influence people's judgement of management decisions.

Considering that the thesis uses social value to determine river health changes, it is vital to also discuss the nature of value changes. Liberati *et al.* (2010) state that, when value change is manifested, it means there is a shift and major reshaping of life circumstances e.g. ecological devastation which also changes how people view and use that resource. Manfredo *et al.* (2017) also argue that when value change happens, it is usually a result of large-scale social-ecological change in a system. The values that change are substantial, as they lead to new behaviours and attitudes (Dietz *et al.,* 2005). However, Manfredo *et al.* (2017) argue that the value shifts in natural resources management build on prior value structures, and there is no complete replacement of the previous values.

Literature shows that a change in the value of one aspect does not lead to a substantial change in all other value aspects of the system. In as much as some values change, there are core held values that are stable that remain and these values are the most fundamental values in that society. As highlighted in the previous section, held values are fundamental and stable as they are the principles, moral standards of a person about what is important and are constructed from life experiences and social characteristics (Lockwood 1999). So, what changes are mostly the assigned values, as these are more related to individuals' feelings that interrelate nature and self (Seymour *et al*., 2010). The value shift proceeds in a path-dependent manner, with no complete replacement of fundamental values but of assigned values. A study by Manfredo *et al*. (2017) on conservation values among residents in the United States revealed a shift from values towards wildlife based on personal experiences, which reflects the assigned values of nature. However, people continued to reflect the cultural orientations in their countries of ancestry, which was grounded on their fundamental values. Inglehart and Baker (2000) studied value shift to determine if modernisation caused values to converge towards a homogenised global culture. The study concluded that whilst assigned value change occurred, the people maintained pre-existing differences (fundamental values) among cultural groups. These studies illustrate that while there is a value shift, it occurs gradually in response to social-ecological changes in its surroundings (assigned values) without affecting the fundamental values. The authors further argue that the value shift proceeds in an incremental manner as the values are varied and exist at all levels and across all social structures, shaped by epigenetic influences.

Assigned values are quick to change and the held and fundamental values are more stable. The incremental changes of values make them suitable for river health determination as these can show incremental changes taking place in the river and this is a similar fashion followed by ecological indicators. Boulton (1999) explain that river health ecological indicators change incrementally as they have different sensitivity levels. The most sensitive disappear first after a pollution event, with the most tolerant remaining. Ormerod *et al.* (2010) support that the impacts of multiple stressors on different ecological indicators is not the same e.g fish and macroinvertebrates have different pollution tolerance levels. Thus the effect of multiple stressors on a water resource is incremental.

Based on the literature reviewed which showed that value change is also incremental, as the fundamental held values remain even after a major social-ecological change which is also similar to how ecological indicators of river health change, this shows that the time-scale of ecological and social values is congruent and thus they can be co-used to explain social and ecological changes in river health. The processes by which the core held values are formed and sustained make them resistant to rapid change without major reshaping (Jackson *et al.*, 2008; Kenter *et al.*, 2015) similarly to tolerant species which take a while to change after a pollution event. Manfredo *et al.* (2016) state that held values is the cognitive foundation on which people's prioritisations are built and transformation thus will shift as a result of a major driver of a value-shift. Whilst assigned values relate to specific natural places, they are better predictors of immediate changes as they are dependent on feelings, therefore that means they are likely to show short term changes, similarly to sensitive ecological indicators that change at the onset of pollution or ecological change. Seymour *et al.*, (2010) expand that assigned values are influenced by the prevailing conditions. This means that the assigned values are good predictors of prevailing river health status as they determine the present status and areas of concern. So, a social value-based approach has the potential to add to the understanding of social-ecological system change, by complementing ecological measures as assigned values can pinpoint exact points of concern and immediate changes (Andrachuk & Armitage, 2015). The value system shows changes based on different interactions that society has with nature. The assigned value's based on feeling can be used to show short term changes and also specific areas to pay more attention to before any catastrophic change which can be shown through change in held values. Thus value can be co-used with ecological indicators in river health monitoring to explain the changes incrementally in response to alterations in the social-ecological context as they tend to respond similarly.

As discussed in the previous sections, several authors support the contention that values are formed from a foundation of attitudes and beliefs, which in turn influence behaviour or intention (Hermans *et al.,* 2006; Horlings, 2015; Kenter *et al.*, 2015; Bogdan *et al.*, 2019). This means that values interact with cognition, as Jones *et al.* (2016) explain that values underpin decisions and behaviour. Therefore, studying social values in river health can provide insight into people's differing viewpoints about the river resources' health status, as well as how it is managed and experienced. Values enhance understanding of the deeply felt and emotional basis of people's interactions with natural systems and improved understanding of how a river as an SES function can be strengthened (Jackson *et al.* 2008). The social value information in SESs is identified in places of special meanings thus any changes in the places over time can lead to social value change (Ives & Kendal, 2014). Social valuing tends to target spatial features which evoke unique experiences (Hussain & Floss, 2016). So, this social value-based approach potentially adds nuance to the social-ecological system by tracking and understanding changes within the system based on experience with the area about the distinct features. Social values are regarded as residing in the environment, so they can identify significant changes based on people's value structures. This can ultimately complement ecological outcomes by bringing in human experience, particularly in areas that experience significant human interaction.

In the SES approach, humans are viewed as an integral part of ecosystems that benefit through ES and it is recognised that they both affect and depend heavily on natural environments *(Petrosillo, et al.*, 2015). Therefore, any change in the SES will be shown by value changes. Values are an important characteristic of people; they help shape judgments people make and explain why different people or social groups make certain decisions (Kenter *et al.,* 2015). Thus, Vugteveen *et al.* (2006) believe river health not only regards the function and structure of the ecosystem but should also include social and human values. Sherrouse *et al.* (2011) used an application called Social Values for ES (SolVES) to integrate attitude and preference survey results on ES with data of the physical environment. This study adopted the SES systems view and embraced that values are goals that one learns and that they relate to an array of behaviours that are readily vulnerable to change. To understand the health of an ecosystem, it is important to understand the flexibility and stability of values and human and nature relationships that exist. The changing human values have a major implication on river health. Ives and Kendal (2014) state that social value knowledge has the potential to vastly improve the management and monitoring of ecosystems, as it shows the relationship between people and the environment.

2.10 Link between fish, macroinvertebrates and social value

As explained in previous sections (2.3-2.5), there are a variety of existing methods and indicators for characterizing river health, though they are typically biased towards a disciplinary (e.g., hydrology, ecology, or economics) framing of the problem. As explained in the sections earlier in the chapter, the existing methods of river health monitoring in South Africa are currently more on ecological indicators which mainly focus on fish, macroinvertebrates, riparian vegetation and water quality conditions. Section 2.9 further explain the need for tools and methods to include social value, an important consideration in rivers as social-ecological systems. Thus, this thesis integrates the river's social value, fish and macroinvertebrates to illustrate the social and ecological linkages within the systems. These linkages draw from Ostrom's (2009) general social-ecological systems framework by characterizing river health based on ecological indicators (fish and aquatic macroinvertebrates) with linkages that highlight human water use (social value) of the river.

The macroinvertebrates, fish and social value were used to propose a social-ecological framework and indicators that are congruent to local communities and measure the ecological condition and social value provided by the river. The use of these three indicators will address the current challenge of monitoring freshwater ecosystems by only emphasizing the ecological dimensions (fish and macroinvertebrates), falling short of integrating social value. These three indicators are considered in this study because of their interlinkages. The first linkage is noted between fish and macroinvertebrates, which is through trophic relationships (Wallace & Webster, 1996; López van Oosterom *et al*., 2013). Macroinvertebrate and fish trophic relationships have been established as essential to maintain river communities through the food chain. Winckler-Sosinski *et al.* (2008) and López van Oosterom (2013) explain that fish species fed on different macroinvertebrates as a major food resource in lotic ecosystems. Thus, benthic macroinvertebrates help in the maintenance of fish communities resulting in the establishment of a linkage in the food chain interactions. This means that changes in macroinvertebrates will affect fish communities.

Secondly, as discussed in section 2.5, fish are an important biota as it represents a variety of habitat use; and respond differently to various environmental stressors (Wichert & Rapport, 1998; Levin *et al.,*2019). The environmental requirements and ecological life history of most fish species are well studied; therefore, can be easily integrated and interpreted to explain the river's ecological health. Moreover, according to literature (Weeratunge *et al.,* 2014; Lynch *et al.,* 2016; Lachs & Oñate-Casado, 2020), fisheries have social and economic roles as they provide food and nutritional resources, thus sustaining the livelihoods and well-being of the communities. As highlighted that fish is an important resource for communities, community involvement in small-scale fisheries also offers an opportunity to understand its social value (Britz *et al.,* 2015; Berkström *et al*., 2019). Thus changes in fish community structure offer a comprehensive indication of the river's ecological state and is also a social value attribute for its livelihood benefit to the communities. Based on the social and ecological attributes of fish in rivers, it is then considered as the most appropriate indicator in this research, to provide a link between ecological and social components of the river's health.

2.11 Water-resource protection measures in South Africa: legislation, policies and governance

Pre 1994, apartheid policies were designed to perpetuate discrimination in water use and allocation (Chibwe *et al.*, 2012). However, after the change in political dispensation from the apartheid system to democracy, there was a reform in water legislation. In 1998, South African Water resource legislation was reformed, and the NWA was enacted. The NWA regards water as a basic human need and recognises the needs of aquatic ecosystems to remain sustainable (Arthington *et al.,* 2018). The NWA also directs the protection, use, management and control of water resources through stakeholder participation (King & Pienaar, 2011). Chapter 2 of the NWA, requires that the minister, establish a National Water Resource Strategy(NWRS). The NWRS is a policy instrument, which flows from the NWA, which stipulates how the coordination, development and management of water, land and related resources will take place (South African Department of Water Affairs (DWA), 2013). The National Water Resource Strategy's edition was produced in 2004 and amended in 2012 which led to the NWRS2. The NWRS2 builds on the first edition to ensure that water resources are protected and used equitably and sustainably (King & Pienaar, 2011). CMAs were identified as the most appropriate local entities to achieve the NWRS principles (Pegram *et al.* 2006; Chibwe *et al.*, 2012). CMAs helped to decentralise the management of catchment through a participatory approach called integrated water resources management (IWRM) which involves all stakeholders: users, planners and policymakers (Chibwe *et al.*, 2012). However, Nare *et al.* (2011) argue that stakeholder participation in catchments does not come with decision making at all levels, other decisions are kept at central, provincial or local levels of government.

The NWA also set out the legal mandate to ecologically assess significant water resources in the country (Cameron, 2018). According to the NWA, after the assessment, the resource is then classified according to a management class and the Resource Quality Objectives (RQOS) are set according to the assigned class of the water resource. The NWRS2 highlights that since water in these major catchments is used for different reasons, it is impossible to set a high protection class without prejudicing the uses (DWA, 2013). Thus, RQOs were set to ensure water is fit for use (DWAF, 2006). Goals relating to the quality and quantity of the water resources, taking into consideration the uses are established into management classes as the RQOs are set. The River Ecostatus Monitoring Programme (REMP) uses the monitoring of ecological and specific biological components that have been established and approved (gazetted) as RQOs (DWA, 2016) as reference for the management of the different sites to meet the desired class for a specific resource. The RQOs can be numeric or descriptive statements relating to the biota, habitat, flow, ecological and user water quality. Each water resources' management class is developed and based on the need to meet the different users' requirements (recreational, agriculture, domestic and industrial) and ecological reserve (DWAF, 2006). Management classes describe the desired condition of the resource and the degree to which it can be utilised, considering the economic, social and ecological goals of the users and stakeholders (Mallory, 2013). The ecological and social needs of the river are stated as measurable goals (management classes) that show how the resources need to be managed.

The RQOs process includes a vision step, where society's aspirations regarding the catchment are discussed and linked to management actions (DWAF, 2006; Mallory, 2013). The desired state is guided by the vision of each management unit as per stakeholder participation. RQOs are established to balance the use and protection of resources. O'Brien and Wepener (2012) state that the RQOs' specific management goals are considered as the first step to allow for the development of suitable endpoints which aim to achieve a balance between use and protection. These goals are aspirational but realistically attainable based on how the river is used. During the RQO determination in the Inkomati Water Management Area, ES were identified based on common land use forms (Mallory, 2013). Although stakeholder participation is encouraged in RQOs determination, in the Inkomati catchment management area, however, the identification of ES important in the area was based on existing data and information with limited stakeholder consultation. The RQOs framework does not cater for the full participation of stakeholders to identify ecosystem services in the catchment and setting up of RQO's' indicators.

2.12 Political ecology

Based on the discussions in 2.6, one can highlight that the SES theory is a broader way of conceptualising the human and nature perspective. Literature also shows that different units which can be social, political, economic and cultural interact with each other in an inseparable manner to produce outcomes at the SES level (Petrosillo *et al.,* 2015). However, some studies (Epstein *et al.,* 2014; Fabinyi *et al*., 2014; Welsh, 2014) as discussed in section 2.6 have indicated that issues of power and contestations are not explicit in most social-ecological studies which discuss human and nature relationships, although power is important in understanding rules governing the system. Therefore, this thesis will explicitly consider political ecology as a way of bringing power and contestations to the forefront of understanding human and nature relationships in river health through the SES theory. The political-ecology concept is more specific as it specifically focuses on power and contestation issues to analyse human and nature relationships in the SESs, through the waterscape and socio-nature concepts.

Political ecology scholars (Swyngedouw, 1999; Boelens, 2014; Bassett & Peimer, 2015; Bourblanc & Blanchon, 2019) have interrogated the social-ecological relationships in water resources through socio-nature and waterscape concepts which are adopted in this thesis. Karpouzoglou and Vij (2017) define waterscape as an outlook to combine societal and natural interaction of water with a critical understanding of nuances from the interactions. The waterscape concept was developed by Swyngedouw (1999) to try and remove the division made between nature and society. The author foregrounded the concept to demonstrate that water and society are deeply intertwined and reflects on the complex ways that make the relationship inseparable. Water's fluid characteristic makes it difficult to capture in one category, as it flows within different physical areas, cultural, social structures and politics (Swyngedouw, 1999; Karpouzoglou & Vij, 2017). These areas, cultures and political traits can be identified in the water resource by the way its governed, used or managed. The waterscape concept has been widely used to explain the relationship between water, society, political and economic contestations (Karpouzoglou & Vij, 2017; Rusca *et al.*, 2017; Swyngedouw & Boelens, 2018; Aigo *et al.*, 2020). The waterscape concept is used to understand the social and political processes through which water is conceived and used. Much attention is paid to understanding the role of power and the contested nature of water in diverse landscapes. Budds and Hinojosa (2012) and Jackson and Barber (2016) conducted studies to understand water-society interactions based on the waterscape concept, which enable the consideration of history and expression of power. Jackson and Barber (2016) and Sen *et al.* (2020) used the waterscape to explain the indigenous people's relationship with the river and power relations that emerge and have the potential to transform with water flow. The studies argued that in as much as water is a natural resource and of societal use, it also possesses political power and history which are embedded in the ecological processes, thus it should be analysed as a waterscape. The studies further use the waterscape concept to argue that natural and social processes and power relations do not work exclusively but rather work as socio-natural conditions.

The waterscape concept helps in bringing in a sharper analysis of existing relationships between water and society within the socio-spatial context of the catchment (Perreault *et al*.,2012). The authors highlight the interactions between the natural and social realms of water through time and space and expand to show that social hierarchies and dimensions materially manifest on the waterscape during the interactions. Thus, according to Cohen and Davidson (2011), waterscapes manifest through interrelationships between social and geo-ecological processes. Sutherland *et al*. (2015) understood waterscape as an outcome from actor coalitions, their power relations, discourses and knowledge, technologies and infrastructures, all embedded in multiple spaces that work together. The multiple actors produce 'spaces' in the waterscape which represent who they are in relation to the water resource.

Zimmerer and Bassett (2003) and Budds (2008) conceptualise the waterscape as not only a produced socio-natural entity but also how water flow is controlled and shaped by social relations, power dynamics, institutions and the responses of nature to this occupancy (Budds & Sultana, 2013). Power dynamics are inherent in interactions between society and nature across multiple scales (Volenzo & Odiyo, 2018). Water flow and local politics strongly influence water use patterns (Venot *et al*., 2007); in the process, a waterscape is produced. Hydraulic infrastructure is regarded as an agent that opens certain trajectories while foreclosing alternative pathways in society (Swyngedouw, 1999; Ahlers *et al.*, 2011; Meehan, 2014). Thus, Karpouzoglou and Vij (2017) explain that studies that focus on waterscapes should be sensitive toward water flow and its uses. Kemerink-Seyoum (2015) used the waterscape concept to not only understand the social and natural constitution but also how this interaction within the produced landscape affects and is affected by physical and hydraulic infrastructure in the catchment. The authors concluded that water's directional flow and fugitive nature have a role to shape and reshape society.

The waterscape concept shows ways in which nature and society are fused making them inseparable and resulting in a hybrid. The concept criticises the notion that nature is a backdrop to society but rather emphasises the production of a socio-nature hybrid between nature and society. Water is described as a hybrid that comprises power, contradictions, tensions, history and conflicts which are a result of the relationship forged between people and water use (Cornut & Swyngedouw, 2000; Loftus & Lumsden, 2008). Water is explained to be naturally and socially produced, as it represents all the power and social dynamics that exist within its space. The social and natural conditions exerted on the water embodies a hybrid. Karpouzoglou and Vij (2017) argue that through the waterscape lens, nature and society are intertwined and produce hybrid socio-natures that cannot be analysed as purely natural or social. Swyngedouw (1999) developed the notion of socio-nature to explain that society and nature, are inseparable from each other and that water landscapes/waterscapes are hybrid. This shows the emergence of a social-ecological entity transformed from ecological and social processes. The newly formed entity cannot be separated back to the original social and ecological condition. The new entity reflects existing multiple traits within the landscape which include the historical-geographical struggles and social power differences and dynamics of the social-ecological change (Swyngedouw,1999; Cornut & Swyngedouw, 2000; Bear, 2017).

The socio-nature concept has been used in the political ecology of water to overcome nature/society divide. Zimmerer and Bassett (2003) argue that the theoretical underpinnings are that social and ecological systems in a natural environment cannot be distinguished and these are characterised as nature-society hybrids. The reproduction of hybrid socio-nature embodies the natural and the social components as one entity that is inseparable (Dempsey & Robertson, 2012). Swyngedouw (1999) through the socio-nature production explains the operations of power and politics in systems, the process of its formation and where the social and natural system's hybrid is formed (Bassett & Peimer, 2015). According to Loftus and Lumsden (2008), socio-natural relations are formed through daily activities and produce social power. Bear (2017) explains that socio-nature is rooted and highly engaged with the processes of production that lead to heterogeneous material and discursive human and nonhuman entanglements. This shows that through daily human interaction power is produced and the same power produced is also critically important to explain water flow patterns.

Whilst political ecology literature may have engaged on waterscape and socio-nature concepts, studies on water and environmental change have analysed the social and nature interactions without analysing the formation of the new intertwined nature of water formed (Zeitoun *et al.*, 2016). According to McIntyre *et al.*(2008) and Hoque *et al.* (2017), environmental change studies are more about values and socio-political factors that look at how people think about the environment without considering the socio-nature formation which has become more crucial. These studies argue that the processes that recognise social-ecological change, capture social, political and material dimensions of the river or water that led to 'hybrid formation' are not clear. The principles of the waterscape concept offer a more focused and sensitive view towards understanding the role of power in water process, flow and uses (Karpouzoglou & Vij, 2017). According to Swyngedouw (2004) and Loftus & Lumsden (2008), the waterscape concept is an entangled view of explaining water's socio-environmental problems based on geographical locations and driven by a need to understand complex interdependent water challenges, that cannot be entirely separated as either natural or social. According to Karpouzoglou & Vij (2017), the waterscape concept is a specific concept that explores contemporary interpretations on the role of power, informal practices specifically to understand water and society relationships. Drawing from the reviewed literature, it is imperative to note that, the waterscape brings out a distinct geographical position and detailed evidence on water and society relationships with major analysis of the spatial relationships and the power contestations that result from these relationships.

This study draws on work by Bouleau (2014), who used waterscape and socio-nature concepts to explain changing water quality and geomorphology in the Rhône and Seine rivers; how the rivers are shaped by external social relations of power and raising place-specific problems. In the analysis, the study demonstrates the destruction of the dual nature/society by showing and explaining the processes through which the water socio-natures are actively reworked as water flows. This research seeks to follow the methodology from this research by presenting how the Lower Komati River health reflects human and social relations and accounts for all the processes through which the socio-nature is formed as water flows through the Lower Komati waterscape. This thesis will take it a step further by identifying the outputs from the hybrid and how they can be used to improve river health monitoring. The thesis argues that understanding the processes leading to the formation of the hybrid through the socio-nature concept will improve understanding of river health and its drivers.

This research considers waterscape and socio-nature as important political ecology concepts to analyse river health social-ecological dynamics as South Africa has a long tradition of linking environmental issues and politics. Pre-1994 (during apartheid), water distribution in South Africa was unequal and disadvantageous as rural areas and townships where blacks mostly resided, were unlikely to be serviced with clean drinking water (Loftus, 2005). Post-apartheid water reforms were introduced and debates on extending water access to all groups started. The debates led to the reform of the Water Act, policies and the development of the Reconstruction and Development Programme (RDP) document. The RDP was the government's commitment to achieving targets of distributing water to all residents (Loftus, 2005). According to Bourblanc and Blanchon (2019), the politicisation of water issues in South Africa is a result of a thriving epistemic community on water sciences and the country's past political history which promoted the development of the political ecology approach to water issues.

Literature on water's political ecology in South Africa has been on how power influences water access and distribution, which is mostly grounded on the political agenda of redressing inequalities toward historically disadvantaged individuals in post-apartheid South Africa (Loftus, 2005; Galvin, 2011; Galvin, 2016). Turton and Warner (2002) discuss how infrastructure and water scarcity may possess the power to show skewed water distribution patterns. The study demonstrates how water infrastructure can be politicised and that water scarcity is not purely a physical attribute but a social-ecological concept that is constructed based on the catchment's history and location. Galvin (2011) reflects on the water dialogues- a multistakeholder process to understand barriers of real participation in rural water service delivery dialogues. The author analyses complexity and dynamics in a rural area in South Africa and argues that, although women actively participated in the water dialogues, the existence of politics of power in municipality structures drowned their voices and opinions. Water access and delivery in the area could not be simply explained as a technical or physical matter but social, political and power implications were identified.

Galvin (2016) also investigated water and sanitation struggles using different forms of civil society's engagement in Durban, South Africa. The author argues that civil society engagement has a great role in addressing sanitation struggles although structural realities are a constraint. The author identifies civil society responses as a catalyst for change, to incite the municipality's water and sanitation interventions and promote relevant policy changes. During the water crisis in Cape Town, Galvin (2018) through a newspaper article analysed the water shortage and argued that drought was not solely responsible for the water shortages. The article explained that the social and political implications should not be overlooked to account for the water crisis. The article argues that water distribution in the city was unfair, with levies imposed on poor households and high water consumption occurring in affluent areas of Cape Town. Bourblanc and Blanchon (2019) focus on water allocation reforms in South Africa whilst politics around water-land resources shared in rural areas is discussed by Marcatelli (2018). Marcatelli (2018) interrogates how structural inequalities in South Africa have led to farm dwellers whose homes remained in the privileged side of the country still lack secure access to water. All these political ecology studies of South Africa's waterscape are largely shaped by complexities in water access, inequalities and unfair distribution in the country. This affirms that society and water are inseparable, which affects water access in South Africa. Thus, it is important to analyse and determine if the same applies to river health in South Africa.

As a result of water studies in South Africa that reflect society, power and nature representations as important to explain how water access and distribution in South Africa is presented, it is apparent that all water management studies should be broadened to analyse all social-ecological dynamics. Thus, it is crucial to understand how this unfolds in river health studies in South Africa, which has not been explored. The socio-nature and waterscape concepts are suitable to explain river health from a social-ecological point of view to understand the products of the interaction between society, power politics and water resources. The waterscape and socio-nature concepts will be used as they have similarities and commonalities as they address the complexity of human and nature interactions and the production of a hybrid from social and ecological components of a natural resource. The concepts complement each other in this study as they investigate ways through which social (such as power relations, political struggles) and water interactions (understood through waterscape concept) lead to the shaping of the social-ecological environment of the river (Boelens *et al.*, 2016). The socio-nature concept analyses the formation of the products and hybrid that come about as a result of the interaction (Karpouzoglou & Vij, 2017). The socio-nature concept interrogates the ontological inseparability of nature and society and looks at how hybrid social-ecological ways of monitoring river health (indicators, knowledge and sampling sites) may be formed. These two concepts will demonstrate an integrated approach to expand the understanding of river health and the multidimensional complexity of the relationship between local communities and the Lower Komati River. The waterscape in this thesis is considered to guide the interpretation and development of new indicators and sampling sites that demonstrate a hybrid. The socio-nature and waterscape concepts allow the consideration of river health as not purely ecological or social but a hybrid of their nature.

2.13 Citizen Science in Water Resources Management

Comprehensive understanding, monitoring and management of natural resources and ecosystems are often confounded by inadequate data and monitoring initiatives, thus non-scientist communities are incorporated and this is termed citizen science (Conrad & Hilchey, 2011; McKinley *et al.*, 2017). In citizen science, scientists and non-scientists work together to collect data, create awareness, track changes and manage natural resources (Kolbe, 2014; Pandya & Dibner, 2019). A typical citizen science project model is that scientists formulate and develop data collection protocols, thereafter recruiting and training participants for the project (Bonney *et al.,* 2009; Bonney *et al.*, 2016). Scientific professionals and experts institute the data collection or monitoring exercises and then collaborate with non-scientist communities who volunteer to collect data and be part of a scientific enquiry (Shirk *et al.*, 2012; Bonney *et al.*, 2016). According to Mahr and Dickel (2019), it brings citizens closer to the core of scientific knowledge by involving them in data gathering, generation and interpretation.

Water resources management has also undergone a major paradigm shift where stakeholder involvement has gained importance in citizen science activities. In water resources management, these communities monitor the quantity, quality or health of water resources they depend on for their health and livelihoods (Kolbe, 2014; Cele, 2015; Long, 2017). Apipalakul *et al.* (2015) and Coetzee *et al.* (2016) recognise the value of citizen science in water resources monitoring programmes, which leads to their sustainability. Public participation has been identified in water resource management as important to involve communities in coming up with management strategies (Mashazi *et al.,*2019; Global Water for Sustainability Program (GLOWS) (2015) which is necessary for better management of the resources. Nare *et al.* (2011) and Tantoh and Simatele (2017) advocate for community participation to improve water resource management, efficiency and efficacy. Communities have taken an active role in monitoring natural resources, which leads to educating and empowering local communities in their proximity (Reed *et al.*, 2008; Cunha *et al.,* 2017).

Some authors advocate for the participation of communities in resources management to be multifaceted - to include engagement enhanced with knowledge and the creation of supportive attitudes, values, capability strengthening and development (Dean *et al.*, 2016; Tantoh & Simatele, 2017; Euler & Heldt, 2018). This means that for a citizenry to be considered as involved they should understand, value and be actively engaged from the inception of the project. Cundill and Rodela (2012) state that community monitoring approaches have changed over time, from engaging to collaborative management, which takes into consideration local contextual issues. Dean *et al.* (2016) state that engaging the community in context is important as it recognises the community's existing local knowledge and experience of water management in that catchment. Manseau *et al.* (2005) explain that stakeholders during citizen science data collection contribute their knowledge, different values and perspectives for the benefit and protection of the natural resource. When working with scientists the local communities, build relationships and offer their broad knowledge which encourages knowledge sharing (Pandya & Dibner, 2019). This shows that monitoring offers a good ground for social learning, as it allows local communities and scientists to learn from each other during the process and may enhance wider participation.

There is a growing body of literature suggesting that a combination of local and scientific ecological knowledge may empower local communities to monitor and manage environmental change easily and accurately (Hiwasaki *et al*., 2014; Medeiros *et al.,* 2018; Williams *et al*., 2020; Hill *et al.,* 2020) This collaborative consideration of the two epistemological knowledge promotes linkages between communities and scientists, as these diverse actors, their knowledge and values are promoted as critical for natural resource management (Williams *et al.,* 2020). Ballard *et al.,* (2008) argue that a combination of scientific and local knowledge has positive outcomes in unearthing values, conflict resolution, institutional trust-building and building capacity to better understand and address environmental issues. The combination of scientific and local knowledge works to understand relationships between people and the environment (Williams *et al.,* 2020). However, an effort must be made to identify and take into account these different knowledge perspectives.

Reed *et al.* (2008) used the Kalahari as an example to show how local and ecological methods can be combined to develop indicators. In this research, environmental sustainability indicators for semi-arid rangelands in the Kalahari, Botswana were developed and used by specialists and non-specialists, by integrating local knowledge with ecological data. The authors found that for the collaborative processes to effectively take place, they should be based on contextual realities. The goal is to develop an approach that combines rigour and accuracy with consideration to relevance and sensitivity to local perspectives and context, for scientists and communities to work together towards shared aims. The conclusions drawn were that indicators developed through the integrated participatory and ecological research could be combined for more accurate and relevant results and that it is important to test local indicator knowledge empirically, to reliably detect long-term trends.

The greatest challenge in citizen science is considering communities' inputs similarly to scientists' input during monitoring. Pandya and Dibner (2019) argue that the community's experiences, realities and monitoring methods are often ignored in natural resources monitoring. Perry (2009) explains that the way local knowledge is expressed may be regarded as political knowledge, not just knowledge about the environment. The author explains that local knowledge is usually expressed by local people who are concerned primarily with political problems regarding environmental rights and access. More to that there are also claims that combining local and scientific knowledge will dilute the rigour and objectivity that comes with science (Karr *et al.,* 2017). Hohenthal *et al.* (2018) attest that local knowledge is positioned within the subaltern position of power. Subaltern refers to subordinate in hegemonic power of the ruling class, where subordinate social groups are displaced to the margins of society (Hohenthal *et al.,* 2018). The failure to consider local knowledge and communicate science as a dominant form of representation shows that local knowledge has a subaltern position. According to Eimer (2020), local knowledge has sometimes been subaltern because of modern systems, the emergence of capitalism and the coloniality of power. The authors highlight that western society has established institutionalised knowledge production and given absolute power to scientific knowledge and proximity of the knowledge to colonial power. Thus, locally produced knowledge often held by indigenous groups belongs to the subaltern strata of society.

In South Africa, the importance of stakeholder participation, input and citizen science in water resources management has been recognised at all levels, such as high-level pronouncements backed with country-specific legislation and policies to support the involvement of communities and all stakeholders. Over the last 20 years, there has been increased recognition of the right of communities to participate in water management decision-making processes (DWAF,2001; Nare *et al.*, 2011). Such initiatives are enshrined in the country's legislation. South Africa's NWA requires that water management be more people-oriented and afford opportunities for the active participation of local communities (DWAF, 2004). Thus, water management in South Africa is restructured to ensure the participation of the public in water resource management (Boakye & Akpor, 2012). The NWA establishes catchment management forums as an institution to offer opportunities for citizens to participate in water resources management. In these forums, decision-making processes involve community participation. Moreover, the National Water Strategy 2 (NWRS2) explains that water management should be within a social, economic and ecological environment and that citizens' participation is prioritised (DWA, 2013). The participation was imagined to increase and balance decision making through community forums and civil society organisation structures.

During the initial design phases of the RHP, a study was conducted to establish a link between the rivers and communities and to ensure the involvement of communities. Roux (2001) states that social and cultural awareness of local people's circumstances on the ground was established during implementation through a project called Grassroots Communication and Environmental Education (GCEE). The awareness ensured a harmonious relationship with the community, during the implementation of the RHP. According to Roux (2001), the main aim of the GCEE was to develop proper means of associating the technically oriented biomonitoring approaches (top-down) with community-based methods of conservation (bottom-up) as a means to advance the RHP. Roux (2001) states that lessons from the case study could be used to develop 'social tools' which would motivate communities to participate in river health monitoring. Conclusions from the GCEE project were that local communities were more interested in their need and use for water and not the impact that the use of the resource has on aquatic organisms. Therefore, this research is inspired by this GEE project study output to determine how local communities' use of the river and relationship with the river may be used to improve understanding and monitoring of river health.

In as much as South Africa clearly states the role of community participation and citizen science in water resources management, there have been several concerns from studies on the reality of the participation. Nare *et al.* (2011) assessed community participation in water quality monitoring and management in the Luvuvhu catchment, South Africa and found that while the legal and policy frameworks of the country support community participation, communities' attitudes, indigenous knowledge and practice integration remains weak. The study shows that there is a weak flow of people's inputs from the community level to the catchment decision-making level. Volenzo and Odiyo (2018) also criticised communities' participation in river health monitoring through the citizen science programme in South Africa, which illustrates passive participation that is without contribution and input in decision making. During data collection, the process does not offer opportunities for communities to influence the programme and offer inputs.

Despite that, the GCEE project, at the initial stage of developing the river health program showed that communities are more interested in their water use and need with less interest with ecological state of the river, the local communities in South Africa still take part in citizen science to monitor water quality and river health using macroinvertebrates. There is no consideration of the communities' needs in monitoring. Cele (2015) explains that citizen science's role in RHP in South Africa role is to strengthen water quality and river health monitoring as it simplified the ecological monitoring to a level understood by communities. Communities' monitor the ecological state of the river. Graham *et al.* (2016) explain that community citizen science-based RHPs were initiated for communities to learn and un-learn together and achieve a deeper understanding of river health. The RHP ecological monitoring tools are simplified for the communities, as the taxonomic complexity of aquatic macroinvertebrates and sampling methods are simplified for non-scientists, by using miniSASS tool (Graham *et al.,* 2004). MiniSASS uses 19 macroinvertebrate groups, simplified and explained for communities. Dickinson *et al.* (2012) and Graham *et al*. (2004) explain that the macroinvertebrates are easy to collect and analyse and the miniSASS also produces results similar to SASS. MiniSASS method used by the communities relies on identifying aquatic invertebrate taxa and analysing their appearance based on a scientifically-determined tolerance to pollution (Graham et al., 2004). Participants use pre-set macroinvertebrates to determine and monitor the river's health.

The development of the river health monitoring programme in South Africa portrays a top-down planning process with community participation incorporated at the implementation stage (monitoring). This approach negates the country's legal and policy frameworks which call for active bottom-up participation. Community knowledge, attitudes and behaviour which have been identified by Ananga *et al.* (2017a) as critical elements in the active participation of communities are not considered at the development and planning stages. Williams (2018) explains that proper participation should involve participants in the planning process and use available information and creativity in society. River health definitions, as argued in Section 2.2, show that it is a product of human-environmental interactions, thus its monitoring should involve active inclusiveness of communities as a critical tool for transforming participatory processes and increasing community resilience.

From the above-reviewed literature, it is clear that over the years, RHP in South Africa has evolved, however, the premise of river health assessment has not changed. Improved knowledge has been simplifying the understanding of biological and physical indicators. The main interest of the RHP has been the development of biological monitoring and assessment tools using only biological and physical variables whilst including communities' participation and simplifying scientific indicators for community understanding and use. Since 2016, these tools have been reclassified into a new programme referred to as the REMP. However, there has been no evidence of attempts to factor in communities' knowledge, the social value of the river, recognise local context, cultural realities and indicators in river health monitoring. Weber *et al.* (2017) state when working with communities in resources monitoring, it is important that the selection of indicators, at the different scales, are guided by their relevance to their important environmental and livelihood assets and values as well as their response to different drivers of change. Therefore, this research will explore the development of community congruent indicators which reflect the meaning of river health according to the stakeholders, through active participation of local communities.

2.14 Social learning in citizen science

Citizen science is inherently social, based on social learning, collective action and commitment to community goals (Lee & Krasny, 2015 & Loucks *et al.*, 2017). It can lead to shared ecological understanding among diverse participants, build trust internally and credibility externally and foster social learning. Wals and Rodela (2014) and Lindley (2015) explained social learning as when individuals learn by observing the behaviour of others and transforming what they have observed into behaviours. The explanation was expanded by focusing on observing and modelling behaviours and attitudes of individuals, as these interact with their environment. Lave and Wenger (1991) and Wenger (1998) argue that social learning takes place by interacting with experienced members of the community of practice through participation. Experienced members of the community of practice interact and share knowledge with newer members regarding social practices (Lave & Wenger, 1991; Wenger,1998; Sabai and Sisitka, 2015). The experienced individuals are knowledgeable and they impart and share knowledge with the less knowledgeable members. What is important in social learning is the involvement of participants in change processes, rather than just 'being there in social practices. Reed *et al.* (2010) suggest that social learning occurs when it has been demonstrated that a change in understanding has taken place in the involved individuals; it is situated within wider social units and the process occurs through social interactions. Inexperienced members of the community of practice are inducted into social practices by the more experienced members, through participation in social practices.

Walmsley *et al.* (2001) and Mostert *et al.* (2008) argue that social learning has developed to be an important component in water management programs. Pahl-wostl *et al.* (2007) state that social learning in water resources management takes place within the governance system, economy and culture (social context) and the hydrological and geographical conditions (natural context). Literature shows that it is important to share knowledge in a trusting environment, specifically directed at resource management or governance outcome (Pahl-Wostl *et al.,* 2007, Cundill & Rodela, 2012; Charles *et al.*, 2020). It encourages learning between stakeholders and supports the management of resources. Mostert *et al.* (2008) state that where it has been used, it had positive societal outcomes, especially in community knowledge and values incorporation, conflict resolution, institutional trust-building and building capacity to better understand and address environmental issues (Pahl-wostl *et al.*, 2007; Wehn *et al.*, 2018). Therefore, if social learning is successful, stakeholders feel more engaged, acquire new skills and knowledge and improve integration between the natural and social context in catchment management.

Cundill and Rodela (2012) cite that social learning may take place in natural resources monitoring as actors engage in interactions and create a space for sharing different ideas and experiences, leading to an agreed manner of approach or addressing challenges that emerge from their context. Social learning is not only through knowledge sharing and exchange; it is also based on landscapes and relevance to community participation (Kolbe, 2014; Sabai & Sisitka, 2015). Charles *et al.* (2020) recognise that social learning is place-based knowledge controlled by local communities. Positive social interactions within communities, reinforce and create opportunities for social learning, which promotes empowerment and fosters multi-stakeholder collaboration (Cele, 2015; Pandya & Dibner, 2019). Social learning is considered as taking place when participants share ideas on the management of the environment, which leads to the production of knowledge and collective meaning-making. Pandya and Dibner (2019) explain that social learning can involve not only new knowledge but also the integration and deconstruction of old knowledge. Social learning as an instrument for empowerment allows iterations of action, reflection and deliberation, creating shared experiences and change to reach a common understanding (Constantino *et. al*., 2012; Diduck *et al.,* (2012). The most important thing in social learning is that learning extends and becomes embedded in a broader social context through interactions among actors in a common social network (Reed *et al.*, 2010). As the social network engages, there is co-production of knowledge, which bridges knowledge gaps within that network (Cundill and Rodela, 2012).

From the reviewed studies, one can pinpoint that central to social learning theory is communities/people learning from each other in a similar context. The focus is on the generation and sharing of knowledge in a practice context, with an interest in the distribution and uptake of knowledge within wider social units (Sabai & Sisitka, 2015). This further suggests that social learning may take place during community participation. With such an understanding of what a social learning process constitutes, this study draws on the processes of social learning that are contextual and take place in a practice context which makes it relevant in community participation and citizen science (Pahl-Wostl *et al.*, 2007). However, this does not mean that the knowledge engaged within social learning is context-bound but rather that context provides an important reference for social learning processes.

In this thesis, the social learning concept has been used to analyse knowledge transfer pathways within communities during river health monitoring with communities. Townsend *et al.* (2012) state that river health monitoring within communities is more than the collection of site-specific data to meet the legal and policy obligations of governments and other organisations. Instead, it is a value-laden exercise that is contested by groups with different power and experiences, who debate and negotiate ways in which environmental issues are commonly understood and represented. The thesis will use the social learning concept to analyse pathways of interactions between communities during river health monitoring in the Lower Komati River. The thesis will also explore social learning knowledge between communities and how it may be used to develop community-relevant indicators. The fundamental bearing is that as monitoring takes place, there is also learning taking place.

2.15 Theoretical reflections

This section presents the different theoretical concepts adopted for the study. The study was built on three theoretical concepts; namely the social-ecological theory, social learning and political ecology concepts. These theoretical concepts have been discussed in the literature review above. The three theoretical concepts were used in an integrated manner for the analysis of the complex interactions between communities and the river, demonstrating the formation of the different components of the integrated social-ecological framework for river health monitoring in the Lower Komati River.

The first concept to be used is the social-ecological theory, which focuses this research and allows the examination of the Lower Komati river’s health as an SES by aggregating social (for example, institutions, property rights, behaviour) and ecological (for example, environmental resources) subsystems (Cabello & Willaarts, 2015). The theory emphasises the notion of ‘people in nature’ and ‘people with nature’ as described by Ostrom (2007) and explained in section 2.9 Therefore, the SES framework will guide the assessment of the social and ecological dimensions of the Lower Komati River and the relationships that unfold which influence river health. Currently, the scales of ecological and social dimensions charged with river health monitoring are not well-matched, so the social-ecological theory in this research will be used to find ways of matching these two dimensions. According to Liehr *et al.* (2017), the SES theory allows interdisciplinary research approaches that promote compatibility between ecological and human systems. Therefore, the SES is used to show the established relationships between ecological and social conditions in the Lower Komati river. This thesis will use the relationships identified through the SES concept to show a holistic understanding of the complex interactions between humans and ecological variables in the Lower Komati river to improve understanding of river health.

This thesis uses the social-ecological concept to unpack the social and ecological value of the Lower Komati River catchment, revealing pathways and interactions between the social and ecological elements of the catchment by focusing on patterns of use of the river. This will be essential to develop river health indicators that take changes that have happened in a river into consideration as per the social and ecological value of the systems. Dale and Beyeler (2001) argue that monitoring programs often depend on singular indicators (ecological) and fail to consider the full complexity of a system. Therefore, embedding the study on SES thinking acknowledges the importance of the formation of strong relationships between social and ecological indicators in the catchment to make the monitoring programme more valuable and increase biological and social relevance. This approach has been adopted in this study as the river catchment is a system made of biophysical and sociological processes, thus it is essential to develop indicators to monitor all these elements during health monitoring.

As already discussed in Section 2.5, the SES concept has its limitations and one major limitation applicable in this thesis is that SES focuses more on institutions and organised social units and nature as a physical unit as separate and that humans are within the environment (Fabinyi *et al.*, 2014). The SES concept does not explicitly interrogate if a new unit is formed. Since the SES concept is much broader, a finer analysis of the natural and societal interaction t is important to understand the relationships formed (Karpouzoglou & Vij, 2017; Bear, 2017). Furthermore, in as much as the SES framework aims to enhance a cross-disciplinary building, it does not explicitly explain how the social and ecological entities may merge to a new unit and the power and contestations, that shape the interaction and material flow within the SES. To address this shortcoming, the political ecology's socio-nature and waterscape concepts were used to complement the SES concept in this thesis. As discussed in section 2.5, political ecology concepts will be used to expand and complement the social-ecological theory by considering power relations and the formation of new hybrid information in the catchment.

The thesis follows Swyngedouw's (2009) description of a river - as a hybridised socio-nature entity that has fused nature and society. The socio-nature concept explains that social and ecological interactions result in the production of a socio-nature hybrid. The socio-nature concept embodies the natural and social components as one entity produced that becomes inseparable. Dempsey and Robertson (2012) argue that it is rooted in the formation of heterogeneous material and broad human and nonhuman entanglements (Bear, 2017). The socio-nature concept explains the new hybrid of indicators and knowledge that unfold from the social-ecological interactions and relationships that exist in the Lower Komati River. The socio-nature concept would not be adequate to answer all the thesis's questions as it is more of a general concept that explains the formation of hybrid information but does not address how power is contested after the formation of the hybrid information. Thus, the waterscape concept is used to explain how power is contested in the system. The study uses the waterscape concept, which is more specific as it specifically addresses power relations and contestations in the catchment when addressing river health and water related issues.

The waterscape concept allows the interrogation of the interactions between society, water, environment and related contestations that emerge from these interactions (Jackson & Barber, 2016). The concept of waterscape in this thesis allows an analysis of the socio-nature hybrid between water and society within a political and power relations context of the Lower Komati River catchment. The waterscape concept interrogates and explains not only the relationship between water and communities but also resultant contestations produced and how they contribute to understanding river health and the production of locally congruent indicators for river health monitoring. It is important to examine water as a socio-nature hybrid and the contestation reproduced, as water resources are influenced by nature and social interactions which results in debates on rights to water access, use, quantity, flow and quality (Loftus & Lumsden, 2008 & Perreault *et al,* 2012). As people interact with a river, there is production and reproduction of a new environment and ways of managing it according to their ideologies, knowledge, socio-economic and political power *(*Boelens *et al.*, 2016). People generate environmental knowledge systems through humanising water based on social, political and cultural visions (Boelens, 2015; Swyngedouw, 2015 & Boelens *et al.*, 2016). Thus, the waterscape concept analyses of the (re)creation of the Lower Komati river as a waterscape, will show how new systems and knowledge are formed as a result of interaction with the river, cultural and political settings of the catchment.

The social-ecological and political ecology's socio-nature and waterscape complement each other as shown in Table 2.4, however they do not consider how the new knowledge in the hybrid/waterscape may be produced and transmitted. The thesis uses the social learning theory to explore knowledge production that takes place during the community interactions with the river. Cundill and Rodela (2012) explain that social learning may take place in natural resources monitoring as actors engage in interactions, creating a space for sharing different ideas and experiences, leading to the emergence of knowledge. Positive interactions in citizen science projects reinforce and create opportunities for social learning, which promotes empowerment and fosters multi-stakeholder collaboration (Cele, 2015; Pandya & Dibner, 2019). The social learning theory is used to analyse and identify social learning pathways that may potentially create avenues for communities during citizen science to generate local knowledge that would be useful in river health monitoring as summarised in Table 2.4. As the new environment (hybrid) identified by the political ecology concepts may produce new knowledge relevant to this catchment, the social learning concept will help identify knowledge shared and understood by all community members, relevant in the catchment which can be useful in the selection of local indicators. Charles *et al.* (2020) recognise that place-based knowledge, social learning, collective action and empowerment are common in monitoring driven by communities. Therefore, the social learning lens interrogates how participants share information about the river, develop indicators of river health and identify new information produced which can be used in river health monitoring.

Table 2.4 Table showing a summary of the contributions of the different approaches used in the study.

Approaches	**Contribution to study**
Social-ecological systems (SESs)	Used to analyse the pathways and interactions between the social and ecological elements of river catchment by focusing broadly on patterns of use of the river, economic and political processes taking place in the system
Socio-nature	Analyse the output which is a 'hybrid' of social-ecological interactions and relationships that exist in the Lower Komati River. The socio-nature concept is used to analyse how the hybrid information from the social-ecological interactions and knowledge can be formed to be part of the integrated framework.
Waterscape	The waterscape concept provides a more focused analysis of the resultant power contestations produced with the catchment from people and river interactions and how this contributes to an understanding of river health and production of locally congruent indicators for river health monitoring. The waterscape concept analyses the catchment's power relations formed as a result of interaction with the river, cultural and political settings of the catchment
Social learning	Interrogates how participants share information about the river, develop indicators of river health and identify new information produced which can be used in river health monitoring.

In essence, the three theoretical concepts have common attributes of acknowledging society-environmental interactions as well as their complexities and related outcomes. However, their main differences are that whilst the social-ecological theory considers the interaction between society and environment, it does not explicitly explain the formation of a new hybrid from this interaction, political processes and knowledge production which are addressed by the waterscape, socio-nature and social learning concepts respectively. The use of these concepts shows an integrated conceptual framework, which brings a better understanding of local communities' dynamics, river health processes from the historical trajectories between the river and the local communities in the Lower Komati River. The use of these concepts shows the complex interplay between humans and the environment. A singular concept can be useful to unpack the different components that make up the integrated river health monitoring framework, thus this research uses multiple theoretical concepts to complement each other. This is because water resources are complex social-ecological entities where people are embedded within the environment. Thus, integrated consideration of theories can tackle the multiple complexities that unfold.

2.16 Conclusion

The chapter discussed the different debates in river health meaning and the different indicators currently used in South Africa and other countries. The literature showed that river health monitoring in South Africa is still confined to the ecological attributes of the river catchment. This is despite the literature which shows that river catchments are SESs and there is a relationship between society and rivers and ES are positioned as a link between them. From this analysis, it is clear that some society-nature interactions influence water management. However, not many studies are currently available to explain the different human and nature relationships and related contestations that emerge related to river health. Thus, this thesis uses multiple human and nature relationships to explain river health and incorporate social attributes of the river in river health monitoring. The multiple relationships that unfold will be explained through the SES framework, social learning and political ecology concepts. These concepts guide the study to the formation of a comprehensive river health monitoring framework that integrates social and ecological attributes in river health monitoring.

3 CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter presents the procedures, methods and techniques that were employed in the research process. The first section of the chapter provides an overview of the research approach; namely how the research was sequenced. It then provides further detail on the research methods and design used to meet each objective. The chapter also shares details of how data generation took place through a series of methods and data analysis that make up the study design. Furthermore, the chapter discusses how validity was maintained throughout the study and sought to ensure that ethical protocols were observed.

3.2 Data collection and analysis sequencing

The study constituted a multi-disciplinary approach as it aimed to incorporate social value data alongside ecological data for river health monitoring. Quantitative and qualitative research methods were adopted in the study for the researcher to gain an in-depth understanding and corroboration of river health monitoring of a catchment as a social-ecological entity. The approach to incorporate social values in river health assessment comprised of progressive steps:

i. determining the ecological river health profile of the catchment, using two commonly used ecological indicators (macroinvertebrates and fish);
ii. mapping water-related ES and social value by local communities and key informants in the Lower Komati River catchment;
iii. determining river health condition based on local communities and water users' perceptions and probable impact on the social values identified and held by the local communities;
iv. identifying opportunities of integrating social and ecological systems to improve river health monitoring in the Lower Komati River;
v. developing a comprehensive river health monitoring framework that incorporates the social values and ecological indicators of the river.

The study was designed and sequenced in phases. In each phase, there were processes of data generation with preliminary analysis conducted between phases. The overall study design and data generation processes are shown in Figure 3.1. The first phase entailed analyses of the river's ecological health profile using existing ecological monitoring indicators (fish and macroinvertebrates) and identifying variables that act as drivers. The use of fish and macroinvertebrates as indicators in this study is important. As discussed in Section 2.10, they are connected through their trophic relationships, thus a change in macroinvertebrates may cascade and show a change in fish community structure. Moreover, fish and macroinvertebrates have been widely used in river health monitoring in South Africa. Section 2.4 of this study shows that fish and macroinvertebrates are regarded as responders and are paired with drivers, for example, chemical and physical water quality variables, and riparian vegetation analyses to explain the state of the rivers in South Africa during the setting of the country's River Quality Objectives (Friberg *et al.*, 2011 & Levin *et al.,* 2019).

These indicators are most preferred since they show the state of the biotic and abiotic variables representing stream health (Karr,1999; Bonada *et al.*, 2006). Thus, they bring in an integrated view on the ecological status of the river, which will be essential to set out the social and ecological framework and indicators, as well as to identify the main drivers of river health. This is based on the idea that biotic communities respond to changes in habitat drivers due to anthropogenic disturbance.

The second phase involved conducting community-mapping exercises to determine Lower Komati water-related ES and social values assigned by the local communities and users. The information derived from the community exercises was corroborated with key informant interviews (elders over 60 and fishers), where the history of the river and its condition were explored. Fishers were selected as fish offers a comprehensive indicator as they can be indicators of river health whilst they may also be attributable as social value entities as communities rely on them for protein (McCafferty *et al.,* 2012). The environmental requirements and ecological life history of most fish species are well studied; therefore, can be easily interpreted to explain rivers' ecological health. Lynch *et al.* (2016) explain that in most countries, fisheries play a crucial role as a source of livelihoods and food security for people. As an important resource for most communities, it was important to ascertain how local communities in the Lower Komati value the river for fishing and how they use fish to ascertain river health. In this case, fish is used as a link to understand the ecological and social value of the river. Based on the social and ecological value of fish in rivers, they are then considered as the most appropriate indicators that would explain river health from an ecological and social perspective. The use of fish as an indicator in river health monitoring and understanding the river's social value is aimed at highlighting the relationship between healthy freshwater ecosystems, society and the flow of ecosystem services that rivers provide to the local communities. This thesis prioritised the use of these variables, as they provide an integrative view through their relationships; and used to develop a set of social-ecological indicators that are more contextually and culturally congruent, which would easily guide community-based monitoring practices and attract wider social learning in the process.

Lastly, the thesis sought to identify points of convergence between the communities' perceptions about the river's health condition using locally congruent indicators and the analysis from the ecological river health. Identifying points of convergence was important to identify opportunities of integrating social and ecological attributes, to improve river health monitoring and come up with the social-ecological river health monitoring framework. Pockets of similarities and differences between the social and ecological indicators used by local communities and in ecological monitoring were identified. This also involved integrating the ecological and social indicators through hotspot mapping. Areas under significant ecological pressure as shown by the ecological indicators (fish and macroinvertebrates) and areas that posed a risk to the communities' societal values and supply of ES were identified. These ecological at-risk areas (identified as ecological hotspots) were identified through ecological river health analysis. The social hotspots were identified by the local communities and key informants as at risk for the river's provision of ES and were thus lowly valued by the participants. The spatial representation of the societal and ecological hotspots data formed part of the comprehensive river health monitoring framework. Social-ecological hotspots were generated to contribute to new knowledge regarding river health monitoring, which considers catchments as social-ecological entities. Detailed discussions on the methods and analytical processes are discussed in different sections of this chapter and summarized in Figure 3.1.

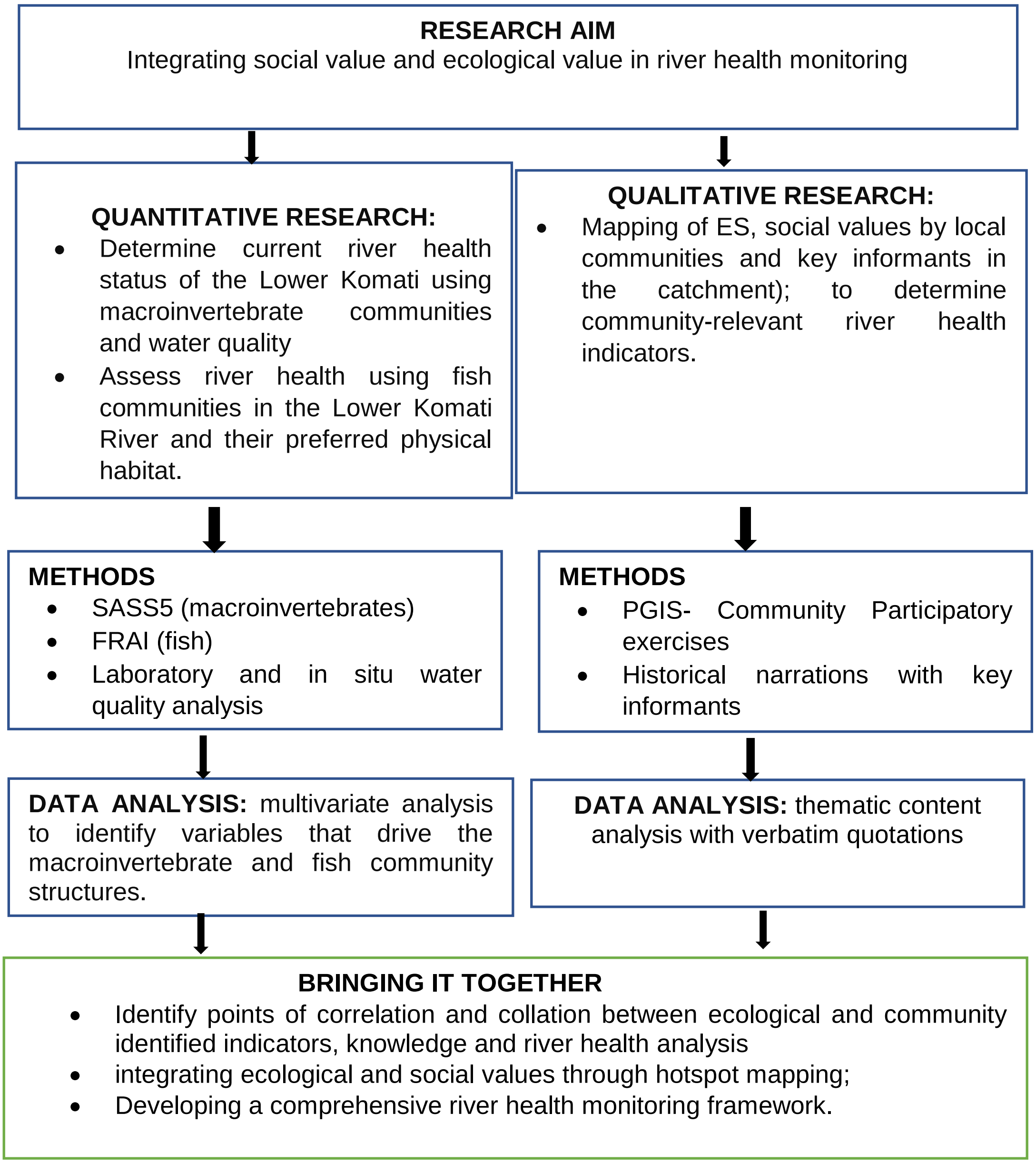

Figure 3.1 Overall research sequencing

3.3 Study area: Lower Komati catchment

This section describes the geographical context of the study, which provides a strong case study to explore the relationships between social values and river health and develop a comprehensive river health framework. The Lower Komati River is a sub-catchment of the Inkomati-Usuthu Catchment and is further divided into three distinct sub-regional geographical and sub-catchments as shown in

Figure 1.2. These sub-catchments are the Lower Lomati sub-catchment, Lower Komati West sub-catchment and Komatipoort. The Lower Lomati sub-catchment and the Lower Komati West sub-catchment have several communities/villages adjacent to the river. The Inkomati Water Management Area has approximately 1.62 million people, who make up 3.7% of the country's population who spread throughout the Water Management Area (WMA). The population is distributed across the WMA's sub-catchments as shown in Table 3.1. The Sand river sub-catchment has the highest population followed by the Middle Crocodile and the Lower Komati catchment. The majority of the population resides in rural areas, comprising 75% of the total population with 25% in urban settlements. Approximately 52% of the population are female residents whilst males constitute 48%.

Table 3.1: Table showing population figures for different sub-catchments of the Inkomati-Usuthu Water Management Area - (DWA, 2013)

Secondary catchment	**Sub-catchment**	**Population**
Usuthu	Usuthu	280 000
Komati	Upper Komati	99,665
	Lower Komati	245,350
	Upper Lomati	1,228
	Lower Lomati	68,956
Crocodile	Upper Crocodile	5,519
	Middle Crocodile	254,780
	Elands	18,284
	Kaap	47,427
Sabie-Sand	Upper Sabie	209,644
	Sand	407,413
	Lower Sabie	245
	Upper Rio Uanetze	228

The Lomati sub-catchment is made of communities from Driekoppies, Midplaas, Schoemansdal and the Komati West sub-catchment, which consists of Mzinti, Kwazibukwane, Sibange and Magudu communities. However, the Lower Komati sub-system (Komatipoort) is a commercial agricultural (sugarcane and banana) sub-catchment with only a few small communities. The communities in this catchment are mostly labourers and migrant workers who work on the farms who have not been residents in the area for over five years and they did not show interest in the study. Thus, no participants were available from the Lower Komati sub-system (Komatipoort).

At the main stem of the Komati River, downstream of the Vygeboom Dam and down to the South African border with Eswatini, there are rapidly expanding villages and towns which are dependent on water from this river reach. The Komati River in South Africa and Eswatini is classified as extensively modified as a result of flow regulation and inundation from the dams and weirs along with the river resource (Mallory, 2013). The majority of the upper reaches of the Lower Komati river catchment is under commercial forestry. There is no major industrial activity upstream of the Lomati and Komati Rivers, thus there are few reported chemical water quality problems. However, numerous weirs and low flow in downstream sections of the Komati have been reported by Faysse and Gumbo (2004) and O'Brien *et al.* (2019) and these are said to interfere with the migration of fish, of which there is a rich diversity in the area downstream of the Lower Komati River in the Komatipoort area where major irrigated crops dominate. Irrigated sugarcane is cultivated on 26 000 ha; other major irrigated crops in the catchment include bananas, litchis, mangoes, papaya and some maize. According to the DWAF (2004), dramatic increases in irrigation water demand are observed in this region as a result of growth in the emerging farming sector.

The IUCMA manages the Inkomati-Usuthu Catchment. Stakeholders in the Inkomati-Usuthu Water Management area are sectoral and regulatory. According to Chikozho (2005), these sectoral groups mainly include water users and interest groups in the catchment, which include the agricultural industry (commercial and subsistence), tourism, fishing, local and provincial government, traditional leaders, international water bodies, sector representative bodies, non-governmental organisations (NGOs) and local community-based organisations. According to Chikozho (2005), the DWS is responsible for sector policy, support and regulation alongside other national government departments and provincial governments and plays an important role in supporting the water services sector. Additionally, Water Services Authorities provide water services and wastewater systems within their area of jurisdiction. Eight (8) local municipalities in the IUCMA are water services providers within different jurisdictions.

3.4 Research methods

Mixed methods (quantitative and qualitative) were used in this study to collect ecological and social data which will lead to the development of an integrated river health framework. The quantitative methods will involve determining the ecological river's health state and the qualitative method involves determining the river's health from the local communities' point of view. The research adopted a multidisciplinary approach to data collection to link human's social with the ecological value of the river to show relationships that exist between social and ecological components of the Lower Komati River. These relationships between the social and ecological components of river health will be used to develop a comprehensive river health assessment framework that demonstrates an improved understanding of river health.

3.5 Study design

The study is constituted as a case study as it sought to access in-depth information about the ecological status of the Lower Komati River using resident ecological indicators (fish and macroinvertebrates) and the significance of social value in river health monitoring from local users. It is envisaged to contribute to the development of indicators that are locally congruent and may be used by communities and water users in the catchment to detect changes, threats, trends and conditions of river health in the Lower Komati River, as explained in Chapter 1. The case study approach is useful in this context as it allows a deeper understanding of the phenomena (river health) and allows researchers to retain holistic and meaningful characteristics of real-life events (Creswell, 2013; Simons, 2014). Simons (2014) emphasise that a case should be studied in its natural setting since it is signified by its context, and the data collection process should be intense. (Gustafsson, 2017) further argues that a single-case study approach investigates questions of 'how' and 'why' a particular phenomenon occurs within contextual settings. A multiple-case study approach would have required additional time and financial resources that would have surpassed the resources available for the project.

The various methods and approaches applied in this study generally took the context and realities of the study area into consideration. Simons (2014) affirms that the case study approach allows various modes of inquiry to be used that collectively contribute to providing in-depth context-specific insights. Therefore, to be able to get in-depth information on the ecological state of the river, communities' social values and river health indicators that are locally congruent, it was important to conduct site-specific ecological river health analysis. This allowed for an in-depth discussion about the river's health and ascertain social values as assigned by communities to different parts of the river through community mapping exercises in groups and key informant interviews with local communities.

3.5.1 Using macroinvertebrates to determine the ecological river health

Macroinvertebrates have been widely used as indicators for routine ecological status or river health assessments in South Africa for different reasons. Macroinvertebrates have been extensively used as indicators, as they accumulate xenobiotic elements or compounds and reflect the contaminant level in the environment (Day, 2000; Agboola, 2017; Dalu & Chauke, 2020; Koehnken *et al.,* 2020. Most of these taxa are sedentary, as they are confined in most parts of the river where the physical and chemical conditions are suitable (Day, 2000). Winckler-Sosinski *et al.* (2008) and Chessman *et al.* (2010) identified different macroinvertebrates as major food resources for fish in lotic systems. The macroinvertebrates help maintain fish communities as established in the food chain interactions, thus a change in either community will cascade to the other. Any impact on macroinvertebrates tends to reflect on the available fish communities, thus making them most suitable in this study which is coming up with an integrative river health monitoring framework.

The macroinvertebrates were sampled from six (6) selected sites which are shown in figure 3.3. These sampling sites included one site upstream of the Lower Komati River with minimal anthropogenic activities which were regarded as a reference site. According to Mpumalanga Tourism and Parks Agency (MTPA) (2015), during the catchment's eco-status determination, the upper part of the Lower Komati River is mostly forestry, with minimal influence of anthropogenic activities on the river and thus a site from this area was used as a reference site. The other five (5) sites are within extensive agriculture, grazing and open water along the Lower Komati River. All these sites have been used as sampling sites during the Inkomati catchment reserve determination, eco-status assessment exercises and ecological monitoring of the Komati River catchment by the IUCMA. These points were selected because, according to AfriDev (2006), they represent critical areas for ecological maintenance, proximity to flow gauges, high diversity of aquatic habitats and biota, ease of access, strategic importance and availability of historical data for comparison purposes. The sampling sites are shown in Figure 3.3 and described in Table 3.2.

Table 3.2. Table describing the six sampling sites selected for the study' ecological river health assessment.

Site	Co-ordinates	Description
1	S -25. 63 447 E 31. 50 451	Located on the Waaiheuvel farm, upstream, where there is a commercial tree plantation. Overhanging vegetation present was with visible land uses around the site - mainly commercial forestry and a few rural settlements. This was regarded as a reference site. The site is characterised by fast-flowing riffles and runs.
2	S- 25.68 629 E 31. 52 879	Located in the Lomati River, downstream of the Schoemansdal town and about 5.3km downstream from Driekoppies Dam Wall. The site is characterised by slow-moving water.
3	S- 25.69248 E 31.73264	Located in the Mzinti River, it is a tributary that originates in Eswatini at an elevation of 580 m.a.s.l, flowing towards its confluence with the Komati River. The site is located at the Mashushe Shangwe Nature Reserve. Land-use in the catchment includes rural settlement areas. The sampling was largely compromised by dense stands of submerged aquatic vegetation, shallow riffles and long stretches of shallow sandy runs and pools.
4	S-25.681 68 E 31.782 95	Located along the stem of the Komati, at the low-water bridge in Kwazibukwane, after the confluence with the Mzinti River. Main activities in proximity to the sampling point include solid waste disposal along the riverbanks, weirs, flood agriculture, laundry and car washing. The site is characterised by a multi-channel river over bedrock with multiple rapids, riffles and runs.
5	S-25.821 88 E 31.826 16	Located along the stem of the Komati River in South Africa, 19.5km downstream from the Eswatini-South Africa border. Activities in this reach include weirs and agriculture and rural communities. Fast and deep riffles and runs characterise the site.
6	S-25.439 01 E 31.973 41	The site is on the Komati River main stem just before the confluence with the Crocodile River and before it enters Mozambique. The site has numerous crocodiles and hippos thus sampling in this site was constrained. This is the last reach in the Komati River, thus most upstream activities would reflect on this site. Fast shallow, fast deep and slow shallow habitats characterise this site.

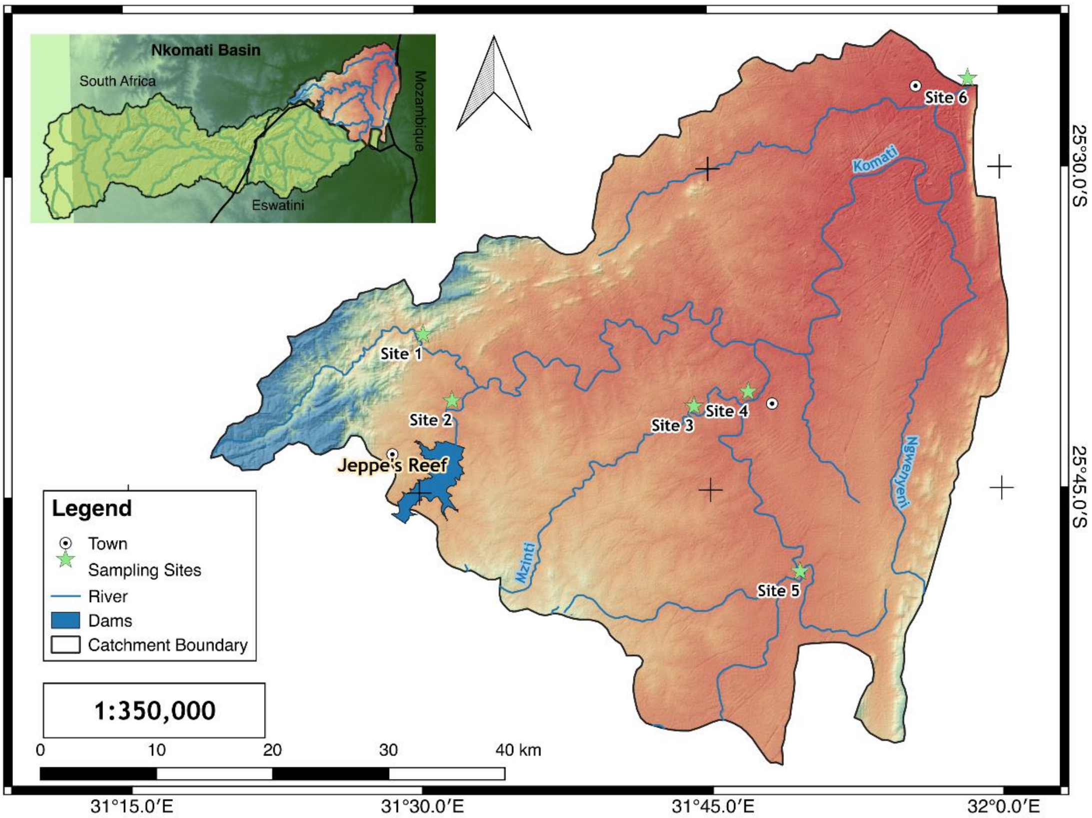

Figure 3.2. A map showing location of the six ecological sampling points along the Lower Komati River

3.5.1.1 Aquatic macroinvertebrates sampling

The SASS5 method was used in the collection, identification and scoring of the macroinvertebrates as suggested by Dickens and Graham (2002). SASS5 is a well-established rapid biomonitoring method used to sample riverine macroinvertebrate communities. This method is usually preferred as it is one of the most widely used and standardised macroinvertebrate sampling procedures which has been incorporated into South Africa's REMP. The SASS5 method provides a general indication of the present ecological state of the aquatic macroinvertebrate community, which also depicts the river's health.

The riverine macroinvertebrates and water quality were sampled from each of the six sites shown in Figure 3.3. In each site, insitu water quality samples were taken, before macroinvertebrates sampling took place at the different selected biological habitat types over four sampling campaigns. These campaigns were performed at different months to represent low and high flows. The first and fourth sampling campaigns were conducted during the low flow seasons (April 2018 and March 2019) with the second and third campaigns conducted during the high flow seasons (September 2018 and December 2018). In each sampling period, the six sites were sampled over three days, as two sites were sampled in a day. Sites 1 and 2 were sampled on the same day, followed by 3 and 4; and 5 and 6 respectively. More frequent sampling over the 2 years of data collection was not logistically possible within the timeframe and with budgetary limitations. About three hours were spent in each site collecting the macroinvertebrates and habitat characteristics. During all these sampling campaigns, the sampling was multi–biotope based because aquatic macro-invertebrates are found in different biotopes. Three major biotopes were considered in each site: (i) the stone biotope, which constitutes bedrock or any hard surface in or out of current; (ii) the vegetation biotope, which constitutes both marginal and aquatic vegetation; and (iii) the gravel, sand and mud biotope. The SASS sampling method is time and space-dependent because sampling from each biotope is timed (for example the kicking of stone biotopes in two minutes) and covers approximately two metres of vegetation. Biotope selection is an important factor in the SASS5 method because according to Dallas (2007a) the diversity of macro-invertebrates is sensitive to biotopes. Invertebrates are sampled from each biotope using a standardised hand net (size 1000μm soft mesh net on a 30cm square frame, with a 135cm aluminium handle).

According to Dickens and Graham (2002), it is important to compensate for the limitations of sampling with a net by including visual observations and handpicking. Supplementary hand-picking is necessary because organisms may not be dislodged or captured from the kicking and netting procedures irrespective of rigour, for example, *Gyrinidae* (Whirligig beetles) are too fast and cannot be easily captured using the net and *Porifera* (freshwater sponges) adhere on hard surfaces and cannot be easily dislodged by netting effort. All identified invertebrate taxa were recorded on a standard SASS5 sheet and awarded quality scores (ranging from 1 to 15). A sensitivity score of 1 is allocated to the most tolerant taxa and 15 to the most sensitive taxa. The different quality scores are allocated on the understanding that the sensitivity/tolerance of invertebrates to pollutants differ from one to the other. This is a common principle underpinning biotic indices (Murphy *et al.*, 2013). The main researcher undertook SASS sampling training before data collection started with an accredited SASS 5 practitioner and also sampled all sites with the accredited SASS practitioner, to ensure quality control of field sampling techniques and data. Training on the use of MIRAI was also offered by one of the supervisors (Dr G. O'Brien) who has had over 10 years of experience working with the tool. MIRAI results and analysis were also checked by the supervisor to ensure quality control.

3.5.1.2 Collection and analysis of water quality data

No single indicator can give a full picture of the ecological state of a river. Kleynhans and Louw (2008) state that it is necessary to look for complementarities among indicators and to identify indicators of change in structural, functional and compositional diversity at a range of scales and levels of organisation. For that reason, a water quality analysis was done. Some water quality variables were measured in situ and others in the laboratory. Water temperature (^{o}C), pH and Dissolved Oxygen (content mg/l and % saturation) were determined in the field (in situ) using a calibrated Bante 901P Portable multiparameter meter. All other variables were measured at the ARC-water laboratory. At each study site, sub-surface water samples were collected for the analysis of ammonia as N(mg/l), nitrate(mg/l) nitrite(mg/l), phosphorus(mg/l), Electric Conductivity (uS/cm), *E.coli* and total coliforms. Water samples for the analysis of ammonium and nitrate were filtered through 0.45 μm pore size membrane filters, stored in a cooler box and delivered to the laboratory for analysis within 24hrs. Nitrate and nitrite were analysed using a Spectroquant Pharo 300, which automatically conducts the chemical analyses. Phosphorus and nitrogen samples were measured using the Bran and Luebbe Auto Analyser 3. The *E.coli* and total coliform were determined using the Colilert-18/ Quanti-Tray. It was important to measure nutrients since major activity in some parts of the catchment is agriculture and most fertilisers used contain major nutrients (nitrogen and phosphorus). Thus, these nutrient levels were measured in different forms as they are continually changing in molecular form and geographical location (Atasoy *et al.,* 2006) Biomonitoring of rivers using SASS5 methods has been used to identify the effects of nutrient enrichment on the river's health (Motistoe, 2015). In this case, it was imperative to determine if the nutrients from the agricultural activities through water quality status, might be contributing to the distribution of macro-invertebrates and the present ecological status of the river.

Microbial studies in South Africa (Luyt *et al.,* 2012; Makuwa *et al.,* 2020) have used faecal coliform, total coliforms and *E.coli* as indicators of water as part of the National Microbial Monitoring Programme. These studies range from determining the compliance of wastewater treatment works, suitability of water quality for domestic use and to identify sources of faecal pollution, which are detrimental to human health. However, these microbial indicators are not considered when reporting on the state of rivers in South Africa - which is part of the REMP. According to DWS (2016), REMP enables the monitoring of the ecological condition of river ecosystems in South Africa and provides information to support the management of rivers for use and protection. The reporting of water' microbial state is done in the National Microbial Monitoring Programme and not in the REMP, to give a comprehensive view of the state of the river's health. This is mostly because, as discussed in Section 2.3, the determination of a river's health should be comprehensive enough to include ecological and social variables that influence human use of the river. According to the South African Water Quality Guidelines for recreational water use (DWAF, 1996c), total coliforms and *E.coli* are important indicators of the hygienic quality of water for communities either for drinking or recreational use.

Therefore, in this study faecal contamination was determined to ascertain if it has any impact on the social valuing of the river and use of the river, which will be discussed in Chapter 6 of this research. The study examined faecal indicator bacteria using *E. coli* and total coliforms as indicators for the environmental health status and suitability of the Lower Komati River water for human consumption and recreational use. Howarth (2018) explains that *E. coli* and total coliform are indicators of faecal contamination and determine the suitability of water for human consumption and recreational water use. The *E.coli* and total coliform were determined using the Colilert-18/ Quanti-Tray. The faecal coliform and *E. coli* levels water quality data was compared to South Africa's Water Quality guidelines for Domestic Use Volume 1 (DWAF, 1996a) and Recreational Water Use (DWAF, 1996c). All the other water quality variables measured were compared to South Africa's Water Quality guidelines for Freshwater Aquatic Ecosystems volume 7 (DWAF 1996b) in Appendix 1B(I). The instruments used to measure the different water quality variables and their limits of detection are described in Table 3.3.

Table 3.3. Table showing instruments used in the determination of the different water quality variables and their limit of detection.

Variables	**Instrument**	**Limit of Detection (LOD)**
Dissolved oxygen, pH and temperature	Bante 901P Portable multiparameter meter	
Electrical conductivity	Cyberscan 300	0 – 10 000 µS/cm
Ammonia as N	Spectrophotometry	0.001 mg/L
Nitrite	Spectroquant Pharo 300	0.007 mg/l
Nitrate	Spectroquant Pharo 300	0.40 mg/l
Phosphorus	Bran and Luebbe Auto Analyser 3	0.01 mg/l
E.coli and total coliform	Colilert-18/Quanti-Tray	<1.0 / 100ml

3.5.1.3 Data interpretation and statistical analysis

SASS5 is interpreted using three metrics - SASS score, number of taxa and average score per taxon (ASPT):

- SASS score: sum of the quality/rating scores for the sampled taxa;
- Number of taxa: number of macroinvertebrates families sampled; and
- ASPT: SASS5 scores divided by the number of taxa.

The SASS5 score and ASPT values were further plotted in a chart and placed within ecological categories as explained by Dallas (2007b). The ecological categories descriptions are described in Table 3.4. The ECs are formed as a result of the overall trends of the macroinvertebrate assemblage analysis from using the SASS5 score and the ASPT score. The SASS5 interpretation guidelines as presented in Table 3.4, are primarily based on the location of the site in the broad Ecoregion Level I biomes (Kleynhans *et al*., 2005a; Dallas, 2007b). In this study, the Lowveld-Lower ecoregion was used to assess the SASS5 results from Site 1-5 and the Lubombo-Lower ecoregion was used for Site 6.

Table 3.4. Table showing the ecological categories for use with the South African Scoring System (SASS5s) and ASPT scores for the Lowveld Lower ecoregion of South Africa, as modelled by Dallas (2007b)

Class	SASS 5 SCORE	ASPT	Condition
A	>174	>6.7	Natural
B	143-173	6.1-6.8	Minimally modified
C	120-142	5.7—6.0	Moderately modified
D	93-120	5.2-.2-5.6	Largely modified
E	<93	>5.1	Seriously modified

After using the SASS and ASPT scores to determine the present ecological status of the six (6) sites using macroinvertebrates, it was important to provide a habitat-based cause and effect analysis. In this case, MIRAI (Macroinvertebrate Response Assessment Index) was used, as a habitat-based cause-and-effect foundation to interpret the deviation of the community structure from the reference state (Thirion, 2007; Thirion, 2016). MIRAI makes use of multi-criteria decision analyses using a Microsoft Excel-based model (Thirion, 2007) to generate different ECs based on a six-point scale, with ranges from ‘A’ (natural) to ‘F’ (seriously modified) similar to Table 3.4. The EC of the macroinvertebrate community within the study area was generated based on flow, habitat, water quality modifications, system connectivity and seasonality that may influence the macroinvertebrates’ community structure (Thirion, 2007; 2016). The change in terms of estimated and frequency of occurrence of macroinvertebrate taxa on different metrics was measured on a scale from 0 (no change from reference) to 5 (extreme change from reference) as guided by the MIRAI model. Each metric was ranked and weighted according to its importance in determining the macroinvertebrate assemblages to develop an EC (Thirion, 2007). To further analyse the community structure, the macroinvertebrates’ diversity and evenness were analysed using Simpson’s diversity index (D). This index takes both richness and equitability into account, as there is a probability that a taxon is selected from different species. The range for Simpson’s index is between 0 and 1 and is based on probability. The greater the value of the index, the higher the diversity.

The Principal Component Analysis (PCA) and Cluster Analysis (CA), both of which are multivariate statistical analysis techniques, were used to determine the relationship between the water quality and sampled macroinvertebrates. The water quality variables and the sample macroinvertebrates at the different monitoring sites were selected for the analysis on PCA. A PCA is based on a linear response model relating species and environmental variables (Van den Brink *et al.* 2003). Results of the ordination are produced as two-dimensional maps of the samples being analysed, where the placements of the samples reflect the similarities or dissimilarities between macroinvertebrate assemblages and abiotic parameters recorded at the sampling sites. The PCA and CA analysis were plotted using the Multivariate Statistical Package (MVSP) version 3.1 (Kovach Computing Services, 1998). PCA reduces the dimensionality of a data set with a large number of interrelated variables but maintains variability in the data set (Vanhatalo & Kulahci, 2016; Sabharwal & Anjum, 2016). The PCA biplots were interpreted to mean: 90 degrees between vectors which indicates that two variables are uncorrelated; zero or 180 degrees between two vectors was interpreted to mean complete positive or negative correlation as interpreted by Buehler *et al.* (2012) and Jollife and Cadima (2016). According to Frigui (2008), CA as a multivariate statistical method, groups a collection of patterns into clusters based on similarity; objects in the same clusters are deemed to be as similar as possible and those from different clusters to be as dissimilar as possible. In this study, the CA was employed for clustering the magnitudes of water quality variables according to sampling period and study sites based on percentage similarity and for clustering sampling sites based on riverine macroinvertebrate composition (Sorensen’s similarity coefficient). Before the data could be analysed, it was log-transformed (log (x + 1), to address skewed data as explained by Feng *et al*. (2014). Despite the common belief that the log transformation can decrease the variability of data and make data conform more closely to the normal distribution, this is sometimes not the case.

3.5.2 Fish communities as ecological indicators of river health

3.5.2.1 Sampling fish communities

To determine Lower Komati river health using fish, the FRAI was used as explained by Kleynhans (2007). The fish were collected from the six sampling sites where the aquatic macroinvertebrates and water quality were sampled. The fish samples were collected twice during the study period between August and December 2019. The first sampling campaign was between the 15th and 18th of August 2019, which was at the end of the low flow season. The second campaign was between the 10th and 13th of December 2019 in the middle of the high flow season. The same sampling pattern followed during the sampling of aquatic macroinvertebrates was used. This involved sampling the sites over three days with two sites sampled per day. This pattern was followed to allow comparative analysis of data. Sampling started upstream with Site 1 and 2, followed by Site 3 and 4 and finally Site 5 and 6.

The sites where the samples were taken are described in Table 3.2. These sites were considered, as they have reference fish data, which is needed during FRAI analysis. The FRAI index uses a multi-criteria decision analysis, Microsoft Excel-based model that has been developed by the DWS (Kleynhans & Louw 2007). In using the FRAI method, the following steps were considered:

a. *Determine reference fish list and frequency of occurrence* (FROC); *for each site;*
    a. Use historical data and expert' knowledge.
b. *Use fish reference Frequency of Occurrence database* (FROC);
    a. Reference data from the Present Ecological State Ecological Importance and Ecological Sensitivity (PESEIS) database by the DWS (South Africa) from the Atlas of Southern African freshwater fishes (Scott, 2007).
c. *Determine present state for driver;*
    a. Involves the application of established driver assessment models; hydrological driver assessment, geomorphological driver assessment and the physico-chemical driver assessment index as explained by Kleynhans and Louw (2007). Expert knowledge was considered to assess the present and historical drivers of the index of habitat integrity.
d. *Select sampling sites;*
    a. Six sampling sites were selected based on potential physical (natural and unnatural) barriers and reference data availability. These sites were also used in previous FRAI assessments. The fish were collected from six sites along the Lower Komati River where the aquatic macroinvertebrates and water quality were sampled. Each site was sampled twice, Once, during low flow conditions (beginning August 2019) and once during high flow conditions (mid-December 2019).
e. *Determine and describe the condition of the fish habitat;*
    a. Assess the habitat potential and prevailing habitat conditions.
f. Sample *representative fish at each site, taking into consideration all velocity classes.*

To sample the fish, electrofishing was performed using a Samus electrofisher (SAMUS 725M Electrofisher, SAMUS Special Electronics, Poland) at each available meso-habitat for 10 minutes (Kleynhans, 2007). A 1 x 5 m seine net was used as a downstream block net on each meso-habitat. Current strength and settings and the electrofishing gear were optimised to sample different species and conditions in the study area (Dolan & Miranda, 2003). Electrofishing was performed for up to 60 minutes per site, covering different parts of the site. The 60 minutes were divided into five minutes per effort (timed). According to Reynolds *et al*. (2003) and Vehanen *et al.* (2013) timing of fishing effort is important for all electrofishing sampling protocols, as it allows some standardisation across sites and over time to provide accurate comparisons in community composition (for example, catch per unit effort).

Efforts were made to sample all available habitats in each site from across banks and mid-channel, starting from downstream to upstream of the reach. The sampled fish for each effort were transferred to 20-litre buckets and basins, containing river water to be identified, counted and Total Length (TL) measured for all fish. The fish TL was measured using a measuring board with a measuring scale on it, with the fish laid flat on the board. The TL was determined for analysis of the population structure, allowing for the consideration of age groups/classes of individuals in a population, which are useful indicators of the state of fish populations (Russell & Skelton, 2005). In examining reference data, it was anticipated that TL for fish in the sample areas would be between 30mm-250mm. Fish that could not fit in the 20-litre buckets were transferred to the basins filled with river water, immediately processed and released back to the river. Only fish (greater than 20mm TL) were identified to species level, fish less than 20mm did not form part of the sample, if caught they were released on-site immediately. No species of special concern (for example, threatened, endangered) were sampled.

Each fish sample was processed according to the individual habitat in which it was found and immediately released back into the stream. An active air pump was placed in the buckets in which the fish were stored, to mitigate fish distress. Fish abnormalities and injuries during sampling were noted in the datasheets. The lowest power required to successfully catch fish was used to minimise potential stress and injury. The output settings were adjusted during the process, by observing fish behaviour and recovery times to ensure the most effective settings were used. To ensure quality control and ethics consideration the main researcher received training on fish sampling and conducted all field identification of fish samplings with the assistance of one of the supervisors (Dr G. O'Brien), an established ichthyologist with over 10 years of experience and is familiar with local ichthyofauna,

3.5.3 Assessing the prevalence of velocity/depth classes and habitats

Velocity/depth classes are the principal habitat availability signifiers on which fish habitat preferences in the FRAI are based (Kleynhans, 2007). Therefore, all velocity depth classes per site (if feasible) were sampled and at least three-stream sections per site were considered. The velocity depth classes were classified as per Jordanova *et al.* (2007):

- Fast deep:>0.3m deep, velocity >0.3m/s (deep runs, rapids and riffles).
- Fast shallow:<0.3m deep, velocity >0.3 m/s (shallow runs, rapids and riffles)
- Slow deep>0.5 m deep, velocity <0.3 m/s (deep pools and backwaters)
- Slow shallow<0.5m deep, velocity>0.3m/s (shallow pools and backwaters)

The Rapid Habitat Assessment Method (RHAM) was performed at each study site (following Kleynhans & Louw, 2008). The velocity/depth for each effort was measured using a Transparent Velocity Head Rod (Fonstad *et al.,* 2005). Furthermore, each biotope was placed into a velocity/depth class as outlined in Kleynhans (2007). All capture results from the different flow depth classes were recorded, as several fish were caught during each effort. The field data were then analysed using the RHAM algorithmic macro in Excel to indicate the dominant velocity-depth class/classes within each of the meso-habitats sampled, per site (Kleynhans & Louw, 2009). The sampled meso-habitats included riffles, runs, pools and pool runs (Kleynhans & Louw, 2009).

Available habitat was visually assessed and described as either marginal vegetation, aquatic vegetation, undercut banks, root wads, substrate, depth/column or open (Kleynhans 1999). The available substrate type for each effort was categorised as either fine/silt, mud, sand, gravel, cobbles, boulders or bedrock (Kleynhans, 1999) as shown in the appendix 1-D. The substrate and cover distribution were rated between 0-100 and 1-5, respectively. The availability and distribution of the in-stream and riparian habitat features were important, as they are drivers of ecosystem health. The physico-chemical characteristics of the river water were measured in situ at the time of sampling. Water quality variables included temperature, pH, oxygen concentration/saturation and conductivity using a calibrated Bante 901P Portable multiparameter.

3.5.4 FRAI manipulation and analysis process

The first step was to collate and analyse fish sampling data per site and transform sampling data to the FROC ratings as per Kleynhans (2007). The observed occurrence rating per fish species per site was assigned based on the availability of velocity-depth classes and observed fish species prevalence data and was then entered into the FRAI Model Version 1 spreadsheet as shown in the Appendix 1-G. The second step was to execute the FRAI model to produce an automated EC score and class for each site.

There was an adjustment process to incorporate the effect of the habitat variables. To carry out the adjustment process, fish species' intolerance and preferred attributes were rated based on how the species relate to the natural attributes and requirements of the reference fish assemblage. The effect of habitat variables was determined using habitat metric groups (Appendix 1-F). The metric groups determined fish species preferences and tolerances and numerically assessed what their role would have been in the divergence of the expected fish assemblage composition at a given site

(Kleynhans, 2007). The natural characteristics of the fish assemblage and its habitat were compared with the assistance of an expert with knowledge of the area (established aquatic ecologist, an ichthyologist with more than 15 years' experience) on how the fish might have been affected by the different fish metric groups (velocity depth, cover, migration, physico-chemical and flow modification). Meanwhile, the FRAI model processed the metric components, weighted and assigned different scores based on their effect on the fish species and habitat. A table was generated by FRAI showing the weightings of the metric groups as shown in Appendix 1-G The variable in the metric group table with the highest percentage was assumed to have a strong influence on the fish communities. A higher metric (compared to all the metrics considered) means that fish communities in these sites are influenced highly by changes in that metric. For example, a species with a known preference for slow-shallow habitat would be given an expected FROC score of 5 if slow-shallow prevalence was 100%, or an FROC score of 1 if the same class prevalence was 25%.

Alongside the metric weightings table produced, outcomes from the FRAI analysis also included the sites adjusted scores (appendix-1-G) reflecting the sites' ecological scores and categories, taking into consideration the effect of habitat. The FRAI outcomes are automated and adjusted scores with the former based on the state of the drivers and the differences between expected and observed species in the assessment alone; the latter based on analysis of present habitat effect. The adjusted FRAI score accounts for the availability of habitat and other fish attribute features which include available substrate types, cover features, velocity and depth, presence of introduced species and barriers for migration in the river (Kleynhans, 2007). Another output of the FRAI model is a Present Ecological Status (PES) percentage for each site with an EC. ECs (ranging from A – 'pristine' to F – 'critically modified') are indicative of the aquatic ecosystem's ecological integrity (Kleynhans, 2007). FRAI calculates the EC for each site based on these impacts and fish data. ECs range between A – F, as shown in Table 3.5 (Kleynhans & Louw, 2007).

Table 3.5. Table showing the description of the ECs used in the eco-classification procedure for the Water Quality, Habitat, Fish, Invertebrates and Eco status in FRAI (Kleynhans & Louw, 2007)

ECs	FRAI Score	Description
A	90-100	Unmodified, natural
B	80-90	Largely natural with few modifications
C	60-79	Moderately modified
D	40-59	Largely modified
E	20-39	Seriously modified
F	0-19	Critically or extremely modified

3.5.5 Data interpretation and statistical analysis

To analyse the water quality data, focus was placed on quantifying the spatial and temporal variation to identify areas of concern in the Lower Komati River. Therefore, summary statistics exploratory data analysis was also carried out. All water quality data were tested for normality using the Shapiro-Wilk test and subjected to summary statistical analysis and presented using boxplots in R-studio (R-Core Team, 2015). The boxplots were plotted to provide a graphical presentation of the summary statistics of physico-chemical water quality data measured in the Lower Komati River between April 2018 to March 2019.

The diversity of macroinvertebrates was determined and analysed using Simpson's diversity index to describe the community structure. According to Mason *et al* (2005) diversity measures are used to describe community structure. Multivariate statistical evaluation of fish community structures was performed, for the direct interpretation of the community structures of fish in terms of the taxa obtained during detailed surveys (O'Brien *et al.,* 2009). To ensure that all families contribute the same amount in the ordination and give a balanced, the community abundance data were analysed and two taxa had a high abundance - which may dominate the ordination. Thus, the data were transformed to normalise it. A search for a continuous pattern in multivariate data using the species composition was performed using Detrented Correspondence Analysis (DCA), to determine if a linear (Redundancy Analysis [RDA]) or a unimodal ordination method (Canonical Correspondence Analysis [CCA]) was essential, as advised by ter Braak & Smilauer (2015). The data followed a linear ordination, thus the RDA was used to determine the relationship between species and the environmental variables and the main drivers behind the groupings seen in the PCA ordination. The RDA relates the species composition to environmental variables and extracts species composition variance directly related to the environment. As a derivative of a PCA, the RDA allowed for the selection of the driving variables that are intended to be overlaid onto the PCA. Metric scores were log-transformed (log (x + 1) before the RDA analysis was done. This was to reduce the effects of extreme parameters which may influence the ordination.

During the RDA analysis, a stepwise selection procedure was conducted to obtain the statistically significant macroinvertebrate metrics and environmental variables that best contribute to the explained variance using the Multivariate Statistical Package (MVSP) version 3.1 (Kovach, 1998). This approach provided constrained analyses of the community structures, which involved overlaying a captured variance of explanatory environmental variables such as habitat and water quality onto fish samples and species ordinations (Legendre & Gallagher 2001; O'Brien et al., 2009). RDA was preferred as it combines regression with PCA and can be described as a direct extension of regression analysis to model multivariate response data (Paliy & Shankar, 2016). The authors further explain that PCA is unconstrained (searches for the variable that best explains species composition) whereas RDA is constrained (searches for the best explanatory variables). Makarenkov and Legendre (2002) argue that the RDA represents objects and response variable relationships in a low-dimensional space. It facilitates the analysis of the relationship between the variation in the set of response variables and the variation of the explanatory variables. The results are presented graphically in the form of scattergrams showing the objects' response variables (usually species) and explanatory variables on the same diagram.

3.5.6 Determine social values and relationships in the Lower Komati River

This section explains the methods used to answer the third question; what are the various human-nature relationships and local communities' shared social values that exist in the Lower Komati river? To address this question, the following methods were used.

3.5.6.1 Participatory mapping

To identify and assess water-related ES and social values assigned by the local communities in different parts of the Lower Komati River catchment, participatory mapping, which is a combination of Participatory Geographic Information System (PGIS) and focus group discussions, was used. The PGIS method uses a participatory approach where communities provide information in addition to the mapping of ES and incorporate community perceptions and stakeholder perspectives of changes in natural resources (Brown & Reed, 2012; Klain & Chan, 2012). Participatory mapping by community members from different parts of the catchment was used in the study to chart ES and social values derived from the Lower Komati River. Participatory Geographic Information Systems (PGIS) is used in this research to determine and identify areas of social values on the catchment map (in other words, important places) by assigning a non-monetary value to that place. Later, this data is used as input to produce social value maps as demonstrated by Brown & Reed (2012) and Klain and Chan (2012) and shown in Section 7.4.4. According to Zolkafli *et al.* (2017), participatory mapping has been increasingly used as a method to bridge the communication gap between experts and the public on the spatial dimension of planning. Belay (2012), Selgrath and Gergel (2019) and Brown *et al.* (2020) state that participatory mapping combines local participation to identify and develop spatial information, engage local resource-users and stakeholders in data gathering and natural resource management.

The participatory mapping was done in groups, as Berkes (2012:221) argues that an individual's knowledge or experience tends to be distinct but "is enriched by the knowledge of the group". Moreover, Rambaldi *et al.* (2006) and McLain *et al.* (2013) argue that the participatory mapping method is a well-established technique to capture group perspectives whilst providing reliable data on topics that are of particular relevance to communities. The participatory mapping in groups was considered useful in this context as it allowed the researcher to probe but also place research participants in their real situations. The discussions during the mapping exercise generated rich descriptions of the topics in question and an in-depth understanding of narratives and perceptions about the river catchment (Bauer & Gaskell, 2000; Nahuelhual *et al.*, 2016; Haklay & Francis, 2018). Nyumba *et al*. (2018) argue that using groups in research, following socially-oriented procedures which can be easily understood, produces results with high face validity as the method allows the researcher to gain information on how people in groups think, perceive, give ideas and share experiences.

To start the mapping process, groups made of five to eight participants were formed as shown in table 3.6. Carlsen and Glenton (2011) suggest between five to ten participants in a group for effective participatory mapping. This was also based on their willingness to participate in the study and more especially the target population. A total of eight group meetings were held in the study area with participants from two sub-catchments of the Lower Komati River. The study had initially targeted communities from the three sub-catchments of the Lower Komati River; Driekoppies/Midplaas communities (Lower Lomati sub-catchment), Kwazibukwane/Mzinti Communities (lower Komati west sub-catchment) and the Komatipoort communities (Lower east sub-catchment). However, communities in the Komatipoort area are mostly made up of commercial farmers and migrants who work on the farms. They declined to be part of the study and most of them had no historical knowledge of the Lower Komati River. The demographic characteristics of the groups formed by the participants are shown in Table 3.6.

Table 3.6. Table showing demographic characteristics of the community groups from the different sub-catchments which took part in the participatory mapping exercise

Sub-catchment	Village	Groups	Gender
Lower Lomati sub-catchment	Midplaas	1	5 Females
	Schoemansdal	2	6 Females
	Driekoppies	3	5 Females
	Midplaas	4	6 Females 2 males
Lower Komati West sub-catchment	Mzinti	1	6 Females
	Sibange	2	7 Females
	Magudu	3	8 Females 2 males
	Madadeni	4	7 Females 1 male
Total participants			50 Females 5 males

Participants from the same village were grouped as shown in Table 3.6. Participants were requested to again group, this time in gender to get gender-focused views. However, that was not accepted by the participants, thus some groups were mixed with females and males. The discussions from the community mapping exercise were biased towards female participants as they comprised 90% compared with 10% of male participants.

The participatory mapping in the groups was guided by a set of questions (Appendix 2-A) that sought to identify areas of social value and the location of main water-related ES in the Lower Komati. Participants were asked to illustrate the catchment as per their understanding with diagrams and show the location of ecosystem services and places of social value in the catchment. The outline of the catchment area was provided as guidance. Places of social value were identified as points they perceived as important for their daily activities.

Figure 3.3. Community members from Midplaas and Sibange taking part in the participatory community mapping exercises. (Pic 1: Midplaas;28/02/2018 and Pic 2: Sibange:09/10/2018)

Participants in the groups were asked to map the location of areas of interest that they use for different activities. Since most of the participants were not familiar with how to read maps, they drew the map of the river as they understood it on the paper provided (Figure 3.4) and located the ES and areas of social value based on their judgment. This is known as cognitive mapping, which is based on the principle that drawing a locality allows an individual to learn, store, recall, use and manipulate information about an area (Kitchin, 2015). According to Wheeldon and Faubert (2009), although the use of cognitive mapping varies depending on the research at hand, they all help to better frame participants' experiences and unravel individual perceptions and the importance of their surroundings.

The location of ES and areas of social value in the catchment were then hand-drawn onto the base maps provided to the participants. Each group produced a map of the area and associated areas of social value to them in the Lower Komati River. To guide their mapping and discussion, a set of guiding questions were developed for this activity. The questions were on the uses, social value and threats that might compromise their use of the river and its products. The map also generated more discussions on the uses and social value of different parts of the river between participants. For example, participants were asked to show areas they use and get services from, to indicate their locations and explain why they prefer to use that particular location of the river. This provided insights on the social value of the Lower Komati river catchment, which other participants might have been aware of. This resulted in the participants discussing amongst themselves.

Once the cognitive maps were produced, the researcher had a discussion with each group on trends or changes in the area or use over time (trend analysis); in other words, *how has the condition of the site changed over the last 20 years? Do you have to use different areas now?* These questions were intended to capture the river's social value and use based on their past and current experience. Participants discussed changes that have taken place in the river and how these might have affected how they use and value the different parts of the river catchment. Participants used colour (red and green) stickers/dots to indicate changes in how they value the different marked areas on the map. According to Brown and Reed (2012), social value data collection can be shown by using a hard copy medium where points are drawn or by using coloured tokens or stickers. In this research, green markers (dots) were used to identify places of positive value to participants (areas that are not under significant pressure or areas that pose no risk to river health). These areas participants were regarded as ideal for use and were socially valued highly. Red markers were placed in areas of negative value, which participants deemed to be under threat in the catchment as well as threats to their use and were not highly socially valued.

Each marker (red/green) was then weighted to show that 1marker=10 points. The weighting was added and used to show mapped point densities (Alessa *et al.*, 2008). These weightings were used to produce social value density maps. This method was used to record 'density' (in other words, number of dots) by asking respondents to use 'positive' and 'negative' dots to indicate important and threatened places (Bryan *et al.,* 2010). As the participants placed the dots in different parts of the map, they had discussions amongst themselves on their placed values. Transcripts were made from the recordings and later validated with a field visit. This helped to understand how social value in the river catchment changed in space, time and definition; any changes in the river's state might affect how the river is valued.

Moreover, the mapping activity provoked conversations between the researcher and participants. Notes and videos were taken during the drawing process. An example of the produced map is shown in Figure 3.4. Participants were allowed to express themselves outside of the guiding questions about any other issues that could be of interest. Interaction between the participants in the different groups was observed and notes were taken. According to Nyumba *et al.* (2018), participant observation is important to uncover a deeper understanding and meaning of their actions and views. This involved taking notes with careful observation of their gestures and listening. The observation helped to intertwine the participants' description and their behaviour when describing the river's health, history and the value placed on the river. Once the participants had finished mapping, a photograph of the map was taken as shown in Figure 3.5.

Figure 3.4. Picture showing cognitive map produced by participants from Madadeni village (09/10/2018)

After the mapping was completed, cognitive maps were produced as shown in Figure 3.5. The researcher, accompanied by two members of each community group, tracked the sites marked by the participants to capture their geographical coordinates using a Garmin eTrex 10 model, global positioning system (GPS). The tracking of the sites for coordinates, was important to verify the location of the areas marked on the maps by community participants. According to Kleinitz and Merlo (2014), tracking is one core activity of PGIS where a GPS unit can be used to track the daily activities of participants, to collect points at particular locations. A GPS at 0.5m accuracy was used to store the coordinates identified where possible for further analysis in ArcGIS 10 software. For this research, tracking was used to elicit more information on the location of areas identified during the participatory mapping exercises.

The project team then digitised the hand-drawn maps using the coordinates collected from tracking to show the exact location of the areas identified by the participants. The participatory cognitive maps were incorporated into a digital database, which allowed the use of traditional GIS techniques to develop a catchment map showing areas of social value in the Lower Komati River. Each map was digitised (using ArcGIS 10 software) into a geodatabase as a point feature shapefile. Each point was given a unique identifier based on the respondent's identification. The areas of social value in the river catchment formed part of the attribute information for the production of maps in the GIS environment. The maps were produced to illustrate the spatial distribution of ES and areas of social value in the study area. Figure 3.6 illustrates the mapping process from participant conceptual mapping to digitisation of the participants' conceptual maps.

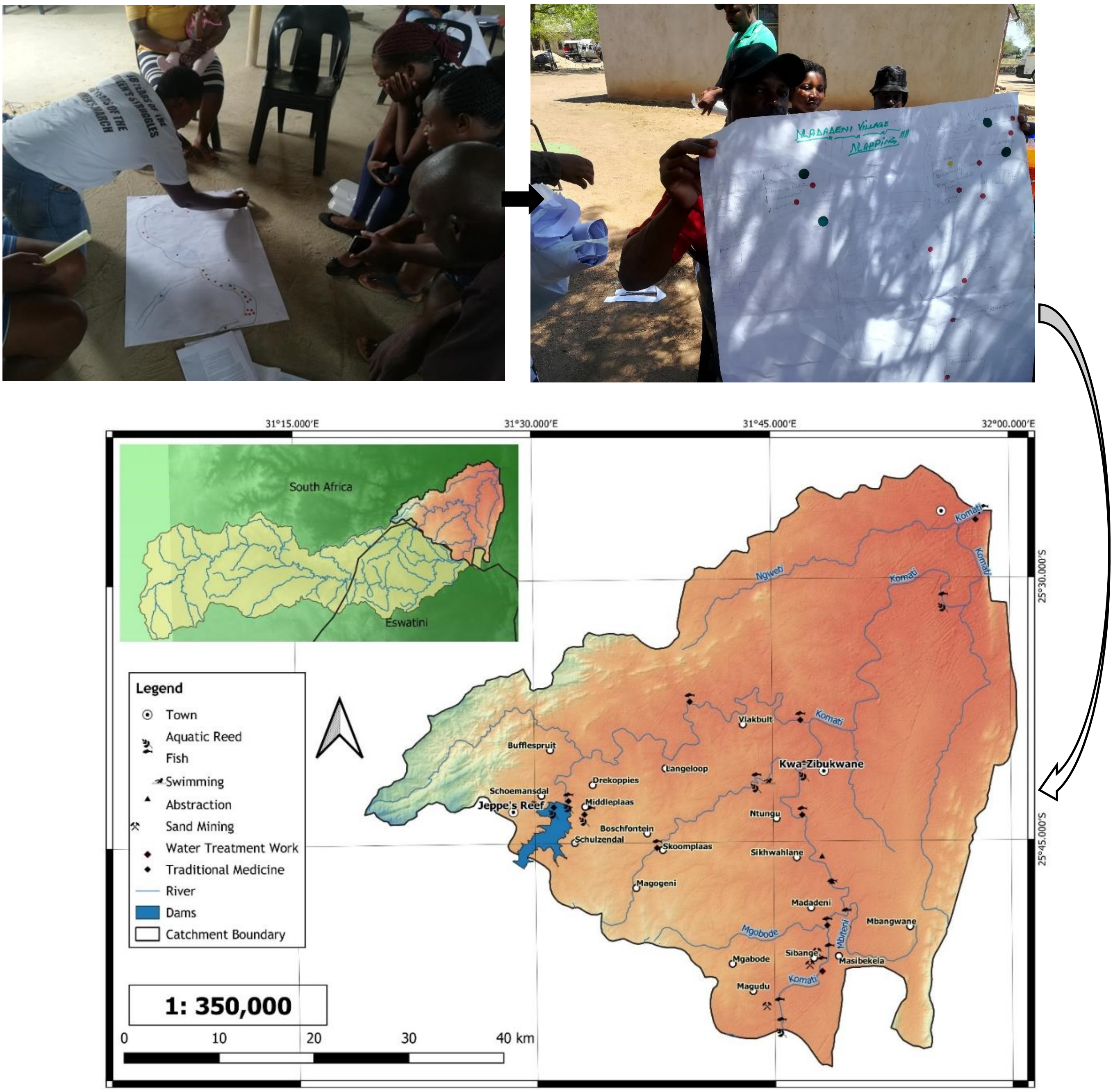

Figure 3.5. Mapping process followed by the research: from participants co-developed conceptual diagrams through to digitised map (source: field data).

3.5.6.2 Key informant interviews elders and informed members of the community

Pursuant to the participatory mapping, key informant interviews with community elders and informed individuals from the communities, on the history of the catchment were conducted. Informed members of the community were identified during the mapping as individuals who seemed to have more information about the history of the river. Elders were also identified as knowledgeable about the history of the river, having spent over 30 years in the catchment and being over the age of 60 years. Semi-structured in-depth interviews on the history of the catchment with the selected participants were carried out. According to Harrell and Bradley (2009), semi-structured interviews are lists of broad, open-ended questions to be addressed to knowledgeable individuals in a conversational, relaxed and informal way. The flexibility of a semi-structured interview keeps the discussion meaningful without limiting the participant (Klain & Chan, 2012; McIntosh & Morse, 2015; O'Keeffe *et al*., 2016). The face-to-face interviews were used as they have the advantage of allowing participants to expand and clarify information (McIntosh & Morse, 2015). Key informant interviews were appropriate to yield in-depth opinions and perceptions about the river, as standardised interviews may exclude values of abstract character and respondents might not be able to answer direct questions about values (Hatton MacDonald *et al*., 2013).

Participants' narrations centred on their personal stories that relate to their involvement with the Lower Komati River catchment as far as they could remember. Hatton MacDonald *et al.* (2013) and Sharp *et al.* (2019) explain that narratives reveal an individual's values and actions on how they have shaped the past and how the past shapes present-day values and actions. According to Cook *et al.* (2014), personal experience of nature shapes an individual's values and knowledge. Such knowledge can inform us about past events or experiences from the perspective of an individual or a group of people. The researcher's role was to probe the participants in cases where some things may not be clear. It also helps the participants to open up and provide more novel perspectives on what has occurred in the environment over time. According to Thurstan *et al.* (2016), historical narrations by key informants can be used in natural resources management to gather and record accounts of the past.

Matsui *et al.* (2016) argue that some history researchers have criticised the reliability of oral evidence and rather advocate for documentary sources (because human views might be subjective). However, Mitchell and Egudo (2003) have shown that oral evidence plays a crucial role in exploring and better understanding indigenous peoples' perspectives on the histories of waterscapes. The authors argue that the process is similar to a documentary investigation in the library and archives. The interviews' in-depth historical representations of the catchment highlighted trends, conditions, threats and changes that had occurred in the river catchment. Participants narrations on the history of the catchment corroborated and supplemented data collected during the participatory mapping.

3.5.6.3 Key informant interviews with fishers

Key informant interviews with fishers were conducted. The interviews with the fishers were deemed necessary as the participatory mapping exercises revealed fishing as the most common activity in the catchment as well as that most parts of the river were highly valued for fishing. Semi-structured in-depth interview sessions with the fishers were conducted and guided by open-ended questions as described in the previous section. The guiding questions were based on how the respondents use the river, followed by identifying any changes that have been noted which might have affected their trade and lastly how the fish condition may be used to reveal the state of the river's health. The fishers were also shown pictures of common fish in the catchment. This is sometimes referred to as photo-elicitation (Harper, 2002) and can be done in various ways, either by participants selecting pictures provided by the researcher or the participants can bring their own pictures (Bignante, 2010; Glaw *et al*., 2017). In this case, photos showing different fish (Appendix 2-D), were provided by the researcher to help the respondents answer some questions easier regarding the fish in the catchment. The priority was on identifying the correct fish.

Data from the interviews with fishers and community key informants were analysed using thematic approaches where key issues from the various respondents were grouped into categories. Collected data was first transcribed from audio into textual format. A coding framework was thereafter developed to allow two main processes; first, sorting and classifying data into specific categories and secondly, identification of emerging themes or sub-themes. This focused on describing emerging themes to the level that would allow them to be further analysed. This was especially helpful to make sense of data at the empirical level. The most important part was what people said about historical experiences, trends, threats and other matters of relevance to the context, as these related to the establishment of indicators. Three types of coding, namely descriptive, topic and analytical were used to work through the emerging themes, as guided by Richards (2005). This form of coding involves working from observations towards inference to local conditions. Descriptive codes identified socio-economic and demographic information about participants for example age and length of residence time in the area. To determine topics respondents' inputs were considered as per their discussions. To analyse the topics the research used explanations provided by participants and also made inference from participants' responses.

3.5.7 Target population and sample size

Before any of the mentioned data collection activities were carried out, a 'familiarisation' of the catchment and area was undertaken. The exercise involved opportunities to engage with the catchment stakeholders' forum, which comprises mainly of users in the catchment from different sectorial groups as shown in Table 3.7. This started conversations and allowed the researcher to get acquainted with different stakeholders and identify the target population, namely local communities who are water users in the Lower Komati River catchment. These water users (communities) came from the sub-catchments of the Lower Komati River as described in Section 3.3 (study area) and are regarded as primary stakeholders, as they have a direct interest in the use of the catchment and are involved in the community river health monitoring programme.

Table 3.7. Table describing the study's target population groups, research and sampling methods aimed at each group.

Research methods	Target Population	Sampling method
Participatory Mapping	Local community members	Purposive and snowball
Key informant interviews	Local elders and middle-aged community members who showed great interest in the catchment during Participatory Mapping	Purposive sampling

The different target population groups were engaged at different times and using the different research methods as shown in Table 3.7. The selection of participants in this research was guided by Verschuren and Doorewaard (1999), who recommend purposive sampling in case studies for in-depth analysis of the study. The research started with the participatory mapping exercise, which targeted all community members within the sites, using purposive sampling. According to Haq (2015) and Tongco (2007), purposive sampling is deliberate in the choice of an informant due to the qualities the informant possesses. Palinkas *et al.* (2015) argue that when using purposive sampling, participants relevant to the research question are selected. In this case, the catchment map outline was used to identify areas around the Lower Komati River catchment to help identify eligible potential participants for the study. The researcher went to these areas to recruit eligible participants for the participatory mapping. The criteria for selection were that the people should have lived within the Lower Komati River catchment for not less than 10 years and have an interest in the river catchment. Participants were first selected randomly and eligibility ascertained. Additional participants were recruited throughout the process via the snowball sampling method (by direct recommendations from respondents).

Generalisation and inference making in this study are not based on sample size, as might be the case in other research approaches; rather, they are based on the generalised views at the level of underlying generative mechanisms that shaped the study (Ylikoski, 2018). Vasileiou *et al.* (2018) argue that choosing population size should be driven by the design for the study. The authors explain that population size should be small enough for case studies to give a 'deep, case-oriented analysis'. Thus, participants chosen for the community key informant interviews were those who showed high knowledge and interest in the history of the Lower Komati River. These participants were identified to be of major influence in the river catchment, thus their inclusion was regarded as paramount in the study. The participants were a mix of middle-aged and older participants from the PGIS groups from each sub-catchment of the Komati River.

To avoid saturation (since detailed information about the river was required in this case study), only eight participants took part in the key informant interviews. According to Saunders *et al.* (2018), saturation is reached when no additional data is necessary for a researcher to develop properties of the category. Similar instances of data are identified from other participants and the researcher becomes empirically confident that a category is saturated. Thus, Marshall *et al*. (2013) suggest that for single case studies;, not more than 30 interviews should be undertaken with participants. The eight participants were selected based on residence time and knowledge of the area. Therefore, based on the criteria of participants and to avoid saturation, the eight participants were chosen. The participants were made of four elders (above 60 years old and resident for more than 50 years) and four middle-aged persons (below 40 years), who have been residents in the area for more than 30 years. These participants came from different communities in each sub-catchment that participated in this exercise. Working with such a small sample was useful for accessing in-depth data, given the intensity of the study. Input from the key informants helped to identify attributes/indicators that had historically been used to identify different aspects of river health. Local elders are a key source of historical perspective of the catchment since they have knowledge and experiences that expand beyond that of other research participants. The identified elders had witnessed and experienced changes in conditions, threats and trends of the river as they had been residents in the catchment for more than 50 years. In the case where an elder participant did not wish to be interviewed, snowball sampling was used to identify a new participant. The middle-aged participants younger than 40 years were selected to be key informants based on their demonstrated interest and knowledge about the river during the participatory mapping exercises. The selection of the fishers was based on i) their involvement in fisheries practice in the study area and ii) being active in fishing activities for at least 5 years. Initially, a purposive sample of 10 fishers was proposed. However, only five agreed to be part of the study. Most of the fishers were practising illegally, so they were adamant not to be part of the study. Those who agreed requested that no photographs or videos be taken, only audio recordings were permitted.

3.5.8 Data interpretation and transcript analyses

To analyse the transcripts from the group participatory mapping sessions, rigorous content analysis was employed and notes were made by the researcher to elicit the answers for areas of social value in the Lower Komati River. The transcript content analysis helped to produce themes from the discussions. Qualitative information on how using the river, ES and social value of the river was changing over the years was gathered from the transcripts. Analysis of words used by the participants to explain river health and suggested indicators of river health was done through Voyant to pick up commonly used words and related descriptors, which were then rigorously analysed (see Section 6.5).

Voyant is a web-based application developed by Sinclair *et al.* (2003) and is used to analyse and detect frequently used words and associated link patterns between the words in a transcript (Welsh, 2014). The transcripts from participatory mapping and informant interviews were analysed by running them through Voyant to create word clouds by detecting patterns, identifying word frequency or associative links between words. Word clouds were produced for all transcripts for communities in each sub-catchment and are useful for preliminary analysis and validation to clear any bias the researcher may have by gathering the general theme of the transcripts (McNaught & Lam, 2010; De

Paolo & Wilkinson, 2014). While word clouds are useful in gathering a sense of the data, they are not a representation of the transcript. They only capture the frequency of the word and not its relevance within the transcript or how the word was used. Thus, they cannot be used as a stand-alone research tool; the frequently identified words from Voyant were analysed based on how they were used in the transcripts to develop themes. The relationship between keywords and common words used by participants was done through Voyant to help support the suggested themes as the programme may clear biases the researcher could have when identifying them. Verbatim quotations are included to provide detail and context to the interpreted results.

3.6 Reflections on researcher's position

As part of my reflection on meaningful participation of local communities in river health assessment, I acknowledge that my position in the research matters, as do power dynamics among participants (Cheng & Randall-Parker, 2017). I recognise that as a researcher, I was driving and facilitating the process, therefore power dynamics were created. I acknowledge that researcher-participant relationships cannot be equal. Furthermore, I am cognizant of the importance of diversity and culture in communities. This is particularly important in a country like South Africa in which social-cultural diversity and social cohesion, particularly between different ethnic groups, are a societal challenge (Seekings, 2008). Thus, in my engagements with stakeholders, I was aware of potential language differences. I worked with experienced translators and students from the communities as assistants where necessary and attempted (as much as possible) to converse directly in local languages, depending on language capabilities in the team (many of us in the research team spoke Siswati, a common local language in these communities)

The level of participation of local community members varied across cases. We acknowledge that in some cases equitable participation and knowledge co-creation was not possible, as some participants declined to be part of the research. However, I endeavoured to facilitate open and participatory processes and all participants were allowed to participate. This process created the potential for more equitable and meaningful participation. I also have an ongoing and open relationship with the participants and I believe the research processes have been perceived as beneficial by participants.

3.7 Ethics considerations

Questions posed and chosen methodologies used during data gathering and recording of research findings were informed by a sensitivity to ethical concerns. Resnik (2020) states that ethics are important to guide how to act and analyse issues and interact with others. The necessary protocol was followed before data collection commenced. Sampling permits were received from the Mpumalanga Tourism and Parks Agency (MP5641 and MP5662) and ethical clearance was received from the University of the Witwatersrand Animal Ethics Research Committee (2020/07/01/B) for fish sampling. (Appendix 1-H). Ethical clearance was also received from the University of the

Witwatersrand Human Research Ethics Committee (non-medical) Protocol number: (H17/08/07) (Appendix 2-F).

Before conducting the study, the purpose of the research was communicated to prospective participants and they were given a chance to agree to participate or not. Approval to conduct the study within the catchment was sought from the catchment agency manager, local authorities and participants (letters attached in Appendices). Written voluntary informed consent was sought from participants, any refusal to participate was respected. Gender and culture were taken into consideration as well. The study was conducted at the time most convenient to the prospective participants. They were also informed of their right to withdraw at any point during the study should they wish. Participants' consent was sought to take pictures and videos and that data taken may be used during seminars and publications. To protect participants' identities, verbatim quotations used in this study in Chapters 6 and 7, do not identify the participants' names and personal details. The study only describes the participants based on the communities, age and date in quotations as shown in different parts of Chapters 6 and 7. The use of the participants' locations and taking of pictures during the mapping process, was ethically consented to by all participants (see copies of consent forms and ethics procedures followed in the study in Appendices).

3.8 Conclusion

The chapter shared insight into the research approach, sequencing, study design, methods and data analyses used in the study to meet the thesis' objectives. The methodology of the study was constituted as a case study and thus 'intensive' methods were used. Methods used to determine the ecological state of the river using fish and macroinvertebrates as ecological indicators were explained. The chapter also clarified how participatory mapping, field tracking and key informants' in-depth interviews were used to ascertain the social value, human-environment relationships between the Lower Komati River and the communities and their potential contribution to river health monitoring. Further, the processes of analysing the data at each stage were explained. Results from the applications of the cited methods and analyses follow in the next chapters (Chapters 4, 5 and 6).

4 CHAPTER 4: MACROINVERTEBRATES AS RIVER HEALTH INDICATORS OF THE LOWER KOMATI CATCHMENT

4.1 Introduction

The chapter fulfils the first research objective of using macroinvertebrate community structures to determine the present ecological health of parts of the Lower Komati River. Macroinvertebrates have been widely used as biological indicators (Day, 2000; Chessman *et al.,* 2010; Agboola, 2017; Dalu & Chauke, 2020; Koehnken *et al.,* 2020) as they are better established in freshwater ecosystems. Macroinvertebrates are usually confined to parts of the river where physical and chemical conditions are suitable. They reflect changes in river conditions, as they differ in tolerance to pollutants and other aspects of water quality making them a preferred choice in river health studies (Anwar Sadat *et al.,* 2020). Macroinvertebrates' composition and abundance are mostly used to indicate the overall ecological state of the water resource, making their diversity a good measure of the health of ecosystems. Riverine macroinvertebrates have various habitat preferences and faunal assemblages' presence or absence in any site is dependent on prevailing water quality, habitat change and seasonal variability (Gyedu-Ababio & van Wyk, 2004; Dlamini *et al.*, 2010; Gál *et al.*, 2020). Dale and Beyeler (2001) support the argument that habitat conditions provide information on the structure, function and composition of the ecosystems. Therefore, aquatic macroinvertebrates have been used for the analysis of parts of the Lower Komati River's ecological health.

The South African Scoring System Version 5 (SASS5) and the MIRAI for macroinvertebrates; two methods widely used to analyse the rivers' health in South Africa using macroinvertebrates were used. These indices incorporated analyses of the macroinvertebrates' abundance and habitat conditions. However, macroinvertebrates cannot give a full picture of the ecological state of a river, thus Kleynhans and Louw (2008) state that it is important to also use water quality to identify indicators of change in structural, functional and compositional diversity. Results from both water quality and aquatic macroinvertebrates analyses were used to indicate the ecological state of the Lower Komati River at the time of sampling.

Water quality and macroinvertebrates samples were collected from six sites, four times, between April 2018-March 2019 at different flow seasons. Two sampling campaigns in April 2018 and March 2019 represented the low flow seasons and the September 2018 and December 2018 campaigns represented the high flow seasons. In each campaign, the six sites were sampled over 3 days starting upstream with sites 1 and 2, followed by sites 3, 4 and finally sites 5, 6. No major climatic event (rain or floods) took place in-between days of sampling, which might have affected results. Thus the sampling sites results were regarded as comparable. Sampling at different flow seasons was important to determine if community structures sampled were a result of flow changes or water quality and habitat changes. From the data collected, macroinvertebrate community structures and water quality were analysed. The number of taxa collected between sample sites were estimated and compared over the four sampling periods. Based on that the need for a full and broad analysis of the sites' habitat and macroinvertebrates, sampling took place during low high flow seasons to capture the impact of flow on community structure. Moreover, more frequent sampling over the 2 years of data collection was not logistically possible within the timeframe and budgetary limitations.

The SASS 5, MIRAI and multivariate statistical techniques were used to analyse the ecological state of the sites using the macroinvertebrate community structure between the six sites. Water quality parameters considered as drivers of macroinvertebrate structure were also analysed. Specifically, inferential and multivariate statistics were used to explore associations and spatial-temporal variations for each data set and physicochemical water quality data collected are presented in Section 4.2. The outcomes of the application and analysis using SASS 5 and MIRAI methods follows in Sections 4.3 and 4.4. Finally, the multivariate statistical analysis showing the relationship between community macroinvertebrates with water quality are presented in Section 4.5.

4.2 Water quality results

Results for the in situ measurements include temperature and dissolved oxygen (saturation & concentration), as shown by the boxplots in Figure 4.1 a) and b). The boxplots in Figure 4.1 are graphical representations of the summary statistics (mean, min and max, median) of the concentrations of the included temperature and dissolved oxygen saturation/concentration measured from the Lower Komati River between April 2018 and March 2019. On all the graphs (Figure 4.1a) to 4.6b), the thick lines represent the median values (50th percentile), boxes represent the 25th and 75th percentiles and whiskers represent the maximum and minimum values within 1.5 times the inter-quartile range.

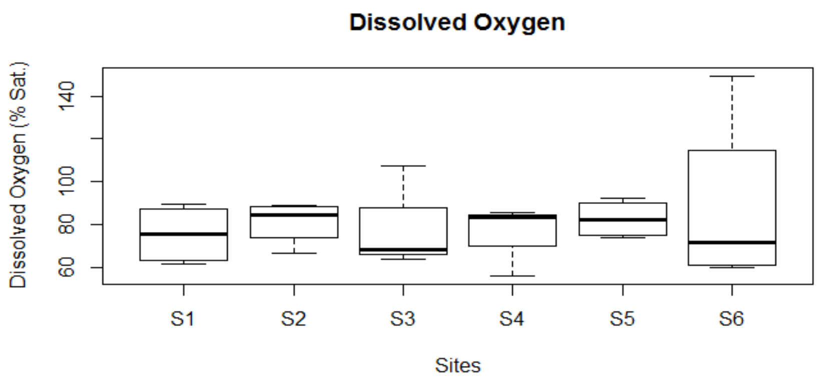

Figure 4.1a). Boxplots summarising concentrations of dissolved oxygen (saturation) in the Lower Komati River water, collected between April 2018 and March 2019 from six sampled sites.

Dissolved Oxygen saturation (%) in Figure 4.1a) shows that Site 4 recorded the lowest reading of 56% during the April 2018 sampling period, with the highest at 149% in Site 6 during March 2019 sampling. The mean from the sites was between 75.4% (Site 1) and 87.9% (Site 6). The Dissolved Oxygen saturation (%) readings were generally within the South African Water Quality Target guidelines for aquatic ecosystems, which recommends a range of 80%-120 as shown in appendix 1B(I).

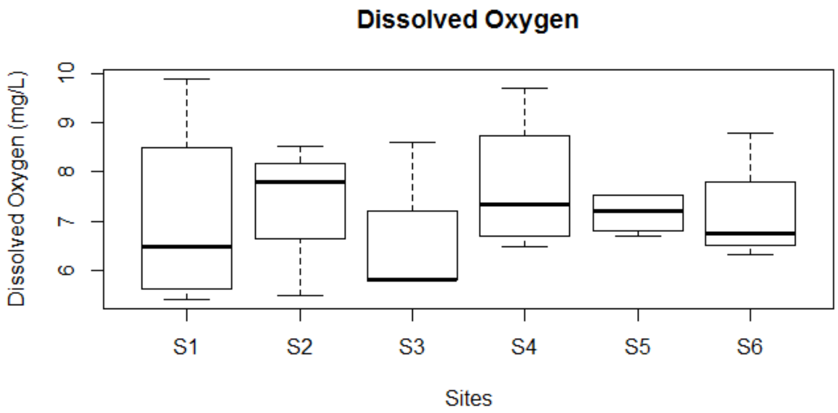

Figure 4-1b) Boxplots summarising concentrations of dissolved oxygen (concentration) in the Lower Komati River water, collected between April 2018 and March 2019 from six sites.

Dissolved Oxygen concentration (mg/l) results as shown in Figure 4.1b), were all above South Africa's Water Quality guidelines for Freshwater Aquatic Ecosystems Volume 7 (DWAF, 1996b), which is set at 4 mg/l. The readings ranged between 5.4-9.7mgl/l as shown in Figure 4.1b). The lowest reading was observed in Site 2 with 5.2mg/l during the September 2018 sampling period and the highest in Site 1 (9.7 mgl/l) during the March 2019 sampling survey. The DO saturation (%) level during the March 2019 survey in Site 6 and 3 might have increased due to the algae bloom in some parts of the sampling sites during sampling. This is consistent with Kunlasak *et al.* (2013) and Huang *et al.'s* (2017) studies that found that areas with high algae bloom and phytoplankton are likely to have increased DO due to low concentrations of oxygen-consuming substances and strong phytoplankton photosynthesis during the day.

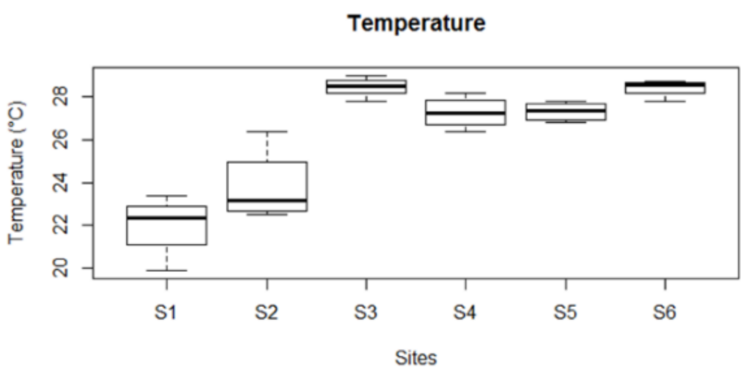

Figure 4.2 Boxplots summarising temperature readings in the Lower Komati River water collected between April 2018 and March 2019 in six sites.

The boxplots in Figure 4.2 show that temperature ranged between 19.9°C in Site 1 and 29°C in Site 3, with the mean ranging between the lowest 22.0°C (Site 1) and highest of 28.4°C (Sites 3 and 6).

As expected, average water temperature values increased with a decrease in elevation (from upstream to the Lowveld/Lebombo) which is supported by Jackson *et al.* (2017).

Electrical conductivity results in Figure 4.3a) show variation between the lowest reading of 26.0µS/cm recorded at Site 4 in December 2018 and the highest of 918 µS/cm at Site 3 recorded in September 2018. Figure 4.3b) shows that, site 3 also had the highest total dissolved solids (TDS) of 96.2 mg/l and the lowest was recorded in Site 6 (32 mg/l), all sampled during the March 2019 sampling period. Figure 4.3 shows that the distribution of these two parameters does not show distinct linear relationships. Rusydi (2018) explains that electrical conductivity and TDS are two parameters that correlate, however, these results show no relationship between Electrical Conductivity and TDS. Rusydi (2018) further states that the relationship between conductivity and TDS is not directly linear; it depends on the activity of specific dissolved ions and the average activity of all ions in the liquid and ionic strength.

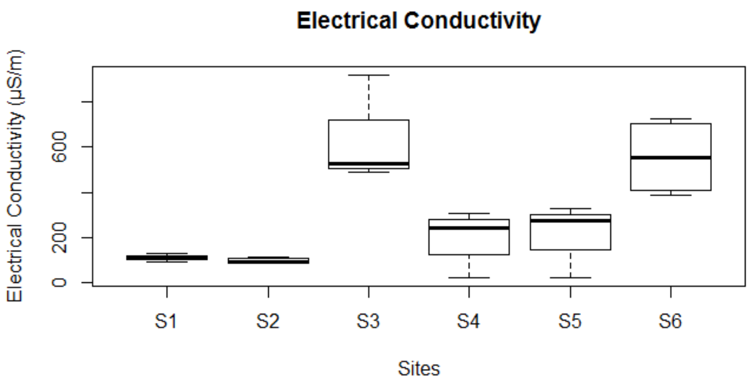

Figure 4.3a). Boxplots summarising electrical conductivity in the Lower Komati River water collected between April 2018 and March 2019 from six sites.

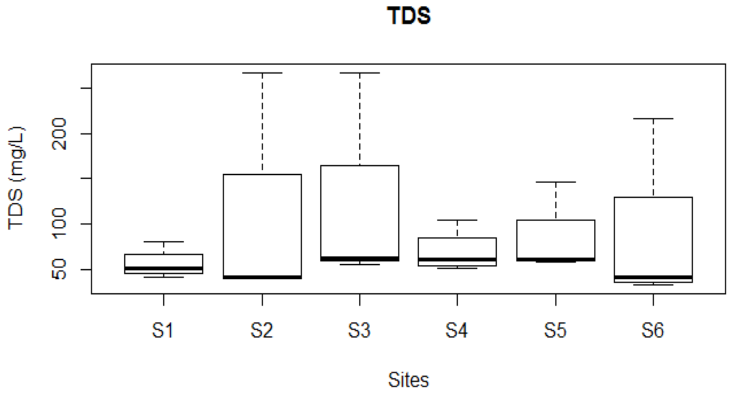

Figure 4-3b). Boxplots summarising Total Dissolved Solids (TDS) in the Lower Komati River water collected between April 2018 and March 2019 from six sites.

Figure 4.4 shows that pH levels ranged between 7.0 to 8.1, which are all within the target range (6 and 8) of the South African Water Quality Guidelines for Aquatic Ecosystems protection (DWAF, 1996b). The measured pH values were consistent with previous studies on water quality in the region (Dlamini *et al.*, 2010; van der Laan *et al.,* 2012). Most freshwater systems in South Africa are relatively well buffered and more or less neutral, with a pH ranging between 6 and 8 (Day & King, 1995; DWAF, 1996a).

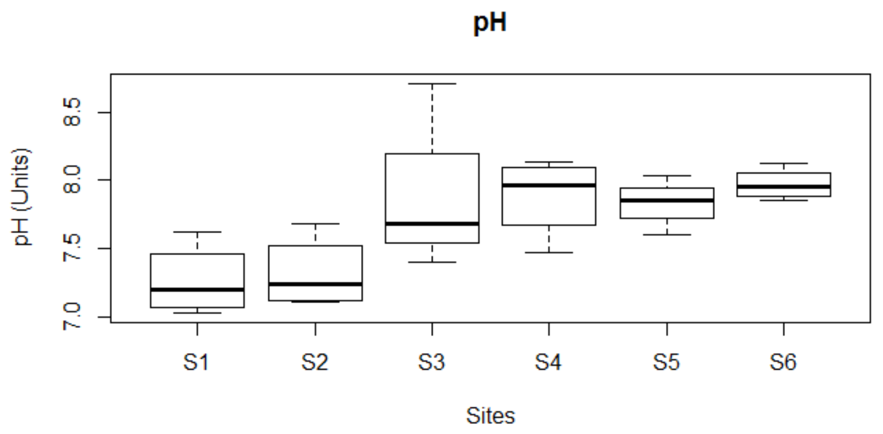

Figure 4.4. Boxplots summarising pH in water samples, collected from six sites along the Lower Komati River between April 2018 and March 2019.

In addition to the in situ physical parameters, nutrients were also determined. Results in Figures 4.5 a), 4.5 b), 4.5 c) and 4.5 d) show that all sites, except Site 1 had all nutrient levels within the tolerable and ideal ranges of the South African Water Quality Guidelines for Aquatic Ecosystems. Nitrate readings were within the tolerable range of 2.5-10mg/l, ammonia and phosphorus levels within the target range of 0.5mg/l compared to the South African Water Quality Guidelines for aquatic ecosystems. However, all nutrient levels in Site 1 spiked in December 2018; with 23.9 mg/l nitrate, ammonium and phosphorus recording 0.93mg/l and 0.92mg/l, respectively. Nitrite levels were also elevated at Site 1 during the December sampling with a high of 3.8mg/l as shown in Figure 4.5c). Otherwise, Site 6 had the highest median of 3.4mg/l.

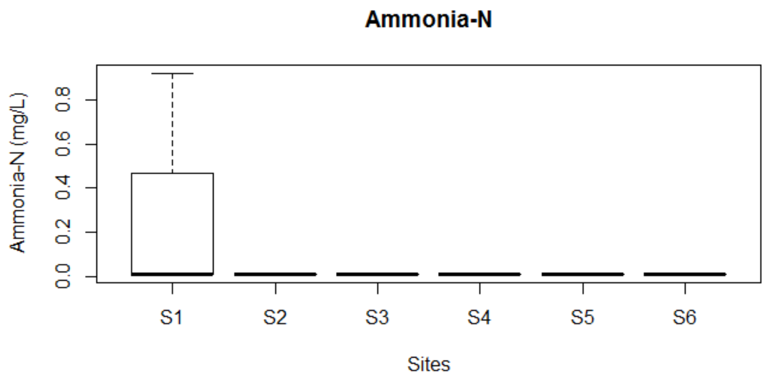

Figure 4.5a). Boxplots summarising Ammonia-N in water samples collected from six sites located along the Lower Komati River between April 2018 and March 2019

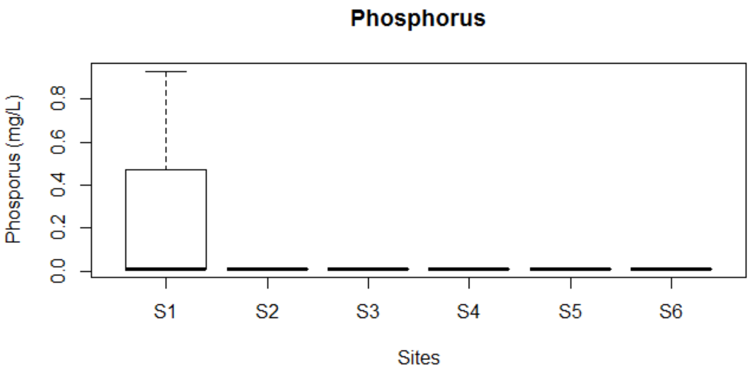

Figure 4-5b). Boxplots summarising phosphorus for water samples collected from six sites located along the Lower Komati River between April 2018 and March 2019.

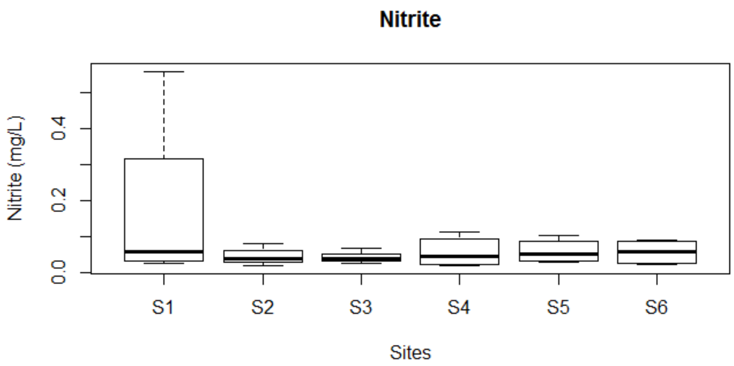

Figure 4-5c) Boxplots summarising nitrite for water samples collected from six sites along the lower Komati River catchment between April 2018 and March 2019.

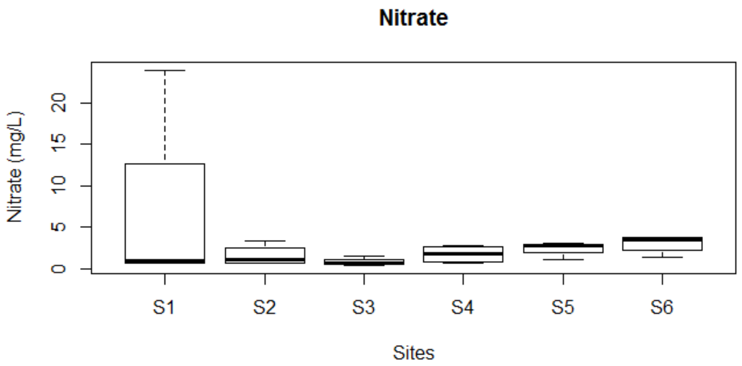

Figure 4-5d). Boxplots summarising nitrate for water samples collected from six sites along the lower Komati River catchment between April 2018 and March 2019.

The water quality results for ammonia, phosphorus, nitrite and nitrate concentrations from all the sampling points except Site 1 were within the acceptable target range, as per the South African Water Quality guidelines for aquatic ecosystems as shown in Figures 4.5 a) to d). The acceptable levels in sites 2-6 along the Lower Komati River mainstem are similar to results by du Plessis (2019), who found that the Inkomati-Usuthu WMA is predominantly of low risk in terms of the selected physical and chemical water quality parameters, as a result of improved agricultural practises. Dlamini *et al.* (2019) also attribute good agricultural practices in catchments, to keeping the concentrations of nutrients low. This shows that it is important that agricultural activities are managed well at farm level to avoid major water quality issues at catchment level.

The research attributes the spike in nitrate recorded from Site 1 in December 2018 to the application of fertilizer by a local farmer and temporary damming of the river upstream of the sampling point a few days before sampling. Based on field observation and information from the farmer's aides, fertilizer was applied in the fields upstream. This fertilizer is attributed to have contributed to the increased nutrient levels in the site, as seen in Figures 4.5a) to 4.5d). Several studies have established a linear relationship between agricultural nitrogen fertilizer application in agricultural lands and increased nitrogen, nitrate, ammonia and nitrite levels in the nearest water resources. Heathwaite and Johnes (1996) conducted a study on the River Windrush, found that concentration of nitrate and nitrite peaked in the spring and summer seasons which correlated with main period of fertilizer application on crop agricultural lands. The fertilizer applied was mostly urea (46% N as NH;), with additional applications of NPK at a total annual application rate of 230 kg N ha. -Conclusions showed that peak concentration of nitrogen in early summer suggests that fertilizers were being applied to the crops above demand. Lam *et al.* (2012) also conducted a study in the Kielstau River catchment and found that, diffuse source pollution of nutrients from farms that apply fertilizers in the vicinity of the river had high nutrient levels and that these amount of nitrate released is influenced by the quantity of fertilizer N applied.

Occasional spikes of nutrient enrichment (N and P concentrations) in some parts of the river associated with agricultural lands was also observed by Dlamini *et al.*(2019) in a study in the Crocodile in South Africa, and these were correlated with fertilizer application in agricultural lands. The spikes in concentration of nitrates and ammonium in water quality were attributed to fertiliser application time and periods of low flow in the catchment. This was similarly observed in site 1 of this study as the spike in nutrient levels in December was also associated with low flow as seen in Table 5.6. The tolerable nutrient levels detected in the Lower Komati River in the other sites may be because the sites are within the Lower Komati River stem, with fast and deep flow class, whist Site 1's flow class was shallow and fast-flowing as seen in table 5.6. Dlamini *et al.* (2019) argue that at low flows, there is often a reduced dilution capacity and contaminants easily exceed acceptable threshold concentrations, thus it is important to properly manage flows to maintain a healthy river. According to Nilsson *et al.* (2008) pollution disturbs the linkage between flow regime and water quality, and causes a change in water quality above natural variability flow variation and flushing capacity. Thus, is it important to continuously monitor water flow during water quality sampling to reliably determine the allowable loading pattern into water resources, and the river's flushing capacity. Thus, according to Dlamini *et al.* (2019), water pollution and compliance status should be based on the flow regime at each season and its ability to flush out pollutants

The effects of increased nutrients from agricultural fields is discussed by different authors; Ashton and Dabrowski (2011) state that intensive agricultural activities can negatively affect the ecological conditions of the river through nutrient enrichment. Hepp *et al*. (2010) explained that agricultural fertiliser nutrients have a significant effect on the structure and composition of benthic aquatic macroinvertebrate fauna. The authors conducted a study along different streams in Brazil and observed agricultural streams' macroinvertebrates' diversity and found that the density of macroinvertebrates significantly decreased in places with higher nutrient concentrations and fine sediments. Niba and Sakwe (2018) in a study in the Mthatha River, South Africa found that macroinvertebrates respond differently to habitat requirements and in areas where water quality showed major changes e.g increased nutrients; the diversity of the macroinvertebrates also changed. Alavaisham *et al.* (2019) also found increased turbidity, temperature, nitrate-N, and ammonium-N downstream of agricultural lands, compared to upstream and these were correlated to decreased macroinvertebrate diversity, richness with sensitive macroinvertebrates decreasing downstream compared to upstream. These case studies demonstrate evidence of the negative effects of agricultural practices on macroinvertebrate communities as a result of increased nutrient levels. Water quality and macroinvertebrates' responses to varying alteration of water quality as a result of agricultural water runoff resulted to changes in species distribution and ecological processes in the ecosystem.

The study also considered faecal coliforms and *E.coli* levels of the river. Howarth (2018) claims that faecal contamination of water is a major health problem and faecal coliforms have been widely used as an indicator of contamination (*E. coli* and total coliform). As the premise of this research is to integrate the social and ecological value of water, it is important to determine faecal contamination of the river's water to ascertain its impact on social value and use of the river by local communities (see Chapter 6). Societies commonly use river water for recreational and domestic which includes direct abstraction. So, the results are compared to South African Water Quality Guidelines for domestic use and recreational use shown in Appendix 1B(I). Results from the study show that faecal coliform and *E.coli* levels were above South African Water Quality Guidelines for domestic use, recreational use (must not be detectable in any 100-ml sample for drinking water and 130ml/100 mL at all sampling points and during all sampling periods. According to the South African Water Quality Guidelines for Recreational use (DWAF, 1996c), the target range for skin contact recreational use e.g swimming; *E. coli* level is not expected to exceed 0-130 CFU/100Ml to minimize the risk of gastrointestinal illness. As shown in Figure 4.6a), the lowest *E.coli* level was 41 CFU/100mL, recorded at Site 3 in September 2018 which was within the target range and the highest *E.coli* was 2417.7 CFU/100mL, recorded at Site 2 in December 2018 which exceeded the target range.

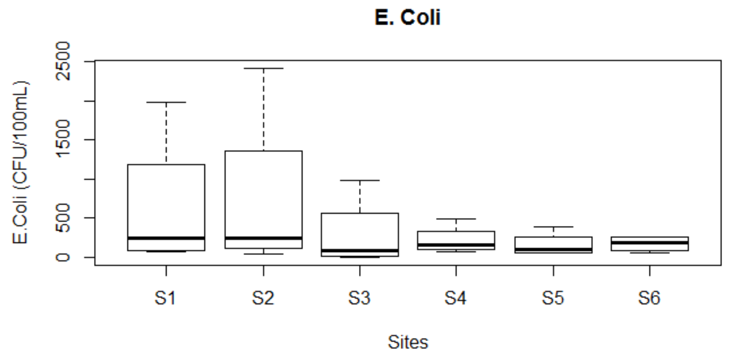

Figure 4.6a). Boxplots summarising the concentrations of *E.coli* for water samples collected from six sites along the lower Komati River between April 2018 and March 2019.

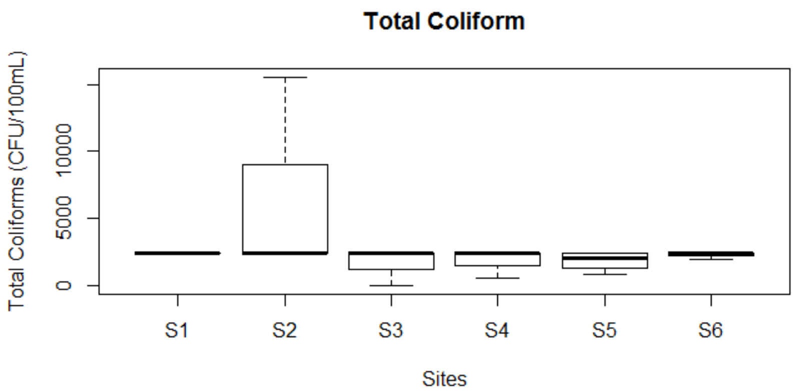

Figure 4-6b). Boxplots summarising the concentrations of total coliforms for water samples collected from six sites along the lower Komati River between April 2018 and March 2019.

The mean *E.coli* level ranged between 160.80 CFU/100mL (site5) and 638.0 CFU/100mL, recorded at Site 1 as shown in Figure 4.6a). These values are all above the target range (0 – 130 CFU/100mL) for recreation water use as per the South African Water Quality Guidelines for Recreational Water Use (DWAF, 1996c). The highest total coliform reading was recorded in Site 2 and the lowest was recorded in Site 3, all during the September 2018 sampling period. However, all these readings were above the target range (0 – 5 CFU/100mL) of domestic water use as stipulated by the South African water quality guidelines for domestic water use (DWAF, 1996b) if the water is to be consumed without any treatment. du Plessis (2019) highlights that the Inkomati Water Management Area is a medium risk area because of high faecal and *E.coli* levels, coupled with low to no flow periods that had never been historically observed. du Plessis (2019) attributes the high faecal coliform in the WMA to animal waste and poorly performing Waste Water Treatment Works (WWTWs). The solid waste dumped in most parts of the catchment and domestic runoff was observed during sampling. All the sample sites are downstream or in the proximity of human settlements, which could be a cause of the high faecal coliforms. The highest *E.coli* levels recorded in Site 2 are attributed to the fact that the sampling site is about 5km from the Schoemansdal area, which has informal settlements and there are several spots along the river where people dump used baby diapers containing faecal matter. Since the data was collected mostly over the wet season, this indicates diffuse pollution from the faecal runoff. The same is highlighted by Pullanikkatil *et al.* (2015), who demonstrated a link between high concentrations of faecal coliforms and *E.coli* in catchments during the wet season. During the rainy season, increased runoff carries pollutants to water bodies. IUCMA (2017) and Soko and Gyedu-Ababio (2017) state that WWTWs in the catchment are under pressure due to increased population, thus most parts of the catchment are characterised by high *E.coli* and total coliform levels from sewage discharge and overflow. Euzen and Morehouse (2011) and Herbig and Meissner (2019) explain that sewage discharge is detrimental as it pollutes water making it unsuitable for human use and imposing great social harm.

E. coli is also widely used as an indicator to determine the quality of recreational waters (Rodrigues, 2017 & Bojarczuk *et al.,* 2018). Bojarczuk *et al.* (2018) found that *E. coli* contaminated water affects tourist activities, as a number of these activities need contact with water. Since results from this study show that *E.coli* levels exceeded the target range (0 – 130 CFU/100mL) for recreation water use as per the South African Water Quality Guidelines for Recreational Water Use (DWAF, 1996c), the water is unsuitable for not only direct human consumption but also skin contact recreational use. Skin contact recreational use of the water may result in disease outbreaks depending on the exposure and duration of recreational activity. Bojarczuk *et al.* (2018) argue that recreational water with *E.coli* levels exceeding stipulated ranges may result in diseases associated with faecal contamination. Rodrigues (2017) argue that high *E.coli* levels in river water is associated with infections or intoxications to users which include; gastrointestinal illness, nausea and cramps, primary amoebae meningoencephalitis

Based on that *E.coli* and Total coliforms, are water quality variables of major concern in this study, as they exceeded the stipulated guidelines set for domestic and recreational use, thus it is important that reporting of these parameters is prioritised in reports of the river's health status. This is mostly because as discussed in section 2.3, a river has social functions and these functions might be affected by the *E.coli* and Total coliforms' as water quality status' variables. Thus, assessments based on its social function (people's use) has the potential to contribute to the sustainable management of the water as Metcalfe and Riedlinger (2009), explain that management of water resources based on social consideration, such as local use, cultural use is more likely to be successful. Harmsworth *et al. (*2016) in a study in the Victoria catchment management area, found that taking into consideration of people's priorities and the community's use of the river led to successful river health management actions. The results also provided benchmarking data to assess changes in the social condition of river health over time in the catchment areas sampled. This emphasizes that river health status' assessment should be based on all the functions of the river. Thus in Chapter 6, the research determines the social functions of the river and explores how these might be prioritised in an integrated river health assessment framework.

In addition to the interpretation of the magnitudes of the physico-chemical variables, the data were further explored for spatio-temporal variation using CA as shown by Figure 4.7. CA determined similarities and clustering of the study sites based on the measured water quality variables. CA was performed on the water quality data sets using the Euclidean distance as a measure of similarity. The water quality data are grouped into clusters as shown in Figure 4.7 of a dendrogram. The dendrogram shows that Site 4 and 5 clustered together with Site 3 and 6 forming another cluster.

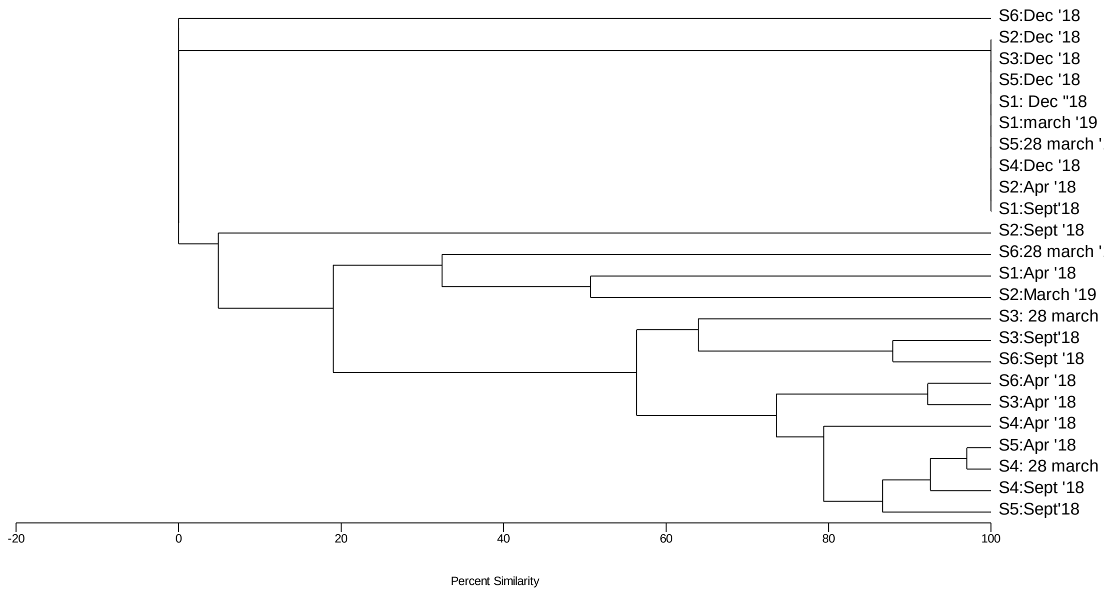

Figure 4.7. CA plot of water quality sampled from the six sampling sites during the sampling campaigns.

Site 4 and 5 in September 2018 which was during the onset of the wet season, Site 4 and 5 in April 2018 and Site 4 in March 2019 which were all during the dry season formed one cluster with similarity at 80%. Site 6 and 3 in Sept 2018 (onset of wet season) and in April 2018 (dry season) also formed another group with similarity at 62%. The clusters are consistent with the water quality parameters observed. Water temperature and DO for Site 5 and 4 were almost similar, as shown in Figures 4.1a) and b) (boxplots). Temperature and DO concentration mean for Site 4 and 5 were 27°C and 32°C; 7.72 mg/l and 7.16 mg/l respectively. The clustering for Sites 4 and 5 demonstrates similarity in the water quality (nutrient levels, *E.coli* and total coliform (as shown in Figure 4.5-4.6) these sites also have similar human activities. Sites 4 and 5 are all in the Lowveld and they are all in proximity to human settlements. Similarly, Electrical Conductivity results for Site 3 and Site 6 were also closer to each other than the rest of the sites, with 644.3 µS/cm at Site 3 and 555.6 µS/cm at Site 6. The similar results and clustering is attributed to similar EC results between Sites 3 and 6 and that both sites are not in proximity of agricultural and human activities. Site 3 is within the Mahushe nature reserve and Site 6 is located in the Kruger National Park; these are both protected areas. Both sites experience less organic enrichment through return-flows, and their results show similarly low EC levels. Comparing the clustering seasonally, the results show that the samples collected at the onset of the wet season were associated with water quality samples during the dry season in site 4. All the sites water quality variables did not differ seasonally; this was attributed to that sampling took place early in the wet season resulting incomparable water quality variables.

Using one-way ANOVA, the significant difference in water quality variables between the six sites were determined. The statistical analysis shows that there is no significant difference ($p>0.05$) in water quality between the sites. This shows that during the sampling periods, there was no longitudinal difference in measured water quality variables. The lack of a significant difference between the sites indicates that the water quality variables are fairly similar across most sites, especially as a result of similar human activities across sites (4, 5 and 6) which are all within the main stem of the Lower Komati river and in areas of agricultural activities. Moreover, the sampling was performed early in the wet summer season r (September 2018) with lower summer rains and early in the winter season just after the summer rains. Furthermore, Sites (2, 4,5 and 6), are within the priority Resource Units of the Komati River System for Resource Quality Objectives, thus management of the water resources in these units is prioritised. The NWA of 1998, explains that the RQOs are clear goals relating to the quality of the relevant water resources for the protection and sustainable use of water resources. This means that the water quality results show that, they are within the catchment’s goals for sustainable use of the resource without compromising its function.

4.3 Macroinvertebrate results analysis

A total of 542 individual aquatic macroinvertebrates were collected during the study across the six sampling sites, from the four sampling campaigns. They belonged to 31 different taxa groups. Site 3 recorded 11 taxa (highest) and Site 4 recorded nine taxa (lowest). Of the 31 macroinvertebrate families identified, 13 were highly tolerant to pollution, 12 moderately tolerant and only five were of low tolerance. The most dominant taxa were the Coenagrionidae (moderately tolerant to pollution) followed by the Amphipoda (low tolerance to pollution) which were sampled in all sites except in Site 1, as shown in Table 4.1. The Coenagrionidae were the most abundant taxa as 68 (23%) individuals sampled. They were most abundant (31 individuals) during the December 2018 sampling period and lowest (none were recorded) during the September 2018 period. Site 2 showed the highest abundance of the dominant taxa (Table 4.1). The Amphipoda were mostly recorded at Site 5 and Site 6. Thiaridae were the third most prevalent taxa and mostly sampled in Site 2, 6 and 3. The Aeshnidae were found in all the sampling sites. The Ephemeridae, which have a low tolerance level to pollution, were sampled once in Site 1 and not in any of the other sites.

Table 4.1. Table showing the sampled taxa's total abundances in counts and percentage (brackets) at each site

Taxa	Total (%)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
	291	31	65	38	53	61	43
Coenagrionidae	68 (23.4%)	0	28	3	19	10	8
Amphipoda	63 (21.6%)	0	9	5	9	28	11
Thiaridae	25 (8.6%)	0	15	4		0	6
Aeshnidae	24 (8.2%)	7	2	3	9	0	3
Veliidae	12 (4.1%)	3	0	3	4	6	2
Gerridae	10 (3.4%)	5	2	0	5	4	2
Elmidae	10 (3.4%)	6	0	1	0	3	0
Libellulidae	8 (2.7%)	2	5	3	5	4	2
Notonectidae	7 (2.4%)	0	0	4	3	0	0
Hydraenidae	7 (2.4%)	0	0	5	0	2	0
Potamonautidae	6 (2.1%)	1	1	0	0	4	0
Gomphidae	6 (2.1%)	2	0	0	2	1	1
Oligochaeta	5 (1.7%)	0	0	3	0	0	2
Corixidae	5 (1.7%)	2	0	0	1	0	2
Baetidae 2spp	8 (2.7%)	0	0	0	2	0	6
Leptophlebiidae	5 (1.7%)	0	0	1	3	0	1
Naucoridae	4 (1.4%)	2	0	0	0	1	1
Chironomidae	3 (1%)	0	1	2	0	0	0
Hydroptilidae	3 (1%)	0	0	0	2	0	1
Leptophlebiidae	2 (0.7%)	1	0	0	0	0	1
Ecnomidae	2 (0.7%)	2	0	0	0	0	0
Ecnomidae	2 (0.7%)	0	0	0	1	1	0
Hydrometridae	2 (0.7%)	0	2	0	0	0	0
Corrixidae	2 (0.7%)	1	0	0	0	0	1

The alien and invasive red claw crayfish (*Cherax quadricarintus*) was sampled in Site 4 (X1KOMA-IFR04), Site 5 (X1KOMA-NYATS) and Site 6 (X1KOMA-LEBOM), where they had previously been observed. Literature shows that red claw crayfish is the main cause of ecological problems resulting in biodiversity reduction (Baudry *et al.,* 2020; Haubrock *et al.,* 2021). Wood *et al.* (2017) and Chaichana and Wanjit (2018) found that these invasive species (crayfish) are potential competitors and reciprocal predators of ecologically important native species.

According to Mason *et al.* (2005), diversity measures are a useful method to describe community structure. To explain the diversity of macroinvertebrates collected, Simpson's diversity index analysis results (presented in Table 4.2) show that the diversity and evenness of macroinvertebrates collected at the six sampling sites varied during the different survey dates.

Table 4.2. Diversity and evenness of macroinvertebrates collected at the six sampling sites during the different survey dates

Sample site and date	D-Index	Evenness
S1:Apr '18	0.78	0.97
S1:Sep '18	0.64	0.96
S1:Dec '8	0.79	0.99
S1:March '19	0.75	0.94
S2: Apr '18	0.75	1
S2:Sep '18	0.34	0.51
S2:Dec '18	0.58	0.73
S2: March "19	0.78	0,91
S3: Apr '18	0.86	0.98
S3:Sep '18	0.7	0.93
S3:Dec'18	0.69	0,93
S3: March '19	0.81	0.98
S4: Apr '18	0.81	0.98
S4:Sep '18	0.63	0.94
S4:Dec '18	0.63	0.83
S4: March '19	0.76	0.89
S5: Apr '18	0.66	0.82
S5:Sept '18	0.63	0.94
S5:Dec '18	0.66	0.77
S5: March '19	0.8	1
S6: Apr '18	0.78	0.93
S6:Sept '18	0.73	0.92
S6:Dec "18	0.83	0.97
S6:March '19	0.77	0.96

Using one-way ANOVA, the significant difference in the diversity between the six sites was determined with N=4 samples per site. The statistical analysis showed that there is a significant difference ($p<0.05$) D-index and evenness between the sites. This shows that during the sampling periods, there was a longitudinal difference in diversity. The lowest diversity was observed at Site 2, sampled in September 2018, the highest was at Site 3 in April 2018, with an evenness of 0.51 and 0.98, respectively. The high calculated Simpson's diversity index level (D') in Site 3 is not surprising; this part of the river is within the Mashushe Shangwe Nature Reserve where human activities are restricted. However, the families collected here are associated with slow-moving water, since this is a slow-moving tributary. The Gravel, Sand and Mud (GSM) biotope from this site had higher diversity than any other site.

The lowest calculated biodiversity levels (D') were in Site 2 in September 2018 and were ascribed to the high number of Coenagrionidae and Thiaridae sampled at this period. The dominance of the Coenagrionidae and Thiaridae families and the lowest number of organisms sampled throughout the study can be attributed to the poor biotope diversity as the site was predominately sandy due to upstream sand mining. These families are known for their specific preference for slow-moving water (Griffiths *et al.,* 2015; Thirion, 2016). Furthermore, all families that were present in large numbers seem to prefer habitats with slow-moving and low water quality resulting from organic enrichment and the majority of these families were collected at all of the sampling sites except Site 1 (Thirion, 2016; Griffiths *et al.,* 2015). In contrast to this, the Amphipoda were; found in all the sites, again, except Site 1. Wolmarans *et al.* (2014) state that these taxa prefer warmer climates with available dead debris and that they mostly survive in instream vegetation.

Based on the sensitivity of taxa, only five sensitive macroinvertebrates were sampled from a total of 31 families. A large number of the collected macroinvertebrates belonged to families that are moderate to highly tolerant to pollution. The most abundant family were Coenagrionidae. This suggests that the levels of water quality in the different parts have not significantly affected the macroinvertebrates' families' diversity across sites. According to Dallas (2007a); Thirion (2016) and Abah *et al.* (2018), Coenagrionidae is associated with natural water conditions instead of being pollutant tolerant and is found around vegetation biotopes and in slow-moving water with a velocity of <0.1m/s. This suggests that where these families are sampled it is less likely influenced by human impact. The family was sampled in sites with vegetation biotopes and was in high abundance at all sites in December, where the nitrate levels were at their highest. Moreover, according to Thirion (2016), Coenagrionidae prefer warm regions, therefore their abundance in the sampling sites is expected as December is the warmest time of year in the area

Amphipoda was second in abundance in all sites except Site 1 and most abundant in Site 2. Site 2 had both GSM and vegetation biotopes and Site 1 had mostly riffle, run and pool biotopes. Therefore, the high availability of the Amphipoda might be due to habitat preferences of this family, which include slow current speed (< 0.1 m/s) and the presence of aquatic vegetation (Thirion, 2006). According to Thirion (2006), Amphipoda is common in healthy rivers as they are sensitive to pollution but prefer GSM and vegetation habitats. However, De-La-Ossa-Carretero *et al*. (2012) argue that a group of Amphipoda can be found in a wide range of pollution levels, as scuds breathe by absorbing dissolved oxygen through their gills but cannot live in severely polluted or stagnant waters that contain no oxygen close to the sediment. The authors explain that some species of the Amphipoda have a certain tolerance to sewage discharge, depending on the organism's living habits, with the burrowing species mostly tolerant to pollution. Since the Amphipoda in this research were sampled in muddy sand and bottom of vegetation, they seemed to be tolerant to nitrate levels as they were sampled even at the times when the levels were high. Furthermore, the high representation of the Amphipoda was as a result of its characteristics as explained by Gesteira and Dauvin (2000) who state that Amphipoda is numerically dominant and exhibit a high degree of niche specificity, with varying tolerance levels to physico-chemical characteristics in sediment and water and with relatively low dispersion and mobility capabilities.

The Thiaridae were the third most sampled family of invertebrates in the study, found in Sites 2, 3 and 6. Their availability in the region is confirmed by Miranda *et al*. (2010), who state that they are present in an increasing number of fresh and brackish water bodies in the Mpumalanga province. Thiaridae prefers warm areas, although they can survive in water with temperatures ranging from 0-47°C (Miranda *et al*., 2010). For this study, the sites where this family was sampled are in the lower part of the catchment, which is warmer. The association between Thiaridae and temperature is also noted through the PCA plot in Figure 4.3. The Thiaridae are closely associated with temperature on axis 1. The large number of Thiaridae collected at the three sites (2, 3 and 6) might be due to the habitat preferences of this family. They were also most sampled during the times when the nutrient levels were elevated in Sites 2 and 6. Thirion (2016), states that this species also prefer areas with slow current speed (< 0.1 m/s) and low water quality with organic enrichment. Previous studies also indicate that Thiaridae *(T. granifera)* proliferate and may displace other invertebrates, thereby causing ecological disturbances and a reduction in biodiversity. However, in this study, that could not be ascertained with the data sampled.

The most sensitive family sampled were the Ephemeridae, sampled once only at Site 1, while none was sampled in the other sites. This may be either due to specific habitat preferences or to other external detrimental impacts on the river. The presence of the highly sensitive family is attributed to Site 1 being upstream in the study area and nearest to the origin with minimal activities. However, this family was not sampled in December 2018 and this is attributed to the high nutrient levels recorded at this site. The high amount of nutrients during the December sampling campaign in Site 1 were due to the sporadic application of organic fertilizer and manure enrichment from farmers. The farmers applied organic manure and fertilizer to their floodplain agricultural plots (which are upstream of the sampling sites) and Ephemeridae are a pollution sensitive family. This is confirmed by Brown *et al.* (2015) and Zedková *et al*. (2015), who state that the Ephemeridae taxa are allocated high sensitivity scores as they are intolerant to water quality alteration or habitat modifications and belong to highly sensitive families. This suggests that the habitat conditions or nutrient pollution could have had a major influence on the species occurrence as the Ephemeridae taxa were not sampled during the December 2018 period when the nutrient levels and farmers upstream interrupted the stream but were found during the other three sampling periods.

Although some of the specified families were highly sensitive, it doesn't fully suggest high water quality in the different parts of the river. This is mostly because, the study used macroinvertebrates at a family level to determine a river's health condition, some species within the same family have varying pollution tolerance levels. Abah *et al*., (2018) and Niba & Sakwe *(2018*) studied macroinvertebrates at species level to determine river health and found that they respond differently to disturbance regimes at different development stages. The authors argue that macroinvertebrates' families used in river health studies are very coarse, as different families have different sensitivity levels. This is because species tolerance to water quality variables; nutrients, pH, temperature, DO differs according to species development stage. However, the authors also explained that conducting river health studies at species level cannot always be possible, due to lack of taxonomic expertise and time constraints. Thus it is advisable to select indicator species in the river catchment and monitor them as surrogates for the community.

The high number of moderate to highly tolerant to pollution taxa in this study shows the importance of maintaining river water quality to be within stipulated guidelines for the maintenance of macroinvertebrates diversity. Pompeu, *et al.* (2005) and Hepp *et al.* (2010) conducted studies in Brazil, on the effects of sewage effluent on water quality and benthic macroinvertebrates and concluded that where water quality in these rivers had declined to intolerable ranges, exceeding the Brazilian law, (regulation number 1469), there was a decline in diversity. Thiere & Schulz (2004) in a study in the Lourens River, South Africa found that where water quality exceeded the allowance ranges as per the country's guidelines for aquatic ecosystems, it resulted in reduced species diversity. These case studies demonstrate that water quality guidelines work as decision support for the protection of aquatic ecosystems. Thus, it is important to manage activities to be within the guidelines' targets for the maintenance of aquatic diversity.

The enumeration of the invertebrates also involved the calculation of the two SASS5 metrics (SASS5 score, ASPT) which are presented in Figures 4.8 and 4.9. Noticeable fluctuations in SASS5 and ASPT scores were observed over the sampling period. SASS5 scores ranged between 8 and 54 from Site 2 in September 2018 regarded as high flow season and Site 1 in March 2019 regarded as a month of low flow, respectively as shown in Figure 4.8. Figure 4.9, shows that the ASPT scores ranged between 2.7 from Site 2 in September 2018 as high flow season and 10.6 from Site 3 in September 2018 which was at the onset of the summer season.

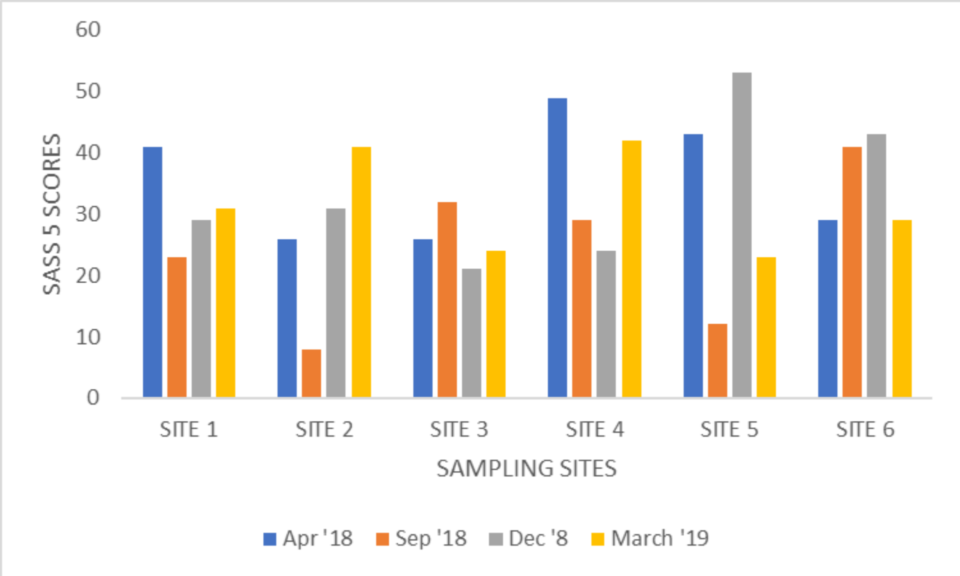

Figure 4.8. Graph showing mean SASS scores for the six sites sampled at different sampling periods

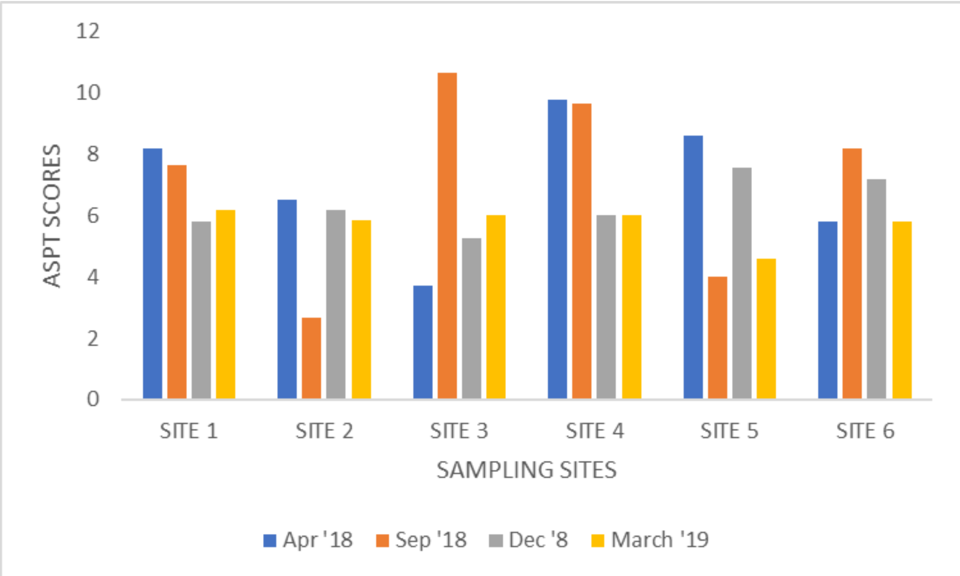

Figure 4.9. Graph showing mean ASPT scores for the six sites sampled at different sampling periods

Based on the two graphs (Figure 4.8 and 4.9) the SASS and ASPT scores varied across sites, depending on the prevailing conditions during the survey period. The September period regarded as high flow sampling period had high ASPT scores in Site 3 and 6. During the high flow season 2nd sampling campaign, in December 2018, Site 5 recorded the highest SASS score. The highest ASPT score of 10.67 was also recorded during the high flow season in Site 3 (September 2018). On average, Site 2 had the lowest ASPT scores throughout the sampling periods compared to all other sites.

The low SASS5 scores based on macroinvertebrates may not be a true reflection of the present state of the macroinvertebrate community and water quality in the Lower Komati River. Dallas

(2007b) explains that SASS5 scores alone do not distinguish between different ecoregions. Dallas (2004) and Dallas (2007a) explain that there is general substantial spatial variation in macroinvertebrate assemblages in rivers within South Africa. Thus, it is important to consider variation amongst regions when interpreting SASS data. The SASS5 and ASPT scores were then placed within the biological bands of Dallas and Day (2007), to assess overall trends in the integrity of the macroinvertebrate assemblages as shown in Table 4.3. The SASS5 interpretation guidelines were based on the site location of Ecoregion Level I biomes (Kleynhans *et al*., 2005b; Dallas, 2007b). In this study, sites 1-5 are in the Lower Lowveld-Lower Ecoregion and site 6 in the Lubombo-Lower Ecoregion.

Table 4.3. Mean values for SASS and ASPT scores at each site

Site	**SASS Score (Band)**	**ASPT Score (Band)**	**SASS health**	**ASPT health**
SITE 1 (*X1MHLA-RUSOO*)	59(E)	5.9.(D)	Seriously modified	Moderately modified
SITE 2 (X1LOMA-SCHOE)	72(E)	6.5 (B)	Seriously modified	Minimally modified
SITE 3 (X1MZIN-MASHU)	75(E)	4(E)	Seriously modified	Seriously modified
SITE 4 (X1KOMA-IFR04)	71(E)	6(C)	Seriously modified	Minimally modified
SITE 5 (X1KOMA-NYATS)	69(E)	6,6(B	Seriously modified	Minimally modified
SITE 6: (X1KOMA-LEBOM)	77(E)	6,4(B)	Seriously modified	Minimally modified

Table 4.3 show that all sites according to the SASS5 scores had seriously modified ecological integrity. However, the ASPT scores classified the sites between b(minimally modified to E(seriously modified) The SASS5 scores demonstrate that there has been a serious modification in community structures present in the different parts of the Lower Komati River. However, ASPT scores show that some sites' community structures have been minimally modified. The SASS5 score and ASPT values were graphed to assess overall trends in the integrity of macroinvertebrate assemblages (Figure 4.10).

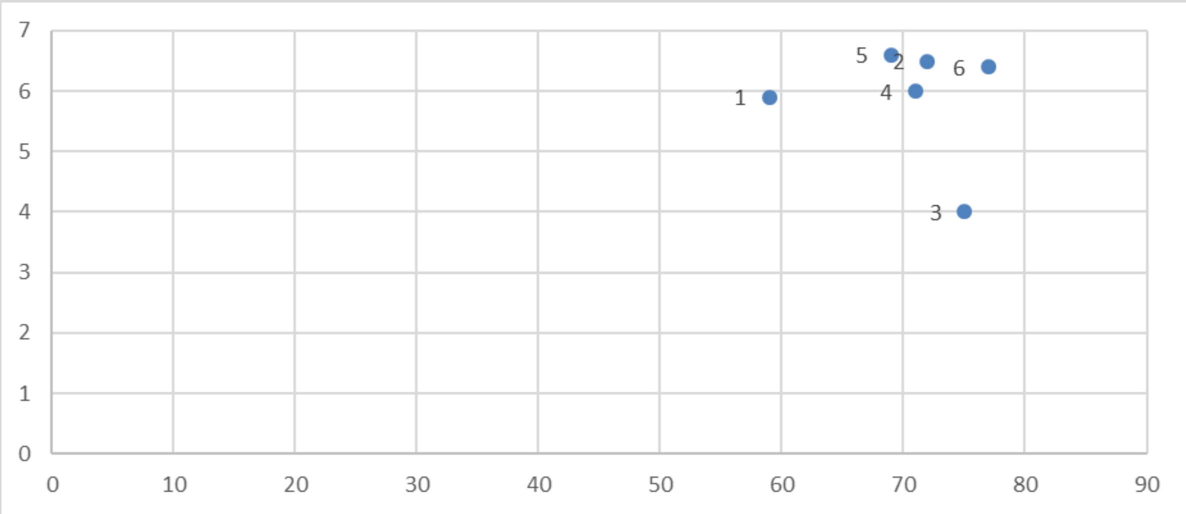

Figure 4.10. Average scores per taxa (ASPT) (y-axis) and South African Scoring System (SASS) scores (x-axis) per site (1-6) for the lower Komati river.

The use of the SASS4 score and the ASPT values provided a means of establishing the river's health status using the macroinvertebrate structure in each site, taking into consideration the ecoregions. Table 4.3, Figure 4.8 and Figure 4.9 show that Site 1 has a low SASS5 score, however, the ASPT value shows a minimally modified category. This indicates a variety of macroinvertebrate fauna in this site, as there are a few sensitive high scoring taxa in this site. This is similar to what was observed by Dallas (1995), who explains that upper mountain streams usually have good water quality and low diversity coupled with low Total Score, as Site 1 is upstream of the catchment. The reverse situation occurs in the other five sites, which have high SASS5 scores because of the high number of taxa present and low ASPT values. According to Dallas (2007b), Dallas (1995) and Dickens and Graham (2002), the ASPT score is the most trusted as it is not affected by sampling efforts. The total SASS score increases with sampling efforts, thus the ASPT which is relatively unaffected by sampling efforts is recommended to interpret scores. The influence of the variability between the scores then calls for consideration of the biotopes available and habitat for the macroinvertebrates. Dallas (2007b) explains that taxa present in stone in current biotopes constitute a high score, with scores for taxa found in instream vegetation having low scores. This shows that habitat conditions can influence the total SASS5 score, making ASPT more stable. The deviation of these two scores provides a means of assessing the degree of impact of habitat changes, which is determined using MIRAI (section 4.4), as it considers habitat conditions based on expert opinion.

The SASS scores between sampling times did not show any apparent differences by sampling period in any of the sites based on observed species sampled as shown in Figures 4.8 and 4.9. The scores between sampling times and site show no effect of season on the taxa sampled, which might be due to that, the sampling in September took place at the onset of the summer season when the rains had just started, hence there is lack of seasonal variation based on SASS score, number of taxa and ASPT. Similar results were found by Fourie *et al*. (2014); there was no seasonal variation in the values of SASS indices, although they differed between sites. Witthüser and Holland (2008), explain that if sampling takes place at the onset of a high flow season with no major rainfall event, similar water levels will be experienced. Likewise, during the September sampling period, no major rainfall or flooding event had occurred before the sampling period

4.4 Macroinvertebrates' analysis with MIRAI

The MIRAI analysis provides habitat-based cause-and-effect to interpret the deviation of the aquatic invertebrate community from an established reference condition (Thirion, 2007). Outcomes from these analyses show that the present EC of the macroinvertebrate community in all six study sites in the Lower Komati ranged between D and E categories. Category D means that the macroinvertebrate communities have been largely modified and category E means they have been seriously modified. Findings from the MIRAI analyses are presented in Table 4.4.

Table 4.4. Summary of the MIRAI assessment outcomes for all six sites and metric ratings

INVERTEBRATE EC METRIC GROUP	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Site 6**
Flow modification	36.1	50.3	57.6	36.9	48.4	33.8
Habitat	40	53.1	45	25	37.5	37.5
Water quality	40	42.5	30	22	46	52
Connectivity and seasonality	40	44.7	65	35	40	55
EC score	38.7	48	48.9	29.8	43.5	44.7
EC Class	D/E	D	D	E	D	D
Human activities observed during sampling.	Road crossings on site.	Effluent discharge upstream of the site.	Sand mining upstream of the site.	Effluent discharge upstream of the site.	Weir and sand mining upstream of the site.	Within Kruger National Park.

The upper reaches of the study area represented by Site 1 (X1MHLA-RUSOO) are in EC D/E with a score of 38.7 (largely modified). According to the metrics weightings, the state of the site is largely in response to flow modification and habitat changes, connectivity/seasonality problems and water quality changes. Flow modification is attributed to the upstream disturbance of the stream, observed during the sampling period; community members dig around the river bank to create a crossing and a large number of cattle trampling around the river results in sand accumulating instream which changed the stream morphology and natural stream bed habitat. Thus, habitat heterogeneity was reduced and the present conditions observed were notably different from those in natural stream ecosystems. Ogren and Huckins (2015), Gál *et al.* (2020) and Koehnken *et al*. (2020) explain that habitat alteration is one of the main anthropogenic threats to freshwater ecosystems and macroinvertebrates are sensitive to habitat transformation. Barnes *et al.* (2013) and Leitner *et al.* (2015) documented that macroinvertebrate communities exhibit low numbers of taxa and changes in trophic structure due to alteration of habitat shown through channel morphology and hydrological alteration. Altering the habitat's substrate composition results in a gradient in density and taxa richness between near-natural and altered conditions. The road crossing in Site 1 resulting in channel morphology changes seem to have had negative effects on the richness and abundance of native macroinvertebrates, as the site is presented as seriously modified when compared with reference data.

Site 1 was initially selected as a reference site and assumed to be the least impacted since it is the most upstream site. According to Thirion (2016), reference sites are assumed to be minimally impacted and located in the upper reaches of rivers. Reference sites are chosen based on the ecological reference conditions, selected through physical, chemical and biological characteristics that represent "least impacted" sites (Bouleau & Pont, 2015; Agboola *et al.,* 2020). However, site 1's ecological category at class D/E (largely modified) shows that it cannot be established as a useful reference site in this assessment as it is impacted. This shows that its reliability as a reference site is subject to scrutiny. The development and activities in the site have impacted its ecological state. The unreliability of reference sites in South Africa is also discussed by Agboola *et al.* (2020) who found that some lowland rivers in KwaZulu-Natal failed the selection criteria for reference sites because of severe river channel modifications as a result of human activities and drought conditions in the region. This affirms that reference sites are continually modified by developments in the catchments.

The Lomati River in Site 2 (X1LOMA-SCHOE), which is below the Driekoppies Dam, shows improvement from the upstream site as the EC is D with a score of 48. This rating exceeded the resource quality objective target class for the site, which is set at class C. According to the metric weightings an impaired water quality metric and seasonality largely influence the status of the site. This is confirmed by water quality results as shown in Section 4.2, which showed that the highest total coliforms were recorded in Site 2. The impact of the water quality can be attributed to the Schoemansdal town effluent discharges. Spillage of sewage from treatment plants in towns in the Lower Komati has been attributed as a cause of the impaired water quality in the catchment, which is explained in Section 4.2 of this chapter. According to Aristi *et al.* (2015), impaired water quality from sewage alters the biological community resulting in the significant modification of macroinvertebrate assemblages. This is further supported by Baloyi *et al.* (2014), who explain that modification patterns are observed at both species and family levels, which is a result of the lower levels of oxygen; effluent nutrients encourage the growth of phytoplankton and algae which require oxygen thus contributing to less available oxygen instream for the organisms. However, this site doesn't show high nutrient levels compared to the upstream site, which is attributed to the dilution from the Driekoppies Dam during scheduled releases. Ciolofan *et al*. (2018) and Darmian *et al.* (2018) conclude that dilution flow can be a practical action to reduce the impact of pollution hazards when discharged pollution to the river is uncontrollable.

The macroinvertebrates community in the Mzinti River, which is Site 3 (X1MZIN-MASHU), had an EC score of 48.9 (D) using MIRAI with the water quality metric and habitat modification contributing most to the ecological state of the site. The site's ecological class is similar to the Resource Quality Objective set at target class D. This is similar to results by Roux and Selepe (2013), who found that habitat quality, availability and water quality were regarded as the main limitation conditions which resulted in lower than average diversity and sensitivity ratings for the site. From field observations, the small-scale sand mining operations, upstream of the sites were identified to have a probable effect on the site's habitat due to sedimentation. Albertson and Daniels (2016) explain that sand mining results in fine-sediment accumulation in downstream sections which have adverse effects on aquatic ecosystems. Sebastiao *et al.* (2017) and Gál *et al.* (2020) highlight that the accumulation of sediment results in habitat changes and changes in macroinvertebrates' trophic structure whilst Dallas (2007a) explains that macroinvertebrates don't like to live in streams with high sediment loads. Thus, macroinvertebrates sampled in Site 3 were dominated by taxa associated with stagnant water. However, the EC score of the site is better than sites 1 and 2. This can be attributed to the site being located at the Mashushe Shangwe Nature Reserve and most anthropogenic activities like subsistence farming and rural settlements are downstream of this site.

Site 4 (X1KOMA-IFR04) along the Komati River, which is downstream of Kwazibukwane Town had the lowest EC score of 29 (E - largely modified) compared to all sites. The MIRAI and SASS5 scores are both in ecological category E, which indicates that the site has been greatly modified. MIRAI analysis shows that the impaired state of the site can be attributed primarily to the water quality and to an extent habitat modification and perhaps flow modification. Similarly, in this site, as discussed in Site 2 (X1LOMA-SCHOE) the present ecological state of the river may be attributed to sewage treatment spillages from the upstream town (Kwazibukwane). Mallory (2013) categorised the Tonga WWTWs on the Komati River as a critical risk because of the high sewage spillage.

Sites 5 (X1KOMA-NYATS) and 6 (X1KOMA-LEBOM) which are both along the stem of the Komati River were in the D ecological category class with a score of 43. MIRAI analysis shows that the state of Site 5 is largely attributed to habitat state and connectivity/seasonality issues. This site is largely impacted by the upstream weir and sand mining, as Albertson and Daniels (2016) and Gál *et al*. (2020) explain that sand mining reduces habitat heterogeneity. O'Brien *et al.* (2019) state that in the Inkomati Water Management area, there are 83 formal gauging weirs and the synergistic effect of multiple land-use activities have a huge effect on the habitat. Mueller *et al*. (2011) and Smith and Sharman (2013) argue that river catchments with a high number of weirs or dams present tend to have both homogenised flows and instream habitat, as these structures replace the diverse stream habitats such as riffles, runs and side channels with slow-flowing sections.

The macroinvertebrate community structure in Site 6 (X1KOMA-LEBOM) is largely influenced by the flow modification metric, followed by the state of the habitat. This site is in the Komatipoort area where agricultural production is high, coupled with increased water demand. This is confirmed by Du Plessis (2019), who explains that the abstraction of water for irrigation in downstream areas of the Inkomati catchment is prevalent and has contributed to the reduction of available surface water volume. Rivers-Moore *et al.* (2011) explain that in South Africa, there is a high demand for water for use in agriculture/irrigation, which may affect the well-being of our aquatic ecosystems. Despite the effect of the flow modification metric, results revealed a good taxonomic diversity within Sites 5 and 6. Pollution intolerant taxa were recorded in these two sites (Amphipoda, Teloganodidae), indicating minimal impact by the anthropogenic stressors. This may be because Site 6 (X1KOMA-LEBOM) is on the Komati River in the Kruger National Park which is a protected area with less human activities and is upstream before the river flows to Mozambique. Site 5 is downstream of the Eswatini-South Africa border. Thus, both sites are gazetted as Environmental Water Requirement sites, which means that their water resources should maintain the RQOs to comply with the tripartite agreement (between South Africa, Eswatini and Mozambique) on the sharing and protection of water resources in the catchment.

Overall, the MIRAI scores highlighted that the macroinvertebrate community structure in the study area was not only influenced by prevailing water quality conditions but also habitat and flow modification. Most sampling sites downstream of sand mining activities (Sites 3 and 5) had high siltation and more sand substrates, which also made sampling difficult as the habitat was almost uniform. The poor sampling in the sand dominated sites may also have contributed to the poor EC. This is supported by Dallas (2007a), who states that macroinvertebrates diversity may be low in sand dominated sites. Leitner *et al.* (2015) explain that sand sediment deposition in stream beds is an increasing stressor for macroinvertebrates. The fine sediment deposition alters the substrate composition and changes the suitability of the substrate for the different taxa. This leads to poor habitat heterogeneity within the study, which negatively impacts the overall abundance and diversity of the macroinvertebrates.

Comparison between the SASS and MIRAI scores shows a compromised macroinvertebrate community integrity in all the sites, as the EC for Sites 1-5 was at D (largely modified) and E (seriously modified). Site 6's SASS score classified the site as EC E(seriously modified) whilst MIRAI scores classified it as D (largely modified). This shows that the ecological category classes between SASS5 and MIRAI are comparable in all sites. This suggests that MIRAI and SASS 5 scores can be co-used for ecological classification to give a comprehensive description of the ecological state of the macroinvertebrates as they complement each other.

The SASS 5 tool considers water quality as a major driver of macroinvertebrate distribution. However, analysis of the state of the river using SASS 5 scores alone, does not provide a comprehensive assessment of ecological river health of the study area as it does not take into consideration the habitat integrity. Thus, the MIRAI tool was found to be more informative by considering the different metrics (stressors) to generate the EC at each site. MIRAI attributes combine the effects of habitat, river flow regimes, seasonal variations, alterations and water quality. This is more evident in this study, as the sites water quality results were within the water quality standards for the aquatic ecosystem, however, the SASS and MIRAI analysis show that the sites are seriously modified for the macroinvertebrate communities. MIRAI considers a variety of habitat conditions in analysing for an ecological category and SASS considers the community structure's sensitivities. This means that basing aquatic macroinvertebrate communities' sensitivities with water quality alone is not adequate to explain the river's ecological status as the habitat's characteristics are equally important. This is affirmed by Bellingan *et al.* (2015); Agboola *et al.* (2019); Dalu and Chauke (2020) who explain that taxa with high SASS values do not necessarily indicate that the river is in good health because aquatic macroinvertebrates are also dependent on specific habitats, flow modification, connectivity and seasonality. This means that the sole use of SASS scores is not conclusive as the scores, do not take into consideration flow variation in combination with the other habitat conditions.

To explain the taxa's composition based on habitats state MIRAI was used. MIRAI places greater emphasis on habitat and flow metrics than on water quality alone (Kleynhans *et al.,* 2005a). Thus, the use of SASS and MIRAI analysis in this thesis shows a more comprehensive analysis of all environmental attributes that would affect the ecological output. Thus, this section concludes that whilst water quality has gained much acceptance in influencing macroinvertebrate distribution, the association between water quality and macroinvertebrate composition, is not adequate without consideration of habitat condition, flow, connectivity and seasonality. This is mostly because, the study findings show that macroinvertebrate communities in each site were influenced by multiple stressors which include; weirs, nutrients and sand mining. These findings are similar to a study by Juvigny-Khenafou *et al*. (2021) who found that multiple stressors which include nutrient enrichment, flow velocity reduction and sedimentation had a major effect on macroinvertebrate community, taxon, functional diversity and trait variables. The authors also found that an increase in sediment deposition led to flow velocity reduction which affected abundances and diversity and functionality.

4.5 Multivariate Analysis

In addition to the determination of the SASS5 and MIRAI metrics for each site, similarities and clusters based on the macroinvertebrate' composition were explored by determining the Sorensen's Similarity Coefficients using the Un-Weighted Pair Group Method with Arithmetic Mean (UPGMA) as suggested by Kovach Computing Services (1998). Additionally, the dendrogram was generated using Multivariate Statistical Package (MVSP) 3.1 software. The clustering method using UPGMA has previously been used in other research (Türkmen & Kazancı, 2011; Zeybek *et al*., 2014; Asfaw *et al*., 2018) to classify different sampling points and other biological variables. Zeybek *et al.* (2014)

affirm that UPGMA analysis can be used in the classification of sampling stations by macroinvertebrate composition. In this case, it is suitable to compare the different sites' macroinvertebrate

composition, particularly because the macroinvertebrate data were collected using the SASS5 protocol where taxa abundances are estimates or censored values as opposed to specific values, for example, abundances are given in ranges (*such as* '1' = 1, 'A' = 2-10, 'B' = 10-100, 'C' = 100-1000 and 'D'>1000). Thus, it is important to analyse how these sites cluster as a result of the macroinvertebrate assemblage composition sampled in each site. As explained in section 3.5.1.3, before the CA could be explored, an insight of the general structure of the data set was explored. Then the data was log-transformed (log (x + 1) to filter off the effect of high abundances, which could dominate our clusters (Feng *et al.,* 2014). Figure 4.11 shows that the CA formed as a result of the macroinvertebrates' composition in the six sampled sites. Sites were partitioned into groups based on the similarity of invertebrate distributions.

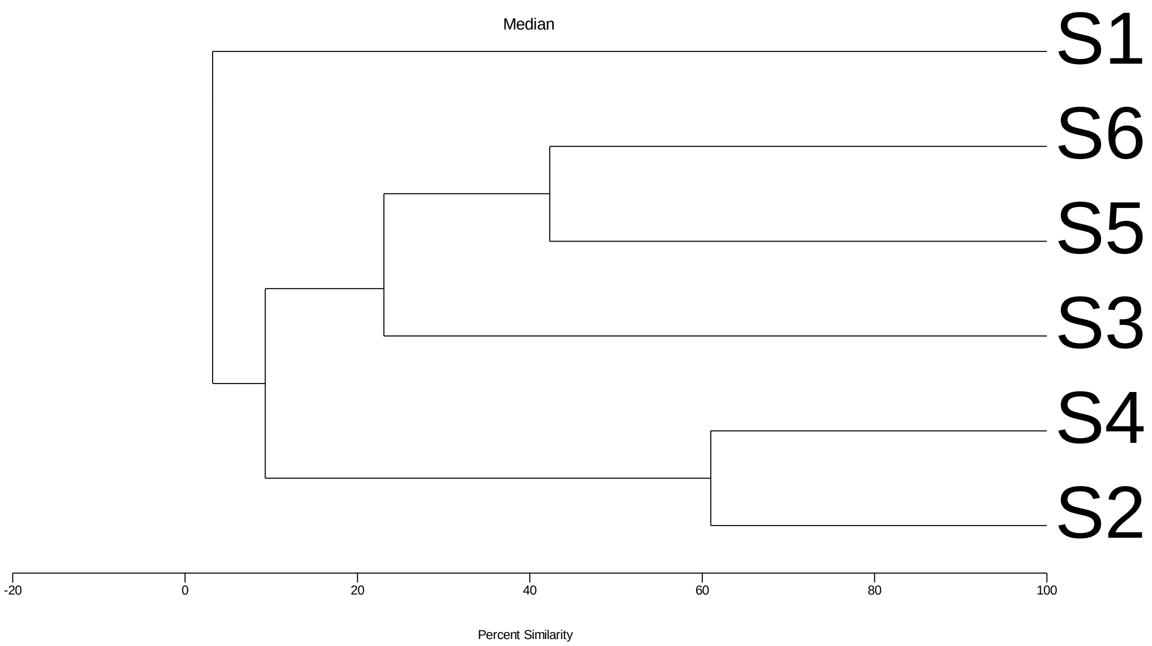

Figure 4.11: Dendrogram showing CA of average macroinvertebrate assemblage composition per site (log-transformed (log (x + 1)) in the six sampled sites.

The dendrogram in Figure 4.11 shows that the six sampling sites split into two significant groups and two sites came out individually. The most prominent level of the split was between Site 1 and the rest of the sites, which shows that Site 1 is the most dissimilar to the rest of the sites. The lowest similarity observed was 3.2% between Site 1 with the rest of the sites, which suggests that macroinvertebrates sampled from Site 1 were completely separate from the rest of the sites. This agrees with observations made in Table 4.1; that the two most common taxa (Aeshnidae and Coenagrionidae) sampled in all the other sites were never sampled in Site 1, with the Ephemeridae only sampled in Site 1. This shows that Site 1's macroinvertebrate community is very different from the results of the other sites in the study area. Another significant clustering was the highest similarity clustering observed between Site 2 and 4, with a similarity of 61,1% formed. The cluster formed between these sites suggests that the macroinvertebrate community compositions sampled were the most similar. This agrees with data shown in Table 4.2; that the sites contained all the common taxa except for the Vellidae.

The sampled macroinvertebrates were further analysed with the observed water quality variables from the six sampling sites, using PCA in Figure 4.12. PCA was used to determine the association between the measured water quality parameters and the different sampled macroinvertebrates in the study. The PCA plot in Figure 4.12 shows that the first two PCA axes explained 55.0% of the total variation of the water quality characteristics and macroinvertebrate distribution.

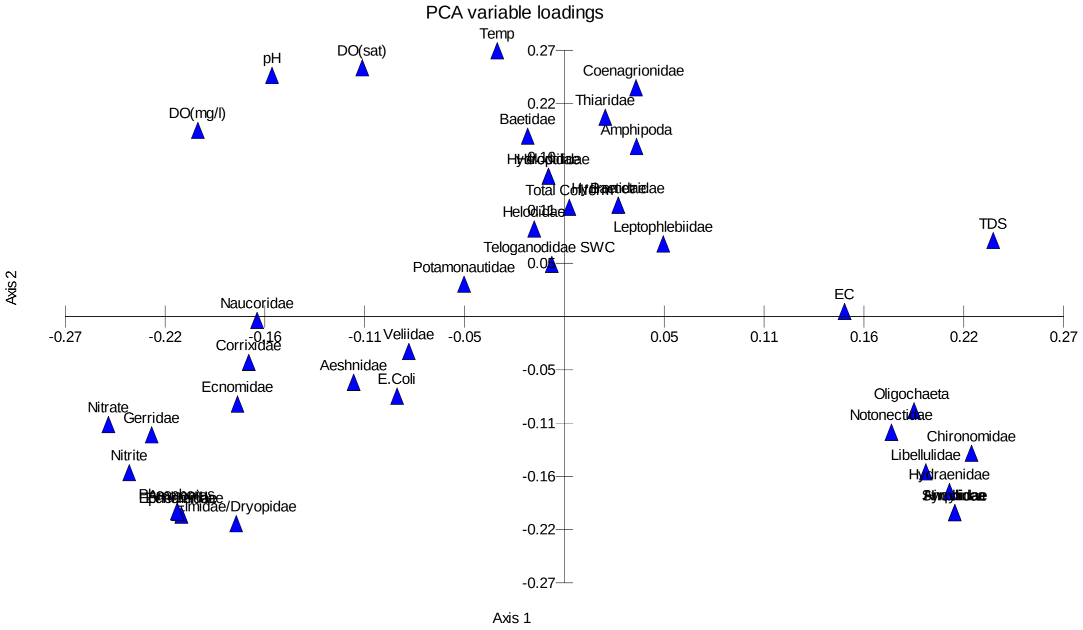

Figure 4.12: PCA plot showing means of water quality variables and sampled macroinvertebrates

The proportion of variance in PCA axis 1 accounted for 32,6% and the second axis for 22,3% in Figure 4.12. The PCA results also show that the water quality variables formed three groups, which points to an association between the water quality parameters. The first grouping is between EC and TDS, followed by pH, DO and temperature and the last grouping is nitrite, nitrate and *E. coli.* The association between temperature and DO is explained by the DO concentration trends in all the sites, showing an inverse relationship with temperature levels. Li *et al.* (2013) explain that higher temperature increases metabolic activities of biota, leading to higher consumption of DO by organisms while the oxygen holding capacity of water also decreases with temperature increases. The grouping of the water parameters shows that there exists complex interaction between water quality variables. Thus if any water quality variable is outside of their target allowable range for aquatic ecosystems, they can have an accumulative effect on the associated macroinvertebrates. Therefore, for effective monitoring of water quality a tiered water quality framework that assesses the integrated water quality effects on the macroinvertebrates is important. This will show how a change in one water quality parameter may trigger an effect on other water quality parameters leading to effects on the biota.

The PCA plot also shows that pH, DO and temperature all clustered in the upper left corner of the quadrant; this is associated with macroinvertebrates like the Baetidae, and Naucoridae (intolerant families). Hence, macroinvertebrate communities in this quadrant are dominated by families that are sensitive to oxygen changes. Tan and Beh (2016) and Kahlon *et al.* (2018) explain that pollution sensitive organisms require high DO and as shown, this quadrant comprises families that are more intolerant to pollution and require high DO. Nitrites, nitrates and *E. coli* are loaded in the bottom left quadrant and are closely associated with the Ecnomidae, Velliade, Gerridae (tolerant families) and Aeshnidae (intolerant families). The top right corner has EC and TDS associated with the Leptophlebiidae, Caenagrionidae and Amphipoda (intolerant families). No water variable is at the bottom right quadrant which is associated with pollution tolerant families such as Oligochaeta and Notonemouridae. These groupings suggest that although differences in macroinvertebrate communities in the study area exist, these organisms are dominated by high diversities of taxa with varying tolerances to pollution. From the PCA results, the groupings between water quality parameters and macroinvertebrates in the different quadrants suggest that no single environmental variable fully explains species composition and distribution patterns.

The macroinvertebrates' composition does not show their groupings based on their pollution tolerance level. This suggests that besides water quality, other factors drive the composition of these macroinvertebrates in the river as indicated by the MIRAI analysis in section 4.4. The groupings of the macroinvertebrates are composed of macroinvertebrates with tolerant and sensitive species clustered in the different quadrants. This demonstrates that the use of one environmental variable(water quality) to explain the distribution of a taxonomic group of organisms may not be adequate in describing the river's health (Baa-Poku *et al.*, 2013; Buss *et al.*, 2015). Paller (2001) argues that the use of a single environmental variable for river health may constitute liability in some cases. Thus, it might be necessary to consider other taxonomic groups and environmental variables that might affect the river's health status. A wide variety of environmental variables are explored in Section 4.4 which have shown that habitats have the potential to influence macroinvertebrate distribution and describe the river's health status. Chapter 5 will use fish assemblages as another taxonomic group of organisms to determine the Lower Komati River's health status.

4.6 Conclusion

This study used macroinvertebrate community structures to ascertain the ecological health of the Lower Komati River. The chapter first concludes that macroinvertebrate community structures in different parts of the Lower Komati (analysed using SASS and MIRAI) show that the condition of different parts of the river ranged from modified to severely modified during the sampling period. However, the overall condition of the Lower Komati River based on the selected physical and chemical water quality parameters was tolerable, except for the nutrients (phosphorus, ammonium, nitrate and nitrites) in Site 1, which exceeded the target range as per the South African Water Quality Guidelines for Aquatic Ecosystems. The water in the catchment was highly contaminated by *E. coli* and Total Coliforms at all sites, which exceeded the South African Water Quality Guidelines for domestic use. The study showed that *E. coli* and Total ColiformS are significant factors that determine the Lower Komati River's water quality. It is therefore important to determine the implication of the contamination for human use and the social value of the river catchment. This will be discussed further in Chapter 6.

The results also showed that the distribution of macroinvertebrates was controlled not only by the status of the water quality but also by other environmental variables, such as habitat stressors. Macroinvertebrate clustering was not based on their pollution tolerance levels and water quality. The presence or absence of macroinvertebrates in the Lower Komati River was a function of habitat quality and physicochemical parameters. Results suggest that the health of the Lower Komati in South Africa and its main tributaries varies across sites depending on the human activities associated with that site, which alter the habitat condition. Considerable variation of macroinvertebrate families was found between each of the sample sites. Coenagrionidae, Amphipoda and Thiaridae are all pollution tolerant taxa, sporadically showing exceptional numerical densities in all sites. While the level of organic enrichment encountered at some of these sites seemed to benefit these families known to be tolerant to or to have a preference for such conditions, the impact of these levels on the ecosystem was not so drastic that highly sensitive families were absent. This demonstrates the importance of analysing multiple stressors on these ecosystems to increase understanding of each stressor on the river's health.

Site 1, the upstream part of the study area, could not be established as a useful reference site for the assessment. The macroinvertebrates community structure showed that this presumed reference site is at EC D/E using the SASS and MIRAI scores. This part of the thesis shows that as a result of development, we are losing reference sites that were regarded as 'pristine', thus the reliability of river health assessment approaches based on reference site conditions are subject to a higher degree of scrutiny. With the continual use of rivers, it is becoming difficult to find sites that are 'least impacted' for use as reference sites. The heavy reliance of ecological indices on the natural condition of reference sites regarded as pristine is not reliable and may lead to misinterpretation of the true state of rivers' health, as people continuously use all parts of the river. Most rivers in South Africa are continuously used as explained in the literature review in Chapter 2. These human activities have an impact on the ecological well-being of the river, thus there is a need to attain a balance between the use and protection of resources in the different sites.

This chapter also highlights that the rationale of selecting key variables in river health only focused on predetermined ecological variables and water quality to explain the river's health is inadequate to explain river health. This is mostly because the availability of macroinvertebrates is influenced by multiple stressors. The study found that nutrient enrichment, flow velocity reduction, sand mining influenced macroinvertebrate community diversity. Thus, it is important to consider multiple stressors on macroinvertebrates structure and functionality to explain river health comprehensively, as illustrated by the variability between the results from the SASS5 and MIRAI analysis in some sites. Furthermore, a single use of a taxonomic group (in this case macroinvertebrates) only offers a narrow explanation of river health based on the effect of the multiple stressors specifically to that group. Thus co-use with other taxonomic groups (e.g. fish) offers an increased understanding of river health. This means more understanding of complex ecological interactions, functionality and stressors on multiple taxonomic groups in the catchment to interpret and broaden results. Thus, Chapter 5 will use fish as another taxonomic group with inclusion of habitat analysis to explain river health.

5 CHAPTER 5: FISH COMMUNITIES AS ECOLOGICAL INDICATORS OF RIVER HEALTH

5.1 Introduction

As discussed in Chapter 3, international and local river health studies have used fish community structures effectively as indicators (Wichert & Rapport, 1998; Das *et al.*, 2013; Herman & Nejadhashem, 2015; Evans, 2017; Levin *et al.,* 2019). Fish species are preferred as they are functionally diverse, use a variety of habitat use; sensitive and respond differently to various environmental stressors over different spatial and temporal scales (Jia and Chen 2013; Levin *et al,* 2019). In this study, they have been chosen as indicators, since the habitat requirements and life history of most fish species are well studied, the presence or absence of species can be easily interpreted. Fish have also been used jointly with macroinvertebrates to assess and monitor rivers ecological status as these are responsive to environmental pollution at different spatial and temporal scales (Paller, 2001; Selego *et al*., 2012; Ogren & Huckins, 2015). Fish are also within the top of the aquatic food chain, they provide an integrated view of the river (Fierro *et al*., 2017). Moreover, fish is an important resource for communities, Lynch, *et al*. (2016) and Nthane *et al*. (2020) explained that small-scale fisheries are essential to the livelihoods of rural communities as they provide food security and employment. However, river health studies have not comprehensively analysed river's conditions based on the existing fish community structures' social and ecological role. Thus, in this chapter fish is used as an indicator for river health, which offers a comprehensive view as they show the river's ecological status and also raise questions of social value as communities rely on them. The fish provide a link between ecological and social components of the river's health.

The sampling of fish was conducted twice in 2019. The first sampling took place between the 15th and 18th of August 2019, which was at the end of the low flow season. The second sampling was between the 10th and 13th of December 2019 in which was the middle of the high flow season. Six sites were sampled as explained in section 3.5.2. The same sampling pattern followed during the sampling of aquatic macroinvertebrates, where sampling took place over 3 days with two sites sampled per day was followed. This pattern was followed to allow a comparative analysis of fish and aquatic macroinvertebrates data to explain the river's health. Likewise, during sampling of fish, no major rainfall even took place which could have had an impact on results. The sampling started upstream in Site 1 until Site 6 downstream of the Lower Komati River.

To better understand the existing fish species in the Lower Komati River, analysis of the habitat condition as drivers of fish community structures was carried out. Understanding the drivers and fish community structure was important to recognise any changes in the river and later determine how these changes affected the fish community structure which reflects on the river's health. O'Brien *et al.* (2009), Avenant (2010) and O'Brien *et al*. (2016) state that determining community structures and the drivers of fish communities is a vital precursor to developing environmental management strategies for the river. However, having knowledge of fish community structure in isolation from the habitat ignores the fact that fish species depend on the habitat. Therefore, this thesis used multiple validated lines of evidence, namely the FRAI as explained by Kleynhans and Louw (2007) and multivariate statistics (RDA) to determine the state of the river and identify the controlling environmental variables over two time periods (low and high flows).

FRAI is a rapid assessment of fish communities and habitat conditions/availability. Community structure evaluations were carried out using a multivariate statistical procedure (an RDA ordination technique) to determine drivers of community structure. Results from both analyses were used to indicate the main determining drivers of the present ecological state of the river. The first section of this chapter (5.2-5.3) presents the results of fish community structure based on two-sample analyses (August and December 2019), which reflect the river's ecological state. The second section (5.4) provides evidence of the drivers of change evaluated using an RDA ordination technique.

5.2 Fish community diversity and abundance

The fish communities were sampled from the six sampling sites along the Lower Komati River mentioned in Chapter 4, which were used to determine the ecological state of the river using macroinvertebrates. A summary of the diversity and abundance of fish obtained during the two sampling campaigns in the study sites is shown in Table 5.1. A total of 12 fish species were collected during the surveys, with 12 species (365 individuals) collected in August 2019 and 10 species (306 individuals) collected in December 2019. The most common species collected were Silver robber *(Micralestes acutidens)* and Red eye labeo (*Labeo cylindricus*.) In August, *Micralestes acutidens* (n=157(43%) and *Labeo cylindricus* (n=66 (18%) were collected and *Labeo cylindricus* (n=51(17%) *Micralestes acutidens* (97(32%) were collected in December as shown in Table 5.1.

Table 5.1. Table showing abundance of the different fish species(abbreviated) obtained during the surveys carried out in August and December 2019 from the six sampling sites

	LCYL		BTRI		CPRE		MACU		OMOS		CGAR		BMAR		MSAL		TREN		BEUT		GCAL		AMOS		FRAI SCORE
	AUG	DEC	AUG	DEC	AUG	DEC	AUG	DEC	AUG	DEC	AUG	DEC	AUG	DEC	AUG	DEC	AUG	DEC	AUG	DEC	AUG	DEC	AUG	DEC	
SITE 1	2	7	2	1	0	1	97	65						4			1		2						C
SITE 2	10	3	4	8	6	4	9	2		2	4	10		3	3	1	2								C
SITE 3	2	1	12	21	1	1			3																C
SITE 4	11	4	7	3	5		26	16	1																C
SITE 5	37	26	7	12	7	3	20	12				3	29	20											C
SITE 6	4	10	0	2	2	7	5	2	12	15	4			1			8	15			20	13		3	C
TOTAL	66	51	32	47	21	16	157	97	16	17	8	13	29	28	3	1	11	15	2	0	20	13	0	3	
PERCENTA	18%	17%	9%	15%	6%	5%	43%	32%	4%	6%	2%	4%	8%	9%	1%	0%	3%	5%	1%	0%	5%	4%	0%	1%	

Abbreviations: LCYL (Labeo cylindricus); BTRI (Enteromius trimaculatus); CPRE (Chiloglanis pretoriae), MACU (Micralestes acutidens;) CGAR (Clarias gariepinus); MACU (Micralestes acutidens); OMOS (Oreochromis mossambicus), BMAR (Labeobarbus marequensis); MSAL (Micropterus salmoides); TREN (Coptodon rendalli); BEUT (Enteromius eutaenia); GCAL (Glossogobius callidus); AMOS (Anguilla mossambica)

The highest number of fish species was collected in Site 6 with 10 species. Silver robber *(M. acutidens)* was present at all sites except site 3 and was the most abundant. Red eye labeo (*L.*

cylindricus) was present in all sites and highly abundant in site 5 (n=37 in August and n=26 in December), with the lowest abundance in Site 1 (n=9) and Site 3 (n=3), which are tributaries of the main river. The high abundance is attributed to its ecological preference. The sampling sites' map is provided in figure 3.3. According to Weyl and Booth (1999) and Scott *(2007)*, *Red*-eye labeo (*L. cylindricus),* favours clear, running waters with rocky habitats in rivers and is endemic to rivers in East Africa, Zambezi through the Limpopo and Komati Rivers to the Pongola River. Melaku *et al.* (2017) conducted a study in the White Nile system within Ethiopia on the *L. cylindricus* and found that it's life histories suggest that they may be vulnerable to overfishing, as they aggregate in mass annually at river mouths. Aspects of the biology of *L. cylindricus* from Lake Baringo, in Kenya were studied by Nyamweya *et al*. (2012) and results showed that it is abundant along its spawning migration routes and in a dammed river.

Exotic and introduced species sampled were Largemouth bass (*M. salmoides)*, which was collected in site 2. *M. salmoides* is a predatory alien and invasive species that have a very negative impact on the native species (Weyl, et al., 2010; Kimberg *et al.,* 2014). Takamura (2007) reviewed the predation of largemouth bass (*M. salmoides*) in Japanese and North America freshwaters and found that they were more pervasive predators on other fish species. The water' light intensity, clarity, oxygen depletion, prey size, behavioural refuge of prey are some factors that affected its predation performance. The fish affected other fish species, benthic macroinvertebrates composition and abundance. *M. salmoides* was introduced into South African waters in 1928 for recreational purposes and quickly spread due to its popularity amongst anglers (Kimberg *et al.,* 2014). According to Mpumalanga Tourism and Parks Agency MTPA (2015), *M. salmoides* were introduced in the Driekoppies dam and have thus entered the Lower Komati River. These exotic fish species when introduced, modify the habitat or predate on indigenous species. *M. salmoides* is a threat to *L. natalensis* as it preys on juveniles and competes with adults for food and habitat (Impson, 2008).

The Mozambique tilapia (*O. mossambicus*) is noted as a near-threatened species by Scott (2007) and Bills (2019) and was most sampled in Site 6. In South Africa, hybridisation and potential loss of genetic integrity of native Mozambique tilapia (*O. mossambicus*) have been reported as a concern due to the rapidly spreading Nile Tilapia (*O. niloticus*) that is being spread by anglers and aquaculture (Ellender & Weyl, 2014). Hutchison *et al.* (2011) studied the Nile Tilapia in Australia and found that it is highly adaptable and aestivated in wet river sands and river pools. This makes it able to rapidly recolonise areas when the dry season ends. Chivambo *et al.* (2019) in a study in Mozambique explain that *O. mossambicus* are extensively used as food by traditional fishers, as they rapidly reproduce. Furthermore, the authors found that *O. mossambicus* is invasive and can dominate aquatic habitats due to it's efficient reproductive strategy and ability to live in a variety of conditions. Thus, native species can be easily outcompeted for habitat and food.

5.3 Observed land-use pressures in the catchment

Surface water has been degraded due to various human activities which have led to lower than ‘good’ ecological status in rivers; these activities have been identified as pressures that affect fish community drivers (Poikane *et al*., 2017). Human land-use activities often affect the quality, quantity and habitat of freshwater ecosystems. Fish have a broad spectrum of sensitivity, thus anthropogenic pressure on species shows different relationships with various fish habitat metrics (Poikane *et al.*, 2017). Fish communities show well-defined microhabitat preferences for depth, velocity and type of substrate, therefore it is important to discuss how human activities such as land-use pressures in the river catchment can be a potential threat to these habitat metrics. During sampling, noticeable human activities along the catchment which have the potential to change the habitat were sand mining, weirs and dams and agriculture.

Sand mining is one of the most prevalent activities in the catchment, which was observed in parts of the river close to Sites 3 and 4. The impact of sand mining on fish communities has been studied and results show that it is detrimental to fish community structures. Paukert *et al*. (2008) and Koehnken *et al.* (2020) argue that during sand mining, marginal vegetation is removed, which changes the area's hydrology and substrate, increases sediment transport, induces channel incision and alters the flow regime, which all result in a change of habitat structure and cover for fish. Fish communities in sand dredged sites become highly variable and less consistent due to habitat degradation in rivers. Smokorowski and Pratt (2016) argue that sand mining in aquatic ecosystems creates a reservoir environment (deep water; low velocity) which is not conducive for flow-dependent species. Heyns-Veale *et al.* (2016) further explain that depth and habitat are important predictors of fish assemblage structure, so any changes in these variables will result in changes in fish structure. Site 3 (X1MZIN-MASHU) had a slow and shallow flow class, which may be attributed to the sand mining taking place about 5km upstream of the sampling site. Paukert *et al.* (2008) argue that sand mining creates low-velocity habitats sites, which may not be suitable for large river fishes and high-velocity fish. Thus, besides looking at the fish community structure it is important to also analyse the activities around the area that might drive it.

Secondly, during sampling, it was noted that the study area has weirs and a dam which might be detrimental to the fish communities. Three weirs were observed in the study sites downstream of Sites 4, 5 and 6; there was also a dam downstream of Site 2. According to O'Brien *et al.* (2019), a high number of weirs and dams along a river offers very little protection to river connectivity maintenance and fish migrations. The presence of weirs constructed within the three sites resulted in damming of the river sites, creating lentic habitat types, which were preferred by the alien Australian crayfish (*C. quadricarinatus),* found around the pool habitats created by the weirs. The absence of the *E. eutaenia* in Site 2 might be indicative of the dam effect, which could be affecting the connectivity between local reaches. O’Brien *et al. (*2019), explain that it is important to understand the potential impact of weirs and the dams on the fish community’s structure and not limit it to attributes of biological communities. Thus when assessing the community structures, FRAI allows the researcher’s judgement on the effect of river connectivity and migration disruption considerations to explain fish community structures. Fish migration has been identified as an important component of the well-being of communities in regions of high fish diversity and endemism in South Africa that need to be managed to maintain healthy water resources (O’Brien *et al.,* 2018). Furthermore, the dam seems to have created a fish habitat for *M. salmoides* which has established itself in the Driekoppies Dam; this species is predacious to the native population. The weirs, as well as land-use practices, have a potential impact on fish habitat and community structure (Mueller *et al.,* 2011). Therefore, it is important to understand the activities and history of the area to explain the potential influence on the fish habitats and community structure.

5.4 Fish response assessment index

FRAI is based on known environmental intolerances and preferences of reference fish species (Kleynhans & Louw, 2007). The index is designed to characterise the present ecological state of fish communities at each site. The index also compares reference and observed data of fish communities (Kleynhans, 2007). Reference fish assemblage was determined using historical data from the Atlas of Southern African Fresh Water Fishes (Scott, 2007) and the PESEIS database on the sub-quaternary catchment code available from the DWS website. The PESEIS database reference is based on a combination of historical data by experts who have worked in the sub-catchments and contributed to the database. The PESEIS database is widely used in South Africa for ecological reserve determination and Ecological Water Resource Monitoring (DWS, 2016). The fish sampling data were collated and transformed into FROC ratings and compared to the PESEIS (reference) FROC. Table 5.2 presents the meaning of the FROC ratings. Outcomes of the FRAI assessment are the present EC of the fish community within the study area for each site and the assessment of various metrics which might influence fish community structures (Kleynhans, 2007).

Table 5.2. Table showing explanations of the FROC ratings

Rating	Rating explanation
-	not expected
0	known to have been present historically but absent now
1	Present but infrequent, based on the local species ‘pool’, PESEIS database it is expected to be present
3	Present and with moderate confidence, based on the PESEIS database and species sensitivity it is expected to be present
5	Present, high confidence, very common. The PESEIS database has not changed to such an extent that it would be expected to be absent.

Table 5.3 lists all species expected (reference) and sampled (observed) species within each site with FROC rated as per Table 5.2. The results show that a large number of species are absent and some species sampled are in low abundance.

Table 5.3 Table showing the derived reference and observed FROC of fishes from the six study sites used during FRAI assessment

Scientific name	**FISH SPECIES**	**Site 1**		**Site 2**		**Site 3**		**Site 4**		**Site 5**		**Site 6**	
		ref	**obs**	**ref**	**obs**	**ref**	**obs**	**ref**	**obs**	**ref**	**obs**	**ref**	**obs**
Acanthopagrus berda	ABER	3	0	-	-	-	-	-	-	-	-	3	0
Anguilla bengalensis	ALAB	3	0	3	0	-	-	3	0	1	0	3	0
Anguilla marmorata	AMAR	5	0	1	0	-	-	3	0	1	0	3	0
Anguilla mossambica	AMOS									-	0	-	3
Oreochromis mossambicus	OMOS	1	0	1	1	1	1	3	1	1	0	-	-
Aplocheilichthys johnstoni	AJOH	-	-										
Enteromius annectens	BANN	5	0	-	-	-	-	5	0	1	0	5	0
Enteromius eutaenia	BEUT	5	1	5	0	-	-	5	0	-	-	-	-
Brycinus imberi	BIMB	-	-	-	-	-	-	5	0	1		5	0
Labeobarbus marequensis	BMAR	5	5	5	5	1	0	5	0	5	5	5	5
Enteromius paludinosus	BPAU	-	-	5	0	5	0	5	0	1	0		
Enteromius radiatus	BRAD	-	-	5	0	-	-	5	0	1	0	5	0
Enteromius toppini	BTOP	-	-	-	-	-	-	-	-	-	-	5	0
Enteromius trimaculatus	BTRI	5	1	5	5	5	5	5	5	5	5	5	4
Enteromius unitaeniatus	BUNI	5	0	5	0	-	-	-	-	-	-	5	0
Enteromius viviparus	BVIV	5	0	1	0			5	0	5	0	-	-
Chetia brevis	CBRE	5	0	5	0	-	-	-	-	-	-	5	0
Cyprinus carpio	CCAR	-	-	5	5	-	-	-	-	-	-	5	0
Clarias gariepinus	CGAR	1	-	5	5	5	-	5	0	5	0	5	5

Chiloglanis paratus	CPAR	-	-	1	0	-	-			5	5	5	0
Chiloglanis pretoriae	CPRE	-	1	5	3	5	1	5	3	-	4	5	0
Chiloglanis swierstrai	CSWI	-	-	1	0	-	-	5	0	-	-	5	0
Glossogobius callidus	GCAL	-	-	1	0	-	-	-	-	-	-	5	5
Glossogobius giuris	GGIU	-	-	1	0	-	-	5	0	-	-	5	5
Hydrocynus vittatus	HVIT	-	-	1	0	-	-	5	0	5	0	-	-
Labeo congoro	LCON	-	-	-	-	-	-	-	-	1	0	5	0
Labeo cylindricus	LCYL	5	5	5	5	1	1	5	5	5	5	5	5
Labeo molybdinus	LMOL	1	0	5	0	-		-	-	-	-	5	0
Labeo rosae	LROS	-	-	-	-	-	-	-	-	-	-	5	0
Micralestes acutidens	MACU	5	5	5	5	-	-	5	5	5	5	-	-
Microphis brachyurus	MBRA	5	0	1	0	-	-	5	0	5	0	-	-
Micropterus salmoides		-	-	-	3	-	-	-	-	-	-	-	-
Mesobola brevianalis	MBRE	5	-	-	-	-	-	5	0	1	0	-	-
Marcusenius macrolepidotus	MMAC	-	-	-	-	-	-	-	-	5	-	-	-
Petrocephalus wesselsi	PCAT	1	0	5	0		-	-	-	-	-	-	-
Pseudocrenilabrus philander	PPHI	5	-	-	-	5	0	-	-	-	-	-	-
Coptodon rendalli	TREN	5	1	-	-	5	0	5	0	-	-	-	-
Tilapia sparrmanii	TSPA	1	0	-	-	-	-	-	-	-	-	-	-
	Total	**18**	**6**	**23**	**8**	**9**	**4**	**21**	**5**	**18**	**5**	**21**	**6**

Table 5.3 shows that, FROC of the different fish species differed markedly between observed and reference in all sites. For example, Site 4 (X1KOMA-IFR04) 21 species were expected but only five were sampled. Most of the expected fish species in the quaternary catchment were not present and even those present were not sampled as frequently as expected in all the sites.

Table 5.4 shows the automated and adjusted FRAI scores and ECs for the different sites, generated by the FRAI model. The FRAI automated score is based on the model's assessment, which takes into account the state of the drivers and the differences between expected and observed species in the assessment alone. The adjusted score is based on intolerance and preference attributes, categorised into metric groups that relate to the environmental requirements and preferences of individual species sampled. To derive the adjusted score, the model allows the user to manually evaluate the state of the drivers of the system, based on the present species preferences. The drivers that are considered during adjustment are the available substrate types, available cover features, velocity and depth, the physical-chemical state of the water, presence of introduced species and barriers for migration in the river which are individually weighted (as shown in Appendix1-G) (Kleynhans, 2007). Assessment of response of the species to the metrics is based on direct measurement during the survey, inference from changing habitat and knowledge of species ecological requirements.

Table 5.4 shows that major differences were observed between the automated and adjusted FRAI scores in all sites. The adjusted scores for all sites were in the EC C, whilst the automated scores ranged between EC D and E. This may be attributed to the low diversity of species sampled versus the expected, and observed changes in environmental conditions observed during sampling in the river which FRAI considers during the adjustment process.

Table 5.4. Table showing the automated, adjusted FRAI Scores and related ECs from all the six sampled sites.

SITE	**Automated FRAI SCORE (%)**	**Ecological Category**	**Adjusted FRAI SCORE (%)**	**Ecological Category**
1	44.9	D	68.3	C
2	47.2	D	68.7	C
3	35.8	E	66.4	C
4	34.9	E	64.8	C
5	48.1	D	67.8	C
6	28.1	E	65.7	C

The adjusted FRAI scores from all the sites during the sampling period indicate that the ecological integrity of the fish communities in all the reaches is in class C, suggesting a moderately impaired fish community that has low diversity and abundance of species. Site 4 (X1KOMA-IFR04) was noted to have the lowest adjusted FRAI score of 64,8% and Site 2 (X1LOMA-SCHOE) was noted to have the highest adjusted FRAI score of 68,7%. Two species, *C. pretoriae* and *E. eutaenia* which have a high intolerance rating to changes in habitat were expected in this site (Site 4 X1KOMA-IFR04). However, only the *C. pretoriae* was sampled. The absence of *E.eutaenia* might be indicative of the weir effect which may be affecting the connectivity between local reaches of most of the species expected in this site. According to O' Brien *et al.* (2019), in the Inkomati-Usuthu catchment, there are 83 formal gauging weirs, although some are fitted with some sort of fish pass facility (as with this site); however, it has varying levels of success which has resulted in habitat fragmentation, affecting fish distribution (Nel *et al.,* 2011).

FRAI classed all the sites in the C category, suggesting that the river is modified. The fish cohorts are not equally represented for most parts sampled compared to the fish communities from the reference data. Site 4 has the lowest EC when using both FRAI (fish indicators) and MIRAI (macroinvertebrates). This suggests that Site 4's river health status is the most modified as per the two ecological indicators used in this study. There are also several anthropogenic activities observed upstream of the site; these include sand mining and weirs. These anthropogenic activities have the potential to change habitat structure in rivers. The construction of multiple weirs in large portions of the river has transformed lotic habitat to a lentic habitat, thus creating suitable habitat for the establishment of alien and invasive species, favouring limnophilic species. Alien species (*M. salmoides*) seem to have established themselves around the lentic habitats in the river catchment especially downstream of the Driekoppies Dam; the Australian crayfish (*C.quadricarinatus)* has established itself mostly around the pool habitats created by the weirs in the last three sites of the study area.

Furthermore, the occurrence of the alien invasive *C. quadricarintus* in Site 4 (X1KOMA-IFR04) may also have had an impact on the low occurrence of some species, as it poses a threat to indigenous populations. A study in Western Australia by Lynas *et al.* (2007) found that *C.quadricarintus* outcompeted three main indigenous fish species in a river. However, in South Africa, no study is available that investigates the impact of the crayfish on the native population, although there are reports of its presence in the Lower Komati River (Nunes *et al.*, 2017; Petersen, *et al*., 2017). Nunes *et al.* (2017), found that the *C. quadricarintus* invasions have generally resulted in strong impacts on recipient ecosystems, especially on native decapods (for example, freshwater crabs). Chaichana and Wanjit (2018) state that Australian crayfish alter habitats and influence other species in shared environments which includes being agonistic (fighting), as well as foraging and burrowing, interrupting the habitats preferred by the native species.

The FRAI adjustment process also involved rating the species intolerance and preference, based on how they relate to the natural attributes and requirements of the reference fish assemblage. Table 5.5 shows the metric rating table produced. The natural characteristics of the fish assemblage and its habitat are considered and compared with how it might be affected by the different fish metric groups (velocity depth, cover, migration, physico-chemical and flow modification); these metric components are weighted in the process. For example, a species with a known preference for slow-shallow habitat would be given an expected FROC score of 5 if slow-shallow prevalence was 100% or a FROC score of 1 if the same class prevalence was 25%. The variable in the metric group table with the highest percentage is assumed to have most influence on the fish communities. In all the sites, the velocity depth metric weighted highly followed by flow modification. This means that fish communities in these sites are influenced highly by velocity-depth changes that are often associated with flow modifications.

Table 5.5. Table showing the metric groups' weightings output from FRAI analysis

METRIC GROUP	**WEIGHT (%)**
Velocity-depth	100
Cover	76.47
Flow modification	88.24
Physico-chemical	85.29
Migration	79.41

From the FRAI analysis and as shown in Table 5.5, since velocity-depth and flow were the two metrics found to have a major influence on fish community structure, it was important to show the different broad flow classes categories of hydraulic habitats described by the depth and velocity measured during the sampling period. Each site's flow class was defined as shown in Table 5.6. Sites 4-5 had a similar flow class (fast deep), Site 3 had a slow shallow flow class, Site 2 had slow deep whilst Site 1 had fast shallow.

Table 5.6. Table showing velocity, depth measurements and flow classes for the six sampled sites.

Site	**Velocity (m/s)**	**Depth(m)**	**Flow class**
1	0.34	0.168	Fast Shallow
2	0.28	0.443	Slow Deep
3	0,24	0.113	Slow Shallow
4	0.33	0.324	Fast Deep
5	0.46	0.394	Fast Deep
6	0.33	0.431	Fast Deep

The importance of velocity and depth in these sites can be attributed to *L. cylindricus,* a flow-sensitive species distribution. *L. cylindricus* was recorded in all sites except Site 3 (X1MZIN-MASHU). Generally, Site 3 (X1MZIN-MASHU), which had the lowest velocity and depth, had no flow-sensitive species. The slow and shallow flow class in Site 3 (X1MZIN-MASHU) is attributed to the sand mining taking place about 5km upstream of the sampling site. According to Russell (2011), *L.cylindricus* prefers clear running waters in rocky habitats of small or large rivers. Other flow-sensitive species sampled were *E. trimaculatus,* which was sampled in all sites and *L. marequensis*, which was not sampled in Site 3 and 4. Paukert *et al.* (2008) and Kjelland *et al*. (2015) found that increased sedimentation may result in decreased fish abundance and biodiversity, where it results in an inversely proportional relationship.

The results also showed that juvenile fish prefer shallow waters and large fish prefer deeper waters. Sites 4 (X1KOMA-IFR04), 5 (X1KOMA-NYATS) and 6 (X1KOMA-LEBOM) which had averagely Fast deep flow class conditions, were preferred by large fish. Larger individuals of *C. gariepinus*, *L. cylindricus* were collected in the deeper pools of these sites suggesting that this habitat was an important refuge for adult fish of all these species. This habitat may be particularly important for these species as both are of high conservation significance. According to Arthington *et al.* (2003), deep pool areas with bedrock, boulders and cobbles are favoured habitat conditions for these species. Site 4, 5 and 6 had a mix of these different substrates, which made them favourable habitats for the large fish. The rocky substrata noted during sampling were preferred by *C. gariepinus*. Skelton (2001) reports that *C. gariepinus* lives in rocky habitats with flowing water and rapids. Juvenile fish were mostly sampled in Site 3 (X1MZIN-MASHU), which was the site with the lowest flow. Smaller fish prefer water with low velocity, so they can move between habitats to maximise their survival and fitness (Paxton, 2004). This shows that different species prefer different habitats and the age of a fish has a significant impact on its habitat preference.

Furthermore, Site 2 (X1LOMA-SCHOE) which is 5km below the Driekoppies Dam, also had fewer species than expected. Of the 23 expected species as per reference data (PESEIS) only eight species were sampled in this site. The site was mostly favoured by *M. salmoides* and *C.rendalli*. The fewer sampled species than expected may be attributed to the dam; according to Paxton (2004) and O'Brien *et al.* (2019) downstream to a dam, the flow becomes insufficient and most fish species are unable to survive. O'Brien *et al.* (2019) explain that dams change habitat and flow, which can threaten indigenous migratory and non-migratory species and ease the settlement of alien invasive species. So, these sampled exotic species may be potentially encouraged by the low flow habitat conditions in the site.

In essence, the FRAI and community structures analysis in the different sites shows that habitat condition is important to determine the presence of species. It is important to analyse the potential drivers of the changes in the fish community structure and potential stressors that may cause changes in the habitat in the Lower Komati. However, basing judgement solely on expert opinion may render the use of FRAI subjective. Lu *et al.* (2015) explain that ecosystem health determination is influenced by value judgment and is not completely objective. Likewise, analysis using FRAI to class a river's ecological state is based on expert opinion only, which may not be fully objective. According to Kleynhans (2007), the FRAI adjusted score is based on expert opinion and knowledge regarding the environmental preferences and intolerances of reference fish assemblages across South Africa, to certain sets of environmental drivers. Expertise may differ depending on familiarity with the sampling site. The FRAI analysis also needs knowledge about the reference species and habitat, which might be available to local communities who fish in the river and are thus more familiar with it. However, FRAI analysis does not allow the consideration of local communities' and fishers' historical and local ecological knowledge about the river and fish species. The experts' analysis may not be comprehensive as they are not residents in the area and don't have first-hand experience on events taking place in the catchment which might have influenced habitat change and fish community assemblage distribution. Thus, the next chapter will ascertain the local communities and fishers' knowledge and experience of river health, fish species and fishing habitats.

Overall, FRAI classed all the sites in the C category, suggesting that the river is modified. The sampled fish cohorts were not equally represented compared to the fish communities from the reference data. Site 4 had the lowest EC when using both FRAI (fish indicators) and MIRAI (macroinvertebrates). This suggests that Site 4's river health status was the most modified as per the two ecological indicators used in this study. There were also several anthropogenic activities observed upstream of the site; these included sand mining and weirs. These anthropogenic activities have the potential to change habitat structure in rivers. The construction of multiple weirs in large portions of the river transformed the lotic habitat to a lentic habitat, thus creating suitable habitat for the establishment of alien and invasive species, favouring limnophilic species. Alien species (*M. salmoides*) were more established around the lentic habitats in the river catchment especially downstream of the Driekoppies Dam. The alien Australian crayfish (*C.quadricarinatus)*established itself mostly around the pool habitats created by the weirs in the last three sites of the study area.

5.5 Analysis of fish community assemblage drivers

To determine drivers of fish' community structure, evaluations were carried out using RDA, an extension of regression that predicts multivariate response data and species distribution (Makarenkov & Legendre, 2002). RDA is a constrained ordination technique, which directly analyses the relationship between multivariate ecological datasets and biological communities (ter Braak & Smilauer, 2015). RDA was preferred since it combines regression with PCA as explained in section 3.5.5. The RDA allowed for the direct interpretation of the community structures of fish in terms of the taxa obtained during detailed surveys and their preferred habitats and drivers. Furthermore, the statistical significance of the hypothesised differences in the community structures was tested as advised by Van den Brink *et al.* (2003). The multivariate statistical procedure assessed how habitat, cover, velocity and depth related to the sampled fish community structures using RDA with R-vegan. RDA also allowed the drivers of change in fish community structures to infer the overall state of the river, based on the wellbeing of fish communities. The resulting plots are shown in Figures 5.1, 5.2 and 5.3. The RDA biplots separated fish data into distinct faunal assemblages driven by the three measured environmental variables as the explanatory variables. Direct interpretation of the community structures of fish obtained during surveys using the environmental variables was done. The species names in Figures 5.1, 5.2 and 5.3 are abbreviated using the first letter of genus and first letters of the species names as shown in the figure captions

Cover was found to be a significant driver of community structure ($p=0.002$). Around 62% of the variation seen in the fish communities is displayed in the first two axes of the ordination; RDA 1 explained 33% and RDA 2 explained 29%, as shown by Figure 5.1. RDA 1 had an eigenvalue of 5.2

and RDA 2 had an eigenvalue of 2.7.Site 3, 4 and 2 were associated with at least four species; CPRE (*C. pretoriae*) AMOS (*A. mossambica)* and BTRI (*E. trimaculatus)* which showed a preference for depth cover type, whilst marginal vegetation was preferred by BMAR (*L. marequensis)*. Marginal vegetation as a cover type has the highest loading (0.53), this shows that the cover type is the most important in the site for the fish sampled. The importance of cover is not surprising, as Beltrão *et al.* (2009) argue that fish assemblage diversity and the composition and structure of their habitat have been linked to variations in the riparian cover. According to Beltrão *et al.* (2009), marginal habitat shows a greater array of habitat elements. These multifaceted habitats provide a growth substrate, source of food and spawning sites, as well as protection from predators for aquatic invertebrates and fish. Vono and Barbosa (2001) and Pusey and Arthington (2003) highlight the close correlation between fish species and the marginal habitat as both studies found that a significant loss of the marginal habitat elements due to different human activities led to changes in fish community structure.

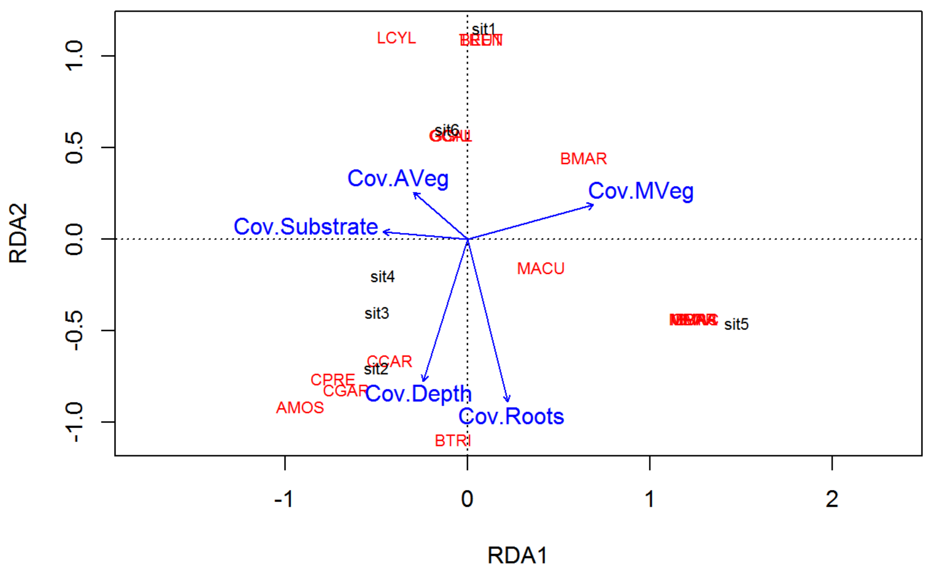

Figure 5.1. Redundancy analysis plot showing dissimilarities based on cover features, fish communities and the different sites sampled. *Abbreviations: LCYL (Labeo cylindricus); BTRI (Enteromius trimaculatus); CPRE (Chiloglanis pretoriae), MACU (Micralestes acutidens) CGAR (Clarias gariepinus);MACU (Micralestes acutidens); OMOS (Oreochromis mossambicus), BMAR (Labeobarbus marequensis); MSAL (Micropterus salmoides);TREN (Coptodon rendalli); BEUT (Enteromius eutaenia); GCAL(Glossogobius callidus);AMOS (Anguilla mossambica)*

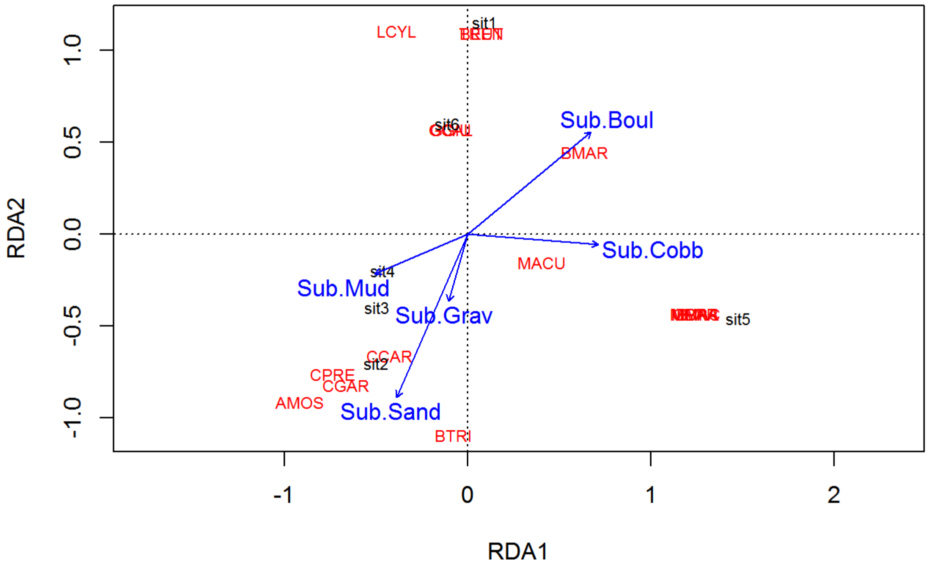

Figure 5.2. Redundancy analysis plots showing dissimilarities based on the substrate types, fish communities sampled in the different sites sampled. *Abbreviations: LCYL (Labeo cylindricus); BTRI (Enteromius trimaculatus); CPRE (Chiloglanis pretoriae), MACU (Micralestes acutidens) CGAR (Clarias gariepinus);MACU (Micralestes acutidens); OMOS (Oreochromis mossambicus), BMAR (Labeobarbus marequensis); MSAL (Micropterus salmoides);TREN (Coptodon rendalli); BEUT (Enteromius eutaenia); GCAL(Glossogobius callidus);AMOS (Anguilla mossambica)*

The substrate was found to be a significant driver of community structure (p=0.002). For the substrate types, 61% of the variation seen in the fish communities in Figure 5.2 is displayed in the first two axes of the ordination where RDA 1 explains 32.4% and RDA 2 explains 28.9%. The eigenvalues were noted as 5.1 for RDA 1, 4.6 for RDA 2. Figure 5.2, also shows that, multiple species - CGAR (*C. gariepinus),* CPRE (*C. pretoriae)*, AMOS (*A. mossambica)* and BTRI (*E. trimaculatus*) showed a preference for sandy, gravel and muddy substrate whilst MACU *(M. acutidens)* preferred cobble; boulders were preferred by BMAR (*L. marequensis)*. LCYL (*L. cylindricus)* displayed a more cosmopolitan preference, as it did not show any preference for a substrate. Cobble substrate had the highest loading of 0.67, followed by boulders at 0.63, which shows that these two substrates are the best predictors of species presence/absence preferred by the fish species sampled. According to Skelton (2001), gravel, cobbles and boulders serve as spawning and feeding grounds for many fish. Kleynhans (2007) confirms that sand, gravel, cobbles and boulders all have the potential to act as cover for fish and when these substrates are inundated with fine silt or mud, they lose their effectiveness. Taylor *et al.* (2019) state that access and quality of spawning habitats are critical for the productivity of substrate-spawning fish. Thus, degradation or loss of appropriate spawning substrate may inherently limit the population growth of these fish species.

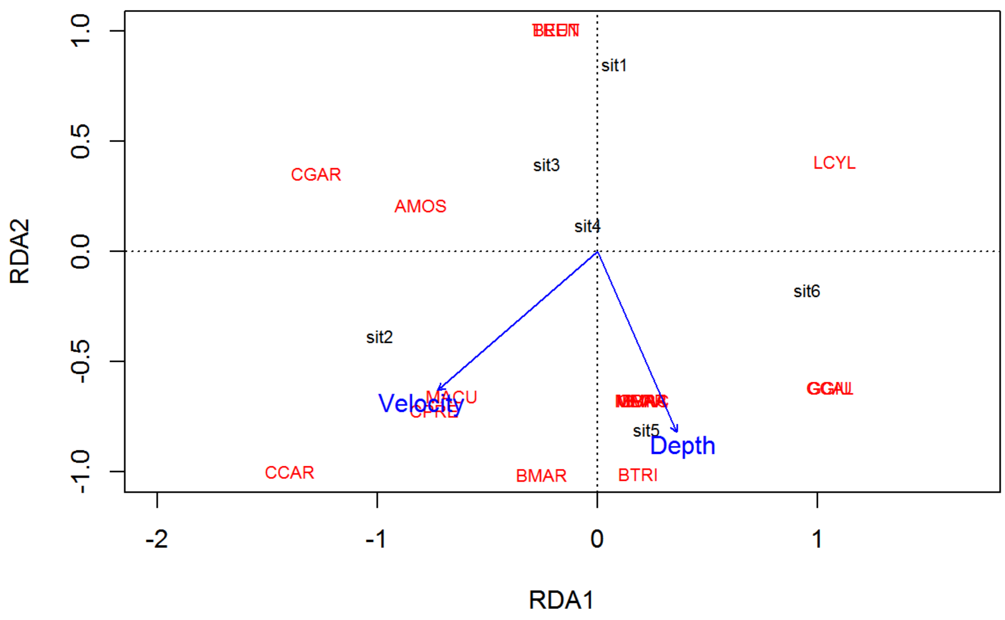

Figure 5.3. Redundancy analysis plots showing dissimilarities based on depth and velocity, fish species and the different sites sampled. *Abbreviations: LCYL (Labeo cylindricus); BTRI (Enteromius trimaculatus); CPRE (Chiloglanis pretoriae), MACU (Micralestes acutidens) CGAR (Clarias gariepinus);MACU (Micralestes acutidens); OMOS (Oreochromis mossambicus), BMAR (Labeobarbus marequensis); MSAL (Micropterus salmoides);TREN (Coptodon rendalli); BEUT (Enteromius eutaenia); GCAL(Glossogobius callidus);AMOS (Anguilla mossambica)*

As shown by Figure 5.3, 99% of the variation seen in the fish communities is displayed in the first two axes of the ordination on velocity and depth. RDA 1 explained 58.8% and RDA 2 explained 41.1 %. The eigenvalues were noted as 3.1 for RDA 1 and 42.2 for RDA 2. Velocity was associated with CCAR (*C. carpio*), MACU (*M. acutidens*) and BMAR (*L. marequensis*). Burnett *et al.* (2018) confirm the association between *C. carpio* and *L. marequensis* in their study these species were found within the same range. The authors explain that BMAR *(L. marequensis)* thrive in rivers that have a near-natural flow regime, as their body and morphological aspects make it suitable to cope with flowing water. Another association was noted between BTRI (*E. trimaculatus*) and GCAL (*G. callidus*), as these species clustered with depth. During sampling, GCAL (*G. callidus*) was caught on numerous occasions, mostly in deep water areas. However, AMOS (*A. mossambica*), LCYL (*Labeo cylindricus*) and CGAR (*C. gariepinus*) did not show any preference for either velocity or depth. MACU *(M. acutidens*) prefers moderately fast-flowing water despite being able to tolerate stagnant water (Skelton, 2001). During sampling, MACU *(M. acutidens*) was observed in sites with fast deep and fast shallow habitats. This is consistent with a study by Mpumalanga Tourism and Parks Agency (MTPA) (2015), that this species was abundant in high-velocity areas during their sampling in 2014 in the Komati River. Therefore, the results from the RDA plots, coupled with observation during sampling, show that fish community structures can be attributed to available habitats at sites. Thus, to explain fish availability, it is equally important to understand the habitats available in the river catchment.

Assessing the ecological state of fish communities and relating them to environmental drivers using FRAI and multivariate statistical methods (RDA) was useful. While FRAI is designed to be a general index of fish community response to environmental change, the results managed to single out important drivers for fish community structures and also estimate the ecological state of the river. Based on the FRAI analysis and multivariate analysis it is important to note that habitats are major influences of fish community structures. The FRAI analysis' metric scores showed that depth and velocity have major impacts on the present community structure when comparing the reference data with sampled species. From the multivariate statistical analysis, cover and substrate were found to be more important. Whilst the two surveys may not have been comprehensive, they provided sufficient evidence to support the claim that habitat condition has a great impact on fish community structures.

Findings from the FRAI assessments/analysis show that the fish community assemblages in the Lower Komati respond to habitat and flow modification. The FRAI adjusted scores which take into consideration species habitat preferences indicate that all sites are moderately impaired, as they were all in EC C. From the RDA analysis, velocity-depth, substrate and cover were found to have a major influence on community structure. Skelton (2001) and Burnett *et al.* (2018) support these findings as they argue that the occurrence of fish species at specific locations in a river can be influenced by microhabitat factors such as substrate, depth and water velocity. Determining both drivers and the ecological state is important for the consideration of the balance between the use and protection of fish communities. Therefore, this study's findings highlight the importance of protecting fish habitats to maintain different fish communities. Understanding the role of drivers on fish communities is also crucial to understanding the overall health of a river, as fish communities have been widely used as indicators in river health studies.

5.6 Comparing FRAI and MIRAI

This chapter provides further evidence to support results from Chapter 4 (using macroinvertebrates), that parts of the Lower Komati River have been modified. However, comparing the macroinvertebrate results in Chapter 4 and the fish results on river health shows that there are major differences in the ECs as classified by these indicators. Analysis of river health using fish index (FRAI) and taking into consideration the habitat as a driver, concluded that the river is in EC C. However, macroinvertebrates' analysis using MIRAI shows that the river is between D and E ecological categories. The disparity of results using these two indicators shows that the responses of fish and macroinvertebrates to landscape factors vary, due to potential differences in their susceptibility to changes in the habitats or to differences in the scale at which landscape factors influence these organisms. The study results show the importance of using different taxonomic groups in river health and that using one taxonomic group of organisms to determine the river health status might not be conclusive, as they react differently to habitat conditions and pressure (Paller, 2001). Therefore, the occurrence of the two taxonomic groups in the river may be subject to several environmental variables which control their tolerance levels. This is evident in this case as macroinvertebrate communities and water quality analysis concluded that the different parts of the river are largely and seriously modified, whilst fish showed that it is was only moderately modified. Thus, an integrated river health analysis index that considers the sampling of fish and macroinvertebrates at the same time must be considered. This will help to give a comprehensive and reflective condition of the river based on the different taxonomic groups' tolerance levels. This is more important as section 2.10 showed that fish and macroinvertebrates are linked through trophic level interaction, thus a change in macroinvertebrates, can trigger monitoring or act as a warning on prospective changes in the fish community structure.

Both indicators (macroinvertebrates and fish) show that Site 1, which is the upstream part of the study area, could not be established as a useful reference site. The fish community structure (using FRAI adjusted) showed that this site is EC C (moderately modified) and macroinvertebrates' community structure analysis (using SASS and MIRAI scores) showed that the site is at D/E (largely modified). All these classifications show that the composition of the reference community structure of both fish and macroinvertebrates has been modified. This is attributed to human activities taking place in this part of the river, which has potentially disrupted the habitat conditions for the macroinvertebrates and fish communities as discussed in section 5.3

These results suggest that, due to the continual use of rivers, it is becoming difficult to assume upstream sites as references to establish indicators and develop composite indices. Bouleau and Pont (2015) and Agboola *et al.* (2020) explain that the ecological reference site's condition is based on the assumed 'less impacted' physical, chemical and biological characteristics. Although Site 1 had been historically regarded as a reference site it could not be established as a reference site in this assessment as its ecological variables show that they have diverted from the reference condition. The site's macroinvertebrates, fish community structures and water quality analyses show that they have been modified and this is attributed to the changes in riparian habitat, flow regime and physical-chemical composition of the water quality. Since human activities are common in rivers, assuming upstream sites' as 'pristine' may not be justified as they may also have been impacted by these activities (Chessman *et al.,* 2008; Dallas, 2013; Chessman, 2014).

Similarly, studies by Hugueny *et al*. (1996); Harris and Silveira (1999) using the Index of Biotic Integrity (BI) to determine rivers' ecological condition showed that the set reference sites had been impacted. The studies which used fish as indicators of the river condition showed that the assumed reference sites' fish community had declined than expected. Hugueny *et al*. (1996) who adapted the IBI index for West African rivers found that there was a low spatio-temporal variation of the IBI scores in reference sites compared to experimental sites. This pattern was attributed to the increased percentage of invasive fish individuals in all the sites and the use of gill nets as a problematic method and it might have not effectively collected some species. Harris and Silveira (1999) who surveyed large-scale rivers in Australia to test the Index of Biotic Integrity (IBI) also could not establish "undisturbed" reference sites to provide a standard against the comparable sites. The ideal “undisturbed or least-disturbed” sites could not be identified, as a great majority of rivers were affected by hydrological disturbances, increase in alien species and damaged riparian zone. This emphasizes the weakness of indices relying on the natural condition of assumed reference sites as it may lead to misinterpretation of the true state of rivers.

Other approaches to river condition, such as the geomorphic approach, have changed from assuming a natural reference point to being considered the ‘best achievable condition’ (Rinaldi *et al.*, 2015). Blue (2018) asserts that the assumption of river health to be largely based on proxies for naturalness cannot be trusted. Thus, the REMP establishes a relative reference condition close to a natural condition, derived from the best available information, which includes consideration of RQOs (DWS,2016). These RQOs take into consideration the river's status quo and that rivers are actively used, which is an improvement from the use of reference sites based on ‘pristine’ conditions (DWS, 2016). Despite progress made to consider ES and ecological indicators to set up the river’s RQOs, river health monitoring only considers ecological indicators. The state of ES through the use of locally relevant social indicators is not covered during river health monitoring, whilst it is considered during RQO determination. Thus, Chapter 6 will consider the active involvement of local communities to identify how they relate to the river and its health based on social value and ES. This will pave the way to identify local indicators that communities can use to determine the river’s health.

5.7 Conclusion

The general health of the river and cohort of fish community illustrate the lack of balance between use and protection of the freshwater ecosystem. The river resource is used without increased protection which is shown by the state of the fish communities and habitat. The disappearance of native species in the sites has a major implication for subsistence fishing, as fishers may depend on these native species. With a notable decline in some fish species and an indication that the river’s health is compromised, this raises a question on how this might impact the local communities adjacent to the river that depend on the fish. Therefore, Chapter 6 will look at how changes in river conditions have affected fishing in the catchment and what the fishers use as their indicators for river health. River health assessments that only pay attention to fish community structure in isolation from understanding the fisher’s perspectives ignore the use and ecosystem services provided by the river. This research attempts to assess river health within a broader approach that endeavours to study fish communities in the Lower Komati River and also involve fishers, as major stakeholders in the catchment where fishing is an important activity. This led to the generation of a comprehensive river health monitoring framework that regards scientific and local communities as well as fishers’ ecological knowledge in river health assessment.

6 CHAPTER 6: HUMAN-SOCIETY RELATIONSHIPS AND SOCIAL DYNAMICS IN THE LOWER KOMATI RIVER

6.1 Introduction

The findings of the previous chapters (Chapters 4-5) highlight the complexity and the uncertainty involved in assessing the river health condition of the Lower Komati River using ecological indicators (fish and macroinvertebrates) and indices. The fish and macroinvertebrate indices involve experts' subjective based rating of the species intolerance and attributes of the species to the habitat. However, there is no consideration of local knowledge, the interest of water users and local communities who have, experience with the use of the river. Moreover, the selection of suitable variables to be monitored for the assessment remains concentrated on the ecological indicators without considering the balance between the river's use and protection.

As previously explained in Chapter 1, local communities are involved in the monitoring of the Lower Komati River through established citizen science tools like miniSASS. However, little is known about the social role, inputs and relationships that exist between the local communities and the river. The geographical context of the catchment provides a strong case study to explore the formation of social values and relationships between the local communities and the catchment, as most of the local communities are near the catchment. Thus, this thesis developed a river health framework that considers social values and human-river relationships in river health monitoring and explores how these can be used as a guide in environmental monitoring by communities. Before the framework can be developed, it is important to understand the relationship between the communities and the river by determining values assigned by the local communities and how they are formed. Therefore, this chapter will address the third research objective and question, which is to identify relationships between the local communities and rivers and how they socially assign value to different parts of the Lower Komati River.

The results are presented in different sections of the chapter; the first two sections (6.2 and 6.3) present the demographic characteristics of the participants and the location of areas of different social value as assigned by the local communities in the Lower Komati River. Section 6.4 highlights the different connections between the local community groups and the river and how this leads to the formation of a mosaic of social values in the catchment. It further pinpoints how these connections are realised and distributed across different groups of people and shaped by physical and social structures, rules and norms. Section 6.5 of the thesis notes the socio-environmental construction of river health by the communities. Section 6.6 describes the different changes observed by local communities and key informants (fishers, informed members of the community) in the river catchment, which also serve as indicators that they use to determine the river health's condition. This section further presents the participants' views on how the current condition of the river has an impact on their use of the river and the social well-being of the community.

Sections 6.7-6.10 explain other themes that emerged during the data collection process. These themes include the participants' feelings of solastalgia when explaining current river conditions, as well as the use of historical and political perspectives in explaining the river's present health. The historical perspective of the catchment is discussed by engaging the political ecology approach and analysing how declining river health is a result of an interplay of physical, historical, social and political conditions in the catchment. The chapter concludes by highlighting that due to the social-ecological construction of river health, it's monitoring also requires social and qualitative approaches, which include epistemic community participation and local knowledge recognition. Lastly, the thesis argues that river health is place-based and thus communities' local ecological knowledge is identified as important and its use in river health is discussed. Verbatim quotations are included throughout the chapter to provide more detail and context to the interpreted results. These quotes are from participants who were part of the study and are necessary to illustrate their different perspectives. The use of direct quotations allows readers to see how participants expressed themselves, and to show the original context associated with participants' responses.

6.2 Socio-demographic characteristics of the communities and participants

Cobb and Rixford (1998) explain that how people value water resources will differ among social groups (for example, age, gender, socioeconomic status) and across different geographic extents and individual experiences (memories of experiences). Walker *et al.* (2015) highlight that social values of water are associated with the unique use of each society, which influences the way that water is managed. Thus, the participants' socio-demographic characteristics must be discussed.

A total of 55 participants took part in the participatory mapping exercise. The aim was to determine how communities and water users who are adjacent to the Lower Komati River catchment, assign social values to different parts of the river catchment. Of the total, 24 of the participants came from the Lower Lomati sub-catchment and 31 from the Lower Komati West sub-catchment. During the community mapping exercise, there were more female participants than male participants, as shown in Table 6.1. Males showed less interest in the study. Most of the communities in the vicinity of the Lower Komati River are Swati.

Table 6.1. Table showing socio-demographic characteristics of the community groups which took part in the community mapping exercises

Sub-catchment	Community	Gender	Years resident in the area
Lomati sub-catchment	1 Midplaas	5 females	14-48 years.
	2 Schoemansdal	6 females	20-50 years
	3 Driekoppies	5 females	25-36 years
	4 Midplaas	6 females and 2 males	10-60 years.
Komati west sub-	5Mzinti/Kwazibukwane	6 females	10-45 years

catchment	6 Sibange	7 females	20-55years
	3 Magudu	8 females and 2 males	25-36 years
	4 Sibange	7 females and 1 male	10-65 years.

Participants have been residents in the area for between 10-65 years and are familiar with the catchment area. All of the participants have used the river in at least one way. The spatial distribution of the different communities is shown in Figure 6.1.

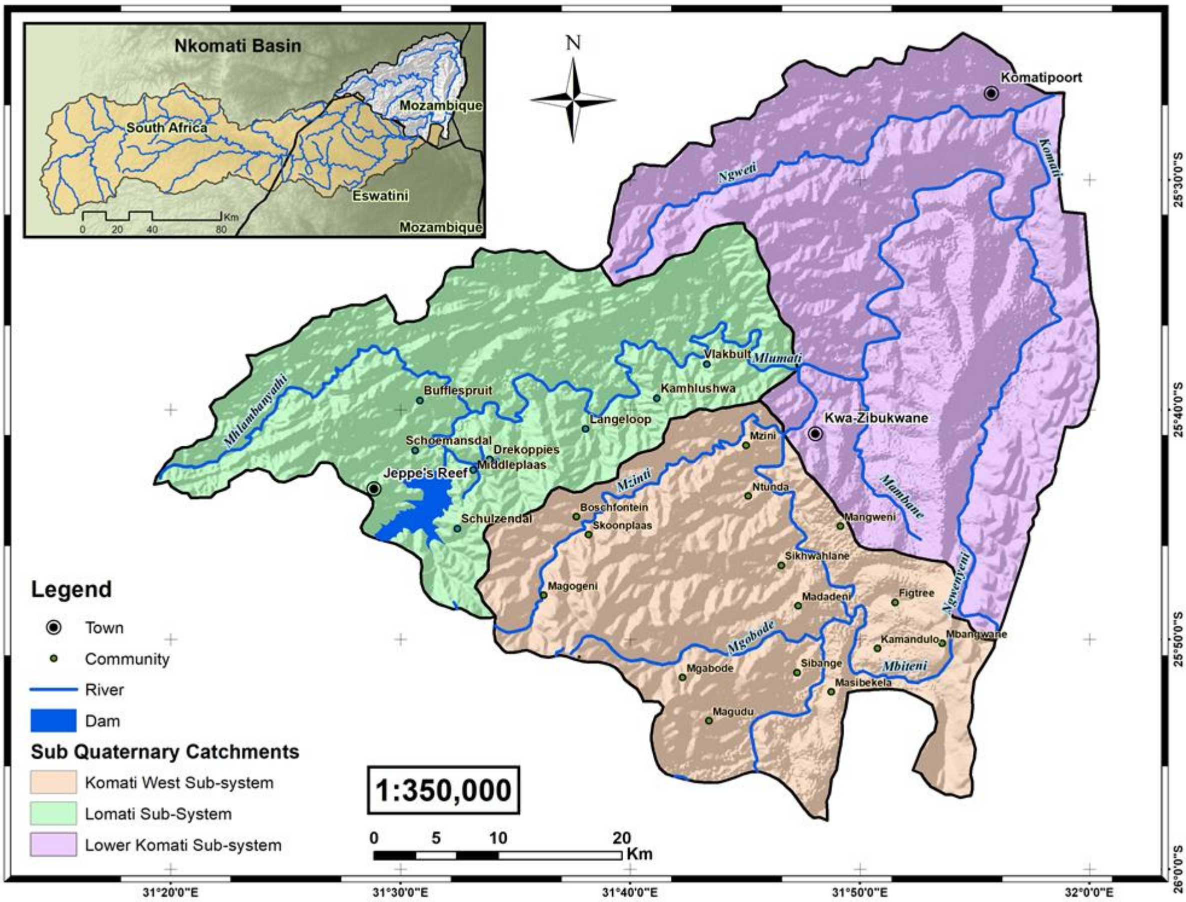

Figure 6.1. Map showing sub quaternary catchments and the spatial distribution of the different communities in the Lower Komati River catchment.

The communities as shown in Figure 6.1 are in proximity to different tributaries, which later confluence with the Komati River main stem. All these communities are rural, except Mzinti, which is in a peri-urban zone of Kwazibukwane town.

6.3 Spatial distribution of the social values in the Lower Komati river catchment

As previously discussed in the literature review in Section 2.7, different authors (Seymour *et al.* 2010; Díaz *et al.,* 2015; Kenter *et al.*, 2015; Jones *et al.*, 2016) attribute social values to the benefits people obtain from the environment which can be place-based and not valued in monetary terms. As explained in Chapter 2, the social value of anything can be assigned and fall under instrumental and intrinsic. The instrumental value is based on the usefulness of nature to people (Nahuelhual et al., 2016; Brown *et al*., 2020) e.g. goods, services or non-tangibles such as information and intrinsic based on itself without considering people' use. As discussed in Section 2.7, the thesis adopted a pluralistic approach of taking into consideration intrinsic and instrumental values as advocated by Arias-Arévalo *et al.* (2017) when collecting data. This was to ascertain how they socially value the river. Notably, these two values (intrinsic and instrumental values) can be individual or shared by a community. This is because people have shared and individual experiences about their immediate environment. Thus even the values generated can be shared values within the society, based on common experiences or individual if it's based on personalised experience. Thus this results section, presents how the river is socially valued based on community shared and individual values. Data was collected through community mapping exercises conducted in groups where views of the community groups emerged (shared values), whilst also individual values emerged as they expressed individual views during the key informant interviews. The results show community shared and individual social values based on what is commonly important (places, attributes or goods and services) within the community and individual participants in the Lower Komati River communities.

To understand the general usefulness of the river to the local communities, community mapping exercises were conducted. Participants in groups explored shared ideas of what is important (places, attributes or goods and services) to them in the catchment throughout the mapping process. Their views were based on people's feelings as they interact with places and the services and goods they derive from that place. The identified socially assigned values to the different places in the river, which demonstrates their instrumental nature and are categorised and presented in Table 6.2. This is because people identified useful areas based on the usefulness of the river at that point to people. From transcript analysis, these values are classified into provisioning; cultural and spiritual and finally place attachment as shown in Table 6.2. According to the participants, the provisioning, cultural and spiritual roles of the river contribute to the importance given to the geographic place leading to place attachment as demonstrated by the participants. Participants discussed the importance of the Lower Komati River, and how the river's attributes, goods and services led to the generation of social valuing of different places in the catchment in no specific order. The values mentioned were a reflection of their individual and group' feelings and perceptions.

Table 6.2. Table showing different categories of social values and their attributes, goods or services that enable the generation of social values by communities along the Lower Komati River.

Category of social value	**Attributes, goods or services that enable the generation of social values**
Cultural and spiritual	Cultural cleansing rituals for widows and stillborn babies
	Important for traditional leaders' (chiefs) rituals
	Spiritual baptism
Provisioning	Municipality water supply for household consumption
	Sand mining
	Incoboza and licunga (aquatic fibre to make grass mats and crafts)
	Small-holder water abstraction for agriculture irrigation
	Subsistence fishing
Place attachment	The connection between people with the river

Table 6.2 also shows different attributes, goods or services that enable the generation of the different categories of social values in the Lower Komati River by local communities. The Lower Komati River is socially valued for the provisioning of material (for example reed), its cultural and spiritual role and place attachment which is instrumental value. The distribution of the ES is linked to areas of importance to the communities which illustrate an instrumental value of the river and these are distributed across the catchment as shown in Figure 6.2, which shows the spatial distribution of the attributes, goods or services as perceived by local communities in the Lower Komati river sub-quaternary catchment communities (Lower Lomati sub-catchment and Lower Komati west). However, to respect tradition, places where rituals are performed (sacred cultural and spiritual places), are not specified on the map. They are grouped under 'traditional medicine' as agreed with participants.

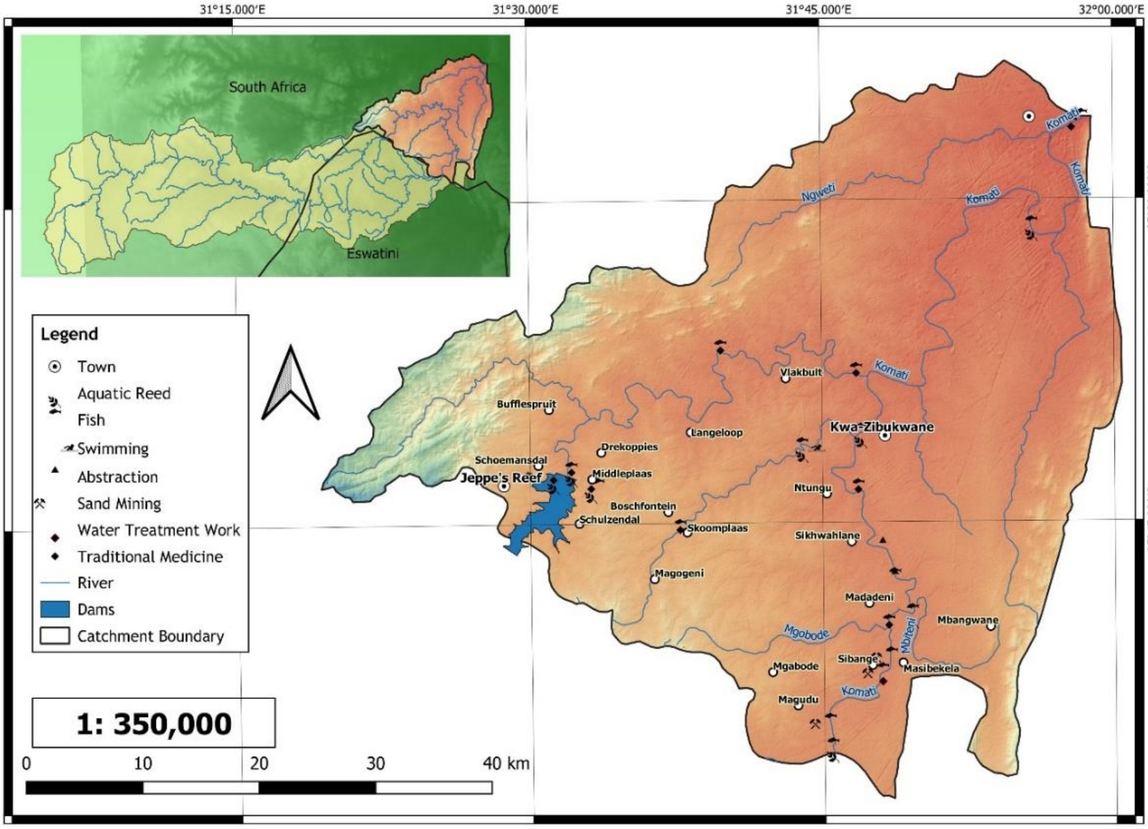

Figure 6.2. Map showing the spatial distribution of areas of ecosystem services in the Lower Komati River catchment according to local communities

The map in Figure 6.2 shows that the areas around the Lower Komati River which are important for the different attributes, goods or services, are mostly clustered around local communities where people live. Figure 6.2 shows that fishing is the most prevalent ecosystem service in the catchment, as fishing is conducted in most parts of the river. The important fishing areas are as shown by the fish symbols which are mostly adjacent to the local communities in the catchment on the map. The fishing areas are spread across the Lomati and Lower Komati West sub-catchments. Some parts of the river offer multiple ecosystem services; a site in the Schoemansdal community downstream of the Driekoppies dam is regarded as important for sand mining, fishing and swimming, there are also different plants used by traditional healers for cultural rituals and traditional medicine. In almost every community; there were areas around the river, which were identified by the community members to be of value for the provision of the different ecosystem services shown in figure 6.2. Brown *et al.* (2015) explain that this is because people are more familiar with their immediate environment, thus will provide more information about those areas. As a result of the interactions between the community members and the river for these ecosystem services, it results in the forging of a people and place connection described as people-place attachment.

6.4 Formation of mosaic of values

Drawing from transcript analysis, participants socially value the river for different attributes, goods or services and these are spatially spread in various areas of the Lower Komati River catchment. Analysis of the different attributes, goods or services is discussed in the previous section and shows that they are a reflection of the interpersonal relationships between the communities and the Lower Komati River. The different attributes, goods or services have resulted in the generation of social values as the communities' interact with the river, which illustrates the formation of a mosaic in the catchment. Chao and Moon (2005) define a mosaic as patterns of images or composite pictures of distinct coloured tiles covering a surface. In this thesis, the participants' social values may be individually distinct but they portray an overall picture of the river as an entity of social value. Therefore, the thesis uses the 'mosaic of values' as a metaphoric conceptualisation of the different attributes, goods or services of the river that lead to the formation of values that form one mosaic 'picture' of the river. This part of the thesis shows how participants' different viewpoints are drawn from the different connections between communities and the river, leading to the formation of three social values about the river which are all connected to form a mosaic, as explained in the following sections.

6.4.1 Provisioning value

The Lower Komati River was identified for provisioning of tangible outputs, which included fish, water, sand, aquatic reed and other resources. Thus, the provisioning value of the river is one attribute that makes up one of the mosaics of social value 'tile' in the catchment. At each group mapping exercise, participants expressed that the Lower Komati River has a major provisioning role that contributes to their economic sustenance. Community mapping Participant 6 in Group 2 from Sibange Village explained that:

> *In some parts of the river, there are huge areas where we used to find reed to build our houses and also fish to feed our families (Community mapping, Sibange Village, 09/19/2018)*

The participant identified reed and fishing as tangible benefits they used to get from the river. This assertion by the participant is supported by Mahlalela (2014), who state that most communities adjacent to rivers make use of aquatic fibre grass; 56% of the annual harvest is sold and the rest is used for households. The use of aquatic reed has been a common activity in most communities in South Africa. Shackleton and Shackleton (2004) surveyed communities in South Africa and found that more than half the households surveyed have used aquatic reed for weaving over the 10 past years.

As a 'second moment' of unlocking additional information, to supplement the community mapping exercise/data collection, fishers and elderly community members in key informant interviews also affirmed fishing as an attribute of the river's provisional social value. During the interviews, they supported the earlier assertions from the community mapping groups. Fisher 1 from Midplaas highlighted that:

> *We [fishermen] mostly sell the fish to the local communities and also feed our families. I have been fishing for the past 5 years, it has been my source of income (Key Informant Interview; 05/12/2019, Midplaas)*

This was supported by a key informant who is an elder in the community, who highlighted that*:*

> *That old lady [fisher] never used to work, her source of income was mainly fishing (Key Informant interview; 19/09/2019, Mzinti)*

The key informant participant (an elder in the community), noted a resident in the area who used to solely rely on fishing for a living. The claims are based on their knowledge of the river and fish resources accumulated over a long period which results from experience in interacting with the river (Berkes, 2017b). The statements from the participants show that they recognise the river's social value for fishing, which is a tangible contribution to the community members' livelihoods and diet. McCafferty *et al. (*2012) state that communities in proximity to rivers in most South African catchments generally benefit from fishing. Fisher 1 states that fishing has contributed to their subsistence living over the past 5 years as a source of income. Vollmer *et al.* (2018) argue that freshwater underpins countless benefits to society, as this case study reveals that rivers provide demonstrable benefits of value to communities through fisheries.

6.4.2 Spiritual and cultural value

The second 'tile' contributing to the mosaic of values in the Lower Komati river, is the river's social value as a result of its use for cultural and spiritual rituals. Literature in Section 2.9.2 shows that in most parts of the world, rivers have cultural and spiritual value formed through cultural and spiritual experiences and a bond with the river (Harmsworth *et al.,* 2016; Kumar, 2017; Acabado & Martin, 2020). In this case, participants illustrated the social value of the river for its cultural and spiritual use to cleanse misfortunes of death, for example, widows believed to have misfortunes as a result of the death of a spouse are cleansed in the river. Participant 3 in Group 1 from Schoemansdal Village, pointed out that:

> *We (community) used the river for death cleansing rituals, some families buried stillborn babies and washed widows from death misfortunes'* [along the river] *(Community mapping, Schoemansdal Village, 28/02/2018)*

Literature shows that the use of the river as a medium for cleansing, reaching and communicating to higher beings is common in the African culture. Bernard (2003) states that in most African cultures, the spiritual cleansing in a river plays an important role in helping people feel a sense of security. The authors explain that these feelings of security and belonging are central to helping people feel that their lives are full of meaning and purpose. Writing about the Kowie River, Cock (2018) describes the river as an ultimate life-sustaining resource that is believed to spiritually cleanse people from misfortunes. The association between river water and life is consistent with the findings of Altman (2008) and Dandekar (2018), who highlight that rivers have enriched several cultures across the world, as the water not only bring people together but also uplifts the depths of the human spirit. Water is regarded as a medium for communicating the sacrality of life and situating life within the spiritual realm (Altman, 2008; Gunasena, 2017). All these views emphasise the cultural and spiritual values of the river water and give a broader view of the spiritual connection between the natural and spiritual world.

Central to the cultural and spiritual role of the river water is that some areas along the river are specifically reserved for chiefs (community leaders) to conduct sacred rituals and cultural cleansings for their communities. This was highlighted by community mapping Participant 1 in Group 3 from Magudu village, who stated that:

> *There used to be areas reserved for the area's chiefs to conduct rituals along the Umgobodzi river [tributary of the Komati River] (Community mapping, Magudu village, 19/09/2018)*

Participant 5 in Group 2 from Midplaas Village emphasised that:

> *Everyone in the village knew those areas (areas upstream of river) to be reserved for such rituals (Community mapping, Midplaas Village, 28/02/2018*

The participants' views show that the sacred places persist in memory. However, in as much as they exist in memory, the social value of places in the river is conceived based on its cultural and spiritual role. The above assertions by the participants emphasise the spiritual and cultural role river water has to generate values between people and their social and physical environments, which leads to the territorial creation of spaces. Bufon (2016) explains that territoriality was defined by Soja in 1971 as a phenomenon that shows connection and organisation of space as important areas or demarcates territories, with common social traits. The author further explains that these spaces are exclusive to a group of people, which enables them to practise their cultural and spiritual rituals. In this study, the sacred places are perceived as defined territories within which only chiefs as leaders of communities have free access and can perform their cultural rituals. Lefebvre (1991) explains that the central aspect of any socially produced space is its multiple layers or facets. Space is simultaneously produced both as a concrete entity and as an abstract entity; perceived and conceived, infused with symbolism and meaning (Perrault, 2012; Karplus & Meir, 2013). Therefore, fundamental to the preservation of territorial sacred places for cultural rituals in the Lower Komati River is also the production of conceived space. This relates to the interaction between people and their social and physical environment, which leads to the territorial creation of spaces of value- a far more abstract concept.

The respect, territoriality and value placed on these sacred places result in the 'chief's areas' being protected from heavy resource use and access. During the mapping validation exercise, participants refused to identify the areas, as culturally only the chief and the village headman can access the areas, re-emphasising this territoriality. According to Bernard (2003), this practice is common to many indigenous groups in Africa, where communities believe that sacred areas are not to be seen by 'outsiders'. In a study in the Eastern Cape, South Africa, Mahlangu and Garutsa (2014) found that river pools were considered abodes for mermaids and used for cultural rituals, thus people were discouraged to venture into such areas in the river. Sacred areas may be important not only for cultural rituals but also for ecological significance, where they are islands of biodiversity and endangered species (Wilson, 1993; Adu-Gyamfi, 2012; Cock, 2018). This results in animal and plant species around these sacred areas being less disturbed than those in other parts of the river.

What can also be noted is that the participants, who highlighted the cultural and spiritual role of the river, have lived in this area for over 20 years. Their claim helps to understand that water users generate experiences over time. Howell *et al. (*2011) and Reker and Woo (2011) argue that experiences in nature are important to adults to make meaning of places. In this case, the participants' 20+ years of experience in the area have allowed them to make meaning of the river as part of their cultural landscape. Furthermore, during the mapping exercise, participants made arguments on the importance of flow to fulfil the cultural role of the river. Community mapping Participant 5 in Group 1 from Midplaas Village noted that:

> *Rituals are performed in different areas where there is ample water available, with the adequate flow (Community mapping, Midplaas Village, 28/02/2018)*

Community mapping Participant 2 in Group 1 further elaborated that:

> *The river will wash it (still born babies) down when the flow is high and water is free-flowing. The free-flowing water will wash down the misfortunes and cleanse the bad luck… (Community mapping, Midplaas Village, 28/02/2018)*

The participants' opinion shows that water is not only a physical and biological resource but also a social connector through its flow. Free-flowing water is regarded as a medium for healing, cleansing and communicating the sacredness of life as they believe that the river water flow washes away misfortunes or dark clouds that envelop people who have lost spouses and children at birth. In Australia, Behrendt and Thompson (2004) found that cultural flows are an essential component of river management where they are set and monitored to ensure the maintenance of cultural practices and connections within the rivers. A river's environmental flows are identified as a surrogate for the protection of cultural values (Tipa & Nelson, 2012). Rinne (2001) and Oestigaard (2009) describe flowing water as alive because of its movement and its suitability for giving life through holy and healing practices. Euzen and Morehouse (2011) describe water flowing from a river as emerging from the depths of the earth, symbolizing its virginity, purity and freshness. This description shows that before human contamination, the river's flow is pristine and signify life-giving. The link of flow as an important attribute to the cultural value of the river is explained by Anderson *et al.* (2019) who argue that river flows connect people, places and other forms of life, inspiring and sustaining diverse cultural beliefs and values. Moggridge *et al*. (2019) affirm that many cultural values require a flow, otherwise, the connection is lost. From the above arguments, the river's flow is considered an intrinsic part of its functionality for cultural values in the Lower Komati River.

The use of the river for cultural and religious rituals denotes strong norms of shared access to communal space, toward a belief in a higher power by the formation of religious-cultural conceptions of the river to cleanse the community of misfortunes. The river is placed in the realm of the divine in addition to its physical realm, reaffirming the river as a social-ecological system. The mentioned cultural practices created shared experiences, values and norms which constitute traditions and cultures that connect the communities and are important for the management of the river. Jackson (2015) explains that water management studies pay little attention to the role of culture and cultural processes to shape the value and management of water. Thus, this part of the research shows that the shared experiences, cultural practises and rituals have become core value systems for communities, which can be organised into a body of collective knowledge to describe the river.

6.4.3 Place attachment (people-place connection)

Repeated interaction between people and the river led to a more intense attachment between local communities and the Lower Komati River, which can be termed place attachment. Place attachment is defined as a connection formed from a relationship and association between people and a particular place that enhances the value of said place (Mooney, 2009; Scannell & Gifford, 2010). Transcript analysis shows that people and the Lower Komati River have formed a connection based on their experience with the river. The attachment to the Lower Komati River is inscribed through narratives of economic survival, social and cultural use and events such as pollution and the political history of the catchment. Participant 1 in Group 2 from Schoemansdal Village showed attachment to the river as a result of being a long-term resident. She explained that:

> *I have been in the area for over 25 years, we have used the river all these years…The river is the mainstay of the community (Community mapping, Schoemansdal Village, 28/02/2018)*

Participant 6 in Group 1 from Mzinti Village concurred with the previous participant by highlighting that:

> *Almost all of us (community members) here we have been using the river growing up in this area. Well, the young ones, maybe don't know much but us the elders we used the river and parts of it daily to wash, some of the users have been cleansed from all bad luck by the river. This river has been part of our daily lives' (Community mapping, Mzinti village,09/19/2018)*

The preceding quotations by the community members portray personal attachment, as Participant 6 in Group 1 from the Mzinti community emphasised that *"it [river] is part of our daily lives".* Participant 1 in Group 2 from Schoemansdal Village argued that *'The river is the mainstay of the community".* The phrases used by the participants all highlight that there has been a personalised relationship formed between the river and the community over time. Participant 1 in Group 2 from Schoemansdal Village's description of the river as a mainstay of the community depicts a positive connection at a personal level. Participant 6 in Group 1 from Mzinti Village depicts the river as part of their lives, showing personal attachment and a relationship formed as a result of their dependence on it. This research theorises that place attachment is conceptualised, measured and linked to different social values. This suggests that place attachment captures participants' social value of the river. These social values are depicted through personal connection that has developed, which has resulted in feelings of attachment, thus describing the river as part of their lives (sociocultural influence). The place attachment provides an indicator of the significance and meaning of the river to the immediate users(communities).

Participant 1 in Group 2 from Schoemansdal further referred to the number of years that she has been in the area and had been using the river, which means this relationship has developed over time. Lin and Lockwood (2014) explain that personal attachment between people and places develop over time from an experience of a long-term affective bond to a geographic area. This is said to happen, where a person has lived in a particular locale over time and that person has developed feelings of affection and a sense of belonging to the area. Tickner *et al.* (2017) argue that rivers convey values associated with the functions attributed to the river and with people's lived experiences. The participant's memories and lived experiences about the river evoke feelings of attachment. Similarly, Cock (2018) explores place attachment as she describes the history of the Kowie River. The author describes the physical structure of the river and explores her relationship to the river through rich history which she traces back to her personal experiences as a child. Ujang and Zakariya (2015) and Verbrugge *et al.* (2019) highlight that experience leads to personal attachment to a place, thus any changes can evoke emotions as a result of physical and social changes. In this study, it can be seen that physical changes in rivers evoke strong emotions and powerful feelings and memories of the river and how the river had a great influence on the local community. The place becomes an anchor of participants identity, priority and value which is portrayed by Participant 1 from Schoemansdal. Thus, understanding what matters to people in particular places may help identify the river health assessment priorities.

The personal attachment to the river led to participants acting as advocates for the environment as they showed being receptive to environmental concerns. This is demonstrated by Participant 1 (resident over 60 years) in Group 1 from the Midplaas community, who said that:

> *We have to respect and take care of this river because we know that it is part of our lives, we depend on it'. It was clean during our time, no one ever dumped rubbish in the river. Not what these young people are doing, they don't care about the river, they dump diapers in the river (Community mapping, Midplaas Village, 28/02/2018)*

The above opinion by the participant shows that because of the attachment, participants feel obliged to take care of the river. The place attachment portrayed may have led to a heightened sense of environmental responsibility. This is supported by Raymond *et al.* (2011), Zhang *et al.* (2015) and Ramkissoon & Mavondo (2017) who argue that place attachment can lead to pro-environmental behaviours among people, which may result in environmental protection. The communities become environmental stewards, instinctively protecting natural spaces and engaging in pro-environment activities. This is theorised by Vorkinn and Riese (2001), who state that attachment to a place involves emotional care and concern for a physical landscape, thus communities exhibiting strong place attachment are more likely to oppose threats to landscape environmental degradation. The personal attachment seems to have created some form of responsibility to keep the river clean.

Literature shows that different factors link place attachment and stewardship towards the environment. Hernandez *et al.* (2012) identified that time spent in an area is related to a greater willingness to fight a threat or to defend a place from environmental change. The authors argue that people with long residence times, people tend to engage in behaviours that help preserve its qualities more often to sustain the area for what it is known for over years. Gifford and Nilsson (2014); Junot *et al.* (2018) explain that if a place is at the heart of people's identity and highly dependent on it, they are more likely to protect the place, and encourage pro-environmental behaviours. The authors argue that dependence on the area' physical aspects and resources leads to environmental protection. This is mostly because, they are dependent on the place for their welfare and well-being, which then leads to motivation to protect the environmental integrity of the place resources. Kuo *et al.* (2021) identified psychological ownership as playing a major role that contributes to place attachment and environmentally responsible behaviour. Psychological ownership allows individuals to regard the environment as an extension of self, inspiring in them a sense of responsibility and positive behaviour towards the environment. Based on the mentioned factors, one can point out that stewardship towards a place is driven by instrument and relational values. This is mostly because, as explained people mostly base environmental protection on benefits and relationships they have with the environment.

In this thesis, the participant who has been around the river for over 60 years highlights young people's attitude towards the river as showing that they do not value the river; he highlights that "*they don't care about the river*". Vaske and Kobrin (2001) and Panelli and Robertson (2006) concluded that there is a loss of sense of place among the young generations, as less time is spent in the area. Thus, in the study, young people are described to be practising activities that pollute the environment, whilst the elders advocate for taking care of the environment. This shows that stewardship of elders towards the environment is a result of high residence time and psychological ownership portrayed by the participants. Hernandez *et al.* (2012) and Anton and Lawrence (2014) theorised that as a result of long residence time, elderly people personalise a place, which leads to the place becoming an extension of themselves and drives motivation to protect it. This is supported by Gustafson (2014), who argues that residence time can be a predictor - the longer a person has lived or spent in a place, the stronger the place attachment and willingness to protect it. This shows that residence coupled with age lead to more attachment to a place.

The differences in attitude between the elders and the youth demarcate boundaries and a clash of values between the two generations. This clash of values creates differences in the two generations living in the catchment. Therefore, internal social stratification and generational classes within the community were formed, which offered spatiality through a differentiated lived experience of each group. In the process, place attachment is formed as a focus of vested meanings and emotional attachments. The river becomes unique and relational to the different generations of people in the communities. As the different generational participants produced space, their footprints are created through manipulating the environment (river) seen through the recent increase in pollution, which resulted in a change of perceptions and how they value the space. This confirms the arguments of Manfredo *et al.* (2017) that people's values towards a place are different, and are manifested as a result of a reshaping by events or of life circumstances. The different circumstances may lead to new behaviours and attitudes (Dietz *et al.,* 2005). In this case, because of the youth's time spent and current pollution circumstances, they view the river different from elders who have lived under different circumstances as they personalised the river. Therefore, this means that social value is not static but changes to portray experience. Based on social value' non-static manner, it can become an important human-based attribute that can be incorporated into river health monitoring to explain and measure river health from people's perspective and experience.

The argument by the community members portraying personal attachment to the river is associated with their lived experiences and features that they value over time. The research suggests that communities' attachment to the river leads to a production of space that emphasises access to the river, surpassing the emotional bond with the river (lived space). This is a clear formation of a lived space through values, as Lefebvre (1991) theorises that lived space imposes order over concrete space through assigned values. Lived space is shaped by the meaning vested in the river by the communities (Karplus & Meir, 2013). The participants perceive the landscape as self-reflection through lived experiences and social integration, which includes values. Thus, the thesis conceptualises place attachment as an agent that emotionally bonds water users to their space, resulting in social valuing of the space which can change based on experience. This argument is theorised based on Ives *et al*. (2018) who argue that people's emotional bond to nature can provide ways to track any changes in the landscape. As landscape changes, attachment and symbolic meaning of the river is also likely to change. Therefore, comprehensive river health monitoring that incorporates human experience involves a better understanding of the human-river emotional bonding to track and explain any changes.

The different social values (provisional, cultural and place attachment) held by the communities show that the Lower Komati river is considered as an object enveloping multiple interests and a variety of social values, as shown in Figure 6.3 portraying the 'mosaic'. The metaphoric use of the mosaic term is inspired by Hermans *et al*. (2006) who developed the concept of mosaic value to capture the different insights on water value for water resources management in the Mkoji catchment. The social values assigned by the participants as discussed above portray different pieces of colour held about the Lower Komati river which gives an overall picture of the social value of the river to the communities. This is supported by Chao and Moon (2005) and Kenter *et al.* (2015)

who explain that one of the principles of the mosaic theory is that individuals draw on different aspects of the landscape, which is similar to this study as participants draw on their different uses of the river to illustrate the river's social value as illustrated in figure 6.3.

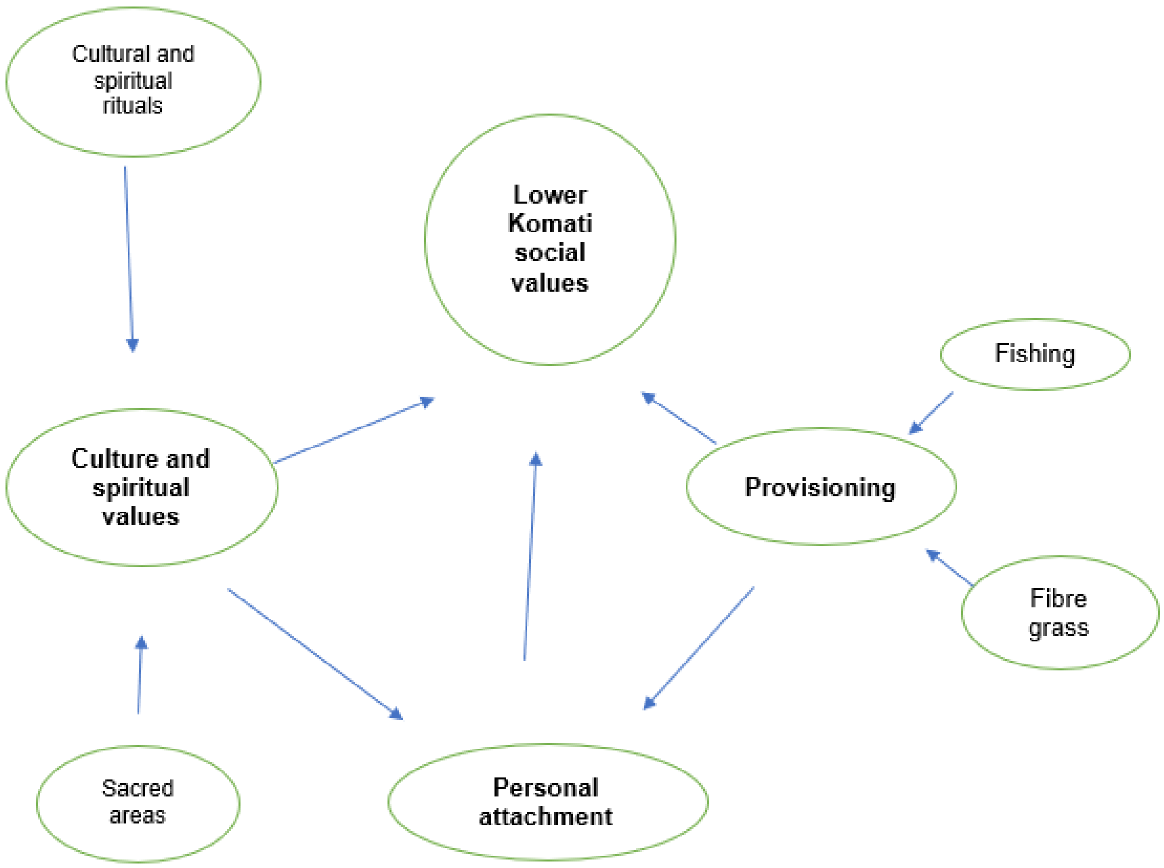

Figure 6.3. An illustration of how communities' identified social values and ecosystem services are connected to form a "mosaic of values" for the Lower Komati River.

Figure 6.3 illustrates the different social values and ecosystem services that co-exist and their interconnections within the catchment which result in a mosaic illustration. The participants' stories about the river's provisioning, cultural values and place attachment are heterogeneous but all lead to portraying the background of the Lower Komati river as an entity of social value. The existence of the heterogeneous stories is regarded as mosaics of social values that exist in the catchment. This is supported by Matsui *et al.* (2016), who describe rivers as cultural-ecological mosaics, which differ in space and time coupled with complex cultural geographies of the area. So, the thesis illustrates the mosaics through the participants' different assertions about their relationship with the river from cultural use, provisioning and personal attachment. The participants' different values regarding the river represent the 'multiple colours' of a mosaic, which forms one picture that describes the overall social status of the river. The interconnections between the ecosystem services and values illustrate the flow of the relationship which trace the root causes of river health and understanding the Lower Komati river as a social-ecological system.

6.5 Meaning of river health from communities' perspective

The essence of the research is to determine how communities' social value and socio-dynamics that exist in the catchment can be integrated into river health monitoring. It is envisaged that the integration of social value and socio-dynamics will open novel ways of understanding, strengthening and transforming river health monitoring in catchments. However, the integration may be undermined by a lack of clarity regarding the meaning of river health based on the communities' perspective. According to Pinto and Maheshwari (2015) researchers and river, managers tend to project their expert view about river health and this has often limited any meaningful engagement between communities and scientists involved in river management. Most river health descriptions available in studies done in South African literature (Odume & Mgaba, 2016; Agboola, 2017; Levin *et al.*, 2019) relate to ecological interactions and do not consider the adjacent communities' definition. However, communities play a significant role in the environment and the river is an important constituent of the community. For these reasons, there is a need to include community dimensions for monitoring the river's health. Vugteveen *et al. (*2006) provide an in-depth analysis of the various ways that river health has previously been described in conjunction with ecosystem health and suggest the importance of understanding its proper meaning from an ecological, social and economic context. According to Delaney (2010) people in a catchment have different personal interests and their level of engagement with the river system differs, which may influence their meaning of river health. Thus, pertinent to this research is how different participants within the Lower Komati river describe river health.

A critical examination of current river health meaning and studies in South Africa as explained in Sections 2.3-2.5 associate it with hydrology, aquatic ecology, limnology and use of ecological indicators. River health descriptions from communities' point-of-view are not prominent, although the need to include social dimensions into the description has been strongly advocated for by literature which considers river health as an integration of ecosystem health and economic and social systems (Meyer,1997; Vugteveen *et al.*, 2006; Tickner *et al.*, 2017; Blue, 2018). To date, the majority of research in river health that considers communities' perceptions and associated values has been conducted in the developed world, namely Australia and Asia as discussed in section 2.5. This restricts the ability to compare these to the South African contexts. Considering the unique geographical nature of the catchment and the ongoing interest of communities in assessing the river's health, there is a need to ascertain how these communities understand river health. To understand participants' definition of river health, one of the key questions during the community mapping exercise was to explain how they determine a healthy or unhealthy river and suggest pointers they use to ascertain if a river is healthy or not.

From the community mapping transcripts, an analysis of words used by the participants to express river health and suggested indicators of river health was done by forming word clouds using Voyant. These word clouds were formed as explained in Section 3.5.8 Frequently used words by the participants to describe river health were abstracted and presented in the word cloud shown in

Figures 6.4 and 6.5. Voyant creates word clouds by identifying word frequency or associative links between words (Welsh, 2014). The word clouds help clear any bias when identifying common themes prevalent within the transcript. Figures 6.4 and 6.5 show the frequently used words and their related descriptors in describing river health in the Lomati and Komati West sub-catchments respectively. The size of each word is proportional to the relative frequency it is mentioned in the transcript.

Figure 6.4. A word cloud showing the most common terms in describing river health (Lomati sub-catchment communities)

Figure 6.5. A word cloud showing the most common terms in describing river health (Komati West communities)

From the word cloud in Figure 6.4, the most common words by the Lomati sub-catchment communities were *macrophytes, fish, diapers, summer, flows, stream, dirty, traditional* and *algae* used to describe river health. From the word cloud in Figure 6.5, *unhealthy, rituals, sand, diapers, healthy, sand, flow, mining, dirty* and *dumped* were the most frequently used words by participants from the Komati West sub-catchment communities to describe river health. From these two words clouds, it can be noted that there are similar words used by participants from these two sub-catchments, for example *diapers, sand, flow* and *dirty.*

After identifying the common words used to describe river health through the word cloud, Voyant was used to determine words that correlated with “unhealthy” and “healthy”. Table 6.3 shows the results from the correlation coefficient calculated from comparing the relative frequencies of the term "unhealthy". According to Welsh (2014), a coefficient that approaches 1 indicates that values correlate positively, they rise and fall together whilst those that approach 0 have little correlation, positive or negative. Results showed that when the word "unhealthy" was subjected to correlation analysis in Voyant, it showed a positive correlation with *dirty, diapers* and *dump*. This means that participants used most of these words in association with unhealthy. *Healthy* did not positively correlate with any word through the Voyant analysis, thus it was not considered for further analysis. This shows that from the transcript, words used to describe the river were not significantly associated with the word "healthy".

Table 6.3. Table showing Correlation between the term 'unhealthy' and other frequently used words by communities.

Term 1	Term 2	Correlation
unhealthy	unhealthy	1
dirty	unhealthy	0.81
diapers	unhealthy	0.75
dump	unhealthy	0.75
algae	unhealthy	0.49

The positive relationship with the terms *dirty, diapers, dump, algae* and *unhealthy* shown in Table 6.3 means that the four terms are closely associated with the term "unhealthy" as per the transcripts. It means participants used these words more often when describing an unhealthy river.

The different words that appeared in the Voyant word count and cloud were further examined in the transcripts based on how they have been used during community mapping exercises and grouped into descriptors. Four themes were developed:

- Visual observations of river health (absence of dumped diapers, clean sand at the bottom of the river);
- river's fitness for use (conducive to conduct cultural rituals and baptism, fishing);
- ability to sustain ecological integrity (for example reed maintaining green colour and height, presence or absence of macrophytes) and
- hydrologic balance (maintenance of the river's natural flow)

6.5.1 Visual observations of river health

To describe river health, participants used different adjectives which relate to river health based on visual observation for example *clean*, *no dirt* and *can see at the bottom*. The words depicted the river's health through sight. To the participants, visual observations were the main determinant to see if a river is healthy or not. The word *clean* was used to refer to a river with no solid waste in sight. Participant 4 in Group 1 from the Midplaas community explains that:

> *When I see that a river is clean I can safely use it. But, when its dirty I lose interest. A healthy river has no dirt on the banks, no algae and you should be able to see*

sand at the bottom, water flows freely (Community mapping, Midplaas Village 28/02/2018)

The above depictions by the participant show that their visual observation is an important measure of river health. A healthy river for the community is a river that is free from substances. The presence of diapers recurs throughout the participants' transcripts and their presence is considered to be a sign of an unhealthy river according to participants. The participants' use of visual observation to assess a river's health is similar to Pinto *et al.'s* (2012) conclusions from a study in Australia where communities determined a waterway's river health based on visual observation. In this study, the participants highlight that a healthy river should be free from algae and dirt. Moreover, it is noted that participants highlight the importance of flow for a river to be viewed as healthy, as flow moves the substances away.

6.5.2 River's fitness for use

Another theme that emerged when participants explained river health and its indicators, was the river's fitness for use which related to its social values (explained in Section 6.4). This theme emphasises the river's social value for fishing, swimming and cultural use. Transcript analysis revealed that participant groups provided perspectives on river health based on the ability of the river to provide for their purpose. All the participants perceived the river to be unhealthy if it could not provide services that are important to them, which include conducting cultural and religious rituals. The following quote by Participant 1 in Group 2 from the Sibange community captures this theme:

> *Some parts of the river are now dirty and unhealthy, we cannot baptize or conduct rituals like we used to, we are scared of catching illnesses…(Community mapping, Sibange village, 28/02/2018).*

To the participant, a healthy river is based on their "*ability to conduct rituals*". To another participant, a healthy river must provide an ideal platform to enjoy swimming, as highlighted in Figure 6.2. However, the river does not adequately currently offer those opportunities and is therefore regarded as unhealthy. Participant 5 in Group 2 from the Mzinti community explained that:

> *Generally, the river is not healthy. People used to swim there but not anymore. People have died in this area, because of the sand mining as the river is now deep, …because of the deep trenches caused by the sand mining (Community mapping, Mzinti village, 28/02/2018).*

The use of the sand mining deep trenches descriptor as a threat to river health is supported by Rainey (2015), who states that excessive erosion is a sign of an unhealthy river that is out of equilibrium. Under the deep trench conditions from sand mining, the river does not offer ideal conditions that make it suitable to meet the community's needs to swim, which means it is unhealthy. Sand mining has thus rendered the river unusable for swimming, making it unhealthy.

Additionally, Fisher 1 in Group 3 from the Driekoppies community, described a healthy river based on fish taste and appearance. The explanation of river health was also based on an observable difference between fish from the tributary (Nyetane) they regard as unhealthy and the fish from the dam they regard as healthy. The participant pointed out that:

> *The fish from a healthy river is different. Fish we get from this tributary [Nyetane] which is not healthy it tastes differently from fish we get from a healthy place like the dam. Fish from the tributary is black and has a muddy, metallic taste, the one from the dam is shiny and tastes differently and it doesn't taste metallic and muddy (Key Informant Interview, fisher, Driekoppies village, 28/02/2018)*

The fisher described river health based on fish taste and colour and differentiated fish found in different parts of the catchment using these attributes. This demonstrates that the participants' have observed and have interests in different parts of the river.

The descriptions of river health by the participants based on the different uses as discussed in the previous paragraphs show the different personal interests of the person who defines it and the purpose for which it is used. In their view, a healthy river should provide an opportunity for communities to enjoy the different activities they value and if they cannot enjoy those activities, the river is assumed to be unhealthy. This is in agreement with Pinto *et al.* (2012), who state that a healthy river means different things to water users; for example, to a farmer, a person involved in fishing or someone who passes by the river regularly can be quite different. This emphasises that river health meaning is contextually different. Thus, to properly monitor, it would be important to understand its meaning from the human's social context. The exposure of the local communities to risks (*catching illnesses, drowning*) which are socially-ecologically constructed problems as a result of river health decline, shows that the river is closely integrated with the human system and both interact as well as influence each other. Zhang *et al.* (2015) explain that river systems and the human system are inseparable, as water acts as a link between the two systems to form a complex system.

6.5.3 Ecological changes

Participants used an array of colloquial terms to explain ecological changes, for example, the appearance of bloom (algae), the colour of reed and condition of riparian vegetation. Participants perceived the colour of riparian vegetation (fibre grass) and the presence of macrophytes and algae (described as bloom) to have a major influence on river health. The following description by participant CMP2V1G1 on the river's health highlights changes in fibre grass colour and structure as she described that:

> *Likhwane [aquatic fibre grass] is not the same its now short and brown. (Community mapping, Midplaas Village 28/02/2018)*

However, other participants described the appearance of bloom (algae) as an indication of a river's health condition. The participant highlighted that:

> *CMP1V1G3: In a healthy river, things like bloom should not be seen in the stream as it is most common when the river is not healthy. I note that during the rainy season, the bloom disappears. When it's summer we don't see this bloom. In summer, people don't perform their rituals associated with the bloom. Thus, the bloom we associate it with unhealthy river (Community mapping, Driekoppies village 28/02/2018)*

From the above assertions, one can deduce that changes in aquatic fibre grass colour, height and appearance of algae as observed by participants CMP2V1G1 and CMP1V1G3 respectively, are observed ecological traits that determine the river's health status. The understanding of changes in structure, the colour of the grass reed and 'bloom' used to describe a healthy river indicates that participants have observed these changes and this has led to the development of local ecological knowledge. This knowledge enables them to identify the important ecological structure of the river and what is important to maintain its health.

The participants also explained that a healthy river should wash down solid waste at high flows. This shows that the participants' theorising of river health is shaped by their understanding of its different dynamics in flow. A close analysis of the representation by the participants indicates that, communities' descriptions of a healthy river do not necessarily mean a pristine river, but rather that health is a dynamic state which fluctuates within different flow threshold limits. This resonates with literature, which shows that a healthy river has different ecological dynamics that should be maintained by the flow. Rainey (2015) and Zhang *et al.* (2015) conceptualise flow as a means to transport and wash away sediment and nutrient pollutants to repair the river and that variability in quantity, timing, frequency and seasons is crucial for a healthy river.

Participant CMP1V1G4 talked about plants in the river that were there in the past but which have disappeared; this is associated with an unhealthy river.

> CMP1V1G4: …*The stream used to flow freely, it was healthy and there were trees. When I grew up parents told us about plants that you find in instream which indicates that the water is clean therefore the river is healthy to drink. Those plants have since disappeared now you hardly find them (Community mapping, Midplaas Village 28/02/2018)*

Overall, the theme 'sustaining ecological integrity' broadly encapsulated the community view of ecological functions, of the river's observed ecological traits. The main point here is that the presence of certain plants was a key indicator of river health for the participants. However, when probed the participants could not recall the names of the plants. Tucker *et al.* (2006)) reported that the community in the Hawkesbury–Nepean catchment used an abundance of native wildlife and plants when describing the health of the river system which was observed over time.

The participants' assessments of river health and observed ecological changes in this study are shaped by historical ecological knowledge about the condition of the river, which enables them to identify ecological changes and assume them as indicators of changes in the status of the river's health. This aligns with Gómez-Baggethun *et al.* (2013) who argued that communities can recollect a record of ecological changes for generations through observations which are regarded as rich information for monitoring environmental change. Participants retained a historical record of how some macrophytes and instream trees and plants disappear and appear and how aquatic fibre has changed colour over time.

6.5.4 Hydrology: Maintenance of the river's natural flow

In Section 6.4.2, participants highlighted the importance of flow for the river to carry out its spiritual and cultural role. Participants further emphasised the importance of river flow as a prerequisite for a healthy river. However, how the participants from the two sub-catchments of the Lower Komati described the function of flow to maintain a healthy river differed. Rural communities, mostly from the Lomati sub-catchment, described flow as important to maintain the river's ecologic function and provide ES. Peri-urban communities, mostly in the Komati West sub-catchment argued that the river's flow needs to be sufficient to sustain riparian aquatic life and flush out the pollutants, which can accumulate in the river during low flow conditions. Participant 4 from Group 1 in the Mzinti community (peri-urban) in the Lomati sub-catchments expressed the importance of flow was that:

> *A healthy river has to be free-flowing, free from stagnant dumped diapers, the water has to be clear such that you are able to see sand at the bottom (Community mapping, Mzinti community, 28/02/2018).*

Participant 5 in Group 3 from the Driekoppies community (rural) in the Komati West sub-catchment attributed flow to be important by stating that:

> *When the water flows freely, the surrounding is mostly green, not brown, for us that river is healthy. In a healthy river, we can drink the water and wash with it. If we can use that water, it means its healthy' (Community mapping, Driekoppies village 28/02/2018)*

The participants' preferences on flow are determined by their sociocultural context. The participant from Mzinti (peri-urban), put more regard on flow to maintain visibility, whilst the Driekoppies (rural) participant placed more regard on the maintenance of the area's ecological integrity and water to drink. The differences in opinions could be because of the location of these areas. The Mzinti community is peri-urban as it borders Kwazibukwane town and, according to Pinto & Maheshwari (2015), people alongside peri-urban landscapes are more attached to a river system through its aesthetic appeal. Tribot *et al.* (2018) argue that landscape aesthetic value is more important to peri-urban communities. To the rural community, the importance of a healthy river is to provide them with ES, whilst the urban population seem to regard visual aspects as more important; thus, the Mzinti participant attributing a healthy river to visibility compared to the participant from Driekoppies who emphasised the provision of drinking water.

Participants also attributed flow variability with seasons. Participant 3 in Group 3 from the Driekoppies community noted that in summer, the river's health improves. The statement is an implication that the catchment mostly receives summer rains, with the ability to increase flows. The participant claimed that:

> *In summer when water flows the river is much healthier… (Community mapping, Driekoppies village 28/02/2018)*

This means that flow increases in summer, can maintain the river's hydrologic integrity, as confirmed by literature (Merolla, 2011; Lakhraj-Govender & Grab, 2019). This indicates that the communities use their local ecological knowledge through observation to identify the importance and timing of flow which help to maintain the river's health. This also explains that the river's resilience (ability to self-cleanse) is dependent on flow. Resilience refers to the magnitude of river health deterioration the system can withstand before it must reorganise itself (Xu *et al.,* 2015). Rapport *et al.* (1998) when describing river health argues that the absence or presence of danger signals in the ecosystem and the ability of the ecosystem's resilience characteristics are important. To the participants, a healthy river needs to have a free flow, which makes it more resilient and provides all the expected services to communities (reducing the vulnerability of communities). This also shows linkages between river flow, river health and human dimensions, which are typically overlooked when river health is presently assessed. The resilience of the river is an important attribute in river health and flow is identified as an important attribute to improve the river's resilience. Resilience thinking has been identified as useful to guide integrative system approach management (Coté & Nightingale, 2012; Xu *et al*., 2015; Hoque *et al*., 2017). This research theorises that resilience thinking provides space to embrace complexity in human-environment relations in river health monitoring. When assessing a river's health, it is important to expand the monitoring beyond the ecological status of the river but consider the river's resilience.

The findings also demonstrate that the communities have a multi-faceted understanding of river health based on their experiences, which shows that they have different interests in the river; such as in fishing, cultural rituals and swimming. Overall, participants' definition of river health based on observed social and ecological roles and changes of the river, highlights the complexity of river health. River health's meaning is socially-ecologically conceptualised by the participants. Participants used the physical outlook of the river and the ability to use the river for different purposes to describe river health. The communities' conceptualisation of river health corroborates other studies showing that that river health should consider the social and ecological functioning of the resource.

6.6 Observed changes in the river

Alongside describing the meaning of river health, the participants also highlighted major changes in the Lower Komati River. This section interrogates different changes that have taken place in the river as perceived by the participants and how these changes are associated with river health. The participants explained past events, trends and experiences about the river. Villaseñor *et al.* (2016) state that understanding the past, trends and changes that have occurred in the river are necessary parameters in participatory monitoring of natural resources. Participants compared past events and trends to highlight river health changes that have taken place based on their relationship with the river. According to Matsui *et al.* (2016) to interpret indigenous water history, it is important to clarify the entangled connections and relations between people and waterscapes. According to Hohenthal *et al.* (2015), it is important to be aware of the trajectories to understand the changes in the ecosystem. The participants' input helped to identify attributes/indicators of river health used by communities. The collected data also reflected the drivers of the changes that have taken place in different habitats, which have shown how the community presently uses the river. The results show that participants used their local ecological knowledge and experiences from a historical experiential perspective, to explain observed changes that have taken place. These observed changes are categorised in four themes and supported with key quotations from the transcripts.

6.6.1 Increase in solid waste leading to decreased flow

Participants strongly voiced their concern over the negative impact of solid waste on water resources, leading to reduced flow associated cultural values, which raised a lively discussion. A major notable recurrence during the discussions with participants is the increase in solid waste (diapers) in the river which affect the flow rate. Participant 2 in Group 2 from Schoemansdal Village noted that:

> *When we (the community) used more cloth nappies, the river was healthy. Now the river is stuck with diapers dumped there. Previously, we only used to find buried kids, they buried stillborn babies which would eventually be washed down during high flows. Now that cannot happen as people have dumped diapers, the river hardly flows now (Community mapping, Schoemansdal Village 28/02/2018)*

The participant highlights a negative attitude towards the use of diapers as she explains that before when they used cloth nappies, the river was healthy but now with the use of disposable diapers, the river is unhealthy. The participant is supported by a key informant (elderly community member from the Mzinti community) who explained that as a result of the dirt *(solid waste) they* have changed locations to perform their rituals. The elderly community member from the Mzinti community explained that:

> *No one can agree to be cleansed with dirty water. I hear some have decided to go use the Mlumati river which is a bit far. We see the dirt and once we see we don't want to do anything with that water. Previously we used it because the water was*

flowing. So we only use it if we see the river flowing, even widows were cleansed in the river with the belief that the bad luck is washed as the water flows downstream but now they also go far to Mlumati River (Community elder, Mzinti Community February 2018)

In analysing the participant contributions, the increase of solid waste in the catchment is a decisive factor influencing movements of people and utilisation of different parts of the river for cultural use. The river has been characterised by a mix of periodic movements by the water users to different parts of the river that are suitable for their needs. Mobility is a feature of the community's production of perceived space. Cultural use of the river is directed towards places where the river's health conditions are of better quality (less solid waste) - some have decided to change spots and use parts of the Mlumati River for rituals. This was due to increased diapers which reduced flow, thus causing negative repercussions on the river's ability to perform a cleansing role as discussed in Section 6.4.2.

A key informant (community elder more than 60 years old of age from Middelplaas) gave a historical account of how they never experienced misfortunes as currently experienced by young people. The participant highlighted how the present dumping of solid waste has made some sites undesirable to conduct rituals:

At our child-bearing stage, we never experienced much [sic] miscarriages in this village. People used to use parts of the river to cleanse the bad luck. However, as a result of people dumping diapers, making those sites undesirable for rituals, the spots had to be changed to other parts which are outside of this village (Key Informant Interview, Midplaas, April, 2018)

In this case, the river is more tightly linked to a successful past, due to its cleanliness and the positive ability to spiritually cleanse and make the river more valuable. All the participants' assertions suggest that at the current status, the river seems not to be functional (to conduct cultural rituals). The inability to use the river for cultural rituals as a result of human disturbances is also discussed by Cock (2018), who stated that sacred sites in the Kowie River are threatened by development projects; mining, agriculture and privatisation which made sacred pools inaccessible for healers. The representation from the participants about the increase of diapers in the river also highlights a threat to the use of the river.

Whilst the participants use the river for cultural use as per Section 6.4.2, they are also compelled to dispose of waste. Small *et al*. (2017) state that sometimes, the source of conflict arises from the multiple uses of river ecosystems. Moreover, as described in Kemerink *et al. (*2011) communities are highly diverse, sometimes their water use is not similar which may result in subsequent conflicting uses of the river. In this case, waste disposal and cultural cleansing are incompatible and in conflict, since the disposed waste is stuck in the stream which renders it difficult for the river to self-cleanse and be suitable for cultural rituals. The participants use the river as a conduit for waste disposal, because of the lack of a solid waste disposal system in place. Research on solid waste management in South Africa shows that indiscriminate solid waste management is common, largely due to an increase in developments that are not coupled with improved infrastructure (Kubanza & Simatele, 2019). In some cases, solid waste community containers are placed on an arbitrary basis to discourage dumping and promote a more organised form of solid waste disposal. Samson (2004) argues that waste collection systems in South Africa must be spatially designed to suit the attributes of a particular community, such as the inclusion of community spatial structures, diverse cultures and socio-economic variability. Unfortunately, the predominant practice of communities in South Africa is to burn, dump or bury waste.

6.6.2 Decline in the quality of reed and fibre grass

Another notable change highlighted by the participants is the quality of reed and fibre grass in the river as observed over time. Participant 6 in Group 1 from the Mzinti community noted that:

> *The small streams that connect to the Komati, have since disappeared and reed, which we used for handicraft to sell, we used to get from these streams. Well in some spots, it's still there but the quality is not as good as it used to, as a result of the deteriorating condition of the river. Presently, we can hardly find well-nourished grass reeds* (Community mapping*, Mzinti village, 28/02/2018).*

This is supported by Participant 2 in Group 4 from the Midplaas community, who agreed that:

> *Likhwane, incoboza (fibre grass) is now brown in colour and thin and hard, when the river was still clean with no dumping taking place, it was green and flexible. We used plenty of it. However, we have stopped using it…(Community mapping, Midplaas village, 28/02/2018).*

Both participants noted that the quality of the fibre grass and reed has changed. Participant 6 in Group 1 from the Mzinti community, in the Lower Komati West catchment, described the reed height, size and compared it to the past which was well-nourished when the river was in good condition. In describing the present reed quality, the participants used adjectives such as "*thin" and "hard"* which denotes negative changes compared to "*flexible*" and "*good condition*" which are positive words used to describe past reed quality. This emphasised that the changes in the reed conditions were not favourable. Participant 2 in Group 4 from Midplaas further explained that as a result of the decline in reed quality, they had to stop using it. The participant's argument shows that the changes in the reed have resulted in changes in their lifestyle, as they cannot use the reed to build houses and craft as previously explained in Section 6.4.1; this portrays existing river and human relationships.

Furthermore, there was a discussion between participants which highlighted some uncertainty and lack of information on where the reed used to be located in the river. The discussion was between

Participant 1 in Group 3 who is about 30-years-old, Participant 2 in Group 3 who is over 60 years old and Participant 3 in Group 3 who is over 50-years-old, all from the Magudu Village. The exchange between the participants was captured as follows:

> *This area used to be rich in aquatic grass (incoboza) we don't get it anymore. We need to put a red sticker on those areas. We don't get reed (Umhlanga) Incoboza and licunga (aquatic fibre) which was used to roof house and for handicraft which we sold at the market (Community mapping, Magudu village 28/02/2018)*
>
> *Where did you find licunga, incobozi and reeds exactly in the river? (Community mapping, Magudu village 28/02/2018)*
>
> *It used to be very close to the river, not very far, it relied on the river to grow. Very close to my home, we used to have lots of it growing there, it was not in the river but around the banks (Community mapping, Magudu village 28/02/2018)*

In this discussion, Participant 2 and Participant 3 who are elders seem to have vast knowledge about the Lower Komati catchment area, more so than Participant 1 who is in her 30s and has not been in the area for long. This conversation highlights that the changes around the river, have been major and the reed has completely disappeared in some areas as a result of stream changes that have taken place, which has been missed by young people. Changes have disrupted the youth's, intergenerational ties to the river as the young participant doesn't seem to recall the location of the reed. The elders' echoes of local knowledge have been retained in the people's stories about the river catchment. Berkes (2012) highlights that people who have lived in an area for a long time have constructed mental images of the ecosystems. This suggests that the elder's constructed mental knowledge about the reed is was useful to provide dependable information about the area. The conversation between the participants depicts socio-cultural learning, a form of learning through oral tradition, where the young people's learning happens as they engage in interpersonal interactions with the elder participants.

The thesis' use of participatory mapping created spaces for social learning, which contributed to the social transformation of understanding of river health. This is supported by Belay (2012) and Hopping *et al.* (2016), who found that as social groups engage themselves, there is likely to be knowledge transfer from experienced members (elders) to the less experienced (youth). Therefore, as the participants drew mind maps and had conversations on the observed changes, there is active knowledge transfer on the locality of the aquatic reed between the older and younger participants. This conversation also shows that knowledge is not entirely uniform in a locality or generation but constituted by individuals as they draw from personal tacit and embodied knowledge produced in repeated interaction with local environments (Fernández-Llamazares *et al.*, 2016). In this case, the youth and the elders are in the same place but they have different knowledge as a result of different intergenerational experiences.

6.6.3 Changes in fish colour, size, skin and abundance

Fishing is one of the major ES provided by the Lower Komati River to the community as noted in Section 6.3. However, participants have noted major changes in the condition of the fish over the years. Participant 3 in Group 4 from Midplaas in the Lower Lomati sub-catchment, explains changes in fish colour that have been observed. The participant described the fish colour as that:

> *…some of these areas are dirty and the fish looks dark in colour, it doesn't appeal to us anymore to eat it, so we don't eat it as we used to…. (Community mapping, Midplaas village, 28/02/2018).*

Besides the changing colour of the fish as an indication of the river's health condition noted by the community members, informant interviews with fishers noted the skin "*elasticity*" as another indicator. The fishers described fish health based on their physical inspection or observation of taste, colour and smell. Fisher 2 explained that:

> *We recognise fish from the river and fish from the dam. Fish from the river is dirty and their bones do not break but bend, it is unhealthy. If the fish is from the dam which is usually clean their bones break easily when it is still raw the fish is healthy. We use that to test for fish freshness. Around Schoemansdal along that River, the fish goes stale within a few hours from fishing. Some old man who fishes in the river, within 4hs his fish goes stale. If you press, it should bounce back if not it means the fish meat is not good the water is contaminated and dirty…(Key Informant Interview, September 2018)*

Should a fisher press down hard on the skin after catching the fish and the skin bounces back to its original form, then it is regarded as healthy. However, if the fish is not healthy, the skin does not bounce back. However, Fisher 1 pointed out that for him the health of a fish is determined through its taste, the time it takes to smell rotten and colour as the main indicators of fish health. Fisher 1 explained that:

> *The fish from the small stream around the village does not taste as good as the fish from the dam, it has a metallic taste, according to us that fish is unhealthy. The fish from the river stream also smells and gets rotten quicker within a few hours of being out of the water. We also inspect the colour, if it is has a dark black colour especially the abdominal area the fish is unhealthy, a healthy fish should be shiny (Key Informant Interview, 18 September 2018)*

A close reading of Fisher 2 and Fisher 1's claim indicates that the fishers have a common way of describing a healthy fish. Both participants regarded fish from the river in their area as unhealthy as they smell and rot faster. Fisher 1 further described the change in colour and taste as another attribute. The change in colour and taste are similar to what was described by community participants during the group mapping exercises regarding observable changes in river health. The similarity shows that the fishers and community groups have a common way of identifying a healthy and an unhealthy fish and associating it with the river condition. Castello *et al*. (2009) argue that local communities have ‘specialised knowledge’ that can be useful in monitoring and management of ecosystems.). Gómez-Baggethun *et al.* (2013) recognise that communities may rely on the use of their specialised traditional ecological knowledge as an input for monitoring not only local changes but also region-wide large scale environmental changes. The specialised knowledge of the visual appeal of the fish is a useful indicator that is understood commonly by community members and fishers. Analysis of the transcript shows that these fishers and community members have accumulated knowledge that has become common amongst them and it is what they rely on to determine fish health.

To participants, it is not just about available fish but also about the visual appeal. The fishers’ use of taste, colour and smell as an indicator of fish health, which is similar to community members’ way of determining fish health, is based on meeting their consumer’s needs, as they pay more attention to details. Maita (2007) explains that fish health according to subsistence fisheries is based on the ability of fish to meet their needs for daily living as well as to meet ecological and economic expectations. Therefore, local knowledge on fish health is socially constructed based on appealing to consumers’ needs, thus the fish health indicators are shared between the customers (community) and fishers.

6.6.4 Changes in the morphology of the river as a result of sand mining

According to the participants, there has been some sand mining taking place, which has led to changes in the morphology of the river. The images in Figure 6.6 show piles of sand mined along the riverbed in the Lower Komati river (Sibange community) which have resulted in changes in the river’s morphology. These sand piles have resulted in impoundment of water on one side of the river, causing the river to change in shape, course and flow as shown in Figure 6.6

Figure 6.6. Pictures taken during fieldwork showing river channel destruction as a result of sand mining (23/10/2018)

Under the sand dredging, significant riverbed deformation is notable. The figure shows the modifications in the river channel due to the sand dredging. Participant 4 in Group 1 from Sibange

Village, in the Lower Komati West sub-catchment noted that sand mining has resulted in trenches and reduced flow. The participant identified the change:

> *Sibange Village is the mostly affected village in this community, there are so many sandpits and trenches as a result of sand mining, thus the flow has been reduced downstream (Community mapping, Sibange village, 28/02/2018).*

The common descriptions used by the participants in describing the river were *'sandpits'* and *'trenches'.* These are all features suggesting the destruction of river structure. The effects of sand mining on the river's morphology are confirmed by the study of Nabegu (2014) on the Kano River, where results revealed that sand mining activities resulted in modification of the river channel, leading to a deep riverbed. The represented knowledge about the river's morphology generally suggests that the physical outlook of a river forms an integral part in determining changes amongst communities. The communities observed these physical changes over time. Furthermore, these participants tied the physical changes to their livelihoods, highlighting vital social dependencies and relationships between people and the river. This is an embedded, reciprocal and constitutive relationship that communities have with the river.

The majority of participants highlighted a direct relationship between diminishing fish species in some areas, around sand mining areas where water flow has slowed down. Fisher 2 and Fisher 4 pointed out that the silver robber which they referred to as "*sardine*" and the yellow fish have declined. Fisher 4 explained that*:*

> *In places where there is sand mining in Sibange, the yellow fish (Labeobarbus marequensis) shiny sardine (silver robber) disappears. This fish also used to be common in the Mzinti area,(pointing at the red-eye labeo) we used to find this fish a lot at Mzinti but now we don't find much of it, they have disappeared (Key Informant Interview, 2018)*

Fisher 2 also confirmed that:

> *The shiny sardine (silver robber) is scarce now, especially around areas where babuli (largemouth bass) is found and also with this sand mining the fish disappears and people here like it, therefore it is expensive. The prices are high because it is a scarce fish (Key Informant Interview, 2018)*

Fisher 2 pointed out that they now compete for the silver robber fish as a result of a decline in the fish' abundance and they sell the fish at a higher price. The decline in the silver robber as explained by Fisher 3 and Fisher 2 is similar to the outcomes from the fish survey (Chapter 5) as none of the species was sampled in site 3 where it was expected. The claim by Fisher 4, that yellowfish (*Labeobarbus marequensis)* disappear around the sand mining areas is similar to the survey results in Chapter 5 which show that yellowfish (*L. marequensis)* was not sampled in Site 3. The site's flow

class was slow shallow, as a result of the upstream sand mining. Mingist and Gebremedhin's (2017) study showed that sand mining can affect a river's ecology by interfering with fish migratory routes, resulting in the loss of their spawning grounds. Sand mining also increases sedimentation. According to Kleynhans (2007) gravel, cobbles and boulders which are good habitats for fish spawning are all susceptible to inundation by sediment, resulting in the ecologically important substrate for fish being lost. It can be deduced that the low abundance of the expected species may be attributed to changes in the flow rate and morphology of the river as a result of the sand mining upstream of the fishing sites.
The participant also identified changes in fish sizes as a result of sand mining by pointing out that:

> *Fish is no longer abundant like before. There was this old person who used to fish in the Mgobodzi stream, where he used to get fish as big as 1m but now we no longer find such big fish. After sand mining started the river diverted, this reduced water flow and now people no longer catch such big fish (Key Informant Interview; Mzinti, 2018)*

The participant associated changes in fish size with the diversion of the stream from sand mining, leading to reduced flows. Skelton (2001) explains that a reduction in flow may result in a shift in the fish community structure. Fish strongly linked with high velocity are likely to decline and the community structure shifts to fish associated with slow-flowing water (for example *Micropterus spp.* and *C. rendalii*). This resonates with evidence in Chapter 5, which shows that flow-dependent fish species were sparse during the sampling period. Moreover, juvenile fish were the most common, which was also attributed to reduced and interrupted flow in some sites. The changes in fish size explained by the participant shows the participants' observation and knowledge accumulated over time. Berkes (2012) explains that local communities have a social memory of past events and can predict environmental changes. In this case, the participants have a memory of when they could catch certain fish in certain sizes, which shows the existence of memory.

Participants described observed changes in the river based on social-ecological construction. Their descriptions showed that they have acquired experience and knowledge about the river based on their use of the river. Elders showed much experiential knowledge in cultural rituals thus they explained observed changes in the river condition based on their historical knowledge and experience of conditions necessary to conduct rituals. Fishers, on the other hand, described the changes based on the physical condition of the fish. Women based it on the changes in the morphology of the river (as their children cannot swim) and the decline in reed quality. In essence, this shows that water users and communities along catchments have experiential knowledge which can be useful in river health monitoring. The participants' experiential knowledge is useful to complement and provide background and historical observation and human experience about the river. The observation and experience provided qualitative insights that may build on a holistic picture of the river's health. This may serve as an important tool for steering the use of local ecological knowledge to enhance the assessment of river health.

6.7 Solastalgia as a result of environmental changes

Another theme that emerged during the in-depth interviews is the expression of solastalgia by elder participants as they described the present health condition of the Lower Komati River. Solastalgia was invented by Glenn Albrecht to describe place-based psychological disturbance and distress caused by environmental change (Albrecht *et al.*, 2007). According to Albrecht *et al.* (2007) and Galway *et al.* (2019), solastalgia gives personal meaning to environmentally induced distress as individuals experience dramatic changes in the environment. Examples of statements expressing feelings of solastalgia from the participants include one by participant *HN1C1P3,* who highlighted that*:*

> *The closest river to us is the small stream Inyetane, which connects with the Komati River. We have been using the river since I was a little girl to swim, get aquatic reed (incoboza) to make grass mats, get water for all domestic purposes. We didn't have to worry about the cleanliness of the river. All that is gone, people now dump diapers in the river, it is not clean as it used to like in the early '90s (Key Informant participant, Driekoppies, 20 April 2018)*

The above expression from a female resident (about 70-years-old), suggests feelings of solastalgia. During the interview, questions about the health of the tributary close to them evoked feelings of distress. This was also deduced from the *'sighs'* in between conversations when she discussed the present condition of the river. The participant reminisces about how they used to swim, get *incoboza* to make grass mats and did not worry about the cleanliness of the river. Her distress and worry were evident when she shared how "*all that is gone*". The older generation has experienced unpleasant dramatic changes in the river, which has resulted in the development of solastalgia. This is supported by Albrecht *et al.* (2007) and Eisenman *et al.* (2015), who argue that people exposed to dramatic environmental change may experience a sense of powerlessness, lack of control and distress over the unfolding changes.

The participant constantly reflected on childhood memories when engaging about the present state of the river and showed feelings of solastalgia. The participant's assertion is supported by Galway *et al.* (2019) and Albrecht (2005), who explain that solastalgia is a useful link between human and ecological health. People see the past condition of the river as better than the present and express that using personal feelings. The solastalgia expressed here negates the feelings of attachment as expressed by participants in Section 6.4.3. This is consistent with how Albrecht *et al.* (2007) described solastalgia; as the feelings of distress by people who had lost place attachment to the territory because of environmental degradation. This means that changes in the river's state triggers changes in attachment and brings about more feelings of solastalgia. The changes in participants depending on the state of the river shows the usefulness of understanding the relationship between rivers and humans.

The elders' expressions of solastalgia contrasted with younger people's expressions. For example, a participant who is a 30-year-old male from the same area claimed that:

> *The river is dirty, as the river flows you can't see the sand at the bottom anymore, you see waste left behind. This shows that the river is no longer able to clean itself. This waste is washed from residences and is mostly deposited along the riverbank. Previously, the river could maintain its natural flow and wash waste downstream, even though it used to affect downstream occupants, waste was never attached along the riverbed but now the waste is no longer able to pass as the river is blocked*. *HN1C2P4 (Key Informant Interview*, *Driekoppies September 2018)*

The 30-year-old participant only reflects on the present changes; the participant did not personalise the representations to exhibit personal feelings of distress. The participant simply described the present state of the river and changes without personal expressions of grief. The 30-year-old participant used "*the river*" but the 70-year-old participant used '*we*' and *'I'm*' most often to relate to how they used the Komati river. The 30-year-old participant used *"The river is dirty...as the river flows you"* and the elder participant used "*we live and most… we ploughed".* The differences in narration between the young and older community members indicate an intimate qualitative difference between elders and young people, which shows that experience and length of residence time are important variables to consider in determining social river indicators.

In summary, the narration by older community members indicated their experience of the place and that the changes have been undesirable and trigger feelings of sadness. The elders' strong connection and association with the Lower Komati River appear to have a key role in influencing their feelings of sadness about the observed changes. This is supported by Dixon and Durrheim (2000), who state that individuals relate safety, comfort and familiarity with a place, which leads to a personal connection with the area. Through routines in that place, people develop links and feelings of belonging (Horwitz *et al.*, 2001). Hanley *et al.* (2017) explain that one's self-reported feelings of happiness and sadness are two key indicators of emotional connection to a place that demonstrate changes. Therefore, the elders visibly upset emotions disturbed when discussing the changes is an illustration of their emotional connection. This shows that over time, a person exhibits strong involvement with the physical environment and a deep sense of belonging which is useful in showing human experience to explain river health.

This solastalgia captures the essence of the relationship between ecosystem health and social values, which can be useful when communities assess the river's health. Solastalgia is therefore identified as an important variable to examine changes taking place in the river. Understanding communities' solastalgia and linking it to the state of the environment opens avenues of research that inquire into a better understanding of rivers from communities' perspectives. Thus, it would be important to examine the concept of solastalgia to see if it provides a potential construct that can be incorporated into river health monitoring indices to enhance monitoring with human experience.

6.8 Use of the past political era to describe changes in the river

Analysing the participants' transcripts shows that participants in the Lower Komati placed river health within the historical context of politics of South Africa. The concept of waterscape seems appropriate to explain the interaction between past politics (apartheid), management of water resources and river health in the Lower Komati River. According to literature, the waterscape concept discusses the interactions between water, power, socio-political dynamics and technology (Swyngedouw, 2004; Budds, 2008; Karpouzoglou & Vij, 2017). By the definition in this research, a waterscape includes the Lower Komati River, users of water (communities), their interactions with the river, feedbacks and external influencing factors (politics). The waterscape concept in the Lower Komati is reflected in the complex ways in which water use and politics are fused to render them inseparable. The intertwined nature of politics with water in the Lower Komati River catchment seems to have led to shaping the river health of the Lower Komati River.

Historical narratives about the Lower Komati River demonstrated links between the river and politics in determining the condition of the river. An elderly participant from the Mzinti community in the Lomati sub-catchment reflected on the past political era and relations between the community and the river. Speaking about the status of the Lower Komati River, the elder shared that:

> *In the farms where we used to work during the apartheid era, we would bathe on our way home and collect water to cook. The only thing we were worried about were crocodiles but on certain parts of the rivers where the water was deep otherwise in running parts of the river it was mostly safe, that's where we mostly got water for our households and took our bath on our way home from working in the farms. These young people cannot experience all that. Presently, we cannot do that, the water is not as clean, we worry about a lot of diseases, that's why the governments introduced water from taps… (*Key Informant Interview, Mzinti, April 2018*)*

The participant's association of the political history with how they used the river shows that, although apartheid might have ended in 1994, it is still a constant reflection for communities who have experienced it and associating it with the river's condition. The participant' recollections about the river are riddled with political history, as he explained that previously they could use the river without worrying about pollution which is currently experienced. According to Tewari (2009) and Tempelhoff, (2017) apartheid legislation discriminated against people of colour, as it controlled their right of access to water resources and by implication proper water supply and sanitation. As a result, water use was reserved for the "white" areas, as there was minimal use of the water, minimal pollution was also experienced. Post-apartheid at the enactment of the NWA of 1998, which call for equitable use of water resources there has been an increase in pollution as more people have access to use water. This demonstrates a relationship between power, unfair resource allocation and resource degradation. According to Steyn (2005), environmental degradation in South Africa has its roots in the apartheid legacy, as the post-apartheid government prioritised equitable access to resources, and did not accommodate environmental protection. The political processes that take place in the area influence water allocation and policies. The influence of the political process on the water resources leads to perceiving the water resource as a waterscape (Irvine *et al.*, 2016). Thus, using the waterscapes lens to analyse participants' presentation, as it can be established that the present state of the river is produced social-ecologically, through the political history of the area. This is in agreement with Molle (2009) who state that river basins are politically and ecologically constructed. The pollution explained by the elder to be experienced post-apartheid is an example of how everyone might have access to the river (trying to balance power), but all leading to an increase in degradation as a shortcoming of the new policies. This is further supported by Roa-García (2014) and Boelens *et al.* (2016) who argue that unbalanced power is likely to influence and shape natural resources access and environmental degradation or crisis. Therefore, the research shows that river pollution in the area is linked to power relations and access to resources that relate to the waterscape concept. This is more evident as other elders also do not only focus on the physical changes (ecological) but also stories about the consequences of politics (social) and the depleting resources.

An elder participant (over 60 years of age) from Sibange elaborated on how the introduction of taps by the new government (post-apartheid) brought about pollution in the river. The participants described the change based on their different lived experiences and relationship with the river. She frames the start of pollution in the river as a result of newly acquired independence. Speaking about the status of the Lower Komati River, the participant stated that:

> *When the new government after the apartheid decided to put in taps for drinking water, that's when also people started dumping used diapers in the stream and the water started getting more polluted and dirtier, no one can drink water from the river now or conduct rituals…since they don't know some of the important things the river used to do for us. Our (community) lives have changed completely* (Key Informant Interview, Sibange, April 2018).

The participant's grievance highlights her experience post-apartheid. The participants' reflection on how the river is not presently clean compared to the apartheid era brings up the relationship between politics and environmental management in South Africa. The South African environment has slowly degraded over the past few decades and according to Steyn (2005), these have roots that go back to the apartheid era. The apartheid period brought so many injustices to the African communities which rendered them poor. Thus, the post-apartheid government introduced policies with great emphasis on reducing poverty levels in the country and to counter poverty-related environmental problems. However, according to Steyn (2005), the policies did not accommodate environmental considerations central to economic and social planning. Thus, degradation of the environment increased, which is also evident from the participants' arguments. The elder participants' historical narratives are intermixed with their grievances of *'unfriendly*' changes which have taken place.

The provision of tap water was to address contamination issues, as Bakker (2012) explains that water links other bodies and effluents, such that there are now discourses of safe water provision. In as much as the taps offer safe water, Hemson (2007) argues that collecting water from taps crosses different cross-cultural advocacy as the older generation considers this activity intrinsic to rural life whilst it might also be detrimental to their health. Whilst taps provided clean water, they changed the communities' social arrangement. This shows that water is not only a physical entity but is also socially constructed which should be considered at all times. This is explained by the waterscape theory - as water flows, a socio-natural entity is produced, which determines and shapes social power (Swyngedouw, 2004; Budds & Hinojosa, 2012). The water from the Lower Komati River is represented as a social-ecological entity characterised by socio-political interactions and physical-environmental dynamics.

Moreover, as a result of the post-new water supply changes (water supply through taps), the participants also highlighted their discontent on how the tap water is rationed, whilst previously there were no limitations. Elder Participant 2 from Driekoppies complained that:

> *The water from the taps is rationed and we (the community) only use it for basic household activities. The water from the river was never rationed, we would collect the water anytime we needed it (Key informant participant, Driekoppies October 2018)*

The participant's assertion pinpoints dissatisfaction with how water is governed now. With the modernisation of the water supply, new forms of governance that administer water use practices emerged. The taps came with the removal of communal forms of water governance that had no restrictions (central to the participants' disappointment). This is supported by Bakker (2012), who argues that once new forms of municipal government emerge to deliver water supply, water becomes an object of government. Bakker (2012) further claims that water is inherently political, not only because it is an object of conventional politics but also because of its material imbrication in the socio-technical formations through which political processes unfold. From the quotation using political ecology and waterscapes lenses, the framing of water management implies a link between political power and the emergence of the Lower Komati as a 'hybrid' of tap water supply, constraints to supply as a result of rationing and also leading to changes in the river's health. The introduction of taps manipulated the hegemony of water access, not by simply changing the physical environment through introducing the taps but also by influencing the river's health and how people relate to the river.

The introduction of the taps transformed the way local communities collected water, leading to a transformation in the relationship and social value between residents and the river. Loftus and Lumsden's (2008) study of domestic water dynamics in South Africa argues that applications of power are not aimed at transforming the physical environment (such as water supply) but shaping how people relate to their environment. In this case, the constructed hydraulic infrastructures (taps) were identified as forces that rearranged communities' social value about the river and river health. The water resource configurations through supplying taps can be conceptualised as outcomes of an interplay between geographical conditions, available technologies and socio-political arrangements leading to a new 'hybrid' of the river catchment. Historical post-apartheid practises contributed to the development of a complex web of pressure and actions (Loftus, 2005) and these have produced the present river health status of the Lower Komati River. This led to the shaping of the Lower Komati's river health waterscape through ecological, social and political attributes. The change in water supply showed the politics of access to water and further informed the various patterns of how water is valued, which also explained the river' health. The explanation of river health by the politics of the catchment becomes a valuable contribution to the study which shows the river as a new formation of a socio-nature where the social, ecological and political attributes intertwine to explain river health. Thus, the research contends that to fully capture the underlying causes of river health deterioration, a more careful conceptualisation of power and politics is important. This is a line of enquiry that shows that a stronger synergy between river health and political ecology is important to address underlying causes of river health deterioration in river catchments. As political ecology scholars conceive water to be a contested resource, similarly river heath is politically contested.

6.9 Representation of local ecological knowledge

Participants' opinions on the Lower Komati River's health revealed the various faces of local ecological knowledge. This section serves to unlock the formulation of local ecological knowledge by water users in the lower Komati River through the generalisation of conversations by different users. Local ecological knowledge is generally understood to be a contextual knowledge resource about the environment or nature, which is rooted in people's experience and can be transferred within generations (Yli-Pelkonen & Kohl, 2005; Berkes 2012; Tomasini & Theilade, 2019). This knowledge is based on human-environment interactions, which informs practices and their knowledge (Raymond *et al.*, 2010). Analysis of transcripts shows that participants' have a profound awareness of their local ecosystems. Participants' local ecological knowledge about the river is evident in conversations about historical changes in resource use and associated rationalities.

Fishers show that they have acquired local knowledge based on their fishing experience. The participants (fishers) seem acquainted with the different species available in the river catchment – this depicts knowledge about the river they have acquired over time. According to Fisher 2, who has been fishing in the Lower Komati River for the past 10 years, the largemouth bass (*M. salmoides* is the most common fish species in the area. The fisher described the fish community as follows:

> *There are different types of this fish, the most common fish in our area, bhabuli (largemouth bass) and the yellow fish (Labeobarbus marequensis). Also, this fish is a common type we find in this area (pointing in a book the redbreast tilapia)(Fisher 2, December 2018)*

The above claim from Fisher 2 shows that he has substantial knowledge of the diversity of fish in the river. The largemouth bass (*M. salmoides)* and redbreast tilapia (*C. rendalli)* shown in Figure 6.7 are the most targeted common species in the catchment. Other fishers pointed out other common targeted species that include the Red eye labeo (*L. cylindricus)*, silver catfish-butter barbell (*S. intermedius*), short spine suckermouth (*C. pretoriae*) and the Mozambique tilapia (*O. mossambicus*). The fishers were able to positively identify the different species from pictures provided by the researcher and identified the largemouth bass as the most common, while also describing their preferred ecological requirements.

Figure 6.7. Pictures taken during fieldwork showing redbreast tilapia (*Coptodon rendalli)* and largemouth bass (*Micropterus salmoides*) from the Lower Komati River (Fieldwork, April 2018)

Fisher 2 explained how the largemouth bass fish selectively locate themselves:

> *The largemouth bass (Bhabuli) is found at the edge of the river and in dirty and muddy water when it is hot, they travel in groups* (Fisher; Driekoppies, April, 2018)

Fisher 3 attributed weather events to how much fish they catch in a day. The participant explained that:

> *Sometimes we go the whole day or at night fishing...on a hot day, we get more*. (Fisher; Midplaas, April 2018)

Fisher 2 also observed that during a rainy period, there is a high interaction with some fish:

> *When it rains, we get a lot of them(fish) or when it is still early in the morning and when the water is dirty* (Fisher; Driekoppies, *April 2018)*

The above quotation shows that the fishers are cognizant of weather and seasonal changes and how they affect catches. Temperature and rainfall are identified as key determinants which affect fish movements and largemouth bass behaviour. This shows that the fishers have acquired experiential ecological knowledge about the fish and their behaviour. The participants' claims are based on forming generalisations, as a result of their observing several fish species and creating a list of common fish in the area. The fishers' statements are consistent with the literature, as Hanson *et al.*, (2007) explain that the largemouth bass seeks out food and warmer water temperatures to enable gonad development needed for spawning. Ayub (2010) confirms that changes in rainfall and temperatures alter the catch of some fishes. According to the participants, water temperature drives the location of the species; the warmer the water, the more the largemouth bass need to eat. Sabai (2014), who interviewed mangrove fishers, also found that interactions with fish increased in the rainy season. Woodford *et al.* (2017) analysed the behaviour of the largemouth bass and indicated that the species were influenced by water temperature and river inflow. The depictions by the fishers are similar to literature (Lehodey *et al.,* 2006; Bruno *et al.*, 2013;) which highlights the existence of a theory that weather variations have a major impact on the abundance of fisheries in an area. The similarity of the fishers' assertions to the different scientific claims qualifies the claims by literature that local ecological knowledge is valuable to use with scientific knowledge in managing the environment (Sabai & Sisitka, 2015; Hill *et al.*, 2020; Cebrián-Piqueras *et al.*, 2020).

Alongside being able to identify and describe the species and environment interaction, participants were also able to identify fish new to the area. Fisher 4 described the new fish species as follows:

> *There is a new fish that is shaped like a prawn which is now common in the area. Once that fish arrives in the area it dominates and you will see another fish disappearing (Key Informant Interview, fisher, Mzinti, September 2018)*

The representation highlights how their experience in fishing has led to acquiring local ecological knowledge, to identify new species that are not familiar in the area. The results show that the fisher used the localised experience to make sense of the observed new fish. The description of the new fish fits the description of a recently discovered invasive species, the alien Australian crayfish (*C.quadricarinatus*). This is further supported by results in Chapter 5, which show that the Australian crayfish (*C.quadricarinatus*) was sampled in sites around the Mzinti and Kwazibukwane area where Fisher 4 comes from. Nunes *et al.* (2017) also confirm the widespread presence of C.quadricarinatus in different parts of the Lower Komati, which is in agreement with the fishers' experiences. The identification of "new fish" species is a result of experience accumulated over the years which is supported by scientific evidence. The fishers' ecological knowledge in this instance is necessary to note any changes in fish communities, which is an important attribute in river health assessments.

The fisher's represented knowledge in the above context helps us to understand the importance of experience by showing key determinants which drive or generate fish behaviour leading to the production of local knowledge. The species interaction-cycle, preferred climatic conditions, fish-catch theories and identification of new species are all local knowledge that informs fishing decisions in the study area throughout the year. The research conceptualises that local ecological knowledge includes the knowledge and practices that are acquired by people over a period of time through the accumulation of experiences and community practices. The fishers' descriptions of the fish and climate interaction are based on empirical experiences, which may not be manipulated or constructed by humans but experienced (Ayre and Nettle, 2015). Fishers used their observation experience from their practices and relationships with the river, to explain changes in the river.

6.10 Empowerment of local people through participatory mapping

Presently in the Lower Komati river, residents as in all other communities in South Africa have avenues to communicate and participate through different stakeholder forums. However, as argued by Galvin (2011) and Molobela and Sinha (2011), genuine collaboration and empowerment are compromised as decision making does not lie with stakeholders (as explained in sections 2.8, and 2.9 and 2.10). Thus, a significant portion of data from this study were collected through participatory mapping exercises to ensure genuine collaboration and stakeholder empowerment, as explained in Chapter 3. Outcomes from the thesis show that participatory maps offered opportunities for communities to collaborate and show spatial relations of the river's social value. The participatory mapping exercises provided tangible results regarding residents' attachment to specific places, as the respondents expressed themselves verbally and drew maps that disclosed more insights into the nature of their attachment and the condition of the river. This was necessary for this research as proper participation involving stakeholders in planning, decision making and making use of community information and creativity is absent, as explained by Williams (2018). Decision making is subject to conditions of the CMA (Lotz-Sisitka & Burt, 2006; Stuart-Hill & Meissner, 2018) and genuine collaboration and use of local's knowledge is not considered. Instead of support that would allow the communities to express their concerns, the management agency holds prescribed river health programs and indicators to monitor without consideration of participants local ecological knowledge inputs. An elderly participant from Driekoppies explained that:

> *We had people from the IUCMA who came to talk about how the stream close to our homes is dirty and how some animals in the water have died. They told us that these animals do not like to live in dirty water. I don't think that helped in any way (Key Informant Interview, Driekoppies village 28/02/2018)*

The prescribed use and prioritising of *'river animals*' by the IUCMA (catchment agency) as important during river health campaigns seems to show control of the monitoring. This does not suggest empowering the local communities by considering their input on what is important to them in river health monitoring. This demonstrates a lack of epistemic participation (where participants can produce knowledge) and empowerment in river health monitoring in the Lower Komati River catchment. Currently, the river health monitoring approaches do not take into consideration local relevant indicators as inputs in health monitoring design and assessment, which shows a lack of epistemic participation. As a result, the campaigns seemed to have not met their objectives. Sekhwela and Samson (2020) found that the complete absence of reclaimer's epistemic participation (Samson, 2015) in the Robinson Deep Solid Waste Project resulted in integration not being achieved. Thus, the study's use of participatory mapping is recognised as a platform for epistemic participation, as the local water users and communities expressed concerns and views on the state of the river using their local indicators and knowledge.

The community mapping exercises also helped reveal participants' heterogeneous values based on their experience and local knowledge. This demonstrates epistemic participation of communities in river health monitoring. Reichmann (2013) argues that epistemic participation not only produces knowledge but also allows communication between actors with different kinds of knowledge. The community mapping exercises embodied epistemic participation as the inhomogeneity of the communities and their knowledge was explored during the process. Morales and Harris (2014) emphasise that to ensure that participation is not superficial, it should be supported by broader considerations from different participants. This thesis has revealed different local ecological knowledge facets (fishers, elders, community members) beyond a basic understanding of the system. When comparing results in Section 6.5 on river health meaning and Section 6.6 on observed changes, these different groups in the community provided an understanding of river health problems and management issues based on their local ecological knowledge and experience. The fishers' local knowledge is based on fish condition and ecology, whilst for the elders, it is based on their ability to perform cultural rituals.

This case study also illustrated the benefits of bottom-up participation through stimulating and prompting community discussions on issues touching their livelihoods (decline of river health which affects their use of the river) and offering guidance on how to involve citizens in planning and monitoring (river health). The participatory exercises worked as knowledge co-production tools which increased understanding of the situated nature of river health. During the participatory mapping exercises, the participants drew mind maps and identified problem areas in the catchment; other participants also learnt about other areas in the catchment they did not know were problematic. According to Brown *et al.* (2005) and Tippett *et al.* (2005), participatory mapping provides a space for reflection and open exchange; these are important for social learning and integration of different knowledge types, norms and values. The maps produced supported the participatory process as water users reflected on the state of the river and shared opinions and knowledge about the river's health condition. Participants expressed that the mapping exercise was useful to indicate areas in the catchment that are problematic and may need more attention during their cleaning campaigns.

The mapping exercises also offered opportunities for social learning about the condition of the river. Some young people expressed how they had never seen some ecological changes in these areas, they relied on stories from elders (discussed in Section 6.5.3). Social learning is characterised by the establishment of new perspectives of the river by other participants and by being aware of the river's problematic areas (Berkes, 2009). In social learning, different stakeholders learn about issues in the social context and the participatory process can enhance knowledge of a specific environmental problem and about the interests and concerns of various stakeholders (Mostert *et al.,* 2008; Muro & Jeffrey 2012). The maps provided opportunities to spatially locate the areas identified by elder participants, which helped unlock information that might be useful during river health monitoring.

Participatory mapping coupled with informant interviews also revealed the facets of local ecological knowledge in river health management. The multi-method participatory mapping process revealed several local ecological knowledge sources (fishers, elders, community members) beyond the basic understanding of the system. These different sources have acquired local ecological knowledge that they use to explain changes in river health conditions depending on their use of the river. The participants addressed historical changes in resource use, social-ecological values and ethics, the significance of the river to culture, spirituality and local worldviews revealing their local ecological knowledge as explained in Section 6.9. The community mapping produced detailed spatial maps, identified as useful tools for communicating local ecological knowledge in a multi-actor setting using bottom-up participation. The study's use of participatory mapping also revealed participants' ethics and values towards different parts of the river, which were heterogeneous. For example, the elders had a negative attitude towards areas with dumped diapers and local water taps as they felt they contributed to the river health problems, whilst the youth felt that the municipality must provide waste collection services and valued areas with taps, as explained in Section 6.6 and 6.8.

Based on the contribution of participatory mapping in offering opportunities for social learning, local knowledge production and stimulating epistemic participation, the research theorises the decolonisation of river health monitoring through epistemic community participatory assessment. This offers opportunities where the communities can develop actions and solutions for water management that are relevant and congruent to their local situation and are closely linked to their relationship to the river.

6.11 Conclusion

This chapter revealed that the Lower Komati River has multifaceted social values as assigned by the local community, shown through the communities and the river relationships. The social values assigned by the participants in different parts of the river portray their lived experience and the communities' relationship with the river and historical knowledge which has accumulated over time. River health meaning from the communities' perspective is a socially-ecologically constructed problem and founded on the various relationships between people and the environment. The meaning of river health in this research is in contrast to the meaning pursued by some literature, as it considers the river's relationship with the local communities whilst past studies only considers the meaning from an ecological point of view. The participatory approaches to this study opened a dialogue on the social-ecological attributes of the river as observed by the participants, which help to explain river health in a simpler way that is locally congruent. The local experiential and local ecological knowledge offers opportunities for river health monitoring to be relevant and understood by the locals instead of imposed upon the local communities.

The participants actively explored their relationship with the river to explain river health, for example, fishers used fish attributes and elders used their experiential knowledge on the river's use for cultural rituals to explain the river's health. The relationship between the river and the local communities was captured through feelings of place attachment and solastalgia, which were exhibited by the participants as they described the present state of the river. The participants' feelings of solastalgia helped to explain the negative effects and changes taking place in the river. The study also concluded that the country's politics produced social dynamics within the catchment, leading to the emergence of a 'hybrid' of the social and ecological state of the river. Water use and past politics in the catchment are fused in a way that renders them inseparable to explain river health.

This study also shows how participatory methods used in river health studies, including historical narratives, help negotiate common understandings about river health problems. The participatory mapping exercises decolonised knowledge on river health and indicators as the participants suggested locally congruent indicators and knowledge about river health. The methodology also showed that it is important to negotiate matters through spatial practices (mind maps) that are meaningful to local communities and open up discussions on matters which might not have been shared before. Sharing of information created spaces for social learning between community members that contributed to the abstraction of locally relevant indicators, as participants shared their knowledge and experiences about the river. Thus, the thesis conceptualises that the participatory mapping process is important and offers opportunities for meaningful participation of communities.

7 CHAPTER 7: BRINGING IT TOGETHER - DEVELOPING AN INTEGRATED APPROACH TO ASSESS RIVER HEALTH

7.1 Introduction

Chapter 1 argues that river health monitoring in South Africa has been confined to ecological dynamics and indicators. Despite efforts to make river health participatory and meaningful to local communities, the inclusion of communities' local indicators, social values and relationships between people and the river are not used during implementation in South Africa. Chapter 2 explores literature and identifies the different ways river health is presently determined in South Africa, which shows that it is based on ecological indicators. However, interrogation of the literature shows that in definition and policy, river health has ecological and social values which converge, which is not how river health is currently presented on implementation.

Gaps on how present river monitoring lacks local congruency and consideration of the multiple relationships between society and environment have been identified. Chapter 3 shows the different methods by which the river's health can be profiled using ecological and social analysis to improve its understanding and monitoring. River health ecological and social profiling and analysis are presented in Chapters 4, 5 and 6. Chapters 4 and 5 profile the present ecological state of the river using fish and macroinvertebrates and identify ecological drivers of river health. Chapter 6 profiles the social role of the river and how river health is theorised and socially valued by communities in proximity to the catchment. Thus, this chapter will explore and identify pockets of integration between the social and ecological aspects of river health. This chapter will try to answer Research Question 5 of the thesis, namely; *What are the opportunities and missing links to merge the existing social-ecological dynamics that exist in the catchment, develop locally congruent social-ecological river health indicators and sampling sites to improve river health assessment in the Lower Komati River*?

This first section of the chapter will summarise the main arguments and findings of the thesis, highlight the novel contribution from the research and how the research questions have been answered. Later, the chapter will show the development of an integrated framework that applies a social-ecological systems approach to account for indicators, monitoring sites and monitoring that reflect both ecological and social dimensions in river health assessment. The framework hopes to address the complexity, variability and shortcomings in the assessment that were observed in Chapters 5 and 6 of the ecological river health assessment by offering a step-by-step guide that considers social-ecological indicators and sampling points that are locally congruent to the catchment.

7.2 Summary of main findings for the case study

Key conceptual issues that emerged were that there is complexity and uncertainty in assessing the river health condition of the Lower Komati using only ecological indicators (fish and macroinvertebrates) and indices. There is also a lack of consideration of local communities' knowledge and full participation in river health assessment. The thesis also considers the epistemological value of participatory methods in river health, how political ecology can facilitate the integration of social and biophysical elements of a river, emergence of space, mosaic value of the river, value of local knowledge in river health assessment and the social production of river health.

7.2.1 Ecological health profile of the Lower Komati catchment

The most degraded sites were Site 1 and Site 4 which is evident through the low ECs from the indices' analysis coupled with a low estimated abundance of fish and macroinvertebrates compared to reference data. The poor ecological condition of Site 1 and 4 is ascribed to the anthropogenic disruptions upstream of the sites. These disruptions have an impact on the ecological well-being of the river, thus there is a need to attain a balance between use and protection of the resource in the catchment This is necessary to understand how to protect the river's ecosystem and how its ability to provide ES and functions may be affected. The general health of the river and cohort of fish and macroinvertebrate communities illustrate the lack of balance between the use and protection of the freshwater ecosystem in the catchment. The use of river resources without increased protection, which is shown by the state of the fish and macroinvertebrate communities and habitat in the different sites. The disappearance of native fish species in the sites has a major implication on subsistence fishing, as local fishers depend on these native species in the catchment.

Secondly, the ecological health profile results show that with the continual use of rivers, it is becoming difficult to find sites that are 'pristine' for use as reference sites to establish indicators and develop indices. Results show that relying on a site's geographical position as a reference site in ecological monitoring, could not be supported in this assessment. The assumed reference site's macroinvertebrates, fish community structures and water quality analysis show that they were degraded with minimal protection. This presents a weakness of relying on a sites' geographical position assumed as a reference site and determining resident species, as it may lead to misinterpretation of the pristine condition. This is largely because people use the river, thus maintaining pristine conditions in catchments is not possible. Literature shows that human modification of river systems poses a difficulty in identifying potential reference sites (Chessman *et al.*, 2008; Dallas, 2013 & Agboola *et al.,* 2020). These authors highlight that there is a need to shift from considering natural reference sites and conditions in river health monitoring as these may change as a result of continual human use. Instead, there is a need to build frameworks that emphasise local histories and trajectories of change as achievable conditions (Rinaldi *et al.*, 2015), which take into consideration uses of the river which is the ultimate goal of this thesis. This would be important as it collates social and ecological parameters in coming up with reference conditions for river catchments.

The ecological profile analysis using fish and macroinvertebrates showed disparities in categorising the river's health condition. Analysis using macroinvertebrates communities showed that the different parts of the river ecological classes ranged from modified (EC D) to severely modified (EC E) and using fish community structure, all parts of the river are at EC C which means they are modified. The river showed better ecological conditions using fish community analysis compared to the macroinvertebrate analysis. The findings are similar to previous studies, which show that macroinvertebrates react differently to drivers compared to fish. Selego *et al.* (2012) found that macroinvertebrates respond quicker than fish communities on an agriculturally impaired reach of the Cacapon River. Ruaro *et al.* (2016) found similar results as macroinvertebrates communities differentiated widely from reference conditions compared to fish when comparing their response to environmental change in southern Brazillian Rivers. Fierro *et al.* (2017) co-used macroinvertebrates and fish in Chile to determine their response to agricultural activities and concluded that macroinvertebrates responded more to substrate composition compared to fish, which responded to stream shape and flow. The different responses of fish and macroinvertebrates in the mentioned case studies show that these two taxonomic groups have different traits and thus react differently to impairment in water resources. Thus, according to Baa-Poku *et al.* (2013) and Buss *et al.* (2015), the use of one taxonomic group of organisms to explain river health may not be adequate to explain the river's overall ecological wellbeing. A singular taxonomic group is not equally sensitive to all the variables that may affect river health as groups respond differently to environmental variables and their rate of reaction is different. Therefore, it is necessary to consider other taxonomic groups and environmental variables to explain the river's health status.

Additionally, the variability between ecological indicators (fish and macroinvertebrates) may be attributed to the different evaluation metrics used by the indices, sampling efforts and also that analyses using these indices are subjective as they often depend on user expertise. This is because all the South Africa ecological health indices methods (FRAI, MIRAI) used to determine the weight values of the different ecological drivers of fish and macroinvertebrates are subjective as they depend on the expertise and knowledge of the species and habitat, which underlines the subjective judgment of the scientists. Similarly, Lu *et al.* (2015) explain that ecosystem health determination is influenced by value judgment and is not completely objective. The methodological approaches of the ecological health indices and outcomes from Chapters 4 and 5 reinforce the subjectivity of the indices, as only experts' data were considered to judge the river's habitat and condition with no participation of local communities on how the different drivers might affect the different species found in the sampled sites.

Statistical analysis is used to minimise subjectivity in identifying drivers that determine the distribution of fish and macroinvertebrates, as explained in Section 3.5.5 and shown in Sections 4.5 and 5.5 However, Zardari *et al.* (2015) and Sutadian *et al.* (2016) raise concerns that statistical-based methods may be inadequate and be less acceptable as their weight identification procedure is not clear during the analysis and advocates for human participatory-based methods where contributions are debated and discussed (as shown in Chapter 6). To further minimise subjectivity, Sutadian *et al.* (2016) suggest that parameter weights should be given based on participatory-based approaches, which may involve key stakeholders such as experts or practitioners and local users of the ecosystems. When developing water quality indices that suit an area, the authors found that the use of local people's expertise and input was important to complement statistical analysis. In the

Philippines, to develop a comprehensive river health index, a participatory and multi-sectoral approach was used to reduce biases inherent in any scoring scheme (Martinez, 2018). Experts and local users from catchments participated in scoring the indicators based on their experience. The authors found that using the integrative method with the active participation of users gave a reliable, localised status of the river and led to the appropriate implementation of programs for river monitoring improvement. This highlights that participatory-based approaches in river health assessments in the Lower Komati are a major gap; giving a human, localised analysis of the river from people with experience with the catchment is beneficial to minimise the biases of statistical procedures. This affirms the importance of community/stakeholder participatory approaches in river health monitoring which are considered in this study.

7.2.2 Mosaic of values formation through communities and river relationship

In trying to determine the role of local communities in river health monitoring, the study showed that water facilitates social interaction between people and the environment where values develop. The research shows that the local communities held multiple values (cultural and spiritual, provisioning and personal attachment) on the river catchment, based on their background and relationship with the river. The values in this thesis seem to have developed through a series of experiences and social connections and they all relate to the condition of the river. The social values expressed by the community in the Lower Komati are explained through a mosaic of values concept. The thesis uses the mosaic value concept to explain that individuals draw on different aspects of the landscape with different expectations associated with how they value the river, as explained by Chao and Moon (2005), Gomez *et al.* (2014) and Kenter *et al.* (2015) leading to different tiles of values connected by relationships. This mosaic value concept shows that the Lower Komati River is made of a series of experiences that lead to values and these can be used to explain the river's health changes. The river's complex system with localised structures links the different values in both an ordered and chaotic way that can also be used to explain the river's social-ecological structure. The different values do not work exclusively but work as a composite leading to the transformation of the previous social and natural conditions to a hybrid. This highlights the complexity involved in understanding rivers - that one should consider the multiple values that make up the catchment.

7.2.3 Connection between macroinvertebrates, fish and people

Results from the last three chapters show a relationship between aquatic macroinvertebrates, fish and the social values of the Lower Komati River. Chapter 4 results show that the introduction of alien macroinvertebrates (Australian crayfish) in some sites have major implication on indigenous fish communities. Previous studies show that the C. quadricarinatus is a major cause of environmental problems resulting in biodiversity reduction (Jose et al., 2009; Chaichana & Wanjit, 2018). Wood et al. (2017) and Morningstar et al. (2020) identified C. quadricarinatus as a potential competitor and reciprocal predator of ecologically important native fish species. This might explain why the endangered Orange-fringed largemouth (C. brevis) (Emery, 2002), which was previously found in sites 4, 5, 6 could not be found in any of these sites which have been infested with the C.

quadricarintus. C. brevis is listed in the Red Data List of Threatened Species because of its limited distribution range and the main threats to this species are alien and invasive fish, subsistence fishing and agricultural activities (Cambray & Swartz, 2007) which are all common in the Lower Komati.

Chivambo et al. (2019) in a study in Mozambique found that the C. quadricarinatus, introduced in the Pequenos Libombos Reservoir has been linked to a reduction in tilapia fisheries. Based on behavioural observations between Mozambique tilapia (O.mossambicus) and C. quadricarinatus, these species compete for shelter and food, resulting in reduced foraging during feeding. . The competitive nature of the alien C. quadricarinatus and the Mozambique tilapia (O.mossambicus) as found in the study raises concerns on the availability of Mozambique tilapia in the Lower Komati over time. This is mainly because the Mozambique tilapia is one of the most preferred species by community members and fishers in the Lower Komati River as discussed in Chapter 6 and this has an implication on the river's social value. This is more important because as discussed in section 2.7, ecosystem services lead to the generation of people's value towards a river, likewise, if there are changes, the value will be affected. So, the effect of the alien macroinvertebrates (C. quadricarinatus) has a cascading effect and connection between the fish community structure and the social value of the river.

Based on the analysis of the human' social value-fish-macroinvertebrates relationship, the thesis shows that human activities or any anthropogenic activity that may affect one indicator has a cascading effect on the rest of the indicators. So, the connection between people, fish and macroinvertebrates provides insight into the importance of understanding all social and ecological attributes of a river in river health monitoring to give a comprehensive view of the prevailing conditions. Understanding the connection between people and fish, and macroinvertebrates in this research, presented an opportunity to reframe and contribute to the formulation of the social-ecological framework and as a way of decolonization single use of indicators.

Although the local communities identified and showed interest in the invasive *Cherax quadricarinatus,* which is an aquatic macroinvertebrate, they did not make any mention of any other aquatic macroinvertebrate during the discussion. This shows that, despite communities' experience and involvement during river health monitoring using macroinvertebrates to as explained in section 2.3, they still did not prioritise them or consider them as important. The mention of the invasive *C. quadricarinatus*, was because it affected fish communities, which are of value to them. This emphasizes that the use of the pre-set ecological indicators (macroinvertebrates) in community river health exercises, is not based on communities' interests. This illustrates that citizen science based on scientists' opinions is not of interest to communities.

7.2.4 Meaning of river health

In contrast to the meaning of river health pursued in literature, where several arguments have advanced it narrowly based on singular social indicators or biophysical and ecological indicators, without showing the multiple connections or relationships and the hybrid nature of rivers, the thesis emphasises that the meaning of river health in the Lower Komati is multi-faceted. Literature in Section 2.2 shows that studies have considered river health based on individualised social and ecological aspects without considering the intertwined nature of rivers. The community members' descriptions of river health not only show the social and ecological aspects of river health but also the different relationships and connections between the two. Therefore, this study shows how a unified social-ecological understanding of river health is formed, based on communities' shared and individual experiences with the river. The participants' views on river health are intricately linked to how they project their personal, collective meanings and observed changes taking place in their surroundings. This is novel, as previous studies focused on social and ecological considerations as individualised indicators as described in Section 2.4 and did not consider existing relationships that have an impact on river health.

Communities related river health to the fitness of the river for different benefits, human observed ecological conditions and river flow for cultural rituals, which all show human and nature connections which have not been explored in most river health studies, as shown in Table 2.3. The communities did not separate themselves from the river as they explained river health and highlighted their different connections to the river, making it increasingly difficult to see a separation between these two realms in river health monitoring. The links and connections between humans and rivers show that the river's health condition is complex and has a deep entanglement with the community and that several external factors (for example politics) influence the river's health. River health is also associated with the area's political history which shows that it is equated as a socio-natural coproduction. This emphasises the consideration that river health should not be narrow and assumed based on singular values but that multiple connections and relationships between the social and ecological aspects should be also be considered during assessment.

7.2.5 Theorising river health using the political ecology approach

Communities portrayed the intertwined nature of society and the environment in the Lower Komati River which seems to have led to ecological and political forces constantly shaping the hydro-social landscape in the catchment, impacting the river's health. Greider and Garkovich (1994:1) explain that "every river is more than one river" and that its physical structure has no meaning without a reflection on the cultural and historical identities of the people and the area. So, the research recognises the history and political nature of the Lower Komati River by analysing the everyday water use praxis in the catchment. This shows that the Lower Komati River is not just a network of habitats as explained in Chapters 4 and 5 but a living entity capable of being influenced by history and politics leading to variable river health states as explained in Chapter 6. Jackson and Barber (2016) explain that in as much as water is a natural resource and of societal use, it also possesses political power and history which are embedded in the ecological processes.

This research adopted socio-nature and waterscape concepts as political ecology approaches to explain the embeddedness of history and politics on river health. These approaches provide a basis to understand how the operations of power and politics in systems, the inextricability of ‘social’ and ‘natural’ objects, the process of its formation and where the social and natural system's hybrid is formed (Bassett & Peimer, 2015). The socio-nature concept showed that socio-politics and natural attributes of the river interact and hybridise over time to co-produce and transform the river’s health conditions and shape the Lower Komati waterscape and its flows. The political history, hydrologic and biophysical conditions are linked in the thesis to show their contribution to the transformation of the Lower Komati waterscape health conditions.

Historical and post-apartheid practices in the catchment significantly contributed to the development of a complex web of pressure and actions that have produced the present river health conditions in the catchment. Results show that due to political, historic policies, taps were introduced without direct consultation with communities. This draws attention to relations between social power and the rerouting of natural watercourses through constructed water taps. The taps meant that the river no longer occupied a central position in the community. The taps changed epistemologies about the river and re-engaged this waterscape, as some cultural hotspot areas were abandoned for new ones. This is in agreement with Molle (2009), who states that river basins are a political and ecological construct; in this case, political actors and the physical environment play a role in framing the Lower Komati waterscape. The physical transformation of the Lower Komati river’s flow led to a shift in the way it is perceived by communities, leading to a fragmented waterscape, although the river catchment remains an integral part of the community. The thesis argues that as a result of politics, the Lower Komati experienced biophysical and water access changes that affected the river’s health. This presents the river as a new ‘hybrid’ of the social-ecological interaction.

This thesis shows that the simplification of river health drivers to habitats only, as expressed by the ecological indices in Chapters 4 and 5, uses methods that are too linear and do not account for complex causes of river health degradation. It conceptualises that there is a need to understand politics and history and engage with questions of water access to better understand river health in the Lower Komati river. The thesis demonstrates that treating the river as a historical and political object adds more layers of meaning, specifically the layers of human experience and historical knowledge in river health. The catchment’s political history and people’s experiences are linked to the river’s changing condition. The local people highlight historical injustices and the loss of control over the water resource (through tap water supply) and how all these influence Lower Komati river health. This shows that the state of the river’s health is recorded in the memories and experiences of the local community from the past which may be useful to expand understanding of river health drivers. Thus, recognition of political rooted asymmetries (brought by apartheid) by the participants provides a step towards social transformation and pluralism in Lower Komati river health decision-making. Consideration of politics, power and pollution as central in river health is one major novel contribution of this thesis. As per section 2.4, there has been much research on river health regarding developing cultural indicators, without considering river health from the political lens.

River health should be treated like all ecosystem processes, which are nonlinear with feedback loops between social, political, biological, physical and chemical processes at different levels to explain complexity (Parker & Oates, 2016). This notion extends to the thesis, with an emphasis on how the multilinearity of the catchment can lead to the formation of waterscapes of river health, as these look at politics, power and ecological systems. Studies (Jackson *et al*., 2008; Harmsworth *et al*., 2016; Gratani *et al.*, 2016) explain that river health from a multi-linear approach has paid attention to culture, social wellbeing and ES without considering politics and power existing in the catchments. Thus, this thesis makes a novel contribution by looking at the river's health through the waterscape lens. The waterscape explores both ecological and political histories to shed light on their long-term effects on the river's health. The thesis shows that processes of political change transform both social and physical environments and produce social and physical settings with new and distinct qualities (changes in river condition). Thus, the production of a waterscape is crucial to understanding river health dynamics, which have not been discussed in most river health studies and is a major contribution of this research. The thesis contends that an interdisciplinary approach, highlighting the interdependencies between politics, power and pollution of rivers, conceptualises and expand understanding of social-ecological river health.

7.2.6 Role of local ecological knowledge in river health assessment

The research shows that communities have acquired local ecological knowledge to explain changes in river health conditions and ecology depending on their use of the river. The local communities referenced their experience and how they perceived the human and river relations as they reflected on the Lower Komati's present river health. Analysis of the communities' conversations showed that local ecological knowledge and practices were acquired through the accumulation of experiences over generations, society-nature relationships and community practices. Local knowledge generated is adaptive and transforms alongside experiences and observation (Menzies and Butler, 2006; Vandebroek *et al.,* 2011; Williams *et al.,* 2020). The chosen descriptions reflect manifestations that have been observed which may not be manipulated or constructed by humans but rather experienced (Corburn, 2003; Bhaskar, 2008). Participants reflected and undertook a comparative analysis of their experience in the use of the river, in the past and what is happening now to describe the river health of the Lower Komati River.

The use of local ecological knowledge uncovered social-ecological dynamics and local indicators to determine river health acquired over the years. The local ecological knowledge was similar across all the participating groups, which shows its usefulness to set river health indicators that are locally understood and meaningful to the community members. The use of communities' local ecological knowledge is mostly un-explored in river health monitoring in South Africa and this is a novel contribution to the study. Local knowledge about the river is identified as a catalyst for indicator development, contributing to the social capital of the catchment. Sabai (2020) argues that indicator development for community monitoring should be rooted in contextual realities to stimulate engagement. The locally represented meanings are embedded in the communities' daily language, which makes them ideal indicators as they reflect their day-to-day activities.

Moreover, some local ecological knowledge was similar to the scientific knowledge established about ecological processes in the river. This shows the co-existence of the two epistemological knowledge (scientific and local knowledge) perspectives, which could be co-used to complement each other during monitoring by analysing where there are contrasts and similarities. Integration of local and scientific knowledge in natural resources management studies is important to enlarge, complement and corroborate shortcomings of each knowledge system (Berkes, 2012; Giordano *et al.,* 2013; Cebrián-Piqueras *et al.*, 2020) and provide a wider process to understand river health monitoring by communities and scientists. Authors (Berkes *et al.*, 2000; Turner *et al*, 2014) advocate for the co-use of local and scientific knowledge and explain that acknowledging different knowledge epistemologies fosters true integration. This study draws insights from Raymond *et al.* (2010) who explains that the existence of different knowledge epistemologies in an SES may result in hybrid knowledge.

In this research, scientific assessment of river health using fish (in Chapter 5) considered abundance and diversity of fish species as indicators, which was also done by fishers using local knowledge. However, the fishers' local ecological knowledge moved beyond just abundance and diversity but also considered the condition of the fish's body. With that said, if locals' knowledge on fish skin condition can be merged with the already used scientific information on fish diversity, new hybrid knowledge (using diversity and skin condition) can be formed. The hybrid knowledge can be used to assess the river's health in a comprehensive way that considers the integrated knowledge systems. The hybrid knowledge addresses both qualitative and quantitative considerations of river health. It is relevant to address the river's social-ecological river health concerns by using locally relevant indicators.

The formation of hybrid knowledge for river health assessments will also help in correcting the notion that local ecological knowledge fills gaps of scientific knowledge and the current discourse that local knowledge assumes a subaltern position. As discussed in the literature review, Shackeroff and Campbell (2007), Hohenthal *et al.* (2018) and Eimer (2020) attest that local knowledge takes a subaltern position, as most often scientific knowledge is regarded as universal while local knowledge's role is to fill in the gaps. The authors suggest the formation of an effective partnership through research between locals and scientists to acknowledge the two knowledge systems and find ways to overcome the divide between these systems, which the integration in this research seeks to achieve.

This research suggests the formation of new hybrid knowledge that considers values of both knowledge systems, social, cultural and ecological contexts so that they are equally considered in use. The production of hybrid knowledge embodies natural and social components as the entity produced is inseparable from new heterogeneous material (Dempsey & Robertson, 2012; Bear, 2017). This shows that with the hybrid knowledge, new information that is grounded on social-ecological values and does not put either local or scientific knowledge as superior emerges. This may be possible if conditions that are necessary for stimulating learning and emerging between these knowledge systems can be prioritised and established through participatory mapping in this research. Moreover, the establishment of symmetric dialogues between scientists and local communities allows the empowerment of local people is recommended.

7.2.7 The emergence of sense of space and solastalgia concepts in river health

The concept of sense of place and solastalgia emerges from interactions about the river's health condition and shows the relationship between social and ecological systems. Albrecht *et al.* (2007) explain that humans respond in different ways when the physical landscape is transformed and stripped of its capacity to provide solace. In this thesis, solastalgia is the main concept that emerged to describe communities' feelings towards changes in the river. Solastalgia has been described as a place-based expression of a feeling of distress about the environment and represents a social-ecological construct that demonstrates links between individuals, society and the biophysical spheres of the river catchment (Warsini *et al.,* 2014; Askand & Bunn, 2018; Nelson *et al.,* 2020). Sense of place and solastalgia allow for an emphasis on the richly intertwined aspect of defining the places that people cherish while acknowledging the changes that are taking place in the natural environment. Solastalgia and space have been discussed in the literature as crucial to explain the relationship between human and ecosystem health and how the accumulative effects of environmental changes have impacted people's emotional and mental wellbeing (Askland & Bunn, 2018; Galway *et al.*, 2019).

As explained earlier in Section 6.4.3, the river has different symbolic significance to local communities, as a place where values and beliefs about the river are shared and reinforced and as a place of history, development, ecological resources and services, recreation, visual aesthetics and nostalgia. The river catchment is interpreted as a 'place' with multiple characters and relationships and all these lead to place attachment. People's interaction with the Lower Komati River led to place-based sentiments, values, beliefs and relationships between humans and the river from which emotional meanings and interpretations arise (Seamon, 2013; Nelson *et al.,* 2020). Thus, when describing the present condition of the river, participants showed feelings of solastalgia for polluted areas. This emphasises solastalgia as a place-based emotion, exhibited as a result of the destruction of the Lower Komati River. Solastalgia is a result of emotions, meanings, experiences and bonds with the Lower Komati River which makes river health personal and place-based.

This research shows that changes in the river's condition and fitness for use of the river are observed or realised from an emotional and personal point of view, thereby visualising the river systems within a coupled human-nature space where sense of place and ecosystem state occurs as continuums from unhealthy to healthy. Thus, the thesis contributes to academic debates by theorising that river health from communities' in the Lower Komati River has solastalgia and sense of place elements, which can be used to explain and predict river health changes taking place. The sense of space and solastalgia is exhibited by the participants as they compared the historical and present state of the Lower Komati river. The relationship shows a better understanding of the interpersonal relations between society and nature in the river health domain. The thesis demonstrates that sense of place and solastalgia are socially constructed and produced through water users' relationships with the river and are controlled by changes taking place in the physical domains of the river. Thus, they constitute an emergent property of social-ecological systems that captures emotional and cognitive aspects of assessing river health. This thesis suggests that a local congruent way to determine river health may be through analysis of communities' solastalgia and place attachment feelings. The communities' expression of solastalgia and sense of place offers a route to preliminary determination of changes in river health since destructive changes are seen through the expression of local communities' distress.

Masterson *et al.* (2017) argue that people have unique sources of variation which are important to understand how individual connection of sense of place in a systems perspective differs. Likewise, this research revealed that an individual's sense of place varies, as patterned, by different experiences, which led to systematic differences in meanings, attachment and behaviour towards the river. The unique variation is shown through captured emotional and cognitive connections to the river which are feelings of solastalgia and place attachment demonstrated by the communities as they explained river health (Comtesse *et al.*,2021). Participants with high residence time showed more solastalgic response, tied to a loss of their sense of place as a result of observed river conditions over time coupled with long-term personal experiences. Thus, in this thesis, solastalgia and sense of place are regarded as predictors of the river's health status and can be valuable to use with community members with high residence time. This thesis argues that there is potential to measure river health based on communities' sense of place and feelings of solastalgia to understand the past and present river' health conditions. Analysing communities' feelings of solastalgia and sense of place opened avenues of research that inquire into the social-ecological relationships between the river and human distress, which is novel in river health monitoring.

Shamai and Ilatov (2005) and Materia (2016) argue that a sense of place and solastalgia may be difficult to measure objectively as they are qualitative concepts that cannot be physically observed, to predict the river's health conditions. Thus, Anderson *et al.* (2019) explain that this can be complemented with biophysical attributes of the river that could be observed and offer a more objective way to determine the river's health as these can be observed and tallied with the feelings expressed. Tallying the qualitative approaches (solastalgia and sense of place) together with quantitative (physical conditions observation) is another form of "hybrid" information development for integrated river health monitoring. This also shows the social-ecological perspective of river health - that people's experiences in a place can be used to complement biophysical observation. The feelings of solastalgia are backed by locally congruent indicators not only understood better by the locals but whose condition can be traced from the past (which can be referred to as a reference period) to the present condition.

7.2.8 The potential contribution of social learning in river health

Participatory mapping encouraged interactions and knowledge sharing which are all necessary elements of social learning (Belay, 2012; Cundill & Rodela, 2012; Pagella & Sinclair, 2014) and leads to new ways of thinking and creative solutions as advocated by Wals and Rodela (2014). Participants' engagement during the community mapping processes led to knowledge sharing and production of knowledge. The new knowledge included descriptions of the river functions and interactions which uncovered social-cultural and ecological values of the river. As shown in Section 6.10, during the participatory mapping processes, knowledge was shared amongst the participants, which attracted interactions and encouraged knowledge sharing and transfer from experienced individuals to the less experienced. The sharing of knowledge about the river and other processes yielded knowledge on changes that have taken place in the river over time and indicators of change. Moreover, the process of naming the different fish species, their ecological niches and changes in the physical description of fish by fishers revealed knowledge that may potentially enrich the existing river health monitoring indices and methods (FRAI) in the study area and might be shared amongst participants.

During the mapping exercises, participants identified areas in the catchment that are problematic and may need attention during river health campaigns. The mapping process allowed them to share and explain to each other why certain areas are regarded as areas of concern. Different participants brought diverse viewpoints, perspectives and values and learned new perspectives and values from each other. Del Amo Rodríguez and Vergara-Tenorio (2007) argue that social learning offers the opportunity for community members to learn from each other and reach an agreement, thus in this case they shared the areas of concern and value in the catchment. To develop the framework in this research, social learning may be used to identify areas of common concern in the catchment, which can be used as monitoring points.

As social learning can lead to co-creation of knowledge, better relationships among participants and common understanding about a problem, this may improve management and collaborative actions among participants (Mostert *et al.,* 2008). In this research, during participatory mapping, there was a co-creation of knowledge between participants on indicators that would determine the river's health condition. The elder used reed which was found in some parts of the river but had dried up as an indicator of when the river was healthy. These reeds had been historically observed in the catchment when the river was regarded as clean, which suggests it as their reference site for a healthy river. As the elders shared about the reed, it sparked a conversation within the group as some participants who had not seen this reed asked about it and agreed that the reed be used as an indicator of river health; this depicted a social learning process. Therefore, social learning offered opportunities to share indicators for river health that are locally relevant and address local socio-cultural and ecological realities.

The thesis also found that local elders' inputs may potentially enrich the social learning process in river health monitoring in the study area. Different scholars have emphasised the contribution of elders in environmental management which stems from a sense of generativity and established sense of place (Bushway *et al.*, 2011; Belay, 2012). However, establishing the centrality of the elders' knowledge in river health monitoring is novel work. The elders' knowledge is enriched with experience, based on daily interaction with the environment (Haines *et al.*, 2017). During the community mapping, there were moments of social learning as experienced elder participants shared knowledge about locally used river health indicators, with less experienced youth (discussed in Section 6.9 and 6.10), which is an important aspect of social learning. The elders used metaphors to explain relationships and meaning of river health, that move across ecological and socio-cultural systems and are embedded in their day-to-day language. This shows that knowledge and perceptions about the river are embedded and shaped by experience within the social context. This knowledge shared by elders also has the potential to offer a foundation for river health assessments. Social learning perspectives provided understandings of historical/contextual aspects of indicators used. In a nutshell, this study suggests that for comprehensive river health monitoring, the process should have platforms conducive for social learning, where the communities share locally relevant and contextual aspects of the indicators (Berkes, 2009). Such forums are necessary as they are likely to generate in-depth insights that reflect community views about the river's health and open social learning platforms to improve monitoring using locally understood indicators (Krueger & Flauger, 2007).

7.3 Pockets of integration between the social and the ecological system to improve river health

The problem presented in Chapter 1 shows that river health is social-ecological thus assessments should consider both ecological and social values. Debates in the literature show that not only is river health a social-ecological concept, rivers are also social-ecological entities. Therefore, it is important to consider social-ecological values during monitoring. Studies that have co-used social and ecological indicators in river health monitoring have considered them separately without considering how these can be co-used. Moreover, the river monitoring process in South Africa does not show an explicit integration of ecological and social values in river health monitoring, particularly in the Lower Komati River. This section seeks to answer the third research question, namely; *What are the opportunities of integrating social and ecological systems to improve river health monitoring in the Lower Komati River*?

This section of the research analyses pathways and identifies pockets of social-ecological integration that exist to improve river health monitoring. The previous chapter showed that there exist different relationships between the Lower Komati River and the local communities and these connections portray the river as a social-ecological system. The different connections and relationships between the river and local communities are uniquely based on the use of the river and the area's past political history. The different relationships are particular to local settings, thus the development of an integrated river health assessment framework that is site-specific which will take into consideration the specific social-ecological variables in river health monitoring is important. Data collected in this research in Chapters 4, 5 and 6 show that the ecological and social data collected have areas of correlation that may be used to develop an integrated river health assessment framework. This section presents how and where the social and ecological findings of the research can be merged for a social-ecological understanding of river health whilst contributing to the formulation of the framework.

7.3.1 Ecological (scientific) and local knowledge

Participants recognised the importance of ecological concepts and also showed high awareness of a variety of ecological changes in the river with supporting depth of understanding, for example, changes in fish abundance and river flow. The fish species and abundances noted by the participants were similar to the findings in Chapter 5 on fish community structure analysis. The commonly mentioned species by the fishers and community (largemouth bass) were also sampled across the catchment. The fishers' claim that the yellow fish (*L. marequensis)* disappears around the sand mining areas is similar to the survey results in Chapter 5, which show that the yellow fish (*L, marequensis)* was not sampled in Site 3 whose flow class was slow shallow as a result of the upstream sand mining. Communities also showed a particular interest in unusual and unfamiliar species (Australian crayfish) (see Section 6.9), which has now invaded most parts of the Lower Komati River. During the ecological sampling, the Australian crayfish was also sampled as described in Chapter 5.

Participants used their local ecological knowledge to explain historical trends of exploited fish species abundance, which was parallel to the fish community structure analysis shown in Chapter 5. The local knowledge considers monitoring of fish traits based on the diversity, abundance and condition of fish as river health indicators. Fish community analysis (scientific knowledge) also considers fish abundance and diversity to measure river health. This shows that the diversity and abundance of fish have a foundation on both local and scientific knowledge. Community participants also discussed how some fish species change in colour depending on the state of the river (Section 6.5.3), by that the fish tends to be darker when the river is not healthy. This is supported by Helfman *et al.* (1997) and Wallin (2002), who state that rapid colour changes in fish may be a result of stress response, although hormones may also be involved. The fish may be under stress from the dirty water and their colour changes denote the stress. The use of colour by the participants shows that they have observed the fish over time and colour changes is one element that was noted to be important.

The synergies and comparisons show how local communities and fishers have a social-ecological explanation for river health, as they describe the ecological observation using social means understood by the locals. This also demonstrates the formation of their local ecological knowledge as similar to scientific knowledge, which involves community observation of ecological processes over time. Schulte-Droesch (2018) argue that local ecological knowledge is not generated by one encounter but by a multiplicity of processes, interactions and observations that take place. The communities' explanation of river health reflects their understanding of ecological river health based on local ecological knowledge laced with experience. This shows that local and scientific (ecological) knowledge co-exist in a social-ecological system such as a catchment that has been generated as a result of the relationships forged between nature and society. The communities' explanation of river health reflects the hybridisation of their local experiences with scientific understanding. Therefore, this research broadly conceptualises the synergy of local's ecological and scientific knowledge as an integral part of the Lower Komati River which can be used to improve river health monitoring by using locally understood explanations and indicators.

Participants also used words with a common understanding of the scientific literature and local ecological knowledge. Participants explained that increased dumping of solid waste leads to the formation of a 'bloom' as explained in Section 6.6.1. This 'bloom' was identified as algae bloom which literature shows grow in areas of high nutrients as an early sign of eutrophication. The locally understood word is formed as a result of observed ecological processes but explained using the locally understood word, which portrays the formation of hybrid knowledge. This existence of similar ecological concepts shows that there exist, contextually relevant information to both communities and scientists. The thesis, therefore, theorises that the existence of similarly understood concepts in river health indications offers opportunities for an integrated understanding that takes into consideration both local and scientific knowledge to improve river health monitoring. This is essential to move beyond segregating `local ecological knowledge' and 'scientific knowledge' towards the emergence of knowledge understood by both scientists and local communities. This offers an opportunity for river health monitoring to be decolonised, which will make river health monitoring relevant and congruent to the local communities while linking it to their local knowledge, as common knowledge contributes more to the societal transformation of understanding river health.

7.3.2 Social-ecological river health variations

Other pockets of integration to strengthen river health monitoring can be through comparing variation of river's health condition as shown by the social and ecological analysis. River health was identified in different sites in the catchment using human experience (social analysis) and ecological analysis. The social and ecological analysis shows that the river's health condition varied within sites and times. The ecological analysis shows that some fish and macroinvertebrates did not occur as expected based on reference data. Site 4 in both fish and macroinvertebrate community structure analyses had the lowest EC score. The ecological state of the river at Site 4 was ecologically categorised to be largely modified. Social analysis of river health showed comparative results for Site 4 river health condition with the ecological analysis.

Social analysis of the river health condition by local communities from Mzinti and Kwazibukwane (areas in proximity to Site 4) showed that fishing areas around this site are unhealthy as they experience low flow and increased solid waste disposal downstream of the Kwazibukwane town which the local communities described as the main cause of the decline in river health. Local communities identified changes in fish abundance and skin condition. The participants attributed the low abundance of fish in this area to increased solid waste disposal, thus they have abandoned some fishing areas around Site 4, which indicates a change in the social value of the area as a result of the river's condition. Van Riper and Kyle (2014) argue that there are identified differences in stakeholders' environmental worldviews and the perceived value of places across spatial scales. Therefore, the participants provided their different perceived views on the state of the river based on experience.

Social and ecological analysis of river health showed comparable results to explain temporal variation in river health. Some expected species were not sampled as explained in Section 5.2, which shows that the river's ecological condition had declined. Social analysis based on participants' experience and their historical knowledge about the area showed that there have been changes in the river's condition over time and the apartheid period in South Africa was identified for reference. Participants used their local knowledge, history and experience of the catchment to provide information on the catchment's temporal river health patterns. This information was collected through historical narration from local communities with experience of the river's condition. Participants noted differences in species present now than previously observed. Participants observed diminishing numbers of the *silver robber* (sardine) in some areas, for example around sand mining areas where water flow has slowed down. The disappearance of the species is confirmed by the ecological data collected in Chapter 5 as no silver robber was sampled in any of the sampling campaigns, whilst reference data from the PESEIS database of the Department of Water and Sanitation (South Africa) and the Atlas of Southern African freshwater fishes (Scott, 2007) show that they were present. This shows that there is a similarity between participants' historical observation and historical ecological reference data. Thus, a river's historical condition can be explained by both ecological data and participants' experiences.

Using historical ecological data and participants' historical information about the river's state extends the investigation and provides more information from human experience and observation to complement historical ecological data collected. The analysis on the sites' river health by participants provided more information on the history, drivers and social and aspects of the river catchment. The mention of locally relevant river health indicators e.g fish skin' condition, increased solid waste which slow river flow, is considered as a starting point to set up indicators appropriate for citizen science monitoring. This addresses the shortcomings discussed in section 2.13, that communities' participation in river health monitoring through citizen science and in environmental education programmes in South Africa, is passive and without the active contribution of stakeholders in all decision making and setting indicators (Odiyo, 2018). The participants' social analysis offered a detailed history of drivers and social aspects of the river's health based on human experience, which would be useful to improve citizen science and communities' environmental education programmes/ The main point of integration is that social analysis provides locally relevant indicators and human experience, which are more personalised and relevant to communities' needs. Thus environmental education programmes that involve social analysis will be more accepted.

7.3.3 Reference sites

As previously discussed in different sections of this research, the perception of a reference site, which is close to the natural state (pristine) in river health monitoring is challenged by the thesis outcomes and literature. Participants did not base it on *pristine* conditions when describing river health (Chapter 6). Rather, participants based it on their ability to use the river and on 'the eye of the beholder'. The results from fish and macroinvertebrate data also showed that the assumed reference Site 1, which is upstream of the catchment, could not be ascertained as a reference site. The ecological analysis showed that it has been impacted by human activities as discussed in Sections 4.4, 5.4 and 5.5. This shows that river conditions have shifted away from natural reference conditions as a primary guiding ideal.

Based on the social analysis, human communities' reference of a healthy river was based on the fish's skin condition, absence of solid waste, and ability to conduct cultural rituals as discussed in sections 6.5 and 6.6. In essence, their reference condition was based on their satisfaction with the use and experience of the river. Thus, the thesis argues that the way a river's reference site is framed and measured, should be a compromise between naturalness and use with a more inclusive understanding of how the river is used by human communities. This takes pragmatic steps towards a 'best achievable condition' instead of having 'pristine' reference sites. Although efforts to use the best achievable condition instead of 'reference sites' has been established in the country through River Quality Objectives as discussed in Section 2.8, the process does not offer adequate opportunities to determine what matters to the local communities (best achievable condition). Thus, a novel contribution of this thesis is the inclusion of social value ratings by communities to determine the reference conditions through the determination of social-ecological hotspots. This is abstracted from the participants' historical, local, ecological knowledge and experience represented by social groups and individuals who encounter the river daily.

The community satisfaction with the use of the river and observed abundance of fish and satisfaction with its condition is suggested as the hotspots 'reference conditions'. The determination of the hotspots is based on how communities value the sites which are then incorporated with the ecological condition of the river based on the ecological assessments. These hotspots are suggested as entry sampling points, and their determination is more participatory, making them more suitable for use in the framework as they determine where to sample based on ecological status and social use of the river. Incorporating these social ratings calls for active participation of local stakeholders at all stages, which is the foundation of the integrated framework from the initial planning stage when deciding what to measure, where to measure and the actual assessment. The use of the social ratings also considers local communities' ecological knowledge, which can be incorporated with scientific knowledge to give an integrated understanding of river health. The co-use of these knowledge systems is an important trait of the framework.

The co-use of scientific and local ecological knowledge to determine reference conditions offers opportunities to improve understanding of river health leading to the emergence of social-ecological reference conditions. These will be the hybrid reference conditions that show that a river has ecological and social importance. This approach will also minimise the subjectivity of the pristine condition to be assumed as reference conditions but rather make use of the best achievable reference point. Neis *et al.* (1999) and Medeiros *et al.* (2018) explain that uncertainties and subjectivities are reduced and evaluations become more convincing when local ecological knowledge is used with scientific validation. In this research, the ecological and community knowledge systems provide a complementary model of how a reference condition provides a fuller understanding of the river's social and ecological priorities. The two different epistemologies used to develop the reference conditions will foster a true integration from social context narratives of a reference site and ecological evaluation to a level well understood by local communities and scientists. Together, they will provide an enriched understanding of what constitutes a reference site from a different worldview in terms of assessing the health of freshwater systems.

7.3.4 The link between the ecological condition of the river and its social function

The thesis shows a link between the ecological condition of the river and its social function (supply of ES), which has not been well represented in river health monitoring in South Africa. Chapter 4 and 5's findings show that the ecological structure (fish, water quality and macroinvertebrates) is compromised and Chapter 6 shows how the social structure (ecosystem service supply) is also compromised. Sections 4.2, 4.3, 5.4, 5.5 of this research show that all parts of the Lower Komati River have deteriorated water quality, changed fish and aquatic macroinvertebrate community structures compared to reference conditions. Chapter 6 shows that increased solid waste has compromised the use of the river for the different social values (cultural use and fishing). The usability and accessibility of some parts of the catchment for cultural use and fishing has decreased, as a result of high solid waste dumping and reduced flow in the river.

The ecological condition of fish, macroinvertebrates and water quality provides insight into the opportunities and constraints on the use of the river for fishing and cultural rituals. As the fish condition is compromised, the value of fish and demand for resources which are attributes of the social subsystem are compromised. This emphasises the relationship between people and the river through reciprocal interactions. The degradation negatively affects local communities' benefits and values which poses a threat to people and the ecological well-being. This shows a linkage between ecological and human well-being and this linkage is in line with the social-ecological system theory as proposed by Ostrom (2009), about the interactions between the societal and ecological systems. The thesis conceptualises that the ecological and social river health subsystems of the Lower Komati

River, are interlinked with feedback loops involving biophysical processes and human behaviour within the social and biophysical contexts of the catchment.

The river's deteriorated ecological condition and threat to use of the river highlights a point of convergence for uniting the social and ecological systems of river health because it embodies a common language of change in terms of the river's ecological condition, social value and use. This portrays a social-ecological and hybrid explanation of river health, which is grounded on the ability to maintain ecological structure and provide social functions. This emphasises that rivers are interconnected SESs embedded in the biosphere, which also applies to river health (Folke *et al.*, 2016). Communities' response to change from the ecological system shows the feedback and relationship between the social and ecological system as explained by the SES theory. The river's ecological resilience is compromised and has a feedback effect on social resilience as the communities seek alternative places. This shows that monitoring from a social-ecological viewpoint not only manages to detect the state of the river ecosystems but also the ability of society to transform and adapt in the face of change.

7.4 Development of the framework

Results from Chapters 4 and 5 of this thesis highlight the inadequacy in assessing a river's health based only on the river's ecological component. Chapter 6 shows that there are several relationships between the local communities and the Lower Komati River and these relationships influenced the meaning of river health and local indicators of river health as perceived by participants. The first two sections of this chapter summarised findings from the previous results chapters and also identified pockets of similarity and integration between the social and ecological analysis of river health whilst explaining how they can be merged for a better understanding of river health and improve monitoring. This next part of the chapter will show how the social and ecological analysis of river health can be merged through the development of a comprehensive river health-monitoring framework. The framework hopes to address the complexity and variability in assessment by considering the ecological and social indicators that are locally congruent to the catchment in river health monitoring. What makes the framework unique is that it allows communities and scientists to collectively reframe river health as a social-ecological concept showing all the social-ecological pathways and relationships.

The literature review showed that rivers are considered as social-ecological entities. However, in South Africa, social and ecological dimensions of river health assessments have not been considered; the formation of an integrative monitoring framework is not available. In the thesis study area, there is limited documented evidence on the social-ecological understanding and monitoring of river health which incorporates local ecological knowledge and indicators in the assessment. Although there have been efforts to incorporate social and ecological attributes in the setting up of Resource Quality Objectives as explained in section 2.11, the framework does not accommodate the use of community-relevant indicators during monitoring. Stakeholders' involvement ends at the specification of ecospecs and priority units. The RQO process also does not consider the involvement of stakeholders at the monitoring stage. Monitoring of RQOs is primarily based on water quality and quantity narrative and numerical limits without considering social indicators. As the DWA explain RQOs are clear goals or numerical concentrations relating to the quality of the water resource which also promotes the inclusion of stakeholders in determining the main water uses in the area. However, the RQO framework does not allow stakeholder participation in setting up locally relevant indicators. Instead, the RQO variables are based on biotic indicators (fish, macroinvertebrates and water quality). There are no social attributes indicators, whilst the river's quality objectives are measured only based on biotic indicators as discussed in section 7.2.4. So there is a need for a framework that takes into consideration of social and ecological attributes of a river and community-relevant indicators in (monitoring).

Hence there is a need for an integrated framework that takes into consideration of social and ecological attributes and indicators through the end of monitoring. Without a clear framework for mutual consideration of social and ecological indicators, there is no space for communities to make any claim during monitoring. Thus the framework advanced in this thesis, offers opportunities for the development of locally relevant monitoring indicators to provide historical and local ecological knowledge about the areas' river health, particularly in places that have not been monitored and where the documented knowledge base is poor. The thesis combines the concepts of SESs (Cabello & Willaarts, 2015), political-ecological concepts; socio-nature and waterscapes (Swyngedouw, 1999; Bassett & Peimer, 2015) and the social learning theory (Mostert *et al.,* 2008) to show how river health monitoring may consider a social-ecological framework in assessments.

The SES framework lays a foundation to explore and unpack the social-ecological relationships in the catchment and how these have led to the current river health condition. Ostrom (2009) and Partelow (2018) explain that the general SES framework considers a list of variables that may be interacting and affecting outcomes in the SES. The SES concept focuses on the interdependent linkages between social and environmental change and how those interdependent linkages influence the management of natural resources at different scales (Fischer *et al.,* 2015). However, the SES framework does not focus on the formation of a new hybrid from social and ecological interaction. The socio-nature and waterscape concepts complement the SES by providing an analysis of how traits of a new hybrid system of ecological and social attributes are formed (Stojanovic *et al*., 2016). This framework will also take into consideration the participation of communities, use of local knowledge, past political history of the area, all analysed using the waterscape and socio-nature concepts.

The waterscape and socio-nature concepts show how the social and ecological interactions in the Lower Komati are understood as a new hybrid that expands the understanding and monitoring of river health. The socio-nature concept is used to analyse how scientific and local ecological knowledge may be formulated to a hybrid kind of knowledge that is unique to the Lower Komati River to improve monitoring. During community interactions, new information is produced and shared amongst the participants. The social learning concept is used to explain the transmission of knowledge between users and identify common knowledge and indicators used to monitor river health trends (Pahl-wostl *et al.*, 2007). Thus, the social learning concept analyses knowledge shared between communities and related contestations that emerge as a result.

The framework for the research is inspired by the human and nature approach. The river health assessment based on such an approach is necessary to show that rivers have unique social-ecological traits (as explained in Section 2.6) which may be important in river health monitoring. To develop the framework, a bottom-up approach was followed to find key variables and factors important during river health monitoring in the Lower Komati River. These include human and nature relationships, relevant knowledge and indicators, and power relations. Section 2.10 of the literature review showed that when working with communities in resources monitoring, it is important that indicators are co-developed with communities to reflect locally relevant changes as understood and experienced by the locals. Thus, the framework process is action-oriented and built on transdisciplinary principles of collaboration, with communities in proximity to the catchment. Validating and applying the framework is beyond the scope of the thesis.

Based on the results of the social-ecological analysis of river health and the number of drivers influencing the condition of the Lower Komati river system, it is now important to develop a framework that considers social-ecological analysis. Section 1.1 shows that the current river health monitoring in South Africa is based on a Decision Support Framework which only distinguishes causes and sources of the river's ecological condition and makes no mention of social condition or the river's social value. The existing river health framework as shown in Figure 1.2 and as explained in Section 2.9 does not offer opportunities to integrate social analysis and active participation of communities in river health monitoring. Thus, this five-tier social-ecological framework is proposed as a novel way to improve the river's health assessment and show how the social and ecological analysis of river health monitoring can be co-used to offer a better understanding of the social-ecological complexity of the Lower Komati River health system. The five key steps proposed in the river health assessment framework are:

i. Assess governance dynamics in the catchment; establish multi-stakeholder groups, their interest, power and enabling environment;
ii. Analyse and link the river system's social and biophysical relationship;
iii. Identify a suite of social-ecological indicators and monitoring techniques appropriate for each indicator;
iv. Identify appropriate sites as entry points for monitoring (sampling sites); and
v. Conduct a river health assessment and determine if the indicators and monitoring techniques are satisfactory.

Figure 7.1 illustrates the proposed river health assessment framework that integrates social and biophysical elements of a river ecosystem.

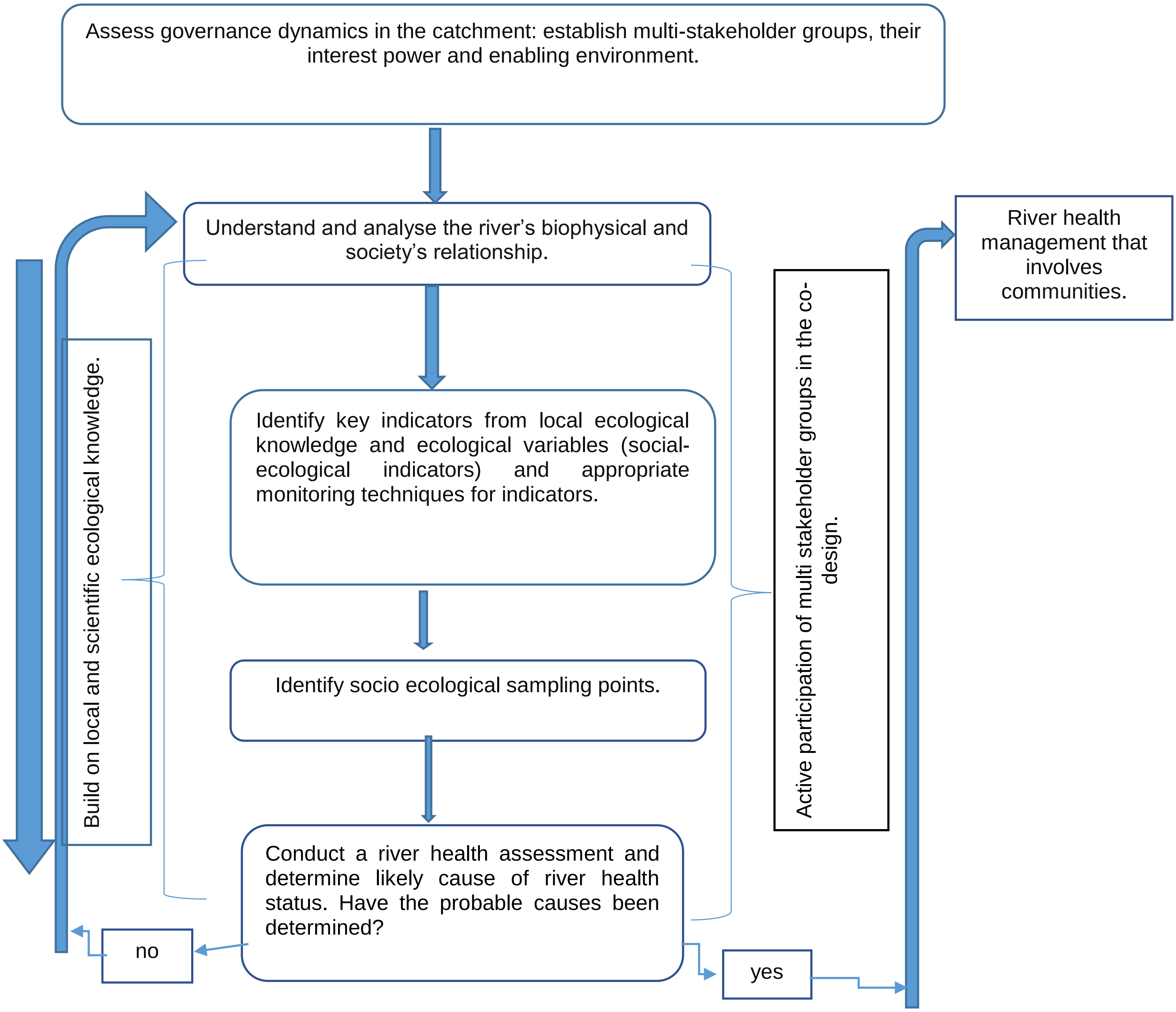

Figure 7.1. Proposed Framework to assess river health condition that integrates societal and ecological factors.

Figure 7.1 shows the development of an integrated framework for river health monitoring that incorporates social values and the biophysical condition of the catchment. The framework suggests that comprehensive river health assessments should begin by analysing stakeholders in the catchment to ascertain their interest and power of influence, thereafter, characterising the social-ecological nature of the Lower Komati, which will then guide the selection of indicators and monitoring sites. These will be social-ecological indicators that are locally relevant and take the uses of the river and drivers of river health into consideration. Thereafter, appropriate monitoring techniques that are suitable for the indicators and locally congruent are identified. This monitoring will be introduced in river health social-ecological 'hotspot' areas (sampling sites) which will be regarded as entry points for the monitoring. Lastly, as Chapters 4 and 5 showed that ecological river health can be uncertain and complex, the framework will be adaptive to any changes in the catchment. During the assessment or after the process it is important to determine if the indicators and monitoring are satisfactory to local conditions. The flexibility also provides the opportunity to link with previous steps and correct if necessary.

7.4.1 Assessment of governance dynamics, enabling environment and establishing stakeholder groups

Before one can construct an integrated river health monitoring framework it is important to consider governance dynamics, which include power relations, that exist in the catchment that will influence the social-ecological framing of the river health monitoring process. Water governance looks at how water resources development and water management decisions are made, making it contextual for each particular water resource (Neef 2009; Megdal et al., 2017; Bertule *et al.*, 2018). Akhmouch and Clavreul (2016) and Wehn *et al.* (2018) recognise stakeholder engagement in water governance processes as an important attribute. Planning and decision making are critical elements for the active participation of all stakeholders (Ananga *et al.,* 2017b; Gray *et al.*, 2017; Thoradeniya *and* Maheshwari, 2017; Sterling *et al.*, 2019). The authors state that decision-making should include outlining of scenarios, discussion of indicators, where to monitor and management options with scientists and managers. According to Galvin (2011) power in water resources management is concentrated at the top of the pyramid, which is the case in Lower Komati.

Discussions with community participants revealed that decisions on what to monitor and where to monitor lie with the catchment agency. Even literature (Nare *et al.*, 2011; Volenzo & Odiyo, 2018) shows that in South Africa, community participation in river health monitoring is without the community's contribution and input in decision making, as they are only involved in data collection. Thus, communities' opportunities to influence the programme and offer inputs are limited, as decisions on where and what to monitor lie with scientists at the catchment agency. This shows a disparity of power. Thus, the first step in this framework is to look at ways of improving governance dynamics by suggesting broad levels of participation. Schoon *et al.* (2015) and Bogdan *et al.* (2019) suggest the polycentricity concept, which enables broader levels of participation between stakeholders. This may also improve connectivity across governance scales that exist in a catchment.

The first step in this process is to establish multi-stakeholder groups in the catchment that will participate in river health monitoring. Wehn *et al.* (2018) explain that stakeholder participation is rooted in community participation approaches, which argue that if the local people are involved in any programme, they must be involved in its decision making. To ensure stakeholder participation, Anokye (2013) and Wehn *et al.* (2018) suggest that a stakeholder analysis by policymakers be conducted to determine the relevant stakeholders for the process. Stakeholder analysis is important to determine their power, influence and interest. According to Saravanan *et al.* (2009), stakeholders do not all have the same power, influence and social position to resolve issues and do not share the same views about what is desirable in water resources management. Anokye (2013) suggests that to determine the relationships between stakeholders, participatory methods that show actor-linkage network analysis are preferred. Thus, in developing the integrated framework for river health assessment, it is important to determine the various stakeholders in the Lower Komati River through participatory methods, which will include the different people who use and value the river to determine their power.

Since the framework is rooted in the bottom-up approach, which overarches active participation of communities in every step, it is important to make sure all stakeholders actively participate. Central to active participation are the dynamics of interaction amongst different stakeholders; water users, their interests, power bases and roles (Jiménez *et al.*, 2020). The stakeholder analysis will determine their power and influence in the catchment for active participation. It is also important when conducting a stakeholder analysis to keep in mind that the stakeholders might have multiple interests in the catchment as seen in Section 6.4. Sections 6.2-6.4 explain that the catchment has varied stakeholders with different socio-demographic characteristics and hold a different mosaic of values distributed across the Lower Komati River. The values vary between cultural, spiritual, provisioning and personal attachment. This shows that communities may be one social unit but they have different interests and power in the catchment. Thus, stakeholder analysis is the first important step to determining their interest and power relations, as well as who makes decisions and how.

Results analysis through the political ecology concept showed that local knowledge held by community members seems to have taken a subaltern position compared to scientific knowledge in the Lower Komati River catchment as it is not considered in monitoring. The power disparities between these knowledge systems need effective integration of local ecological and scientific knowledge. The preferment of scientific knowledge over "'local' knowledge should be addressed through meaningful engagement of the communities from the planning stages of the monitoring, which will lead to sharing of power between communities and scientists. Power is shared when communities, scientists and all decision-makers engage to coproduce the agenda (Bovaird, 2007; Rose *et al.,* 2019). Power dynamics that exist in the catchment may influence decision making on what indicators or knowledge should be integrated or used.

Participation that engages with people's power and creates spaces to deepen the understanding of the catchment is essential for creating change. Galvin (2011) and Ayre and Nettle (2015) state that the active participation of communities that considers their involvement from the initial planning stage is pivotal – their involvement specifies what to monitor (indicators), where (sites), what knowledge systems are appropriate and what methods will work. To consider the active participation of communities, David *et al.* (2013) encourage a co-design approach which will also be used in this framework. The authors regard the co-design approach as an important participatory approach in which community members are regarded as equal collaborators. This is a way of sharing power between scientists and communities, which also allows meaningful participation and contribution of both local ecological and scientific knowledge, leading to the new hybrid of social-ecological knowledge that is locally congruent to the Lower Komati River.

7.4.2 Understand and analyse the river system' social and biophysical relationship

The second step is to characterise and describe the social-ecological nature of the river system, to provide information on the river's attributes and existing relationships with the communities. To understand the river's attributes and relationships with communities, ecological and social surveys were conducted (Chapters 4, 5 and 6). The emphasis here is to establish an in-depth understanding of human activities, the biotic (fish and macroinvertebrates) community structures, the local communities' knowledge about the catchment and the relationship between the river's biophysical system and society (communities).

The in-depth analysis of the Lower Komati river's social and biophysical components and resultant feedback formed are illustrated in Figure 7.1 and grounded on the SES, waterscape and socio-nature concepts. Figure 7.1 shows a range of outcomes from ecological and societal relationships that exist in the catchment. In this research, the Lower Komati River's health has been represented based on its biophysical (Chapters 4-5) and societal structure (Chapter 6). Each dimension and relationship that unfold as shown in Figure 7.1 is a criterion for characterising the Lower Komati River and consideration for river health assessment in this catchment. The diagram illustrates the dynamics of the Lower Komati catchment and the cause-and-effect interactions between society and the river's biophysical structure. Figure 7.1 illustrates that the river operates within the biophysical structure (discussed in Chapters 4 and 5), socio-cultural and as well as social factors emanating from outside and within the catchment area (for example politics), leading to the human and nature connections and relationships.

The river embodies biophysical properties, cultural and symbolic meanings and socio-political characteristics simultaneously and inseparably - which illustrates its socio-nature. The biophysical system is envisioned as having a fundamental capacity to produce conditions to deliver material and non-material flows to local communities (society). This leads to the human and nature connection of these subsystems; it produces several social values as explained in Section 6.4. The social values are an 'add on' to the ecological indicators analysed in Chapters 4 and 5, whilst the ecological indicators may show the ecological status and the habitat change as drivers of the ecological community status. The social values go beyond these regular investigative tools used by ecologists but explain the root of problems rather than explaining the symptoms. In this instance, the analysis of the interaction showed that the areas' political history has a role in human's behaviour (dumping solid waste) which then leads to change in the river's flow rate and community of indicators.

The political history analysis broadens and deepens the knowledge base necessary to holistically understand the Lower Komati River's health. Bixler (2013) and Stott and Sullivan (2000) argue that politics reveal the depth, drivers and complexity of environmental problems. The analysis showed that post-apartheid government policies (politics and history) resulted in changes to water access (introduced tap water), as a result, the human and nature connection changed, resulting in human behaviour changes (started dumping solid waste) which degraded the river's condition. Bourblanc and Blanchon (2019) championed the idea that local environmental changes often need to be understood as the outcome of non-local but political processes, structures and events. Understanding the extent of political and historical regimes affecting the river catchment offered a better understanding of the pressures and drivers of the river's health. An analysis of the social and natural interaction in a river unearths empirical complexities and social-ecological drivers of river health, which ecological indicators alone cannot do. The Lower Komati River's current river health issues are attributed to the colonialist power interlinked with anthropogenic changes affecting the system, which have increased communities' vulnerability and decreased the river's resilience. This shows that the effects of human behaviour on the biophysical system and their relationship to other social subsystems (for example, the political system) are reflected in the river's health. Its consideration as a component in the river health assessment framework unlocks a higher level of understanding about what drives the catchment's health condition.

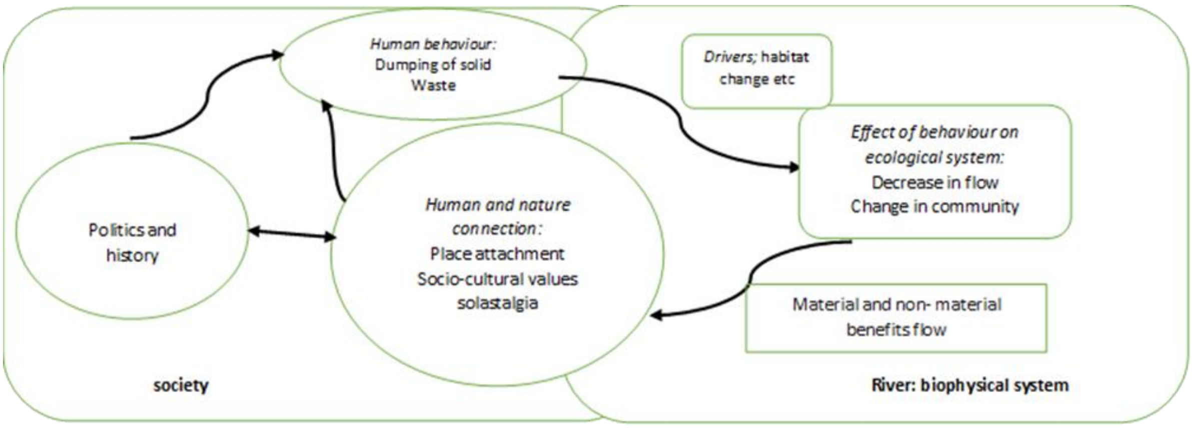

Figure 7.2. Interactions between social and natural systems in the catchment through human and nature connection.

Figure 7.2 shows that in trying to establish and understand the human and nature relationship formed in the Lower Komati River catchment, two major concepts emerged; place attachment and solastalgia. These concepts are embedded in socio-cultural values held by the communities and show that relationships exist between the river and local communities which can be used to describe river health. These concepts work as points of connections between nature and society, to define what matters in the river, which helps to identify and prioritise values to monitor. As a result of the human and nature interaction, place attachment and solastalgia feelings developed in the Lower Komati communities.

The feelings of solastalgia and attachment highlight how the communities' value about the river changes as per the river's condition. Dietz *et al.* (2005) argue that individual characteristics such as values, remain stable throughout a person's life and only change when there are changes in the biophysical system. The communities' emotions shown through feelings of solastalgia are sensitive to the situational contexts. For example, in areas where communities derive abundant fish, they showed high place attachment, while in areas where there is high solid waste disposal leading to decreased river's flow and unhealthy conditions, participants showed feelings of despair described as solastalgia. The human and river relationship analysis highlights that key stakeholders in the catchment, (local communities, fishers and elders) provide a wealth of first-hand information, particularly in characterising the social-ecological river's health condition. They may, directly and indirectly, show important social-ecological attributes important to being considered in river health assessment.

7.4.3 Identification of indicators and monitoring technique for each indicator

The second step in developing the integrated river health assessment framework is to identify appropriate indicators to determine the river health status. Indicators are important measures in making river health assessment decisions. In this instance, the indicators identified trends and changes in the social and ecological structures of the river identified in the previous section. It is important to identify or develop appropriate sets of indicators for river health monitoring that are contextually relevant, locally congruent and ensure practicality in measurement. Thus, suitable key indicators for river health assessment in this section will provide valuable information on the state of the different characteristics of the river that are relevant for both the ecological structure of the river and the communities involved in monitoring. The framework allows for the integration of diverse indicators which include ecological and social variables. The ecological indicators are more focused on measures of the ecological variables of the river, whilst the social indicators measure communities' social value based on their dependence on the river.

As explained earlier in the first chapter, river health involves inherent value judgments about what actions are socially desirable, thus identification of indicators requires community involvement (Lackey 2001). To determine indicators, historical narrations with key informants (fishers and elders) and mapping exercises with local community members were conducted to extract indicators. The participants provided qualitative insights on attributes or indicators of the river's health. The suggested river health indicators showed a link between communities and the river ecosystem through local ecological knowledge, where social-ecological indicators were identified based on what is important to the participants. Transcript analyses showed that their indicators were identified through observing the river condition and fish species based on historical knowledge and experience about the area. The suggested indicators by the participants served as an important tool for directing experiential learning and showing interactions between people and the river.

The participants' descriptions helped extract and understand past ecosystem events, structures or mechanisms that determine ecological interactions and relations, such as the effect of solid waste on fish interactions. Qualitative indicators (shown in Table 7.1) were identified by the communities based on observed ecological changes as explained in Section 6.6, highlighting the different community (society) relationships with the Lower Komati River. Analysis showed that community members and fishers (particularly those that have lived in the area for longer periods) have valuable information that is not recorded by authorities, particularly relating to longer-term changes and trends about the river. The following were the criteria followed by participants in identifying the indicators:

1. the river' attributes under pressure (for example habitat, aquatic reed), species (fish), how the pressure is indicated (colour of reed);
2. condition of the indicators before the pressure (for example flexible and green aquatic reed);
3. current condition of the indicator after the pressure (for example short and brown aquatic reed) and before the pressure and;
4. how the indicators support the human and nature relationship (cultural value or provisional value) and their effects on social value

The identification criteria of indicators by communities were based on, first, identifying the river attributes and pressures that are relevant to their interests, which portrays the local communities and the Lower Komati River catchment relationships. The choice of indicators was based on what component is important to the participants, their knowledge and interests; for example, fishers considered fish condition and river status, whilst elders paid more attention to free-flowing areas for cultural water use. The trends and changes of various variables for example fish skin properties and river flow are regarded as indicators and based on presently and historically identified states using personal experience. Based on their experience living in the river catchment, participants could distinguish thresholds between natural (before pressure) and human-induced impacted (after pressure) conditions of the river. Lastly, the participants explained how the indicators predictor and response affected the river's social value for example; cultural value.

Table 7.1 presents the river attributes/components and indicators that were considered by participants as more contextually congruent to monitor river health, based on the analysis of predictor response. The 'attribute' is what the communities deem to be important and what responds to changes in the river, thus it needs to be monitored. The second column describes the condition of the attribute to indicate change. The third column shows the relationship between the community-suggested indicators and the existing scientific indicators. This shows possible synergies, contrasts, relationships and comparisons between the local communities' indicators and scientific ecological indicators which are from two different frameworks of knowledge. The fourth column shows the monitoring technique to measure each indicator suggested by communities, which are mostly based on communities' experience and relationship with the river.

Fish community structures and stream flow patterns are attributes commonly regarded as important to indicate a river's health condition by both local communities and existing river health indices. Therefore, the fish community structure and flow may help to show the link between ecological and social river health. Both community and scientific indicators prioritise fish community structures as indicators, based on communities' experience and physical observation, whilst scientists base it on comparing present, sampled species population and historical data comparison. In addition to the population structure, communities physically observe the body condition of the fish through touching and feel – an association that depicts that they have intimate knowledge about the fish. Fishers determine a river's health by pressing a fish's skin to determine if it bounces back, as well as fish colour and taste to assess the river's health as explained in section 6.6.3. The fishers use of skin, colour and taste depicts the importance of experience and also deepens the understanding of river health, shows synergies, contrasts in the two systems of indicators and uncovers snippets of integration between ecological and societal indicators.

Table 7.1 illustrates that the identified attributes of river health identified by communities in this study have the potential to complement and expand on what is presently measured by ecological indicators leading to the production of social-ecological indicators which are part of the integrated framework. Fish was identified as an important social-ecological indicator based on its physical condition (social trait) and diversity (ecological trait). Thus to measure social and ecological river health the fish's ecological attributes as used in FRAI and fishers' social traits as described by the fishers' can be co-used to form the social-ecological indicators in the proposed social and ecological framework. For example, fish skin, colour and smell are social important attributes for the local communities and fishers. So, if these attributes are co-used they would widen the river health scope by providing a social and ecological understanding of river health.

Flow is also identified as a social-ecological indicator. The river's flow patterns are important for the communities' social values (cultural use, swimming and fishing) as the use of the river for these values is directly underpinned by river flows (see Section 6.4.2 and 6.5.4) and for ecological maintenance of the fish habitat (see Sections 5.4 and 5.5). Thus, changes in flow patterns have a great impact on both river's social values and ecological condition. Flow as an indicator by communities shows that health is a dynamic state that fluctuates within different flow threshold limits. For example, participants in Section 6.5.4 explained that a healthy river can wash down solid waste at high flows and at a low flow rate the river is regarded as unhealthy because it cannot cleanse and wash away solid waste. Sections 4.4 and 5.5 explain that fish and macroinvertebrates as ecological indicators strive in different flow regimes. This shows the different dynamics in the river and river health indicator threshold. Flow proves to be an integrated indicator that accommodates social, ecological and cultural interactions, which originate from the local ecological and scientific knowledge systems. The indicators and attributes suggested by the communities are based on the communities' priorities, contextual realities (benefits derived) and maintenance of ecology, which shows social and ecological considerations. The social and ecological epistemologies demonstrated through the indicators show relationships between the social and biophysical systems of the river. Reason and Bradbury (2001) suggest that these knowledge systems may be used to supplement each other and empower subjugated communities to equally produce practical knowledge which can be used for the transformation of river health monitoring to include a social-ecological consideration. This is a phase of producing hybrid knowledge (interdisciplinary integration) which includes knowledge and practices from both local communities and existing scientific monitoring.

Table 7.1. Table showing the different river health attributes, and indicators based on communities' and scientific knowledge

Attribute	Indicator	Type of knowledge indicator derived from	Monitoring technique
Community structure of fish	Changes in fish catch frequency indicate abundance of population. Species type indicates changes in the river's health.	Community's and scientific ecological knowledge	Monitor most frequently caught fish species and abundance.
Fish skin	A healthy fish skin bounces back when pressed and unhealthy skin leaves a thumb mark when pressed.	community's ecological knowledge.	Fishers press caught fish with their thumb at a fish-landing site to observe if skin bounces back or not.
Fish colour and taste	If fish looks dark in colour and tastes metallic the fish is unhealthy. If the fish does not have a metallic taste and its skin is shiny it is regarded as healthy.	Community's ecological knowledge.	Fishers monitor fish colour at the landing site and communities (buyers) observe taste.
Solid waste and suspended material	The healthy river must be free-flowing, free from stagnant, dumped solid waste, the water has to be clear such that you can see the sand at the bottom. The presence of solid waste and macrophytes indicate an unhealthy river.	Community's ecological knowledge.	Local water users observe and note the presence or absence of solid waste trapped instream and algae which have developed instream.
Aquatic fibre and reed colour and height	Healthy aquatic fibre and reed should be green and tall. The unhealthy ones are short and brown.	Community's ecological knowledge.	Physical observation of leaves, branches and stems
Flow pattern	Free-flowing river water with no solid waste in sight regarded as healthy. Flow should also be suitable for fish and macroinvertebrates	Community and scientific ecological knowledge.	Detect river flow patterns, variability and long-term changes in flow regime.

Source: Developed from field data

7.4.4 Identification of sampling points that take into consideration social and ecological value

The current framework for river health assessment is based on monitoring sites for natural characteristics and anthropogenic activities in the catchment, which drives the ecological indicator changes. There is no consideration for the changes in social values of the areas where local communities derive different benefits. Therefore, the integrated framework identifies river health monitoring points that consider the river's social and ecological value. This is based on how people have experienced the particular location which is assigned value. Section 2.9 of this thesis explains that the assigned value provide insight into people's viewpoints about natural resources based on people's interactions with the environment. Furthermore, as supported by Seymour *et al.* (2010) and further explained in Chapter 2, Section 2.9 assigned values have been adopted in this thesis as they focus on determining a measure of worth (monetary and non-monetary) relative to other places. So, this section shows how monitoring points may be determined through assigned values, based on people's feelings as they interact with places and the services and goods they derive from that place. So, this section shows how monitoring points may be determined through assigned values, based on people's feelings as they interact with places, the services and goods they derive from that place. This is because people interact with the environment as they get services and goods that enable the generation of values, which can also shift (Seymour *et al.* 2010; Díaz *et al.* 2015; Kenter *et al.*, 2015).

As highlighted at the beginning of this section, the human-river interaction occurs within geographical space (catchment) that is ecologically and socially interconnected. Thus, monitoring sites were chosen based on the connections between the ecological and social systems. Figure 7.2 shows that in the Lower Komati River catchment, the human and nature relationships formed are embedded based on how it is used, thus influencing how different parts of the river are assigned social value by the communities. Thus, this part of the thesis shows that monitoring sites should be based on social and ecological considerations.

This part of the thesis demonstrates the identification of the social-ecological sites based on the concept of social-ecological 'hotspots'. Specifically, Alessa *et al.* (2008) describe social-ecological 'hotspots' as places that are both ecologically and socially important for practical application to environmental planning, use and management. The map in Figure 7.3, reveals the critical areas deemed to be threatened ecologically and socially, which will be identified as entry points for social-ecological monitoring. Developing the social-ecological hotspots follows transdisciplinary research that specifically relates to the socio-nature approach that balances social and ecological disciplines to come up with the social-ecological hotspots which are inseparable. According to Dempsey and Robertson (2012); Bassett and Peimer (2015) the socio-nature approach overcomes the social and ecological divide by having homogenous material with no traits of either discipline overriding to explain the system.

The social hotspots formation was based on the social valuing of different parts of the river by communities based on what is important to communities and ecological hotspots were based on the results of the determined ecological state of the sites. During social valuing, communities identified areas based on how they value them and threats posed to them based on how they felt and also how they use it. The communities distinguished how they valued the different areas by use of coloured dots (green - less threatened areas and highly valued; red - under threat and less valued), as explained in Section 3.4.5. Green dots were used to mark areas that participants regarded as ideal for use and highly socially valued; these sites were mostly associated with Site 6. This result corroborates the ecological river health results in Chapter 4 (Sections 4.3), which show that Site 6 has better ecological integrity; as the SASS and ASPT, scores both classified it at EC A (which shows that most of its attributes are not modified but are almost similar to its natural state). This is because Site 6 (X1KOMA-LEBOM) is on the Komati River in the Kruger National Park, which is a protected area with less human activities and is upstream before the river flows to Mozambique.

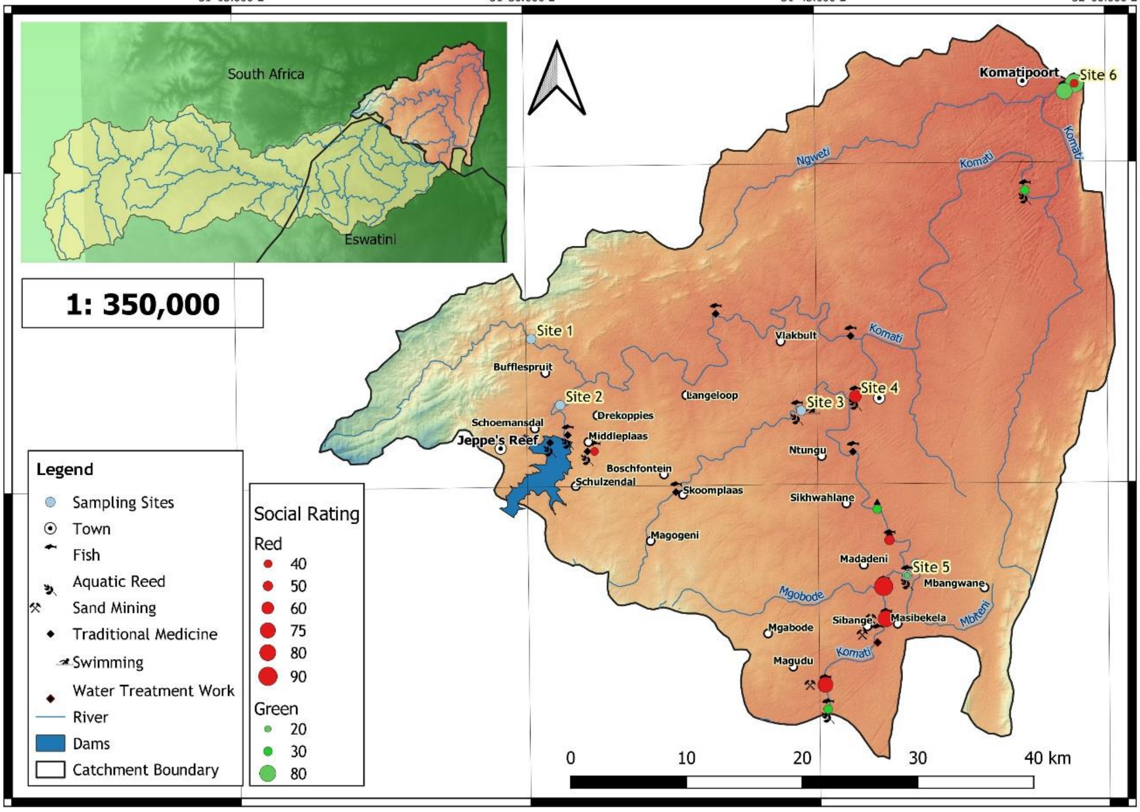

Figure 7.3. Social-ecological hotspots identified in the Lower Komati River

Figure 7.3 shows how research participants (communities) socially value different parts of the river based on their relationship with it. Lowly valued areas were marked in red dots. Participants regarded these areas as areas that pose a threat to their use and relationship with the river. These are areas where there is increased solid waste, resulting in a flow decrease. Community members cannot practice cultural and spiritual rituals and the fish are less appealing. This supports the principle of the place-based value approach, which emphasises that the experience of place is not just physical but also a key source of evidence in understanding social values. Ujanga and Zakariyab (2015) explain that people are likely to place low value in places where they feel a strong sense of dissatisfaction towards arising issues affecting these places. Participants' ability to use those sites is compromised, which also threatens their wellbeing as explained in Section 6.6, thus, they are dissatisfied. One of the participants from Magudu said that:

> *Some parts of the river are now dirty and unhealthy, reduced flow and full of dumped diapers. We cannot baptize or conduct rituals like we used to, we are scared of catching illnesses. Let's mark these areas in red (Community mapping participant, Magudu village 28/02/2018)*

Figure 7.3 shows that the most threatened areas were sites that participants used for fishing and cultural activities. Fishing areas were mostly negatively marked in the Driekoppies areas (a tributary adjacent to Site 2) and cultural activity areas were generally negatively marked in the Mzinti areas (which are mostly upstream of Site 4 and 5). The state of the sites corroborates the ecological river health status as explained in Chapters 4 and 5. Site 4 had the most modified fish and macroinvertebrate community structures compared to available reference data of the area and all other sites. Sites 5 was also largely modified; this was attributed to the state of the habitat at the site, which is impacted by an upstream weir and the presence of sand mining. The presence of weirs is likely to have changed the habitat state of the river, affecting the fish and macroinvertebrate communities as explained in Sections 4.4,5.3, 5.4 and 5.5. Furthermore, in Sites 4 and 5, the alien and invasive red claw crayfish (*Cherax quadricarintus*) was sampled, and participants attributed it to the disappearance of native fish species in these sites. A fisher from Mzinti explained that:

> *There is a new fish that is shaped like a prawn which is now common in the area. Once that fish arrives in an area it dominates and you will see other fish disappearing*. (Key Informant Interview, fisher, Mzinti, September 2018)

The fisher's used their experience to identify changes in the sites caused by the introduction of alien crayfish. The association of Site 4 and Site 5 with the alien species led to the sites being devalued and marked as threatened sites with a high density of red dot as shown in figure 7.3. Based on the threat to biological diversity and reliance of communities on fish, the associated sites are regarded as areas of mutual concern ecologically and socially and 'hotspots'. The social-ecological hotspots suggest threats between ecological biota and people's social values. Thus, sites 4 and 5 will be regarded as 'hotspot' and entry points for social-ecological monitoring since they are of concern to communities and also ecologically. The identified hotspot areas are intertwined product of social and ecological attributes with no prioritizing of either discipline. This embodies a balance in the use of knowledge and prioritizing areas of concern during monitoring. The identification of social hotspots by the local communities also emphasized that people are place-makers who attach meaning and value to space which emerge through experience (Sherrouse *et al.,* 2011). In this case, participants made a judgement on the area based on their experience with the river over time which coincided with the ecological state of the place as measured. This reflects an intimate relationship between humans and the environment. The identification of the social-ecological hotspots for the framework does not advocate pristine or natural conditions as reference sites as the river use is an important aspect in identifying the sites. The identification of the hotspots is based on human experience and available biota at the time. The process embraces present use and present ecological attributes of the system. The identification of areas of social-ecological concern as hotspots and priority areas for monitoring is another novel contribution of this thesis as it has not previously been done. Previously, monitoring sites have been solely based on areas of ecological concern without considering inputs from local communities.

7.4.5 Determine the river health assessment and the likely cause of river health status.

The final phase of the integrated river health framework is to monitor and determine the river's health using social value and ecological conditions. During this stage, the various combinations of social-ecological indicators are monitored to understand the state of the river from an ecological and social point of view. During the process, predictor and response variables of the monitoring based on the indicators are evaluated. The conceptual framework should be applied to determine root causes or drivers of the current river health status and if they are suitable, to ensure that the process evolves to assess the river conditions effectively. This can also be done with the communities by setting up a selection criterion to assess each key indicator. The interrelationships of the predictor and response variables would predict a river health response (such as discolouration, algal bloom, reduced fish catch). According to Brown *et al.* (2018), ecosystem assessment frameworks should provide a flexible approach, so that users can modify if outcomes do not fit the aims of the assessment. So, this framework allows flexibility in that if it fails to predict the river health condition and their probable causes there is a need to repeat the previous steps. If the tools indicate the effects and probable causes of river health decline, management actions to restore the river's health will be determined.

7.5 CONCLUSION

This section showed the development of an integrated river health framework for a holistic social-ecological river health assessment. The development of the framework showed the explicit connection of the social-ecological components of a river's health which ranged from indicators, monitoring sites and knowledge and emphasised the participation of communities during the process. The framework enables the selection of locally congruent monitoring points. The development of locally relevant and social-ecological indicators and monitoring sites can be seen as a step towards practical involvement of local communities in decision making on what to measure and where to measure as envisaged by the country's legislation on participation. The framework is also useful to better understand the relationship between people and rivers and how this expands understanding of river health and shows its effects on the provision of ecosystem services.

8 CHAPTER 8: SYNTHESIS, CONCLUSIONS AND CONTRIBUTIONS

8.1 Introduction

The study was inspired by the fact that river health in definition considers the social and ecological components of the river which include; social-ecological interactions, ecosystem services for people and its ecological function and processes as explained in section 2.3. However, the present river monitoring framework, indices and indicators used in South Africa as discussed in section 2.4 are solely based on ecological variables and processes. Moreover, communities in proximity of the Lower Komati River communities have been highly involved in river health programmes to improve the river's health, however, there is no evidence of their inputs in making decisions on what and where to monitor. Despite community clean up campaigns and monitoring programmes introduced in the area, there have been continued reports of increased solid waste in the river by the communities, which contributes to river health deterioration. This research acknowledged the linkages between rivers and society, however, little research has been done that recognises this linkage to improve river health. Despite the involvement of local communities in river health assessments, the active monitoring was still centred on ecological indicators and sampling sites. Thus, this research was set out to develop a social-ecological framework that takes into consideration the participation of local communities at all stages, deriving indicators and sampling sites that acknowledge the social-ecological relationships between rivers and local communities in river health monitoring in the Lower Komati River.

This is based on the understanding that environmental issues are complex and require an interdisciplinary approach that considers social-ecological dynamics and the active participation of stakeholders to bring in a solution**.** Therefore, it was important to carry out a social-ecological assessment with the active participation of local communities, to understand the human and river dynamics in the catchment and how these may be used to improve river health and monitoring in the river catchment. The social-ecological assessment included consideration of the political, spatial, cultural and ecological facets in the catchment which may be exerted on the river's health dynamics. The assessment was underpinned by the political-ecology, social-ecological systems and social learning concepts. This chapter, therefore, presents a synthesis of the key findings of the study and its contribution to conceptual frameworks.

8.2 Synthesis of findings

The study's overarching question was*; how social, ecological dimensions, human and river interactions in the Lower Komati River may be used to expand and transform the way river health is understood and assessed*, by developing an integrated social-ecological framework for monitoring. The framework hopes to address the complexity and variability in assessment by considering ecological and communities' social value and indicators that are locally congruent in the catchment. The main question was addressed based on six research questions.

The first question was; *What is the present ecological health profile of the Lower Komati catchment system based on water quality, macro-invertebrates and fish communities as indicators?* To address this question the ecological health profile of the Lower Komati River was determined using macroinvertebrates and fish communities as ecological indicators. The results showed a notable decline in species when compared to historical data. Results analysis showed that there is increased pressure on rivers which compromises the ecological communities' diversity and abundance in all sites. These results illustrate a lack of balance between the use and protection of the freshwater ecosystem.

The second question was; *what are the controlling variables that act as drivers on the ecological river health profile of the Lower Komati River?* The research results identified habitat changes as the main causes of the decline of fish and macroinvertebrates species, leading to a decline in the river's health. However, analysis of the history of the habitat relied on expert views, yet these experts did not have the historical and human experience of the habitat. The ecological health results also showed the weakness of relying on assumed 'natural' conditions for reference sites to compare with collected data. Natural reference site conditions show no clear link between people and the consideration of the river's use. Human modifications are widespread in the river and the assumed upstream site 1 as a reference site did not show a true reflection as it was impacted by human activities. The 'best achievable condition' that considers the use of the river is advocated. These reference sites' determinations should be through active participation of communities to 'achievable condition' based on their experience, what the communities value and the river's ecological requirements. The currently used indices, FRAI and MIRAI, to analyse fish and macroinvertebrates respectively do not consider the importance of human knowledge or experience on the catchment's historical activities to determine reference conditions and potential stressors.

The third question was; *what are the various human-nature relationships and local communities' shared social values that exist in the Lower Komati River?* Chapter 6's analysis shows that several relationships exist between the local communities and the Lower Komati River as a result of experience, historical knowledge and multiple social values assigned by the communities. These relationships include personal attachment and solastalgia. These concepts are embedded in socio-cultural values held by the communities about the river and work as connections between the communities and the river to define, identify and prioritise what matters in river health monitoring. The use of the river over time resulted in personal attachment to different parts of the river, whilst despair over the current state of the river was expressed through feelings of solastalgia. People's attachment to the river shaped notions of solastalgia. The communities' description and feelings of solastalgia and attachment about the state of the river's health are based on social-ecological construction, showing that the river system itself is a social-ecological entity.

The research also untangled how the country's political history shaped the connection between the Lower Komati River and local communities, which were also identified as a driver of river health. The research shows that political historic policies and changes in water access signalled a new era of transformation within the catchment which led to river health changes. The waterscape concept explained that social power and the rerouting of natural watercourses through constructed water taps brought different epistemologies about the river, resulting in the Lower Komati River no longer holding a central position in the catchment. The research also recognised that there is a constant transmission of knowledge between local communities, which supports social learning and reflects the relationship between rivers and local communities. The knowledge transmission pathways were identified as opportunities to share locally understood/community-used river health indicators that can be considered during monitoring. Based on the results, the research' main argument is that river health is associated with human-nature connectedness, which is a multifaceted concept incorporating:

- material connections, such as resource use;
- experiential connections;
- cognitive connections, such as beliefs;
- emotional attachment responses; and
- political history.

The fourth question answered by the research was; *What are the opportunities of integrating social and ecological systems to improve river health monitoring in the Lower Komati River*. From Chapters, 4,5 and 6, the research then identified points of integration between social and ecological analysis to show the connectedness between the communities and the river in Chapter 7. These included the formulation of social-ecological indicators, local-ecological knowledge, setting up reference sites and sampling sites based on the river's value to the community as well as ecological considerations. All these points of connectedness were used to formulate the integrated river health framework which answered the last question; *How can a suitable integrated river health monitoring framework that incorporates social and ecological dynamics of the river be developed for the Lower Komati River.* The framework is a five-step tiered decision-making tool on how to monitor a river considering the social-ecological relationships, social values, locally congruent social-ecological indicators, social-ecological monitoring sites and ensuring the active participation of community members. One of the important attributes of this integrated framework approach is considering communities' position and power in the catchment, active participation of communities and offering opportunities for social learning during the monitoring process. Thus, monitoring indicators and sampling sites suggested were all social-ecologically based and took into consideration social-learning pathways and existing relationships. The framework does not consider any reference sites to be pristine reference sites, instead, it recognises that there should be a balance between use and protection by using the 'best achievable condition'.

8.3 Conclusion

The research has shown that ecological indicators (fish and macroinvertebrates) are inadequate to assess the overall river health condition of the Lower Komati River. The fish and macroinvertebrate communities showed a decline as a result of changes in habitat conditions. However, analysis on the history of the habitat relied on expert views, who did not necessarily have a personal history of the human experience of the habitat to explain the root causes of the river health decline. The ecological river health analysis lacked human experience and local knowledge to fully explain habitat changes and root causes of river health decline from a social-ecological system's perspective. As rivers are regarded as social-ecological entities, their health must be determined from a social-ecological perspective. Thus, in the river health framework, community-understood indicators based on locals' experience, priorities, contextual realities and knowledge were also determined. Results from this research showed that local communities have forged multiple relationships and hold varied social values about the river which they use to explain the river's health. These relationships between the river and the local communities are shown through feelings of solastalgia and place attachment portrayed by the communities. These are social-ecological concepts embedded in social values assigned by the communities about the river; they were used to describe river health based on individuals' feelings and emotions. Results analysis showed that experience and use of the river over time resulted in feelings of place attachment, which have resulted in community members placing social value on different parts of the river. However, the river health condition presently shows that it is degraded and community members exhibit feelings of solastalgia towards large rivers (feelings of despair and distress as a result of river health deterioration).

Additionally, through the active participation of local communities, the research shows that local communities use their local knowledge, history, experience and social values not only to explain river health but also to identify root causes/drivers of river health deterioration. Participants used their local knowledge, history and social values to identify drivers of river health by providing more information about the river' health beyond the regular investigative tools used by ecologists, by explaining the root problems rather than just explaining symptoms. Stets *et al.* (2020) found that despite best management practices of water deterioration, the deterioration cannot be fully addressed without understanding the main drivers and root causes. The authors argue that analysing root drivers of river health assists to identify ways to mitigate and identify best management practices of river health. Martin *et al.* (2016) highlight that tackling environmental crises requires social values, principles and attitudes analysis. In this research, participants identified a political history and policy changes as root drivers of the prevailing river health conditions.

Analysis traced how policy changes post-apartheid changed the river from being the central water supplier, as taps were introduced without direct consultation with communities. The introduction of tap water signalled a new era of transformation within the catchment as the river's health began declining. This change brought with it different perceptions of the river and changed epistemologies of water within these communities. The connection between the local communities and the river was disrupted, and re-engaged, leading to a shift in the way it was perceived by communities. The communities now perceive the river as a fragmented waterscape, although it remains an integral part of the community even in its fragmented state.

The participatory approach used in the study encouraged and yielded opportunities for knowledge sharing through interactions amongst participants. This offered opportunities for the local community members to decide which indicators were relevant to monitor in their community and also identify valued sites which could be priority areas for monitoring. This shows that communities share and transmit local ecological knowledge about the Lower Komati River's health. Analysis using the social learning concept revealed the pathways of knowledge sharing and transmission amongst local communities in the Lower Komati River as embedded through learning by interaction. As fishers interacted during the fishing processes, they shared knowledge about determining the river's health. Likewise, community members also shared through interaction during the mapping process.

Experienced participants used their feelings, experience and historical knowledge to reflect on the river's health, which was shared with the young and inexperienced. This knowledge revealed trends and indicated the condition of the river which was shared amongst peers and with young people and in the process, common knowledge is shared. According to Jiménez *et al.* (2019) developing common knowledge about a shared resource can be the foundation for achieving the practical benefits and serve as a foundation for a cooperative relationship regarding resource' management. In this research, sharing of common local knowledge between the communities revealed a common understanding of river health and identified river health indicators that are locally congruent and commonly understood, which had not been done in previous river health studies.

In essence, the research that river health in the Lower Komati River is complex and is a social-ecological concept linked to the biophysical condition, past political history and relationships formed between communities and the river. Thus, it was necessary to analyse to develop an integrated social-ecological river health monitoring framework. The integrated river health monitoring framework puts together multiple lines of evidence, from local communities' experience, historical and local knowledge and ecological analysis to show how river health may be analysed comprehensively. The framework shows that the effective integration of local and scientific knowledge removes disparities that show privileges of scientific knowledge through meaningful participation of communities at all stages of monitoring and co-producing of social-ecological indicators.

A major strength of the framework is that decisions on what (indicators) and where(sites) to monitor are based on the active participation of local communities. The selected social-ecological monitoring sites and indicators reflect the different relationships between the communities and the Lower Komati River. The social-ecological indicators and monitoring sites identified by the framework show that people have 'felt values' which were identified through social valuing their feelings, personal attachment and solastalgia. These were merged with the ecological/scientific knowledge and showed that knowledge systems complement each other and also offer more information about the river's health. What makes the framework unique is that it allows the reframing of river health as a social-ecological concept showing all the social-ecological pathways and relationships.

8.4 Contribution of study

A few notable substantive theoretical and methodological contributions can be derived from this study. Theoretical contributions of the study are centred on the advancement and refinement of understanding river health. This study made theoretical contributions by emphasising the importance of recognising human-environment relations, human experience, local knowledge and politics in river health monitoring. The social-ecological systems and political ecology theories were used to examine river health in an ecosystem-based management approach that seeks to consider and understand links between biophysical and social dimensions of the environment, which is novel in river health studies. Within the social-ecological system approach, the thesis utilised social data to determine communities' social values and integrate these with the ecological data for river health assessment. The social values reveal relevant human processes in concert with the biophysical process in the catchment to expand understanding of river health as a social-ecological concept.

Another contribution made by the thesis is the formulation of locally relevant social-ecological indicators and river social-ecological hotspots, which were identified as priority areas for river health monitoring. The research uses place-based analysis to produce a new hybrid of social-ecological sampling sites and indicators from ecological and social value analysis. Scholars have repeatedly shown that natural systems are influenced by human inventions, leading to them being characterised as nature-society hybrids (Swyngedouw 1999; Zimmerer & Bassett 2003; Bassett & Peimer, 2015; Stojanovic *et al.*, 2016). This thesis expands by demonstrating the formulation of social-ecological monitoring sites and indicators through 'hybridising' social and ecological analysis to improve river health monitoring which can be used to improve river health analysis from ecological analysis to a social-ecological analysis.

Formulation of social-ecological indicators and monitoring sites offered opportunities for communities to merge knowledge from both ecological and social perspectives, which broadens river health understanding. This has not been done before as shown by literature on river health in South Africa (Sections 2.3 and 2.4). Previous studies show that river health in South Africa is solely based on ecological indicators and monitoring sites without considering people's social values, experience and knowledge. The hybridising of community-relevant indicators and ecological indicators is novel information as merging ecological and local communities' knowledge bases was not done before. With hybrid indicators, a combination of the current state of ecological indicators and past historical human experience is shown, which is broader and holistically explains river health.

The hybridising of the locally relevant indicators and ecological indicators also emphasized the relationship between macroinvertebrates, fish and social value which is explained in section 2.10. The research showed that the introduction of alien macroinvertebrates (Australian crayfish as explained in section 4.3) may have led to the destruction of the habitat preferred by the indigenous fish community. These have consequences on the fish's community structure (section 5.5) and the availability of preferred fish species for the local communities (explained in section 6.9). Some fish species which were commonly preferred by communities and available in different parts of the river were not sampled during the research period and their disappearance was confirmed by the local fishers. Thus, this shows that changes in one indicator can cascade through the linkage between the river's ecological function and social values.

Methodologically, the research's contribution is the use of an inclusive participatory research approach to understand river health assessment at a place-based level. The required knowledge is extracted from the people who understand the different social, political, environmental and place-based river health issues in the river catchment, through participatory mapping exercises. The study shows shortcomings in the involvement of participants from the planning stage to the implementation stage. The major shortcoming is that current citizen science in river health monitoring only considered the involvement of communities during the implementation stage and they were not involved in making decisions on what and where to monitor. However, this research shows how local communities can be involved in decision-making processes on what to monitor (indicators relevant to the communities) and where to monitor (through determining river health hotspots). While the importance of community input in decision making is mentioned in the water management literature (Rapport *et al.*, 1998; Li *et al.,* 2013), this is not reflected in current river health assessment indices and during the assessment processes.

A major contribution from this study is that the participation of local communities when prioritized facilitates the process of bringing together a variety of people with different interests, and attitudes who have rich information from their areas of experience. This was evident as participants supported their different views leading to a deeper and broader understanding of why some areas are more polluted than others and historical changes that drive river health. This increases understanding of river health as the social and ecological analysis showed the different links and root causes of river health decline and identified root causes in the hotspots. Employing participatory mapping also allowed local communities to be more interactive and to promote a sense of collaboration and ownership towards the management of the river resources important to them (Chapin & Knapp, 2015). This was a move towards building trust and open dialogue for locals on the condition of the river and why it was important to protect river health.

Thirdly, the process of identifying community-relevant indicators for river health opens avenues for knowledge exchange, sharing and social learning facilitated through community participation, which is also novel in this research. The research showed different ways through which communities can represent local ecological knowledge and community congruent river health monitoring indicators. The accounts from participants showed that knowledge can be shared with other community members and be transferred between them - which is social learning. The role of social learning is identified as crucial in cultural and historical knowledge, to help improve citizen science and cannot be underestimated (Lee & Krasny, 2015; Charles *et al.*, 2020). During the identification of the locally-used river health indicators, participants shared local knowledge which also revealed root causes of river health. Elder participants in the river catchment shared historically different features of the catchment with the young participants that had disappeared, thus transmitting new knowledge leading to wider social learning (Reed *et al.,* 2010). The knowledge produced informed the new indicators, which expanded understanding of river health as it now included ecological and community relevant ones. This also led to the co-production of social-ecological knowledge through stakeholder engagement, which promotes stewardship towards the river. This has the potential to strengthen existing collaborations and even transform relationships between the local communities, water users, scientists and the Inkomati-Usuthu Catchment Management Agency. This is identified as an avenue to develop collaborative solutions for river health by both scientists and the community as a holistic assessment that incorporates multiple perspectives from multi-water users.

The research makes use of a social-ecological water framework and also shows the relationships and hybrid formations between social and ecological dynamics of river health as an extended and broader way to improve river health monitoring. The study contributes to improvements by showing that the development of the framework breaks down barriers that separate human and natural systems, local and scientific knowledge. The integrated framework includes the relationships and links between humans and river health as drivers of river health. This is an aspect of river health that is ignored and poorly understood, although it is often at the centre of a debate on how humans can lead to environmental destruction. This thesis framework shows how the relationships captured in the framework may change over time as a result of changing dynamics over the waterscape, for example, politics and how this may be reflected in the river's health.

8.5 Reflection on the difficulties of combining quantitative and qualitative datasets

One of the most challenging issues during the research process was converging the field-oriented quantitative data sets collected (fish and macroinvertebrates), and qualitative social data collected through interactions with people. The greatest challenge was that these data sets are based on two separate epistemological models; the MIRAI and FRAI scores from macroinvertebrates and fish communities analysis are quantitative-based on numerical limits whilst qualitative is based on local communities and fishers' perceptions and beliefs shaped by multiple realities context, which makes it more complex to merge. The greatest challenge was making sure that none of the datasets is superior, but a balance between these approaches is maintained as per the theoretical grounding of this research.

Many times, I had to introspect and see if there is a balance between these data sets, as literature (Driscoll *et. al.,* 2007; Haq, 2015; Halcomb, 2019) show that in merging qualitative and quantitative data sets, the researcher's interests and context shapes it. During the process, I reflected to ensure no biases were made towards a single data set. I had to learn to fully detach from either qualitative or quantitative data and deal with my subjective nature during the process. Combing the data sets was also time-consuming and needed constant reflections, to make sure that a fair connection between the two is made. Lessons learnt during the process was that a combination of qualitative and quantitative data can improve understanding and ensure that the limitations of one type of data are covered by the strengths of another. For example, the fisher' use of skin colour and condition to determine river health, combined with scientific consideration of fish communities' diversity and abundance to come up with the social-ecological indicator is a typical example where a combination of qualitative and quantitative data is equally used without prejudice. The integration of the fishers' fish colour and scientific data also generated insights that enriched understanding of river health based on human experience and scientific observation/measurement.

8.6 Recommendations

- Since the integrated river health monitoring framework was only developed and not applied in this study site, it is recommended that it be applied in the site and other different geographical locations and results are compared. The development of the social-ecological framework is influenced by the uses of the river and local communities' relationship with the river, so further research is proposed to apply this framework in different rivers to determine and compare the relationships and social values that exist. This is to verify if the framework can consistently produce comparable desired results, despite the unique social-ecological characteristics and relationships of each river catchment.
- More work still needs to be done to fully establish and test the use of the social-ecological indicators, social-ecological monitoring points and consider local communities' historical knowledge in conjunction with ecological indicators currently used river health indices (FRAI and MIRAI). The present study has laid the foundation to facilitate such work by identifying points of convergence in local ecological knowledge and scientific knowledge as starting points of constructing social-ecological indicators. The use of these social-ecological indicators complements the existing ecological indicators as local ecological knowledge expands and incorporates other indicators based on human/community's experience. The social-ecological hotspots as monitoring points allow the equal involvement of scientists and local communities in determining and identifying priority areas to monitor.
- This study supports the call for more research to provide more comprehensive analyses to further our understanding of the social values of rivers and compare catchments across South Africa. This is mainly because catchments are unique because of their communities' social values. The challenge is to understand the relationships between the rivers, human perceptions, feelings, social values and knowledge and to express these relationships in ways that are useful for river health monitoring in a particular catchment.
- It is also recommended that the potential value of the comprehensive river health framework be tested in other existing water resources management approaches in South Africa, for

example in determining RQOs. This is to test its ability to meet the objectives, improve participation of local communities and ‘hybridise’ social and ecological requirements in determining the conditions of the resource objectives. This will unearth the full spectrum of the social and ecological traits of the river catchments without considering them individually (as currently used).

The thesis contributed by showing that the involvement of local communities in river health monitoring unearths new information and provides more human experience and historical knowledge. This gave a comprehensive view of the Lower Komati River’s health. These findings need to be expanded by focusing more on how meaningful participation that fosters information sharing and exchange between local communities and scientists can be encouraged for decentralised and more comprehensive river health monitoring and management. Having decentralised river health monitoring does not mean granting all power to the communities to monitor the river’s health but rather advocates for decision making as well as equitable dialogues based on communities and scientists’ interests. In as much as the communities’ local knowledge have a major role to play, it is also important to understand the physical or ecological processes and maintain a balance between the two, which should be continuously explored in river health monitoring.

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APPENDICES

Appendix 1-A. Macroinvertebrates data and dates sampled

TAXON	species	ASS Scor	S1:Apr '18	S1:Sep '18	S1:Dec '8	S1: March '19		S2: Apr '18	S2:Sep '18	S2:Dec '18	S2: March ''19		S3: Apr '18	S3:Sep '18	S3:Dec'18	S3: March '19		S4: Apr '18	S4:Sep '18	S4:Dec '18	s4: march '19		S5: Apr '18	S5:Sept '18	S5:Dec '18	S5: March '19		S6: Apr '18	S6:sept '18	S6:Dec ''18	S6:March '19	
Oligochaeta (Earthworms)		1					0					0	1			2	3					0					0	1		1		2
Hirudinea (Leeches)		3					0					0		1		1	2					0					0					0
Amphipoda (Scuds)		13					0	1		6	3	10		4		1	5	2	1		6	9	8		20		28	4	1	3	3	11
Potamonautidae* (Crabs)		3				1	1		1			1					0					0		1	2	1	4					0
Ephemeridae		15	1				1					0					0					0					0					0
Leptophlebiidae (Prongills)		9				1	1				1	1					0					0					0					0
Teloganodidae SWC (Spiny Crawlers)		12					0					0					0					0	1		2		3					0
Coenagrionidae (Sprites and blues)		4					0	1		20	7	28	1			2	3	1		10	8	19	2		7	1	10	2		2	4	8
Aeshnidae (Hawkers & Emperors)		8		4		3	7	1		1		2		3			3	1	2	5	1	9					0		3			3
Libellulidae (Darters/Skimmers)		4					0					0	2		3		5					0		2		1	3					0
Corixidae* (Water boatmen)		3			2		2				1	1					0					0					0		1		1	2
Gerridae* (Pond skaters/Water striders)	gerries sp.	5	2		1	2	5				2	2					0				2	2				1	1					0
Notonectidae* (Backswimmers)		3					0					0	2		2		4			1	2	3					0					0
Veliidae/M...veliidae* (Ripple bugs)		5	1		2		3					0	1				1					0	2	1	3		6	1	1			2
Ecnomidae		8	1				1					0					0		1			1					0					0
Elmidae/Dryopidae* (Riffle beetles)		8	1	3	2		6					0			1		1					0	2		1		3					0
Helodidae (Marsh beetles)		12					0					0					0	1				1					0					0
Hydraenidae* (Minute moss beetles)		8					0					0		5			5					0			2		2					0
Chironomidae (Midges)		2					0		1			1	1			1	2					0					0					0
Syrphidae* (Rat tailed maggots)		1					0					0	1				1					0					0					0
Ancylidae (Limpets)		6					0					0	1		1		2					0					0					0
Helodidae (Marsh beetles)		12					0					0					0					0					0		1			1
Naucoridae* (Creeping water bugs)		7		2			2					0					0					0				1	1			1		1
Ecnomidae		8			2		2					0					0					0					0					0
Hydrometridae* (Water measurers)		6					0			2		2					0					0					0					0
Baetidae 1sp		4					0				2	2					0					0					0					0
Baetidae 2sp		6					0					0					0	1			1	2					0			3		3
Hydroptilidae(larva)		6					0					0					0					0					0				3	3
Corrixidae		3				1	1					0					0					0					0	1				1
Leptophlebiidae (Prongills)		9					0					0				1	1			3		3					0			1		1
Thiaridae* (=Melanidae)		3					0	1	8	4	2	15					0	2			2	4					0	2		2	2	6
No of Taxa		**10**	**5**	**3**	**5**	**5**		**4**	**3**	**5**	**7**		**7**	**3**	**4**	**4**	**10**	**6**	**3**	**4**	**7**	**10**	**5**	**3**	**7**	**5**	**12**	**5**	**5**	**6**	**5**	
SASS Score		**59**	**41**	**23**	**29**	**54**		**26**	**8**	**31**	**41**		**26**	**32**	**21**	**24**	**71**	**49**	**29**	**24**	**42**	**69**	**43**	**12**	**53**	**23**	**35.5**	**29**	**41**	**43**	**29**	
ASPT		**8.11667**	**8.2**	**7.667**	**5.8**	**10.8**		**6.5**	**2.67**	**6.2**	**5.86**		**3.714**	**10.67**	**5.25**	**6**	**7.46**	**8.167**	**9.7**	**6**	**6**	**6.19**	**8.6**	**4**	**7.57**	**4.6**	**6.74**	**5.8**	**8.2**	**7.1667**	**5.8**	

Appendix 1-B-(I) Target water quality ranges for Domestic Use (Volume 1) and Aquatic Ecosystems (Volume 7). (DWAF 1996 a,b)

Variable	Unit	Aquatic ecosystem	Domestic use
Temperature	°C	<2°C, <10%Δ	-
pH		>0.5 or 5% Δ	6-9
Dissolved oxygen	mg/l	80 % - 120 % of saturation	-
Conductivity	mS/m	>15% Δ	0-70
Salinity	mg/l	10% Δ	-
Alkalinity	mg $CaCO_3$/l	-	-
Calcium	mg Ca/l	-	-
Chlorophyll 'a'	µg/l	-	0-1
Chloride	mg Cl/l	-	0 -100
Chemical oxygen demand	mg O_2/l	-	-
Conductivity	mS/m	-	-
Fluoride	mg F/l	0.75	0-1
Sodium	mg Na/l	-	0-100
Ammonia	mg N/l	0.007	0 – 1.0
Nitrite	mg N/l	-	0-6
Nitrate	mg N/l	-	0-6
Sulphate	mg SO_4/l	-	0-200
Soluble reactive phosphate*	µg P/l	-	-
Phosphate	µg P/l	<15% Δ and no change in trophic status. IN ADDITION THE RQO LIMIT > 0.125mg/L.	-
Turbidity	NTU	-	0-1

Appendix 1-B(II) Water Quality data and dates of sampling

PARAMETER	S1:Apr '18	S1:Sept'18	S1: Dec ''18	28-Mar-19	S2:Apr '18	S2:Sept '18	S2:Dec '18	28-Mar-19	S3:Apr '18	S3:Sept'18	S3:Dec '18	S3: 28 march '19
Temp(°c)	19.9	22.3	23.4	22.4	23.5	22.5	26.4	22.8	28.5	27.8	0	29
DO(mg/l)	7.1	5.83	5.4	9.9	7.8	5.47	7.8	8.52	5.8	5.8	0	8.6
DO(%sat)	89.3	65.3	61.4	85.6	81.2	66.7	89.0	87.3	68.0	63.8	0	107.5
pH(units)	7.1	7.3	7.03	7.62	7.13	7.36	7.11	7.68	7.4	8.71	0	7.8
EC(µS/m)	92.8	130.4	114.2	110.2	91.8	86.4	98.7	117	490	918	0	525
TDS	41.2	52.3	79.8	49.9	40.2	41.2	39.3	267	62.5	54.6	0	267
Nitrate mg/l	0.71	0.69	23.9	1.28	0.7	0.7	3.4	1.64	0.417	0.69	0	1.55
Nitrite mg/l	0.075	0.025	0.56	0.04	0.081	0.021	0.04	0.04	0.067	0.025	0	0.04
Ammonia as N mg/l	0.01	0.01	0.92	0.01	<0.01	0.01	0.01	0.01	0.01	0.01	0	0.01
Phosphorus mg/l	0.01	0.01	0.93	0.01	<0.01	0.01	0.01	0.01	0.01	0.01	0	0.01
Total Coliform per 100ml	2419.6	2419.6	2419.6	2419.6	>2419.6	15531.1	2419.6	2419.7	2419.6	2419.6	0	2419.6
E.Coli per 100ml	107.6	70.8	1986.3	387.3	178.5	41	2419.7	307	160.7	17.3	0	980.4

PARAMETER	S4:Apr '18	S4:Sept '18	S4:Dec '18	S4: 28 march '19	S5:Apr '18	S5:Sept'18	S5:Dec '18	S5:28 march '19	S6:Apr '18	S6:Sept '18	S6:Dec '18	S628 mar
Temp(°c)	27	28.2	26.4	27.5	27.8	26.8	27.6	27.1	28.5	28.6	27.8	28.7
DO(mg/l)	6.9	6.47	7.8	9.7	6.7	7.5	6.9	7.53	6.3	6.8	6.7	8.79
DO(%sat)	56	83.7	83.5	85.6	73.6	87.6	76.5	92.2	59.6	80.2	62.6	149.4
pH(units)	8.14	8.05	7.47	7.87	7.85	8.03	7.6	7.85	8.13	7.99	7.92	7.85
EC(µS/m)	308	229	26	258	274	331	24	278	426	726	683	387.3
TDS	64.2	50.5	55.8	103.5	60.1	58.5	61.2	146.8	32.7	38.9	42.6	216
Nitrate mg/l	1.084	0.69	2.81	2.55	1.126	2.88	3.1	2.82	1.33	3.76	3.2	3.83
Nitrite mg/l	0.115	0.024	0.02	0.07	0.104	0.034	0.03	0.07	0.087	0.023	0.03	0.09
Ammonia as N mg/l	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Phosphorus mg/l	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total Coliform per 100ml	2419.6	579.4	2419.6	2419.6	2419.6	866.4	1732.9	2419.6	1986.3	2419.6	2419.6	2419.6
E.Coli per 100ml	135.4	70.3	179.3	488.4	139.6	59.8	56.5	387.3	57.6	111.9	248.1	261.3

Appendix 1-C. Anova analysis for water quality between sites

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
21.325	11	2749.064	249.9149	293567.4
27.275	11	2546.311	231.4828	335099
27.325	11	2428.851	220.8046	301276.3
28.4	11	3243.353	294.8502	474133.3

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	35250.98	3	11750.33	0.033475	0.991652	2.838745
Within Groups	14040761	40	351019			
Total	14076012	43				

Appendix 1-D Fish data and habitat characteristics collected-august 2019

SITE 1

SITE: System Name	Effort no	Depth (mm) 1	Depth (mm) 2	Depth (mm) 3	Depth (x̄, mm)	TVHR - Value 1a	TVHR - Value 1b	Velocity (m/s) 1	TVHR - Value 2a	TVHR - Value 2b	Velocity (m/s) 2	TVHR - Value 3a	TVHR - Value 3b	Velocity (m/s) 3	Velocity (x̄, m/s)	Sub. Silt	Sub. Mud	Sub. Sand	Sub. Grav	Sub. Cobb	Sub. Boul	Sub. Bed	Sub. Other	Sub. Total	Cov. Undercut Bank	Cov. Roots	Cov. Substrate	Cov. Depth	Cov. A Veg	Cov. M Veg	Cov. Slack water	Cov. Other	Cov. Total	Genus	Species	Taxa (Abbr.)	Abundance	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49
SITE 1: Lower Komati RIVER	1	110	100	120	110	120	140	0.34	100	110	0.21	120	140	0.34	0.30	-	0	10	30	30	30	-		100	-	2	0	3	3	4	0	0	12	MICRAL	ACUTIDEN	MACL	4	50 60 60 60
SITE 1: Lower Komati RIVER																																		Enteroı	EUTAENIA	BEUT	2	90 100
SITE 1: Lower Komati RIVER	2	230	200	170	200	220	240	0.34	180	200	0.34	160	170	0.21	0.30		0	10	40	20	30			100		3	1	2	4	3			13	MICRAL	ACUTIDEN	MACL	25	40 55 40 30 50 45 50 50 50 50 40 50 40 40 55 40 50 40 45 60 45 40 60 65 50
SITE 1: Lower Komati RIVER																																		TILAPIA	RENDALLI	TREN	1	65
SITE 1: Lower Komati RIVER																																		Labeob	MAREQUENS	LMAR	1	60
SITE 1: Lower Komati RIVER	3	230	260	150	230	200	210	0.21	250	260	0.21	150	170	0.34	0.25			10	20	30	40			100		1	2	2	3	3			11	MICRAL	ACUTIDEN	MACL	51	60 60 60 50 60 70 60 50 50 60 40 50 50 80 80 80 60 40 50 60 60 50 60 40 70 50 50 55 50 60 50 60 70 65 55 65 50 50 50 30 60 8 70 70 70 60 50 50 60 60 70
SITE 1: Lower Komati RIVER																																		Enteroı	TRIMACULAT	BTRI	2	70 65
SITE 1: Lower Komati RIVER																																		LABEO	CYLINDRICU	LCYL	2	78 80
SITE 1: Lower Komati RIVER	4	100	130	140	130	150	140	0.21	160	180	0.34	130	100	0.45	0.33			20	30	20	30			100		1	3	2	3	2			11	Labeob	MAREQUENS	LMAR	3	85 60 80
					168									0.34																				MICRAL	ACUTIDEN	MACL	17	50 55 65 45 60 65 70 55 65 60 50 55 60 60 60 45 55

SITE 2

Lower Komati RIVER	2	320	400	410	400	49.33	530	420	0.96	620	520	0.91	380	360	0.34	0.74	0.34	0	0	40	30	20	10	-		100	-	2	0	3	3	4	0	0	12	101-671	Chilogl	pretoriae	Cpre	2	35	40		
																																					LABEO	CYLINDRICU	LCYL	4	225	120	200	180
																																					MICRAL	ACUTIDEN	MACL	3	20	35	40	
Lower Komati RIVER	1	350	340	460	350	66.58	350	360	0.21	330	320	0.21	470	460	0.21	0.21	0.00		10	40	30	20				100		3	3	4		3			13		Clarias	gariepinus,	Cgar	1	190			
																																					LABEO	CYLINDRICU	LCYL	3	150	200	220	
																																					MICRAL	ACUTIDEN	MACL	3	40	30	50	
																																					TILAPIA	RENDALLI	TREN	2	75	70		
																																					LABEO	CYLINDRICU	LCYL	1	150			
Lower Komati RIVER	4	320	300	280	300	20.00	300	320	0.34	390	400	0.21	400	410	0.21	0.25	0.08			30	30	20	20			100		1	3	4	2	1			11		Chilogl	pretoriae	Cpre	4	40	30	40	40
																																					Clarias	GARIEPINU	CGAR	3	260	230	270	
Lower Komati RIVER	5	340	300	350	340	26.46	350	360	0.21	300	340	0.53	350	370	0.34	1.78	4.18		10	30	30	20	10			100		2	2	2	2	2			10		Enteroı	TRIMACULAT	BTRI	4	70	65	80	70
																																					LABEO	CYLINDRICU	LCYL	2	150	120		
																																					MICRAL	ACUTIDENS	MACL	3	50	60	65	
																																					Micropterus	*salmoid*	M	3	80	75	60	

SITE 3

Collection summary		Depth summary				Velocity summaries										Substrate distributions									Cover distributions									Summary fish data								Length measurements						
System Name	Effort no	Depth (mm) 1	Depth (mm) 2	Depth (mm) 3	Depth (x̄, mm)	TVHR - Value 1a	TVHR - Value 1b	Velocity (m/s) 1	TVHR - Value 2a	TVHR - Value 2b	Velocity (m/s) 2	TVHR - Value 3a	TVHR - Value 3b	Velocity (m/s) 3	Velocity (x̄, m/s)	Sub. Silt	Sub. Mud	Sub. Sand	Sub. Grav	Sub. Cobb	Sub. Boul	Sub. Bed	Sub. Other	Sub. Total	Cov. Undercut Bank	Cov. Roots	Cov. Substrate	Cov. Depth	Cov. A Veg	Cov. M Veg	Cov. Slack water	Cov. Other	Cov. Total	PHOTO	Genus	Species	Taxa (Abbr.)	Abundance	Abnorm. Rev (%)	Male gen. cond.	Female gen. cond.	1	2	3	4	5		
Lower Komati RIVER	1	120	100	110	110	130	120	0.21	100	120	0.34	380	360	0.34	0.30	-	0	40	30	20	10	-		100	-	2	0	3	3	4	0	0	12	101-671	Entero	trimaculatu	BTRI	7				35	40	50	55	40	40	40
																																			LABEO	CYLINDRICU	LCYL	2				120	100					
																																			Chilogl	pretoriae	Cpre	1				70						
																																						0										
Lower Komati RIVER	2	120	140	160	140	120	110	0.21	130	120	0.21	470	460	0.21	0.21		10	40	50					100		3	3	4		3			13		Oreoch	mossambicu	Omos	3				90	95	80				
Lower Komati RIVER	3	100	95	120	100	140	130	0.21	100	129	0.44	100	130	0.45	0.36			40	30	30				100			3	1	2	1			7		Entero	trimaculatu	BTRI	5				30	40	35	40	35		

SITE 4

Collection summary		Depth summary				Velocity summaries										Substrate distributions									Cover distributions									Summary fish data								Length measurements																									
System Name	Effort no	Depth (mm) 1	Depth (mm) 2	Depth (mm) 3	Depth (x̄, mm)	TVHR - Value 1a	TVHR - Value 1b	Velocity (m/s) 1	TVHR - Value 2a	TVHR - Value 2b	Velocity (m/s) 2	TVHR - Value 3a	TVHR - Value 3b	Velocity (m/s) 3	Velocity (x̄, m/s)	Sub. Silt	Sub. Mud	Sub. Sand	Sub. Grav	Sub. Cobb	Sub. Boul	Sub. Bed	Sub. Other	Sub. Total	Cov. Undercut Bank	Cov. Roots	Cov. Substrate	Cov. Depth	Cov. A Veg	Cov. M Veg	Cov. Slack water	Cov. Other	Cov. Total	PHOTO	Genus	Species	Taxa (Abbr.)	Abundance	Abnorm. Rev (%)	Male gen. cond.	Female gen. cond.	1	2	3	4	5			6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Lower Komati RIVER	3	190	260	1000	260	190	160	0.45	260	280	0.34	80	90	0.21	0.33	-	20	50	30	-	0	-		100	-	2	0	3	3	4	0	0	12	101-671	LABEO	CYLINDRIC	LCYL	2				50	30																								
																																			Chilogl	pretoriae	Cpre	1				80																									
Lower Komati RIVER	2	280	290	300	290	340	350	0.21	300	320	0.34	280	290	0.21	0.25			20	20	30	20	10		100		1	2	4	2	1			10		LABEO	CYLINDRIC	LCYL	3				50	65	55																							
	1	170	170	330	170	200	210	0.21	220	240	0.34	300	310	0.21	0.25																		0		MICRAL	ACUTIDENS	MACL	26				70	60	70	65	65	70	65	60	70	65	70	60	55	65	60	60	65	60	55	55	55	65	55	60	65	65
																																			LABEO	CYLINDRIC	LCYL	1				85																									
																																			Entero	TRIMACUL	BTRI	2				70	70																								
Lower Komati RIVER	6	350	260	350	350	340	360	0.34	300	320	0.34	340	350	0.21	0.30		10	30	20	30	10			100			3	2	3	2			10		OREOCI	MOSSAMB	OMOS	1				70																									
																																	0		LABEO	CYLINDRIC	LCYL	2				70	60																								
																																	0		Chilogl	pretoriae	Cpre	4				30	45	30	40																						
Lower Komati RIVER	5	390	430	500	430	300	360	0.68	40	42	0.03	51	46	0.12	0.27			40	30	10	10	10		100	0	3	1	3	3	4	0	0	14		LABEO	CYLINDRIC	LCYL	3				180	120	150																							
																																			Entero	TRIMACUL	BTRI	2				80	70																								
Lower Komati RIVER	4	390	430	500	430	360	300	0.68	260	290	0.45	300	330	0.45	0.52			10	30	30	20	10		100			2	3	2	1			8		Entero	TRIMACUL	BTRI	3				75	70	80																							
Lower Komati RIVER	7	360	340	320	340	340	300	0.53	300	280	0.34	300	310	0.21	0.36				30	40	30			100		3	2	2	2	1			10		*Cherax*	quadricar	C qu	2				80	90																								

SITE 5

Collection summary		Depth summary				Velocity summaries										Substrate distributions									Cover distributions								
System Name	Effort no	Depth (mm) 1	Depth (mm) 2	Depth (mm) 3	Depth (x̄, mm)	TVHR - Value 1a	TVHR - Value 1b	Velocity (m/s) 1	TVHR - Value 2a	TVHR - Value 2b	Velocity (m/s) 2	TVHR - Value 3a	TVHR - Value 3b	Velocity (m/s) 3	Velocity (x̄, m/s)	Sub. Silt	Sub. Mud	Sub. Sand	Sub. Grav	Sub. Cobb	Sub. Boul	Sub. Bed	Sub. Other	Sub. Total	Cov. Undercut Bank	Cov. Roots	Cov. Substrate	Cov. Depth	Cov. A Veg	Cov. M Veg	Cov. Slack water	Cov. Other	Cov. Total
Lower Komati RIVER	2	320	340	410	340	530	420	0.96	620	520	0.91	380	360	0.34	0.74	-	0	40	30	20	10	-		100	-	2	0	3	3	4	0	0	12
Lower Komati RIVER	1	320	400	410	400	340	280	0.68	440	350	0.85	440	360	0.80	0.78									0									0
Lower Komati RIVER	3	390	430	500	430	900	650	1.50	650	490	-0.11	380	320	-0.11	0.42																		
Lower Komati RIVER	4	430	440	400	430	450	350	0.91	400	350	-0.11	400	450	-0.11	0.23																		
Lower Komati RIVER	5	370	360	400	370	400	350	0.61	350	380	-0.11	450	500	-0.11	0.13																		
					394										0.46																		

Collection summary		Summary fish data				Length measurements																										
System Name	Effort no	Genus	Species	Taxa (Abbr.)	Abundance	1	2	3	4	5			6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Lower Komati RIVER	2	Labeob	MAREQUENS	LMAR	26	160	120	140	130	140	130	140		130	110	130	120	115	90	120	130	95	120	110	110	110	110	100	100	80	40	30
		LABEO	CYLINDRICU	LCYL	16	110	100	90	80	70	60	70	50	80	50	50	50	50	40	50	50											
		MICRAL	ACUTIDENS	MACU	8	50	70	60	50	60	50	60	60																			
		BARBUS	TRIMACULAT	BTRI	1	50																										
		CHILOG	PRETORIAE	CPRE	4	50	40	40	30																							
		Enteroı	TRIMACULAT	ETRI	2	55	50																									
Lower Komati RIVER	1	LABEO	CYLINDRICU	LCYL	14	110	100	110	120	60	50	55	50	40	40	45	70	55	50													
		Labeob	MAREQUENS	LMAR	2	100	60																									
		MICRAL	ACUTIDENS	MACU	5	65	60	45	45	50																						
		Enteroı	TRIMACULAT	ETRI	2	75	60																									
		CHILOG	PRETORIAE	CPRE	3	30	30	30																								
Lower Komati RIVER	3	LABEO	CYLINDRICU	LCYL	2	250	120																									
Lower Komati RIVER	4	LABEO	CYLINDRICU	LCYL	3	210	150	70																								
		Labeob	MAREQUENS	LMAR	1	200																										
Lower Komati RIVER	5	LABEO	CYLINDRICU	LCYL	2	160	140																									
		MICRAL	ACUTIDENS	MACU	7	70	60	60	65	65	50	65																				
		Enteroı	TRIMACULAT	ETRI	2	60	80																									
		Cherax	Quadricarin	CQua	2	65	70																									

SITE 6

Collection summary		Depth summary				Velocity summaries										Substrate distributions									Cover distributions									Summary fish data								Length measurements						
System Name	Effort no	Depth (mm) 1	Depth (mm) 2	Depth (mm) 3	Depth (x̄, mm)	TVHR - Value 1a	TVHR - Value 1b	Velocity (m/s) 1	TVHR - Value 2a	TVHR - Value 2b	Velocity (m/s) 2	TVHR - Value 3a	TVHR - Value 3b	Velocity (m/s) 3	Velocity (x̄, m/s)	Sub. Silt	Sub. Mud	Sub. Sand	Sub. Grav	Sub. Cobb	Sub. Boul	Sub. Bed	Sub. Other	Sub. Total	Cov. Undercut Bank	Cov. Roots	Cov. Substrate	Cov. Depth	Cov. A Veg	Cov. M Veg	Cov. Slack water	Cov. Other	Cov. Total	PHOTO	Genus	Species	Taxa (Abbr.)	Abundance	Abnorm. Rev (%)	Male gen. cond.	Female gen. cond.	1	2	3	4	5		6
Lower Komati RIVER	1	940	640	600	640	340	230	0.96	150	135	0.28	220	210	0.21	0.48	-	20	50	30	-	0	-		100	-	2	0	3	3	4	0	0	12		CHILOG	PRETORIAE	CPRE	2				65	60					
																																			Clarias	GARIEPINU	CGAR	1				290						
																																			MICRAL	ACUTIDEN	MACU	5				20	35	40	30	30		
																																			Glosso	giuris	Ggiu	1				100						
																																			TILAPIA	RENDALLI	TREN	5				65	65	80	70	70		
																																						0										
Lower Komati RIVER	2	330	320	420	330	330	310	0.34	320	310	0.21	420	410	0.21	0.25						20	80		100	0	1	1	2	1	1			6		Glosso	callidus	Gcal	1				60						
Lower Komati RIVER	3	840	700	700	700	0	0	-0.11	0	0	-0.11			-0.11	-0.11	0	0	0	0	0	0	100		100	0	2	3	3	1	3			12		TILAPIA	RENDALLI	TREN	3				75	90	75				
Lower Komati RIVER	4	350	300	380	350	360	390	0.45	300	290	0.21	390	370	0.34	0.33					40	10	50		100	0	3	3	1	2	3			12		Glosso	callidus	Gcal	4				110	85	80	80			
Lower Komati RIVER	5	240	450	260	260	230	220	0.21	490	440	0.61	300	260	0.53	0.45	0	0	0	5	15	30	50		100	0	1	5	1	1	1			9		Glosso	callidus	Gcal	4				100	70	60	40			
																																			Cherax	Quadricar	CQua	1				65						
Lower Komati RIVER	6	240	150	230	230	380	360	0.34			-0.11			-0.11	0.04	0	0	0	0	50	10	40		100	0	1	2		1	1			5		CHILOG	PRETORIAE	CPRE	0										
Lower Komati RIVER	7	1000	200	600	600	900	800	0.91	240	190	0.61	600	560	0.53	0.68					10	10	80		100	0	0	3	4	1	1			9															
Lower Komati RIVER	8	260	350	370	350	380	360	0.34	360	390	0.45	360	400	0.53	0.44					40	30	30		100	0	1	4	3	1	1			10		Clarias	GARIEPINU	CGAR	2				280	220					
																								0									0		Glosso	callidus	Gcal	3				120	70	70				
																								0									0		Oreoch	mossambi	Omos	2				105	50					
																								0									0		Cherax	Quadricar	CQua	2				80	80					
Lower Komati RIVER	9	360	420	290	360	350	380	0.45	390	420	0.45	230	330	0.91	0.60					30	50	20		100	0	1	4	2	1	1			9		Clarias	GARIEPINU	CGAR	1				250						
																								0									0		Cherax	Quadricar	CQua	1				60						
																								0									0		Glosso	callidus	Gcal	3				140	70	100				
																								0									0		Oreoch	mossambi	Omos	3				90	200	190				
Lower Komati RIVER	10	480	510	400	480	490	480	0.21	550	540	0.21	380	370	0.21	0.21					20	70	10		100	0	1	2	4	1	1			9		LABEO	CYLINDRIC	LCYL	2				200	220					
Lower Komati RIVER	11	440	460	440	440	420	410	0.21	470	460	0.21	450	440	0.21	0.21					50	30	20		100	0	2	3	2	1	2			10		LABEO	CYLINDRIC	LCYL	2				200	155					
																																			Glosso	callidus	Gcal	4				120	90	45	60			
																																			Oreoch	mossambi	Omos	7				115	60	110	65	55	70	65

APPENDIX 1-E FISH DATA and habitat characteristics collected-DECEMBER 2019

Site 1

Collection summary		Depth summary			Velocity summaries									Substrate distributions									Cover distributions								
SITE: System Name	Effort no	Depth (mm) 1	Depth (mm) 2	Depth (mm) 3	TVHR - Value 1a	TVHR - Value 1b	Velocity (m/s) 1	TVHR - Value 2a	TVHR - Value 2b	Velocity (m/s) 2	TVHR - Value 3a	TVHR - Value 3b	Velocity (m/s) 3	Velocity (x̄, m/s)	Sub. Silt	Sub. Mud	Sub. Sand	Sub. Grav	Sub. Cobb	Sub. Boul	Sub. Bed	Sub. Other	Sub. Total	Cov. Undercut Bank	Cov. Roots	Cov. Substrate	Cov. Depth	Cov. A Veg	Cov. M Veg	Cov. Slack water	Cov. Other	Cov. Total
SITE 1: Lower Komati RIVER	1	90	80	120	120	140	0.34	100	110	0.21	120	140	0.34	0.30	-	0	10	30	30	30	-		100	-	2	0	3	3	4	0	0	12
SITE 1: Lower Komati RIVER																																
SITE 1: Lower Komati RIVER	2	200	180	150	220	240	0.34	180	200	0.34	160	170	0.21	0.30		0	10	40	20	30			100		3	1	2	4	3			13
SITE 1: Lower Komati RIVER																																
SITE 1: Lower Komati RIVER																																
SITE 1: Lower Komati RIVER	3	200	260	120	200	210	0.21	250	260	0.21	150	170	0.34	0.25			10	20	30	40			100		1	2	2	3	3			11
SITE 1: Lower Komati RIVER																																
SITE 1: Lower Komati RIVER																																
SITE 1: Lower Komati RIVER	4	140	130	140	150	140	0.21	160	180	0.34	130	100	0.45	0.33			20	30	20	30			100		1	3	2	3	2			11
SITE 1: Lower Komati RIVER													0.34																			

Summary fish data				Length measurements																						
Genus	Species	Taxa (Abbr.)	Abundance	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
MICRAL	ACUTIDEN	MACU	4	50	60	60	60																			
LABEO	CYLINDRICU	LCYL	3	65	70	65																				
MICRAL	ACUTIDEN	MACU	23	40	55	40	30	50	45	50	50	50	50	40	50	40	40	55	40	50	40	45	60	45	40	35
MICRAL	ACUTIDEN	MACU	8	40	45	60	45	40	60	65	50															
Labeob	MAREQUENS	LMAR	1	60																						
MICRAL	ACUTIDEN	MACU	20	60	60	60	50	60	70	60	50	50	60	40	50	50	65	65	60	60	40	50	35			
Entero	TRIMACULAT	BTRI	1	60																						
LABEO	CYLINDRICU	LCYL	4	70	75	65	70																			
Labeob	MAREQUENS	LMAR	3	65	60	70																				
MICRAL	ACUTIDEN	MACU	10	50	55	65	45	60	65	70	55	65	60													

Site 2

Collection		Depth summary					Velocity summaries										Substrate distributions									Cover distributions									Summary fish data								Length measurements					
System Name	Effort no	Depth (mm) 1	Depth (mm) 2	Depth (mm) 3	Depth (x̄, mm)	Depth (SD, mm)	TVHR - Value 1a	TVHR - Value 1b	Velocity (m/s) 1	TVHR - Value 2a	TVHR - Value 2b	Velocity (m/s) 2	TVHR - Value 3a	TVHR - Value 3b	Velocity (m/s) 3	Velocity (x̄, m/s)	Sub. Silt	Sub. Mud	Sub. Sand	Sub. Grav	Sub. Cobb	Sub. Boul	Sub. Bed	Sub. Other	Sub. Total	Cov. Undercut Bank	Cov. Roots	Cov. Substrate	Cov. Depth	Cov. A Veg	Cov. M Veg	Cov. Slack water	Cov. Other	Cov. Total	PHOTO	Genus	Species	Taxa (Abbr.)	Abundance	Abnorm. Rev (%)	Male gen. cond.	Female gen. cond.	1	2	3	4	5	
SITE 2:Lower Komati F	2	400	380	410	400	15.28	460	400	0.68	560	520	0.53	380	360	0.34	0.52	0	0	40	30	20	10	-		100	-	2	0	3	3	4	0	0	12	101-671													
																																				Enteroı	TRIMACULAT	BTRI	2				85	70				
																																				Clarias	GARIEPINU	CGAR	3				100	130	150			
SITE 2: Lower Komati I	1	350	340	460	350	66.58	370	320	0.61	330	320	0.21	450	410	0.53	0.45		10	40	30	20				100		3	3	4		3			13		Clarias	gariepinus,	Cgar	1				190					
																																				LABEO	CYLINDRICU	LCYL	3				70	75	65			
																																				MICRAL	ACUTIDEN	MACU	1				40					
																																				Labeob	MAREQUENS	LMAR	3				200	180	220			
																																				Clarias	GARIEPINU	CGAR	2				100	90				
SITE2: Lower Komati F	4	320	300	280	300	20.00	300	260	0.53	360	300	0.68	400	410	0.21	0.47			30	30	20	20			100		1	3	4	2	1			11		Chilogl	pretoriae	Cpre	4				40	30	40	40		
																																				Clarias	GARIEPINU	CGAR	4				200	180	250	150		
SITE2: Lower Komati F	5	340	300	350	340	26.46	400	360	0.53	380	340	0.53	370	360	0.21	1.36		10	30	30	20	10			100		2	2	2	2	2			10		Enteroı	TRIMACULAT	BTRI	6				70	65	75	70	80	75
					348										0.32																					Oreoch	mossambicu	Omos	2				95	80				
																																				MICRAL	ACUTIDENS	MACU	1				50					
																																				Microp	salmoides	Msa	1				150					

Site 3

Collection summary		Depth summary					Velocity summaries											Substrate distributions									Cover distributions									Summary fish data								Length measurements									
System Name	Effort no	Depth (mm) 1	Depth (mm) 2	Depth (mm) 3	Depth (x̄, mm)	Depth (SD, mm)	TVHR - Value 1a	TVHR - Value 1b	Velocity (m/s) 1	TVHR - Value 2a	TVHR - Value 2b	Velocity (m/s) 2	TVHR - Value 3a	TVHR - Value 3b	Velocity (m/s) 3	Velocity (x̄, m/s)	Velocity (SD, m/s)	Sub. Silt	Sub. Mud	Sub. Sand	Sub. Grav	Sub. Cobb	Sub. Boul	Sub. Bed	Sub. Other	Sub. Total	Cov. Undercut Bank	Cov. Roots	Cov. Substrate	Cov. Depth	Cov. A Veg	Cov. M Veg	Cov. Slack water	Cov. Other	Cov. Total	PHOTO	Genus	Species	Taxa (Abbr.)	Abundance	Abnorm. Rev (%)	Male gen. cond.	Female gen. cond.	1	2	3	4	5		6	7		
Lower Komati RIVER	3	200	260	100	200	80.83	230	200	0.45	280	260	0.34	80	90	0.21	0.33	0.12	-	20	50	30	-	0	-		100	-	2	0	3	3	4	0	0	12		LABEO	CYLINDRIC	LCYL	3				70	65	75							
Lower Komati RIVER	2	260	240	270	260	15.28	340	350	0.21	300	320	0.34	280	290	0.21	0.25	0.08			20	20	30	20	10		100		1	2	4	2	1			10		OREOCH	MOSSAMB	OMOS	2				75	85								
	1	170	170	330	170	92.38	200	210	0.21	220	240	0.34	300	310	0.21	0.25	0.08																		0		MICRAL	ACUTIDEN	MACU	9				65	60	70	65	65	70	65	60	70	70
																																					Entero	TRIMACUL	BTRI	2				70	70								
Lower Komati RIVER	6	350	260	350	350	51.96	340	360	0.34	300	320	0.34	340	350	0.21	0.30	0.08		10	30	20	30	10			100			3	2	3	2			10		OREOCH	MOSSAMB	OMOS	2				70	75								
																																			0		MICRAL	ACUTIDEN	MACU	7				70	60	55	65	60	60	65			
																																			0																		
Lower Komati RIVER	5	390	430	500	430	55.68	310	370	0.68	70	65	0.12	100	110	0.21	0.33	0.30			40	30	10	10	10		100	0	3	1	3	3	4	0	0	14		LABEO	CYLINDRIC	LCYL	1				150									
																																					Entero	TRIMACUL	BTRI	1				70									
Lower Komati RIVER	4	300	400	450	400	76.38	300	280	0.34	200	270	0.74	280	330	0.61	0.56	0.20			10	30	30	20	10		100			2	3	2	1			8		Cherax	quadricar	C qu	4													
Lower Komati RIVER	7	320	280	260	280	30.55	340	300	0.53	300	280	0.34	300	310	0.21	0.36	0.16				30	40	30			100		3	2	2	2	1			10		*Cherax*	quadricar	C qu	2				70	65								

Site 4

Collection summary		Depth summary					Velocity summaries											Substrate distributions									Cover distributions									Summary fish data								Length measurements									
System Name	Effort no	Depth (mm) 1	Depth (mm) 2	Depth (mm) 3	Depth (x̄, mm)	Depth (SD, mm)	TVHR - Value 1a	TVHR - Value 1b	Velocity (m/s) 1	TVHR - Value 2a	TVHR - Value 2b	Velocity (m/s) 2	TVHR - Value 3a	TVHR - Value 3b	Velocity (m/s) 3	Velocity (x̄, m/s)	Velocity (SD, m/s)	Sub. Silt	Sub. Mud	Sub. Sand	Sub. Grav	Sub. Cobb	Sub. Boul	Sub. Bed	Sub. Other	Sub. Total	Cov. Undercut Bank	Cov. Roots	Cov. Substrate	Cov. Depth	Cov. A Veg	Cov. M Veg	Cov. Slack water	Cov. Other	Cov. Total	PHOTO	Genus	Species	Taxa (Abbr.)	Abundance	Abnorm. Rev (%)	Male gen. cond.	Female gen. cond.	1	2	3	4	5		6	7		
Lower Komati RIVER	3	200	260	100	200	80.83	230	200	0.45	280	260	0.34	80	90	0.21	0.33	0.12	-	20	50	30	-	0	-		100	-	2	0	3	3	4	0	0	12		LABEO	CYLINDRIC	LCYL	3				70	65	75							
Lower Komati RIVER	2	260	240	270	260	15.28	340	350	0.21	300	320	0.34	280	290	0.21	0.25	0.08			20	20	30	20	10		100		1	2	4	2	1			10		OREOCH	MOSSAMB	OMOS	2				75	85								
	1	170	170	330	170	92.38	200	210	0.21	220	240	0.34	300	310	0.21	0.25	0.08																		0		MICRAL	ACUTIDEN	MACU	9				65	60	70	65	65	70	65	60	70	70
																																					Entero	TRIMACUL	BTRI	2				70	70								
Lower Komati RIVER	6	350	260	350	350	51.96	340	360	0.34	300	320	0.34	340	350	0.21	0.30	0.08		10	30	20	30	10			100			3	2	3	2			10		OREOCH	MOSSAMB	OMOS	2				70	75								
																																			0		MICRAL	ACUTIDEN	MACU	7				70	60	55	65	60	60	65			
																																			0																		
Lower Komati RIVER	5	390	430	500	430	55.68	310	370	0.68	70	65	0.12	100	110	0.21	0.33	0.30			40	30	10	10	10		100	0	3	1	3	3	4	0	0	14		LABEO	CYLINDRIC	LCYL	1				150									
																																					Entero	TRIMACUL	BTRI	1				70									
Lower Komati RIVER	4	300	400	450	400	76.38	300	280	0.34	200	270	0.74	280	330	0.61	0.56	0.20			10	30	30	20	10		100			2	3	2	1			8		Cherax	quadricar	C qu	4													
Lower Komati RIVER	7	320	280	260	280	30.55	340	300	0.53	300	280	0.34	300	310	0.21	0.36	0.16				30	40	30			100		3	2	2	2	1			10		*Cherax*	quadricar	C qu	2				70	65								

Site 5

Collection summary		Depth summary				Velocity summaries										Substrate distributions									Cover distributions									Summary fish data					Length measurements								
System Name	Effort no	Depth (mm) 1	Depth (mm) 2	Depth (mm) 3	Depth (x̄, mm)	TVHR - Value 1a	TVHR - Value 1b	Velocity (m/s) 1	TVHR - Value 2a	TVHR - Value 2b	Velocity (m/s) 2	TVHR - Value 3a	TVHR - Value 3b	Velocity (m/s) 3	Velocity (x̄, m/s)	Sub. Silt	Sub. Mud	Sub. Sand	Sub. Grav	Sub. Cobb	Sub. Boul	Sub. Bed	Sub. Other	Sub. Total	Cov. Undercut Bank	Cov. Roots	Cov. Substrate	Cov. Depth	Cov. A Veg	Cov. M Veg	Cov. Slack water	Cov. Other	Cov. Total	PHOTO	Genus	Species	Taxa (Abbr.)	Abundance	1	2	3	4	5			6	7
Lower Komati RIVER	2	320	340	410	340	530	420	0.96	620	520	0.91	380	360	0.34	0.74	-	0	40	30	20	10	-		100	-	2	0	3	3	4	0	0	12		Labeob	MAREQUENS	LMAR	8	100	120	140	130	140	130	140		130
																																			LABEO	CYLINDRICU	LCYL	5	90	85	90	80	70				
																																			MICRAL	ACUTIDENS	MACU	5	65	70	65	50	60				
																																			Entero	TRIMACULAT	ETRI	1	60								
																																			Entero	TRIMACULAT	ETRI	4	55	50	60	55					
Lower Komati RIVER	1	320	400	410	400	340	280	0.68	440	350	0.85	440	360	0.80	0.78			30	20	40	10			100									0		LABEO	CYLINDRICU	LCYL	5	100	90	85	90	60				
																																			Labeob	MAREQUENS	LMAR	9	100	60	70	65	110	110	120	80	90
																																			MICRAL	ACUTIDENS	MACU	3	60	60	45						
																																			Entero	TRIMACULAT	ETRI	3	75	60	60						
																																			CHILOG	PRETORIAE	CPRE	3	40	45	35						
Lower Komati RIVER	3	390	430	500	430	900	650	1.50	650	490	-0.11	380	320	-0.11	0.42			20	30	30	20			100											LABEO	CYLINDRICU	LCYL	6	110	90	60	65	60	65			
Lower Komati RIVER	4	430	440	400	430	450	350	0.91	400	350	-0.11	400	450	-0.11	0.23			20	30	30	20			100											LABEO	CYLINDRICU	LCYL	5	120	100	70	65	50				
Lower Komati RIVER																																			OREOCI	MOSSAMBIC	OMOS	1	100								
Lower Komati RIVER	5	370	360	400	370	400	350	0.61	350	380	-0.11	450	500	-0.11	0.13			10	30	40	20			100											LABEO	CYLINDRICU	LCYL	5	120	110	95	85	90				
					394										0.46																				MICRAL	ACUTIDENS	MACU	4	75	65	60	60					
																																			Entero	TRIMACULAT	ETRI	4	60	80	65	70					
																																			Cherax	Quadricarin	CQua	2	65	70							
																																			OREOCI	MOSSAMBIC	OMOS	3	150	80	75						
																																			Labeob	MAREQUENS	LMAR	2	85	90							
																																			Clarias	GARIEPINU	CGAR	2	250	180							

SITE 6

Collection summary		Depth summary				Velocity summaries										Substrate distributions									Cover distributions									Summary fish data								Length measurements					
System Name	Effort no	Depth (mm) 1	Depth (mm) 2	Depth (mm) 3	Depth (x̄, mm)	TVHR - Value 1a	TVHR - Value 1b	Velocity (m/s) 1	TVHR - Value 2a	TVHR - Value 2b	Velocity (m/s) 2	TVHR - Value 3a	TVHR - Value 3b	Velocity (m/s) 3	Velocity (x̄, m/s)	Sub. Silt	Sub. Mud	Sub. Sand	Sub. Grav	Sub. Cobb	Sub. Boul	Sub. Bed	Sub. Other	Sub. Total	Cov. Undercut Bank	Cov. Roots	Cov. Substrate	Cov. Depth	Cov. A Veg	Cov. M Veg	Cov. Slack water	Cov. Other	Cov. Total	PHOTO	Genus	Species	Taxa (Abbr.)	Abundance	Abnorm. Rev (%)	Male gen. cond.	Female gen. cond.	1	2	3	4	5	6
Lower Komati RIVER	1	640	640	600	640	340	230	0.96	150	135	0.28	220	210	0.21	0.48	-	20	50	30	-	0	-		100	-	2	0	3	3	4	0	0	12		OREOCI	MOSSAMB	OMOS	4				80	75	120	100		
																																			LABEO	CYLINDRIC	LCYL	3				100	90	85			
																																			CHILOG	PRETORIAE	CPRE	4				55	55	70	65		
																																			Coptod	rendalli	Cren	2				85	90				
																																			Labeob	MAREQUEI	LMAR	1				85					
Lower Komati RIVER	2	330	320	420	330	330	310	0.34	320	310	0.21	420	410	0.21	0.25						20	80		100	0	1	1	2	1	1			6		CHILOG	PRETORIAE	CPRE	3				55	60	65			
Lower Komati RIVER	3	840	700	700	700	0	0	-0.11	0	0	-0.11			-0.11	-0.11	0	0	0	0	0	0	100		100	0	2	3	3	1	3			12		Enteroı	TRIMACUL	ETRI	2				70	60				
Lower Komati RIVER	4	350	300	380	350	360	390	0.45	300	290	0.21	390	370	0.34	0.33					40	10	50		100	0	3	3	1	2	3			12		LABEO	CYLINDRIC	LCYL	3				80	75	90			
Lower Komati RIVER	5	240	350	260	260	230	220	0.21	490	440	0.61	300	260	0.53	0.45	0	0	0	5	15	30	50		100	0	1	5	1	1	1			9		Coptod	rendalli	Cren	3				90	75	80			
																																			Cherax	Quadricar	CQua	1				65					
Lower Komati RIVER	6	240	150	230	230	380	360	0.34			-0.11			-0.11	0.04	0	0	0	0	50	10	40		100	0	1	2		1	1			5														
Lower Komati RIVER	7	100	200	600	200	900	800	0.91	240	190	0.61	600	560	0.53	0.68					10	10	80		100	0	0	3	4	1	1			9		MICRAL	ACUTIDEN	MACU	2				60	80				
Lower Komati RIVER	8	280	350	370	350	380	360	0.34	360	390	0.45	360	400	0.53	0.44					40	30	30		100	0	1	4	3	1	1			10														
																								0									0		Coptod	rendalli	Cren	5				100	85	90	95	120	
																								0									0		Oreoch	mossambi	Omos	2				100	75				
																								0									0		Cherax	Quadricar	CQua	2				80	80				
Lower Komati RIVER	9	360	420	290	360	350	380	0.45	390	420	0.45	230	330	0.91	0.60					30	50	20		100	0	1	4	2	1	1			9														
																								0									0		Cherax	Quadricar	CQua	1				60					
																								0									0														
																								0									0		Oreoch	mossambi	Omos	3				100	200	150			
Lower Komati RIVER	10	480	510	400	480	490	480	0.21	550	540	0.21	380	370	0.21	0.21					20	70	10		100	0	1	2	4	1	1			9		LABEO	CYLINDRIC	LCYL	4				200	220	250	150		
Lower Komati RIVER	11	440	460	440	440	420	410	0.21	470	460	0.21	450	440	0.21	0.21					50	30	20		100	0	2	3	2	1	2			10		Oreoch	mossambi	Omos	6				120	60	110	65	55	70
					395										0.33																				Coptod	rendalli	Cren	5				120	180	150	120	170	

Appendix 1-E Expected fish in the Lower Komati River (SCOTT, 2017)

ORDER_	FAMILY	*TAXON*	CATEGORY	ABB	CRITERIA
Anguilliformes	Anguillidae	*Anguilla bengalensis labiata*	Least Concern	LC	
Anguilliformes	Anguillidae	*Anguilla bicolor bicolor*	Least Concern	LC	
Anguilliformes	Anguillidae	*Anguilla marmorata*	Least Concern	LC	
Anguilliformes	Anguillidae	*Anguilla mossambica*	Least Concern	LC	
Atheriniformes	Poeciliidae	*Aplocheilichthys johnstoni*	Least Concern	LC	
Characiformes	Characidae	*Brycinus imberi*	Least Concern	LC	
Characiformes	Characidae	*Hydrocynus vittatus*	Least Concern	LC	
Characiformes	Characidae	*Micralestes acutidens*	Least Concern	LC	
Cypriniformes	Cyprinidae	*Enteromius afrohamiltoni*	Least Concern	LC	
Cypriniformes	Cyprinidae	*Enteromius annectens*	Least Concern	LC	
Cypriniformes	Cyprinidae	*Enteromius crocodilensis*	Least Concern	LC	
Cypriniformes	Cyprinidae	*Enteromius paludinosus*	Least Concern	LC	
Cypriniformes	Cyprinidae	*Enteromius radiatus*	Least Concern	LC	
Cypriniformes	Cyprinidae	*Enteromius toppini*	Least Concern	LC	
Cypriniformes	Cyprinidae	*Enteromius trimaculatus*	Least Concern	LC	
Cypriniformes	Cyprinidae	*Enteromius unitaeniatus*	Least Concern	LC	
Cypriniformes	Cyprinidae	*Enteromius viviparus*	Least Concern	LC	
Cypriniformes	Cyprinidae	*Labeo congoro*	Least Concern	LC	
Cypriniformes	Cyprinidae	*Labeo cylindricus*	Least Concern	LC	
Cypriniformes	Cyprinidae	*Labeo molybdinus*	Least Concern	LC	
Cypriniformes	Cyprinidae	*Labeo rosae*	Least Concern	LC	
Cypriniformes	Cyprinidae	*Labeo ruddi*	Least Concern	LC	
Cypriniformes	Cyprinidae	*Labeobarbus marequensis*	Least Concern	LC	
Cypriniformes	Cyprinidae	*Mesobola brevianalis*	Least Concern	LC	
Cypriniformes	Cyprinidae	*Opsaridium peringueyi*	Least Concern	LC	
Mormyriformes	Mormyridae	*Marcusenius pongolensis*	Data Deficient	DD	
Mormyriformes	Mormyridae	*Petrocephalus wesselsi*	Least Concern	LC	
Perciformes	Cichlidae	*Chetia brevis*	Endangered	EN	B1ab(iii,v)+2ab(iii,v)
Perciformes	Cichlidae	*Oreochromis mossambicus*	Near Threatened	NT	A3e
Perciformes	Cichlidae	*Pseudocrenilabrus philander*	Least Concern	LC	
Perciformes	Cichlidae	*Coptodon rendalli*	Least Concern	LC	
Perciformes	Cichlidae	*Tilapia sparrmanii*	Least Concern	LC	
Perciformes	Gobiidae	*Glossogobius callidus*	Least Concern	LC	
Perciformes	Gobiidae	*Glossogobius giuris*	Least Concern	LC	
Siluriformes	Amphiliidae	*Amphilius uranoscopus*	Least Concern	LC	
Siluriformes	Clariidae	*Clarias gariepinus*	Least Concern	LC	
Siluriformes	Mochokidae	*Chiloglanis bifurcus*	Endangered	EN	B1ab(i,ii,iii,iv,v)+2ab(i,ii,iii,iv,v)
Siluriformes	Mochokidae	*Chiloglanis emarginatus*	Least Concern	LC	
Siluriformes	Mochokidae	*Chiloglanis paratus*	Least Concern	LC	
Siluriformes	Mochokidae	*Chiloglanis pretoriae*	Least Concern	LC	
Siluriformes	Mochokidae	*Chiloglanis swierstrai*	Least Concern	LC	
Siluriformes	Mochokidae	*Synodontis zambezensis*	Least Concern	LC	
Siluriformes	Schilbeidae	*Schilbe intermedius*	Least Concern	LC	

Appendix 1-F Table showing the metric groups and considerations for their assessment used in the Fish Response Assessment Index(FRAI)

METRIC GROUP (EXCEL SHEET IN MODEL)	CONSIDERATIONS		SPECIES RESPONSE METRICS: RATING CRITERIA
	HABITAT INDICATORS: COMPARED TO REFERENCE	SPECIES RESPONSE OBSERVED OR DERIVED FROM HABITAT INDICATORS: COMPARED TO REFERENCE	
Velocity-depth (VEL_DEPTH)	Changes in: Fast-deep, fast-shallow, slow-deep and slow-shallow. Causes – changes in hydrology; zero flows, base flows, moderate floods and freshes. Seasonality. Changes in sediment capacity and supply (sedimentation and scouring)	Depends on reference species in the fish assemblage able to utilize velocity-depth, cover, modified flow or physico-chemical conditions.	-5 or 5: Extreme loss (absent)/increase (completely dominant) from reference -4 or 4: Serious loss/increase from reference -3 or 3: Large loss/increase from reference -2 or 2: Moderate loss/increase from reference -1 or 1: Small loss/increase from reference **0: No change from reference**
Cover (COVER)	Changes in: 1. Overhanging vegetation. Causes – altered water levels, bank erosion or physical destruction of overhanging vegetation. Increase in vegetation due to increased nutrients and alien vegetation. 2, Undercut banks and root wads. Causes – altered water levels, bank erosion or physical destruction of overhanging vegetation. 3. Particular stream substrate type. Causes – changes in sediment transport (supply & capacity), benthic algal growth due to increased nutrients. 4. Instream vegetation. Causes – invasive alien macrophytes, changed water levels, physical destruction. 5. Water column. Causes – altered water levels or loss of depth due to sedimentation (in pools).		
Flow Modification (FLOW_MOD)	Changes in hydrology: 1.Increase or decrease in no-flow conditions 2. Increase or decrease in low-flow conditions 3. Increase or decrease in moderate events 4.Increase or decrease in events (high flow, floods) Change in seasonality is considered for each.		
Physico-Chemical (PHYSCHEM)	Changes in: 1. pH 2. Salts 3. Nutrients 4. Temperature 5. Turbidity 6. Oxygen 7. Toxics		
Migration (MIGRATION)	Any modification that results in the fragmentation of fish populations is considered. The presence and extent of the following are considered in evaluating the impact on and response of migratory species – 1. Weirs and causeways 2. Impoundments 3. Physico-chemical barriers 4. Hydrological modifications	Depends on reference species in the fish assemblage	0: None, or no potential impact on movement. 1: Small; limited, with small potential impact. 2: Moderate; notable and with potential impact. 3: Large; clear potential impact. 4: Serious; clear and serious potential impact. 5: Extreme; clear and critical potential impact.

Appendix 1-G: FRAI computed (automated and adjusted) ecological categories

Site 1

AUTOMATED	
FRAI (%)	44,9
EC: FRAI	D
ADJUSTED	
FRAI (%)	68,3
EC: FRAI	C

Site 2

AUTOMATED	
FRAI (%)	47,2
EC: FRAI	D
ADJUSTED	
FRAI (%)	68,7
EC: FRAI	C

Site 3

AUTOMATED	
FRAI (%)	35,8
EC: FRAI	E
ADJUSTED	
FRAI (%)	66,4
EC: FRAI	C

Site 4

AUTOMATED	
FRAI (%)	34,9
EC: FRAI	E
ADJUSTED	
FRAI (%)	64,8
EC: FRAI	C

Appendix 1-H Sampling permit

Mpumalanga
TOURISM AND PARKS AGENCY

MPUMALANGA TOURISM & PARKS AGENCY
P/BAG X 11338 NELSPRUIT 1200
2020 -06- 19
WILDLIFE PROTECTION SERVICES
PERMITS

MPB. 5662

PERMIT

TO ~~HUNT~~/CATCH / COLLECT AND CONVEY FISH FOR SCIENTIFIC PURPOSE
(Issued in terms of the provisions of the Nature Conservation Act 10 of 1998)

Name and residential address of permit holder: ***V.K. Dlamini***
University of Witwatersrand
1 Jan Smuts Ave
Johannesburg 2000

Name and address of institution or department of whose behalf shall be hunted and conveyed: ***University of Witwatersrand***
JOHANNESBURG

PARTICULARS OF FISH WHICH MAY BE ~~HUNTED~~/CATCH / COLLECTED

Number	Species
Open	*Aquatic macro-invertebrates & Fish*

PLACE: MPUMALANGA PROVINCE

In terms of and subject to the provisions of the Nature Conservation Act (Act No. 10 Of 1998) and the regulations framed thereunder , the above-mentioned person is hereby authorised, subject to the conditions and requirements appearing and this permit, to ~~hunt~~/catch/collected fish referred to above during the period of validity of this permit on behalf of the institution or department referred to above

- **Report of the results of the study, with GPRS readings of localities where specimens were collected, should be submitted to MTPA**

Period of validity of permit: From date of issue to: ***31 May 2021***

....
for CHIEF EXECUTIVE OFFICER

....
Signature of permit holder

CONSERVATION SERVICES
Private Bag X11338, Mbombela, SOUTH AFRICA, 1200 Tel: +27 (13) 759 5300/1 Fax: +27 (13) 759 5490 www.mpumalanga.com

SEE CONDITIONS AND REQUIREMENTS ON REVERSE SIDE

MPUMALANGA
THE PLACE OF THE RISING SUN

MPUMALANGA TOURISM & PARKS AGENCY
P/BAG X 11338, NELSPRUIT 1200
TEL: 013 759 5300/1
2020 -06- 19
FAX: 013 759 5490
WILDLIFE PROTECTION SERVICES
PERMITS

Mpumalanga
TOURISM AND PARKS AGENCY

As per permit MPB 5662 dd. 19 June 2020

ORDER_	FAMILY	TAXON	SPECIES	POINT_SHP	CATEGORY
Anguilliformes	Anguillidae	Anguilla bengalensis labiata	51	1	Least Concern
Anguilliformes	Anguillidae	Anguilla mossambica	54	1	Least Concern
Atheriniformes	Aplocheilidae	Nothobranchius orthonotus	341	1	Least Concern
Characiformes	Characidae	Brycinus imberi	244	1	Least Concern
Characiformes	Characidae	Hydrocynus vittatus	248	1	Least Concern
Characiformes	Characidae	Micralestes acutidens	249	1	Least Concern
Cypriniformes	Cyprinidae	Barbus afrohamiltoni	69	1	Least Concern
Cypriniformes	Cyprinidae	Barbus annectens	73	1	Least Concern
Cypriniformes	Cyprinidae	Barbus paludinosus	137	1	Least Concern
Cypriniformes	Cyprinidae	Barbus radiatus	142	1	Least Concern
Cypriniformes	Cyprinidae	Barbus sp. 'viviparus cf. Mozambique'	3012	1	Least Concern
Cypriniformes	Cyprinidae	Barbus toppini	151	1	Least Concern
Cypriniformes	Cyprinidae	Barbus trimaculatus	154	1	Least Concern
Cypriniformes	Cyprinidae	Barbus unitaeniatus	155	1	Least Concern
Cypriniformes	Cyprinidae	Barbus viviparus	157	1	Least Concern
Cypriniformes	Cyprinidae	Labeo congoro	168	1	Least Concern
Cypriniformes	Cyprinidae	Labeo cylindricus	169	1	Least Concern
Cypriniformes	Cyprinidae	Labeo rosae	176	1	Least Concern
Cypriniformes	Cyprinidae	Labeo ruddi	178	1	Least Concern
Cypriniformes	Cyprinidae	Labeobarbus marequensis	187	1	Least Concern
Cypriniformes	Cyprinidae	Mesobola brevianalis	193	1	Least Concern
Mormyriformes	Mormyridae	Marcusenius pongolensis	30	1	Data Deficient
Mormyriformes	Mormyridae	Petrocephalus wesselsi	45	1	Least Concern
Perciformes	Cichlidae	Chetia brevis	360	1	Endangered
Perciformes	Cichlidae	Oreochromis mossambicus	374	1	Near Threatenec
Perciformes	Cichlidae	Pseudocrenilabrus philander	381	1	Least Concern
Perciformes	Cichlidae	Tilapia rendalli	401	1	Least Concern
Perciformes	Cichlidae	Tilapia sparrmanii	403	1	Least Concern
Perciformes	Gobiidae	Awaous aeneofuscus	427	1	Least Concern
Perciformes	Gobiidae	Glossogobius callidus	428	1	Least Concern
Perciformes	Gobiidae	Glossogobius giuris	429	1	Least Concern
Siluriformes	Clariidae	Clarias gariepinus	296	1	Least Concern
Siluriformes	Mochokidae	Chiloglanis paratus	317	1	Least Concern
Siluriformes	Mochokidae	Chiloglanis swierstrai	320	1	Least Concern
Siluriformes	Mochokidae	Synodontis zambezensis	335	1	Least Concern
Siluriformes	Schilbeidae	Schilbe intermedius	284	1	Least Concern

Private Bag X11338 Mbombela 1200. N4 National Road, Halls Gateway, Mataffin, MBOMBELA - MPUMALANGA. www.mpumalanga.com
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THE PLACE OF THE RISING SUN

Appendix 1-I: Animals research ethics clearance certificate

ANIMALS RESEARCH ETHICS COMMITTEE (AREC)

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

STRICTLY CONFIDENTIAL

CLEARANCE CERTIFICATE NUMBER: 2020/07/01/B

APPLICANT: Ms V Dlamini

School: N/A ; Department: Geography; Location: Lower Komati River

PROJECT TITLE: Determining the present well-being (ecological state) of fish communities in the Lower Komati, Mpumalanga;

Category: B; Species and Numbers involved: *Various species of male/female fish of different weights and ages*

Approval is hereby given for the use of animals for the research project named above and described in the application reviewed by a quorate meeting of the AREC held on 28 Jul 2020. This approval remains valid until 21 Sep 2022 and is conditional to the following (if blank there are no special conditions):

Condition 1	Condition 2	Condition 3	Condition 4

All material changes to the approved research must be reported to the AREC before they are implemented. Failure to do so will invalidate this clearance certificate.

An annual progress report must be provided to the AREC.

The use of these animals is subject to AREC guidelines on the use and care of laboratory animals, is limited to the procedures described in the application and is subject to additional conditions listed below:

I, the Chair of the AREC (or my designated representative) am satisfied that the proposed research is ethical as judged by local law, international standards and University policy.

Signed: __________ _______ Date: ____22/09/2020

(Chairperson of the AREC)

I am satisfied that the persons listed in this application are competent to perform the procedures described in the application, in the context of Section 23 (1) (c) of the veterinary and Para-veterinary Professions Act (19 of 1982).

Signed: ______ ___________________ Date: ____22/09/2020_______________

(Registered Veterinarian)

CC: Student supervisor: «Title1» «Initials1» «Supervisor_surname»
Director Central Animals Service: Dr Kim Jardine

A**ppendix** 2-**A**: **Participatory mapping guiding questions to identify social values and uses of the lower komati river by the local community**

Introduction
Good morning/afternoon. I am Vuyisile Dlamini a PhD student at the University of the Witwatersrand. For my PhD research I am carrying out a research study on integrating social indicators in river health assessment in the Komati catchment. Thank you for taking your time to participate in this participatory mapping exercise with **local community** participants who are water users in the Lower Komati river catchment. This mapping exercise is part of data collection method for my research to explore ways of integrating local views in river health assessment. This exercise will be divided into two parts; we will first do participatory mapping as a group. To fill up gaps on the mapping exercise I would like to accompany two (2) individuals for one day as they go about their daily life activities to mark important places we talked about during the mapping process.

Many thanks for having agreed to be part of the study. As we discussed when you read/listened to the informed consent statement about my project and signed the informed consent form, the information you provide is strictly confidential and your personal details will remain anonymous and protected. Notes and videos will be taken during the process. For this exercise you'll work in groups. I will ask just a few conversational questions and sometimes I will request you to draw maps so that I can understand the issues better. You are free to withdraw your participation from this study at any time when you so wish.

---

1. **Familiarization/introductory exercise**

Before we start, I would like to remind you that there are no right or wrong answers in this discussion. I am interested in getting your views, so please feel free to share your point of view. Your opinions are important for the study. Please treat others in the group as you want to be treated by not sharing any this from this discussions with anyone outside this group. Let's start by going around the circle and having each person introduce themselves, I will introduce myself first; as the researcher and moderator for the discussion.

- Please introduce yourself; briefly relate your interests in the Komati river catchment.
- Describe the type of area where you live ; e.g community or reserve
- How long have you lived in that area or how long have you been a member of the Komati river catchment user forum?

2. **Ecosystem services mapping exercise**

Instructions
This is a mapping exercise where I would like to know about any specified services you get from the Komati River catchment and to mark the specific areas where you derive and use the specific services in the outline map provided. This will help me identify areas and services that are important to you in the catchment.

Step by step process on how to map.
I will provide you with one outline map of the Komati River only showing the catchment boundary. I will also provide you with another map with physical features around the catchment e.g. roads, buildings so that you can easily recognise areas you may want to mark. However, you will only mark and work on the outline map. Please give each other in the group to mark on the map as you may be getting different benefits at different place. Discuss amongst yourselves as you draw. I will provide you with different a pens of different colours. Label each marked area with codes as specified in brackets

i. **Provisioning ecosystem services in the catchment for local communities'**
- How do you use the land within the Komati river catchment?

- o To grow, harvest, hunt, fish for food around the river catchment, indicate the areas where you do that.
  - o Mark the places where you use the land in the catchment and trace the path you travel from your house to that place.
- Please indicate if you grow, harvest, hunt or fish for food or to sell for profit.
- Do you collect freshwater from the Catchment or any other source within the area other than from municipal water system?
  - o Mark the places where you get the water from, please trace the path you travel from your area to that point.
- For your building do you get any material around the river catchment? Please mark the area
- Any other tangible products you get from the catchment other than the ones we have discussed and when in season do you collect these product. Mark the area on the map

ii. Cultural services in the catchment

- Does the river have any significance role in any spiritual or cultural activity you might practise e.g meditation, self-rejuvenation, spiritual ceremonies.
- If you feel comfortable with it you can mark them, however if you feel they are sacred you are free to leave them out.
- Have you ever visited specific local areas within the catchment for their cultural and/or historical heritage and ho(i.e. Historical homestead, birth sites, burial sites, etc
- How often have you visited those areas and what has influenced those visits
- Overall how are the places in the catchment important to your overall feeling of belonging? If you are comfortable with that please indicate where these are located

iii. Recreational and Aesthetic and services in the catchment

- Are there places of nature in the catchment which are solely important to you for their aesthetic, scenic, or inspiring beauty? Mark them on the map
- How often do you visit the area (once a month, yearly)
- What determines your visits (e.g. season, cleanliness)
- Do you regard any parts of the catchment as places for inspiration e.g. for art, song, stories, dance, etc.? Indicate where these places
- Do you have people from outside the catchment coming in the area for recreational activities?
- How often do they come (every weekend, on school holidays)
- Do you gain anything from their visits?

iv. Mapping areas of river health concern

- What do you understand by a river's health
- In your opinion, what are the signs of an 'unhealthy river' and a healthy river?
- Can you share your thoughts about the current health of the Lower Komati river compared to your previous/past experiences with this river as far as you can recall?
- What has influenced the current river health status?
- Who has the current river health status impacted your current use of the river?

You will be required to show areas of importance and threat to you in the catchment by arranging and placing red and green plastic dots (moveable plastic discs about 10 mm in diameter) on the provided map. The green dots will be used to identify the places of importance to you and which have continuously meet your needs and expectations. The red dot will be placed in areas which you deem to be under threat and failing to meet your needs and expectations.

i. On he map you have been working on, identify areas which have continuously afforded the needed services without any disruption or problem over time (adequately useful). For this areas place a green dot.

ii. Mark areas which you have not been able to adequately harvest from or get much needed services with a red dot.
iii. In what ways has the marked areas in river catchment enhanced or threatened your way of living. (If positively place green dot, if negatively place a red dot)
iv. Have you been able to adequately access these marked areas in a satisfactory way (if access has been adequate place green dot and if there has been inadequate access place a red dot.)
v. What has been the greatest hindrance to access in the different areas
vi. Over the years which places have maintained in offering all services you need adequately. Place green dot on those
vii. Which areas have declined in offering your required services? Place a red dot
viii. Which areas have been the greatest disappointment in the catchment according to you mark with red dot.
ix. How would you compare state of the river over the years since you started using it (any threats, decline, and extinctions).

Tracking exercise with Key Informants

- To help me fill up gaps, and mark areas mentioned during the mapping exercise, I would like to accompany you for one day as you go about your typical daily activities from waking up to sleep at different seasonal times.
    - I will be carrying a GPS to mark coordinates of the places we have talked about during the mapping exercise.
    - I will mark the routes we travel as go about your daily activities around the catchment.
- As we walk through I will also ask the following questions:
    - What influences your chose of routes as you go about your daily activities(e.g ease of access, scenery)
    - Do your typical daily activities change due to seasonal changes?

That concludes the participatory mapping exercise. If you have any comments to add or questions before we conclude the session I will take them. Thank you so much for participating and sharing your thoughts and opinions with us, your views are important and valuable for this research.

Appendix 2-B: Informant interview schedule with local community key informants.

Introduction
Good morning/afternoon. I am Vuyisile Dlamini a PhD student at the University of the Witwatersrand. For my PhD research I am carrying out a research study on integrating social indicators in river health assessment in the Komati catchment. Thank you for taking your time to participate in this life history narration as a water user in the Lower Komati river catchment. This oral narration is part of data collection method for my research to determine how social value can be used with ecological indicators in river health assessment.

As you have agreed to be part of the study and as we discussed when you read/listened to the informed consent statement, about my project and signed the informed consent form, the information you provide is strictly confidential and your personal details will remain anonymous and protected. Notes and audio recordings will be taken during the process. I will ask a few conversational questions, sometimes I will request you to mark some areas on a map so that I can understand the issues better. You are free to withdraw your participation from this study at any time when you so wish.

3. Familiarization/introductory exercise

Before we start, I would like to remind you that there are no right or wrong answers in this discussion. I am interested in getting your views, so please feel free to share your point of view. Your opinions are important for the study.

Introduction
For us to carry out that exercise I will allow you to briefly narrate personal stories about the river catchment. You will be guided by the following questions.
.

Gender:

Were you born in this area?
a. Yes__________
b. No __________, how long have you lived in the area? What brought you here?

What is your year category (25-34), (35-44), (45-54), (55-64), (64-74), 74-upwards

1. **Memories about the river.**

Relate on your earliest memory on your first contact with the lower Komati river catchment

- How you used to use it
- Activities that took place around the river
- visits to the river catchment for services.
- relate how many times did you visit the different locations e.g. once a month)
- What did you like most about the river catchment

2. **Opinions on the present use of the river**
    - Activities that you do around the river
    - Are the visits to the river catchment for services still the same, e.g. changed places, variation in trips? explain any changes that have taken place
    - *For younger participants*: What experiences did the river offer that were important to previous generations that you think are important to present and future generations and why (your parents and grandparents)?
    - Are any of these experiences important across generations and why?

How much of the experiences do you think is related to the state of the environment?

3. **Opinions about the present state of the river?**
    - How would you describe the present state of the river?
    - With the present state of the river, has there been any change on how you use the river (e.g any change in the kind, quality or amount of services your derive or benefits from the river, amount, no of visits to aesthetics/cultural areas)
    - What is your understanding of river health?
    - Do you think river health is important and why is it important?
    - What indications would you point out to explain the health of a river?
    - How would you compare the present and past health of the Lower Komati river.
    - What do you think has controlled those changes over time?
    - Are there specific areas along the river that concern you?
    - How is your life affected by the present state of the river?

4. **Aspirations placed on the river**

i. What role do you think rivers play in our daily lives and do you get that from the Komati
    - In what ways has the river catchment enhanced your livelihoods over the years
    - Would you credit the river for anything good in your daily activities
    - Over the years which places have been good to you

- How would you compare state of the catchment over the years since you started using it(any threats, decline, extinctions)

ii. In your daily life or operation which is more important to you, none interruption of supply/availability of a service, or its meeting the expected quality standards?

- river catchment offers/meets your needs?
- What are the benefits of a clean water supply, environment and adequate water supply to you?.
- What do you think can damage/compromise the river stretch's quality according to you?
- What can be done to protect the river from such threats

That concludes our exercise. If you have any comments to add or questions before we conclude the session I will take them. Thank you so much for participating and sharing your thoughts and opinions with us, your views are important and valuable.

Appendix 2-C: Key informant interview schedule with local fishers

Introduction

Good morning/afternoon. I am Vuyisile Dlamini a PhD student at the University of the Witwatersrand. For my PhD research I am carrying out a research study on integrating social indicators in river health assessment in the Komati catchment. Thank you for taking your time to participate in this interview as a fisher in the Lower Komati river catchment. This is part of data collection method for my research to determine how social value can be used with ecological indicators in river health assessment.

Many thanks for having agreed to be part of the study. As we discussed when you read/listened to the informed consent statement, about my project and signed the informed consent form, the information you provide is strictly confidential and your personal details will remain anonymous and protected. Notes and audio recordings will be taken during the process. I will ask a few conversational questions and at the end of the sometimes I will request you to draw maps so that I can understand the issues better. You are free to withdraw your participation from this study at any time when you so wish.

---

4. Familiarization/introductory exercise

Before we start, I would like to remind you that there are no right or wrong answers in this discussion. I am interested in getting your views, so please feel free to share your point of view. Your opinions are important for the study.

Gender___________________________________

What is your age category (25-34), (35-44), (45-54), (55-64), (64-74), (74-upwards)?

Fish types and fishing conditions

1. How long have you been fishing in the river? ---
2. Which fish would you identify as being 'common' now in the area and please identify them on the pictures provided? --
3. What were the main kinds of fish you catch when you started fishing?......................
4. How do you select the best fishing location each time?

Accessibility_____________	
Because there are lots of fish easy to find fish	

there(describe the environment) rocky, lot of plants sandy etc.	
safety	
other	

5. Do you fish for consumption/selling/both or other?
6. What methods of fishing do you use? E.g handline, rod,net(drag or gill), traditional method……….
7. Averagely a day how many fish do you get of each kind and time spent fishing? E.g 3fish/day in 3hrs
8. How would you describe your fishing trend (s) over years, any changes you might have noted or made e.g no of fish per day, type of fish(species), size of fish? When did you start noting those changes, what do you think has caused them?
9. How would you identify a healthy fish from an unhealthy one and what techniques do you use to determine the fish's health status?
10. What would you identify as determinants of a good or bad fish breeding area?
11. Have you ever noticed any large fish death, if so where, when and what do you think caused it?
12. What are the greatest challenges you have experienced as you fish and how would you overcome them. E.g too many fishers, fish quality, rains, less fish, water……

River's status, fishing and human well being

1. Since you started fishing has the river and the kinds of fish you catch changed?
2. According to you is it still good enough to allow you to continue with fishing?.........
3. How would you describe the past and present *condition/status* of the river?...
4. What would you consider to be common *threats* to the river in your area?----------------
5. How would you identify a healthy river from an unhealthy one; and what would you identify as determinants of good healthy versus poor healthy river?------------------------
6. The present state of the river, how has it affected your livelihood---------------------------
7. What other livelihood alternatives do you have besides fishing?___________________

Illustrations of fish species common from in the Lower Komati River from the Atlas of Southern African Freshwater Species - SAIAB (Scott et al., 2007) and fish pictures from the Ecostatus of the Komati River Report (MPTA, 2015) were used to help communities identify the fish types common in the area)

Appendix 2-D (I) Pictures of fish commonly found in the Lower Lomati River (MTPA, 2015)

FAMILY MORMYRIDAE - SNOUTFISHES	
Marcusenius pongolensis (previously - *macrolepidotus)* Bulldog	
Petrocephalus catostoma (wesselsi) Southern churchill	
FAMILY ANGUILLIDAE - FRESH WATER EELS	
Anguilla mossambica Longfin eel	
Anguilla marmorata Giant mottled eel	
FAMILY CYPRINIDAE - BARBS, YELLOWFISH, LABEOS	
Mesobola brevianalis River sardine	
Opsaridium peringueyi Southern barred minnow	
Barbus anoplus Chubbyhead barb	
Barbus annectens Broadstriped barb	
Barbus brevipinnis Shortfin barb	
Barbus neefi Sidespot barb	
Barbus unitaeniatus Longbeard barb	

Appendix 2-D (ii) Pictures of fish commonly found in the Lower Lomati River. (MTPA, 2015)

Barbus viviparus Bow stripe barb		
Barbus toppini East coast barb		
Barbus radiatus Beira barb		
Barbus trimaculatus Three spot barb		
Barbus eutaenia Orange fin barb		
Barbus argenteus Rose fin barb		
Barbus paludinosus Straight fin barb		
Barbus afrohamiltoni Plump barb		
Labeobarbus polylepis Bushveld small scale yellowfish		
Labeobarbus marequensis Lowveld large scale yellowfish		
Varicorhinus nelspruitensis Incomati chisel mouth		
Labeo congoro Purple labeo		

APPENDIX 2-D (III) Pictures of fish commonly found in the Lower Komati River (MTPA, 2015)

Labeo cylindricus Red eye labeo	
Labeo molybdinus Leaden labeo	
Cyprinus carpio Carp	
FAMILY CHARACIDAE - CHARACINS	
Brycinus imberi Imberi	
Micralestes acutidens Silver robber	
Hydrocynus vittatus Tigerfish	
FAMILY AMPHILIIDAE - MOUNTAIN CATFISHES	
Amphilius natalensis Natal mountain catfish	
Amphilius uranoscopus Common or stargazer mountain catfish	
FAMILY SCHILBEIDAE - BUTTER CATFISHES	
Schilbe intermedius Silver catfish or Butter barbel	
FAMILY CLARIIDAE - AIR-BREATHING CATFISHES	
Clarias gariepinus Sharptooth catfish	
FAMILY MOCHOKIDAE - SQUEAKERS, SUCKERMOUTH CATLETS	
Chiloglanis anoterus Pennant-tailed suckermouth or rock catlet	

APPENDIX 2-D (IV) Pictures of fish commonly found in the Lower Komati River (MTPA, 2015)

Chiloglanis bifurcus Incomati suckermouth or rock catlet	
Chiloglanis paratus Sawfin suckermouth or rock catlet	
Chiloglanis pretoriae Short spine suckermouth or rock catlet	
Chiloglanis swierstrai Lowveld suckermouth or rock catlet	
FAMILY SALMONIDAE - TROUTS	
Oncorhynchus mykiss Rainbow trout	
FAMILY CENTRARCHIDAE - BASSES AND SUNFISHES	
Lepomis macrochirus Bluegill sunfish	
Micropterus salmoides Largemouth bass	
FAMILY CICHLIDAE - CICHLIDS	
Pseudocrenilabrus philander Southern mouth brooder	
Chetia brevis Orange-fringed river bream	
Tilapia sparrmanii Banded tilapia	
Coptodon rendalli Red breast tilapia	

Oreochromis mossambicus Mozambique tilapia	
FAMILY GOBIIDAE - GOBIES	
Glossogobius giuris Tank goby	

APPENDIX 2-G Approval letter from traditional authority

Hhoyi Traditional Council
Stand 098C
Hhoyi Trust
1348

BAKA NGOMANE

P.O.Box 1
Hhoyi
Mpumalanga
1348

Mobile1 : 079 947 7733
Mobile 2 : 076 898 7751
Email : info@bakangomane.org.za

UNIVERSITY OF MPUMALANGA

NELSPRUIT MAIN CAMPUS

25 July 2019

Attention : Ms Vuyisile Dlamini

RE: REQUEST FOR PERMISSION TO CONDUCT RESEARCH

As per your letter dated 19 June 2019

I write to inform you that the Hhoyi Traditional Council has granted you the permission to conduct a research within its area of Jurisdiction, i.e. Hhoyi and Goba areas.

We do believe that this exercise will not only pave a way to your PhD achievements, but will also help Nkomazi to enhance proper preservation of our environment in the future.

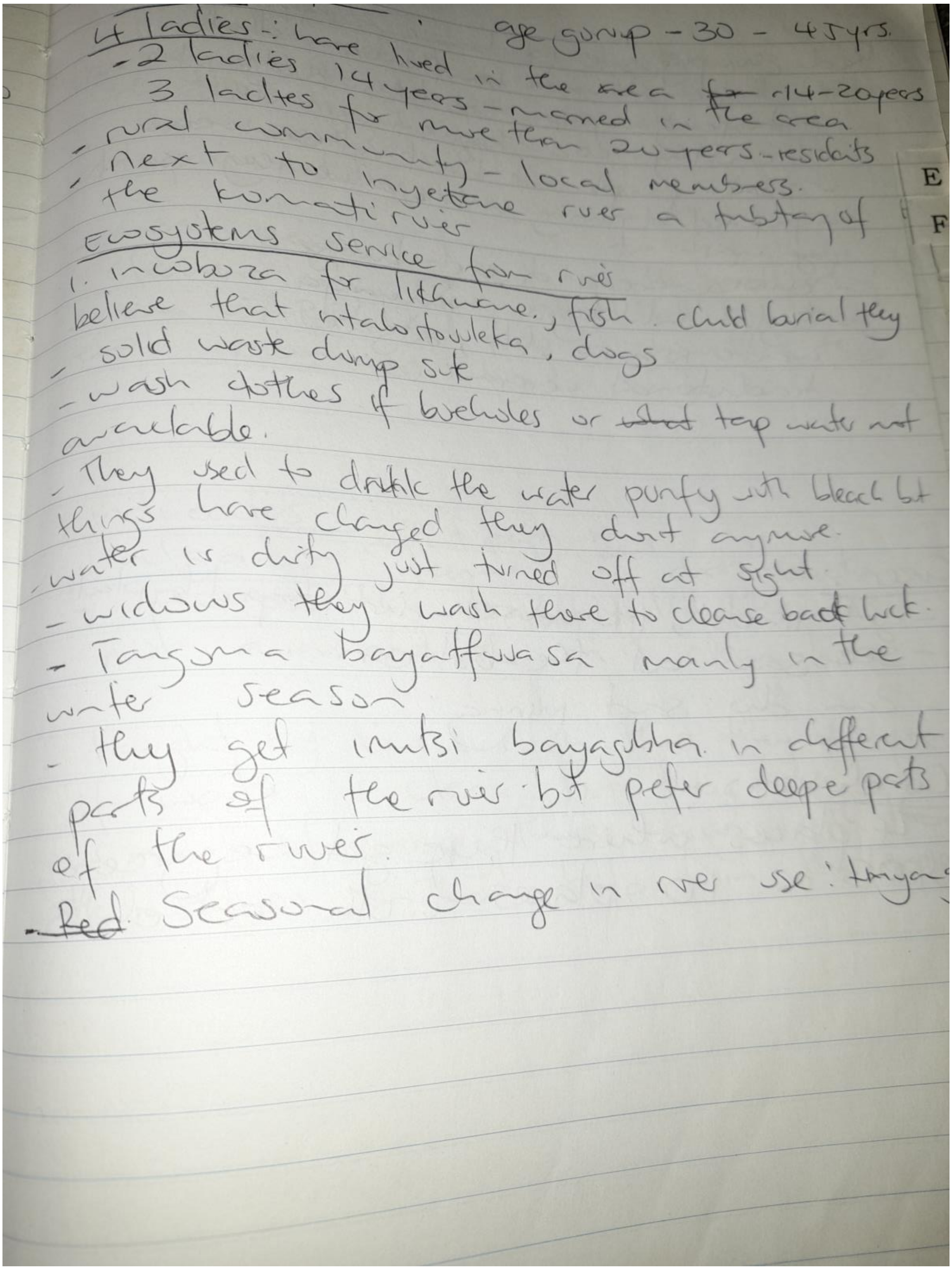
We trust that you will enjoy interacting with our community in this regard.

Your's Truly,

Inkosi SG Ngomane

Ngomane! Mshika! Mganu Lowahluma Emini KaMandlazi Kwatsi Entsambama Wabhohloka !

APPENDIX 2-H Example of field notes taken by researcher during group mapping exercises


4 ladies: have lived in the area ~~for~~ 14-20years age group - 30 - 45yrs.
- 2 ladies 14 years - married in the area
3 ladies for more than 20 years - residents
- rural community - local members.
- next to Inyetane river a tributary of the komati river

Ecosystems service from rivers

1. incwaba for lithwane, fish. child burial they believe that ntalo/fowleka, dogs
- solid waste dump site
- wash clothes if boreholes or ~~what~~ tap water not available.
- They used to drink the water purify with bleach but things have changed they don't anymore.
- water is dirty just turned off at sight.
- widows they wash there to cleanse back luck.
- Tangoma bayatfwasa manly in the winter season
- they get imitsi bayagubha in different parts of the river but prefer deeper parts of the rivers.
- ~~Red~~ Seasonal change in river use: tinyanga

APPENDIX 2-I Human Research Ethics Clearance Certificate

Research Office

HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)
R14/49 Dlamini

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER: H17/08/07**
PROJECT TITLE	Integrating social indicators in river health monitoring in the Komati catchment
INVESTIGATOR(S)	Miss V Dlamini
SCHOOL/DEPARTMENT	Geography, Archaeology and Environmental Studies/
DATE CONSIDERED	18 August 2017
DECISION OF THE COMMITTEE	Approved
EXPIRY DATE	07 November 2020

DATE 08 November 2017 **CHAIRPERSON** (Professor J Knight)

cc: Supervisor : Dr M Samson and Prof C Curtis

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University. Unreported changes to the application may invalidate the clearance given by the HREC (Non-Medical)

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to completion of a yearly progress report.**

Signature ______________ Date ____/____/____

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES

APPENDIX 2-J: Letter of support from Catchment Management Agency

Suite 801, 8th Floor
The MAXSA Building
13 Streak Street
Mbombela

Private Bag X11214
Mbombela
1200

Tel 013 753 9000
Fax 013 753 2786

INKOMATI-USUTHU
CATCHMENT MANAGEMENT AGENCY

Enquiries: Remo Morekesi
Reference: 2/4/3
Email: Morekesir@iucma.co.za
thomasga@iucma.co.za

Date: 13 June 2017

Dlamini Vuyisile Khetsiwe.
PhD student: University of Witwatersrand
Lecturer: University of Mpumalanga Email:
vuyisile.dlamini@ump.ac.za or 1571341@students.wits.ac.za.

To whom it may concern

RE: INTEGRATING SOCIAL INDICATORS IN RIVER HEALTH MONITORING IN THE LOWER KOMATI CATCHMENT, SOUTH AFRICA

The Inkomati-Usuthu Catchment Management Agency (IUCMA) has been informed of the research on "Integrating social indicators in river health monitoring in the lower Komati Catchment, South Africa" by Dlamini Vuyisile Khetsiwe. PhD student: University of Witwatersrand.

The IUCMA will support this research initiative through the participation in project activities as deemed appropriate. The IUCMA believes that this initiative will be beneficial to the communities involved in this research.

The research has now been registered with the IUCMA so that provision of our services and support could be regularised. We hope to have a good working relationship with the researcher on this project.

Sincerely yours

Dr Thomas Gyedu-Ababio
Chief Executive Officer