The Effects of Land Use Change on Water Quality in the upper Berg - and Breede River catchments, Western Cape, South Africa

by

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Abstract

Pollution of surface water resources is gaining global attention due to increasing freshwater stress and scarcity. This study assessed how land use changes in the upper catchments of the Berg and Breede rivers affect water quality. Land Cover Data, covering a 22-year period, was prepared, categorised, and analysed. Land use classes include “natural”, “urban”, “agricultural”, “water bodies”, “mining” as well as “degraded land, bare rock, and soil”. Changes of these land use classes were analysed to establish their influence on water quality parameters such as electrical conductivity, pH, total nitrogen including ammonium, nitrate and nitrite, orthophosphate, and sulfate. In the Berg River catchment, urban, natural, water bodies and degraded land, bare rock, and soil increased while agricultural and mining decreased. In the Breede River catchment, urban, water bodies and degraded land, bare rock, and soil as well as mining increased while agricultural and natural decreased. In the Berg River catchment, Dissolved Inorganic Nitrogen (ammonium, nitrate and nitrite), as well as pH increased while electrical conductivity, sulfate, and orthophosphate decreased. In the Breede River catchment, ammonium and orthophosphate increased while a decrease in electrical conductivity, nitrate and nitrite, pH, and sulfate was noted.

In the Berg River catchment, the following correlations, or relationships, were noted. Urban land was correlated with ammonium and sulfate; agricultural land was correlated with electrical conductivity and sulfate, natural land cover was correlated with electrical conductivity, orthophosphate, and sulfate. Water bodies were correlated with orthophosphate, sulfate, degraded land, bare rock, and soil was correlated with ammonium and mining was correlated with electrical conductivity, orthophosphate, and sulfate. In the Breede River catchment, urban land was correlated with ammonium and orthophosphate, agricultural land was correlated with nitrate and nitrite and pH, and natural land cover was correlated with electrical conductivity, ammonium, and sulfate. Water bodies were correlated with electrical conductivity, nitrate and nitrite, and sulfate, degraded land, bare rock, and soil were correlated with electrical conductivity, ammonium, orthophosphate, and sulfate, and mining was correlated with electrical conductivity, ammonium and sulfate.

The study therefore recommends that we mitigate land use change impacts on water quality by enforcing strict land-use regulations, promote sustainable agricultural practices, protect riparian areas and wetlands, implement better stormwater and wastewater management, educate the public, and coordinate integrated water resource management efforts to reduce pollution of scarce surface water resources.

Declaration

I declare that this research report is my own, unaided work. It is being submitted for the Degree of Master's of Science at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

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(Signature of candidate)

20th day of September 2024 at 13:00

This declaration should appear on a separate page and each copy of the thesis should be individually signed by the candidate.

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Glossary of Terms

Term	Definition
"Day-Zero"	Refers to the point in time when a city, such as Cape Town, is expected to run out of water due to severe drought and inadequate water supply. It signifies the day when municipal water sources are predicted to be depleted, leading to strict water rationing measures and potentially requiring residents to queue for limited water supplies.
Acid Mine Drainage	The acidic runoff generated from mining activities, typically from abandoned or active mines. It occurs when sulfide minerals in rocks exposed during mining react with oxygen and water, producing sulfuric acid. This acidic runoff can contaminate water sources, harming aquatic ecosystems and posing risks to human health.
Anthropogenic	Anything caused or influenced by human activity.
Biophysical factors	The physical and biological components of an environment that influence living organisms, including factors such as climate, soil type, topography, and biodiversity.
Climate change	Climate change refers to long-term alterations in temperature, precipitation patterns, and other atmospheric conditions primarily resulting from human activities, notably the release of greenhouse gases into the atmosphere.
Economic development	The sustained increase in the wealth, standard of living, and overall economic well-being of a region or country, typically measured by factors such as gross domestic product (GDP) growth, employment rates, income levels, and infrastructure improvement.
Ecosystem services	The benefits that humans obtain from ecosystems, including provisioning services (such as food and water), regulating services (such as climate regulation and water purification), supporting services (such as nutrient cycling and soil formation), and cultural services (such as recreation and spiritual enrichment).
Eutrophication (Cultural eutrophication - process accelerated by human activities)	The process by which bodies of water, such as lakes or rivers, become excessively rich in nutrients, typically due to runoff of fertilizers and other pollutants from human activities. This nutrient overload stimulates the growth of algae and other aquatic plants, leading to oxygen depletion, water quality deterioration, and ecological imbalances.
Industrialization	The process of developing industries and transitioning from an agrarian or rural economy to one dominated by manufacturing, technology, and urbanization.
Land cover	A descriptor of the status of the vegetation at a site
Land use	The management regime humans impose on a site
Mean Annual Precipitation	The average amount of precipitation that falls over a specific area over a one-year period. Precipitation refers to water, in liquid or frozen forms, that is released from clouds.
Non-Point source pollution	Pollutants that come from diffuse sources, such as agricultural runoff, urban runoff, or atmospheric deposition, making it challenging to pinpoint a specific origin.
Point source pollution	Contaminants released from a single, identifiable source, such as a pipe or outfall, into the environment.
Smart agriculture	Smart farming encompasses a broader range of technologies and approaches that go beyond precision farming. It integrates advanced technologies such as Internet of Things (IoT), artificial

Term	Definition
	intelligence (AI), robotics, and automation to create a more interconnected and automated agricultural system.
Social factors	The elements of human society that influence individual behaviour, attitudes, and interactions, including cultural norms, socioeconomic status, education, family dynamics, and community relationships.
Sulfate reduction	A microbial process where sulfate (SO_4^{2-}) is converted into sulfide (S^{2-}) through biological activity, typically in anaerobic environments.
Technological advancements	Improvements and innovations in technology that lead to the development of new products, processes, or systems, resulting in increased efficiency, productivity, and capabilities.
Urbanization	The process of increasing population concentrations in urban areas
Water quality	The physical, chemical, and biological characteristics of water that determine its suitability for specific uses, such as drinking, recreation, or supporting aquatic life.
Water quality indicators	Parameters used to assess the physical, chemical, and biological characteristics of water. They provide insight into the overall health and safety of water sources for human and environmental use.
Water security	The availability, accessibility, and sustainable management of water resources to meet the needs of people, communities, and ecosystems. It encompasses ensuring reliable access to clean water for drinking, sanitation, agriculture, industry, and environmental sustainability, while also addressing challenges such as water scarcity, pollution, and climate change impacts.

List of Abbreviations

Abbreviation	Meaning
AI	Artificial Intelligence
AMD	Acid Mine Drainage
BGCMA	Breede-Gouritz Catchment Management Agency
CARA	The Conservation of Agricultural Resources Act 43 of 1983
CoCT	City of Cape Town
DEFF	Department of Environment, Forestry and Fisheries
GIS	Geographic Information Systems
GPS	Global Positioning System
IoT	Internet of Things
MAP	Mean Annual Precipitation
miniSASS	Mini South African Scoring System
NAEHMP	National Aquatic Ecosystem Health Monitoring Program
NEMA	National Environmental Management Act 107 of 1998
NEMBA	National Environmental Management: Biodiversity Act, 2004
NWA	National Water Act 36 of 1998
REMP	River Eco-Status Monitoring Programme
RHP	River Health Programme
SASS	South African Scoring System
SPLUMA	Spatial Planning and Land Use Management Act No. 16 of 2013
WC	Western Cape (Province)
WCWSS	Western Cape Water Supply System

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1 CHAPTER ONE – Introduction and Background.

1.1 Introduction.

The escalating impact of human activities on the natural environment, coupled with the consequences of climate change and urbanization, poses a profound threat to water security and quality. This thesis addresses the multifaceted challenges arising from habitat destruction, biodiversity loss, and the over-exploitation of natural resources due to increasing human population (Zhang, 2015). Climate change, a direct result of human activities, manifests in global temperature rise, altered weather patterns, and intensified extreme events, influencing the physical environment and ecosystems (Klingelhöfer, et al., 2020). Such changes reverberate through agricultural production, water availability, and biodiversity, creating interlinked consequences (Klingelhöfer, et al., 2020).

As one of Earth's most precious resources, water faces escalating pollution from anthropogenic activities, jeopardizing aquatic ecosystems, biodiversity, and clean water availability for human consumption (Rahman, et al., 2021). Urbanization, characterised by increased population concentration in cities, exacerbates these challenges by inducing land use changes and habitat loss (Zhang, 2015). Developing countries like South Africa grapple with managing environmental impacts tied to urbanization and climate change, with potential adverse effects on water availability and the economy (Cullis, et al., 2019).

South Africa's Mean Annual Precipitation (MAP) falls below the global average, making water availability crucial for economic activities. Rapid population growth and urbanization further strain water resources through land cover changes, impacting hydrological processes and water quality (Khatri & Tyagi, 2015). The Western Cape Province (WC), characterised by winter rainfall, faces historical water shortages, exemplified by the recent severe drought from 2014 to 2017/2018 (Botai, et al., 2017). This led to stringent water-saving measures to avert "Day Zero," the day when taps would run dry (Stafford, et al., 2019).

Water management studies at the catchment level gain relevance in assessing human impacts on water quality. Legislation like the National Water Act 36 of 1998 (NWA) and programs such as the National Aquatic Ecosystem Health Monitoring Program

(NAEHMP) underscore the importance of catchment-level management (Brainwood, et al., 2004). This study aligns with these efforts, employing tools like Geographic Information Systems (GIS) and statistical analyses to unravel spatial data-water quality interactions (Sliva & Williams, 2001).

The intricate relationship between land cover and water quality is a central focus of this study, aiming to discern links between different land uses and their impact on water quality parameters. The study analyses a 22-year dataset, focusing on upper catchments in the Western Cape, crucial for the region's water supply. Objectives include identifying, mapping, and analysing land uses, as well as assessing water quality changes and exploring potential correlations between water quality and land use changes.

The research report includes the following chapters:

CHAPTER TWO – Literature review which includes a thorough and comprehensive review on aspects that are associated with the focus of this study. Factors that impact land use changes are discussed with specific reference to biophysical factors, climate change, population growth and urbanization, economic development and industrialization, agricultural practices and food demand, technological advancements, and innovation as well as policy and governance. The literature review also includes impacts of land use and land use change on water quality. Specific land uses selected in this study that are discussed includes natural land cover, urban, agricultural land, water bodies, mining, and degraded land, bare rock, and soil. Water quality indicators in this study include electrical conductivity, pH, ammonium, nitrate and nitrite, orthophosphate, and sulfate. These water quality indicators are discussed thoroughly with the aim to align past research with possible results expected in this study. A link is then made to other past research and studies to show relevance of this specific research study. The specific characteristics of the two selected study areas are then discussed and motivated as to why these two were specifically selected and then finally the relevance of this specific research study is highlighted.

CHAPTER THREE – Methodology and data collection. Here the study area with the respective selected sites, their specific locations, and characteristics of the selected study areas are shown. The study design is then explained and discussed with reference to how land use data are collected and selected, then how land use data are prepared and analysed. The next part of the study design entails how water quality data are collected, selected, and then prepared and analysed. An important part of the study is the determination of how land use change affected specific water quality parameters. The data are then interpreted and pre-selected to discard irrelevant correlations that are not statistically significant.

CHAPTER FOUR – Results and discussion. Land use change is analysed and shown over the study period with correlations. Student's t-tests were conducted to determine whether there were significant changes in land use over time. Water quality results are then presented and discussed. Water quality change is explored over the study period using correlations. Student's t-tests were also done here to investigate significant change over time. These results are displayed in graphs and tables and discussed as well. The final part of the results, land use changes impacting on water quality, is displayed in correlations and confidence levels. These findings and relationships are discussed, with reference to previous studies noted in the literature review. Specific interesting, and contrasting, findings are discussed, and possible explanations are given. An interesting and unexpected finding in this study is linked to the prominent sulfate reduction observed in both study areas and suggest optimal conditions for sulfate reducing bacteria.

CHAPTER FIVE – Here I highlight the interesting results and draw conclusions. Limitations and further research possibilities are identified.

1.2 Research objectives and questions.

1.2.1 Study aims and objectives.

The primary aim of this study is to examine land use changes over time to draw conclusions on the impact these have had on water quality in the upper Berg River and Breede River catchments in the Western Cape Province of South Africa. This assessment of the change in land use could be used by policymakers, researchers and governmental land use planners to make informed decisions regarding the consequences of land use change on water quality, which will help with development planning. It is important to understand the changing of land use patterns and the impact these have on water quality in the upper catchments of these two very important rivers.

The objectives of this research are to:

i. Identify, map, and populate the different applicable land uses over a specified time in the upper Berg River and Breede River catchments.
ii. Analyse, populate and compare water quality data over the specified time period in the two catchments.
iii. Investigate if and how the water quality and land use change are correlated.

1.2.2 Hypothesis and Research Questions.

The central hypothesis of this research is: the change in land use associated with a reduction in natural land cover will decrease water quality in the study area.

To address the study aim, I ask the following research questions:

iv. What were the predominant land use changes from 1996 – 2018 in the upper Berg River and Breede River catchments?
v. What were the primary water quality changes from 1996 – 2018 in the upper Berg River and Breede River catchments?
vi. Is there a relationship between specific land use type and water quality changes during the period of 1996 – 2018 in the upper Berg River and Breede River catchments?

2 CHAPTER TWO – Literature Review.

2.1 Introduction.

Human activities have over time impacted and modified the natural environment. As human population increases, the effect on the natural environment becomes increasingly pronounced. Habitats are impacted and modified or destroyed, resulting in biodiversity loss, decreased water security, overexploitation of remaining natural resources and increased land degradation (Zhang, 2015).

Climate change is a consequence of human activities and impacts Earth in a variety of different ways. Some of these ways include global temperature rise that affects weather patterns, changing precipitation patterns, oceanic changes, intensity, and occurrence of extreme weather events which all have knock-on effects on the physical environment and its ecosystems (Klingelhöfer, et al., 2020). These changes can also impact agricultural production, ecosystem changes, water availability and biodiversity loss (Klingelhöfer, et al., 2020).

Water can undoubtedly be seen as one of the most valuable resources for life on earth. Water is key for the survival of living organisms. Increasing population growth and density, as well as anthropogenic activities, contribute to water body pollution, affecting aquatic ecosystems, biodiversity, and the availability of water for human consumption. A decrease in this valuable resource has major impacts on earth and its organisms and an increase in urbanization, combined with climate change, makes the management of this valuable resource increasingly difficult (Rahman, et al., 2021).

Urbanization can be defined as the process of increasing population densities in urban areas, such as cities (Zhang, 2015). Inevitably the size of these developed areas would increase as an increase in development occurs. Urbanization usually results in land use change and habitat loss due to the increased size of the urban areas having profound implications upon water resources. Global urbanization trends show that urbanization in developed countries is slowly coming to an end and urbanization rates in developing countries are rapidly increasing (Zhang, 2015). Developing countries, like South Africa, face the challenge of managing the environmental impacts linked with both increasing urbanization and climate change. Further, negative impacts that result from climate change and urbanization would likely have negative impacts on water availability and thus a significant impact on the economy (Cullis, et al., 2019).

South Africa has a MAP of between 450 mm and 500 mm (GCIS, 2020). Compared to the global estimated MAP of 990 mm, South Africa's rainfall is lower and subject to high variability. Water yield underpins most economic activities and land use change is an important factor that affects water availability and security. Rapid population growth and an increase in urbanization is converting natural land cover to agricultural, industrial, and urban areas. This can result in changes in the hydrological processes including erosion, sedimentation, and nutrient load, all of which can affect water quality as well as water flow patterns (Khatri & Tyagi, 2015).

While the Western Cape (WC) receives most of its rainfall in the winter months, the rest of the country generally falls within summer rainfall regions (GCIS, 2020). The WC MAP varies with some mountainous areas receiving up to 3 000 mm of rainfall and some low-lying regions receiving less than 200 mm (DWAF, 2007). The WC receives an average of 350 mm of rainfall per year and is thus well below the national average. The WC is well known for historic water shortages experiencing a recent drought over the 2014 to 2017/2018 summer period as the worst in 113 years (Botai, et al., 2017). Stringent water saving measures were put in place for industry, agricultural, residential, and other water users, to avoid the day that taps would run out of water, "Day Zero" (Stafford, et al., 2019).

Water research management studies at catchment level are becoming more relevant and important to explore negative human impacts on water quality. Water quality studies provide valuable information and assist in the development of strategies, policies and plans in many sectors that will in turn help in the management of precious water resources and sustainable development (Brainwood, et al., 2004). Relevant measures regarding management at a catchment level include the NWA. The NAEHMP is a national program that monitors national aquatic ecosystems. One of the components of the NAEHMP is the River Eco-Status Monitoring Programme (REMP), that evolved from the River Health Programme (RHP). The NAEHMP's focus is to monitor the ecological conditions in river ecosystems (DWS, 2019). This study will thus also aid in providing valuable information about already established catchment level legislation and programmes.

By using effective analysis tools, such as GIS and statistical analysis programs, the complex interactions between spatial data and water quality can be interrogated. Statistical analysis and GIS are two common tools used in catchment and water resources management and will also be used in this study (Silva & Williams, 2001).

The land cover within a catchment has a direct impact on the specific water quality but this impact is often complicated and difficult to assess due to the variety of factors that influence its extent. This study ultimately aims to explore a possible link between different land uses and how these affect different water quality parameters by integrating the degree of land use change over a 22-year period with the observed water quality changes over the same period. The study area selected in this study focuses on upper catchments of key rivers in the WC. The selected study area is responsible for the main water supply in the WC.

2.2 Factors impacting land use change.

Throughout history, humans have engaged in the utilization, alteration, and modification of the Earth to fulfil their needs (Meneses, et al., 2015). These anthropogenic activities have led to natural resources modification, impacting the environment and human well-being (Li, et al., 2022). Consequently, such alterations and modifications can result in adverse effects on the environment. While it is noted that land use cover change may, in certain instances, be attributed to biophysical processes, the predominant driver is often anthropogenic activities (Briassoulis, 2009).

Natural land cover is converted to agriculture, industrial land, grazing areas, and urban areas for humans to live. Human infrastructure, such as roads and dams, are rapidly being built and increased. Lands are mined for resources and wetlands are drained to meet agricultural needs. Agricultural practices are intensified to meet the increasing demand for food and dams are built to supply water as well as electricity through hydroelectric dams. Some residential areas increase, and others are converted to commercial or industrial use, and vice versa. Overexploitation of land also results in land degradation and erosion (Briassoulis, 2009). All these changes play an important role in land use change and are important factors to consider obtaining a holistic understanding of land use trends. Multiple factors can exert significant influences on the process of land use change, as discussed previously. These factors can vary in their influence and can interact with each other, leading to very complex dynamics. These factors are thus interrelated and interact with each other in complex ways. It is important to understand and consider these varying factors for effective land use planning aimed at sustainable development, and to minimize possible social and environmental impacts (Briassoulis, 2009). These factors are considered here.

2.2.1 Biophysical factors.

The initial factors influencing land use can be linked to various biophysical factors. Biophysical factors influence the broad patterns of land cover and land use and can vary in time, including periods as short as a few days to longer periods such as centuries (Duveiller, et al., 2020). Some examples of biophysical factors that can play a role in affecting land use type and land use change include weather and climate, the atmosphere, geological types, landforms, soil types, hydrological regime, vegetation, fauna, and environmental disturbances (Briassoulis, 2009).

The interactions of the various biophysical factors are responsible for the geological and geomorphic processes, such as earthquakes, floods, erosion and sedimentation, the biogeochemical cycles, and plant succession, included in vegetation dynamics. In the absence of human impacts, the distribution of land cover types is mostly determined by natural biophysical factors (Briassoulis, 2009).

More recently, in the last century, land use changes are mostly due to human impacts, whether directly or indirectly. Biophysical factors are constraints, regulators, and/or modifiers of specific human activities, that limit, or set out, specific socially and economically feasible land use. The combination of biophysical and social factors thus influences land cover type and land use change (Briassoulis, 2009). Examples where biophysical factors are seen as constraints, regulators and modifiers include where water availability limits specific agricultural practices, hilly terrain limits urban development and warmer climates attract tourists, thereby increasing development in certain areas. In many water-scarce areas, biophysical factors impact the choice of development, agricultural practices as well as tourism potential, which in turn impacts land use type (Briassoulis, 2009).

2.2.2 Climate change.

Changes in land use can be expected to be linked to changes in climatic conditions especially in large river basins and coastal areas (Koomen, et al., 2012). Land use types will be affected by climatic variability and thus affect different economic sectors such as housing, natural habitat and ecosystems, agriculture and through changing of the water resources system (Koomen, et al., 2012). Local agricultural and hydrological conditions will change due to climate change and will thus impact the economic development potential of the specific area and the suitability of space for certain types of land uses (Beinat & Nijkamp, 1997).

An example of the way climate change and socio-economic developments can affect the land use, are through physically altering or modifying certain aspects of the land, that will result in the specific area now to no longer being suitable for its original past use. Climate change can change the productivity of processes within sectors such as agricultural lands resulting in more land needed to produce the same amount of crops. Extra demand for space is also predicted because of adaptation strategies within certain sectors that can alter specific land use. In essence, land use will change to adapt to a changing climate and the impact of climate change (Koomen, et al., 2012).

2.2.3 Population growth and urbanization.

Population size and growth are linked to anthropogenic factors influencing land use type and land use change. The “Principle of Population”, by Thomas Malthus in 1798 suggested that population growth will outpace what the environment will be able to supply and thus lead to the exhaustion and depletion of land and natural resources needed to sustain life. This could lead to social and economic issues (Malthus, 1798). Malthus further believed that human populations have a natural tendency to grow rapidly and argued that the population increases through natural means such as birth rates, whilst the food supply can only grow at a slower pace, due to limitations of land, resources, and technology (Malthus, 1798).

The interplay between technological innovation and its environmental ramifications has been systematically examined through the IPAT equation (Ehrlich & Holdren, 1971). This equation serves as a conceptual framework, capturing the notion that environmental impact (I) is intricately linked to the multiplication of population (P), affluence (A), and technology (T). Formally expressed as "*I = PAT"*, this neatly expresses the complex relationship between human activities, technological advancements, and their resultant ecological footprint. Environmental impacts (I) refer to the impacts of human activities on the environment, such as resource consumption, land degradation, habitat destruction, pollution, and other forms of environmental degradation. Population (P) sets out the size of the population and acknowledges that when the size of the population is increased it is linked to the number of resources needed which in turn leads to an increase in Environmental Impacts (I). Affluence (A), or wealth, considers the level of resource consumption per capita and considers factors such as income, consumption patterns and lifestyle choices, that usually show that a higher affluence is linked to greater resource consumption and greater Environmental Impact (I). Technology (T) considers the techniques and tools used in the production of resources and resource utilization. Better and improved technologies can reduce Environmental Impacts (I) (Chertow, 2008).

In this equation, one can clearly see that an increase in population leads to an increase in anthropogenic effects, and factors that influence land use and land use change through the ever-increasing need of resources. Population growth is closely related to urbanization. The definition of urbanization refers to the process by which rural and less developed areas become urbanized, or more developed, because of economic development and industrialization (Peng, et al., 2011).

Urbanization has a significant impact on land use change. As urban and developed areas expand, there is a conversion of land from natural, rural, and/or agricultural areas to urban and built-up spaces. This thus has closely been linked to rapid population growth. Currently a lot of focus is being placed on the relationship between urbanization and the impact it has on the environment. Accelerated urbanization, linked to a rapidly increasing population, has increased the rate to which natural resources are being depleted, the amount of environmental pollution taking place and an increased rate of climate change (Peng, et al., 2011).

2.2.4 Economic development and Industrialization.

Economic development and industrialization are also closely linked to urbanization and population growth. These also contribute to the growth and transformation of economies. Economic development refers to the overall growth of the economy and has various indicators, such as income levels, employment opportunities, infrastructure, healthcare and living standards that it considers seeing how developed a country is. Industrialization aids in the economic development of a country and is the process where rural processes are replaced with manufacturing and industrial activities (Hatami & Shafieardekani, 2014). To move to a more industrial and manufacturing orientated economy, an increase in industries, factories, and manufacturing processes are needed. These processes are usually driven by technological advancements and capital investments (Kniivaliä, 2007). Industrialization usually leads to an increase in productivity and thus better economic development. Thus, the relation between economic development and industrialization is significant. Industrialization is often seen as a key driver of economic development (Kniivaliä, 2007).

Land use change is often affected by economic development and industrialization as rural and often natural land cover, is transformed to industries, factories, and manufacturing land (Hatami & Shafieardekani, 2014). These industries can have significant environmental impacts even with technological advancements. While industrialization can bring many economic benefits, it also presents challenges and considerations, including environmental impacts, resource depletion, social inequalities, and the need for sustainable and inclusive industrial development strategies to counteract these impacts (Kniivaliä, 2007). Economic development and industrialization should be pursued in a balanced and sustainable manner, considering social, environmental, and governance factors (Hatami & Shafieardekani, 2014).

2.2.5 Agricultural practices and food demand.

Agricultural practices have significant impacts on land use. As food demand increases the amount of agricultural land, primarily for food production, also tends to increase. Agricultural lands are primarily used for producing food to meet the demand of a rapidly increasing population and the food demand linked to it (Kanianska, 2016). Land use patterns usually reflect the interactions between human activities and the environment. Agricultural land is vital to produce crops and raising livestock to meet the ever-increasing demand for food (Kanianska, 2016). It provides the necessary space and resources for cultivating crops and grazing animals. The availability and allocation of agricultural land directly impact the quantity and variety of food that can be produced.

Natural land cover often gets converted to agricultural lands and is an important land use change. Increasing agricultural intensity puts pressure on land resources as well as the environment making it a top priority to manage both for economic and environmental purposes (Kanianska, 2016).

To meet rising food demand, agricultural practices often intensify on existing agricultural land. This includes the use of technologies, such as high-yielding crop varieties, precision farming techniques, smart agriculture, and improved livestock management, to enhance productivity per unit of land, and in turn to minimize the environmental impacts while maximizing food production without significantly expanding the land (Zinke-Wehlmann & Charvát, 2021). Other intensification of agricultural practices, such as increased stocking and shifting from free range to pens, can have negative environmental impacts. Precision agriculture and smart agriculture are two very important measures to maximize agriculture with minimizing land use change and environmental impacts using technology.

2.2.6 Technological advancements and Innovation.

Technology has had a significant impact on land use change. These impacts are still controversial with the Borlaug hypothesis (Borlaug, 2002) stating that technological advancements have the potential to reduce environmental impacts by increasing production in current agricultural lands and the Jevons paradox (Jevons, 1906), where technological advancements make land use more efficient, or productive, and thus increasing the demand for land instead of decreasing the demand. Jevons paradox is thus seen as a paradoxical effect and occurs because increased efficiency typically lowers the cost of utilizing land, making it more attractive for various purposes such as agriculture, urban development, or industrial activities. In essence, the paradox highlights the complex relationship between technological progress, resource efficiency, and environmental impact in the context of land use change (Rocha, et al., 2019). In any case, technological advancements and innovation can have positive impacts when implemented in agricultural practices such as having precision and smart agriculture practices implemented.

Precision agriculture, or precision farming, is an approach to agricultural management that uses technology and data-driven techniques to optimize crop production and resource use (Karunathilake, et al., 2023). It uses technology such as GPS (Global Positioning System), GIS, remote sensing, and data analysis to advise on precise decision making that relates to various aspects of the farming operations. Precision agriculture focuses on the precise management of inputs, such as water, fertilizer and pesticides, as well as resources, such as like land and labour, to maximize yield and minimize waste (Zinke-Wehlmann & Charvát, 2021). Smart agriculture is similar to precision agriculture in terms of achieving higher yields of agricultural land while minimizing environmental impacts. Smart agriculture refers to the use and integration of modern technologies and data-driven solutions into agricultural practices to improve efficiency, productivity, and sustainability. It aims to produce higher yields with lower environmental impacts. Smart agriculture, or farming, uses advanced technologies such as the Internet of Things (IoT) providing real-time information, enabling farmers to monitor and manage their operations more effectively, artificial intelligence (AI), big data analytics, automated robotics, and remote sensing to enable smarter decision-making and management practices in agriculture (Rogotis & Marianos, 2021).

While technological advancements and innovation in agriculture can offer opportunities for more efficient and sustainable land use, it is important to note that its impacts can vary depending on how it is implemented and managed. Policy and governance are thus important to take into consideration to ensure that technological advancements promote responsible land use practices and contribute to long-term sustainability and minimizing environmental impacts.

2.2.7 Policy and governance.

Specific land uses are linked to key issues like urban development causing affordable housing crises, gentrification, and environmental harm. Agriculture struggles with food security and land degradation, deforestation and biodiversity loss. Industrial use leads to pollution and health hazards. Balancing these land use challenges is essential for sustainable development. Sustainable development, economic development, reducing territorial inequalities and the rights of future generations are some of the issues connected to land use. It is important that land use and land use change is understood properly to be managed correctly through policy and governance (Krawchenko & Tomaney, 2023). Policy and governance frameworks thus play an important role in land use planning by establishing land use planning processes that can serve as guidance on how land is allocated and utilized. These frameworks set out which areas of land are to be used for residential development, agriculture, industrial areas and protected natural areas to mention a few. Land use policies also influence the scale, intensity, special distribution, and location of specific land uses.

National policies such as the National Environmental Management Act 107 of 1998 (NEMA), the National Environmental Management: Biodiversity Act, 2004 (NEMBA), the National Water Act 36 of 1998 (NWA), The Conservation of Agricultural Resources Act 43 of 1983 (CARA), and the Spatial Planning and Land Use Management Act (SPLUMA) provide frameworks for environmental governance in South Africa. NEMA focuses on sustainable development and environmental management principles, while NEMBA addresses biodiversity conservation and the sustainable use of biological resources. The NWA ensures the sustainable and equitable management of water resources, and CARA aims at conserving agricultural resources by controlling erosion and combating invasive plants. SPLUMA establishes consistent procedures for spatial planning and land use management, promoting sustainable land use and public participation. Local implementation of these policies involves activities like environmental impact assessments, biodiversity conservation projects, water management plans, soil conservation programs, and the development of spatial development frameworks. Municipalities and local bodies, such as environmental management departments, water boards, and planning tribunals, play crucial roles in applying these national frameworks to address specific environmental challenges and ensure sustainable development within their jurisdictions.

Policy and governance also include zoning and regulations that set out allowable land uses in specific areas. In South Africa the SPLUMA defines a spatial development framework that regulates and manages land use and land use rights using schemes and land development procedures. Specific land use zones decide what land use may be used in certain areas, such as residential, business, or industrial (de Visser, 2016). Setting out specific land use zones helps to prevent incompatible land uses and promote orderly and more controlled and thus sustainable developments.

Environmental considerations, such as the impact of land use on water resources, are often incorporated into policy and governance to mitigate adverse impacts on natural resources (Nkosi, et al., 2021). Policies aimed at environmental protection can influence land use decisions to minimize ecological degradation and protect sensitive areas.

Effective policy and governance frameworks are thus essential for managing land use change in a sustainable and equitable manner. Policies and governance frameworks help balance competing interests, protect natural resources, support economic development, and ensure that land use decisions align with broader societal goals and priorities. Compliance, enforcement, and governance issues are critical in implementing South Africa's environmental laws and regulations such as NEMA, NEMBA, NWA, CARA, and SPLUMA. Compliance and enforcement face challenges like resource constraints, limited technical expertise, and poor coordination among agencies, leading to inadequate monitoring and inconsistent enforcement (SALRC, 2019). Public participation is often low, reducing community involvement in monitoring and reporting violations. Additionally, corruption and political interference can undermine regulatory processes, while legal loopholes and weak penalties make it difficult to prosecute violators effectively. Governance issues include the integration of environmental policies with other sectoral policies, balancing national directives with local autonomy, and managing fragmented institutional frameworks. Inadequate data management hampers informed decision-making, and stakeholder engagement often lacks inclusivity, reducing policy legitimacy. Adaptive governance is also a challenge, with rigid structures slow to respond to emerging issues. Addressing these issues requires enhancing resources and capacity in regulatory agencies, improving coordination, promoting public participation, strengthening legal frameworks, ensuring transparency and accountability, and adopting adaptive management practices (SALRC, 2019). By tackling these challenges, South Africa can improve the effectiveness of its environmental policies and achieve more sustainable resource management.

2.3 Impacts of land use and land use change on water quality with land use Indicators.

A change in land use, due to anthropogenic factors, can be seen to have a noticeable impact on water quality (Dabrowski & de Klerk, 2012). By changing land use, the environment is being altered to suit human needs and this will inevitably have some effect on the ecosystems. Surface water is highly affected by land use change. Water quality parameters have been linked very closely to different types, or proportions, of land uses within a catchment. The impacts of land use on water quality are mostly caused by human activities (Tu, 2011). Water quality impacts can also be linked to the intensity and specific type of land use and land use change.

The relationship between land use and water quality is complex and even though some general observations can be made, the correlations are study area specific, due to its complex interactions, site specific variables and relationships (Baker, 2006).

Land use changes can impact water quality in various ways. Urban areas, agricultural lands and construction sites are land use examples that all have impervious surfaces or soils that are disturbed (Issaka & Ashraf, 2017). These impervious surfaces and disturbed soils attribute to an increased amount of stormwater runoff. Stormwater runoff ultimately ends up in surface water systems. This runoff could carry pollutants, sediments, nutrients, pesticides, and cause pollution to water bodies. Erosion stemming from land use change, such as intensive agriculture or any land use requires the removal of natural vegetation, can also affect water quality through increased amounts of sedimentation ending up in water bodies (Issaka & Ashraf, 2017).

Agricultural land use, and specifically intensive farming practices, have been linked to nutrient loading of water bodies. The use of fertilizer and/or manure in combination with poor management can be linked to excess ingress of nitrogen, phosphorus and potassium into surface water bodies. Excessive amounts of the nutrients nitrogen (N) and phosphorus (P) in water bodies can accelerate processes such as eutrophication, which leads to algal blooms and accelerated build-up of organic material, depleting oxygen in water bodies and a lower quality of water (Schoumans, et al., 2014). Chemicals and pesticides are often used in urban as well as agricultural areas and can also end up in water bodies. These chemicals and pesticides can cause significant harm to aquatic ecosystems and human health (Zalidis, et al., 2002).

Habitat loss is another significant attribute that can lead to water degradation. Natural habitats that provide ecosystem services, such as wetlands, are converted into urban areas, agricultural land, or industrial areas (Moor, et al., 2017). The removal of natural habitats that provide ecosystem services results in a degraded water system.

As seen previously there are a variety of land uses that can affect water quality. These land uses are determined by their biophysical aspects, such as geology, topography, and precipitation, as well as human factors, such as population density, economic development, agricultural practices, food demand as well as policy and governance.

The South African Scoring System (SASS) and its simplified version, miniSASS, are biotic indices used to assess the ecological health of rivers and streams based on the presence and diversity of aquatic macroinvertebrates. SASS involves collecting and identifying these invertebrates, assigning scores based on their sensitivity to pollution. Sensitive species receive higher scores, indicating better water quality and ecosystem health. In contrast, a low SASS score suggests poor water quality (Graham, et al., 2002). MiniSASS is designed for use by schools and community groups, providing a hands-on, educational approach to understanding river health. By using a simplified identification and scoring process, miniSASS empowers communities to monitor and protect local water resources, raising awareness about the impacts of land use on water quality (Graham, et al., 2002). Both tools are essential for detecting changes due to anthropogenic activities and guiding conservation efforts. Biotic indicators were not used for the specific study due to limitations in data collection.

The following land use indicators have been identified and will be discussed in more detail regarding their impact and effects on water quality.

2.3.1 Natural land cover.

Natural land, or natural land cover, can be classified as land that is minimally altered or unaltered through human activities. Natural land has retained most of its original ecological characteristics, ecosystem functions as well as biodiversity. Natural land can include various types of environments such as forests, grasslands, fynbos, woodlands, thicket and shrublands (Tu, 2011). Natural land plays a vital role in supporting and sustaining the Earth's ecosystems and biodiversity. It provides habitats for a wide range of plant and animal species and thus contributes to the correct functioning of ecological processes, while offering important ecosystem services. These services can include water purification, pollution buffers, carbon sequestration, soil formation, flood control and climate regulation (Vigerstol, et al., 2021).

Natural land cover is usually associated with good water quality. Preserving natural land is thus necessary for conserving biodiversity, protecting sensitive ecosystems, and maintaining the health and resilience of the environment while assisting in water security (Vigerstol, et al., 2021). The correlation between the amount of undeveloped natural land, and concentrations of water pollutants are usually negative, i.e., the more natural land there is the better the general water quality is expected to be (Tu, 2011).

A potential negative impact on water quality can be due to fire as a natural ecosystem function. Fire plays an important role in shaping landscapes and influencing water quality. Fire is a natural part of many ecosystems and can have significant and sometimes complex impacts on water quality, both immediately after the event and over the long term. Fires can be linked to an increased amount sedimentation due to soil erosion, as fires remove vegetation cover, exposing soil to wind and water erosion. This can lead to more sediment being washed into nearby water bodies during rain events. Fires also release nutrients like nitrogen and phosphorus that can end up in water bodies (Pheko, 2021). In the long term, fires can alter water chemistry by changing soil chemistry, affecting the pH and conductivity of runoff water, impacting aquatic ecosystems. The removal of riparian vegetation due to fire reduces shading of streams and rivers, potentially increasing water temperatures, decreasing dissolved oxygen levels, and stressing aquatic life (Britton, 1991).

It is known that when a catchment is dominated by natural land use then that water, that originates from the natural land, will be of a much better quality compared to water that originates from other land use types (Buck, et al., 2004).

2.3.2 Urban areas as land use.

Urban land use is a broad class and includes built-on, residential and commercial smallholdings and villages, industrial activity, roads, and railways, as well as sports and recreational facilities amongst others. Urbanization is the process where a pre-existing type of land cover becomes modified to an urban type of land use and leads to the increase of impenetrable surfaces and point sources of pollutants. Urbanization adds to water pollution through an increase in surface runoff from buildings, roads, industries, sewage treatment plants, pollution from point sources as well as nutrient and chemical loading etc. from non-point sources. (Li, et al., 2008). Water infiltration into the soil is much less in urban areas than in natural lands (Kim, et al., 2016). Water runoff is thus much higher and results in pollution ending up in rivers more rapidly than in natural land.

Urban land is usually linked with a negative impact on water quality. Urbanization is known to affect water quality through increasing surface water flow, larger quantities of sewage needing treatment and other human, as well as animal waste, that results in an increase in phosphate and ammonium in the water resource. Urban areas often also increase the quantity of pathogens into water bodies, affecting water quality (Chen, et al., 2016).

Even though urban land use typically occupies smaller areas compared to other land uses, it is expected to have significant impacts on water quality. Water quality degradation and pollution are usually linked to human activities such as recreation, industrial, commercial, and residential uses, which can be attributed to various pollution sources (Camara, et al., 2019) Urban land use contributes to different types of pollutants and is often recognized as a source of point source pollutants, such as domestic runoff and sewage (Bartram & Ballance, 1996)

Informal settlements often face challenges related to sanitation and waste disposal infrastructure. In these areas, an increase in organic matter, from human and other organic pollutants, enter rivers and water bodies (Cullis, et al., 2019). These increased levels of organic waste may trigger and over stimulate processes such as sulfate reduction. Sulfate reduction is a microbial, bacterial, process where micro-organisms decrease sulfate levels due to natural and anthropogenic causes. In water bodies with poor oxygenation, such as those impacted by high organic loads, and very often present close to informal settlements, anaerobic conditions may be dominant (Leonov & Chicherina, 2008). Anaerobic conditions are favourable to sulfate reduction processes, as certain bacteria thrive in the absence of oxygen.

2.3.3 Water bodies.

In our study area, water bodies include various types, including permanent and seasonal rivers, wetlands (which may be temporarily, seasonally, or permanently wet or saturated), pans, swamps, estuaries, and riparian areas, natural lakes, and dams although dams are technically the only anthropogenic use of land. Water bodies play an important role in the water quantity and quality of a catchment as they are responsible for the dilution and mixing of pollutants and the transportation of these pollutants away from the source (Cullis, et al., 2017).

Water bodies, especially wetlands, are responsible for the filtration and purification of water by removing pollutants through various processes that improve water quality and slow down the surface water flow to allow for water retention and filtration into the soil (Vigerstol, et al., 2021). Nutrient levels and cycling are also processed through water bodies. Biological processes responsible for the continuous cycling of nutrients such as phosphorus and nitrogen are key because an abundance of these nutrients can become harmful. Water bodies thus assist in maintaining this important balance of nutrients and water quality (Vigerstol, et al., 2021).

Dams are of strategic importance and if not managed properly can pose a serious risk to users of the dam, and the downstream environment. Dams are important, specifically in the study area of this project, as the water quantity is controlled by an inter-basin transfer scheme. Dams are also known to, in some cases, act as a sink for pollutants that can influence the water quality (Oberholter, et al., 2010). The Western Cape Inter-Basin Transfer Scheme (WITS) is a water infrastructure project in South Africa that transfers water between the Breede River and Berg Rivers. The project was initiated to address water scarcity and ensure a sustainable water supply for the growing population and various sectors in the region (Steynor, et al., 2009). WITS is responsible for storing water during periods of excess supply and releasing it during times of scarcity. These storage capacities help regulate water availability and provide a buffer against seasonal variations or droughts downstream of the dams. These dams regulate water flow to the downstream users of the river and play a vital role in the water quantity and availability.

This study will not focus on the quantity of water available but only on the quality. It is still necessary to note the importance of water quantity in the study area, due to the linkage of water quantity and water quality. The chemical signature of the water contained in a dam can be very different from the water that flows into or out of the dam (McCartney, et al., 2001)

2.3.4 Agricultural land use.

In 2011, out of the total global land surface area of 13.4 billion hectares, approximately 3.9 billion hectares (29%) were covered by forests, while approximately 5 billion hectares (37%) were dedicated to the agricultural sector. Between 1985 and 2005, there was a net increase of 154 million hectares (approximately 3%) in the combined area of agricultural land globally (Foley, et al., 2011). Agriculture can thus be seen, in quantitative terms, as the single most important land use sector and without doubt of great importance when looking at sustainable land use. In this study, agricultural land and practices include plantations, cultivated lands, livestock farming, improved grasslands, and commercially planted croplands amongst others.

Agricultural land use has also been linked and identified as a major contributing source of sediments, nutrients and other pollutants entering water bodies (Cullis, et al., 2005). Additionally, there have been strong links found between an increase in agricultural land and a decrease in general water quality in catchments (Buck, et al., 2004).

Freshwater is highly susceptible to pollution and contamination from agriculture and can lead to the degradation of both surface and groundwater resources. Agricultural practices mostly require some support to achieve maximum yields and the use of fertilizers, pesticides as well as herbicides are used causing nutrients to be added to the system (Tu, 2011). These nutrients usually include nitrate, nitrite, ammonia, phosphate, and sulfate and are leading contributors to water pollution (Tu, 2011).

It is also important to note the cumulative effect that many farms, even those of small size, can have in a specific area. Depending on the spatial scale, individual farms may have a smaller impact on the catchment, but multiple farms together could result in much higher contributions of water pollution when their accumulative effects are considered (Schröder, et al., 2004).

2.3.5 Mining as a land use.

Mining activities are known to alter the natural environment significantly even if the activities are small in footprint. These activities can have major impacts on water quality by introducing pollutants into waterways. Mining operations usually involve some sort of excavation and removal of soil and rock. Mining practices are known to be linked to soil erosion and thus the release of sediments, chemicals associated with mining activities and minerals into nearby water resources (Mulaba-Bafubiandi & Mamba , 2009). Erosion of soils can lead to increased turbidity and sedimentation in water bodies. Sediments can also transport other pollutants attached to the particles, exacerbating water quality degradation (Bendito, et al., 2023). Mining activities result in a loss of natural vegetation, and the organic-rich H-horizon of soil, leading to a degradation of the ecosystem together with loss of ecosystem functions.

Acid mine drainage (AMD) is seen as one of the most significant water polluting issues that is associated with mining activities. AMD can pose short and long terms pollution threats. Short term threats relate to the generation of AMD when underground mines are rewatered where long term threats are linked to the seepage of acidic water into the water table from waste dumps. AMD is unfortunately an unavoidable mining byproduct that contains heavy metals, high concentrations of sulfate and a low pH (Udayabhanu & Prasad, 2010). The process of AMD occurs naturally as the weathering of rocks occur, mining increases this rate of AMD generation significantly through the exposure of sulfide minerals to oxygen and water (Udayabhanu & Prasad, 2010). AMD can have severe impacts on aquatic life and water quality for periods long after mining has come to an end and is thus of great importance when looking at pollution impacts through different land uses (Naicker, et al., 2003). Sulfate reducing bacteria are used more often as a sustainable effective tool for AMD remediation and play a vital role in the control and treatment of mine wastes. Sulfate reducing bacteria occur naturally and can significantly decrease the amount of sulfate in a system (Ayagnemro, et al., 2018).

Mining-related activities can be linked to elevated nitrate and ammonia levels due to nitrate and ammonia-based explosives used in mining activities (Bros & Loredo, 2008).

2.3.6 Degraded land, bare rock, and soil.

Bare and degraded land use includes gullies, dongas, degraded land, bare rock and soil and other eroded areas. These landforms can result in impacts on water quality due to higher risks of soil erosion, increased runoff, reduced water retention and infiltration, as well as exposing soil nutrients and pollutants directly to water (Osuagwu, et al., 2014). Natural land and agricultural land are most likely the land uses that will be converted to degraded land, bare rock, and soil. The reduction of natural land and agriculture should thus be looked at together with the increasing degraded land, bare rock, and soil in a specific area.

It is important to consider the impacts of bare and degraded land on water quality and quantity. This requires the implementation of appropriate land management and restoration practices and tools. The interdependence of land and water resources is important in approaches linked to land and water management.

2.4 Water quality indicators.

Water quantity is not the only important factor to consider when looking at water security. There are many water systems with adequate water quantity, but the water is so polluted it cannot be used. Water quality thus also plays a vital role in water availability. Many important water systems are polluted to the extent that the water is not suitable for its intended use. There is no single definition of water quality due to its dependence on its intended use (Fuggle, et al., 2009). Water quality plays an important role in water security and there are many anthropogenic and natural factors that could impact on water quality.

Natural factors, or processes, that can have an impact on water quality include geology, hydrology, climate, vegetation cover, topography, and some biological processes (Khatri & Tyagi, 2015). Natural ecosystems are adapted to a certain water quality and any change or alteration can be disruptive to the natural ecosystem.

Anthropogenic factors include impacts due to agricultural, mining, deforestation, urbanization, industrial and domestic waste, and recreational activities (Khatri & Tyagi, 2015). Anthropogenic impacts can be widespread and the degree to which they disrupt the natural ecosystem can vary significantly.

These impacts can be classified as point source or non-point source (Viman, et al., 2010). Point sources of pollution are easier to identify and to measure, as their origin is from a single source, such as a sewage or an oil spill and specific industrial pollution (Puckett, 1994). Non-point sources of pollution are much harder to identify as these sources can come from many different, and in some cases very small, sources over a larger area, over long timeframes and can involve complex interactions (Viman, et al., 2010). Non-point sources can include nitrogen sources over a catchment (Puckett, 1994). Different sources of pollution can also accelerate a variety of different environmental processes and give rise to water quality issues (Silva & Williams, 2001), such as cultural eutrophication and acidification.

The degree or extent to which human land use will have an impact on water quality is related to the specific land use type as well as the intensity of the land use. Previous research states that there is a strong correlation between water quality and the type of land use within a catchment (Lee, et al., 2009).

The measurement of water quality is through indicators. Some of the most important water quality indicators are discussed here including how land use impacts them.

2.4.1 Electrical conductivity.

Electrical Conductivity (EC) can be a very useful parameter to assessing water quality. It provides valuable information about the ability of water to conduct an electric current. EC is often used as a proxy for estimating the concentration of Total Dissolved Solids (TDS) in the water (Mehaffey, et al., 2005). TDS refers to the cumulative concentration of inorganic salts, minerals, and other dissolved substances in the water. Higher EC readings indicate a higher TDS concentration, although the specific relationship may vary depending on the types of ions present. Common examples of dissolved solids that can contribute to an increased EC are iron and calcium. EC is also closely related to the salinity of water. Salinity refers to the concentration of dissolved salts, primarily sodium, potassium, and chloride, in the water. Saltwater has a higher electrical conductivity compared to freshwater due to the increased concentration of ions (Mehaffey, et al., 2005).

Natural and anthropogenic factors can affect the EC of surface water. EC of surface water can vary significantly depending on the geology of the area, hence the soil and rock types that the water has come in contact with (Mehaffey, et al., 2005). Organic decay through biological processes also affects EC by increasing the dissolved solids. Anthropogenic activities such as surface water pollution can also affect EC. Examples include discharge of soaps from washing as well as cemeteries leachate to the surface (Akhtar, et al., 2021). Agricultural and residential land can raise EC through the addition of phosphate and nitrate containing fertilizers that end up in rivers and streams (Mehaffey, et al., 2005).

Low EC values are usually an indication of better water quality and lower concentrations of dissolved ions. Pure water, without any dissolved substances, is considered a poor conductor of electricity (Chapman, 1996). Electrical Conductivity measurements are widely used in environmental monitoring programs to assess changes in water quality over time. By tracking conductivity levels at specific locations, makes it possible to identify variations and potential sources of contamination (Chapman, 1996). Sudden or significant increases over time in EC may indicate pollution events in the water.

It is important to note that while EC is a valuable water quality indicator, it should be used in conjunction with other parameters and analytical techniques to obtain a comprehensive assessment of water quality. Significant changes in the EC can indicate a source of pollution. Factors like pH, dissolved oxygen levels, specific ion concentrations, and presence of pollutants should be considered alongside conductivity measurements for a more complete understanding of water quality conditions (Chapman, 1996).

2.4.2 pH.

pH is a measure of the acidity or alkalinity of a solution. It quantifies the concentration of hydrogen ions (H^+) present in a solution. The pH scale ranges from 0 to 14, where 7 is considered neutral. A pH value below 7 indicates acidity, while a pH value above 7 indicates alkalinity (Talling, 2010). The pH of naturally occurring fresh waters usually have a pH in the range between 6.5 and 8.5 and is important as it affects the solubility as well as availability of nutrients and how these nutrients get utilized by organism (Stone, et al., 2013). In more technical terms, pH is defined as the negative logarithm of the hydrogen ion concentration. The formula to calculate pH is: $pH = -Log[H^+]$

pH plays an important role in the survival and health of aquatic organisms in aquatic life as different species have different pH requirements (Stone, et al., 2013). Extreme changes in pH levels can thus harm organisms.

It is important to note that while pH is an important factor in water quality, as with EC, it should be considered alongside other parameters such as temperature, dissolved oxygen levels, nutrient concentrations, and the presence of contaminants or pollutants to comprehensively assess water quality (Chapman, 1996).

2.4.3 Total nitrogen: ammonium (NH_4^+), nitrate (NO_3^-) and nitrite (NO_2^-).

i. Total Nitrogen (TN).

Total Nitrogen (TN) in water refers to the measurement of all forms of nitrogen that is present in water and includes ammonium (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-) and dissolved particulate organic nitrogen (Allan & Castillo, 2007).

ii. Ammonium (NH_4^+).

Ammonium is a dissolved gas that is naturally present in surface waters and is the main nitrogenous waste product of fish and the result of organic matter decomposition. Ammonia is soluble in water, especially in low pH conditions and is removed by plants and bacteria where it is used as an energy or nutrient source (Stone, et al., 2013). Ammonia in water is present in the unionized form of ammonia (NH_3) and ionized form of ammonia (or Ammonium (NH_4^+). The proportion of unionized and ionized ammonia is dependent on the pH and temperature of the water. The presence and concentration of ammonia can have both positive and negative effects on water quality, depending on the context (Stone, et al., 2013).

Ammonium serves as a nutrient and energy source for aquatic plants, particularly algae and in ecosystems where there is a balanced in nutrient levels, ammonium can support healthy plant growth and contribute to a productive and diverse aquatic environment (Stone, et al., 2013).

Excessive levels of ammonium, along with other nutrients like phosphorus, can lead to eutrophication of larger water bodies such as lakes. When there is an abundance of nutrients in water bodies, such as rivers, lakes, or coastal areas, it promotes the rapid growth of algae and aquatic plants. This excessive growth can lead to the depletion of dissolved oxygen in the water, causing harm to fish and other organisms that depend on oxygen. Eutrophication can result in the degradation of water quality, leading to algal blooms, foul odours, and can severely degrade the aquatic environment (Harding, 2015).

Ammonium can be converted to the more toxic form of ammonia, at elevated temperatures and high pH. High levels of ammonia can disrupt the respiratory systems of fish and impair their ability to absorb oxygen. Ammonia toxicity can also affect other aquatic organisms, such as invertebrates and amphibians, and lead to ecological imbalances (Stone, et al., 2013).

In biological wastewater treatment processes ammonium is converted to nitrate by beneficial bacteria through processes like nitrification and this is an important factor to consider (Allan & Castillo, 2007). However, if wastewater treatment systems are not functioning optimally, ammonium can be discharged into receiving waters, causing water quality issues downstream (Lutz, 2009). An Increased amount of wastewater treatment plant failures can be linked to rapid urbanization and the increase of population.

An increase in ammonium in surface water could also be linked to agricultural practices. Ammonium compounds are often used in fertilizers due to their ability to provide plants with a readily available source of nitrogen and are commonly used in agriculture to enhance plant growth (Lutz, 2009).

In addition to its role in fertilizers and linkages to wastewater treatment plants, ammonium is also found in various household cleaning products. Ammonium compounds can also be used in certain industrial processes and as a source of nitrogen in laboratories (Allan & Castillo, 2007). Ammonium concentration increases can thus be linked to an increase in urban areas as well as an increase in agricultural practices.

It is important to note that the effects of ammonium on water quality can vary depending on factors such as the concentration of ammonium, pH, temperature, and the presence of other nutrients or contaminants. Regular monitoring and appropriate management of ammonium levels are necessary to maintain healthy aquatic ecosystems and ensure the safety of water resources.

iii. Nitrate (NO_3^-) and nitrite (NO_2^-).

Nitrate and nitrite are two other common forms of nitrogen in water and are frequently used as proxy water quality indicators (WHO, 2017). Nitrate and nitrite are often found in the effluent from various natural, agricultural, and industrial processes *(Nezhad, et al*., 2017) (Liu, *et al*., 2005). Nitrate is commonly found in soil, water, and plants and is an essential nutrient for plant growth. It is often applied as a fertilizer in agriculture. Nitrite is formed through the oxidation of nitric oxide (NO) and ammonia (NH_3) or the reduction of nitrate (WHO, 2003). Nitrate and nitrite can undergo chemical reactions and transformations in various environmental and biological processes. Nitrate and nitrite play essential roles in the nitrogen cycle, which is the natural process that converts nitrogen between different chemical forms in the environment (WHO, 2003).

Humans have increased the natural rate of increasing nitrates in the environment by burning fossil fuels, by using fertilizers for agriculture, producing explosives for mining, and planting nitrogen fixing crops (Vitousel, *et al*., 1997). Elevated levels of nitrate in drinking water can pose health risks, especially for infants and pregnant women (WHO, 2003).

Excess nitrate levels in surface water bodies can contribute to an increased rate of eutrophication. Nitrate promotes the growth of algae and aquatic plants. This can lead to algal blooms, decreased water clarity, and oxygen depletion, impacting aquatic ecosystems, fish populations, and overall water quality negatively (Vitousel, *et al.*, 1997). While nitrate and nitrite are naturally occurring and have important biological functions, excessive exposure to nitrate and nitrite compounds can pose health risks to humans. These health risks include methemoglobinemia, or blue baby syndrome, in infants (Knobeloch, *et al.*, 2000), cancer (Ward, *et al.*, 2018), endocrine disruptions (Albouy-Llaty, *et al.*, 2016) and cardiovascular health risks (Ward, *et al.*, 2018).

Nitrate contamination is a significant concern in groundwater, particularly in agricultural and mining areas where nitrogen-based fertilizers and explosives are used (Vitousel, *et al.*, 1997). Nitrate is highly soluble and can leach into the groundwater, making it vulnerable to contamination. Elevated nitrate levels in groundwater can make it unsuitable for drinking or agricultural purposes, leading to economic and environmental implications (Vitousel, *et al.*, 1997). Monitoring nitrate levels helps identify areas where agricultural management practices may need to be improved to reduce pollution and protect water quality.

Nitrate and nitrite levels in surface water could also be as a result in wastewater influent and effluent from urban areas. Monitoring these nitrogen forms helps evaluate the performance of nitrification and denitrification processes in wastewater treatment plants (Brody, *et al.*, 2006). Adequate removal of nitrate and nitrite ensures that wastewater discharges do not contribute to nutrient pollution or eutrophication of receiving water bodies.

Regular monitoring of nitrate and nitrite levels in water sources is essential for maintaining water quality, protecting human health, and preserving the integrity of aquatic ecosystems. It helps identify potential pollution sources, guide appropriate management strategies, and assess the effectiveness of mitigation measures.

2.4.4 Orthophosphate as phosphate (PO_4^{3-}).

Phosphates are essential for various biological processes and are found in many natural substance including minerals, rocks, soil, and water. Phosphorus (P), in natural conditions, is almost entirely present in the phosphate form. There are three major phosphate groups including orthophosphates, organically bound phosphates, and condensed phosphates (Clesceri, *et al.*, 1998). The most commonly occurring is the dissolved inorganic orthophosphate (Clesceri, *et al.*, 1998).

Orthophosphate compounds are often and commonly used in fertilizers due to their importance in promoting plant growth. They provide plants with the necessary phosphorus needed for processes like root development, flowering, and fruiting. These fertilizers, when applied in large quantity, are carried into surface waters increasing the process of eutrophication and cyanobacterial growth (Clesceri, *et al.*, 1998). An increased eutrophication process, and cyanobacterial growth, can change a water system to autotrophic instead of heterotrophic, and harms other organisms in the ecosystem (Peterson, *et al.*, 1985).

Orthophosphates are also commonly found in rivers and water bodies through the failure of sewage and wastewater treatment plants (Cullis, *et al.*, 2019). Orthophosphates are present in human waste, including urine and faeces. Many household detergents and cleaning products also contain phosphates that end up in wastewater treatment plants. Wastewater treatment plants that function poorly result in phosphates ending up in water systems (Cullis, *et al.*, 2019).

Overall, phosphates play critical roles in biological processes, agriculture, industry, and environmental systems. Understanding their functions and the implication of their use is important for maintaining a balanced and sustainable approach.

2.4.5 Sulfate (SO_4^{2-}).

Sulfur (S) occurs naturally in minerals, soils, and rocks as well as in the air, groundwater, plants, and food. Sulfur is mostly found in rocks and minerals as well as salts in ocean sediments. Sulfur has a solid and gas phase and thus appears in atmospheric and terrestrial processes (US: EPA, 2003). Sulfur found in sediments and rocks is exposed through weathering processes and are readily converted to sulfate (SO_4^{2-}) when exposed to air (Granat, *et al.*, 1976).

Sulfate is often associated with mining activities, metal and plating industries, water and sewage treatment facilities, various chemical manufacturing processes and in the agricultural sector ammonium sulfate applied as fertilizer (US: EPA, 2003).

Sulfur is a very abundant element on Earth and even more abundant in sediments (Kaplan, 1972). Anthropogenic impacts on the sulfur cycle are significant with an estimated 80% of global sulfur dioxide (SO_2) emissions and more than 45% of sulfates occurring in rivers being traceable to human related activities (Moore, 1991)

Sulfate in lower concentrations is generally not considered to be harmful to the environment (US: EPA, 2003). Elevated sulfate levels in water bodies often resulting from industrial activities or mining, can contribute to water pollution and affect aquatic ecosystems severely (Moore, 1991). Understanding the role of sulfate in various applications and their impact on water and the environment is fundamental for ensuring their responsible use and mitigating potential adverse effects.

Sulfate reduction in natural water bodies and natural ecosystems is another important water quality process to discuss. Sulfate reduction that takes place in natural microbial processes occur in various anaerobic environments, such as wetlands, sediments and waterlogged soils. During the process of natural sulfate reduction, sulfate ions (SO_4^{2-}) are transformed into sulfide ions (S^{2-}), through an array of microbial reactions, carried out by sulfate-reducing bacteria (Leonov & Chicherina, 2008). Intensified sulfate reduction in water bodies and natural ecosystems can be due to increased anthropogenic impacts. Nutrient enrichment increased organic matter, industrial discharges acid mine drainage and climate change may all impact and increase the rate to which sulfate reduction takes place. These can contribute to, and stimulate, an increase rate of sulfate reduction to occur and will thus result in a reduction in sulfate concentrations observed in water bodies as well as the natural ecosystem (Leonov & Chicherina, 2008). Sulfate-reducing activities among different water catchments can be attributed to a combination of natural environmental factors and anthropogenic influences. Factors that could contribute to an increased amount of sulfate reduction include the geological characteristics, specific anthropogenic activities such as urbanization, industrial discharges as well as mining, organic carbon availability, hydrological conditions, temperature and climatic conditions, oxygen availability, pH levels, natural ecosystem characteristics and nutrient levels (Holmer & Storkholm, 2001) and (Leonov & Chicherina, 2008). Understanding the specific combination of these factors in each catchment is crucial for comprehending variations in sulfate-reducing activity. Anthropogenic impacts, such as pollution and land use changes, can significantly alter these natural factors, further contributing to differences in microbial processes among water catchments.

2.5 Result of other studies and research.

A similar study as this one, to assess the relationship between river water quality and land use and land cover change, was done in the Nawuni Catchment of the White Volta Basin, Northern Region, Ghana (Tahiru, *et al.*, 2020). This study used land use indicators and their change to see how this would impact water quality parameters. The land use indicators used included closed savannah, open savannah, agricultural land/grassland, water bodies, settlements, and bare land. Water quality indicators included turbidity, ammonia, and total coliforms. A 15-year period was considered, and it was revealed that land cover change did indeed impact water quality parameters in the Nawuni Catchment. Increasing levels of turbidity and ammonia alongside a decline in total coliforms are observed. A positive correlation between land use and land cover changes and water quality parameters thus suggests the impact of land use change on water quality (Tahiru, *et al.*, 2020).

An important study done in 2021 used remote sensing to review the relationship between land use and surface water quality (Cheng, *et al.*, 2022). This study again showed that there are many factors that affect water quality and the interactions between land use and water quality are very complex. Understanding these interactions will contribute to better management of this valuable resource. The study done in 2021 reviewed already published studies and concluded, through this review, that agricultural land use and urban built up, or constructed areas, had the most significant impacts on water quality. The study done by Cheng et al also showed that the most common statistical methods of determining the impact of land use change on water quality included that of correlation analysis regression analysis and redundancy analysis. (Cheng, *et al.*, 2022).

The studies presented in **Table 1**: Relevant previous studies showing linkages between Land Use types and specific water quality parameters. showed a relationship between specific land use types and water quality parameters.

Table 1: Relevant previous studies showing linkages between Land Use types and specific water quality parameters.

Study reference	Land use types affecting specific water quality parameters	Water quality parameters affected by land use
Factors influencing natural water quality and changes resulting from land-use practices (White, 1976)	Urban, Agriculture	Electrical conductivity, pH, nitrate, phosphate, sulfate.
Ground water quality in Northern Michigan ecosystems as affected by land use patterns and geological characteristics (Richardson, 1979)	Agriculture	Total nitrogen
The Effects of Farming Practices on Groundwater Quality in the United Kingdom (Oakes, *et al.*, 1981)	Agriculture	Nitrate
Estimation of Surface Water Quality Changes in Response to Land Use Change: Application of The Export Coefficient Model Using Remote Sensing and Geographical Information System (Mattikalli & Richards, 1996)	Agriculture	Total nitrogen
Effects of agriculture on discharges of nutrients from coastal plain watersheds of Chesapeake Bay (Jordan, *et al.*, 1997)	Agriculture	Total nitrogen, phosphate
Comparative assessment of runoff characteristics under different land use patterns within a Himalayan watershed (Sharma & Rai, 1998)	Urban, Agriculture	Total nitrogen, phosphate, pH
Modelling the relationship between land use and surface water quality (Tong & Chen, 2002)	Agriculture, Urban	Electrical conductivity, pH, total nitrogen, Total phosphorus,
Land Use and Water Quality Relationships in the Lower Little Bow River Watershed, Alberta, Canada (Little, *et al.*, 2003)	Agriculture, Bare land	Total nitrogen, total phosphorus
The influence of land-use patterns in the Ruvu river watershed on water quality in the river system (Ngoye & Machiwa, 2004)	Natural land, Urban, Agriculture	Electrical conductivity, pH, total phosphorus, total nitrogen
Relationships of land use and stream solute concentrations in the Ipswich River basin, Northeastern Massachusetts (Williams, *et al.*, 2005)	Agricultural, Urban	Total nitrogen, total phosphorus, sulfate.
Water quality in relation to land use and land cover in the upper Han River Basin, China (Li, *et al.*, 2008)	Urban, Natural land, Bare rock and soil, agriculture, water bodies	pH, total nitrogen, total phosphate,
Impacts of Land Use on Surface Water Quality in a Subtropical River Basin: A Case Study of the Dongjiang River Basin, Southeastern China (Ding, *et al.*, 2015)	Natural land, Urban, Agriculture	Electrical conductivity, total nitrogen, total phosphorus,
Spatial-Temporal Variations of Water Quality and Its Relationship to Land Use and Land Cover in Beijing, China (Chen, *et al.*, 2016)	Natural, Urban, Water Bodies, Agriculture	Total nitrogen,
Land Use Land Cover Changes in Detection of Water Quality: A Study Based on Remote Sensing and Multivariate Statistics (Hua, 2017)	Urban, Natural, Water Bodies, Agriculture, Degraded Land.	Electrical conductivity, pH, total nitrogen,
Assessing how spatial variations of land use patterns affect water quality across a typical urbanized watershed in Beijing, China (Liu, *et al.*, 2018)	Natural Land, Urban, Water bodies, Agriculture,	Total nitrogen, total phosphate
Spatial variation impact of landscape patterns and land use on water quality across an urbanized watershed in Bentong, Malaysia (Shebab, *et al.*, 2021)	Natural Land, Urban, Agriculture	Electrical conductivity, pH, total nitrogen, total phosphorus, sulfate

Additionally, it is important to note that a relationship between a land use type and water quality parameter in one study could be different or even the opposite to a relationship of a land use type and water quality parameter of another study. The relationships between land use type and water quality parameters are complex and differ significantly over space. Different catchments have different characteristics and pollution sources and can make general assumptions very difficult when it comes to predicting land use type and water quality parameter relationships (Tu, 2011).

2.6 Discussion of the sites selected for this study.

The three sub-catchments responsible for the main water supply to the WC include the Berg-, Breede- and Olifants Catchments and are part of the Western Cape Water Supply System (WCWSS). The WCWSS ensures adequate water supply to the important City of Cape Town (CoCT), and its surrounding areas, as well as critical agricultural and ecological areas that depend on this resource (Midgley, *et al.*, 2014).

The two sub-catchments that this study will focus on are the upper parts of the Berg and Breede sub-catchments. These sub-catchments are important due to their intensive agricultural production and processing potential, as well as ecological and social value. The Berg River and Breede River are also connected through an inter-basin transfer system where water is transferred from the Theewaterskloof Dam, in the Breede River Catchment, to the Berg River Dam in the Berg River Catchment. This is important as the Berg River Catchment does not have sufficient storage available during the dry season for the water demand of water users in the Berg River Catchment (Steynor, *et al.*, 2009). These two catchments are both important and responsible for the supply of water to the CoCT and they are connected via the inter-basin transfer scheme.

The Breede River is the largest river in the WC and has a total catchment area of 12 600 km^2 (Steynor, *et al.*, 2009). The total natural runoff from the Breede River sub-catchment amounts to an estimated 1803 million m^3/year and about 60% of this natural runoff is generated in the upper Breede sub-catchment (Flemming & Martin, 2021). The Breede River originates in the Ceres Valley approximately 100 km north-east of the CoCT and then drains south easterly into the Indian Ocean flowing for about 320 km and through a key agricultural region. The Breede River supplies valuable water to the Breede River Estuary that is about 12 km^2 in size (Flemming & Martin, 2021).

The Berg River has a total catchment area of approximately 9 000 km^2. The total natural runoff from the Berg River sub-catchment amounts to an estimated 931 million m^3/year and 70% of this natural runoff is generated in the upper Berg sub catchment (Midgley, *et al.*, 2014). The Berg River originates in the Hottentots-Holland Mountains flowing for about 300 km towards the Atlantic Ocean and supplying 65% of its water to agricultural purposes as well as an ecologically important RAMSAR Site estuary that is also about 12 km^2 in size, namely the Berg River Estuary (de Villiers, 2007).

2.7 Relevance of Study.

With a projected decrease in overall river runoff, due to climate change and urbanization, land use planning and water management are becoming increasingly complex. Further research is needed to assess the impacts of land use change on river runoff, which can aid in planning for land and water use amidst the growing effects of these challenges on this valuable resource (Steynor, *et al.*, 2009).

It is evident that land use change has an impact on different water quality parameters. This study will put more focus on which specific land use changes impact which specific water quality indicators and reasons behind these will also be given. Land use has significant impacts on water security, specifically water quality. This research hopes to guide further research questions and recommendations for future studies.

3 CHAPTER THREE – Methodology and data collection.

3.1 Study area.

3.1.1 Site selection.

The two sites selected for this study, are part of the Berg and Breede river catchments and fall in the upper parts of these catchments, the upper Berg and Breede River catchments. The sites were selected due to their importance, falling in the water supply catchment area of major dams in the WC, as well as being a water source to agriculture and important estuaries.

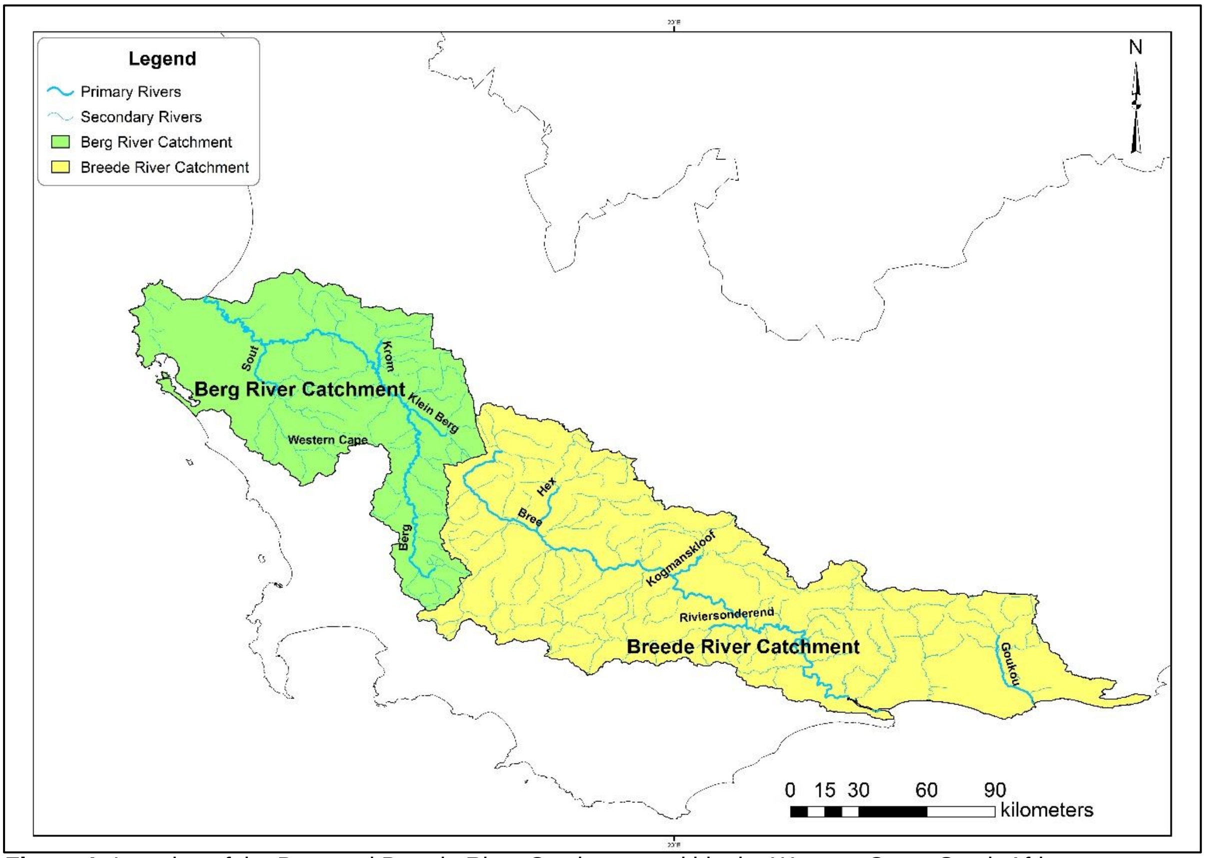


Figure 1: Location of the Berg and Breede River Catchments within the Western Cape, South Africa.

The Berg and Breede River Catchments, **Figure 1**, are classified as large catchments with an area of 7 704 km^2 and 12 526 km^2, respectively (Watson, *et al.*, 2021). The mean annual precipitation for the Berg River Catchment is around 487 mm/year and around 429 mm/year for the Breede River Catchment (Watson, *et al.*, 2021). Both the Berg and Breede River Catchments fall within a winter rainfall region. It is important to note that the upper catchment mountain areas here receive of the highest rainfall in the country and not shown by simply looking at the MAP of the catchments.

Surface water was the primary focus of this study because it provides a more direct connection to potential water quality changes resulting from land use changes, unlike groundwater. Two sites in the upper river catchments were selected as these are further upstream, thus minimize the effects that internal processes have, such as evaporation and internal loading, and to provide a more direct comparison between land use change and its effects on water quality (Eyre, 1997).

The Berg River Catchment originates in the Groot Drakenstein Mountains near Franschhoek, then flows in a generally north-western direction towards the West Coast, where it enters the sea at Velddrif. The Berg River catchment is dominated by the Klipheuwel and Malmesbury Group rock types that comprise of argillaceous rock. Argillaceous rock refers to sedimentary rock mainly composed of clay or clay-sized particles, such as shale, greywackes mudstone, and claystone. These rocks are formed from the compaction of fine sediments (Department of Water Affairs and Forestry, 2004).

The Breede River Catchment originates in the Ceres Valley, near the town of Ceres, and flows towards the south-east towards the Southern Cape Coast where it reaches St Sebastian Bay, near Witsand/Cape Infanta. The Breede River catchment is comprised of a similar geological setting as that of the Berg River catchment. The Malmesbury Group is prominent throughout the entire catchment and the Cape Granite protrudes the Malmesbury Group. The Cape Supergroup, which constitutes Table Mountain Group, or the Table Mountain Sandstone, overlies the Malmesbury and Cape Granite rocks (Department of Water Affairs, 2011).

3.1.2 Location.

The upper Berg River catchment has an area of 4 026 km^2 originates in the Groot Drakenstein Mountains near Franschhoek and flows in a north-western direction. The Berg River Dam, Wemmershoek Dam, Voelvlei Dam and the Misverstand Dam is located further downstream and northwest of the study area, **Figure 1**.

The upper Breede River catchment has an area of 3 438 km^2 and originates in the Ceres Valley, near the town of Ceres, and flows in a south-eastern direction. The Theewaterskloof Dam is located to the south of the study area, and the Brandvlei Dam south of the town of Worcester, on the eastern side of the study area, **Figure 1**.

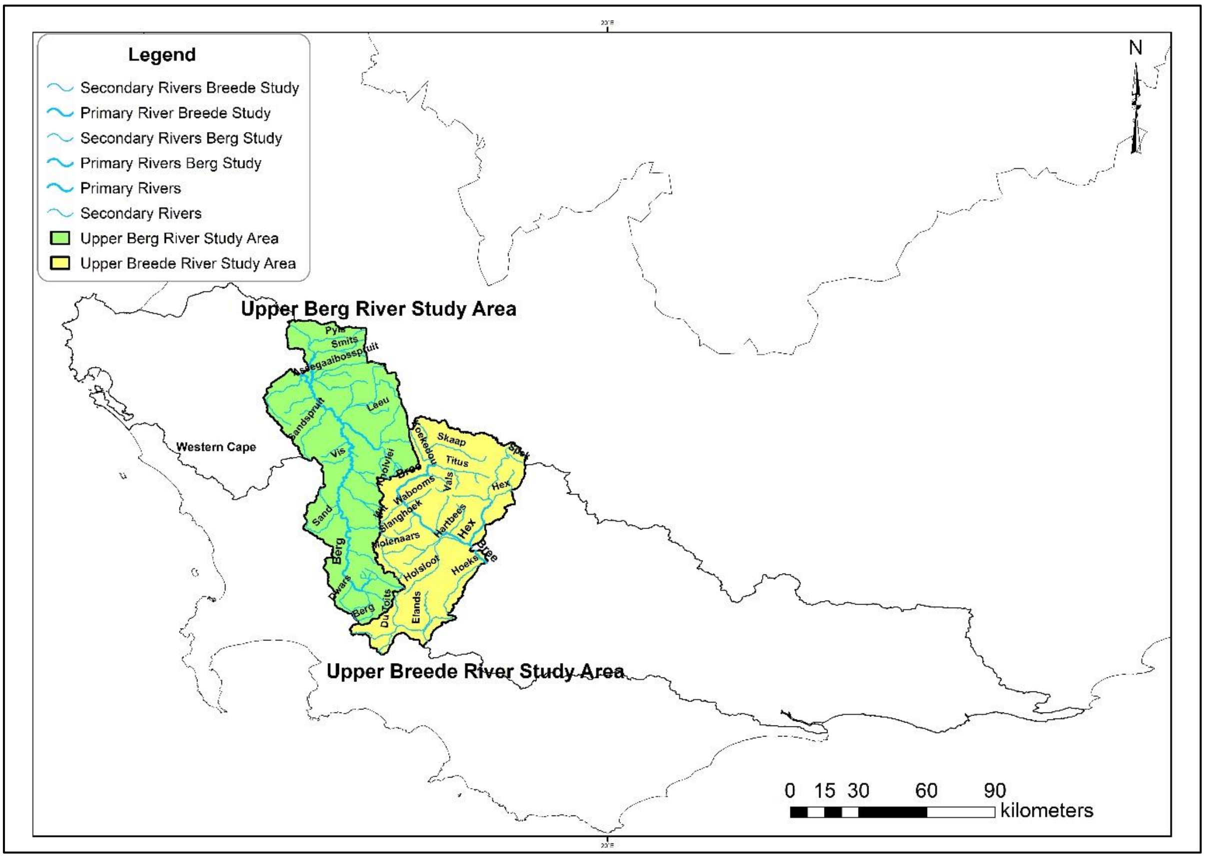


Figure 2: Location of the upper Berg and Breede River catchments.

3.1.3 Topography, Geology and Mean Annual Precipitation.

The upper Berg River catchment altitude, Error! Reference source not found., have a m aximum of 2 048 meters above sea level (m.a.s.l.) and a minimum of 15 m.a.s.l. The dominant geological formation, Error! Reference source not found., is Malmesbury S andstone.

The upper Breede River catchment altitude, Error! Reference source not found., have a maximum of 2 235 m.a.s.l. and a minimum of 167 m.a.s.l. The dominant geological formation, Error! Reference source not found., is that of Table Mountain Sandstone.

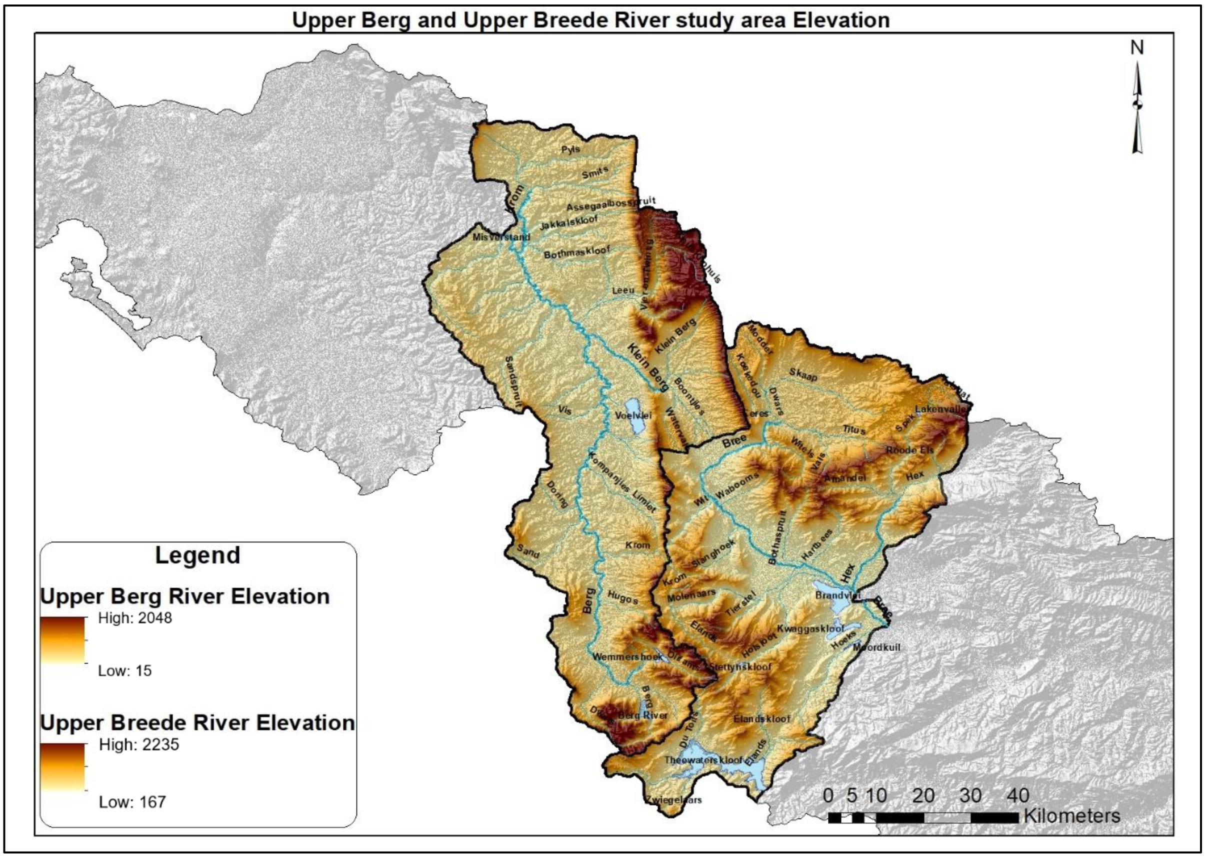


Figure 3: Elevation of the upper Berg and Breede River Catchments

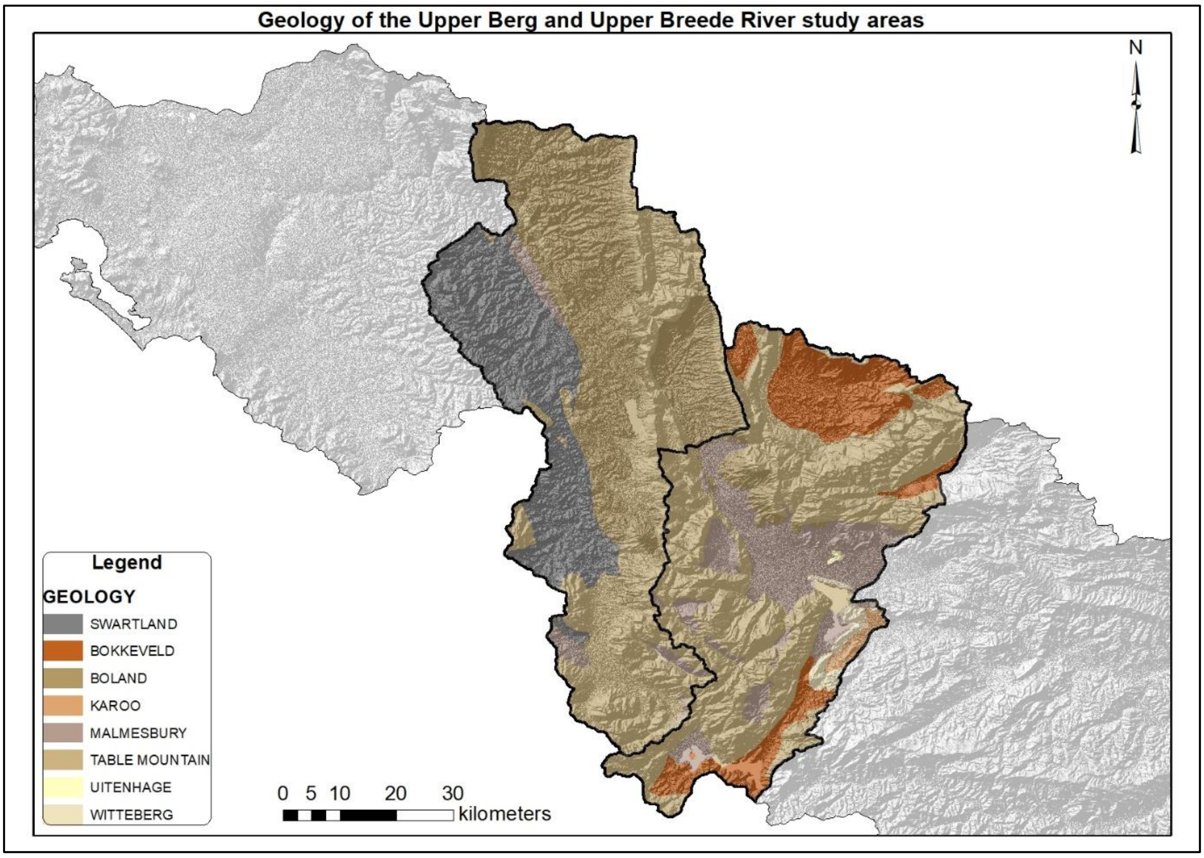


Figure 4: Study area Geology.

Error! Reference source not found., illustrates the Mean Annual Precipitation (MAP), s ourced from the South Africa National Land-Cover dataset, across the study area. The upper Berg River catchment experiences an estimated MAP of 840 mm, while the upper Breede River catchment registers a slightly higher average of 970 mm. It's important to note that both catchments fall within a region characterised by winter rainfall.

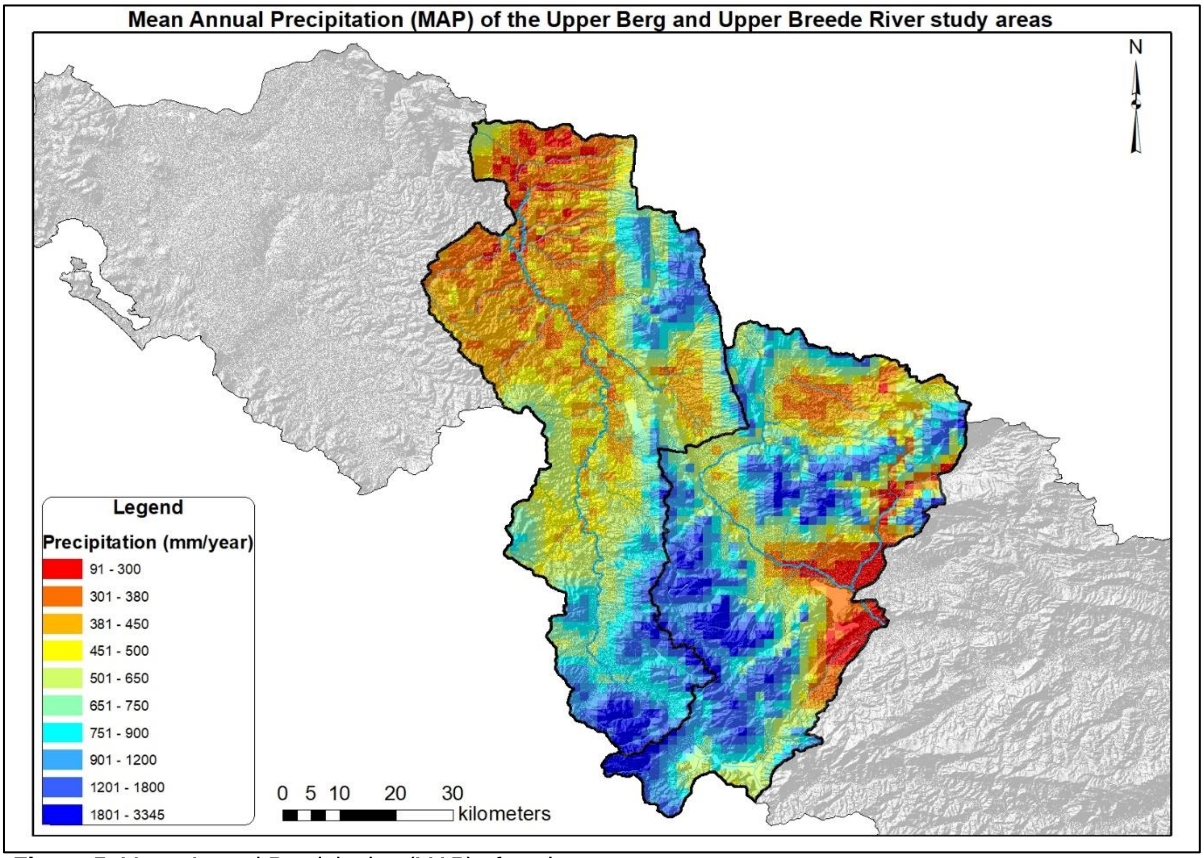


Figure 5: Mean Annual Precipitation (MAP) of study area.

3.2 Study Design.

The study design is broken down into five parts. Land use data collection and selection, water quality data collection and selection, data analysis and data interpretation.

3.2.1 Land use data collection and selection.

The South Africa National Land-Cover data were obtained from the Department of Environment, Forestry and Fisheries (DEFF). The land cover data covered a period of 22 years and included the years 1996, 2000, 2009, 2013, and 2018. There will only be a focus on the main groups of land uses that occur within the study area and the following classes will be used: natural, urban, agriculture, water bodies, mining, and degraded land, bare rock, and soil.

3.2.2 Land use data preparation and analysis.

Many different land use types and sub classes occur in the study areas. These are classified and put into six major land use types and include natural, urban, agriculture, water bodies, mining and degraded land, bare rock, and soil.

Geographic Information Systems (GIS) analysis, using ArcMap 10.4, was done to combine the subcategories of land use classes into the six major land use types. Natural land includes subcategories such as woodlands, a combination of open and dense bush, thicket, shrubland fynbos and low shrubland. Urban land use includes townships, residential areas, industrial land, commercial land, and built-up urban areas. Agricultural land use includes cultivated lands, planted forests and improved grasslands. Water bodies include wetlands, farm dams, large dams as well as rivers. The mining class includes all mining-related activities such as tailings dams, mine pits, quarries and mine dumps. Degraded land, bare rock, and soil include land that is degraded, has open rocks, eroded soils or has dongas and gullies. These six major land use types were combined and clipped to the specific two study areas and for each of the data years selected for this study.

The land use data selected for the study covered five different periods of time, namely 1996, 2000, 2009, 2013 and 2018. The maps thus encompass a 22-year period. These intervals were selected because of the availability of data and maps. Appropriate maps were generated to show how land use had changed over the 22 years.

Land use percentage of the overall area was calculated. Bar graphs charts were created for each of the five periods and for both study areas. Scatter plots with their respective trendlines, are displayed on the scatter plots indicating the R^2 value on the charts to show the statistical measure that represents the proportion of the variance for the dependent variable, land use change. The Bar graphs and scatter plots were used to show the change in land use over the selected time in both the study areas and is displayed in **CHAPTER FOUR - under Results and Discussion**.

Two-sample t-tests, or Student’s t-test, assuming independent variation, was done in Microsoft Excel to establish the differences between the different periods of study to see how the land use data changed over the four periods of time. These results are displayed in **Table 4** for the upper Berg River catchment and **Table 5** for the upper Breede River catchment.

3.2.3 Water quality data collection and selection.

Water quality data of the Berg River Catchment, and Breede River Catchment, were collected from the Department of Water Affairs and Sanitation (DWS) water quality national database to correlate with the land use data periods and maps that were created. Specific water quality indicators, or parameters, were selected based on the availability of data supplied by the DWS. Water quality samples were needed from 1996 – 2018 to correlate with the land use change timespan.

The specific water quality parameters that were used in the study are listed in **Table 2**, with their respective units of measurements and include Electrical Conductivity (EC), ammonium (NH_4^+), nitrate and nitrite (NO_3^-/NO_2^-), pH, orthophosphate as phosphate (PO_4^{3-}) and sulfate (SO_4^{3-}).

Table 2: Selected water quality parameters used in this study, and their abbreviations.

Water Quality Parameters Abbreviation	Water Quality Parameters Name	Units
EC	Electrical conductivity	mS/m
NH4 (NH_4^-)	Ammonium	mg/l
NO3_NO2 (NO_3^-_NO_2^-)	Nitrate/Nitrite (nitrate and nitrite)	mg/l
pH	pH	pH Units
PO4 (PO_4^{3-})	Orthophosphate as phosphate	mg/l
SO4 (SO_4^{3-}).	Sulfate	mg/l

These parameters were selected as a representation of the general status of the surface water over the study area and point sources of pollution will thus not be considered. Water quality guidelines are not relevant in the study as only the increase or decrease of specific parameters were investigated and levels of contamination for specific water quality parameters not. By creating land use maps one can link how different land use types over time affect the water quality of the study area.

Fourteen sample points were selected in the upper Berg River catchment and 20 sampling points in the upper Breede River catchment to represent the general water quality trends in the respective catchments. These specific sample amounts and locations were selected because they represent the water quality of the primary and secondary rivers in the study areas. These sampling points have water quality data for the different time periods of study and are displayed, in **Figure 6,** and **APPENDIX A**.

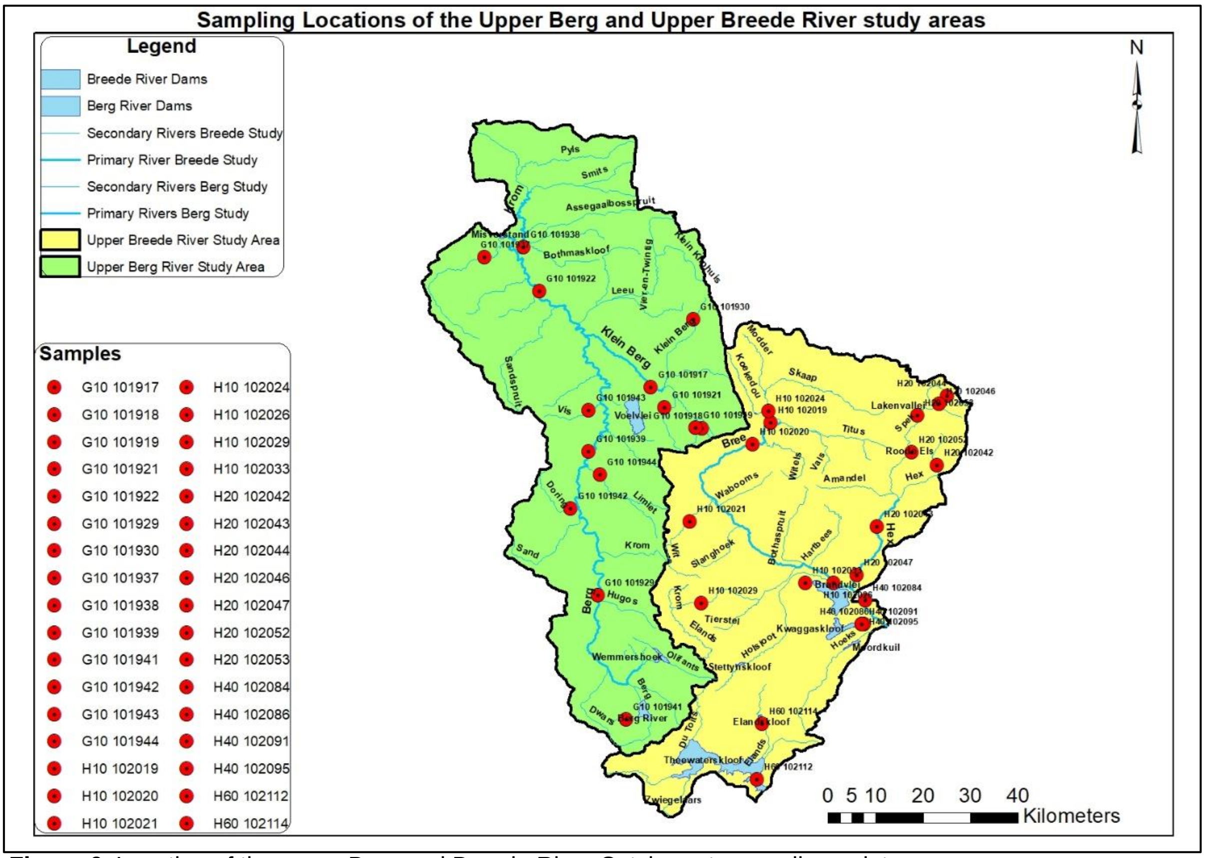


Figure 6: Location of the upper Berg and Breede River Catchments sampling points.

3.2.4 Water quality data preparation and analysis.

Multiple samples were taken per month at each of the sample sites over the 22 years. The yearly average was then determined. This minimizes the effect of seasonal variety, as well as outliers, to get a more accurate estimate of how the respective water quality parameters changed over the 22-year period.

Two-sample t-test, or Student’s t-test, assuming independent variation, was done in Microsoft Excel to investigate the differences among the different periods of study

3.2.5 Land use cover change correlation to water quality change.

The land use change data were correlated against annual water quality average values, for the respective years, to determine the correlation coefficients. Correlation coefficients are the statistical analysis that shows the degree of association between two sets of values (Hammond & McCullagh, 1974). Pearson Product Moment Correlation (Pearson's correlation coefficient) were used because it measures the linear relationship between two variables, land use change and water quality change.

The Pearson's correlation coefficient has several limitations and assumptions important to consider when analysing relationships between variables. It assumes a linear relationship between the variables. Pearson's correlation coefficient may not accurately describe non-linear relationships, potentially underestimating or missing them entirely. It also requires that both variables be continuous and normally distributed, with constant variance across the data. Significant outliers must be absent, as they can influence the correlation. The method assumes independence among paired observations, which can be violated in time series or clustered data. Limitations include the fact that Pearson's correlation coefficient only measures linear relationships and does not imply causation. High correlation thus does not mean one variable causes change in the other but shows a relationship. Pearson's correlation coefficient is sensitive to non-normal distributions and unequal intervals between data points, which can skew results.

The statistical significance of the correlations was then set out by using the equation, $t = \frac{r\sqrt{(N-2)}}{\sqrt{(1-r^2)}}$ where r is the correlation coefficient and N is the sample size. The p-value was used to show the confidence level of the data. Significance testing was done with a 95% confidence interval level to set out the significance. The correlation (r) between land use change and water quality change with respective confidence levels, in percentage, is displayed in **Table 9** and **Table 10** for the upper Berg and Breede catchments, respectively.

3.2.6 Data Interpretation.

Data with strong (0.6 to 0.79 or -0.6 to -0.79) or very strong (0.8 to 1.0 or -0.8 to -1.0) correlations and with a confidence level of above 90% were looked at in a lot of depth. Results with a confidence level between 90% and 95% are also discussed as these are also relevant with a sufficient degree of precision and confidence in the correlations between land use change and water quality changes. Correlations that were not observed, but were expected to have correlations, were also included.

4 CHAPTER FOUR – Results and discussion.

4.1 Land-use change in the upper Berg and Breede catchments between 1996 and 2018.

Land use types of the upper Berg River and Breede River catchments are displayed as Bar graphs, **Figure 7**. These graphs document the change in land use over time starting from 1996 and ending in 2018 with data sourced from the Department of Environment, Forestry and Fisheries as described in **Section 3.2.1, "Land Use Data Collection and Selection".**

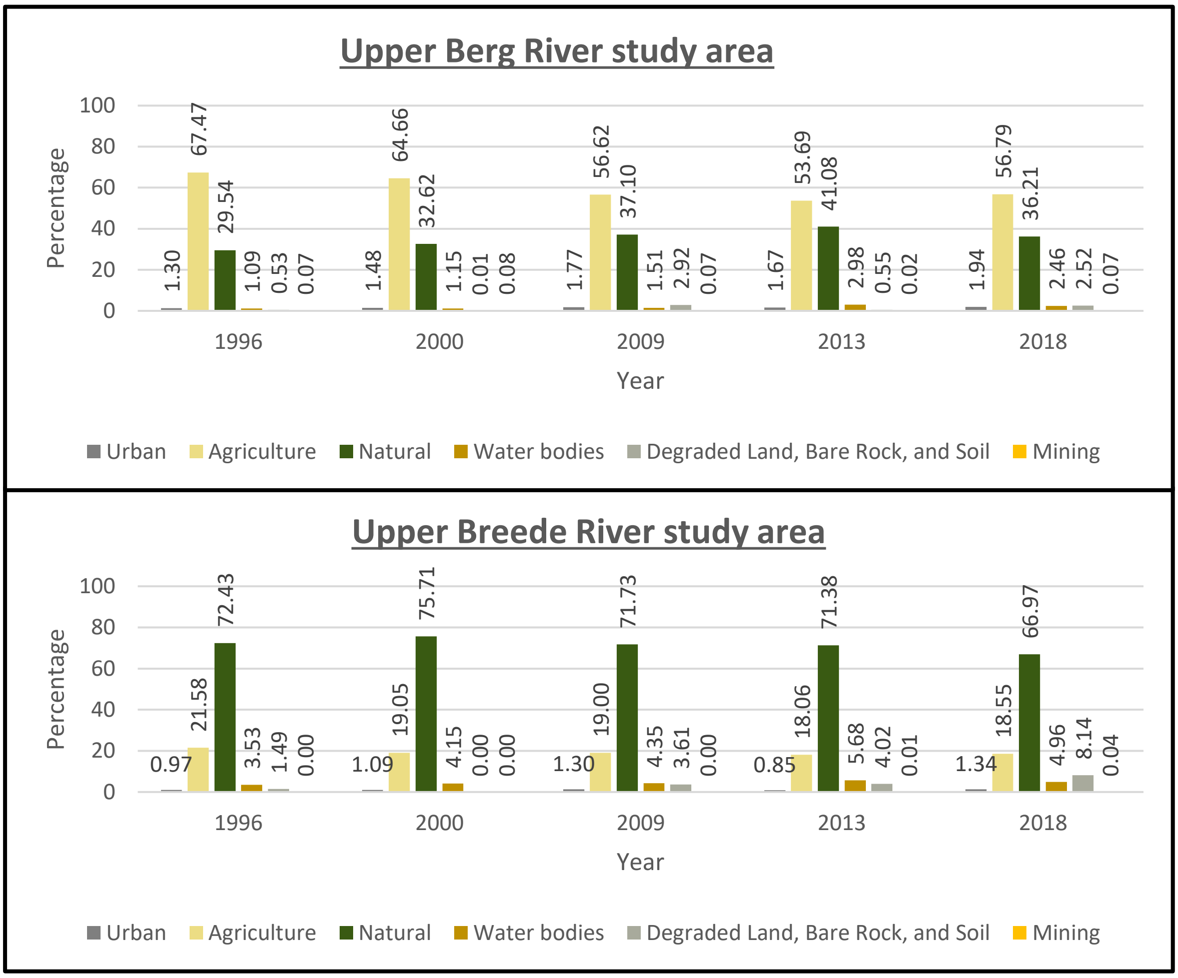


Figure 7: Bar Graphs indicating Land Use Percentages changes with time

Agricultural land is the most dominant land use in the upper Berg River catchment, with a maximum of 67% in 1996 to a minimum of 56% in 2013. Natural land was the second most dominant increasing from 29.54% in 1996 to a maximum of 38% in 2013 and decreasing to 36% in 2018. Agricultural and natural land use were the two most dominant land use types in the upper Berg River catchment and together account for between 93% to 97% of the overall land use types over the study period.

The most dominant land use type in the upper Breede River catchment was natural land, ranging from approximately 72% between 1996 and 2013 but decreasing to 67% in 2018. Agriculture was the second most prevalent land use and decreased from 22% in 1996 to approximately 19% in 2018. Together, natural land in combination with agricultural land account for between 86% and 94% of the total land use in the upper Breede River Catchment over the study period.

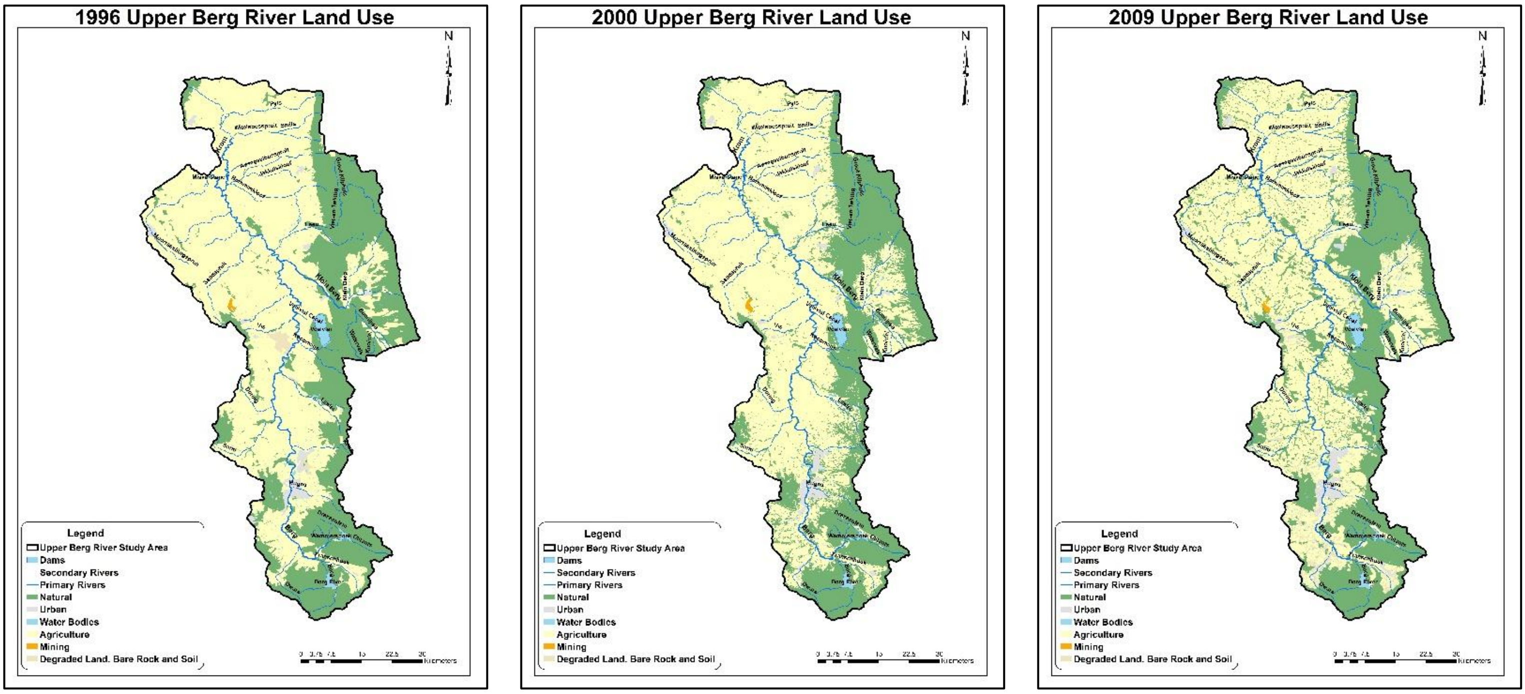


Figure 8: Land use of the upper Berg catchment area for period 1996 – 2009.

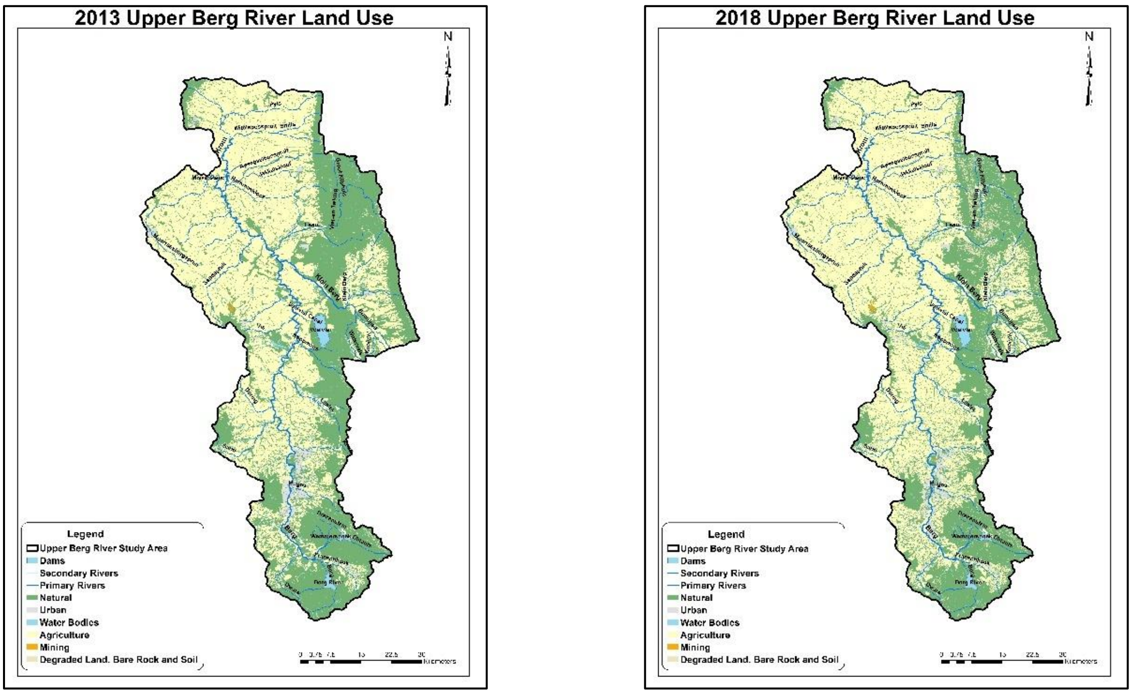


Figure 9: Land use of the upper Berg catchment area for period 2013 – 2018.

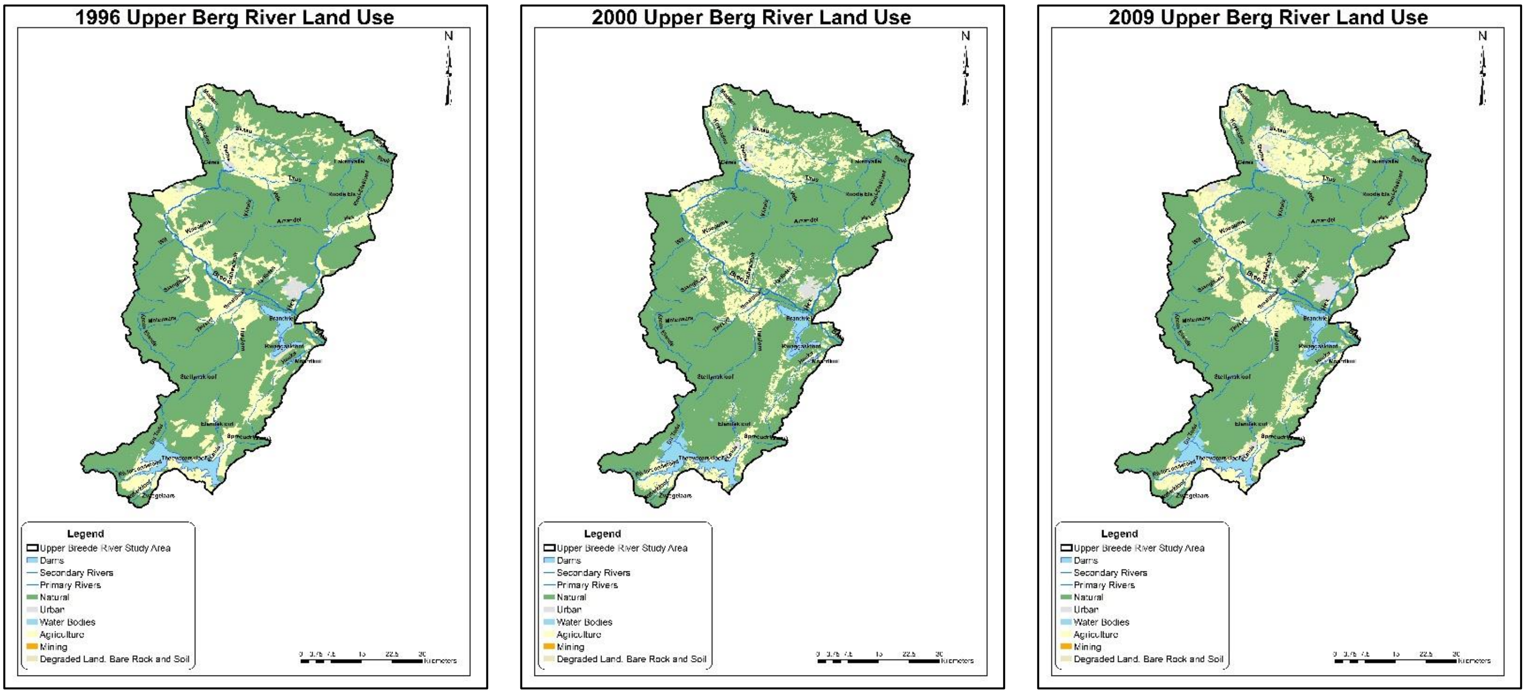


Figure 10: Land use of the upper Berg catchment area for period 1996 – 2009.

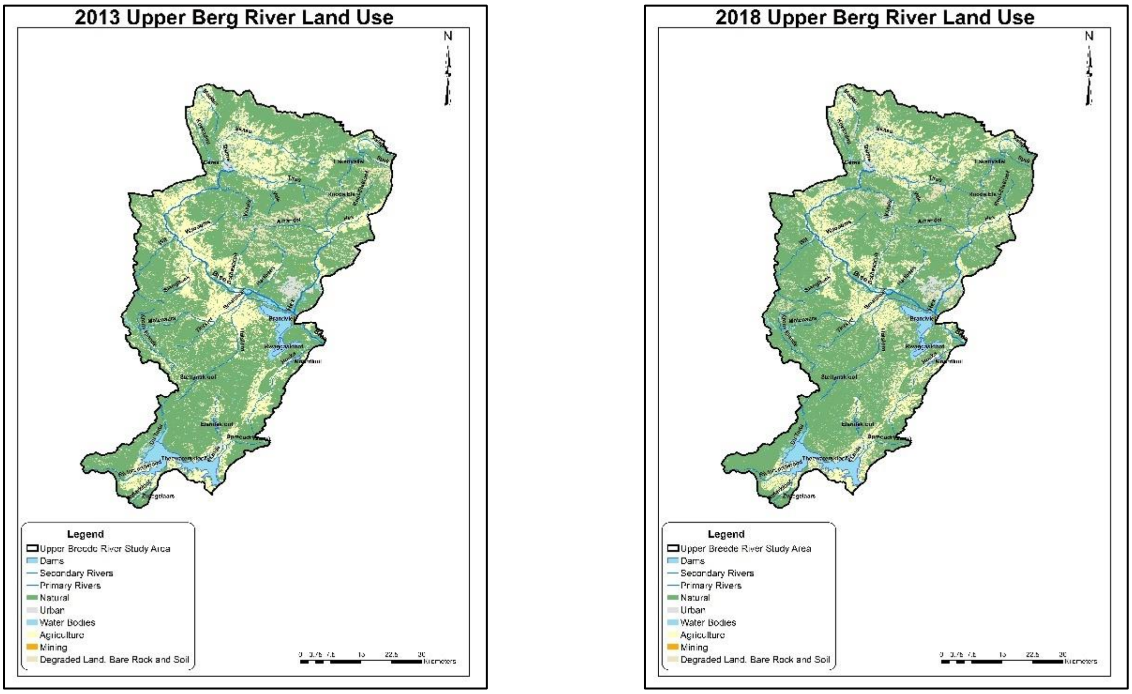


Figure 11: Land use of the upper Berg catchment area for period 2013 and 2018.

The land use types of the upper Berg and Breede river catchments are visually displayed in **Figure 8** to **Figure 11,** and **APPENDIX A**, and numerically displayed in **Table 3**. This table also include the R^2 values with the linear trendline equations, showing change in land use cover over the given time, calculated using Microsoft Excel, as indicated in the graphs in **Figure 12**.

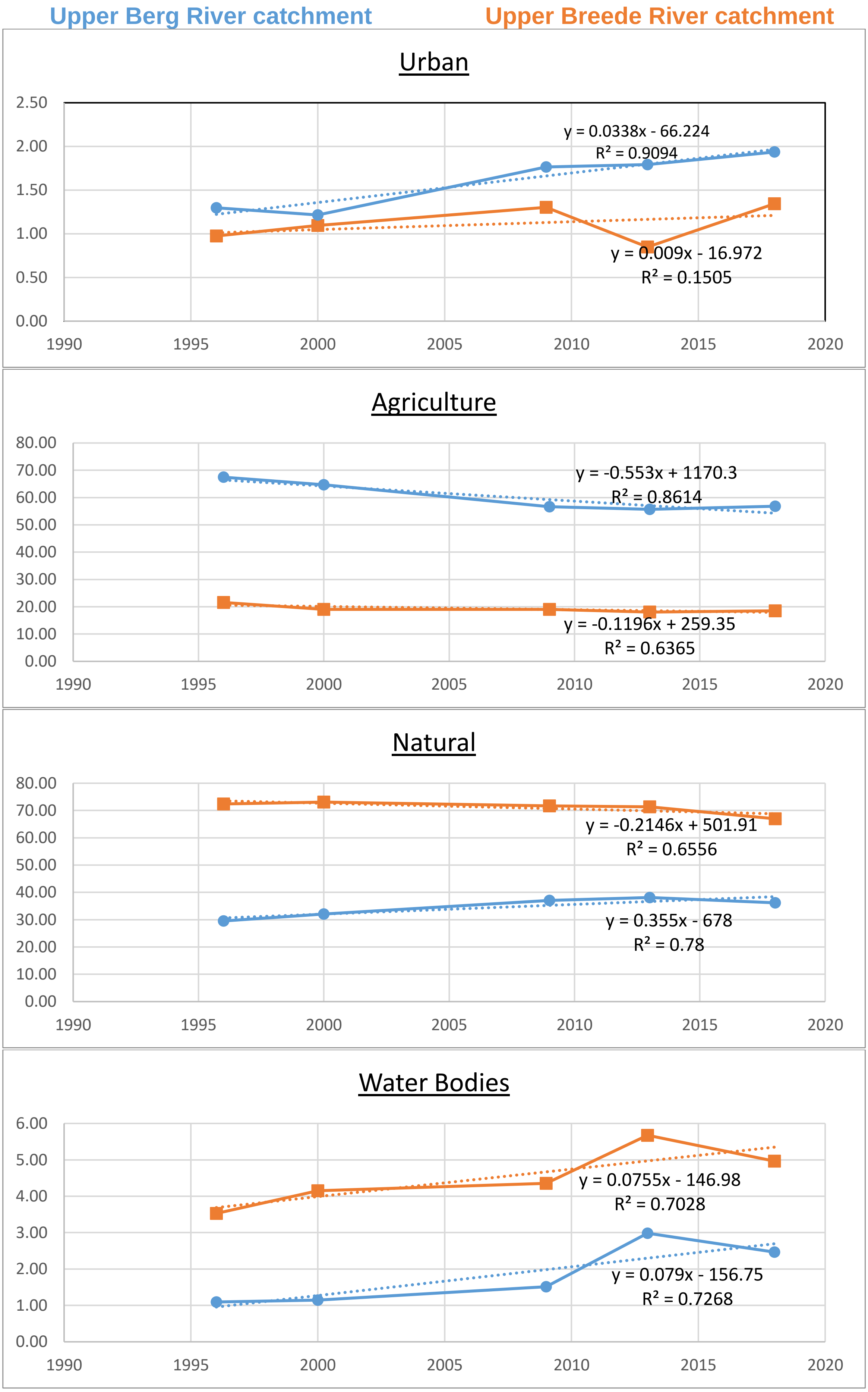
In the upper Berg river catchment, urban and agriculture had very high correlations with their respective R^2 value as 0.91 and 0.86. This very high R^2 value, or correlation, suggests that the regression line explains 91% and 86% of the variability in urban and agriculture over the study period. The same is true for the high R^2 value of natural land, 0.78, and water bodies 0.73 where the regression line explains 78% and 73% of the variability over the study period. In the upper Breede River catchment, degraded land, bare rock, and soil has a very high R^2 value of 0.80. Water bodies, natural land, agriculture, and mining has high R^2 values indicating that the land use change in time, have strong relationships with the dependent variable.

Table 3: Land use of the upper Berg River and Breede River catchments (all values except R^2 are given in percentages - %).

Upper Berg River catchment							
Year	**1996**	**2000**	**2009**	**2013**	**2018**	**R^2**	**Regression Line Equation**
Urban	1.30	1.22	1.77	1.79	1.94	0.91	y = 0.0338x - 66.224
Agriculture	67.47	64.66	56.62	55.70	56.79	0.86	y = -0.553x + 1170.3
Natural	29.54	32.05	37.10	38.13	36.21	0.78	y = 0.355x - 678
Water bodies	1.09	1.15	1.51	2.98	2.46	0.73	y = 0.079x - 156.75
Degraded Land, Bare Rock, and Soil	0.53	0.84	2.92	1.37	2.52	0.56	y = 0.0862x - 171.32
Mining	0.07	0.08	0.07	0.02	0.07	0.13	y = -0.001x + 1.9749
Upper Breede River catchment							
Year	**1996**	**2000**	**2009**	**2013**	**2018**	**R^2**	**Regression Line Equation**
Urban	0.97	1.09	1.30	0.85	1.34	0.15	y = 0.009x - 16.972
Agriculture	21.58	19.05	19.00	18.06	18.55	0.64	y = -0.1196x + 259.35
Natural	72.43	73.08	71.73	71.38	66.97	0.66	y = -0.2146x + 501.91
Water bodies	3.53	4.15	4.35	5.68	4.96	0.70	y = 0.0755x - 146.98
Degraded Land, Bare Rock, and Soil	1.49	2.63	3.61	4.02	8.14	0.80	y = 0.2483x - 494.38
Mining	0.00	0.00	0.00	0.01	0.04	0.64	y = 0.0015x - 2.9242

The change in percentage land use for each region and type of land use is presented in **Figure 12**, as graphs, corresponding to the information in **Table 3**. These have been plotted with their respective R^2 values and regression lines indicating the land use change against time.

In the upper Berg River catchment, the following can be noted regarding the regression, or trendlines, of the different land use types. Agriculture is the only land use with relevant correlation that shows a decreasing trendline over the study period. Urban, natural land and water bodies all had increasing trendlines over the study period. In the upper Breede River catchment, agriculture and natural land use show a decreasing trendline and water bodies, degraded land, bare rock, and soil and mining showed an increasing trendline over the study period.


Upper Berg River catchment
Upper Breede River catchment
Urban
y = 0.0338x - 66.224
R² = 0.9094
y = 0.009x - 16.972
R² = 0.1505
Agriculture
y = -0.553x + 1170.3
R² = 0.8614
y = -0.1196x + 259.35
R² = 0.6365
Natural
y = -0.2146x + 501.91
R² = 0.6556
y = 0.355x - 678
R² = 0.78
Water Bodies
y = 0.0755x - 146.98
R² = 0.7028
y = 0.079x - 156.75
R² = 0.7268
1990
1995
2000
2005
2010
2015
2020

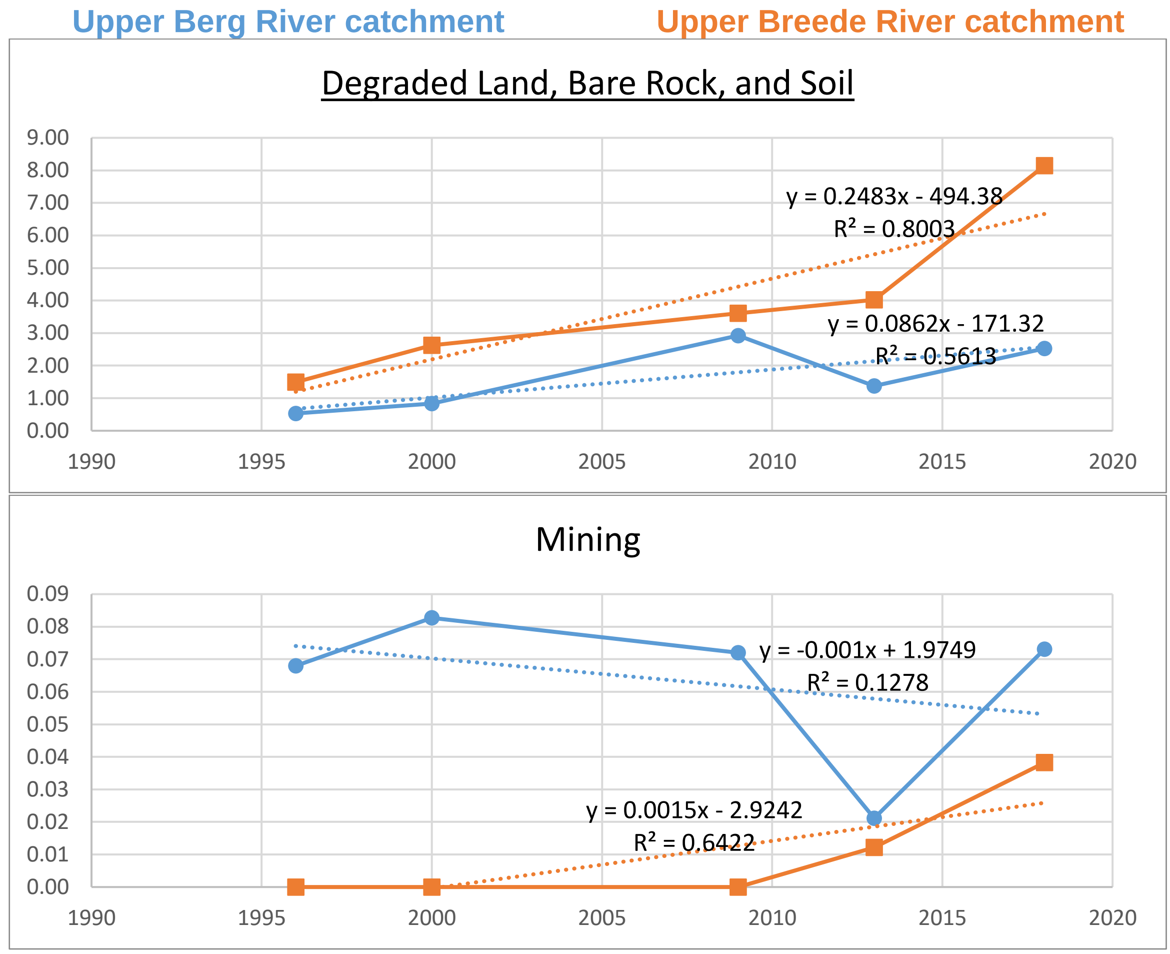


Figure 12: Linear regression line charts indicating land use change over the study period with the trendline equation and R^2 value displayed.

The results from a Student's t-test, as displayed in **Table 4** for the upper Berg River catchment and **Table 5** for the upper Breede River catchment. The results are indicated using p-values and shows the statistical significance of the findings.

A confidence level of 95% is selected as a level of precision and confidence. The Null Hypothesis (H_0) being that there is no significant land use change over the different periods of study. The Alternative Hypothesis (H_1) would thus be that there is significant land use change over the different periods of study.

Table 4 contains the p-values for the upper Berg River catchment and can be interpreted as follows. From the year 2000 to 2018, the urban land use p-value is **0.0014** and indicated with **bold** in the table. Another interpretation example is indicated in *italics* for the year 1996 to 2000 where the p-value was *0.0003*.

Table 4: Student's t-test table indicating the significant changes over periods of study as p-values in the upper Berg River catchment.

Urban	1996	2000	2009	2013	2018
1996	-	*0.0003*	0.0010	0.0013	0.0017
2000	*0.0003*	-	0.0007	0.0010	**0.0014**
2009	0.0010	0.0007	-	0.0003	0.0007
2013	0.0013	0.0010	0.0003	-	0.0004
2018	0.0017	**0.0014**	0.0007	0.0004	-
Agriculture	**1996**	**2000**	**2009**	**2013**	**2018**
1996	-	0.000003	0.00001	0.00004	0.0002
2000	0.000003	-	0.00001	0.00003	0.0003
2009	0.00001	0.00001	-	0.0002	0.0007
2013	0.00004	0.00003	0.0002	-	0.0002
2018	0.0002	0.0003	0.0007	0.0002	-
Natural	**1996**	**2000**	**2009**	**2013**	**2018**
1996	-	0.00001	0.0001	0.0001	0.0008
2000	0.00001	-	0.00003	0.0001	0.0009
2009	0.0001	0.00003	-	0.0001	0.0007
2013	0.0001	0.0001	0.0001	-	0.0001
2018	0.0008	0.0009	0.0007	0.0001	-
Water Bodies	**1996**	**2000**	**2009**	**2013**	**2018**
1996	-	0.0003	0.0010	0.0012	0.0017
2000	0.0003	-	0.0007	0.0008	0.0014
2009	0.0010	0.0007	-	0.0001	0.0006
2013	0.0012	0.0008	0.0001	-	0.0004
2018	0.0017	0.0014	0.0006	0.0004	-
Degraded Land, Bare Rock, and soil	**1996**	**2000**	**2009**	**2013**	**2018**
1996	-	0.0003	0.0007	0.0013	0.0016
2000	0.0003	-	0.0004	0.0010	0.0013
2009	0.0007	0.0004	-	0.00005	0.0007
2013	0.0013	0.0010	0.00005	-	0.0002
2018	0.0016	0.0013	0.0007	0.0002	-
Mining	**1996**	**2000**	**2009**	**2013**	**2018**
1996	-	0.0003	0.0010	0.0014	0.0018
2000	0.0003	-	0.0007	0.0010	0.0014
2009	0.0010	0.0007	-	0.0003	0.0007
2013	0.0014	0.0010	0.0003	-	0.0004
2018	0.0018	0.0014	0.0007	0.0004	-

In our case, the p-values suggest the probability that the Null Hypothesis (H_0) is true. If the p-value is lower than 0.05, as the selected confidence level, then the Null Hypothesis (H_0) is rejected. In the upper Berg River catchment, it is thus implied that there is sufficient evidence to suggest a significant difference in land use change over time due to the very low confidence level in the Null Hypothesis (H_0).

Table 5, contain the p-values of the Breede River catchment, and can be interpreted as follows. From the year 2000 to 2013, the urban land Use p-value is **0.0010** and indicated with **bold** in the table. Another interpretation example is indicated in *italics* for the year 1996 to 2013 where the p-value was *0.0014*.

Table 5: Student's t-test table indicating the significant changes over periods of study as p-values in the upper Breede River catchment.

Urban	1996	2000	2009	2013	2018
1996	-	0.0003	0.0010	*0.0014*	0.0017
2000	0.0003	-	0.0007	**0.0010**	0.0014
2009	0.0010	0.0007	-	0.0003	0.0007
2013	*0.0014*	**0.0010**	0.0003	-	0.0004
2018	0.0017	**0**.0014	0.0007	0.0004	-
Agriculture	**1996**	**2000**	**2009**	**2013**	**2018**
1996	-	0.00001	0.0007	0.0009	0.0015
2000	0.00001	-	0.0007	0.0010	0.0014
2009	0.0007	0.0007	-	0.0002	0.0007
2013	0.0009	0.0010	0.0002	-	0.0004
2018	0.0015	0.0014	0.0007	0.0004	-
Natural	**1996**	**2000**	**2009**	**2013**	**2018**
1996	-	0.0002	0.0010	0.0014	0.0010
2000	0.0002	-	0.0006	0.0009	0.0005
2009	0.0010	0.0006	-	0.0003	0.0001
2013	0.0013	0.0009	0.0003	-	0.000002
2018	0.0010	0.0005	0.0001	0.000002	-
Water Bodies	**1996**	**2000**	**2009**	**2013**	**2018**
1996	-	0.0002	0.0010	0.0012	0.0017
2000	0.0002	-	0.0007	0.0009	0.0014
2009	0.0010	0.0007	-	0.0001	0.0007
2013	0.0012	0.0009	0.0001	-	0.0003
2018	0.0017	0.0014	0.0007	0.0003	-
Degraded Land, Bare Rock, and soil	**1996**	**2000**	**2009**	**2013**	**2018**
1996	-	0.0001	0.0008	0.0011	0.0008
2000	0.0001	-	0.0006	0.0009	0.0006
2009	0.0008	0.0006	-	0.0003	0.0001
2013	0.0011	0.0009	0.0003	-	0.000002
2018	0.0008	0.0006	0.0001	0.000002	-
Mining	**1996**	**2000**	**2009**	**2013**	**2018**
1996	-	0.0003	0.0010	0.0014	0.0017
2000	0.0003	-	0.0007	0.0010	0.0014
2009	0.0010	0.0007	-	0.0003	0.0007
2013	0.0014	0.0010	0.0003	-	0.0004
2018	0.0017	0.0014	0.0007	0.0004	-

Again, as with the upper Berg River catchment, the p-values suggest the probability that the Null Hypothesis (H_0) is true. If the p-value is lower than 0.05, as the selected confidence level, then the Null Hypothesis (H_0) is rejected. The p-values in **Table 4** of the upper Breede River catchment show similar values to that of **Table 5** of the upper Berg River catchment with p-values all less than 0.05 indicating that the Null Hypothesis (H_0) can be rejected. In the upper Breede River catchment it is thus implied that there is sufficient evidence to suggest a significant difference in land use change over time due to the very low confidence level in the Null Hypothesis (H_0).

4.2 Water quality change in the upper Berg and Breede catchments between 1996 and 2018.

The water quality of the upper Berg River and Breede River catchments are numerically displayed in **Table 6**. This table also includes the R^2 values with the linear trendline equations, calculated using Microsoft Excel, as indicated in the scatter plot graphs in **Figure 14**. R^2 values indicate the goodness of fit meaning how well the regression models fit the respective datasets and how much of the variability in the dependent variable, change in water quality, they explain. These tables and graphs document the change in water quality over time starting from 1996 and ending in 2018 with data sourced from the DWS's National water quality database, as described in **Section 3.2.3, "Water Quality Data Collection and Selection".**

Table 6: Water quality of the upper Berg River and Breede River catchments (all values except R^2 are given in percentages - %).

Upper Berg River catchment							
Year	1996	2000	2009	2013	2018	R^2	**Regression Line Equation**
EC	191.3451	165.3460	144.6165	132.4872	172.6440	0.27	y = -1.3309x + 2832.7
NH_4^-	0.0647	0.0569	0.0810	0.0612	0.0978	0.47	y = 0.0013x - 2.4929
NO_3^-_NO_2^-	0.6310	0.7192	0.6884	0.6666	0.7843	0.18	y = 0.004x - 7.3806
pH	7.5366	7.3017	7.4391	7.4669	7.5920	0.40	y = 0.0052x - 2.9121
PO_4^{3-}	0.0853	0.0811	0.0799	0.0706	0.0815	0.28	y = -0.0003x + 0.7212
SO_4^{3-}	72.4425	65.1977	57.4176	47.8198	55.5822	0.76	y = -0.9062x + 1878.7
Upper Breede River catchment							
Year	1996	2000	2009	2013	2018	R^2	**Regression Line Equation**
EC	64.2843	71.9712	52.7067	41.1892	40.6168	0.85	y = -1.4079x + 2880.2
NH_4^-	0.0420	0.0493	0.0605	0.0514	0.0752	0.72	y = 0.0012x - 2.3317
NO_3^-_NO_2^-	0.4322	0.3221	0.3381	0.2876	0.3726	0.19	y = -0.0026x + 5.5637
pH	7.1115	6.9976	7.0657	7.0263	7.0236	0.19	y = -0.0021x + 11.329
PO_4^{3-}	0.0342	0.0519	0.0469	0.0355	0.0597	0.20	y = 0.0005x - 1.0382
SO_4^{3-}	66.9442	69.6262	49.6972	32.6880	33.7972	0.90	y = -1.835x + 3733.8

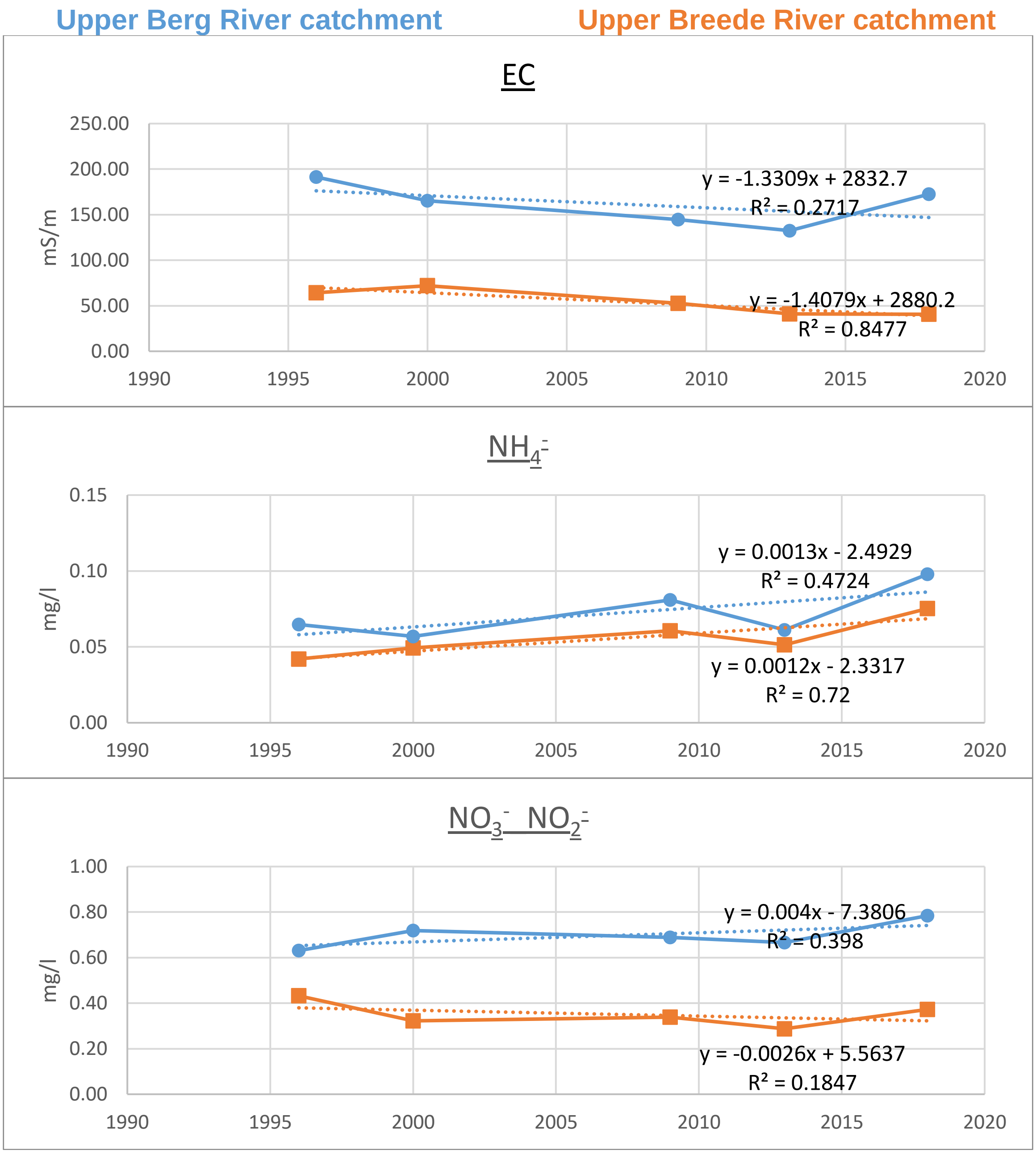
EC in the upper Berg River Catchment ranged from 132.49 mS/m in 2013 to 191.35 mS/m in 1996. EC shows a decreasing trend from 1996 to 2013, followed by an increase in 2018. There is a notable drop from 1996 to 2009 and a subsequent increase in 2018. Ammonium concentrations ranged from 0.057 mg/l in 2000 to 0.098 mg/l in 2018. Ammonium concentration has a fluctuating pattern over the years. There is an increase in 2009, followed by a decrease in 2013 and a slight increase in 2018. Nitrate and nitrite concentrations had a range from 0.63 mg/l in 1996 to 0.78 mg/l in 2018. Nitrate and nitrite concentration shows a stable trend with slight variations. The values seem to oscillate around a central range with no significant upward or downward trend. pH had a low of 7.30 in 2000 and a high of 7.59 in 2018. The pH values are stable over the years. There is a slight decrease from 1996 to 2000, followed by a gradual increase in subsequent years. Fluctuations are within a narrow range. Orthophosphate concentrations ranged from 0.07 mg/l in 2013 to 0.085 mg/l in 1996. Orthophosphate concentration exhibited a stable trend with minor fluctuations. There is a decrease from 1996 to 2000, followed by a stable pattern in later years. Sulfate concentrations ranged from 47.82 mg/l in 2013 to 72.44 mg/l in 1996. Sulfate concentration shows a decreasing trend over the years. The values drop consistently from 1996 to 2018, indicating a decline in concentration.

Electrical conductivity in the upper Breede River Catchment ranged from 40.62 mS/m in 2018 to 71.97 mS/m in 2000. There is a notable decrease in EC from 1996 to 2018. Ammonium concentrations ranged from 0.042 mg/l in 1996 to 0.075 mg/l in 2018. Ammonium concentration exhibited an increasing trend over the years, peaking in 2018. Nitrate and nitrite concentrations had a range from 0.29 mg/l in 2013 to 0.43 mg/l in 1996. Nitrate and nitrite concentration exhibits variations over the years. There is a decrease from 1996 to 2000, followed by a subsequent increase in 2018. pH had a low of 7.00 in 2000 and a high of 7.11 in 1996. The pH values show a stable pattern over the years. Fluctuations are within a narrow range, and the values are generally within the acceptable limits, between 6.5 – 8.5, for aquatic ecosystems. (DWAF & Forestry, 1996) Orthophosphate concentrations ranged from 0.03 mg/l in 1996 to 0.06 mg/l in 2018. Orthophosphate concentration displays fluctuations with an overall increase from 1996 to 2018. Sulfate concentrations ranged from 32.69 mg/l in 2013 to 69.63 mg/l in 2000. Sulfate concentration shows a substantial decrease from 1996 to 2018.

From the R^2 values, as indicated in **Table 6**, of the upper Berg River catchment, sulfate presented the only significant R^2 value with 0.76. Thus, the change in time can explain 76% of the variability of the sulfate concentration. In the upper Breede River catchment, EC, ammonium, and sulfate concentrations all show a strong relationship with the change of time with 0.85, 0.72 and 0.90 R^2 value, respectively. Nitrate and nitrite, pH, and orthophosphate showed very low R^2 values with 0.19, 0.19 and 0.20 respectively and this the independent variable, change over time, not explaining the variability of the dependent variable, water quality concentrations.

The change in water quality in both the upper Berg River and Breede River catchments over the study period is presented in **Figure 13**. These have been plotted with their respective R^2 values and regression lines indication the change with time and are also displayed in **Figure 13**.

In the present study, the environmental parameters of the upper Berg River catchment and upper Breede River catchment were investigated, and trendline linear equations were derived to model the relationships between key water quality indicators and change over time. The resulting equations provide insights into the anticipated changes in these water quality parameters based on the change over time.



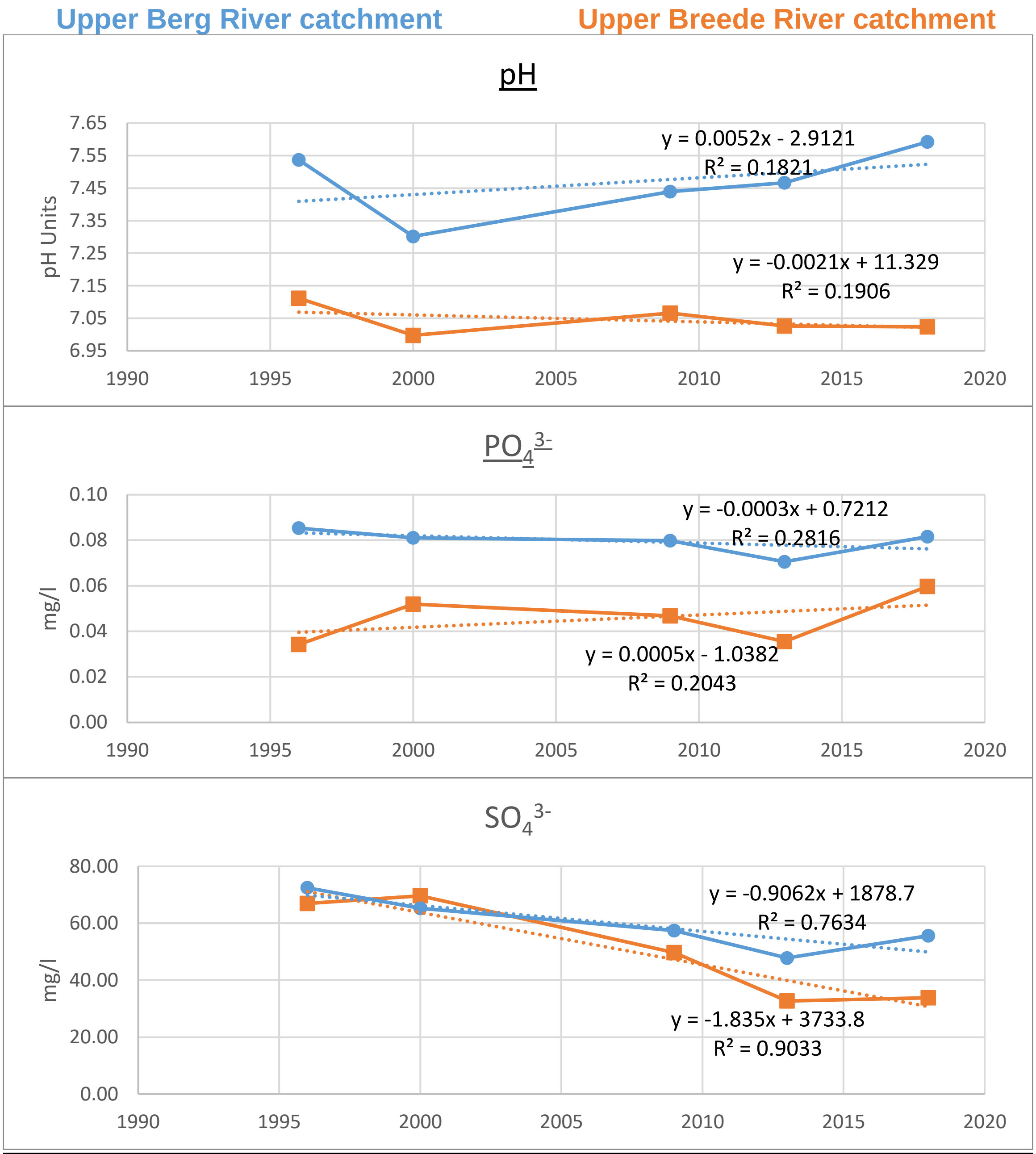


Figure 13: Linear Regression Line Charts indicating Water Quality change over the study period.

A surprising result in could be the decrease of sulfate observed in both the study areas. This could be linked to the sulfate reduction Sulfate reduction takes place, through sulfate reducing bacteria, and with optimal nutrients, organic matter, climatic conditions and other natural and/or anthropogenic impacts, a reduction of sulfate over time is observed. In combination with upgraded wastewater treatment plants and sewage treatment facilities better agricultural practices, such as smart agriculture, one could explain the reduction in sulfate levels over the study period.

Table 7 contains the p-values for the upper Berg River catchment and can be interpreted as follows. From the year 1996 to 2018, the EC p-value is **0.0053** and indicated in **bold** in the table. Another interpretation example is indicated in *italics* for the year 1996 to 2009 where the p-value was *0.0022*.

Table 7: Student's t-test table indicating the significant changes over periods of study as p-values in the upper Berg River catchment.

EC	**1996**	**2000**	**2009**	**2013**	**2018**
1996	-	0.0016	*0.0022*	0.00004	**0.0053**
2000	0.0016	-	0.0054	0.002	0.0034
2009	*0.0022*	0.0054	-	0.0017	0.0115
2013	0.00004	0.002	0.0017	-	0.0095
2018	**0.0053**	0.0034	0.0115	0.0095	-
NH_4^-	**1996**	**2000**	**2009**	**2013**	**2018**
1996	-	0.0003	0.001	0.001	0.0017
2000	0.0003	-	0.0007	0.001	0.0014
2009	0.001	0.0007	-	0.0003	0.0007
2013	0.001	0.001	0.0003	-	0.0004
2018	0.0017	0.0014	0.0007	0.0004	-
NO_3^-_NO_2^-	**1996**	**2000**	**2009**	**2013**	**2018**
1996	-	0.0003	0.001	0.0014	0.0017
2000	0.0003	-	0.0007	0.001	0.0014
2009	0.001	0.0007	-	0.0003	0.0007
2013	0.0014	0.001	0.0003	-	0.0004
2018	0.0017	0.0014	0.0007	0.0004	-
pH	**1996**	**2000**	**2009**	**2013**	**2018**
1996	-	0.0003	0.001	0.0014	0.0017
2000	0.0003	-	0.0007	0.001	0.0014
2009	0.001	0.0007	-	0.0003	0.0007
2013	0.0014	0.001	0.0003	-	0.0004
2018	0.0017	0.0014	0.0007	0.0004	-
PO_4^{3-}	**1996**	**2000**	**2009**	**2013**	**2018**
1996	-	0.0003	0.001	0.0013	0.0017
2000	0.0003	-	0.0007	0.001	0.0014
2009	0.001	0.0007	-	0.0003	0.0007
2013	0.0013	0.001	0.0003	-	0.0004
2018	0.0017	0.0014	0.0007	0.0004	-
SO_4^{3-}	**1996**	**2000**	**2009**	**2013**	**2018**
1996	-	0.0002	0.0002	0.0001	0.0007
2000	0.0002	-	0.0007	0.0001	0.0022
2009	0.0002	0.0007	-	0.00001	0.0011
2013	0.0001	0.0001	0.00001	-	0.0025
2018	0.0007	0.0022	0.0011	0.0025	-

In **Table 7**, the p-values again suggest the probability that the Null Hypothesis (H_0) is true. If the p-value is lower than 0.05, as the selected confidence level, then the Null Hypothesis (H_0) is rejected. In the upper Berg River catchment, it is thus implied that there is sufficient evidence to suggest a significant difference in water quality change over time due to the very low confidence level in the Null Hypothesis (H_0).

Table 8, like **Table 7**, contains the p-values of the Breede River catchment, and can be interpreted as follows. From the year 2000 to 2009, the EC p-value is **0.0013** and indicated in **bold** in the table. Another interpretation example is indicated in *italics* for the year 1996 to 2013 where the p-value was *0.0001*.

Table 8: Student's t-test table indicating the significant changes over periods of study as p-values in the upper Breede River catchment.

EC	**1996**	**2000**	**2009**	**2013**	**2018**
1996	-	0.0001	0.0002	*0.0001*	0.0004
2000	0.0001	-	**0.0013**	0.0006	0.0014
2009	0.0002	**0.0013**	-	0.0001	0.0001
2013	*0.0001*	0.0006	0.0001	-	0.0007
2018	0.0004	0.0014	0.0001	0.0007	-
NH_4^-	**1996**	**2000**	**2009**	**2013**	**2018**
1996	-	0.0003	0.001	0.0013	0.0017
2000	0.0003	-	0.0007	0.001	0.0014
2009	0.001	0.0007	-	0.0003	0.0007
2013	0.0013	0.001	0.0003	-	0.0004
2018	0.0017	0.0014	0.0007	0.0004	-
NO_3^-_NO_2^-	**1996**	**2000**	**2009**	**2013**	**2018**
1996	-	0.0003	0.001	0.0013	0.0017
2000	0.0003	-	0.0007	0.001	0.0014
2009	0.001	0.0007	-	0.0003	0.0007
2013	0.0013	0.001	0.0003	-	0.0004
2018	0.0017	0.0014	0.0007	0.0004	-
pH	**1996**	**2000**	**2009**	**2013**	**2018**
1996	-	0.0003	0.001	0.0014	0.0018
2000	0.0003	-	0.0007	0.001	0.0014
2009	0.001	0.0007	-	0.0003	0.0007
2013	0.0014	0.001	0.0003	-	0.0004
2018	0.0018	0.0014	0.0007	0.0004	-
PO_4^{3-}	**1996**	**2000**	**2009**	**2013**	**2018**
1996	-	0.0003	0.001	0.0013	0.0017
2000	0.0003	-	0.0007	0.001	0.0014
2009	0.001	0.0007	-	0.0003	0.0007
2013	0.0013	0.001	0.0003	-	0.0004
2018	0.0017	0.0014	0.0007	0.0004	-
SO_4^{3-}	**1996**	**2000**	**2009**	**2013**	**2018**
1996	-	0.0002	0.0002	0.0003	0.0007
2000	0.0002	-	0.0015	0.0017	0.0021
2009	0.0002	0.0015	-	0.0001	0.0004
2013	0.0003	0.0017	0.0001	-	0.0002
2018	0.0007	0.0021	0.0004	0.0002	-

As with the upper Berg River catchment, the p-values suggest the probability that the Null Hypothesis (H_0) is true. If the respective p-value is lower than 0.05, as the selected confidence level, then the Null Hypothesis (H_0) is rejected.

The p-values in **Table 8** of the upper Breede River catchment show similar values to that of **Table 7** of the upper Berg River catchment with p-values all less than 0.05 indicating and thus indicating that the Null Hypothesis (H_0) can be rejected.

In the upper Breede River catchment it is thus implied that there is sufficient evidence to suggest a significant difference in water quality over time due to the very low confidence level in the Null Hypothesis (H_0).

4.3 Land use change impact on water quality.

The correlations between land use change and water quality change as well as their confidence levels are indicated in **Table 9** for the upper Berg River catchment and **Table 10** for the upper Breede River catchment.

Only relevant data are discussed and interpreted. Relevant results are those with Strong (<u>0.6 to 0.79 or -0.6 to -0.79</u>) or Very Strong (**0.8 to 1.0 or -0.8 to -1.0**) correlations and with a confidence level of above 95%, also in **Bold**.

The confidence level of 95% is chosen to get a greater degree of precision and confidence in the correlations between land use change and water quality changes. Strong and very strong correlations with a confidence level of 90%, <u>underlined</u>, is also discussed as these are also relevant with a sufficient degree of precision and confidence in the correlations between land use and water quality change.

In the upper Berg River catchment, there is a strong and positive correlation, with r of 0.739, between the increase in urban land use and ammonium levels, indicating in our catchment, that if urban land use increases, so does the ammonium concentrations. The correlation is statistically significant with a confidence level of 96.4%, suggesting a high degree of certainty in this relationship. Wastewater treatment systems serve the purpose of removing ammonium from wastewater. An increase in wastewater treatment plant failures, due to rapid urbanization, mismanagement of resources as well as power failures, could thus lead to the increase in ammonium concentrations, due to an increase in urban land (Allan & Castilo, 2007) (Lutz, 2009). Ammonium is also found in many common household cleaning products. Rapid urbanization also thus linked to an increase in ammonium concentrations that end up in water bodies

(Allan & Castilo, 2007). The correlation between urban land use and sulfate is very strong and negative, with r of -0.821, and has a 98.9% confidence level. Sulfate levels would thus decrease as urban land increase. This is unexpected as urban land usually contributes to higher sulfate levels. The large number of informal settlements close to surface water bodies could be the reason for this unexpected relationship (Leonov & Chicherina, 2008). Sulfate reduction takes place in conditions with increased amounts of organic matter, such as resulted from informal settlements, and in water with low oxygen levels. The oxygen levels are not known in this study and could be beneficial to understand the complete system and how sulfates are decreased with an increase in urban land in the upper Berg River catchment. Sulfate reduction in the upper Berg catchment seems to have a stronger impact on the reducing of sulfate levels in comparison to increasing sulfate levels as noted in different catchments through industry, water and sewage treatment facilities and soaps used for washing urban land. There is thus an overall reduction in sulfate levels observed.

Agricultural land use has a very strong positive correlation, with r of 0.943, with sulfate, with a 98.1% confidence level. This result is as expected and relates to various other study findings (Shebab, *et al.*, 2021) (Williams, *et al.*, 2005). Agricultural land decreases over the study period and could be linked to a decrease in sulfate concentrations. In agricultural land use, sulfates are used in fertilizers, pesticides, and present in manure of livestock. Agricultural practices thus result in sulfate that ends up in streams, dams and rivers and is linked to an increase in sulfate levels. Agricultural land use in the upper Berg River catchment also presents a strong positive correlation with r of 0.769, with EC with a 91.4% confidence level. Agricultural fertilizers often contain soluble salts, such as nitrates, phosphates and potassium salts that add to the EC levels of surface water bodies. Tillage of lands, for agricultural purposes, also exposes the soil to faster weathering rates and will result in an increase in EC. Irrigation used will increase the quantity of salts that leaches into water and hence play a role in the increase EC levels (Mehaffey, *et al.*, 2005). A very strong positive correlation between agriculture and nitrate and nitrite is also expected but, in this study, not observed. This could be because of the implementation of Smart Agricultural practices in the Berg River Catchment. The Western Cape Government had implemented and is advocating Best Practices in agriculture to reduce and mitigate the negative impacts of agricultural practices on the Berg river's water quality

(WCG, 2012). This is done in combination with the Western Cape Government's Riparian Rehabilitation plan that also mitigates the impacts of agriculture on the Berg river's water quality (WCG, 2012). This could explain the reason this relationship between agriculture and nitrate and nitrite was not observed.

Natural land use has a very strong negative correlation, with r of -0.847, with EC with a confidence level of 99.4%, a very strong negative correlation, with r of -0.963, with sulfate with a 100% confidence level as well as a strong negative correlation, with r of -0.759, with orthophosphate with a 97.2% confidence level. Natural land is land that has retained most of its original ecological characteristics, ecosystem functions and biodiversity. Natural land plays an important role in maintaining biochemical processes, and a decrease in natural land would decrease ecological and ecosystem functions, such as water purification. It is noted in **Table 9** that an increase in natural land would result in a decrease in EC, orthophosphates as well as sulfate levels in the water. The same is true for the decrease of natural land that here result in the increase in EC, orthophosphates and sulfate levels in the water (Buck, *et al.*, 2004) (Tu, 2011) (Vigerstol, *et al.*, 2021). Sulfate levels are also seen to decrease and could be due to optimal conditions for sulfate reducing bacteria to live and thrive in.

Water bodies have a very strong negative correlation, with r of -0.903, with sulfate with a 99.9% confidence level as well as a strong negative correlation, with r of -0.785, with orthophosphate with a 98.0% confidence level. Water bodies in our study area also include wetlands which are very important filtration and purification agents. Water bodies, especially wetlands, thus assist in maintaining a balance of nutrients as well as general water quality (Vigerstol, *et al.*, 2021). The increase of the amount of Water bodies could also result in surface water being more diluted and this having lower concentrations of pollutants. Sulfate reduction is also very prominent in wetlands with abundant organic matter as well as anaerobic conditions present. This would thus ultimately lead to the overall reduction in sulfate levels with increased water bodies in the upper Berg River catchment (Leonov & Chicherina, 2008).

Degraded land, bare rock, and soil has a very strong correlation, with r of 0.812, with ammonium with a 98.7% confidence level. Degraded land, bare rock, and soil usually occur where other land uses are removed. This land use is more prone to erosion and flooding due to the lack of vegetation present that is retaining soil and water. This land use also does not have its natural ecological characteristics, ecosystem functions and services present, an example could be that the populations of nitrogen-fixing bacteria may be reduced which limits the conversion of atmospheric nitrogen to ammonia (Stone, *et al.*, 2013). An increased runoff in the upper Berg River catchment is linked to an increase in ammonium concentrations in surface water.

Mining has a very strong positive correlation, with r of 0.862, with orthophosphate with a 99.6% confidence level. Mining activity has been linked with increased levels of orthophosphate in water bodies. Weathering of rocks that contain phosphates ultimately end up in rivers and surface water bodies. A strong positive correlation, with r of 0.664, with sulfate with a 93.1% confidence level is also present. This is in line with what is expected from mining activities that, through AMD, significantly increase sulfate levels in rivers. The release of sulfate occurs naturally as rocks weather but mining significantly increases this process through the exposure of minerals to oxygen and water (Naicker, *et al.*, 2003) (Udayabhanu & Prasad, 2010). Sulfate reduction seemed to not be as prominent and present here with mining activities contributing to higher levels of sulfate than what could have been decreased by bacteria. Mining is also observed to have a strong positive correlation, with r of 0.662, with EC, with a 90.8% confidence level in the upper Berg River catchment. Mining activities can elevate EC levels in water through processes such as the leaching of ions from exposed rocks and minerals, the dissolution of minerals containing soluble ions and runoff from mine sites salts. These mechanisms contribute to an increase in the ability of water to conduct electricity, thus increasing EC levels.

Table 9 Correlation ("r") between Land Use change and Water Quality change with respective confidence levels (In percentage) of the upper Berg River catchment.

Upper Berg River catchment	**Urban**		**Agriculture**		**Natural**	
	"r"	**% confidence**	**"r"**	**% confidence**	**"r"**	**% confidence**
EC	-0.503	83.8	0.769	91.4	**-0.847**	**99.4**
NH_4^-	0.739	**96.4**	-0.524	80.1	0.410	77.7
NO_3^-_NO_2^-	0.448	80.2	-0.407	74.0	0.342	73.2
pH	0.563	87.4	-0.234	64.1	0.124	58.5
PO_4^{3-}	-0.471	81.7	0.684	87.7	-0.759	**97.2**
SO_4^{3-}	**-0.821**	**98.9**	**0.943**	**98.1**	**-0.963**	**100.0**
Upper Berg River catchment	**Water Bodies**		**Degraded Land, Bare Rock, and Soil**		**Mining**	
	"r"	**% confidence**	**"r"**	**% confidence**	**"r"**	**% confidence**
EC	-0.583	88.6	-0.414	78.0	0.622	90.8
NH_4^-	0.295	70.0	**0.812**	**98.7**	0.279	69.0
NO_3^-_NO_2^-	0.289	69.7	0.535	85.7	0.388	76.3
pH	0.403	77.3	0.282	69.2	-0.177	62.1
PO_4^{3-}	-0.785	**98.0**	-0.133	59.1	**0.862**	**99.6**
SO_4^{3-}	**-0.903**	**99.9**	-0.556	87.0	0.664	93.1

In the upper Breede River catchment, urban land has a very strong positive correlation, with r of 0.829, with orthophosphate with a 99.1% confidence level. This relationship is well known due to wastewater and sewage linked to urban land that contribute the orthophosphate levels in rivers. Rapid urbanization leads to wastewater treatment facilities not being able to handle the increased loads and thus increased wastewater treatment plant failures that is linked to an increase quantity of urban pollutants in the rivers (Cullis, *et al.*, 2019). Urban land also has a strong positive correlation, with r of 0.794, with ammonium with a 98.3% confidence level. Similar as to those results of the upper Berg River catchment, and a well expected result that an increase in urban land would result in an increase in ammonium. Ammonium is found in many common household cleaning products and rapid urbanization can thus be linked to an increase in ammonium concentrations in water bodies (Allan & Castillo, 2007).

Agricultural land has a very strong positive correlation, with r of 0.862 with nitrate and nitrite with a 95.1% confidence level. An increase in agricultural land is thus linked to an increase in nitrate and nitrite concentrations in surface water. This result can be explained due to the nitrogen-based fertilizers used in agricultural practices. Nitrate is highly soluble in water and excess fertilizers can lead to leaching into water bodies (Vitousel, *et al.*, 1997). Agricultural land also has a very strong positive correlation, with r of 0.811, with pH and a 93.1% confidence level. An increase in agricultural land use would thus result in more alkaline water, with a higher pH. Farming practices often use agricultural lime added to soil to enhance nutrient availability. Lime can dissolve in water and be transported into nearby water bodies through runoff leading to an increase in pH levels (Mant, *et al.*, 2013).

Natural land cover has a very strong negative correlation, with r of -0.892, with ammonium with a confidence level of 99.9%. As previously mentioned, natural land serves important functions, such as ecosystem services and to maintain biochemical processes. Ammonia gets taken up by plants and is naturally decreased by vegetation (Buck, *et al.*, 2004) (Tu, 2011) (Vigerstol, *et al.*, 2021). A strong positive correlation, with r of 0.747, with EC with a 96.7% confidence level is also observed. A decrease in natural land use in the upper Breede River catchment has been linked to a decrease in EC levels. This is usually not an expected result or finding as high EC levels are usually associated with bad water quality. It is important to note that EC levels should be used in conjunction with other water quality parameters to obtain a comprehensive overview of the water quality. pH, dissolved oxygen levels, specific ion concentrations as well as the presence of other parameters should be considered alongside EC to get a complete understanding of the water quality conditions. All possible parameters affecting EC was not looked at in this study to know why EC is decreasing with a decrease in natural land. A further, more comprehensive, study can thus be done to assess specific influences of water quality parameters and their impact on EC levels in the upper Breede River catchment. A strong positive correlation, with r of 0.728, with natural land and sulfate with a 96.0% confidence level was also observed. Sulfate levels were seen to decrease with a decrease in natural land. Sulfur is found in sediments and rocks and when exposed through weathering processes converted to sulfate. Less natural land in the upper Breede catchment would this be linked to less sulfur being exposed through natural processes and then converted to sulfate when exposed to air (Granat, *et al.*, 1976). The opposite is usually expected in catchments where less natural land is linked to higher levels of sulfate in rivers. Sulfur is a compound of organic matter and decomposition of organic matter release sulfate ions into water. Sulfate reduction increased through organic content and with increased organic matter, due to the large amount of natural land, sulfate levels would decrease (Leonov & Chicherina, 2008).

Water bodies have a very strong negative correlation, with r of -0.821, with EC with a 98.9% confidence level, a very strong negative correlation, with r of -0.891, with sulfate and a 99.9% confidence level as well as a strong negative correlation, with r of -0.730, with nitrate and nitrite and a 96.1% confidence level. As with the upper Berg River catchment, water bodies include wetlands. Wetlands serve a very important function in catchments where they regulate flow, add to the biodiversity, maintain ecosystem services, and thus serve as water purification systems (Vigerstol, *et al.*, 2021). The total increase in the amount of water bodies over the study period in upper Breede River catchment, similarly to that observed in the upper Berg River catchment, could also result in the dilution in pollutants. This would thus explain the decrease observed in EC, nitrate and nitrite and sulfate concentrations. The reduction in sulfate concentrations again could be linked to the increased microbial activity in wetlands, where sulfate concentrations decline with abundant organic matter and anaerobic conditions (Leonov & Chicherina, 2008).

Degraded land, bare rock, and soil had a very strong correlation, with r of 0.947, with ammonium with a 100% confidence level. This is similar to what was observed in the upper Berg River catchment. This land is prone to erosion and flooding because of the lack of vegetation to retain soil and water. Natural ecologically characteristics and ecosystem services are reduced and could be the result of the increase in ammonium concentrations. Increases in ammonium is especially associated with degraded land, bare rock, and soil near agricultural activities as nutrient runoff, can contribute to increased ammonium levels in water. Ammonium could come from fertilizers, organic matter decomposition, or other sources associated with disturbed land (Osuagwu, *et al.*, 2014). A strong negative correlation, with r of -0.753, with EC with a 96.9% confidence level was also observed. This correlation contrasts with what is usually expected. One would usually find that degraded land, bare rock, and soil contribute to higher EC levels. This correlation needs to be viewed with the correlation of natural land and EC levels. As noted with the correlation of natural land use and EC, EC levels should be viewed and analysed with other water quality parameters. One cannot obtain a comprehensive overview by not looking at other water quality parameters such as pH, dissolved oxygen levels, specific ion concentrations as well as the presence of other, chemical, and biological, parameters (Chapman, 1996). These other parameters should be considered alongside EC to get a complete understanding of the water quality conditions. This study did not investigate all possible parameters that could impact EC levels and more research could be done to understand this complex relationship in the upper Breede River catchment. This correlation could also be linked to the results observed under natural land, as discussed earlier, where a decrease in natural land would be linked to a decrease in EC levels. Natural land usually gets transformed into degraded land, bare rock, and soil. Natural land use and degraded land, bare rock, and soil would thus, as shown in the results, have opposite correlations to one another. A strong positive correlation, with r of 0.709 with orthophosphate with a 95.2% confidence level is also observed. These expected result and correlations could be due to the increased rate of weathering and erosion taking place and resulting in phosphate releases into water (Osuagwu, *et al.*, 2014). Degraded land, bare rock, and soil, when lacking vegetation cover, is very prone to soil erosion that transports sediments into water bodies and thus increasing the sediment load in the water. These sediments can contain minerals that contribute to an increase in orthophosphate in the water (Cullis, *et al.*, 2019).

Degraded land, bare rock, and soil had a strong negative correlation, with r of -0.771, with sulfate with a 97.6% confidence level in the upper Breede River catchment. This result is the opposite of what is expected and means that sulfate levels are expected to decrease as degraded land, bare rock, and soil increase. In the upper Breede River catchment, degraded land, bare rock, and soil increases as natural land decreases. Natural land has a positive correlation with sulfate concentrations. The strong negative correlation between degraded land, bare rock, and soil should thus be looked at in unison with the natural land correlation. The degradation of natural land, as discussed in the literature review, is almost directly related to the amount of degraded land, bare rock, and soil that has increased in the upper Breede River catchment. Natural land decreased by approximately 5.46% and degraded land, bare rock, and soil increased by approximately 6.65% in the upper Breede River catchment. These changes almost directly impact each other and could be the reason the correlation is observed in contrast to what is usually expected.

Mining had a very strong positive correlation, with r of 0.820, with ammonium with a 98.9% confidence level. Mining related activities, usually due to the use of ammonia-based explosives, can be linked to the increase of ammonium concentrations in water. This is an expected correlation. A strong negative correlation, with r of -0.732, with EC with a 96.2% confidence level is observed. With a strong negative correlation, with r of -0.737, with sulfate, that has a 96.4% confidence level. A reduction of EC and sulfate due to an increase in mining activity is in contrast with what is usually expected. As with the relationship between natural land and degraded land, bare rock, and soil, a similar conclusion can be made between the relationship between the increase in mining activity and the reduction of natural land. Other land uses would normally not be mined, and natural land again is sacrificed in order to do mining activities. Natural land has a positive correlation with EC and sulfate concentration in the upper Breede River catchment. The opposite correlations are seen with mining. One can thus again assume that the reduction in natural land and its correlations is directly related to the increase in mining activity and its specific correlations. This relationship could be the reason the correlation is observed in contrast to what is usually expected. Other possibilities for the unexpected correlations between mining and EC and sulfate, without looking into relationships with other land uses, could be that technological advancements in mining result in treatment of water used in the mining activities.

Mining activities in this area are strictly monitored due to the pristine status of this catchment. The most abundant form of mining in the upper Breede River catchment is that of sand mining (Western Cape Government (WCG), 2017). Sand mining operations often involve the use of water for activities such as washing and processing the extracted sand. If this process water has a lower conductivity and sulfate concentration compared to the natural water in the area, its introduction into water bodies can lead to dilution, and ultimately result in the reduction of EC and sulfate concentrations. Natural sulfate levels are seen to relatively high in the upper Breede River catchment. Mining of sand, with sulfate-bearing minerals, could lead to the reduction of sulfate as these natural minerals and materials are now removed and not replaced. Sulfate reduction, due to suitable conditions for the sulfate reducing bacteria, could also result in the negative correlation that is unexpectedly observed in the upper Breede River catchment.

Table 10 Correlation (r) between Land Use change and Water Quality change with respective confidence levels (In percentage) of the upper Breede River catchment.

Upper Breede River catchment	**Urban**		**Agriculture**		**Natural**	
	"r"	**% confidence**	**"r"**	**% confidence**	**"r"**	**% confidence**
EC	-0.145	59.9	0.597	83.7	0.747	**96.7**
NH_4^-	0.794	**98.3**	-0.581	82.9	**-0.892**	**99.9**
NO_3^-_NO_2^-	0.185	62.7	**0.862**	**95.1**	-0.122	58.3
pH	-0.117	58.0	**0.811**	93.1	0.211	64.4
PO_4^{3-}	**0.829**	**99.1**	-0.441	75.8	-0.602	89.7
SO_4^{3-}	-0.130	58.9	0.705	88.7	0.728	**96.0**

Upper Breede River catchment	**Water Bodies**		**Degraded Land, Bare Rock, and Soil**		**Mining**	
	"r"	**% confidence**	**"r"**	**% confidence**	**"r"**	**% confidence**
EC	**-0.821**	**98.9**	-0.753	**96.9**	-0.732	96.2
NH_4^-	0.450	80.4	**0.947**	**100.0**	**0.820**	**98.9**
NO_3^-_NO_2^-	-0.730	**96.1**	-0.128	58.7	0.020	51.4
pH	-0.570	87.8	-0.443	79.9	-0.354	74.0
PO_4^{3-}	0.095	56.5	0.709	**95.2**	0.575	88.1
SO_4^{3-}	**-0.891**	**99.9**	-0.771	**97.6**	-0.737	**96.4**

5 CHAPTER FIVE – Discussion and Conclusion.

The purpose of this study was to examine land use changes over time to see how these changes impacted water quality in the upper Berg and Breede River catchments. These results can be used to assist policymakers, researchers, and governmental land use planners to make better-informed decisions regarding the consequences of land use change and what impacts they have on water quality in these two areas.

The first research objective considered was to investigate the predominant land use changes in the study area over the study period.

The specific research questions posed are as follows:

1. What were the predominant land use changes from 1996 – 2018 in the upper Berg River and Breede River catchments?
2. What were the primary water quality changes from 1996 – 2018 in the upper Berg River and Breede River catchments?
3. Is there a relationship between specific land use type changes and water quality change during the period of 1996 – 2018 in the upper Berg River and Breede River catchments?

<u>Question 1. What were the predominant land use changes from 1996 – 2018 in the upper Berg River and Breede River catchments?</u>

In the upper Berg River catchment, agricultural land was the most dominant land use form. Agricultural land had a range between 67.47% and 55.70%. A decrease was noted over the study period. The second most dominant land use in the upper Berg River catchment was that of natural land which ranged between 29.54% and 38.13%. A general increase in natural land was noted and this could be due to rehabilitation projects being implemented by different interested and affected parties in the area. A decrease in agriculture and mining was also noted together with an increase in urban, natural, water bodies and degraded land, bare rock, and soil.

In the upper Breede River catchment, natural land was the most dominant land use ranging between 73.08%. and 66.97% A slight decline was observed over the study period. Agricultural land use was the second most dominant land use with percentages ranging between 21.58%. and 18.06% A decline was also noted here. A decrease in land use was noted in agriculture and natural land and an increase was noted in urban, water bodies, degraded land, bare rock, and soil as well as mining land use. Similarities in both catchments observed were that urban, water bodies and degraded land, bare rock, and soil increased, and agricultural land use decreased.

Question 2: What were the primary water quality changes from 1996 – 2018 in the upper Berg River and Breede River catchments?

In the upper Berg River catchment, EC, orthophosphates as well as sulfate concentrations were found to decrease over time and ammonium, nitrate and nitrite as well as pH levels increased. In the upper Breede River catchment, ammonium and orthophosphate concentrations increased over the study period and EC, nitrate and nitrite, pH, and sulfate concentrations has decreased over the study period.

In both areas ammonium concentrations increased overall and EC and sulfate decreased over the study area. A lowering in sulfate was not expected because an increase in urban land, as seen in both study areas, usually results in higher concentrations of sulfate through anthropogenic activities.

Question 3: Is there a relationship between specific land use type changes and water quality change during the period of 1996 – 2018 in the upper Berg River and Breede River catchments?

In the upper Berg River catchment, the overall increase in urban land was positively correlated to an increase in ammonium concentrations and a decrease in sulfate concentrations. The relationship of sulfate was not expected. Agricultural land decreased, and this was correlated with a decrease in EC as well as a decrease in sulfate concentrations. A correlation that was not observed, is that of nitrate and nitrite - which is normally strongly linked to agricultural practices. Natural land has increased in the upper Berg River catchment. This was correlated with a decrease in EC, orthophosphate, and sulfate concentrations. Water bodies increased and resulted in the decrease in orthophosphate and sulfate concentrations. Degraded land, bare rock, and soil has increased and an increase in ammonium concentrations was linked to this increase. Mining activities were seen to decrease, and this correlated with the decrease of EC and sulfate concentrations. An increase in orthophosphate was noted with a decrease in mining activities.

In the upper Breede River catchment, the increase of urban land is correlated with the increase of ammonium and orthophosphate. Agricultural land use decreased in the upper Breede catchment, and this correlated with decrease in nitrate and nitrite concentrations as well as pH in the surface water. The amount of land classified as natural decreased over time, and this was correlated with a decrease in EC, and sulfate concentrations, which is unexpected.

Concluding remarks and avenues for further research

Limitations of this study include the duration of data used. Land use information was only taken for the years 1996, 2000, 2009, 2013 and 2018. This means that only 5 sampling intervals occurred over a 22-year period. If more land use information could be collected, it would be possible to conduct more accurate statistical analyses. Additionally, if a larger study area were considered, it might have been possible to observe more generalised trends and correlations. Land use classes were grouped and classified into 5 broad classes. Errors could have occurred taking such a large amount of different land use typed and grouping them into 5 classes. On a much more detailed study, specific classes under the sub classes of land use, could be studied to see how their changes affect water quality parameters. More water quality parameters could be included if they can be collected, but, unfortunately, they were not available for this study. Notwithstanding these limitations, the work presented in this study has value in detailing of evolving land use patterns and their implications on water quality within the upper catchments of these essential rivers is also needed within the South African context, a country characterised by water scarcity.

Further research can be done to explore the “ideal” future land use type for optimal water quality. This would include modelling of the data and estimations and simulations based on the principals of what this research has shown. Deep diving into subcategories of the specific land uses, and how they affect water quality, could also be studied to show where the biggest contribution of decreasing water quality can be expected. This could then direct focus towards those land uses to combat water quality deterioration. A specific consideration for future research could be to investigate the changes linked to agricultural practices and how the potential intensification of this land use type would have an impact on water quality parameters. To effectively reduce the negative impacts of certain land use changes on water quality, a comprehensive approach will be needed, especially in water-scarce catchments such as the Berg and

Breede River Catchments. Strict land use planning and regulations should prioritize the protection, conservation, and improvement of the water resource.

The Breede-Gouritz Catchment Management Agency (BGCMA), responsible for managing water resources in the Breede catchment area, emphasizes the importance of safeguarding important ecosystems. Zoning laws and land use restrictions must be enforced in areas like wetlands, floodplains, upper catchments, and riparian zones to prevent degradation. These areas are vital for maintaining healthy water systems and reducing pollution, despite the challenges posed by growing populations. More sustainable agricultural practices play a key role in this effort, and the BGCMA advocates for techniques that minimize soil erosion, nutrient runoff, and pesticide contamination, while also promoting water conservation in catchments. Encouraging precision agriculture and the adoption of conservation methods such as cover cropping and integrated pest management can significantly reduce environmental impacts, particularly on surface water resources. Additionally, managing invasive species that consume excessive water is part of BGCMA's approach to ensuring the balance of ecosystems and water supply.

Riparian buffers and wetlands act as natural filters, trapping pollutants before they reach water bodies. Thus, protecting and restoring these habitats is of vital importance to leverage natural ecosystem services in reducing pollution and improving surface water quality. In urban areas, effective stormwater management through green infrastructure and retrofitting can further minimize the transport of pollutants into rivers and lakes. Upgrading essential water treatment facilities also plays a critical role in ensuring that pollutants do not end up in water systems. Public education and outreach programs, especially those that engage communities, are key to raising awareness about sustainable land management practices and the interconnectedness of land use and water quality. By promoting community involvement, agencies like the BGCMA can foster a culture of responsible land and water stewardship.

Finally, integrated water resource management plans, paired with collaboration among government agencies, stakeholders, and communities, can facilitate stronger efforts to address water quality issues. Through these efforts, we can work together to mitigate the adverse impacts of land use changes on water quality, promoting the sustainable management of our natural resources.

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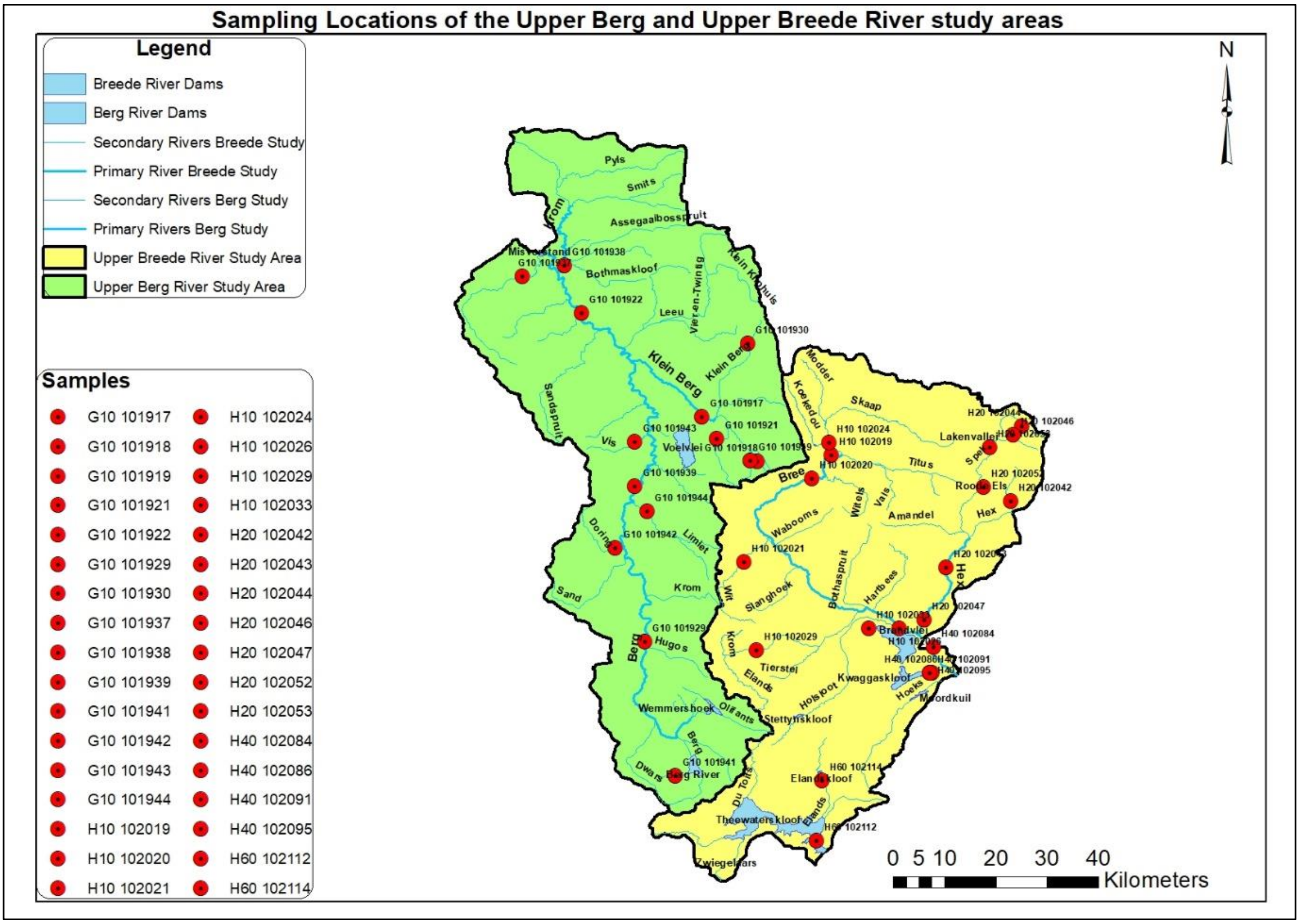
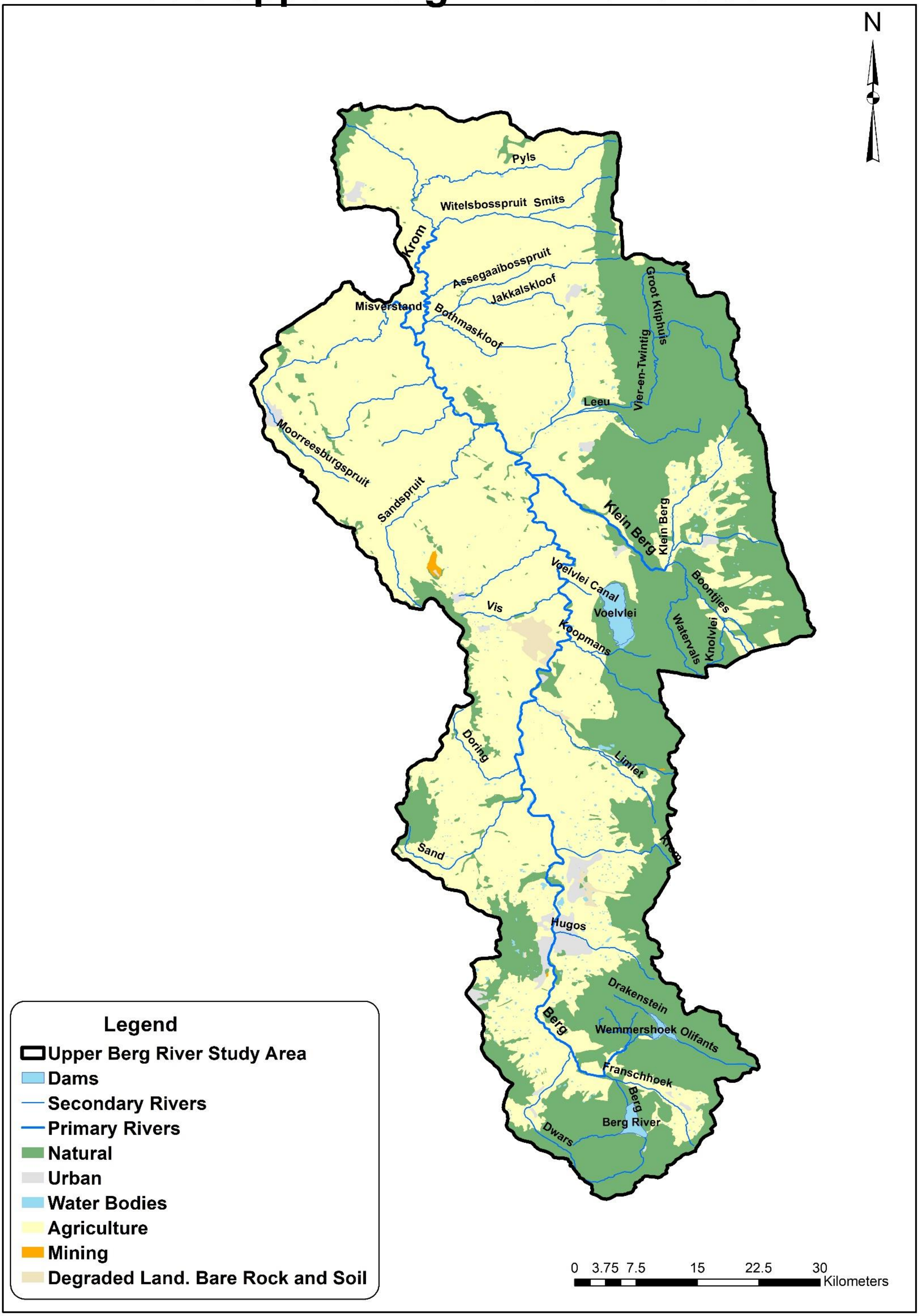
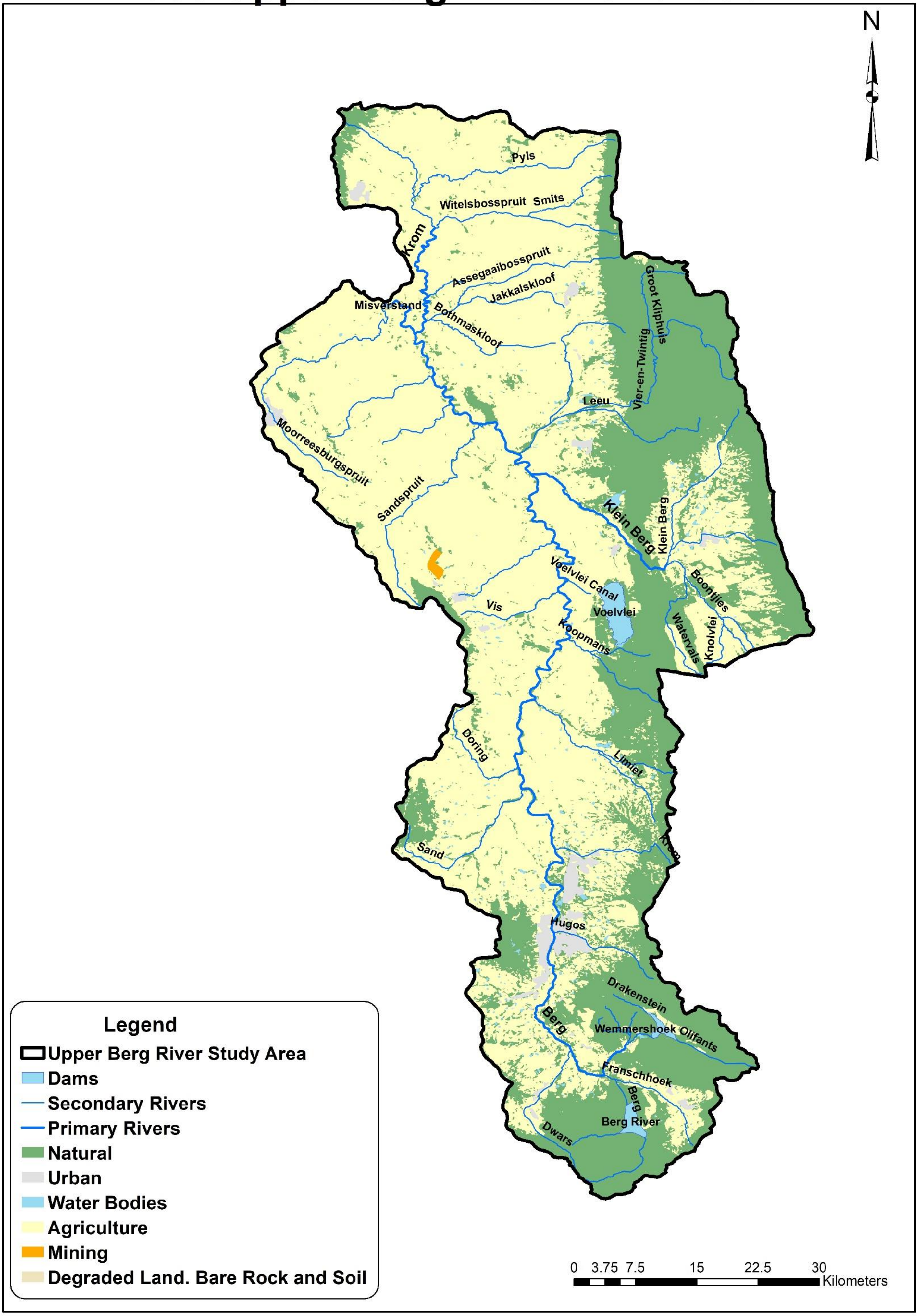
APPENDIX A – Land Use Maps of the upper Berg and Breede River catchments



1996 Upper Berg River Land Use



2000 Upper Berg River Land Use



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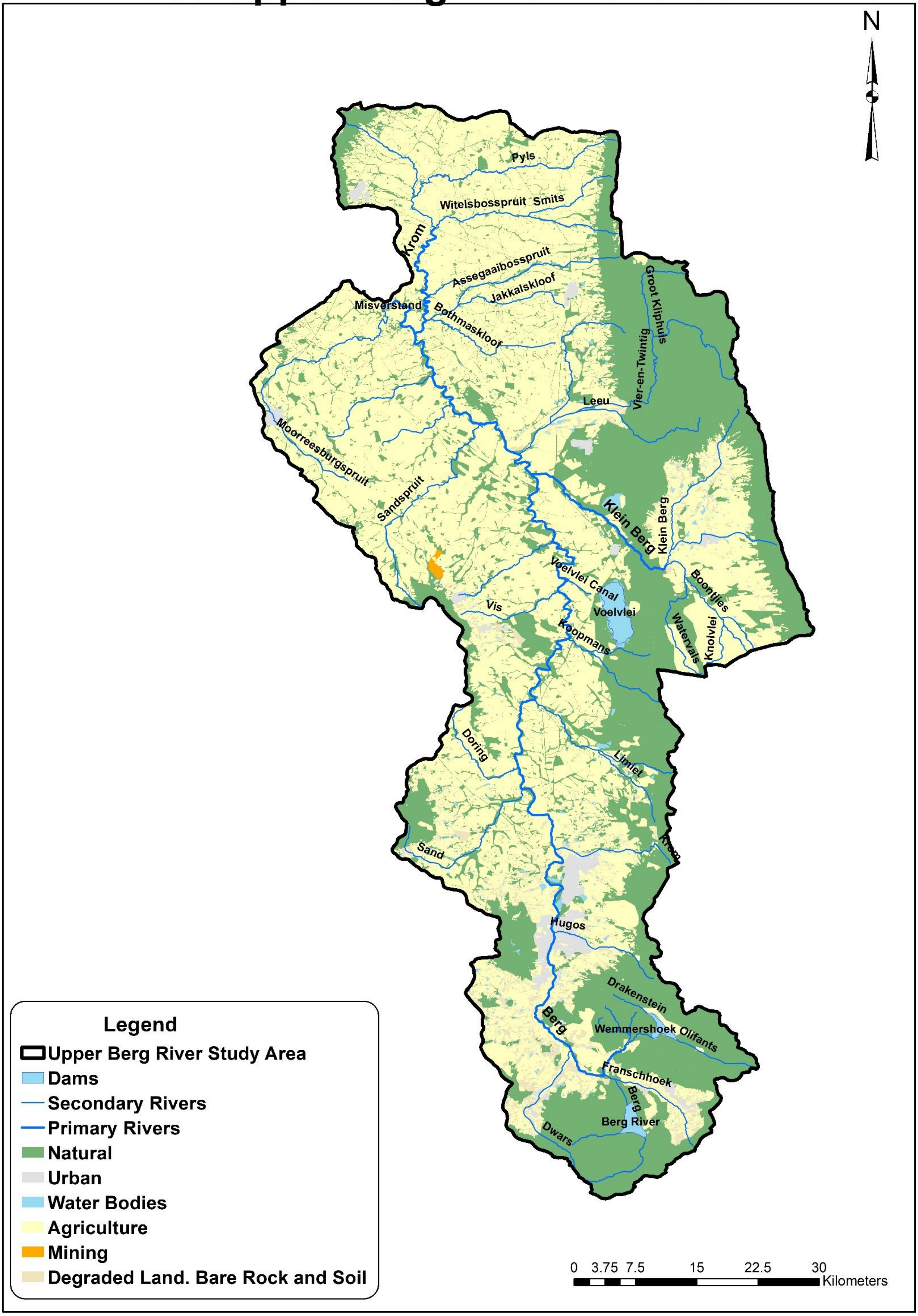
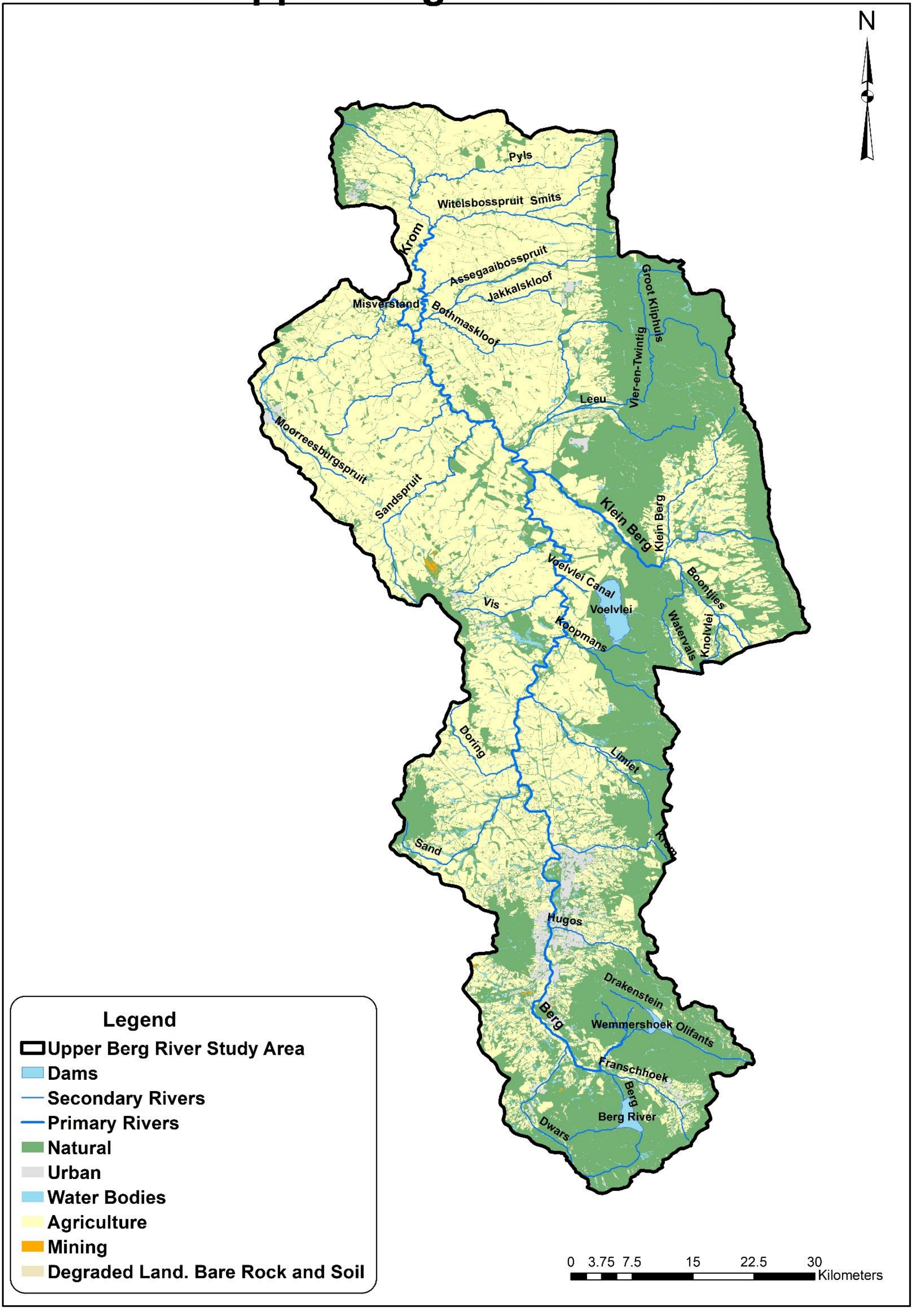
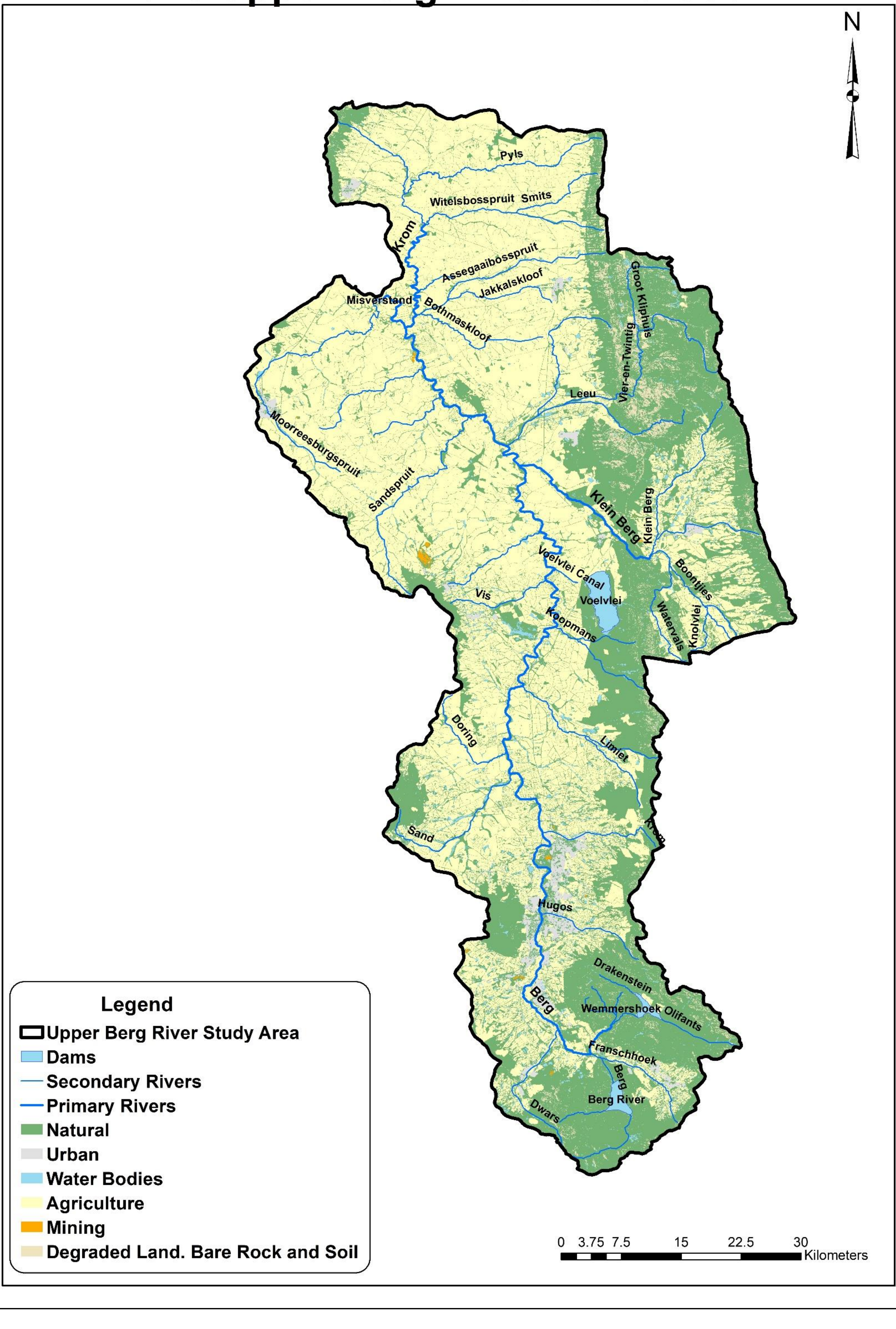


2013 Upper Berg River Land Use



2018 Upper Berg River Land Use



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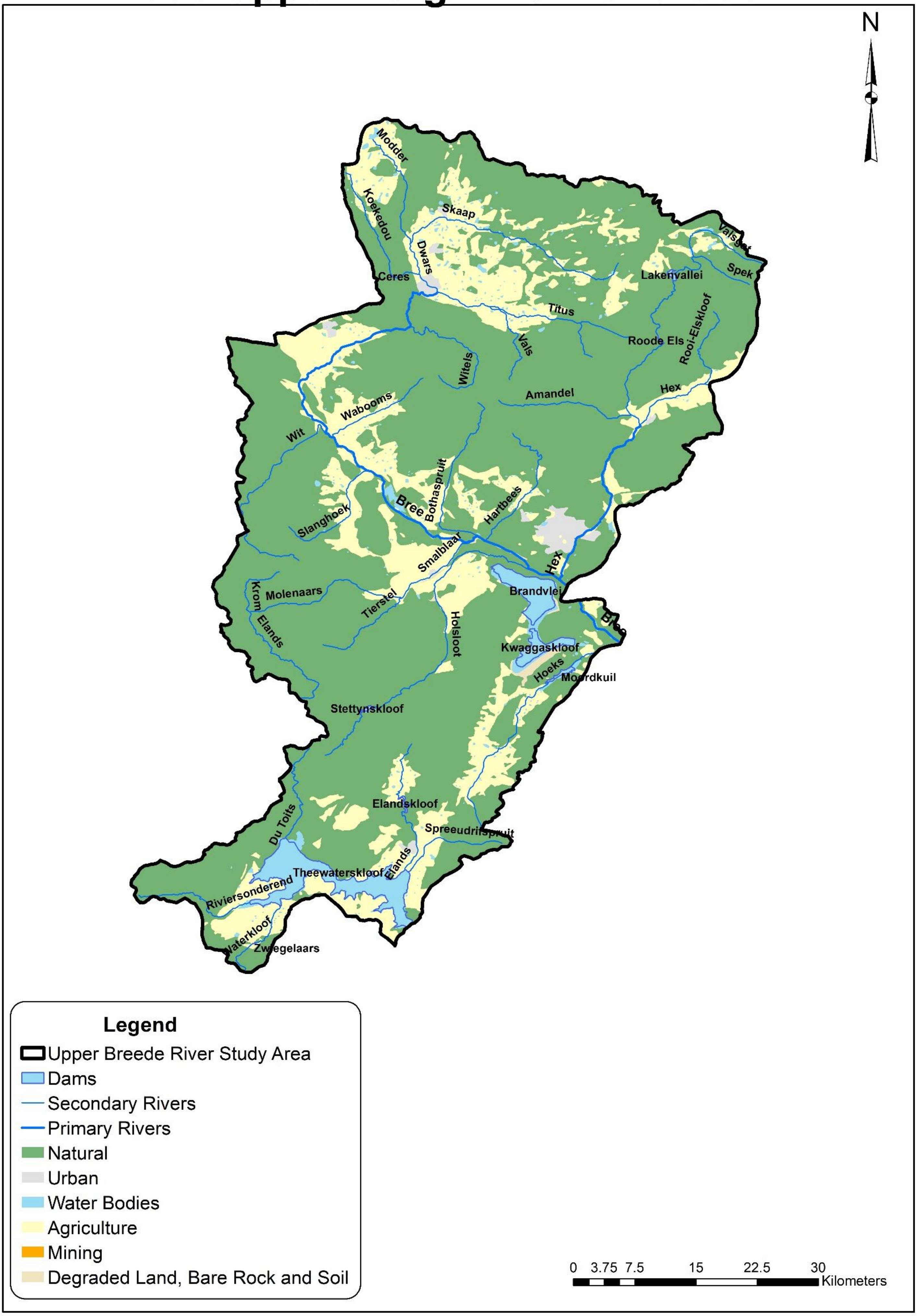

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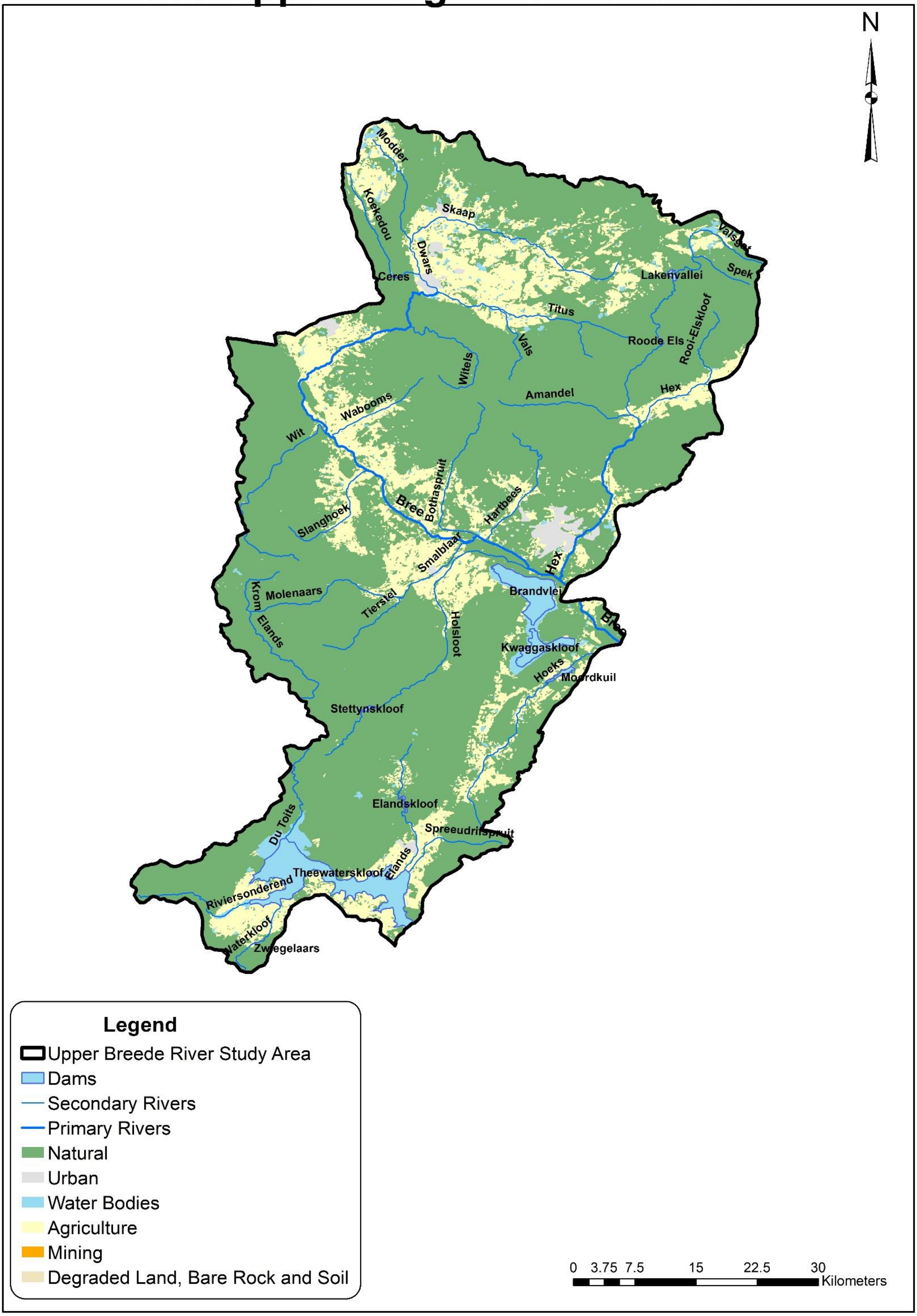

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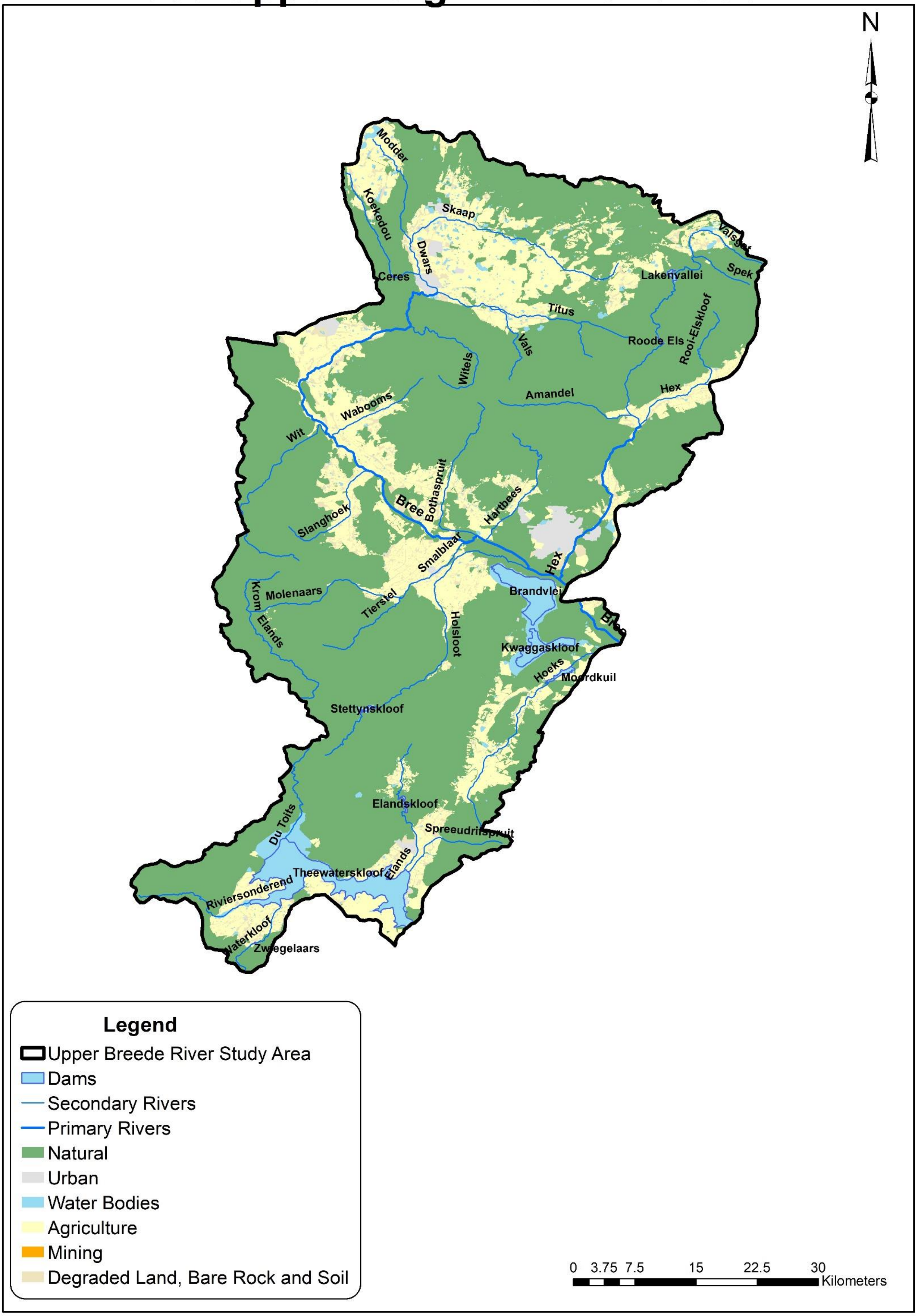

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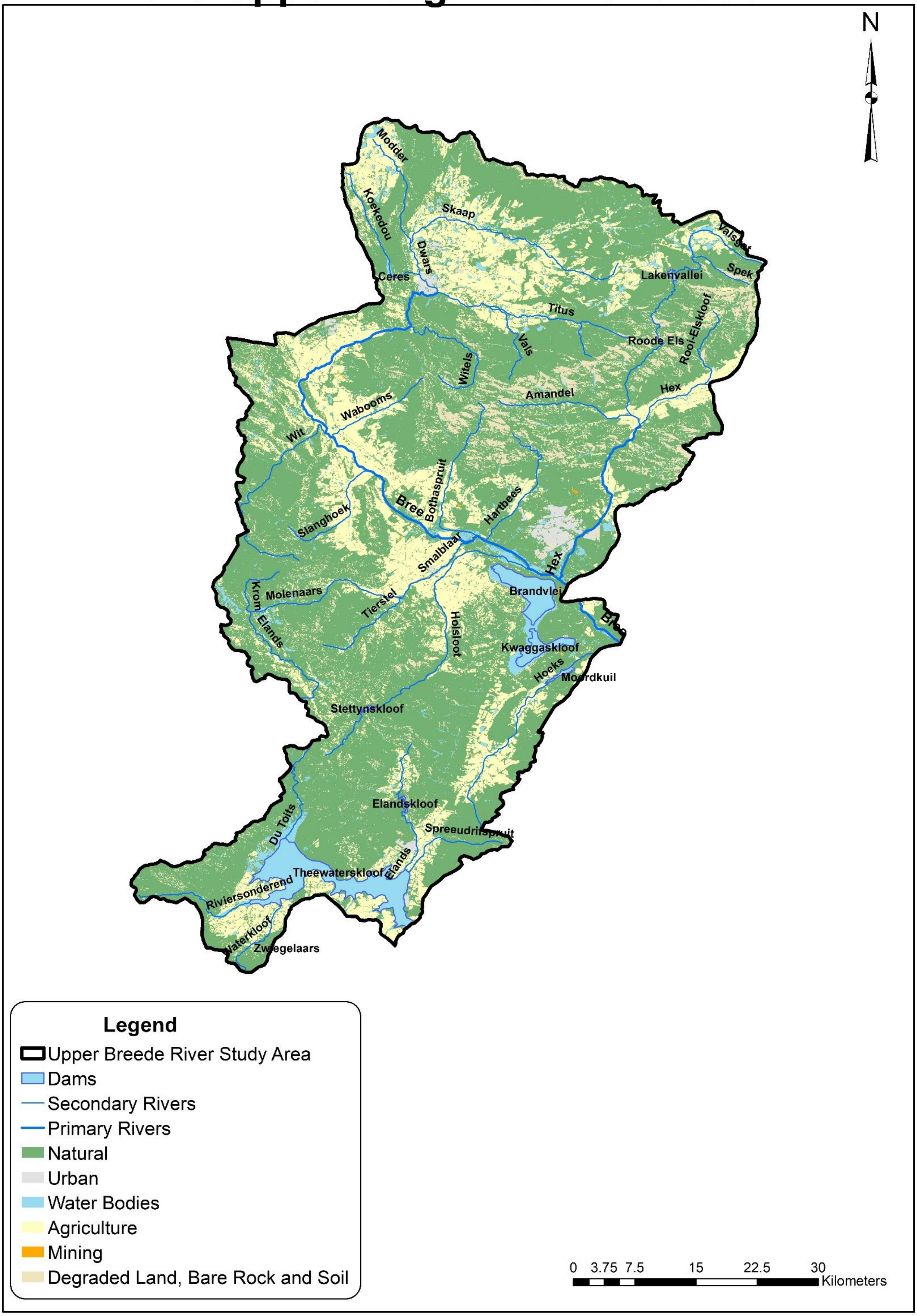

2018 Upper Berg River Land Use