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2014-07-31
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AN INVESTIGATION INTO PAN HYDROLOGY AND ECOLOGY IN THE MAKULEKE CONCESSION, NORTHERN KRUGER, SOUTH AFRICA



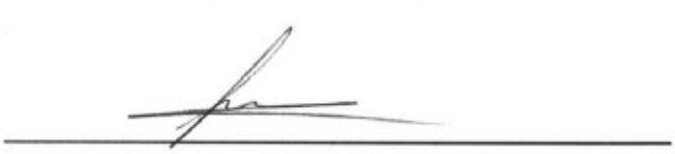
Kelly Paige Nesbitt

A Dissertation submitted to the Faculty of Science, University of the Witwatersrand, in the fulfilment of the requirement for the Degree of Master of Science

Johannesburg, April 2014

Declaration

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



(Signature of candidate)

20 April 2014 in Johannesburg

Abstract

This research was undertaken to assess the validity and applicability of the pan systems' current Ramsar classification. In areas of the Ramsar classification scheme where the classification was considered lacking, a regional classification was offered based on the fieldwork and lab work analysis. Physical variables such as soil moisture content, combustible organic carbon content and soil particle size distribution surrounding the pan systems were measured during the wet and dry periods of the fieldwork sampling. Aquatic invertebrates were selected for the study as they are known to be good indicators of ecosystem health. The macro aquatic invertebrates were sampled within the pan systems over the wet and the dry periods. The investigation showed that the pan systems supported mainly tolerant macro aquatic invertebrate species as expected, however sample sites Mapimbi and Nwambi due to their access to the water table were able to support sensitive aquatic invertebrate species. The use of these pan systems by the macro aquatic invertebrates was then compared to the water quality found within the pans. Water quality in the pans was affected by the types of inflow they received and how regularly this inflow occurred. The data for the physical and ecological assessment of the pan systems was then considered and related to the current use of the Ramsar classification scheme. The results showed that the current Ramsar classification scheme does not capture all of the ecological, water quality and morphological properties of the systems. The classification too does not allow for environmental changes within the systems. This research proposes a regional or localized classification scheme to be used in conjunction with the international Ramsar classification scheme. The combined use of the international and regional classifications allowed for the seven systems within the network of wetlands in the Makuleke area to be distinguished as individual systems with unique properties that can be defined locally and not conformed under an international umbrella-type classification scheme.

Key Words: Classification, Wetlands, Aquatic Invertebrates

Acknowledgements

Geography, "It has its feet in the ground and its head in the clouds"

Valerie Banks

Firstly I would like to thank the Wilderness Trust and Jennifer Lalley for providing me with this project and allowing me to do research in the beautiful Makuleke Concession.

I would also like to thank Jasper Knight for taking me and my Masters on at such a late stage into my studies. Thank you for the outstanding supervision throughout my time with you. Your patience and guidance was much appreciated, my thesis would not be at this level without your help.

Thank you to the examiners for the time they have spent reviewing my thesis and for the feedback that I received.

Mom, "I love you around the world and back," this is for you. I would not be where I am now if it were not for your love and support. You have always pushed me to be my best and this was something I never thought possible. Thank you for always being behind me mom. I love you.

Dad, thank you for all the love and support throughout my studies. Thank you for stepping up when I needed you most. I love you.

A special thank you to Avril and Steve, my Masters was just a thought before you both made this degree a reality. Thank you for providing me with the means to further my education and path in life.

To the Goodman family, thank you for all the support during that dark period, the help you all gave me will not be forgotten.

Gina Martin, Pafuri Fieldtrips trips would not have been Pafuri Fieldtrips trips without you. Thank you for all your help with fieldwork, lab work and emotional breakdowns. Our times spent lugging around heavy equipment, sorting through smelly samples, sweating at "death pan" and swearing at "thorn in foot pan" will not be forgotten.

Thank you to Romy Antrobus, Roxanne Pride, Clair Knight, Blair Zoghby and Miranda Muller for help in the fieldwork and lab work.

To my Geography girls, silly tea room chats, rants and raves, laughter, tears and support, all of it added to the specialness of these past three years, thank you all for the parts you played in my life.

My loving girlfriend, your support, patience and understanding over the years has been unwavering. You put up with the hysteria, the tantrums and the crying and you're still here. No words could express my gratitude. This Masters is mine, as much as it is yours. Thank you. Thank you. Thank you. I love you.

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Chapter 1 Introduction

Wetlands are important because they provide a habitat for plants and animals and are areas of high biodiversity (Davies and Day, 1998). They are valuable because they support vegetation, act as hydrological controls, collecting and releasing water slowly as well as allowing for the trapping of sediment and the removal of chemicals from this sediment (Fisher and Acreman, 2004). Wetlands have the ability to remove toxins from the water body namely organic pollutants, viruses and metals (Kotze and Breen, 1994). The vegetation found alongside and within the systems aids purification of the systems by their high rate of mineral uptake (Verhoeven, et al., 2006). Wetland "health" is very important as a number of species utilize these landscape features for either their entire life span or for a short period of time whilst passing through the area. The concept of wetland "health" can be defined as, "a measure of the natural or reference condition (Macfarlane, et al., 2008). Historically, wetland habitats have been and are still used extensively by humankind for agriculture, forestry, livestock grazing, water supply schemes, water abstraction and daily livelihoods (Grundling, 2000; Sliva, 2004). The Ramsar wetlands (study sites) are located within the Makuleke Concession in the Kruger National Park (KNP) however, are unique in that they are protected as Ramsar identified wetlands, although legal policy states they are protected they are still threatened by external hydrology impacts. This is because the two main rivers that support the wetland systems are not protected by legal policy or protection seen from a reserve boundary. Indirect affects like flood reduction, groundwater recharge and pollution to these two main river systems impact heavily on the protected Ramsar wetlands found in the northern part of the KNP, South Africa. The wetland/pan systems are important because they perform a variety of ecological services and provide unique habitats to a wide variety of biota (Töyrä et al. 2002). The present and future water quality of these systems is important as water quality affects the biota that utilizes these systems. Macfarlane et al. (2008) stated in the Wet-health report that there is no specific means for assessing the impacts of altered water quality on biota; however aquatic invertebrates are known to be used as bioindicators which may assist in assessing wetland "health." A bioindicator can be defined as, "a species or group of species that readily reflects the abiotic and biotic state of an environment, represents the impact of environmental change on a habitat, community, or ecosystem, or is indicative of the diversity of a subset of taxa, or of a wholesale diversity, within an area" p185 (McGeoch, 1998). All of the above mentioned components (hydrology, geomorphology, vegetation and water quality) are connected in the functioning of wetland systems as each of these components has the ability to influence the one another within the system. These components are therefore essential in assessing wetland classification schemes and their relevance.

Classification systems that define, sort and class these wetland systems are filled with inherent problems. The difficulty is in determining what is included (e.g. flow regime, vegetation, sediment water chemistry, semi or arid environments, man-made or natural) or excluded from the classification. Higher priority is also placed on individual variables depending on the researcher's purpose, often creating a bias in the classification. Previous wetland classification systems however, have based priority on hydrology or geomorphology (Brinson, 1993). These classification characteristics often differ from place to place, and are often incorrectly classed, as the same wetland type (differences in local vs. international terminology). Differences in wetland terminology across the globe vary greatly and often have very precise meanings, for example vlei, rybnik, lochan, valle, turf moor, hummock, rhyne, turlough, qa and jheel, to name a few (Scott and Jones, 1995a). These differences

and the inter-relationships between wetland ecology, hydrology and limnology of the local wetlands also impede wetland classification (Scott and Jones, 1995a).

Significant sites such as the Makuleke Ramsar wetland sites require a thorough review as these wetlands have been classified using the Ramsar wetland classification which is an internationally used wetland classification, and although it may talk to certain characteristics of the study sites it may overlook specific local attributes of the wetlands. This study will test the validity of the current Ramsar classification given to the Makuleke wetland areas and assess if there is not a site specific classification that may be developed to better classify each system within the area. The proposed local/regional classification systems will be used in conjunction with the Ramsar classification as it is an internationally recognised classification scheme. The sampling periods undertaken for this project are pre rainy season (November-Dry Period) and Post rainy season (March-Wet Period). These sample periods allow for contrasting understandings to be formulated about the study sites. A complete understanding of these periods and the changes that occur pre and post rainy season are of vital importance especially in the coming years of exposure to climate change and further river exploitations by human activity. Due to the scope of the project, 7 wetland/pan systems were selected along both the Luvuvhu and Limpopo Rivers respectively to sample the wide range of environmental types and water bodies within the region. The research is aimed at developing an additional classification scheme which can support the international classification scheme (Ramsar) by assessing the hydro-geomorphic properties with a local classification scheme to create a well rounded and more accurate understanding of the areas wetlands.

1.1 Threats to Wetlands

WWF (2012), considered the principal threats of wetlands to be the conversion from one form of habitat to another, therefore changing the status of the wetland and reduction in size, often resulting in the total demise of the wetland habitat. Conversion of these habitats is usually as a result of damming upstream, which leads to insufficient water, the inundation of water that a wetland cannot support, and pollution. Factors contributing to the pollution of wetlands are as a result of human activities upstream such as agricultural and the use of fertilizers and pesticides and industrial/ mining runoff which increases the amount of minerals found in the water. These types of changes upstream have damaging effects on wetland drainage and flood pulse ability due to the fact that these systems are highly dependent on hydrology. These conversions result in changes in structure of biota in the wetland and as a result the migratory species that visit the wetland. The dumping of pollutants into wetlands, or rivers that flood wetlands are harmful as it increases *Escherichia coli* and compounds such as phosphates and nitrates in the system (Mucina and Rutherford, 2006). In relation to pan systems, the increase of animals frequenting the water system also increases the organic matter levels. Alien invertebrates and vegetation species are also a threat to wetland areas as they are intensified by the above mentioned nutrients and can lead to increased vapour-transpiration from water and change the nutrient and oxygen levels in the water. Water extraction from aquifers is another threat to wetland systems today. This extraction can occur by means of 1) mining companies using the water in their plants to clean the minerals found and cool the plants down, 2) agricultural purposes to water crops or 3) domestic water extraction. Mining and agricultural practices are located along or next to the rivers which feed the wetland systems. Specifically the Limpopo River which also act as a border at the confluence of South Africa, Mozambique and Zimbabwe and as

a result is exposed to more pollution and abstraction than that of the Luvuvhu River which only flows through South Africa.

The IUCN Red List and the Nature Conservancy have stated that there are serious threats and degradation affecting inland water bodies worldwide (Darwall and Vié, 2005). South Africa's water resources are already under threat from destruction or alteration due to building, mining, agricultural activities and climate change. Climate change is an unknown variable in the determination of the exact threats it poses to wetlands. Literature has provided researchers with a basis for describing main wetland types, their status and major threats. As temperatures are said to increase, areas inland will become more arid as a result of less precipitation and may be destroyed by droughts as a result (WWF, 2012). The loss of biodiversity as a consequence of climate change and both reduction of a wetland area or the deterioration of a wetlands condition are highly variable geographically (Brinson and Malvarez, 2002). Another concern is that of an increase in flooding and storm surges resulting in low lying wetlands disappearing (Nicholls et al. 1999). This has led to further difficulty understanding the threats to these systems from climate change, where there is a lack of accuracy in inventories of wetlands and differences in classification systems. According to Lombard et al. (1997), the two most threatened ecosystems in South Africa are wetlands and vleis. The Makuleke concessions wetlands are classified as floodplain vlei type according to the Ramsar classification scheme.

1.2 Wetland Importance and Misconceptions

In 1971, the International Union for the Conservation of Nature (IUCN) started identifying wetlands of international importance. These sites are now known as Ramsar sites. For a wetland to be classified as a Ramsar site, the wetland must meet certain criteria. The criteria for this classification are as follows (Ramsar, 2009):

Table 1-1: Ramsar wetland criteria. The criterion in bold, holds relevance to the study sites' wetlands

Group A of the Criteria: Sites containing representative, rare or unique wetland types.

Criterion 1	**A wetland should be considered internationally important if it contains a representative, rare or unique example of a natural or near-natural wetland type found within the appropriate bio-geographic region.**

Group B of the Criteria: Sites of international importance for conserving biological diversity. (Criteria based on species and ecological communities)

Criterion 2	**A wetland should be considered internationally important if it supports vulnerable, endangered, critically endangered species or threatened ecological communities.**
Criterion 3	**A wetland should be considered internationally important if it supports populations of plant and/or animal species important for maintaining the biological diversity of a particular bio-geographic region.**
Criterion 4	**A wetland should be considered internationally important if it supports plant and/or animal species at a critical stage in their life cycles, or provides refuge during adverse**

	conditions. (Specific criteria based on water birds)
Criterion 5	**A wetland should be considered internationally important if it regularly supports 20,000 or more water birds.**
Criterion 6	**A wetland should be considered internationally important if it regularly supports 1% of the individuals in a population of one species or subspecies of water bird. (Specific criteria based on fish)**
Criterion 7	**A wetland should be considered internationally important if it supports a significant proportion of indigenous fish subspecies, species or families, life-history stages, species interactions and/or populations that are representative of wetland benefits and/or values and thereby contributes to global biological diversity.**
Criterion 8	**A wetland should be considered internationally important if it is an important source of food for fishes, spawning ground, nursery and/or migration path on which fish stocks, either within the wetland or elsewhere, depend. (Specific criteria based on other taxa)**
Criterion 9	**A wetland should be considered internationally important if it regularly supports 1% of the individuals in a population of one species or subspecies of wetland-dependent non-avian animal species.**

There are 20 Ramsar sites in South Africa (Ramsar, 2009). The wetlands investigated in this study are in the Kruger National Park (Makuleke Wetlands) and in a Ramsar site and have therefore been deemed of international environmental importance. The Makuleke wetlands were declared wetlands of importance on the 22/05/07, covering 7757 ha (Peace Parks Foundation, 2007). The Makuleke wetlands are a good example of a floodplain vlei. Prominent features include riverine forests, riparian floodplain forests, floodplain grasslands, river channels and seasonally inundated flood pans. These wetlands are important as they can provide a means for natural water quality improvement, flood protection, erosion control, natural products, recreation, aesthetic appreciation and ecological factors as discussed below (Ramsar, 2009).

The area is has the last remaining herd of Hippopotamus, east of Beit Bridge, which utilize Makwadzi pan. The area supports Red List Data species such as the Nile Crocodile (*Crocodylus niloticus*, CITES App. II; SA Red List Data: Vulnerable) and the African Python *(Python sebae*, CITES App. II; SA Red List Data: Vulnerable) and species such as the Aardwolf (*Proteles cristatus cristatus*) – (South African Red List: Rare), Brown hyena (*Hyaena brunnea*) - (South African Red List: Near-threatened), Serval (*Leptailurus serval*) - (South African Red List: Near-threatened), Leopard (*Panthera pardus*) – (South African Red List: Rare, CITES App. I) and African wild dog (*Lycaon pictus*) – (South African Red List: Endangered, EN), (IUCN, 2012; CITES, 2013). There are also critically endangered plant species found in the Makuleke area such as the cycad (*Encephalartos hirsutus*, CR). The area supports many species, some of which are known to have their home ranges within the Makuleke Concession. Few species have been reported to only utilize the areas around the wetlands. Species that show significant use of the Ramsar area are recognized below (Deacon, 2008). The rare samango monkey (*Cercopithecus mitis erythrarchus*), four toed elephant-shrew (*Petrodromus tetradactylus*) and African civet (*Civettictis civetta*) occur in the riparian areas along the Luvuvhu and Limpopo Rivers. Rare bird species such as

pygmy goose (*Nettapus auritus*), white crowned plover (*Vanellus albiceps*), and nesting white backed vultures (*Gyps africanus*) occur here, while the highest densities of pel's fishing owl (*Scotopelia peli*) in South Africa are found in the Luvuvhu River valley. The Böhm's (*Neafrapus boehmi*) and mottled spine tails – species of swift (*Telacanthura ussheri*), which are rare in South Africa occur along the lower reaches of the Ramsar site. This area also represents the south-western limits of the range of distribution for the Dune squeaker frog (*Artholeptis stenodactylus)*, and are the only records of their presence within the northern parts of South Africa. Other frogs that are associated with the area are the African bullfrog (*Pyxicephalus edulis*), the common River frog (*Rana angolensis*) and the Foam Nest frog (*Chiromantis xerampelina*). A number of species found in the Ramsar site are endemic to the area. Bats such as Rüppels bat (*Rhinolophus fumigatus*), Swinny's horseshoe bat (*Rhinolophus swinnyi*), the Madagascar large free-tailed bat (*Tadarida fulminans*) and Commerson's leaf-nosed bat (*Hipposideros commersoni*) are only known in the country from specimens collected in the areas neighbouring to, and constituting, the Ramsar site. The floodplain area and pans also support the breeding and feeding populations of many terrestrial and aquatic animals such as breeding aquatic birds. The pans act as a refuge for water dependent fauna such as Lowveld fish species, frogs and wading birds (many of these wading birds can be found at Makwadzi pan). Many rare species occurring here are, at some stage, connected or dependent on the wetland. The wetland or pan systems provide habitat for breeding fish. This takes place during the flooding season of the alluvial floodplains where migration into these areas and spawning occur. Fish that use these floodplains extensively are the small minnow species that utilize the inundated grass and overhang for shelter: Hamilton's barb (*Barbus afrohamiltoni)*, Straight fin barb (*Barbus paludinosus*) and East coast barb (*Barbus toppini)* (Deacon, 2008). Tiger fish (*Hydrocynus vittatus*) and Silver robber fish (*Micralestes acutidens* and *Brycinus imberi*) breed in the shallow backwaters and feed on the other fish and invertebrates present. Fish that prefer to breed in the shallower floodplains are: *Labeo rosae*, *L. congoro* and *L. ruddi*. Other pool fish such as *Schilbe intermedius* and *Synodontis zambezense* also make use of these still waters to feed and breed. If no annual flood event occurs, the floodplain pans become an important food source for piscivorous animals (fish eating animals) including large numbers of birds, mammals and reptiles. As a result of the above species/habitat interactions criteria 1,2,3,4 and 8 have been applied to the Makuleke Ramsar Site (Ramsar, 2009).

A temporary wetland can be defined as "A type of wetland in which water is present for only part of the year, usually during wet or rainy seasons" (The Groundwater Foundation, 2013). They are typically found in areas where water is scarce (semi-arid areas), and as a result wetland resource problems are more severe. Temporary wetlands experience intra and inter-annual fluctuations of their communities and ecosystem processes. For this reason temporary wetlands have been identified as biodiversity "hotspots" as they provide fundamental ecosystem services (Angeler, 2008). These temporary wetland systems (figures 1.1 and 1.2) are utilized seasonally by birds for many purposes such as breeding, feeding or resting whilst migrating and for many other different biotas from invertebrates, amphibians to mammals, fish and plants. Wetlands are the only places they can survive as the habitat is unique to their needs (Ramsar, 2009). These wetlands are generally present when and where the water table is high. As such, even when the large water body dissipates, the presence of groundwater, certain plant species, softer mud and surrounding eco-tones are utilized by other species making use of the wetlands. Ecotone areas are higher in diversity of biota relative to homogeneous habitat types (Riekerk and Wenner, n.d). Moreover, temporary systems' value is seen as less important than that of

permanent, larger ones and has led to these types of wetlands becoming threatened (Davies and Day, 1998). The ecology of temporary wetland systems is poorly studied and with increased disappearance of these systems it has become increasingly harder to understand them (Angeler, 2008). Minimal conservation efforts are made for temporary wetlands as their water is usually only present for certain periods of time in the year, namely the rainy seasons. Larger pans such as Etosha in Namibia and the Makgadikgadi pan system in Botswana are protected indirectly as they fall within national parks. There is a misconception that temporary wetlands are of less importance because they are not present year round or sometimes seasonally (Davies and Day, 1998). This has resulted from the lack of knowledge by non-environmental scientists not privy to wetland ecology and a lack of education on these systems.

Managing wetland ecosystems is difficult because the land they occupy is valuable to humans, often leading to them being physically damaged or completely destroyed. This can occur in a number of ways; land reclamation, farming, drainage of the fertile lands and construction of dams upstream (Department of Ecology State of Washington, 2011). Wetlands also provide humans with natural economic products such as fish, freshwater shrimps, soils, plants and timber (Anon, 2012). Therefore, stripping of these resources from the wetlands also leads to damage or destruction. Presently, conservation areas are selected based on the assumption that the area protects the native species, ecological communities, physical features, and ecosystems of an eco-region and the underlying ecological processes that sustain them (Groves, 2002). For the reasons above, freshwater biodiversity should be included in conservation areas as they are a vitally important part of the ecosystem and are highly endangered (Master et al., 1998). Wetlands have also been identified by the IUCN as being the third most vital life support systems on the planet (Dini, 1999).

Figures 1.1 and 1.2 below of Nwambi pan in the Makuleke region. Nwambi pan (figure 1.1) is an example of a permanent wetland in an arid area. However, the water body is still subject to natural, seasonal fluctuations in water the level, which allows the biota to adjust accordingly. However, figure 1.2 depicts Nwambi pan after periodic flooding over a few years. These large scale events have the ability to change the "original" wetland composition and current ecological functioning of the system. Flooding events of this nature have the ability to change topography, sediment composition, hydrology, water chemistry and ultimately the biota utilizing the permanent or temporary wetland. Flooding of this scale has the ability to disturb or destroy micro-habitats which affect the local biodiversity that utilize the body of water. These ecosystem and wetland system changes result in inadequately defined or classified systems due to the constant changes in the environment. As a result careful management of these sensitive systems is required.



Figure 1.1: Nwambi Pan at its normal water level in March 2011 (photographs are researchers own)

The above photograph taken during the fieldwork depicts a lower water level with hydrophytic vegetation that is exposed. Alongside the edges of the water body is riverine vegetation. The water within the pan is cloudy, indicating possible disturbed or suspended sediment.



Figure 1.2: Nwambi Pan after an irregular flood event (Anonymous, 2012)

The figure above depicts Nwambi pan after the flood event of 2012. Here no substrate or hydrophytic vegetation can be seen. The water is still however cloudy/muddy again indicating the pan is dominated by suspended sediment. The water level has increased substantially with no change seen in the riverine vegetation.

1.3 Benefits of Wetland Conservation

The natural benefits to humans and the environmental benefits associated with the preservation of wetlands are now beginning to be understood (Department of Ecology State of Washington, 2011). This has resulted in a better understanding of the negative effects humans are having on wetland systems. As a result, a move towards wetland conservation has been pursued (Davies and Day, 1998). Freshwater bodies support high species richness and diversity when compared to other habitats. According to Taylor et al. (1995), South Africa's wetlands in particular are the most physically and biologically diverse in the world and support multiple uses and ecological services. The value of wetlands and their international importance are because these habitats are vital for supporting ecosystems and, in particular, niche habitats for endangered or rare species. Commercial uses of wetlands include agriculture, dumping of waste and the development of infrastructure, damming of upstream rivers, water extraction and pollution. These types of uses can cause wetland loss or degradation (WWF, 2012). According to the Department of Environmental Affairs and Tourism (2006), South Africa is a water scares country. As a result there is a need for better water management of wetland habitats (Cross, 2011).

1.4 Classification and Wetlands

Limitations with the classification of wetlands begin with the definition or term given to the wetland system itself. Across the globe, many different terms and definitions are provided for wetlands, creating confusion (Cowardin and Golet, 1995). Cowardin and Golet (1995) and Pressey and Adam (1995) agree that a detailed classification of habitats may be extensive and may be even irrelevant to any one specific site, and state that wetland classification is inundated with problems as it is "an attempt to place artificial boundaries on natural continua" pp151(Cowardin and Golet, 1995). The multiplicity of definitions and terms for wetland systems may not cause confusion on a national level in terms of management and conservation, but internationally these differences may prove difficult (van der Valk and Finlayson, 1995). The Ramsar Classification System for Wetland Type "is used to varying degrees for a number of applications by over one hundred signatory countries to the Ramsar Convention," the Makuleke area is one of these signatories (Ramsar Convention Bureau, 1997). The overarching problem with this classification used is that the definition it uses to describe wetland types is based on the definition used for the U.S. wetlands and does not consider the climate of southern Africa. Little value is placed on constituents that make up its classification such as geomorphology and overall wetland functioning. Wetland functioning generally falls into three major categories, namely:

1. hydrological (the storage of surface water);
2. biogeochemical (the transport and removal of elements and compounds); and
3. the physical habitat (topography, depth of water, number and size of trees).

The inadequate use of classification schemes can lead to incorrect wetland inventories, incorrect management and inappropriate conservation methods for this unique area.

Classification has been described by Morant (1983) as a process by which similar objects are grouped and dissimilar objects are separated. Morant (1983) went on to say that it is primarily an information technique that brings order to our thinking and communication by systematically naming the objects being classified and showing the relationship among them. In theory, classification is very effective in simplifying large amounts of data and ordering it in a manner which the observer can understand the basic connections between variables. However, in systems such as that of wetlands, clear cut classification of variables into boxes easily neglects other relationships between variables in nature. In wetland classification there are many different approaches that have been taken by different groups on different scales for different reasons. The reason for these differences in classifications is that the constituents (vegetation, hydrology, biota, topography, soil composition etc.) that make up wetlands have been given different values or weightings depending on what is to be achieved out of the classification.

The classification of wetlands is complicated due to the fact that it provides both a quick and efficient solution to understanding wetland systems but it also confines these perpetually-fluctuating systems into a single group. By grouping similar objects and separating dissimilar ones, classification inadvertently excludes valuable aspects in individual wetland systems. Grouping similar objects assumes that all wetlands are the same and ignores associations between the classes within wetland classification. Understanding the limitations in the classification of wetlands is important as it allows one to examine how and why certain classification schemes, or components that make up different classifications schemes were chosen.

1.5 Why This Research is Being Completed

- This research is being completed to encourage the use of a local classification, like the National Wetland Classification Systems for South Africa (NWCS) discussed in section 2.2, to better understand the wetlands in the Makuleke Concession. The (NWCS) was chosen as this classification is adapted to the South African definition for a wetland and consequently better defines the local wetlands than the Ramsar wetland definition and classification system is able to (section 2.1.1).
- The literature component of this study considers the international classification assigned to the wetland/pan areas as well as the wetland classification provided on a local scale by the (NWCS)
- Selective classifications such as the Hydro-Geomorphic Method (HGM) by Arkansas (2001), classification of wetland deep-water habitats of the United States by Cowardin et al. (1979), Ramsar wetlands and classifications and wetland functioning ideas by Kim et al. (2006) have been assessed and provided the outline for the suggested local classification characteristics to follow when studying these systems. See Results and Discussion sections (chapter 6 and chapter 7) (Scott and Jones, 1995a; Frazier, 1999).
- The fieldwork portion of this study saw the following wetland characteristics being quantified: geology, hydrology, topography, soil composition, flood occurrences, gradient, orientation, pan depth and vegetation and environmental variables such as water chemistry, temperature, water depth, oxygen levels, total suspended solids (TSS), physical pan properties and salinity have been assessed to develop an overall understanding of ecological functioning of the study sites.
- By assessing these wetland characteristics, local or possibly site specific variability can be determined and used in conjunction with the Ramsar classification scheme.

Aquatic invertebrates were chosen as the selected biota for this project as they are well known for their sensitivity to changes in their environment (Davies and Day, 1998). This research will add to current knowledge of aquatic invertebrate distributions and how these are affected by their physical surroundings and the hydrology of the wetland/pan systems in which they are found. An assessment of their presence or absence and abundance according to site specific pan characteristics will also be completed. These differences in species could also be indicative of wetland characteristic differences. Sampling of the wetlands' aquatic invertebrates for this research will also aid databases in the KNP as there is limited research on the pan/aquatic invertebrate distributions in pans in the Makuleke area of the KNP. When considering bodies of water, it is important to establish their water source (surface or ground water, rainfall-fed). In terms of the KNP, the Limpopo and Luvuvhu Rivers flow through the KNP from outside the park boundaries. The sources of these rivers are important as their water's quality, which has the ability to affect aquatic invertebrates, is therefore determined by upstream activities. Understanding a systems different dynamics and overall ecological functioning (i.e. habitat and physical variables) are important for improved conservation efforts in Ramsar sites and associated protected areas. The framework of endorheic systems and thus pan dynamics, by Cowardin et al. (1979) and other associated classification literature, will be used to identify which environmental variables are best to assess pan ecosystems and characteristics. Different definitions and classification techniques of wetlands/pans will also be drawn on to assess previous variables used in the understanding of pan dynamics. This type of assessment will allow for a baseline understanding of the immediate wetland/pan dynamics and how these influence the chosen biota in this

study. The environmental variables component of this study allows for correlations to be made between biotic and abiotic variables within the environment.

The purpose of this research is to assess the validity of the current definitions and classifications used for the wetlands in the Makuleke region. To achieve this, a basic understanding of measurable wetland characteristics have been selected in the form of soil particle size distribution, combustible organic carbon, water chemistry, flood regimes, geology, topography and macro aquatic invertebrates to assess these systems functioning. The selected physical and ecological characteristics found in wetland/pan areas are known to have an effect on aquatic invertebrates (Clark and Samways, 1996). Freshwater conservation is very important and leads to the better management of these fragile resources. This evaluation of differences in definitions and classification schemes by assessing the current physical and ecological attributes will lead to better methods of classifying, inventory and in due course the correct management scheme and conservation of these wetland systems.

The proposed method for classifying the study areas in question (section 7.6) intends to use the data collected to describe the physiology and variability found within each of the wetland/pan systems. The reason for this approach is that the single classification provided for the network of wetland/pans within the Makuleke Ramsar site presents a great deal of variability. The aim of the research as a result is not to discard the Ramsar classification given to the wetland/pan areas but rather propose an additional method of classifying the systems. This method therefore allows for the proposed classification to be used in conjunction with the Ramsar classification initially provided and in addition provide a localized/regional understanding of the individual systems.

Chapter 2 Literature Review

2. Introduction

2.1 Types of Classification Systems

2.1.1 Definitions of Wetlands

Over the past 40 years, many papers have tried to define what a wetland is but none has developed an effective definition that adequately describes the wetland type. The manner in which wetlands have been classified could be the cause of this definition issue in the literature. Current definitions in literature trends are inclined to include "permanent lakes, small to large seasonal lakes, small to large areas of seasonally waterlogged soils, fluviatile systems, estuarine systems, and marine systems" (Semeniuk and Semeniuk, 1995, p. 104). Earlier literature had a tendency to focus only on lakes and water saturated basins. The classification of wetlands has been difficult because of differences in definitions and has therefore resulted in convenient categories (Davies and Day, 1998). For example, many wetlands being grouped into general categories, resulting in unique differences that separate these wetland systems being overlooked. These previous errors made in definitions and classification schemes have derived from previous study approaches that have been developed for river systems and a different scale (i.e. international vs. local) and herein lies the need to adapt relevant approaches to a collection of wetlands (Davis et al. 2001). The definitions below contain common factors such as the presence of water, unique soils that differ from adjacent uplands, and vegetation adapted to wet conditions (Mitsch and Gosselink, 1986). These common characteristics, selected by the researchers, are presumably more important in defining a wetland.

Below is a summarized list of the definitions currently being used by: researchers in different contexts, non-governmental organisations (NGO's) and environmental governmental departments worldwide.

1. A comprehensive definition for conservationists and scientists has been the U.S Fish and Wildlife Service definition. Here wetlands are described as 'the transitional zone between terrestrial and aquatic systems, where the water table is usually at or near the surface or the land is covered by shallow water' (Cowardin et al. 1979, cited in Aber et al. 2012, p. 16; Cowardin and Golet, 1995a, cited in Aber et al. 2012, p. 16). Attributes include, at least periodically, the land supports predominantly hydrophytes, the substrate is predominantly under drained hydric soils and the substrate is non-soil and is saturated with water or covered by shallow water at some time during the growing season of each year (Cowardin et al. 1979; Cowardin and Golet, 1995).

2. Ramsar (1971), articles 1.1 and 2.1, define wetlands for convention purposes as 'wetlands are areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish, or salt, including areas of marine water the depth of which at low tide does not exceed 6 m' (Department of Water Affairs and Forestry, 2004; Finlayson and Van der Valk, 1995, p. 186). This definition by itself is not suited to the endorheic systems in the Makuleke region. Although aspects of the definition remain true, reference to a marine system would not be appropriate,

as there are no immediate links to the ocean. Other systems mentioned in this definition are found in other settings.

3. A definition by the Directorate of Environmental Affairs in Namibia, which includes arid land, states that wetlands are 'the interfaces between aquatic and terrestrial ecosystems, whether permanent or ephemerally inundated with fresh or salt water' (Davies and Day, 1998: pp. 114 - 115). This definition does not include vegetation as a defining characteristic. This is most likely due to the climate in Namibia being arid, and as a result, this localized definition, excluding vegetation in and around wetlands, is suitable for this pan study as hydrophytic vegetation in the study areas pans is not a defining feature. The reference to salt water is again, not applicable for the Makuleke area. No reference is made to artificial wetlands (man-made) as well, which suits the sites pan systems as they are naturally occurring.

4. In South Africa, wetlands were defined in the National Water Act (no. 36, 1998) as 'land which is transitional between terrestrial and aquatic systems, where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil' (Ollis, et al., 2009, p. 6). This definition for South African wetlands is an adequate but broad definition. There are marine, estuarine, riverine, lacustrine, palustrine and endorheic wetland systems present around South Africa; this definition provided does not account for all the individual differences between these systems. Often, these differences in flow regime, chemistry, vegetation and topographical location or, position in the landscape etc. contribute to the development of different wetland systems entirely.

5. 'Wetlands occupy an intermediate position between truly terrestrial and aquatic ecosystems and therefore encompass a diverse array of habitats' (Cowardin and Golet, 1995b, cited in Finlayson and Van der Valk, 1995, p. 186; Gopal et al. 1990, cited in Finlayson and Van der Valk, 1995, p. 186; Pakarinen, 1995 cited in Finlayson and Van der Valk, 1995, p. 186; Scott and Jones, 1995b, cited in Finlayson and Van der Valk, 1995, p. 186). This base definition used by the aforementioned authors has merit in that it distinguishes between terrestrial and aquatic ecosystems, but there is no reference to the presence of water, vegetation and soils. This definition does not account for the transition zone or wetted buffer in between, which is vital in the fluctuating nature of the water levels in these systems, which will therefore change the size of the wetland. This may therefore become problematic during delineation and small-scale management. However acknowledging the wetland's ability to 'encompass a diverse array of habitats' may serve as a beneficial tool in the conservation and management of these systems, wetted area or transitional zone.

6. Hill (1978) and Semeniuk (1987, p. 105), described wetlands as 'the presence of hydrophilic vegetation typically adapted to life in areas inundated or saturated by water with the appropriate duration and frequency to promote that vegetation.' Although this definition and use of characteristics is very specific, it limits the type of wetlands it describes, as it does not include wetlands with no vegetation.

The location of the wetland in the landscape together with hydrology and flow regime are not explored enough to provide a holistic understanding of the wetland type being described.

7. Bates and Jackson (1980) and Semeniuk (1987, p. 105), defined wetlands as 'a general term for a group of wet habitats and included areas that are permanently wet and/or intermittently water covered, such as costal marshes, tidal swamps and flats and associated pools, soughs and bayous.' This type of definition does not account for isolated wetlands in the landscape, but rather focuses on a group of wetlands. Also the duration and frequency is not distinctly defined by, i.e. seasonality or cycles, and there is no mention of occurrence to vegetation or lack thereof. This type of large scale definition which encompasses many wetlands in close proximity to one another is beneficial for conservation purposes as many systems can collectively be managed and conserved. The definition includes both fresh and salt water, which is also good for conservation purposes, however in this instance; the salt water systems are not applicable.

8. Zoltai and Pollet (1983) and Semeniuk (1987, p. 105), defined wetlands as 'areas where wet soils are prevalent, having a water table near or above the mineral soil for most of the thawed season, supporting a hydrophilic vegetation, and pools of open water (<2m deep), including shallow open water.' Both the Bates and Jackson (1980) and Zoltai and Pollet (1983) definitions do not account for those areas that are temporarily flooded, but remain relatively well drained even during the growing season. However, many of the important defining characteristics such as hydrology, soils vegetation and depth are spoken for in this definition.

9. Semeniuk (1987, p. 105), adopted from the Wetlands Advisory Committee (1977), define a wetland as 'areas of seasonally, intermittently or permanently waterlogged soils or inundated land, whether natural or otherwise, fresh or saline.' Semeniuk's definition is on unifying features such as wetland landform and hydrology. This type of approach is useful in that it can be applied to all wetlands regardless of climate and vegetation types. Focused on the aforementioned unifying features provides a means to use a classification system such as the hydro-geomorphic classification to assess the physical, chemical and biological functions of wetlands (Brinson, 1993). Semeniuk's definition also allows for inundation zones which further distinguish wetland systems, namely permanently inundated, seasonally inundated or seasonally waterlogged by water table rise.

10. In the past, isolated wetlands have not been consistently defined. The National Research Council (1995) and Frohn et al. (2009, p. 931), defined an isolated wetland as 'a wetland not adjacent to a water body,' meaning the wetlands method of inundation is not because of flooding by rivers. Inconsistencies in definitions have resulted in tentative ideals about where the boundary of a wetland starts and ends, together with complex hydrological systems and methods of inundation and flow regime, isolated wetlands are still poorly understood. However, an 'isolated wetland' may be one way of assessing and deconstructing pan systems.

11. Tiner et al. (2002) and Frohn et al. (2009, p. 931), define isolated wetlands, in terms of their 'relationship to surface waters, as wetlands with no apparent surface water connection to perennial rivers and streams.' This definition has a heavy influence from topography and landscape position, but neglects to assess characteristics such as flow regime, vegetation presence or absence or soil saturation.

12. Frohn et al. (2009, p. 932), defined geographically isolated wetlands as 'wetlands that are completely surrounded by uplands, with no apparent connections to perennial surface waters.' It is evident that definitions for isolated wetland systems rely heavily on the geographical location and proximity to a river source or coastal wetlands. No mention in the definitions excludes sub-surface water, i.e. the presence of a high water table. The importance of vegetation type, soil saturation and flow regime also neglect this definition.

Many problems have arisen in the past from poor terminology, with generalisations causing confusion (Butcher, 2003). However, it is important to realise that there will be different forms of terminology according to terms of monitoring and assessment, and address these differences accordingly in the classification of systems. Definitions are developed and designed for different purposes, often based to what is being studied, or as a result of a particular outcome of a study, this has resulted in different definitions that are often incompatible and are confused in literature, and whilst developing classification systems and inventories. An alternative to a singular concise definition for wetlands may be a collection or assortment of definitions applicable to a study or classification type, and use relevant aspects of these to formulate an individual wetland concept with which a precise site-specific definition is developed.

2.1.2 Wetland Classification

Classifications are sought to facilitate simplifying, organising and understanding complex entities. It is important to remember that classifications are not natural, although 'natural' characteristics are used to pre-determine the criteria with which the classifications should be made (Eekhout et al. 1997). Figure 2.1 shows the current wetland classification types developed by Cowardin et al. (1979), with the addition of the endorheic system. The endorheic system was added to recognise the significant ecological role that pans play in the ecosystems of South Africa (Goudie and Thomas, 1985). The Cowardin et al. (1979) classification system is the most widely recognised classification scheme and has provided a basis for other classifications to be developed as a result.

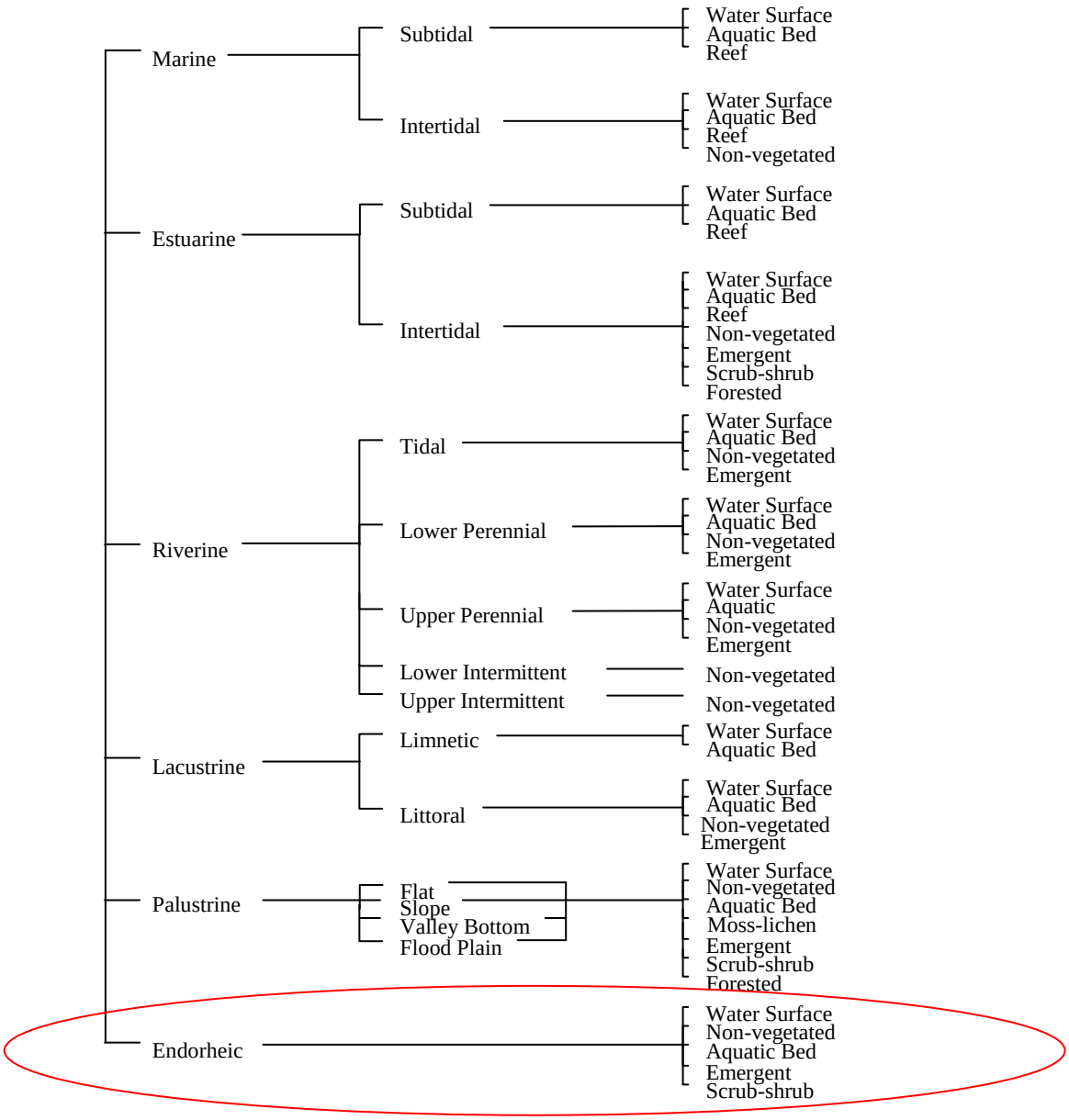


Figure 2.1: The proposed South African wetland classification system, to class level

This figure depicts the proposed South African wetland classification system, to class level (Dini et al. 1998). The system circled in red is the endorheic system, which, comprises of wetlands that would be otherwise classified as palustrine or lacustrine (Dini et al. 1998). This category consists of pan systems and it is therefore important to assess this method of classification to understand pans better. The systems characteristics are discussed below in this section.

Specific reference to the endorheic system in the proposed South African wetland classification system is made, which deals with inland depressions or pan systems that contain unique characteristics relating to physical and environmental determinants and ultimately the surrounding habitat. However, these classifications also show that some systems share similar geomorphology such as basin shape, depth, ability to hold water for periods and an unconsolidated sediment filled bottom. Systems sharing these similar properties are namely the riverine, palustrine, lacustrine and endorheic systems.

The way in which entities are classified is pre-determined by criteria followed when assessing the topic of interest. 'Grouping like with like' is the most common way to classify, whereby similar entities based on one or more criteria are grouped (Department of Water Affairs and Forestry, 2004). This idea gives rise to a further two methods of classification, 'bottom up' or 'top down' both of which are hierarchical in nature (Cowardin et al. 1979). If the researcher uses physical variables such as; climate, topography, geology and soils and relates them to scale, i.e. regional to local, a 'top down' approach would be used. These variables are often referred to as driving variables. In contrast, the 'bottom up' approach uses biotic and site-specific attributes and the advantage here is that biota can be more ecologically meaningful however data may be insufficient. These variables are also referred to as response variables (Eekhout et al. 1997). The Cowardin System structures the classification around what the wetland is, whereas previous wetland classifications structured classifications around what needs particular groups of users have (Dini et al. 1998). The Cowardin System follows the 'top down' method; this allows researchers to select the appropriate scale when using the classification. This method is effective for classifying pans but is less effective for lotic, or rapidly moving freshwater as lotic system variables will fluctuate more frequently and widely. A 'top down' approach is effective in a semi-arid area such as northern KNP because the pan systems in the Makuleke concession are closed systems, receiving less than 500 mm of rainfall annually. The physical/driving variables are known to the researcher and are measurable.

The introduction of the new classification group called the endorheic system was much needed, as the other two groups, palustrine and lacustrine, did not encapsulate what a pan ecosystem is comprised of individually, but allowed the ecosystem to fit in both groupings with no precise definition. In the new endorheic system, subsystems, namely hydrological features such as water permanence, closed drainage and water depth (less than 3 m when fully inundated) are key variables. For example, a pan with a shallow depth will have changes in evaporation with changing water permanence, depending on the season and how much rain has fallen. The physical composition (closed drainage basin) of a pan means that it can only be recharged when rains occur. These variables are important to this study as they indicate a different means of water loss as apposed to the marine, estuarine, riverine and lacustrine systems. At a system level, aspects such as hydrological, geomorphological, physical, chemical and biological features that pans share in common can be assessed and classified (Cowan, 1995). The endorheic system was not originally included in Cowardin's five wetland systems; however it is now included due to the recognition of the significant importance pans play in ecosystems (Goudie and Thomas, 1985). Wetland/pan or closed drainage basins contain common factors such as the presence of water, unique soils that differ from adjacent uplands and vegetation adapted to wet conditions (Mitsch and Gosselink, 1986). The Fish and Wildlife Service (see section 2.1.1 for definition) have produced the most comprehensive definition for conservationists and scientists alike.

Each wetland type is classified according to natural hydrological, geomorphological, and ecological characteristics (Department of Water Affairs and Forestry, 2004). Problematically, a wetland is difficult to define as it encompasses many different types of water bodies, including those which may hold no water. A basic definition for a wetland is, "a region in which the soils show evidence of water-logging" (Davies and Day, 1998: p. 105). However, definitions tend to vary according to scientists and researchers focusing on particular aspects of wetlands (see section 2.1.1). For example, riparian wetlands are found adjacent to a river and are influenced by fluctuations of the water level in the riparian zone (Mitsch and Gosselink, 1986). This particular

zone can be defined by the geomorphology of the river and slope, the nature of the substratum and its hydrological regime. This gives way to a longitudinal zone of vegetation parallel to the river, which makes up the riparian zone. The spatial extent of the zone is commonly open; this makes the wetland highly sensitive to changes that occur within the riparian landscape (Rogers, 1995). Rogers (1995), defines the riparian wetland area in South Africa as "open ended" (exorheic system), which, is adjacent to river and stream channels and where plant species distribution and growth is determined by at least intermittent soil saturation or inundation as a consequence of fluctuations in flow. Rogers (1995), further breaks down the riparian wetland into five categories; riparian fringes, riparian swamp forest, Karoo salt flats, floodplain vleis and storage floodplains. In addition to these categories, Rogers (1995), states that the Limpopo River contains a floodplain vlei and storage floodplain type and the Luvuvhu River the storage floodplain type. Floodplain vleis experience a short duration of flooding either annually or for a period of a few years. Storage floodplains, on the other hand, are seasonally flooded and retain standing water for periods between floods. According to the Wetlands Conservation Programme of the Department of Environmental Affairs and Tourism (DEAT), an endorheic system is defined as a wetland that would otherwise be classified as palustrine or lacustrine but contains additional characteristics such as circular to oval in shape, flat basin floor, less than 3m deep and a closed drainage system. These systems are commonly referred to as pans in South Africa and have irregular inundation (Cowardin et al., 1979). Seasonal inundations are common and water may remain for a long period, however water will ultimately drain from the basin or evaporate. Cowardin et al. (1979) originally named five wetland systems namely marine, estuarine, lacustrine, riverine and palustrine but did not include the endorheic system until later to accommodate a more accurate representation of the pan system. In South Africa, the classification system developed by Dini et al. (1998) is based on the Cowardin system, which recognises six wetland types illustrated in Figure 2.1. This classification system was developed as a means to categorize wetland types for researchers and environmental agencies alike and to develop inventories to better understand the water systems present and their purposes. With the use of Cowardin et al. (1979), "the user can envision what the wetland looks like" (Natural Resources Conservation Service: Technical Note No, 2008).

In 1980 it was recognised that there was a need for establishing a database to hold the information on the wetlands that had been declared of international importance. The database established by the Ramsar Convention Bureau developed their own wetland classification (depicted in figure 2.1) of wetland type aimed at standardising data gathered from the respective Ramsar sites (Scott and Jones, 1995a). The sites of national importance were chosen on three basic criteria; (a) the representative character or uniqueness of the site; (b) the value of the sites for threatened or endemic species of animals or plants and for the maintenance of biodiversity; and (c) the importance of the sites for populations of waterfowl (Scott and Jones, 1995a). Scott and Jones (1995a) suggest that the Ramsar classification adaptation of Cowardin et al. (1979) classification system is utilized globally as many contracting parties and international inventory projects accept it. The reason for this move to accept this classification is a need for simple classification. On a local/regional scale, Scott and Jones (1995a) state that they believe classifications should be as detailed as possible; however, the broader categories should still be compatible with the Ramsar classification scheme.

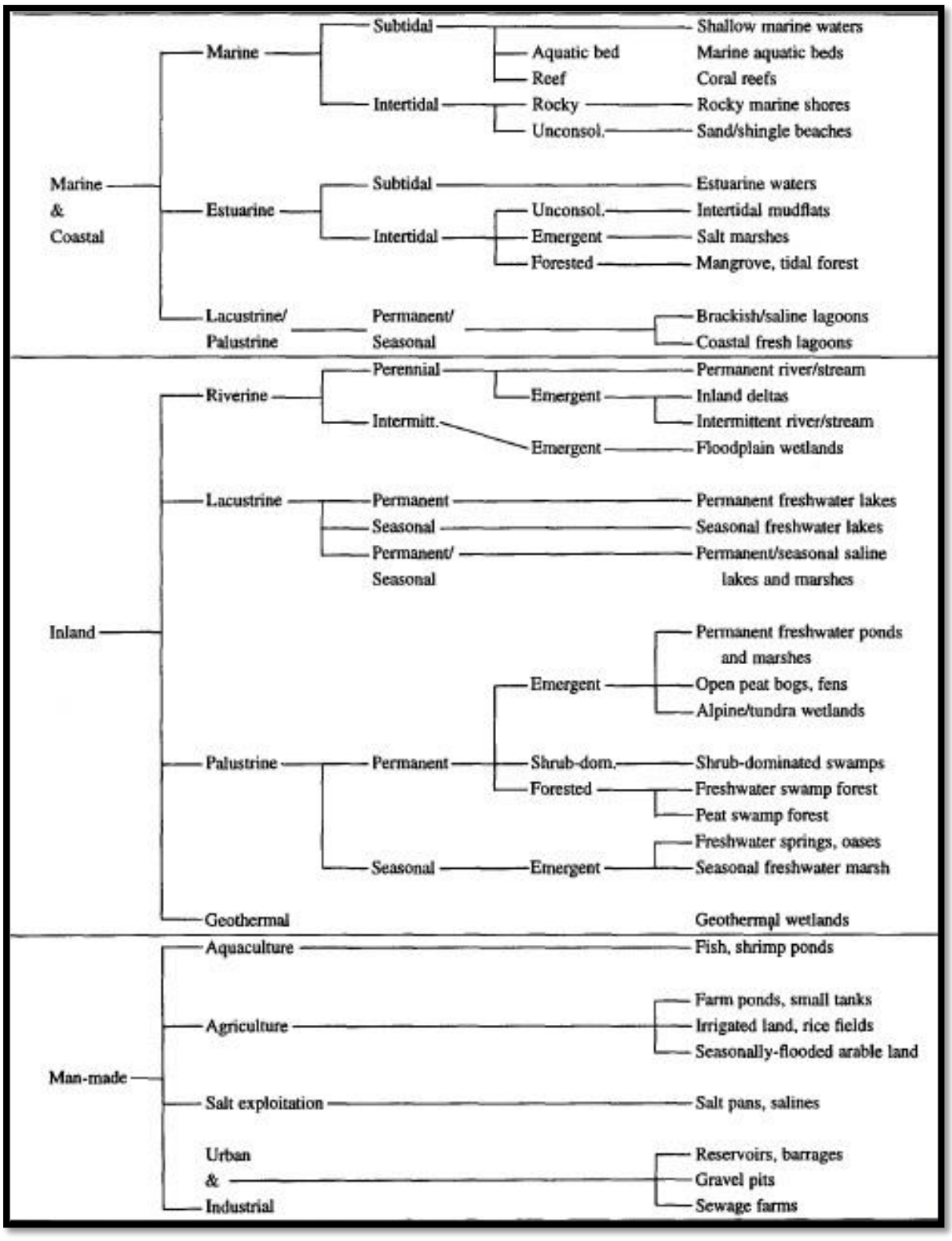


Figure 2.2: Wetland classification used by the Ramsar Convention Bureau

Figure 2.2 is based on the classification of wetlands and deep-water habitats of the United States (Cowardin et al. 1979). Pan systems are part of a new wetland classification called the endorheic system and are also known as internal drainage systems (Cowardin et al. 1979). This classification is because of wetlands that would otherwise be classified as palustrine or lacustrine but have additional characteristics (Cowardin et al. 1979). Certain features such as geographical position, size, geology and vegetation characterize the palustrine system

(figure 2.3). Specifically, a wetland is considered to be a palustrine system if it comprises of one of these three criteria (Cowardin et al. 1979):

1. Is considered a non-tidal wetland which is dominated by trees, shrubs, persistent emergent, mosses or lichens which are greater than 30% of the total surface area coverage
2. A tidal wetland with a salinity of less than 0.5 g/l, or
3. Wetland systems deficient in vegetation found in point 1 above, but are characterised by an area less than 8 ha, the depression's depth is less than 2 m in its deepest part at its low water mark, lacking in wave formed or bedrock shoreline features and a salinity of less than 0.5 g/l as a result of ocean derived salts.

Palustrine emergent wetlands are dominated by herbaceous vegetation. These types of wetlands may be flooded for short periods (weeks) or permanently flooded for the growing season. Differences in local hydrology affect the wetness of a palustrine system; this in turn affects the corresponding vegetation type. These systems occur in a number of places near a water source, namely parallel to rivers, in upland depressions and in seepage areas along slopes.

The palustrine system changes a system classification from a palustrine system to the endorheic system if a system has the above characteristics together with all of the following characteristics listed below: A fairly circular to oval shape which can be kidney-shaped or lobed, has a flat basin floor, a depth of less than 3 m deep when fully inundated, and has a closed drainage (Cowardin et al. 1979).

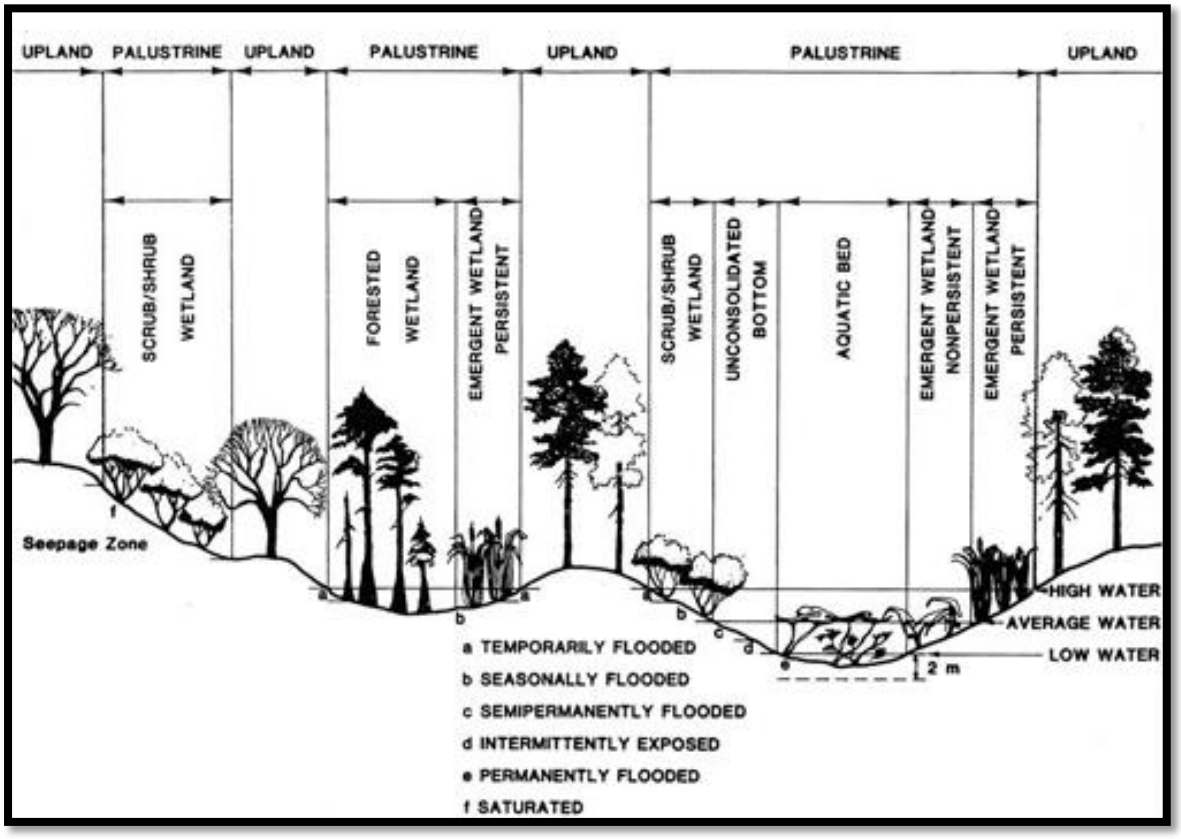


Figure 2.3: The palustrine system significance depicted according to its position during different flooding periods and the elements with which it is comprised. (US Fish and Wildlife Service, n.d.)

These systems are generally found on shoreward river channels, lakes or estuaries and on river floodplains and in isolated catchments. Lacustrine systems hold the following characteristics (Cowardin et al. 1979):

1. The system is found in a topographical depression,
2. The area is greater than 8 ha,
3. The surface area is covered by mosses and lichens, trees, shrubs and persistent emergent's which are less than 30 % of land cover.

This classification further includes smaller wetlands if they possess at least one of the following characteristics (Cowardin et al. 1979):

1. Water depth that exceeds 2 m in the deepest part of the basin, or has
2. A wave formed or bedrock feature makes up all or part of the boundary.

As above in the palustrine system characteristics: if the lacustrine system possesses its system distinguishing features and all of the above endorheic listed additional features, then the systems classification changes to fall within the endorheic system.

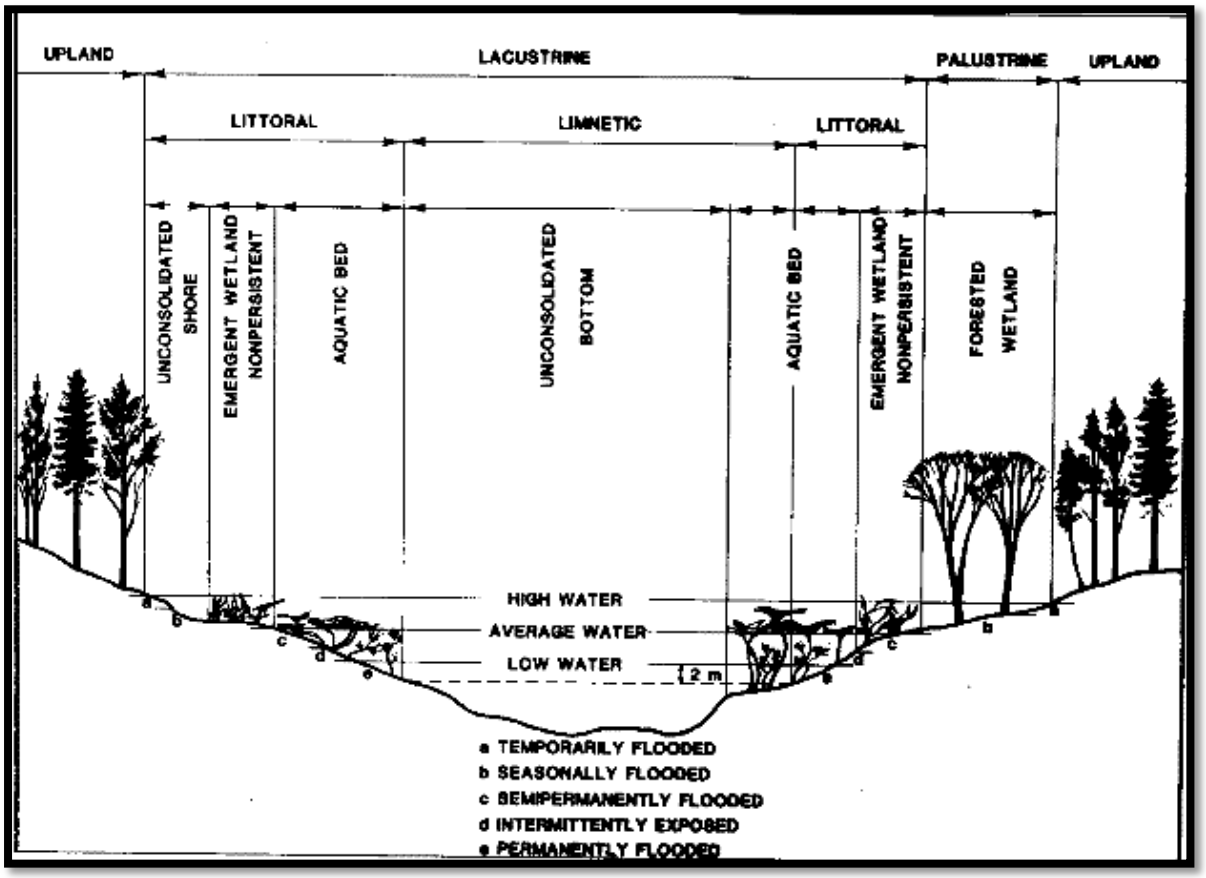


Figure 2.4: Distinguishing features and examples of habitats on the lacustrine system (National Wetland Inventory, n.d.)

Lacustrine systems can be found in areas of permanently flooded lakes or dams with waters that can be tidal or non-tidal with a salinity of less than 0.5g/l as seen in figure 2.4. Lacustrine systems can be broken down further into subsystems (Natural Resources Conservation Service: Technical Note No, 2008):

These systems include both wetlands and deep-water habitats with the following characteristics (Cowardin et al. 1979):

1. They are situated in a topographic depression or a dammed river channel
2. Lacking trees, shrubs, persistent emergent's, emergent mosses or lichens with greater than 30% coverage
3. Total area exceeds approximately 8 ha.

The catchments themselves are less than 8 ha in size and are included under this category if they have one of the following:

1. A wave formed or bedrock feature forms all or part of the shoreline boundary, or
2. The catchment has at low water a depth greater than 2m in the deepest part, or
3. These systems are situated in topographical depressions.

Palustrine, lacustrine and endorheic subsystems and classes can be seen in figure 2.1.

Endorheic systems are closed drainage basins that retain water, not allowing outflow to larger bodies of water, namely rivers and oceans. Water however, can be seen to flow out of these features on the earth's surface or by means of diffusion through infiltration of permeable rock. Water that has collected in the pan by precipitation or groundwater seepage is generally lost by evaporation or seepage (Ramberg and Wolski, 2008). The geology and geomorphology of internal drainage systems are very important. By understanding a system's geology one can interpret the region's vegetation, hydrology, microclimates and biomes. Pans are generally large enough to fill by means of their catchment during rainfall and are recharged when a flood occurs. Riparian wetlands are commonly associated with a pan system; as a result, many species rely on these pans for part of their life cycle and often for their existence (Naiman et al. 1995).

2.1.3 Problems with Wetland Definitions

The definition of a wetland is the most basic step in wetland classification, inventory, and management (Cowardin and Golet. 1995: p. 146).

Cowardin and Golet (1995), draw on four conceptual/practical problems within the definition of a wetland:

1. The moisture gradient in nature is continuous and obvious breaks along the continuum are seldom observed
2. Scale often makes it practically impossible to write a concise definition which, will cover all situations
3. While it is difficult to develop a sound definition for a wetland, it is more difficult to develop reasonable, practical rules for the application of the definition in the field
4. Although the definition of a wetland is a scientific matter, it also may be highly controversial because of land use or regulatory implications.

In the past, wetlands have been defined, or described, as being areas with waterlogged soils and dominated by hydrophilic vegetation (Mitsch and Gosselink, 1986). Early wetland definitions described wetlands to include a variety of types of soggy areas and as useless, mosquito-filled wastelands taking up valuable space for development (Mitsch and Gosselink, 1986). This misconception of wetlands being places of no use makes wetlands one of the most threatened ecosystem types, and losing them was thought to have no further impact on

the surrounding environment (Davies and Day, 1998). Since then however, much recognition of their importance has been noted with the Ramsar implementation. In South Africa specifically, wetlands are the fastest disappearing group of inland water systems as due to human activities making them vulnerable (Davies and Day, 1998). Semi-arid environments dominate South Africa and as such, water is a scarcity. Losses in wetlands are due to the incorrect or excessive extraction of groundwater for mining and farming activities and damming of rivers upstream. Losses also occur when a wetland become polluted and is no longer able to sustain or support life. An overarching issue, however, is that the world is currently facing global warming, causing normal climatic conditions experienced to change and become erratic.

Wetlands are commonly described in literature as being situated in between terrestrial and aquatic ecosystems. Therefore, any definition given to the upper or lower limits, in terms of gradient in a wetland, is an arbitrary boundary. This is because there is no precise way to classify these systems as they are constantly changing. Complications occur in regions of wetter or drier conditions experienced by the wetland. As a result, it is difficult to distinguish where to draw boundaries to state what is and is not classified as a wetland area. As a result, there has been a lack of concise definition, incoherent management, inventory and classification of wetlands. This problem was identified in section 2.1.3, as the classification of a pan system (endorheic system) was previously inadequately described and was also included in two all encompassing systems, the palustrine and lacustrine systems. This hierarchical classification system is effective on paper as it allows researchers to understand broadly a system that is studied but it also limits knowledge and understanding of the systems we are researching as it limits us to specific definitions and does not allow for the natural evolving of a system or changes due to anthropogenic means over time. This said it is possible that there is a problem with the way in which the classification systems are set out and applied to practical situations, rather than the classifications themselves.

There are many ways in which previous researchers have tried to categorize wetland areas, namely by using factors such as geology, soil-type, topography and climate (Brady and Weil, 2008; Stolt et al. 2000; Gertenbach, 1983; Winter, 2000). This study too utilizes aspects of these variables but incorporates other variables considered appropriate for the study site (section 5).

The aforementioned factors used in classifying wetlands prove to be complicated. Measuring these variables is difficult and time consuming. This is because, for any of the data used in determining its validity to be a part of a definition or classification, long-term monitoring must occur. Modifiers (i.e. water regime, soil type and water chemistry) are constantly changing in wetlands, this too, makes defining the systems difficult (Cowardin and Golet, 1995). Wetlands have specific functions, and are effective flood control agents, they store and release floodwaters slowly into channels, which, reduce flood peaks. They also act as filters, trapping pathogenic bacteria and sediments. Wetlands are some of the most productive areas on the planet, with the vegetation using the large quantities of carbon dioxide they produce for respiration. The biodiversity of wetlands is close to that of the tropical forests (Davies and Day, 1998).

2.2 National Wetland Classification Systems for South Africa

In 1999, Duthie, Harding, Kotze and Marneweck compiled the requirements for South African wetland ecosystems for the Department of Water Affairs and Forestry (DWAF). Dini et al. (1998), developed a classification based on the Cowardin system, here six wetlands are recognized: marine, estuarine, riverine, lacustrine, palustrine and endorheic. This system is included in the Wetland Reserve Determination Process (Duthie, 1999). This adaptation was derived from the generic Reserve Determination method, which was previously used for river systems. This classification was designed to address three wetland system types in Dini et al. (1998), namely: the lacustrine, palustrine and endorheic systems. The method was designed to identify the hydrodynamics of the wetland, i.e. groundwater or river influence. In other words, "the user can envision how the wetland works" (Natural Resources Conservation Service: Technical Note No, 2008). The importance of identifying the hydrodynamics of a wetland is so that researchers can understand that although wetlands may be unique, each can be placed into similar categories, sharing functional properties. These properties can be seen in the form of hydrological and geomorphic controls according to the Hydrogeomorphic Classification (HGM) system, which was originally developed for the US Army Corps of Engineers (Brinson, 1993). This classification method focuses on the abiotic features of wetlands. Kotze et al. (2004) adapted a simple system in wetlands for wetland inventory, it focused on the hydro-geomorphic determinants of wetlands, i.e. floodplain, valley bottom with channel, valley bottom without a channel, hillslope seepage feeding a stream, hillslope seepage not feeding a stream and depressions (including pan systems).

As stated in section 2.2.2, South Africa follows the Cowardin method of classification. The problem with this is that this system was developed for inventory purposes in the United States of America and as a result is difficult to implement and apply in South Africa. This method has also been found to be time consuming where resources are limited (Thompson et al. 2002). This is not ideal in South African classification terms because resources to develop a wetland classification system are limited (Scott and Jones, 1995a; Department of Water Affairs and Forestry, 2004). As a result, it is evident that there is a need for easier means and a more concise ways of classifying these pan systems.

In 2009, wetland classification for South Africa was again addressed, this time by the South African National Biodiversity Institute (SANBI). However, like other classification systems, it is broad and all encompassing, but it does provide insight into how wetland systems have been further defined in the country, for example, the Primary Discriminators and the Secondary Discriminators (figure 2.5). The proposed National Wetland Classification System (NWCS) follows the hydrogeomorphic (HGM) approach, therefore factors influencing wetland function, namely geomorphology and hydrology as fundamental features determining the presence of wetlands. The HGM process is said to be sound as a result (Ollis et al. 2009). Whereas the previous classification methods, such as the Cowardin approach, although relatively easy to identify wetlands from remote sources, it is a structurally based design resulting in an ineffective manner of grouping wetlands in terms of functional features. A flow diagram illustrating the proposed structure for the NWCS is shown in figure 2.5.

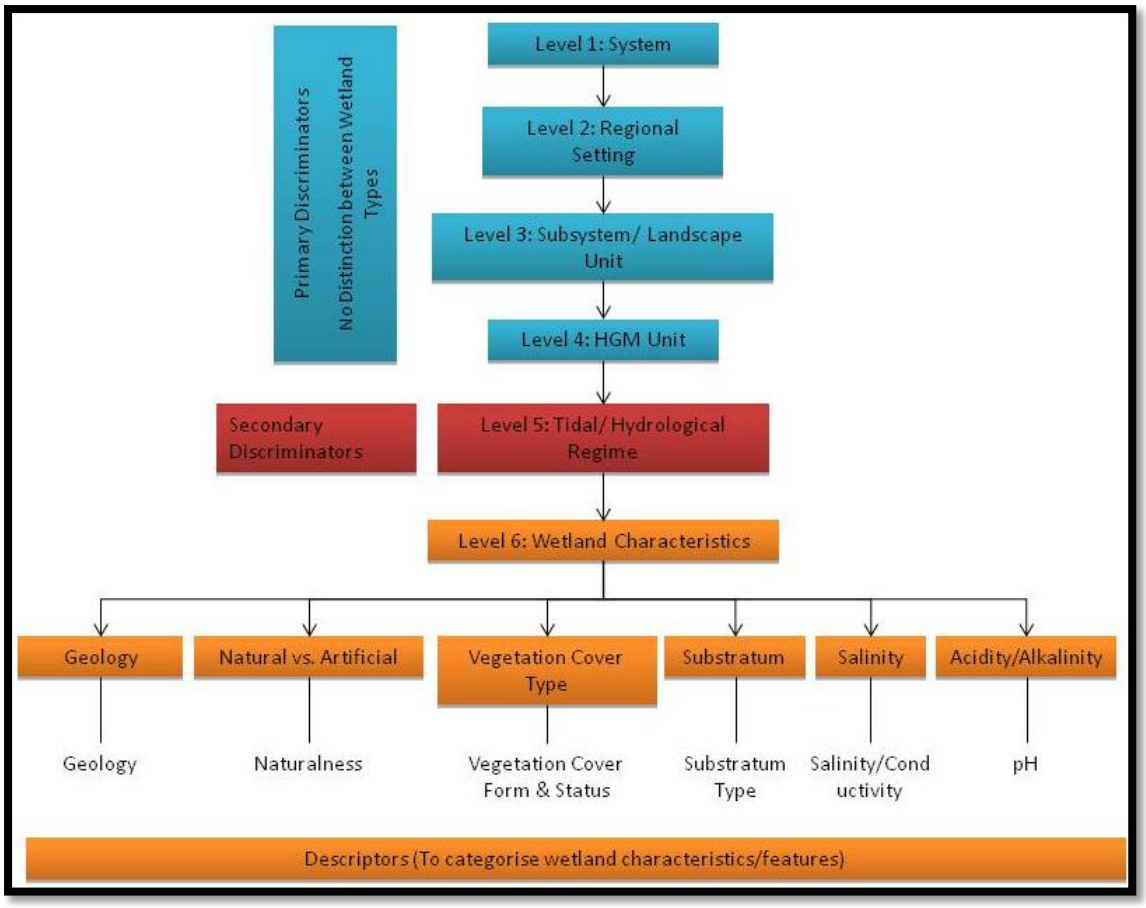


Figure 2.5: The basic structure of the proposed (NWCS) showing how 'primary discriminators'' are applied up to level 4 to classify Hydrogeomorphic (HGM) Units, with 'Secondary discriminators' applied at level 5 to classify the tidal/hydrological regime, and 'Descriptors' applied at level 6 to categorise the characteristics of wetlands classified up to level 5 (Ollis et al. 2009)

The NWCS has seven levels, as seen in figure 2.5; four levels are spatially orientated unit levels that follow the hierarchical method to distinguish different wetland types. This structure then progresses from a systems level at level one to hydrogeomorphic (HGM) units in a spatial scale at level four (Ollis et al. 2009). At a systems level (Level 1), the proposed classification system differentiates between the body of water and its connectivity to the open ocean, like in Cowardin et al. (1979), distinguishing between an estuary or endorheic system, for example. Level 2 in the classification is based on how the regional setting is characterised, for example, the eco-region, bio-region or bio-geographic zone. Level 3 in the proposed classification system deals with subsystems or landscape units such as its linkages to the ocean or if it is a system that is found to be bound by land (topography). Level 4 of the classification sees the secondary discriminators utilized. Here, HGM units are used to classify this level in the following manner: (a) the landform: which describes the shape and locality of the wetland, (b) the hydrological characteristics (movement of water in and out of the system), and (c) the hydrodynamics which assesses the strength of the water flow through the wetland. This level addresses geomorphological processes (erosion and deposition) and biochemical processes (Ollis et al. 2009). Level six in the classification breaks down a wetland's characteristics as the descriptors to categorise wetland features. Level 7 is the exact output from level 6's characteristics/features, i.e. Acidity/Alkalinity = pH (Ollis et al. 2009).

In summation, the Ramsar convention selects its wetlands of importance based on predetermined criteria (section 1.4); including ecology, botany, zoology, liminology and hydrology are selected. These sites that are determined of international Importance according to the convention are assigned the Ramsar classification system (section 2.1.2). Even though the Ramsar convention notes that there are a multitude of wetland types and that wetlands cannot be exclusively characterized as either one or the other. However, the Makuleke concessions wetlands have been given one classification type by the Ramsar convention of "floodplain vleitype", thereby blanketing the wetland/pan network of some 30/31 systems under the same classification type. This over arching classification type given to the systems may largely be as a result of the difficulty in delineating the wetlands as it is easier to count wetlands and/or their habitat types then it is to delineate wetlands. This study aims to further quantify the raw data collected to develop a more accurate understanding of the individual wetland/pan systems. Dugan (1990) stated that at the time of his paper there were over 50 separate wetland definitions in use even then. As a result the Ramsar convention has defined wetlands in the most global way as possible. This general/broad scope has resulted in the 5 basic systems previously discussed (lakes, rivers, swamps, estuaries and marine wetlands) in the Ramsar classification.

Scott and Jones (1995a, p15) suggest that, "regional, national and local classifications can and should be as detailed as is necessary or feasible. However, for ease of international exchange and transfer of information on key sites, it is preferable if the broader categories in such classifications are compatible with the Ramsar hierarchy." This suggestion proposed by Scott and Jones (1995a) to utilize a regional classification to obtain the required detail of a system is a better suited direction to be undertaken in the Makuleke concession where wetlands/pans are concerned. The hydrogeomorphic classification is a regional classification which focuses hydrodynamics and functional properties allowing for a bottom up approach to understanding individual systems.

As previously stated the proposed local/regional classification in this study suggests a way in which the systems can be further classified. The local classification is not a means to replace the Ramsar classification initially provided but simply to provide a further analysis of the individual systems and the systems are dynamic and complex. This research will show that these habitats can rarely be assigned exclusively to one system.

2.3. Pans

Pans are common geomorphic features in many semi-arid areas across the globe, including the Pampas of Argentina, the periphery of the Indus Plain in Pakistan, the High Plains of the USA, Pantanal of the Brazilian Mato Grosso, some parts of southern and western Australia and the western parts of southern Africa (Goudie and Thomas, 1985). In North America, pans or similar forming landscape features are referred to as geomorphological features called 'playa' (Neal, 1975). Worldwide these landscape features are commonly referred to as an 'inward drainage basin'. A 'pan' is a southern African vernacular term for a closed basin that collects rainwater (Cilliers and Bredenkamp, 2003). Pans are large, flat, sediment filled, deflated or eroded depressions that hold water after rain. These landscape features are circular to oval in shape, generally consist of a flat basin floor and are less than 3 m deep when full.

Pan features are predominantly found in arid and semi-arid areas of southern Africa. Their general development particularly in the Lake Chrissie area has been attributed to wind erosion, lack of vegetal cover, wind deposition

or biogenetic origins (Wellington, 1943). In South Africa, most pans occur on the arid side of the 500mm mean annual isohyets and 1000 mm free surface evaporation loss isoline (Goudie and Thomas, 1985). This is important because evaporation rates exceed the amount of rainfall this region receives. Areas included in this area are north of the Vaal River, Cape Province and the Free State (Grobler and Loock, n.d.). In Botswana, pans are abundant in the southern Kalahari with watersheds and dry river systems, which direct to the Makgadikgadi depression. There are over 1000 pans in this area, of which most are small and dry (Lancaster, 1978). An earlier study in this area completed by Laloy (1905) stated that the pans were due to animal action alone. Zimbabwe too hold pans, they can be found in a region of 600mm mean annual rainfall in the Matabeleland, but are prolific in Hwange National Park with an estimated 2449 of these features occurring (Goudie and Thomas, 1985). Noticeable features of these pans are that they rarely exceed 200m in diameter (Goudie and Thomas, 1985). In Zambia, pans are also referred to as "plains" and are found on the western Kalahari Sand. These geomorphic features occupy watershed locations and their size is relatively similar to that of South African/Botswana pans. Two types of pan systems are recognised, the first being an endorheic system or an inwardly draining drainage system and the second being floodplain pans (Davies and Day, 1998).

2.3.1 Pan Hydrology

Water systems are classified into two general groups according to Davies and Day (1998). These groups are lentic systems and lotic systems. Lentic systems are comprised of standing water bodies such as lakes, ponds, estuaries and some wetlands. Lotic systems are flowing systems, such as rivers, streams or floodplains. Southern Africa has an erratic rainfall pattern, which can lead to changes in systems. For example, a wetland can change from lentic to lotic and vice versa, or the systems can dry up all together until the next rains (Gerber and Gabriel, 2002). This results in different species being able to occupying different systems. Rivers are divided into three different zones, the headwater zone, middle zone and lower zone (Dallas and Day, 1993). This is a guideline, as river rejuvenation can occur causing a river's characteristics to resemble that of a headwater zone or middle zone. The lower zone is of interest as it is where the streambed of the river consists of mainly sand and silt. Here the water quality can often be poorer due to the collection of excess minerals from upstream tributaries. Leaching and weathering of rocks within the surrounding area, although both occurring naturally in the environment can result in additional minerals in the water increasing the concentrations that ecosystems are generally exposed to. These additional minerals in the water contribute to eutrophication. Algae are reliant on sunlight and low turbidity, where sunlight can penetrate the water column. The conditions in the lower zone provide adequate nutrient conditions, light, temperature and pH. These types of conditions may lead to increased algae levels (Gerber and Gabriel, 2002).

Marshall and Harmse (1992) concluded that there are three basic mechanisms with which a pan systems can develop; (a) suitable substratum (easily weathering rocks such as those of the Karoo Super group sediments), (b) disturbed drainage (induced either by tectonic or climate change processes), and (c) geological structure (including the presence of dolomite sills). However, the subtropical pans found in the Lowveld/Central Bushveld regions are said to be remnants of drainage systems that have not been functioning correctly, or systems that are no longer draining in historic times or have formed as a result of being on drainage lines of intermittent rivers. These systems are populated by hygrophytes and hydrophytes (Cook, 2004). Pan systems are particularly common in regions that receive a mean annual precipitation (MAP) exceeding 500-600mm. These

systems are able to develop due to shallow gradients and soils that remain wet without erosion from flowing water. They are characterised by the presence of alluvium, which is deposited because of flooding. These terraced formations are built of assorted sedimentary material and generally are located on slow flowing areas of rivers. Alluvium can undergo rebuilding by erosion of either old or new sediment (Mucina and Rutherford, 2006). Mucina and Rutherford (2006), state that alluvium has the capacity to support habitat development through the interplay of ecological factors such as 'temporary and spatial sedimentation-to-erosion rates, water sediment load, water chemistry and nutrient content, frequency and duration of flooding, soil texture and soil nutrient status etc'. Van Coller (1993) identified that vegetation on alluvium areas is primarily structured by environmental gradients depicting the habitat differences in a number of ways, for example, vertical, lateral and longitudinal. Vegetation change along elevated levels of the gradient is natural due to flooding frequencies. Pans are also known for their ability to support macrophytic vegetation on the water's surface or in the water column.

Pan systems are generally higher saline habitats than others wetland types. The concentration of salts accumulates in a number of different ways depending on the habitat. Some regions accumulate saline concentrations through prolonged dry periods, others from salt-bearing substrate, mineral rich groundwater aquifers or due to seepage to the surface. Concentrations are intensified by evaporation. When evaporation increases, salt accumulation increases on the bottom and surface of the water body. These conditions are favourable to the presence of halophytic vegetation types (sodium chloride tolerant). Pan vegetation is influenced not only by a soils mineral composition but is strongly controlled by the water regime. Differences in water regime between seasons have a direct affect on the germination and establishment of plant communities (Barrett et al. 2010). Factors such as, season, frequency, duration and depth of flooding and the period between flooding events contribute to variations seen in plant communities in floodplain wetlands (Blanch et al. 1999; Blanch et al 2000; Froend et al., 1993; Nielsen and Chick, 1997; Robertson et al., 2001). Playa-lakes of southern Spain such as the pans of southern Africa are either temporary or permanent and are disconnected from permanent river systems. These systems are said to be linked to the watershed as they are considered sinks for substances, which drain through the catchment (Rodriguez-Rodriguez, 2007).

2.3.2 Flow regime

Rivers flow from higher inland areas towards the sea. These rivers start out as springs or occur because of seepage, eventually joining up with tributaries and lead to estuaries (Gerber and Gabriel, 2002). These wetland areas eventually fill with silt and become dominated by emergent and terrestrial plant species local to the area (Gerber and Gabriel, 2002). Water sources such as rivers have different characteristics due to different geographical attributes. These differences are generally caused by; geology, geomorphology, climate, soils and human activities present in the catchment areas (Gerber and Gabriel, 2002).

The movement of surface and groundwater is largely controlled by the topography and the geological framework of the area. A wetlands location within this landscape is an important factor to consider when assessing a wetlands flow regime. The position of the wetland within the landscape is likely to determine how the wetland is recharged and how frequently (Webster, 2000). Kratz et al. (1997) and Soranno (1999) stated that wetland landscape position could be measured in three different ways. Each of these metrics addresses an aspect of hydrological connectivity:

1. The relative position of a wetland within a groundwater flow system
2. A wetlands landscape position concerning wetland connectivity along a linear chain through primarily surface flow systems (Soranno, 1999) and
3. Wetland order, which is often determined by the stream order of the outlet stream connection.

Not only is a wetlands location in the landscape important but the same is true for its hydrology. This is because in wetland or pan systems, hydrology is the mechanism behind sediment delivery, deposition and erosion (Cahoon et al., 2011). Hydrology also influences processes such as sediment flux and nutrient cycling (Heath and Plater, 2010). Pan sedimentation is dependent on the maintenance of water levels during the year as a function of floodwater input, precipitation, evaporation and groundwater influences (Turner and Plater, 2004). Pan systems that are entirely reliant on water influx during flood events tend to have higher minerogenic sediment. Irregular flow regimes in semi-arid areas tend to have a more severe impact on the hydrology and ecology of an area. Today, flow regime is greatly affected by anthropogenic influences, namely water abstraction, diversion and damming. Increased use of water for irrigation in agriculture upstream of pan systems reduces the total water supply downstream. The damming of rivers and diverting water creates an irregular flow regime downstream. This is particularly prevalent on the Zimbabwean side of the Limpopo River. Sub-tropical floodplains have highly variable and distinctly seasonal rainfall patterns (Grenfell et al. 2009). In this regard, the flow regime is essential because if the frequency and duration begin to change and the isolated water bodies do not receive the regular hydrological influx of water to create a heterogeneous environment and fill the pans, ecological effects will begin to be seen.

Changes in flow regime have the ability to drastically affect a stream bed's composition. A stream bed's composition according to Mackay and Eastburn (1990) is very important as a physical factor which controls the structure of freshwater invertebrate communities. The physical changes of the flow regime upstream also have an inherent effect on the chemical composition of the water column, which drastically affects invertebrate communities downstream. One way to assess the invertebrate communities found in a particular area is to break the systems down into biotopes. A biotope is considered to be, "the environment of a community of closely associated organisms" (Gerber and Gabriel, 2002). These biotope environments are defined in many ways, namely rocky areas, shallow areas, open water, vegetated, sandy or muddy (Dickens and Graham, 2002). The environmental gradients together with the aquatic biota that utilize them constitute fluvial systems (Ward, 1998).

2.3.2 Aquatic Macro Invertebrates and Aquatic Ecosystems

Freshwater invertebrates are described as animals that do not have backbones and that live parts of their lives in a freshwater biotope (Mackay and Eastburn, 1990). Invertebrate characteristics differ according to the adaptations they have developed to survive in their particular ecosystems. Some aquatic invertebrates prefer fast flowing waters in the mountains and others, the slower, flatter parts of the rivers downstream. As there are differences in biotopes, differences in types of invertebrates and their communities can be expected.

The biotopes present in river systems will be adapted to the pan systems where samples were taken. These biotype systems are riffles and runs, pools, aquatic vegetation, marginal vegetation and algae (Gerber and Gabriel, 2002). A pool can be defined as an area of a stream where it is deep or water flows slower, and an area

where the collection of water is not in the main stream (hollows in the bedrock) where the water is flowing. Aquatic vegetation consists of plants that live in the water and are fully or partially submerged. Marginal vegetation is the vegetation that is found at the water's edge, namely, reeds, grasses and sedges (Gerber and Gabriel, 2002). Algae are usually found in the warmer months as they require the sun and warmth to photosynthesis (Wetzel, 1983). They are more dominant where the water is nutrient rich as it accelerates their growth. Aquatic ecosystems should be seen as a resource base through which many uses can be provided, namely:

- The capacity of certain water bodies for self-purification of wastes,
- Providing an aesthetically pleasing environment,
- A resource used for recreation,
- Providing a sustainable livelihood to communities, depending on water bodies for a multitude of resources, and
- Maintain the biodiversity by providing habitats to biota dependent on aquatic ecosystems.

Aquatic ecosystems have been defined by the water quality guidelines (Department of Water Affairs and Forestry, 1996, p 8) as 'the abiotic (physical and chemical) and biotic components, habitats and ecological processes contained within rivers and their riparian zones, reservoirs lakes and wetlands and their fringing vegetation.' Terrestrial biota, other than humans dependent on aquatic ecosystems for their survival is included in this definition. The above definition includes three primary abiotic and biotic components which are sediments (bottom or suspended), water and the riparian zone. Aquatic species present are determined by their respective biotopes or preferred habitat. Biotopes for aquatic invertebrates are seen in the form of vegetated areas on the water's edge, a rocky area in the water, shallow warmer water, deep waters, algae covered water surfaces, algae covered substrate, open clear water, shady dirty water etc.

Aquatic invertebrate species are divided into five trophic groups, according to Merritt and Cummins (1996). The group and related characteristics are as follows:

- **Shredders:** These aquatic invertebrates have strong, sharp mouthparts which allows for the shredding and chewing of live or decomposing plant matter, e.g. caddisflies and stoneflies,
- **Collectors:** these aquatic invertebrates collect fine suspended sediment in the water column by utilising the hairs present on their bodies to filter the water, e.g. black fly larvae and mayflies
- **Scrapers:** Scrapers graze on the algae present on the surfaces of rocks and debris within the water column, e.g. caddisflies and mayflies,
- **Piercers:** Piercers are able to penetrate a plants tissue cells and suck the fluids from them, e.g. caddisflies,
- **Predators:** Predators prey on other living creatures either eating parts of the body whole, e.g. dragon flies, stoneflies and caddisflies or such as the piercers method, piercing the body of the aquatic invertebrate and sucking the tissue fluid out (Motta and Uieda, 2003).

Davies and Day (1998) provided a list for key taxa of invertebrates found in South African inland waters, the list is as follows; *Porifera* (sponges), *Bryozoa*, *Cnidaria*, *Mollusca* (snail), *Arthropoda* (crabs), *Annelida* (worm-like

authropods), *Platyhelminthes* (flat worms), *Nemertea* (ribbon worms), *Nematoda* (round worms), *Mematomorpha* (horsehair worms) and Odenata and Plecoptera (damselflies, dragonflies and stoneflies).

Aquatic ecosystems are complex systems, which include several species, habitats and processes. All of these are interlinked and interdependent which require management to keep these systems healthy if they are to be maintained in the future. The interlinked nature of the systems effects changes in water quality and can often be indirect. For example, the Flat-headed Mayfly prefers fast moving water, where water does not stagnate or collect high concentrations of chemicals. If running water were to cease and ultimately expose this species to the high chemical concentrations, it is likely that it will die. This in turn will affect those species, which would generally prey on their larvae or adults. Biological variables are used in bio-assessment and monitoring (Department of Water Affairs and Forestry, 2004). Aquatic invertebrates can be used in this sense as they are sensitive and show response to dissolved oxygen, sediment, metals, other toxins and organic enrichment. Managing and understanding cause and effect relationships within aquatic ecosystems is difficult as little is known about the exact effect water quality has on organisms. Current water quality guidelines have been extrapolated indirectly through known effects of water quality on a few organisms. Internationally, aquatic macro-invertebrates are commonly used variables in wetland assessment, but this is counter intuitive as there is high hydrological variability in wetlands over space and time (Department of Water Affairs and Forestry, 2004). It is difficult to improve poor water quality in a natural ecosystem context. This is because we cannot introduce chemicals into a natural system or park to reverse poor water quality as it may decrease water quality further. As a result, prevention is a better option in conservation rather than mitigation measures required to fix a problem.

Due to South Africa's semi-arid climate, fluctuations in water levels within the environment occur. The alteration of flow regimes has previously claimed to be the most serious threat to ecological sustainability or rivers and their associated floodplain wetlands (Naiman et al. 1995; Sparks, 1995; Lundqvist, 1998; Ward et al. 1999). The concepts raised with 'aquatic habitats and feeding or breeding grounds are gained or lost, as light, climate and wave impacts change to mention only a few phenomena' (Wantzen et al. 2008). Although flood pulse has been effectively studied in river systems, there is much data still lacking in wetland systems (Junk et al. 1989). It is, however, important to remember that water level fluctuations (WLF) are natural occurrences in nature and guarantee productivity and biodiversity. The exchange of water from a river to a cut-off water body aids nutrient recycling (Vannote et al. 1980). Extreme flood events, as discussed in chapter 1 (figures 1.1 and 1.2) have damaging effects on macro invertebrates (Wantzen et al. 2008). This is because changes occur with the water chemistry, temperature, soil composition and vegetation (Dienst and Ostendorp, 2004) within the pan. Many of the changes that the floodplain areas in Southern Africa are currently experiencing are attributed to a steady increase in anthropogenic pressures, for example, unsustainable water management practices and higher nutrient inputs due to upstream agriculture and urban development's, the consequence of these pressures is a reduction in biodiversity (Rouget et al. 2003).

2.4 Water Quality within Rivers and Pans

Pan chemistry has three main influences, hydrology, geomorphology and climate. Geology and soils of a catchment area are also highly influential on the type of chemical composition that is found in the pan or wetland area. Hydrology is influential in that the rivers act as a method of transportation of these minerals

within the upper catchment, downstream into the depression areas. Once minerals settle within the pan system, their concentrations can be greatly affected by extreme events such as flooding or drought. Extreme climatic events have the ability to influence the waters chemistry or quality. Pan systems in particular, due to their geographical location being in arid areas, are subject to high evaporation a rate, which increases the concentration levels of the water body. The opposite effect would be a flooding event, which has the ability to dilute the sensitive systems such as pans water chemistry or introduce more minerals depending what is transported within the river system (Burt and Pinay, 2005). As discussed previously in section 2.3.2, the flood pulse concept is a naturally occurring feature that does influence the nutrient content in pan systems. The floodplain and its features receive all classes of nutrients directly from the main channel (Junk et al. 1989). Junk et al. (1989), state that floodplain features, however, will establish their own cycles because of organisms and environmental conditions that influence biogeochemistry cycles which differ to those of the main channel.

The South African Water Quality Guidelines were developed as a result of the lack of generally accepted quality criteria for a South African application (Department of Water Affairs and Forestry, 1996). The Department of Water Affairs and Forestry (DWAF) has developed a set of water quality criteria for the preservation of fresh water ecosystems. It is hoped that the development of these guidelines will lead to the improvement and decision support tools needed to manage South Africa's water resources. Below is a summary of the DWAF water quality source.

2.4.1 Importance of Water Quality

According to DWAF water quality can be defined as "the physical, chemical, biological and aesthetic properties of water that determines its fitness for a variety of uses and for the protection of the health and integrity of aquatic ecosystems. Many of these properties are controlled or influenced by constituents that are either dissolved or suspended in water." Aquatic invertebrates that were found during the site visits for each pan system will be compared to the water quality of the system to determine if their presence or absence may be linked to the type of water quality found in each system during the sampling period. The species sensitivity to water pollution in the ecosystem according to the Department of Water Affairs and Forestry (1996), will be determined by a sensitivity scale provided. The rationale being, that if a highly sensitive species is present then the water quality is good, if there is a highly tolerant species present then the water quality is likely to be poor. The "sensitive species" chosen is selected by assuming that they are continuously exposed to a given water quality of an area and are sensitive to changes in their environment (Department of Water Affairs and Forestry, 1996). Water quality limits for aquatic ecosystems in South Africa are used to determine if the levels of mineral variables present in the pan systems are acceptable for the aquatic invertebrates to exist in. Water quality is important in pan systems because the most favourable water conditions will harbour a functioning ecosystem. These systems are sensitive to changes in water quality because they are prone to changes in system variables, which are likely to affect smaller aquatic organisms' respiration, reproduction and overall health. Wetland invertebrates differ from invertebrates found in streams, invertebrates found in wetlands are more tolerant of low dissolved oxygen concentrations (Department of Water Affairs and Forestry, 2004).

2.4.2 Water Quality Variables

The water quality categories types used in this study to asses the possible effects of water quality on aquatic invertebrates are: toxic metals, environmental variables, cations and anions.

Toxic metals

Toxic metals seldom occur in high concentrations in non-impacted systems. Examples of toxic metals: Al, As, Cd, Cu, F, Hg, Mn, NH_4. Organic metals: phenol and atrazine.

Environmental Variables

Total Suspended Solids (TSS). Total Suspended Solids (TSS) concentration is "a measure of the amount of material suspended in the water" (Department of Water Affairs and Forestry, 1996). Concentration of TSS increases with the discharge of sediment washed into rivers due to rainfall and the re-suspension of deposited sediments. When flow decreases, suspended solids settle at a rate depending on the particle size and water velocity.

Natural variations in TSS are governed by the geomorphology and hydrology in a particular area. The majority of rivers in South Africa have been found to become turbid during the rainy seasons according to the amount of recharge and disturbance the rivers experiences due to rainfall higher up in catchment areas, which fills tributaries and transports the sediment load down-stream. Changes in site specific levels of TSS can affect aquatic organisms by decreasing light penetration of the water and reducing photosynthesis, resulting in less food production, and suspended solids affecting macro organisms gill functioning and foraging ability due to visibility (Junk et al., 1989). Deposited sediment into pan systems does however; aid fertility of the entire system; but this is dependent on the sediment that is deposited. Ions flowing into the depressions are generally not toxic, however in large amounts can be (Department of Water Affairs and Forestry, 1996).

Nitrogen is an inorganic component that can be found in water naturally and as result of upstream fertilization of crops in agriculture. Ammonia and ammonium are both reduced forms of inorganic nitrogen. These can have toxic effects on aquatic organisms, as they are sensitive to these elements. Both forms can subsist as dissolved ions or can be absorbed onto suspended material. Changes in the amount of nitrogen in a system can affect the rate at which photosynthesis, respiration and transpiration processes occur in plants. An increase in nitrogen is of concern as it increases the growth of algae and aquatic plants. The surface runoff from a catchment area and animal excretion are the main sources of inorganic nitrogen entering the system. Types of bacteria have also been known to convert organic nitrogen into inorganic nitrogen during the decomposition phase of organic material. However, inorganic nitrogen is rarely found in natural conditions as it is rapidly taken up by aquatic plants and converted into proteins and other organic forms. High concentrations of inorganic nitrogen will create changes in the trophic status in water bodies.

Total Dissolved Solids. Non-toxic inorganic constituents can cause toxic effects in extreme concentrations but are usually 'system characteristics.' Their natural concentrations depend on localized geochemical, physical and hydrological processes. Total dissolved solids and total suspended solids (TSS) are measured constituents (Department of Water Affairs and Forestry, 1996).

Total dissolved solids concentration is defined by (Department of Water Affairs and Forestry, 1996) as 'a measure of the quantity of all compounds dissolved in water.' Total dissolved (TD) salts are 'a measure of the quality of all dissolved compounds in water that carry an electrical charge.' Total dissolved salts are directly proportional to the electrical conductivity (EC) of water. EC is used to test the ability of water to conduct an electrical current. Natural water bodies contain total dissolved salts in varying quantities depending on the surrounding minerals in rocks, soils and decomposing plant material. (Furch, 1984). Other dissolved nutrients such as phosphorous and nitrogen have been known to limit productivity within the water body (Fisher, 1979).

Gaseous compounds such as Carbon Dioxide (CO_2), Oxygen (O_2), Methane (CH_4), Hydrogen Sulphide (H_2S) and Nitrogen (N_2) are produced in floodplain areas under natural flood pulses (Junk et al., 1989). Over time, and with changes in temperature as discussed in section 2.4.2, concentrations are altered. Hydrogen sulphide found in the water body is a by-product of decomposition. This is usually attributed to decomposing organic material within the water body. High temperatures and rapid O_2 consumption result in CO_2 release near the bottom of the water column resulting in hypoxic and/or anoxic conditions (Schmidt 1973, Melack and Fisher, 1983, Junk et al., 1983). The presence of methane in water bodies is attributed to the large amount of animals that frequent such as pans to drink, cool down and take mud baths. Animals spend a large amount of time here, which lead to many animals defecating in the same area; much of this by product finds its way into the water. Nitrogen concentrations in the water column are due to the surrounding soils mineral composition. The above-mentioned gaseous compound concentrations change drastically between flood and dry periods.

Total Dissolved Salts. TD salts concentration depends on physical processes such as evaporation and rainfall. TD salt concentrations are generally found to be low in rainwater, low in well-leached soils and high because of evapo-concentrations. This is important because pan systems have a low rainfall rate but a high evaporation rate leading to increased salt concentration, which may affect aquatic organisms. Changes to the TD salts in site-specific levels will cause changes in ecosystem structure and function. This occurs, for example, when the chemical composition of the water is changed, which leads to either an increase or decrease of vegetation depending on its tolerance for higher salt content, thus affecting emergent vegetation. Changes in the concentration can affect aquatic organisms at three levels, namely: (1) effects on adaptations of individual species, (2) effects on community structure, and (3) microbial and ecological processes.

Environmental variables are critical as they regulate ecosystems processes such as spawning and migration. Biotas are generally adapted to natural seasonal cycles, which include changing water quality. Changes in frequency, amplitude and the duration of cycles of a particular exposure can cause major disruptions to the ecological and physiological functioning of aquatic organisms. Such variables also consist of temperature, pH, dissolved oxygen, total suspended solids/salts (TSS) and the non-toxic inorganic constituents being the total dissolved solids (Ollis et al. 2009).

Temperature. Temperature is defined as 'the condition of a body that determines the transfer of heat to, or from, other bodies' (Department of Water Affairs and Forestry, 1996). As temperature increases viscosity, surface tension, compressibility, specific heat, the ionization constant and the latent heat of vaporization decrease, whereas thermal conductivity as vapour pressure increase. The solubility of the following gases H_2, N_2, CO_2, and O_2 decrease with increasing temperature (Department of Water Affairs and Forestry, 1996).

Temperature is one of many factors that play an important role in water as it affects the rates of the above chemical reactions, and thus the metabolic rates of organisms. Temperature may also result in the distribution of aquatic organisms. Organisms use the variation in temperature due to seasonal cycles to initiate their natural activities such as emergence, spawning and migrations. In South Africa, inland temperatures generally range from 5-30°C. Water temperature is influenced by relative contribution of ground water and rate of the discharge, climatic factors such as air temperature, cloud cover, wind speed, vapour pressure and precipitation events, and structural characteristics of a catchment area, its topographical features, water volume, depth and vegetation cover. Higher temperatures decrease the concentration of dissolved O_2 in water thus decreasing its overall concentration available to aquatic organisms. The water body can also be affected by both spatial and temporal variability. Spatial variables consist of geographic differences, temperature differences with depth and longitudinal differences. Temporal variability consists of daily differences, rapid rates of temperature range and seasonal differences (Department of Water Affairs and Forestry, 1996).

Hamilton (2010) stated that the most important effects temperature change has in aquatic ecosystems is changes in aquatic thermal and hydrological regimes. Higher temperatures affect the rate at which mineral weathering and solubility occurs, which affects the waters chemistry. Abnormal increases in temperature also contribute to the spread of invasive species as they are able to expand the areas they can exist in. Increases in abnormal temperatures have the ability to affect aquatic organisms in the following ways; biological limitations (enzyme denaturation), loss in membrane function and increased growth efficiency (Talling and Lemoalle, 1998). Exposure to rapid increases in temperature can result in reductions/shifts in biotic composition and diversity.

pH. The pH value is defined as ‘a measure of the hydrogen ion activity in a water sample’ (Department of Water Affairs and Forestry, 1996). Surface water has been found to have a typical pH value of between 4 and 11 and is usually controlled by atmospheric conditions and geological influences. Specifically, South African surface waters have a relative pH value of approximately 6–8. pH varies according to diurnal and seasonality fluctuations. Seasonal variability is linked to the hydrological cycle and diurnal fluctuations can occur in productive systems where rates of respiration and photosynthesis vary over a 24-hour period, because photosynthesis changes the carbonate/bicarbonate equilibrium by removing CO_2 from the water source. These fluctuations can vary from below 6 to above 10 within a 24 hour period (Department of Water Affairs and Forestry, 1996). pH is greatly affected by temperature, inorganic concentrations, biological activity and organic ions. In fresh water pH is known to decrease by 0.1 of a unit with an increase of 2°C. The pH of a water source has the ability to change the toxicity of metals in the aquatic environment. Metals that can thus be harmful to aquatic ecosystems in this case are silver, aluminium, cadmium, cobalt, copper, mercury, manganese, nickel, lead and zinc (Department of Water Affairs and Forestry, 1996). Certain pH levels have the ability to dissolve these minerals, which have biogeochemical implications for pan systems (White and Blum, 1995).

The above-mentioned variables are also subject to the possible effects of climate change. According to Hamilton (2010), who makes use of a diagram developed by Poff et al. (1997), in which the ways climate change is hypothesised to affect riverine and floodplain biochemistry. The hydrological regime indicates the following; ecological disequilibrium, geomorphological disequilibrium, sediment fluxes, fire regime, salinity stress, increases in pressure to develop water supplies and transport limited elemental fluxes (Poff et al. 1997; Hamilton, 2010).

Target Water Quality Range (TWQR)

Target Water Quality Range (TWQR) is defined as 'the range of concentrations or levels within which no measurable adverse effects are expected on the health of aquatic ecosystems, and should therefore ensure their protection; these ranges assume life-long exposure' (Department of Water Affairs and Forestry, 1996). TWQR is used as a management tool, not as a water quality criterion. The two values that measure this are the chronic effect value (CEV) and the acute effect value (AEV). Chronic effect value (CEV) is defined as 'that concentration or level of constituent at which there is expected to be a significant probability of measurable chronic effects to up to 5% of the species in the aquatic community. If such chronic effects persist for some time and/or occur frequently, they can lead to the eventual death of individuals and disappearance of sensitive species from the aquatic ecosystems' (Department of Water Affairs and Forestry, 1996). This can have an immense impact on aquatic ecosystems as all components of ecosystems are related. It is important to remember that even if concentrations are below CEV there is still a risk that the more sensitive organisms will be affected. If CEV is exceeded, chronic effects will be widespread, therefore increasing the acute effects (Department of Water Affairs and Forestry, 1996). The Acute Effect Value (AEV) is defined as 'that concentration or level of ions above which there is expected to be a significant probability of acute toxic effects up to 5% of the species in the aquatic community'. If such acute effects persist or occur at too high a frequency, they can quickly cause the death and disappearance of sensitive species or communities from aquatic ecosystems' (Department of Water Affairs and Forestry, 1996) . This type of exposure, even over short periods can have a negative effect on the health of aquatic ecosystems (Department of Water Affairs and Forestry, 1996).

Water quality is strongly linked to the hydrological regimes and sediment composition of an area. Changes in the discharge patterns of the rivers and flood regime may enhance sediment fluxes within the system. Abnormal sediment fluxes affect the natural geochemistry within the water body. Natural sediment fluxes within the water body are important mechanisms with which nutrients are received and maintained. Due to the nature of pan systems and their location within arid areas, higher salinity is experienced by systems. Changes in salinity can cause shifts in biotic production and composition. By assessing floodplain landscape features such as pans, it is evident that there is a diversity of habitats, each with different physical and chemical conditions. These diverse habitats support diverse biotic communities, 'they may act as either a sink, or as a source with respect to each nutrient, depending on the circumstances' (Junk et al. 1989). Water and its quality are extraordinarily important for pan systems. This is because pan systems are sensitive environments and are susceptible to changes in water chemistry. Water chemistry influences water quality and therefore effects the environment. Underlying geology of the pan systems gives rise to the soil types that are found in the pans. The soil types, by the nature of its composition, give rise to the type of water chemistry in a specific pan. The soil types then generate certain plant species that also have an effect on the water's quality. The type of aquatic environment that is created by the physical composition of the pan, and the environmental variables, determines the types of organisms that live in the pan and utilise its water at some point in their life cycle.

The quality or health of the surrounding rivers and ground water aquifer is significant because it has a knock-on effect with surrounding ecosystems and the organisms utilizing it. Pans also play a part in bio-geochemical cycling and storage whereby transforming ions and breaking down organic compounds. Due to pan systems being closed systems, they are highly susceptible to changes in the environment. Seasonal inundations influence

water quality, vegetation and sediment patterns experienced by the pans. It is essential to remember that the organisms themselves have the ability to affect and change water quality and, as a result, be adversely affected themselves. Climate Change is also affecting the hydrological driving variables of systems, which in turn affects the saturation of soils and presence of hydrophytes. As a result of these physical and environmental variables and their interactions, it is evident that pan systems are vulnerable systems together with the biotic and abiotic relationships present, particularly in semi-arid areas such as the study area. Their vulnerability as a system, therefore inadvertently makes the organisms utilizing the system vulnerable. These types of environmental variables thus show potential to affect the species richness in the study areas. The environmental variables together with their effects on the aquatic invertebrates located in the pan systems discussed in the literature review are responsible for wetland functioning. As a result, they are important and must be assessed as they form a vital component of the wetland classification scheme. By understanding the biotic aspects of the pan systems and their reactions to changes in the abiotic aspects of the pan systems, an integrated/holistic view of these environments can be achieved.

Chapter 3 Research Questions and Rationale

3.1 Rationale

The aim of this project is to use field evidence to critically assess the current wetland classification for seven wetland areas in the Makuleke concession in the northern Kruger National Park (KNP). Literature on wetland classification around the world has struggled in providing sound definitions for wetlands (Van der Valk and Finlayson, 1995). Multiple differences in definitions have led to inconsistencies in wetland classification. Globally, wetlands have previously been classified for different reasons, namely for waterfowl habitat, vegetation type identification and wetland loss/distribution identification (Frohn et al., 2009; Morant, 1983; Van der Valk and Finlayson, 1995). The general sentiment towards wetlands was that they were considered wastelands. However, in the past twenty years, wetlands have been recognised for their functional benefits and values and their biodiversity. This has resulted in a different approach being undertaken in the studies of these systems. Wetland ecological function is now being assessed, which is comprised of the physical properties of the wetlands and the interactions of relevant biota. The biota selected for this research was aquatic invertebrates. In the northern KNP, certain pan dynamics were selected for this study with the aim of contributing to the idea of "ecological functioning." Both physical and environmental wetland dynamics are essential components in understanding wetland systems. An approach has been taken to combine the selected pan dynamics identified during fieldwork in conjunction with the Hydro-geomorphic classification (HGM), to further our understanding of the Makuleke Ramsar wetlands and ultimately their ecological functioning with respect to sustainable ecosystem management. Due to the small scale of the project, only certain measurable aspects were selected in this study which provides an overall holistic view of the Makuleke wetlands.

By comparing and analysing the concept of wetland definitions and wetland classifications, the observer is forced to accept that these terms/methods are flawed in nature. No wetland definition or classification will truly be correct. However, this does not mean, as researchers, that one should cease to determine the most correct method of classification. In the case of this research, the international Ramsar classification and its application to the Makuleke wetlands, it is proposed that a local or regional classification system may add individual system value to the way in which these systems are classified. In essence, a localized classification scheme together with the umbrella-international Ramsar classification scheme may allow for an improved understanding of the systems.

3.2 Research Questions

The research questions below are aimed at engaging with current literature on classification together with fieldwork data collection to suggest that a localized classification scheme be utilized in conjunction with the current classification scheme.

There are four research questions:

1. Do the current classifications for the Makuleke wetlands adequately define their ecological properties at a local level?

2. Which physical wetland characteristics should be used in a local classification system for the Makuleke wetlands?
3. Do aquatic invertebrates contribute meaningfully in the assessment of wetland ecological functioning?
4. Does a localized classification scheme assist the Ramsar classification scheme in providing a better understanding of the wetlands and pans as individually unique systems?

3.3 Objectives

These research questions will be answered through the following objectives.

1. Objective one addresses research question one by considering literature on the Ramsar classification and what it includes as a classification scheme and how it has been used for the Makuleke Concession.
2. Objective two addresses research question two by assessing local classification schemes within South Africa. An assessment of what characteristics are used together with a fieldwork assessment of the study area to determine the wetland characteristics that may be quantified for the study.
3. Objective three assesses research question three by assessing whether aquatic invertebrates provide a means of quantifying ecological functioning within the systems and are they a good measure as of ecosystem health.
4. Objective four assesses research question four by providing an additional classification level based on localized characteristics. The method of applying a local classification to a system does not reclassify the system, it is merely an attempt at assessing the physical and ecological variables available within the study area at a local level to provide a better understanding of the systems and their uniqueness even though they have been classified as floodplain vlei by the Ramsar Convention.

3.4 Outcomes

It is anticipated that this research will, by a process of quantifying the attributes of the physical and ecological characteristics of the wetland and pan systems may provide a means whereby local / regional attributes provide an in-depth understanding of the systems. This approach simply, allows for differentiating between the systems within the Makuleke Concession by their dominant characteristics. An assessment of both the primary data (e.g. soil particle size distribution analysis, combustible organic carbon analysis and aquatic invertebrate abundance and richness) and secondary data (e.g. previous studies completed for the wetlands, namely water quality and vegetation indices), may assist in determine the variables that are the most important in determining the ecosystem functioning of the wetlands. Assessments like this can be used to develop a baseline for the ecosystems. This is important as today's water resources in southern Africa, particularly in arid regions like that of the Makuleke Concession will require a consideration as to how the surface water within the northern parts of the park is being affected by water availability. Detailed baseline information of important variables like geomorphology, hydrology, vegetation and how biota interact with their systems is very important to this region as it is considered a Ramsar site or an area of international importance.

Chapter 4 Study Area

Figure 4.1 depicts the area of consideration in this study. The map of South Africa to the left indicates the Kruger National Park (KNP) in red, below the map of South Africa is a map of the KNP indicating the portion of the KNP where the study sites may be found. The largest image in the figure on the map depicts the study area and its two main rivers, the Limpopo River and the Luvuvhu River and their proximity to the surrounding countries. The Limpopo River and the Luvuvhu River meet at the confluence where South Africa, Zimbabwe and Mozambique meet.

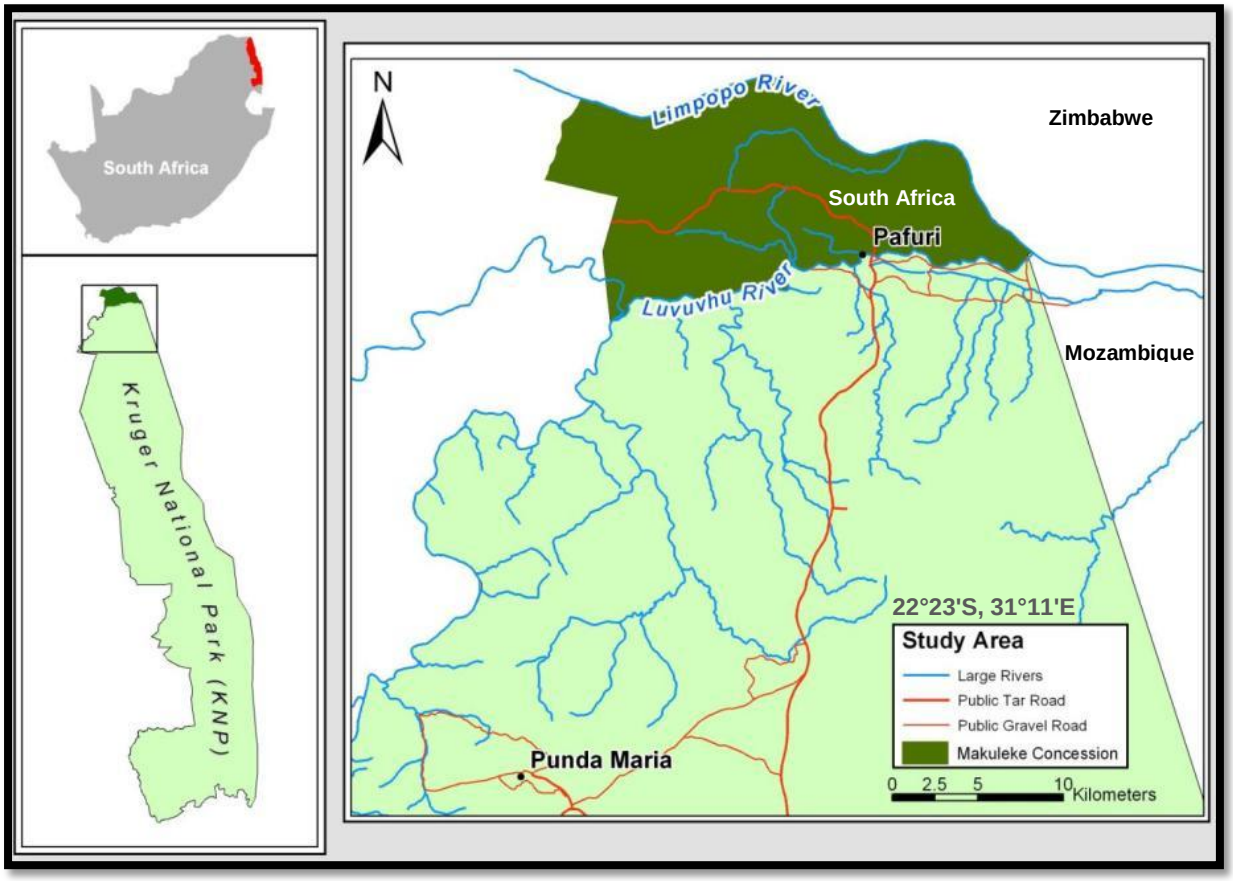


Figure 4.1: A map showing the location of the Makuleke Concession Park in the Kruger National Park and the Limpopo and Luvuvhu Rivers

The study area is located in the greater Limpopo Makuleke Concession (figure 4.1). This area is part of the Transfrontier Conservation Area (TFCA), which encompasses South Africa, Zimbabwe and Mozambique (Spierenburg et al. 2008). The areas that will be studied are in the Pafuri floodplain area of the northern part of the Kruger National Park on the South Africa side of the border. This forms part of the Makuleke Wetlands Ramsar site (7,757 ha, located at 22°23'S, 31°11'E) (Viljoen, In Prep). In 1969 the Makuleke people were forcibly removed and placed outside Punda Maria. In 1998 the Makuleke people won their land back and decided to venture into a partnership with Wilderness Safaris to pursue ecotourism. The Pafuri area holds 75% of the KNP's total biodiversity (Spierenburg et al., 2008). For more information on the Makuleke and their successful land claim see (Spierenburg et al., 2008) as the focus of this study is directed at understanding the physical variables used in the classification of wetland and pan areas and not the Makuleke Community itself.

To obtain variety in study sites within the area, pans were selected according to their perenniality, locality and accessibility. Previous work on the area by Viljoen (In Prep), and his paper on, *Pans and alluvial plains of Northern Kruger* provided baseline knowledge of the Makuleke pan systems. In figure 4.2 below, four pans (Likangwa, Makwadzi, Nhlangaluwe and Mapimbi) were selected on the Limpopo River and three pans (Gwalala, Magomugomu and Nwambi) on the Luvuvhu River. These pans were selected for different reasons, e.g. Gwalala is the first pan to flood, Likangwa has the potential to dry out, and Makwadzi is a perennial river.

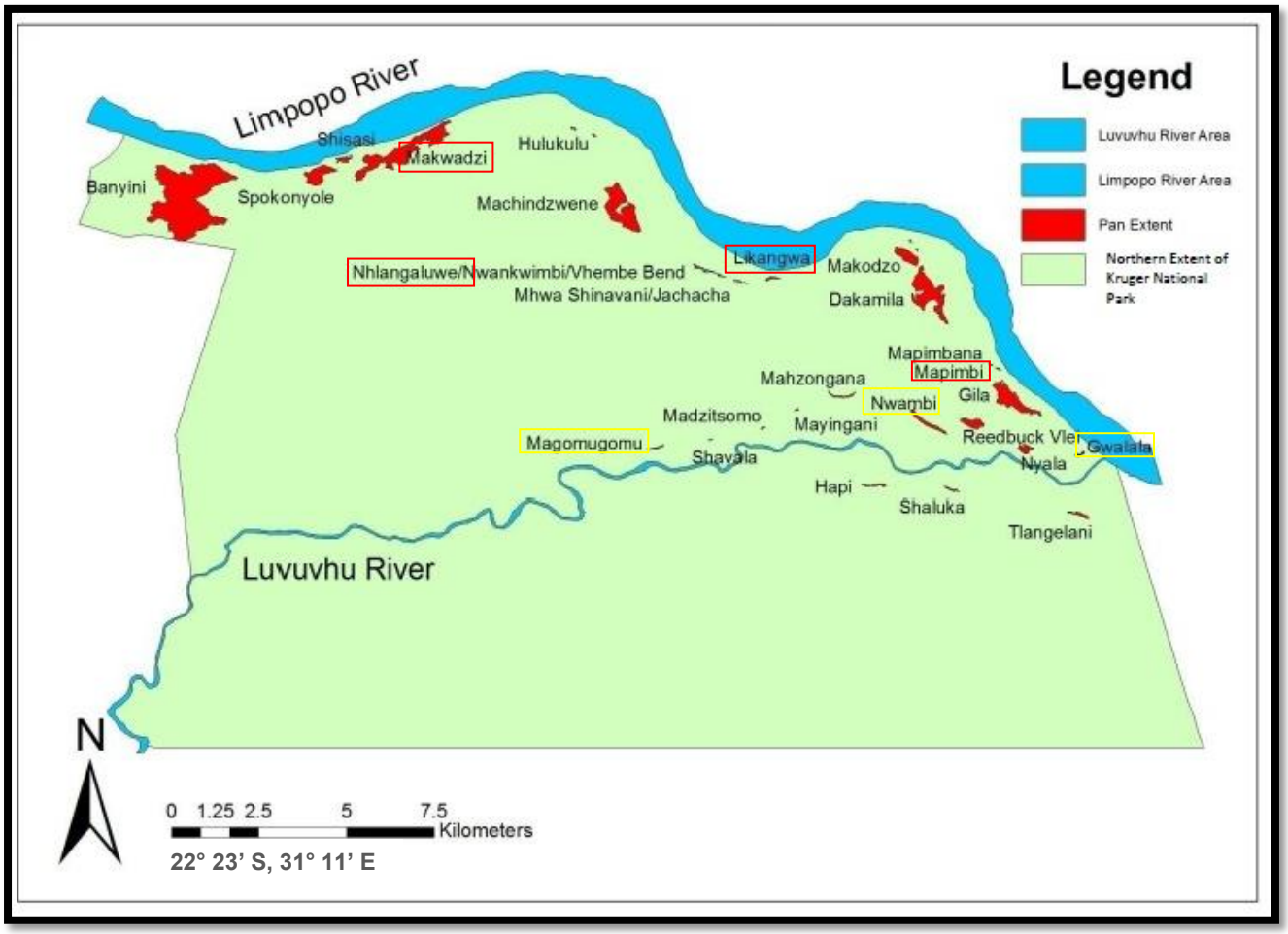


Figure 4.2: A map showing all 29 pans located within the Makuleke Concession Park in the northern section of Kruger National Park. The pans highlighted in the red boxes receive water from the Limpopo River and the pans highlighted in the yellow boxes receive water from the Luvuvhu River (Martin, 2011)

Figure 4.2 depicts all the pans present in the Makuleke concession, and this study's seven sites, namely Makwadzi, Nhlangaluwe, Likangwa, Mapimbi, Gwalala, Nwambi and Magomugomu. The GIS (figure 4.2) shows the potential relationship between pan localities and water sources found in the Limpopo River or the Luvuvhu River. The pan extent measured in March 2011 is illustrated in red. This figure also demonstrates that Nhlangaluwe pan, when in flood, has the capability to swell and become part of a greater and interlinked pan system, merging Nwankwimbi, Vhembe Bend and Mhwa Shinavani. The pans found on the Limpopo River are on average have a noticeably larger surface area than the pans found on the Luvuvhu Rivers source.



Figure 4.3: A photo taken during the wet period depicting Nwambi pan (photographs are researchers own)

Nwambi pan's source is the Luvuvhu River, has a north to south orientation. Figure 4.3, shows a flooded Nwambi pan during the rainy seasons. The water is a reddish brown colour, an indication of fine, suspended sediment, possibly disturbed by heavy rainfall and animal disturbances when utilizing the pan's water. Vegetation is seen on the embankments in the form of shrubs and large trees with no riparian zone present.

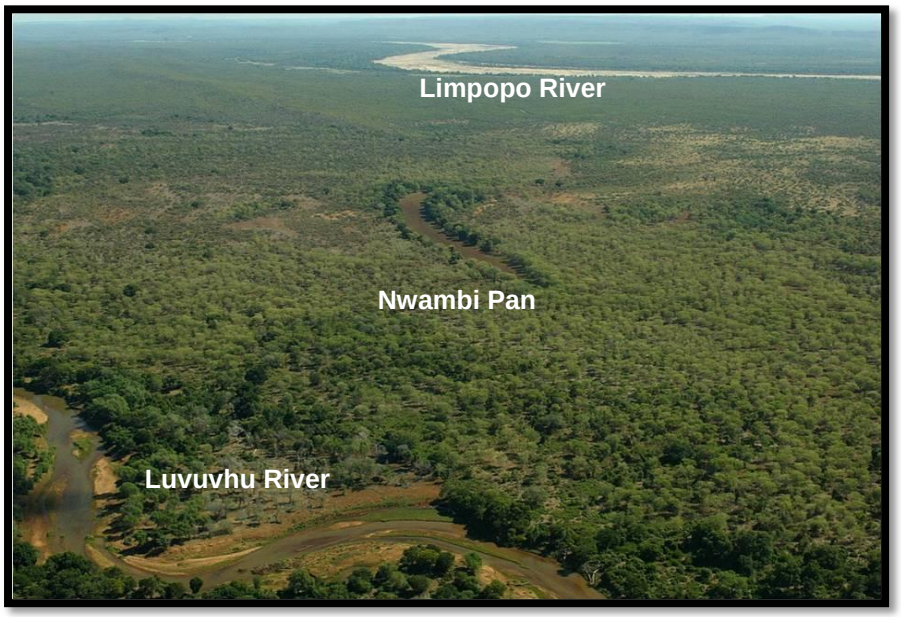


Figure 4.4: Aerial photograph of Nwambi pan's location to both the Luvuvhu and Limpopo Rivers (Source: Wilderness Safaris)

Figure 4.4 is an aerial photograph which provides the locality for both the Limpopo and Luvuvhu rivers systems. Nwambi pan can also be seen from this image.



Figure 4.5: The photo depicts the pan Nhlangaluwe during the wet period (photographs are researchers own)

In contrast to Nwambi pan in figure 4.3, Nhlangaluwe pan's source is the Limpopo River (figure 4.5). Nhlangaluwe pan has a north to south orientation. During the course of heavy rainfall years, Nhlangaluwe, Nwankwibmi, Vhembe Bend and Mhwa Shinavani have been known to swell and spill over into one another and form one large pan extent. The water is clear and indicates undisturbed, coarser sediment or a lack of suspended sediment in the water. The soil present at this pan is coarse and consists of calcrete deposits. There is evidence of a riparian zone with smaller shrub-like vegetation present around the water's edge leading into elephant grass and then into woodland areas. Both pans and wetland types created different types of accessibility problems for sampling as there were heavily vegetated parts during the wet periods and dangerous animals in both wet and dry periods. These pans will contribute to on-going studies, making the selected sites suitable for research purposes.

4.1 Geology and Geomorphology

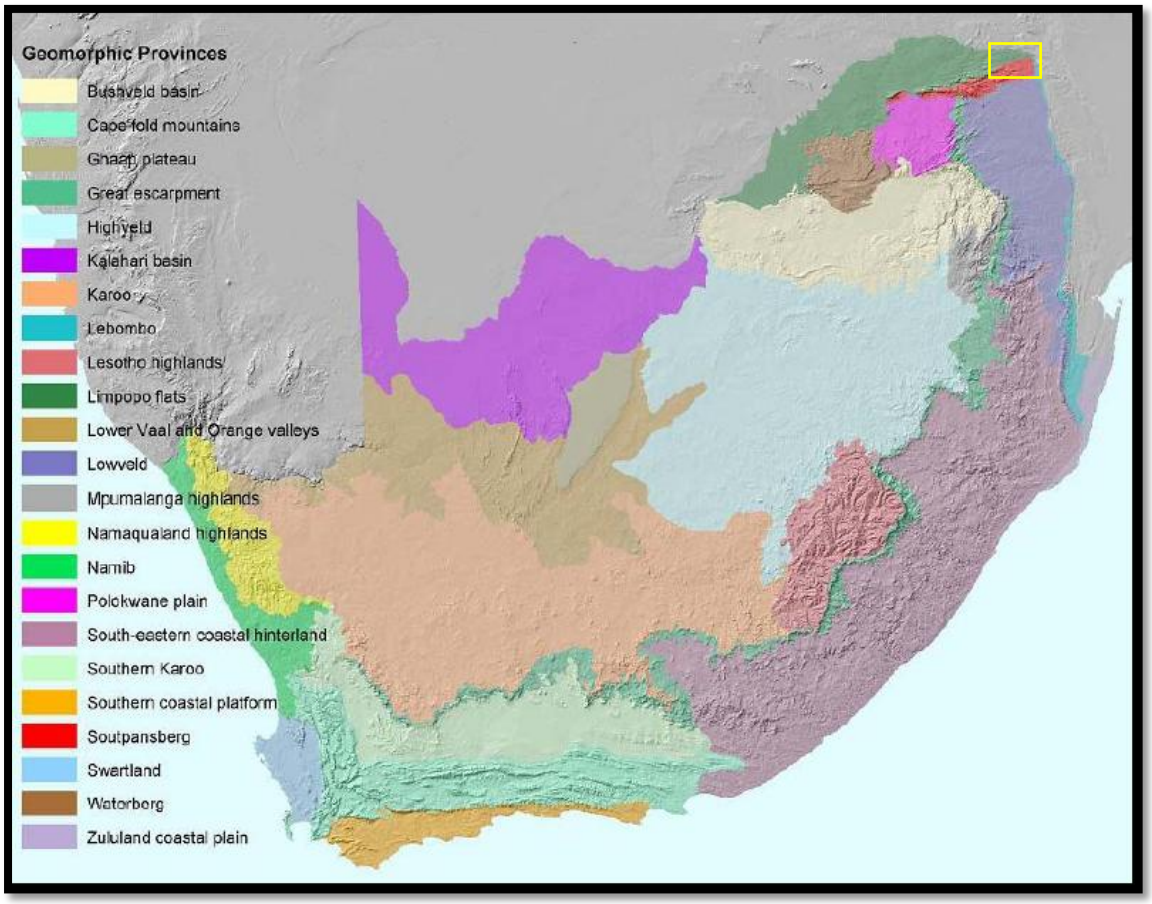


Figure 4.6: The geomorphic landscapes in the study area (Nel et al. 2004). The yellow block indicates the Pafuri Concession. According to the figure above the study area is located in the Soutpansberg, Lebombo and Limpopo flats geomorphic landscape

The geological characteristics in the Luvuvhu sub-catchment share many characteristics with the neighbouring sub-catchment to the west. There are several acidic, intrusive granites and gneisses of the Sand River formation that underlie the uppermost parts of the sub-catchment. Whilst younger consolidated and silicified sedimentary strata, predominantly sandstones and quartzite's of the Soutpansberg Group (figure 4.6) have intruded and overlain these to form steep-sided hills and mountain of the eastern portion of the Soutpansberg mountains, located in the headwaters of the catchment (Ashton et al., 2001). Further downstream, the sub-catchment is comprised of silicified sandstone and quartzites from the Soutpansberg Group followed by carbon rich mud stones, shale and basalts from the Karoo Sequence. In the northern parts of the catchment closest to the Limpopo River, the compact extrusive and intrusive rocks from the Beit Bridge Complex can be found, indicating the mineralized Limpopo Mobile Belt (Ashton et al., 2001). Quaternary sandy deposits of semi-consolidated sandy materials cover large areas of the central and northern parts of the sub-catchment.

4.1.1 Geology and Soils Specifically Related to the Study Site

Limpopo Ridge Bushveld

This area consists of mostly rocks from the Beit Bridge Complex together with sediments from the Sandstones of the Clarens Formation and Basalt from the Karoo Supergroup. Shallow gravel and sand, namely Glenrosa and Mispah soils forms are present together with calcareous clayey soil (Mucina and Rutherford, 2006).

Mopane Basalt Shrubland

The area is almost entirely Basaltic (tholeiitic and picritic) from the Letaba formation or Lebombo Group, Karoo Supergroup. The soils found here are deep, dark in colour in the lower regions, becoming red on the middle to higher slopes. They also have high clay content (Mucina and Rutherford, 2006).

Makuleke Sandy Bushveld

The soils in this region are as a result of the Soutpansberg Group of sandstone and smaller amounts of conglomerate, shale and mostly basalt. The area consists of deep sands to more shallower sandy lithosols, with a few limited areas displaying B-Horizon soil properties (Mucina and Rutherford, 2006).

Lowveld Riverine Forest

These areas are consistent with alluvial soils with deep, fine textures, i.e. Dundee soil. This soil type is subject to heavy/ frequent flooding (Mucina and Rutherford, 2006).

Subtropical Alluvial Vegetation

The deposits supporting this vegetation unit are alluvial with fine structured sandy to loamy soils such as Dundee, Estcourt, Valsrivier, Sterkspruit and Oakleaf. These soils are generally waterlogged as they are exposed to floods, especially in the rainy seasons. Salt is often common in alluvial soils due to evaporation (Mucina and Rutherford, 2006).

Geology and geomorphology play a significant role in the formation of wetland/pan areas. There are two main formations found in the Pafuri region, these being an area of sandstones of the Clarens Formation and basaltic lavas of the Karoo (Viljoen, In Prep). Much of the Pafuri landscape is faulted and therefore it has been suggested that ephemeral pans have formed as a result of the two different types of bedrock next to one another, causing an environment for pans. The resistant bedrock present is sandstone and basalt. Specific geological and topographical controls have been identified for the wetland/pan formations along the Limpopo and Luvuvhu rivers.

4.2 Soils

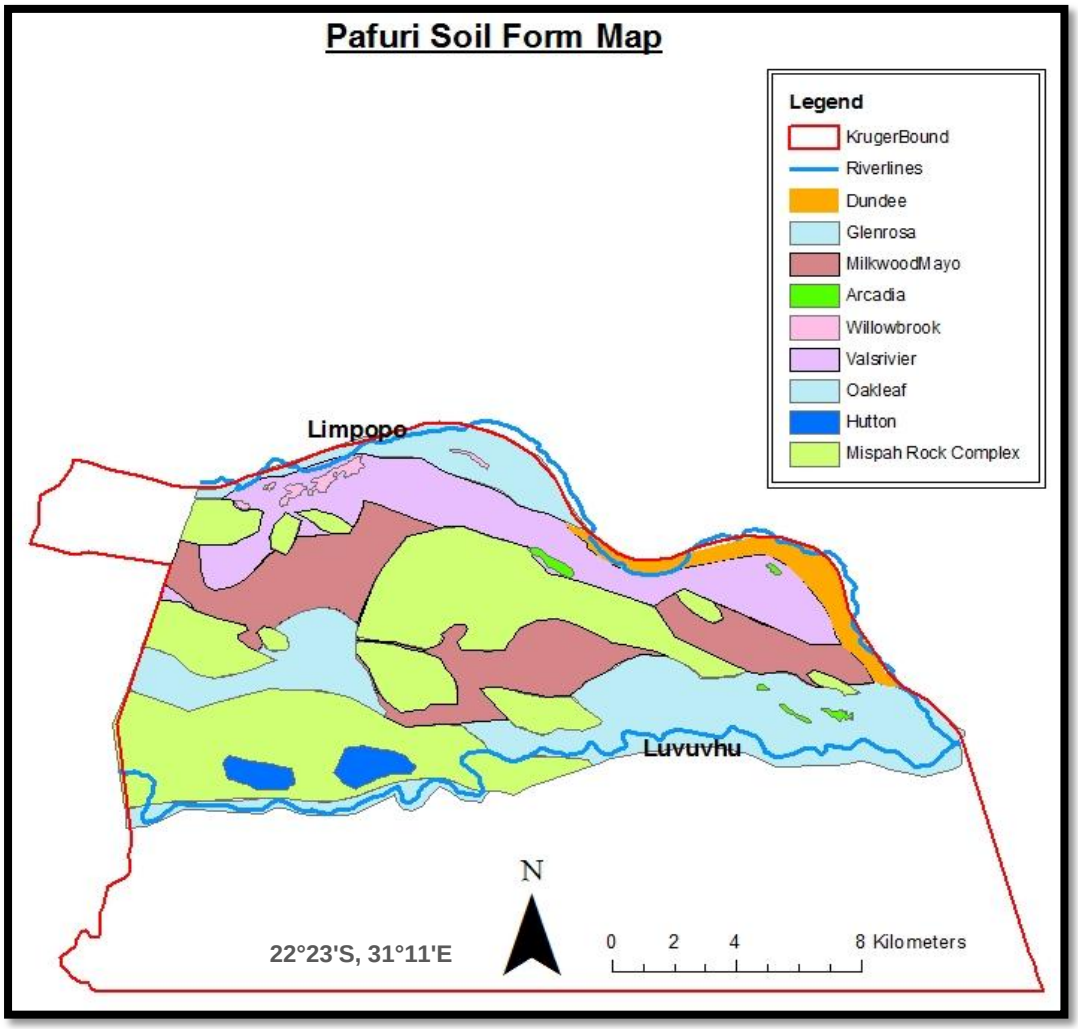


Figure 4.7: A GIS generated figure depicting Pafuri's soil form in the Northern KNP (Nortje et al., 2012)

Soils are classified in South Africa in a manner which permits a means of identifying and naming soils in a consistent manner that distinguishes between certain properties and behaviour that demands that they be separated (Macvicar et al., 1977). There are two categories that are used to classify soils in this system, Soil Forms and Soil Series. Each soil form can be found in the upper general levels. Soil forms are classified at a class level determined by a unique vertical sequence of indicative horizons. Forms are then divided into series, varying from two or more, which all have common properties of the particular form. The soil forms present in the Makuleke Concession are depicted in figure 4.7.

Below is a summary of Macvicar et al. (1977) description of the soil forms pertaining to the pan systems and the relevant pan (marked in bold) found to hold the specific soil form according to GIS analysis.

4.2.1 Dundee Form

- Orthic A: A surface horizon that does not qualify as an organic, humic, melanic or vertic topsoil although it may have been darkened by organic matter,
- Stratified alluvium, and
- Underlying material not specified

- This soil form occurs under a range of conditions. Orthic topsoil is known to vary in organic content, colour, texture, structure, base status and mineral composition,
- **Mapimbi** ;

4.2.2 Arcadia Form

- Vertic A: Have both a high clay content and a predominance of semectitic minerals,
- Possess the capacity to swell and shrink in responses to moisture changes,
- Underlying material not specified,
- Dark,
- **Nwambi** and **Nhlangaluwe**;

4.2.3 Willowbrook Form

- Melanic A: Well structured topsoil that develops under semi-arid to sub-humid climates. Usually found at foot slopes which are affected by lateral drainage of water,
- No diagnostic organic component with 35% clay content,
- Dark coloured, grey soils,
- **Makwadzi**;

4.2.4 Valsriver Form

- Orthic A: A surface horizon that does not qualify as an organic, humic, melanic or vertic topsoil although it may have been darkened by organic matter,
- Underlying material is diagnostically unconsolidated,
- Underlying saprolite or hard rock,
- Dark coloured B horizons,
- Associated with Swartland Form,
- **Nhlangaluwe** and **Likangwa**;

4.2.5 Oakleaf Form

- Orthic A: A surface horizon that does not qualify as an organic, humic, melanic or vertic topsoil although it may have been darkened by organic matter,
- Underlying material is unconsolidated,
- Red, brown, both red and brown and non red colours,
- Associated with Neocutanic B Horizons: Unconsolidated material, aggregation of soil particles to the extent that it is no longer loose and non uniform colour. Any horizon may develop from its unconsolidated materials due to varying climate and relief,
- **Magomugomu, Gwalala** and **Nwambi**;

4.2.6 Mispah Form

- Orthic A: A surface horizon that does not qualify as an organic, humic, melanic or vertic topsoil although it may have been darkened by organic matter,
- Hard rock with underlying calcrete deposits (organic matter and or iron oxides),

- Grey,
- **Mapimbi**.

Soil forms across the Limpopo basin reflect underlying parent rock material, biological activity and climatic features. The prevailing soil types in the basin are moderately deep sandy to sandy-clay loams in the south, grading to shallower, sandy soils in the north and deeper sandy soils in the west and east (Ashton et al., 2001). The valley bottom soils along all of the tributary rivers and the main Limpopo channel are by and large of colluvial or alluvial origin. In the hilly regions or steep sloping areas fragile, shallow, stony soils are found. In the endorheic areas, most soils have a somewhat high sodium or clay content and are dispersive (Ashton et al., 2001).

The Luvuvhu sub-catchment soils however, have been sub-divided into 3 groups by Ashton et al., (2001):

- Moderately deep, red-coloured sandy clay with loam soils on the tops of the hill slopes and undulating terrain in the uppermost reaches of the sub-catchment;
- Shallow to moderately deep, reddish to tan coloured sandy soils lining the valley bottoms in the middle reaches of the sub-catchment; and
- Small areas of clay-rich, blackish or mottled soils with high organic content covering flood terraces close to the lower reaches of the Luvuvhu River and the Limpopo River; in some parts (e.g. the Pafuri floodplain), these soils have high sodium content and dispersive characteristics.

Understanding soil composition aids in recognizing the more complex components of vegetation, hydrology and biota. Dark clay soils are said to be dominant in tropical and sub-tropical regions, however they are not exclusively found. During seasonal weather shifts from moist to dry and vice versa, severe shrinkage and swelling has been seen to occur in dark clay soils, causing fissures and cracks (Dudal, 1962). Many dark clay soils also possess evidence of calcium carbonate. In South Africa the topographic position where dark clay can be found in is often low, with an undulating topography (Dudal, 1962). Simulation models have been developed to quickly and effectively assess water retention and hydraulic conductivity connected to the swelling and shrinkage of clay (Gregory et al., 2010). These models aid water management with soil utilization conditions, understanding moisture flow and ground water levels in wetland areas (Bronswijk, 1988). Clay soils have previously shown characteristics to hold water over a period of time (Viljoen, In Prep). Many of the soil types around the wetland/pans in this study are clay or silt based. Understanding the types of soil present and their particle size/distribution in the Pafuri region is important as it provides the researcher with reasons for the capacity of the soil for water retention and drainage, the types of habitats that should occur and how it is being kept in the area for a period of time.

4.3 Topography

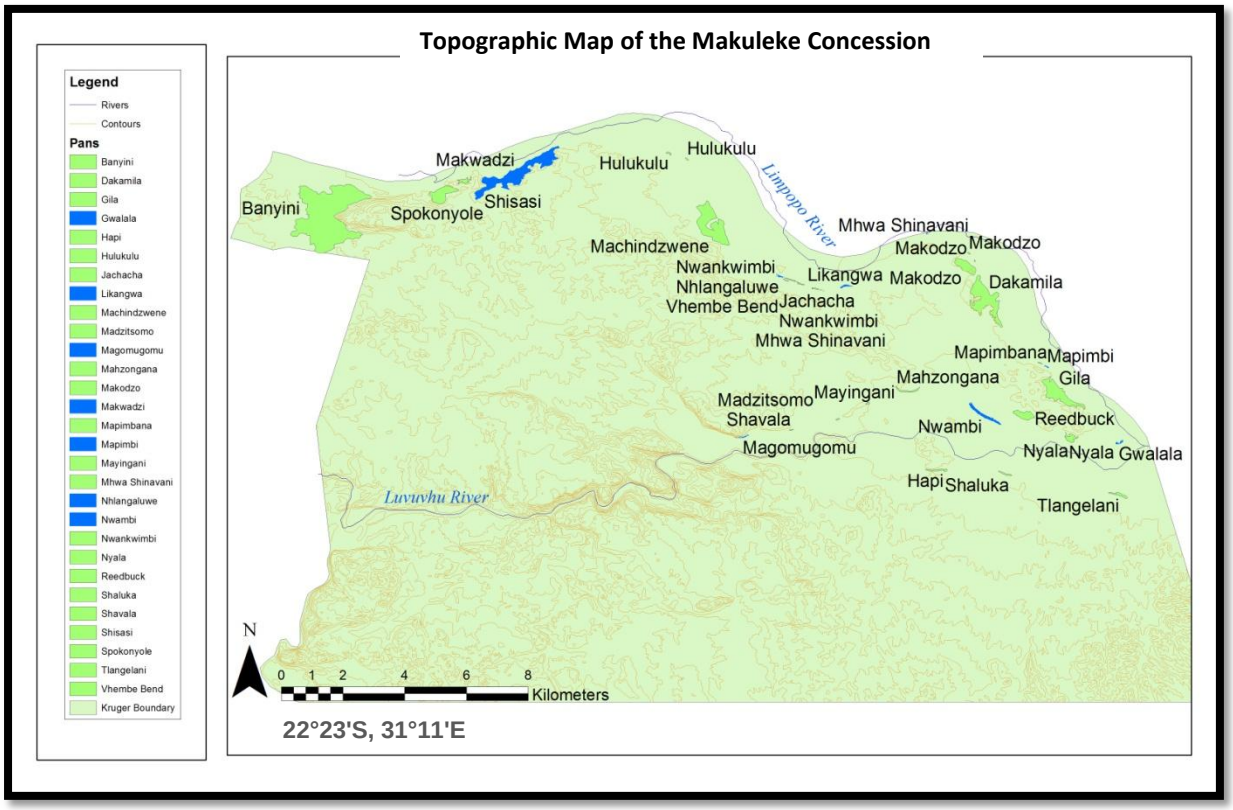


Figure 4.8: A GIS topographical map showing the relief for the Makuleke Concession. The contour intervals are 10m. The two rivers that feed the pan systems in the concession are the Limpopo and Luvuvhu Rivers. All the pan systems within the Concession are depicted in this figure in green, the seven pans in question for this study are coloured in blue

The topography in the Limpopo basin is particularly varied, ranging from a minimum elevation of 190m asl at the Limpopo-Luvuvhu confluence to a maximum elevation of 235m asl at Banyani pan (figure 4.8) and over 2400m in the mountains region marking the traverse position of the northern extent of the Drakensberg Mountains (Ashton et al., 2001). Most of the basin consists of undulating terrain between ranges of mountains and hills. The northward flowing tributaries of the Limpopo River have carved gorges through these mountains and are now visible as erosional remnants. Some areas of the Limpopo River are broad and extend into flat, sandy countryside (Ashton et al., 2001). Large areas of the central and western parts of the Limpopo basin have exceptionally little or poor drainage and as such are generally considered endorheic. These areas are characteristic of saltpans or clay-bottomed pans where rainfall collects and evaporates. These formations are characteristic of physical weathering processes, unlike in the headwater regions where chemical weathering occurs in the tributaries. The study area is considered to be a floodplain vlei and "comprises of a number of landscape features that include riverine forest, riparian floodplain forest, floodplain grassland, river channels and pans" (Deacon, 2008: p. 3). The riverine forest is mostly confined to the banks of the Limpopo and Luvuvhu Rivers, and consists of large, broad canopied trees over 20m in height (Deacon, 2008).

4.4 Pan Geomorphology

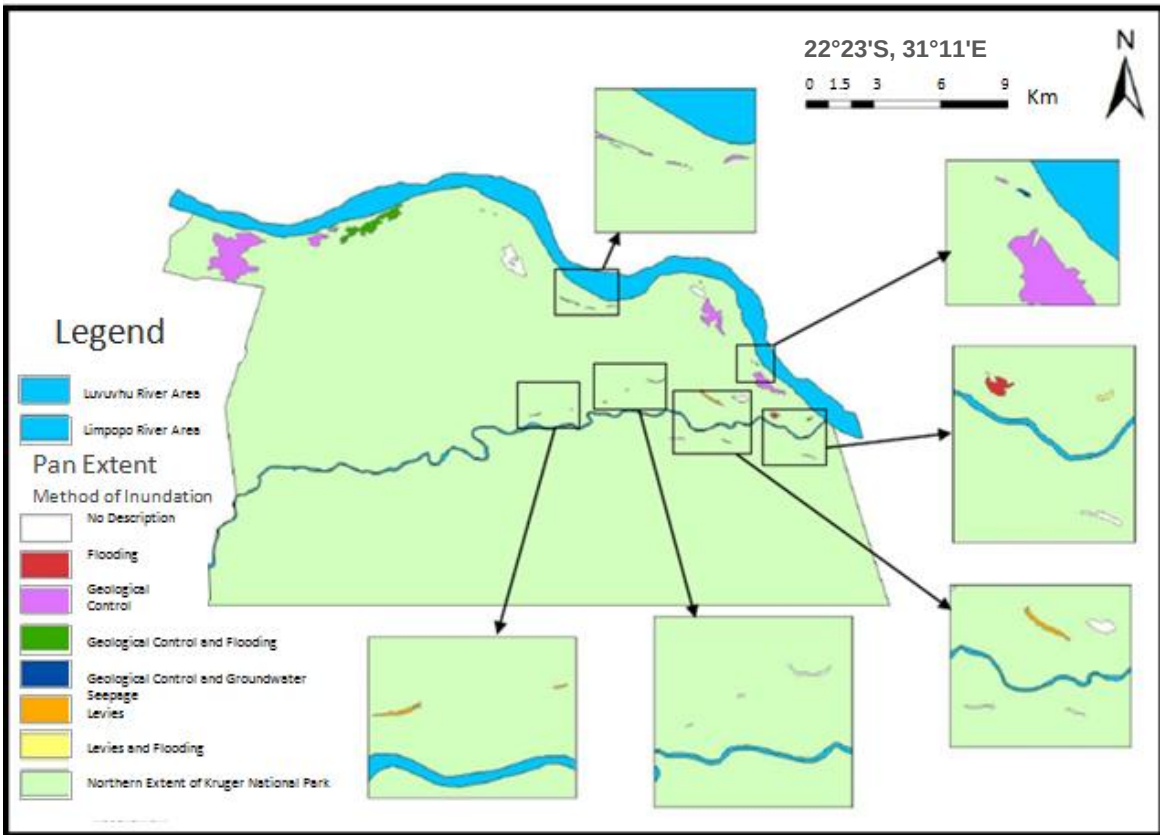


Figure 4.9: A GIS figure created by Martin (2011), showing the proposed method of inundation of the pans in the Makuleke Concession

Martin (2011), proposed the above sources for the pans depicted in figure 4.9 in relation to the geology of the area by Viljoen (In Prep). Martin pg:18 (2011), in conjunction with Viljoen's (In prep) analysis of the surrounding geology, stated that the, "**Geologic control** represents basaltic outcrops controlling the formation of these pans, **flooding** refers to pans being filled by over-spilling of the Limpopo and Luvuvhu rivers, **levees** suggest pans being influenced by raised, sandy deposits of the rivers, which sometimes allow water through in flood events. **Ground water seepage** represents the filling of pans through underground water through the pans being very deep water bodies or water bodies over faults."

The Limpopo pans are found in an alluvial floodplain which is characterized by a well developed levee and adjacent floodplains (Deacon, 2008). According to Viljoen (In Prep), the wetland/pan features, "appear to be strongly controlled by resistant, geo-topographical protuberances or impediments along the southern floodplain." These landscape features are often created by high velocity flood events. This explains the alluvial sediment found in these areas because alluvial sediment is fine grained fertile material that is deposited by water flowing over the bedrock and thus floodplains. The wetland/pan areas are recharged during the rainy summer months when the Limpopo spills its banks; Makwadzi is recharged in this way (Viljoen, In Prep). In contrast, Mapimbi is said to refill by means of subterranean seepage from fluctuations in the water table, receiving water earlier in the year than the other wetland/pans on the floodplain. Gwalala, Nwambi and Magomugomu have been associated with alluvium and are possibly controlled by levees on the Luvuvhu floodplain (Viljoen, In Prep). Clay/silt deposits have been found deposited on the water-body bed and form an impermeable base in the

wetland/pan (Bilotta and Brazier, 2008). As well as forming a base where water can collect, clays and silts influence water quality and aquatic invertebrates. A study by Bond (2004) showed that the rates of fine sediment transport were a hundred times greater in sandstone-bed streams than in cobble or gravel bed streams. Suspended solids need to be considered as they ultimately settle at the bottom of these wetland/pan areas and present environmental issues (Quinn et al., 1992). The discussion section (chapter 7) talks to the development of a newly proposed classification scheme, which assesses as one of its determining factors, the permeability of the pan base and/or the systems method of inundation. The clay/silt deposits from the particle size and distribution analysis will be assessed as to their contribution influence on the wetland/pan systems aquatic invertebrates. The type of geological and geomorphological control (as suggested in figure 4.9) present at each wetland/pan system is important, as a result an assessment as to how the pans are filling is vital in determining the systems functioning. Geological control affects the sediment type and water quality present in a wetland/pan system. Previous research has shown that suspended solids affect organisms in wetland/pan systems (Bond, 2004). The study will assess the classifications these pan systems have been previously assigned. The accuracy of the geological controls provided in figure 4.9 will be assessed in the results (chapter 6) and discussion (chapter 7) sections.

4.5 Hydrology

4.5.1 Limpopo Basin Hydrological Characteristics and Water Availability

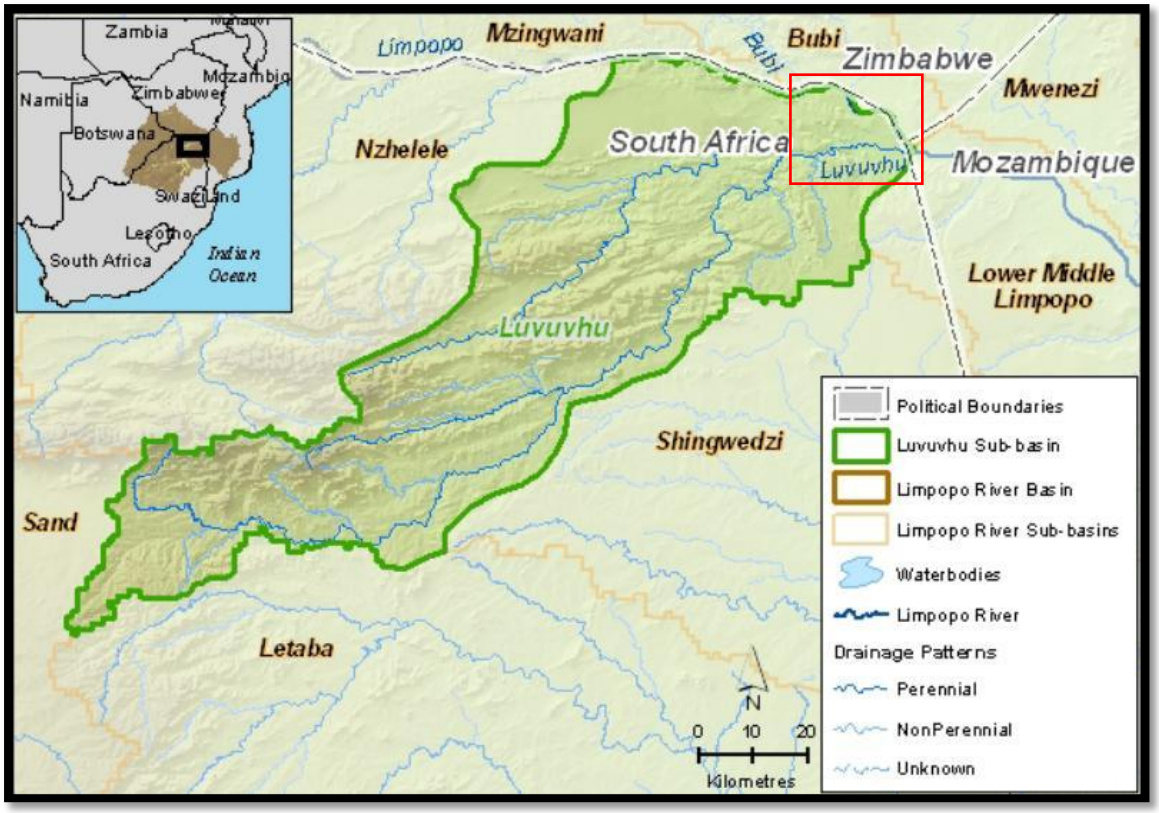


Figure 4.10: A figure showing the catchment area that the study area (red square) is located in, together with the Luvuvhu sub-basin in particular (South African River Health Programme, n.d.)

The Luvuvhu River catchment seen in figure 4.10 is approximately 4826 km^2 in extent, and has a mean annual run-off (MAR) of 2290 million m^3 (Pullen, 1994). The Limpopo River is known to have a dense network of

tributaries even though most of these are only either seasonal or episodic. The river is now a weak perennial river where flow frequently ceases during drought periods and often has no surface flow in the middle to lower parts. The Limpopo basin encompasses an important ecological transition zone that marks the intersection of four separate bio-climatic areas. As a result, the area holds an array of diverse flora and fauna (Ashton et al., 2001).

Rainfall, and as a result, water flow reaching the Limpopo tributaries is determined by the duration and intensity of the rainfall received in the basin. The uneven distribution of rainfall in the basin can be seen in the uneven distribution of water resources in the four basin countries. The Limpopo's larger tributaries show noticeable seasonal cyclical patterns of high and low flows and many of the smaller tributaries are exclusively seasonal or episodic (Ashton, 2000). Seasonal flows in the Limpopo cause visible changes during dry years when surface flow ceases even though groundwater continues to flow in the deeper alluvial deposits. A number of small but ecologically important wetlands can be found in the Limpopo basin (Midgley et al., 1995; Boroto and Görgens, 1999). These wetlands are known to occur on the shallow-gradient reaches of tributary rivers in the South African region of the basin and the Mozambique coastal plain. Throughout the Limpopo River and its tributaries, water quality is generally good. There are increasing problems however, in the central part of the basin due to the increase in salinity.

The Luvuvhu River differs from the Limpopo River as a result of the rock types over which it flows namely quartzite and sandstone of the Soutpansberg Group and the sedimentary rocks of the Karoo sequence (Tinley, 1978); The Luvuvhu River has an abnormally deep and narrow valley as a result of its erosive properties towards the sandstone and resistance quartzite. As a result the Luvuvhu River deposits a large alluvium sediment load into the floodplain area (Venter, 1990).

4.5.2 The Hydrology of the Kruger National Park

The Limpopo River is known as one of the most significant rivers in southern Africa. The Limpopo basin comprises of four countries; Botswana; Mozambique, Zimbabwe and South Africa. The basin can be found between 19.5° and 26.5° S and between 25.5° and 34.5° E and its basin size consisting of approximately 282,000Km^2.

Table 4-1: The table below shows the areas statistics for the four countries encompassing the Limpopo basin; this excludes the Olifant's sub-basin. The data were obtained from Midgley et al., (1995), SARDC (1996), and Boroto and Görgens (1999)

Country	Total Area of Country (km^2)	Country Area in Basin (km^2)	Proportion of Country Area (%)	Proportion of Basin Area (%)
Botswana	600,370	70,000	11.7	24.8
South Africa	1,219,912	102,900	8.4	36.5
Mozambique	801,590	59,000	7.4	20.9
Zimbabwe	390,759	49,900	12.8	17.8
Totals:	3,012,631	281,800	9.4	100.0

Although South Africa's total area in the basin is the highest total area, it is very important to monitor and study this basin as these countries all affect the water sources that ultimately reach the KNP. This is because upstream on the Limpopo River is the Venetia Diamond mine and cultivation occurring in the Limpopo floodplain on the Zimbabwean side. Other activities occurring near the Luvuvhu River are exotic forestry, commercial fruit irrigation, damming and erosion and siltation from subsistence agriculture and habitation. Similarly, all four countries are experiencing the same water problems due to climatic conditions, availability (arid areas) and quality.

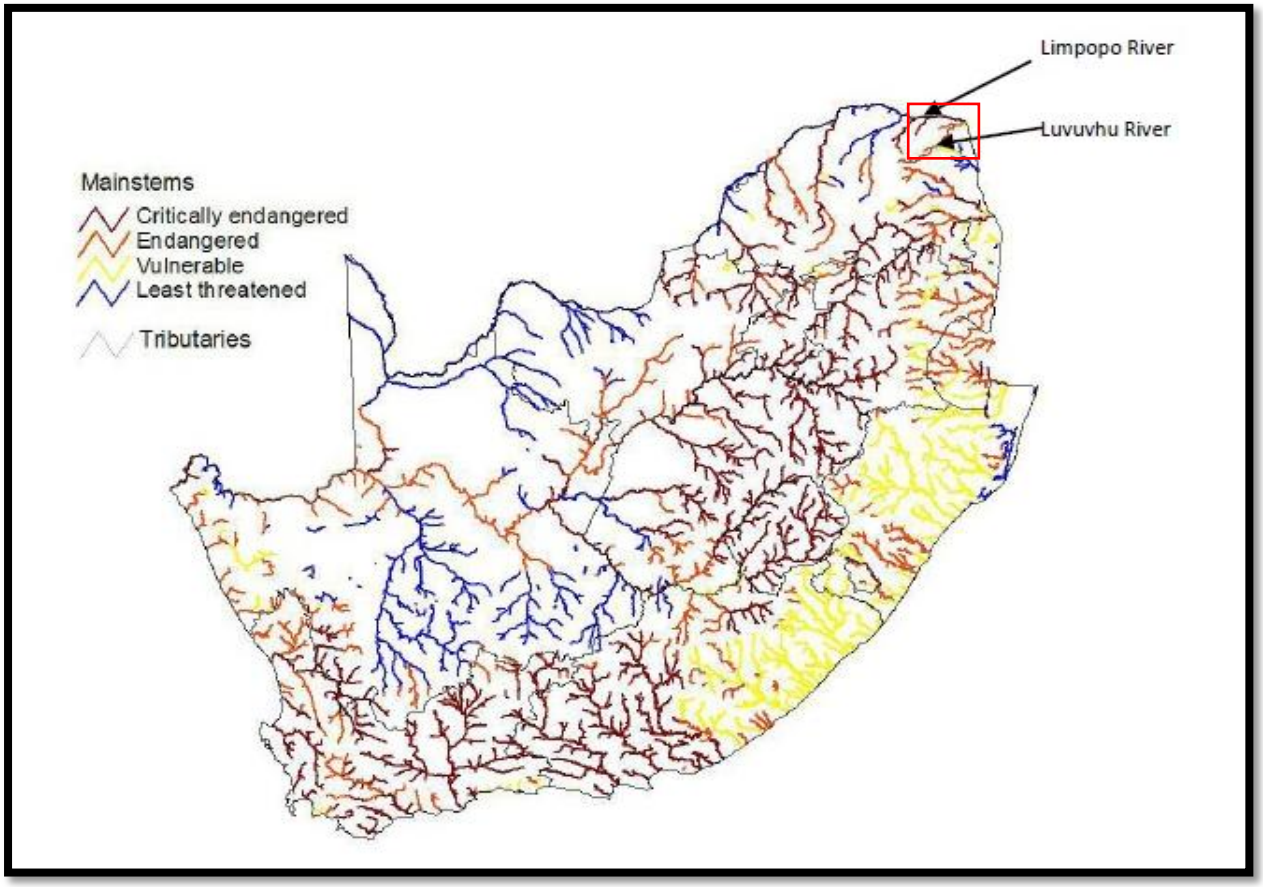


Figure 4.11: Map provided by Nel et al. (2004) shows the status of rivers throughout South Africa, indicating that the Limpopo River is critically endangered and the Luvuvhu is considered vulnerable

By 2005, the National Spatial Biodiversity Assessment (NSBA) provided statistics showing the vulnerability of the water systems in South Africa (Nel et al. 2004). Of South Africa's 120 rivers, 82% are threatened. These threatened rivers are further divided into categories: 44% are critically endangered, 27% endangered, 11% vulnerable and 18% least threatened (Martin, 2011).

As discussed previously, the northern KNP is a semi-arid area. Figure 4.11 confirms that the status of the rivers found in the Limpopo basin in the northern KNP are classified as poor and are more likely to be susceptible to anthropogenic changes and climatic changes as a result.

In the KNP, there are a number of major rivers flowing from west to east. They are the Luvuvhu, Shingwedzi, Letaba, Olifants, Sand, Sabie and Crocodile Rivers. Increasing human population, extraction and siltation upstream of the KNP has led to increased water resource demands and pollution in these rivers. The Luvuvhu

and Letaba are no longer perennial rivers and this is threatening biodiversity downstream. The general objectives for the Luvuvhu in particular are defined as conserving the rivers as closely as possible to their natural conditions and to maintain their essential ecological functions (O'Keeffe and Davies, 1991). These objectives being water supply, self-purification, sediment transport, vegetation maintenance and habitat maintenance for riverine fauna. It is also important to monitor behaviour of groundwater. The Limpopo and Luvuvhu River floodplains in the Ramsar area are monitored by boreholes in the Limpopo floodplain. This monitoring has yielded considerable fluctuations due to flooding and rainfall events in the area. According to Deacon (2008), the depths can range from 2.4 – 6.86m below the ground surface. During droughts however, the water table has previously dropped as much as 4m in some areas.

4.6 Biomes and Bioregions

To understand the concept of a biome, ecoregion or bio region we need to understand the concept of scale and a biotic community (Mucina and Rutherford, 2006). Mucina and Rutherford (2006) refer to the term 'community' as, an assemblage of living organisms sharing the same portion of space during a certain period of time, and also state that we can then define a biome in the same manner. A biome consists of the uppermost part of the hierarchical unit and not characterized by individual species but rather emergent properties of vegetation structure, climate or any environmental factors (O'Neil, 1986). Lower hierarchical levels consist of individual species. Figure 4.12 illustrates the nine bio-regions, of which the seven pans were originally thought to fall into six of these bio-regions. However, the three bio-regions that the pans actually fall into are discussed later on in section 7.1. The overarching biome of the study area is however, Savannah Biome (Mucina and Rutherford, 2006). This biome is the most widespread in Africa. In South Africa, the biome covers most of the far northern part of the Northern Cape, the western and the north eastern parts of the North West Province, western parts of the Free State Province, northern Gauteng, the northern parts of Mpumalanga, parts of Kwazulu-Natal and Eastern Cape and the entire Limpopo Province.

4.6.1 Bio-Regions

Mucina and Rutherford (2006), describe a bio-region as a, "spatial terrestrial unit defined on the basis of similar biotic and physical features and processes at the regional scale". Herein, the immediate level of vegetation organisation between vegetation type and biome is considered the bioregion level. A more common term used for bio-region however, is eco-region. The Savannah Biome consists of six bio-regions, the Central Bushveld Bioregion which has the highest number of vegetation types, the Mopane Bioregion, the Lowveld Bioregion, the Sub-Escarpment Savannah Bioregion, the Eastern Kalahari Bioregion and the Kalahari Duneveld Bioregion (Mucina and Rutherford, 2006). The Central Bushveld Bioregion, Mopane Bioregion and the Lowveld Bioregion have been identified as bioregions within the study area. These Bioregions have been further divided into vegetation units.

4.7 Vegetation in Northern Kruger

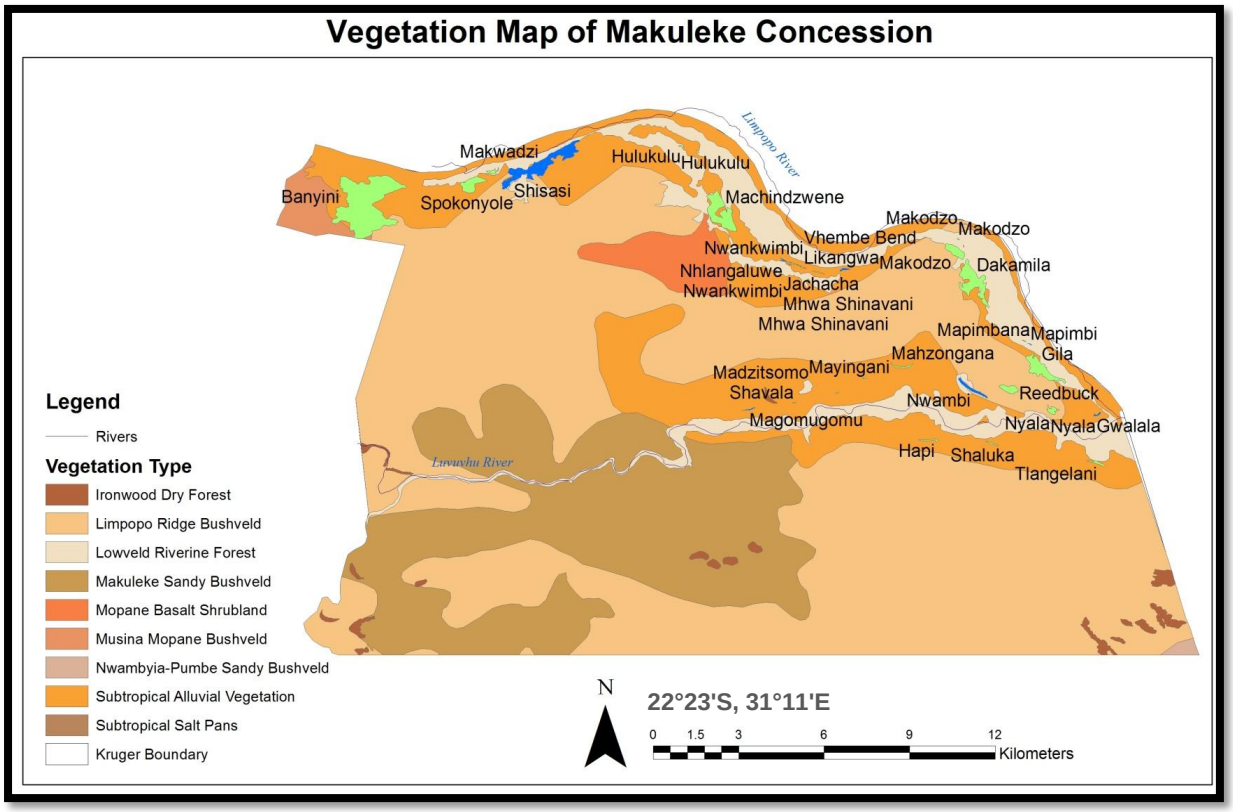


Figure 4.12: A GIS figure depicting the vegetation types provided by Mucina and Rutherford (2006) in the Makuleke Concession together with the pan systems in the area and the relevant study sites overlay

The following vegetation types are a summary of Mucina and Rutherford (2006) and depicted in figure 4.12. The section below, on the vegetation bioregions, makes linkages to the pan systems found in the regions and the soil forms present and their characteristics in relation to vegetation, as seen in section 4.2:

4.7.1 Limpopo Ridge Bushveld

The Limpopo Ridge Bushveld vegetation unit is distributed on hills and ridges which cover vast areas including: the lower Magalakwena River Basin, the pontdrif area, Mapungubwe National Park and downstream of the Limpopo River. It consists of irregular plains with ridges and hills with moderately open Savannah and a poorly developed ground layer. Taller species such as *Kirkia acuminate* are prominent on ridges whilst *Adansonia digitata* are found on shallow calcareous gravel. Smaller shrubs such as *Catophractes alexandri* are dominant in this vegetation unit as a result of calc-silicate soils.

The vegetation found in this bioregion is associated with well drained, shallow sandy soils. It is also characterized by hot, dry areas with alluvial flats near rivers and rocky slopes. (Bushveld, woodlands, savannah or hillslopes). The study sites that can be related to this vegetation group and soil characteristics are: **Makwadzi** and **Nwambi**.

4.7.2 Lowveld Riverine Forest

This vegetation unit can be found in the Limpopo, Mpumalanga and KwaZulu-Natal Provinces and Swaziland. It is also dominant on rivers draining the northern provinces of South Africa, i.e. the Limpopo and the Luvuvhu.

The vegetation is characterised by tall forests fringing larger rivers or water pans. These forests can become levelled, dense and tall with a dense shrub layer. Species: *Ficus sycomorus* and *Diospyros mespiliformis* (Mucina and Rutherford, 2006).

The vegetation found in this bioregion, i.e. savannah/woodland areas, are associated with well drained, shallow sandy soils. These soils are generally associated with an adequate water supply or in close proximity to the water table. The study sites that can be related to this vegetation group and soil characteristics are: **Makwadzi**, **Nwambi**, **Mapimbi** and **Nhlangaluwe**.

4.7.3 Subtropical Alluvial Vegetation

Subtropical alluvial vegetation is also distributed across Limpopo, Mpumalanga and KwaZulu-Natal Provinces and in Swaziland. It is found in broad river alluvium and around some river fed pan systems in the eastern parts of South Africa. Specifically, this vegetation unit can be found in the Lowveld, Central Bushveld and Kwazulu-Natal. It is found (amongst others) on the Limpopo and Luvuvhu River systems in the Savannah Biome (Mucina and Rutherford, 2006).

The landscape supporting this vegetation is associated with wet soils (not well drained) that can support macrophytic vegetation. The bioregion is synonymous with alluvial flats and riverine terraces supporting riparian thickets, reed beds and flooded grasslands. The study sites that can be related to this vegetation group and soil characteristics are: **Makwadzi**, **Likangwa**, **Nhlangaluwe**, **Magomugomu**, **Nwambi and Gwalala**. Appendix F depicts the results of a vegetation study completed by Zoghby (2011) where pans were selected from the vast network of systems within the Makuleke Concession.

4.8 Climate in KNP

The study area falls into the Savannah biome region which has its own climatic influences. Savannahs are for the most part tropical. The Savannah biome region is closely linked to climatic differences experienced between the Indian and Atlantic Oceans along the South African coast (Mucina and Rutherford, 2006). Changes in climatic conditions can be felt by the KNP in the form of differences in seasonality of precipitation and a sub-tropical thermal regime. The Inter-Tropical Convergence Zone (ITCZ) plays a major role in the climate experienced by the KNP, it moves north and south but reaches its southern-most point at 23°S in summer which in turn causes the Indian Ocean to reach temperatures of 27.5°C at this latitude in mid-January. Together with the ITCZ and the relative longitudinal and latitudinal position of the South Atlantic and South Indian Ocean anti-cyclones leads to the source of precipitation for southern Africa and the KNP specifically (Tyson, 2006).

The northern part of the KNP is considered as a semi-arid area, and has higher evaporation rates in particularly hot areas. The surrounding areas average annual potential evaporation is higher than the rainfall experienced in the area. Seasonal rainfall is often high intensity storms with a short duration which results in runoff wastes such as silt, organic/inorganic materials which accumulate in the catchments. Differences in environmental factors and features such as, climatic conditions and geology types across the study area have resulted in a range of different bio-zones. These bio-zones consist of different bioregions which allows for different types of aquatic ecosystems and their respective biota. Therefore, the biotas are generally well adapted to their surroundings. Changes in the type of water quality, flow frequency and duration that they are accustomed to can be very

destructive. Different biotopes also develop as a result micro climates that develop within pan systems attributing to differences is presence or absence and richness of species.

Rivers within the study area vary in flow rates due to their perennial/non-perenniality. Abstraction of water from rivers, lakes, dams and pans alike for water supply within South Africa may lead to unnatural flow conditions, as a result causing stress on aquatic ecosystems. The occurrence of unnatural flow regimes may result in increased concentrations of minerals due to the remaining water and soil type and water temperature changes resulting from depth change due to increased evaporation. This type of stress on biota for example would make organisms already stressed by flow fluctuations more susceptible to water quality than that of un-impacted systems.

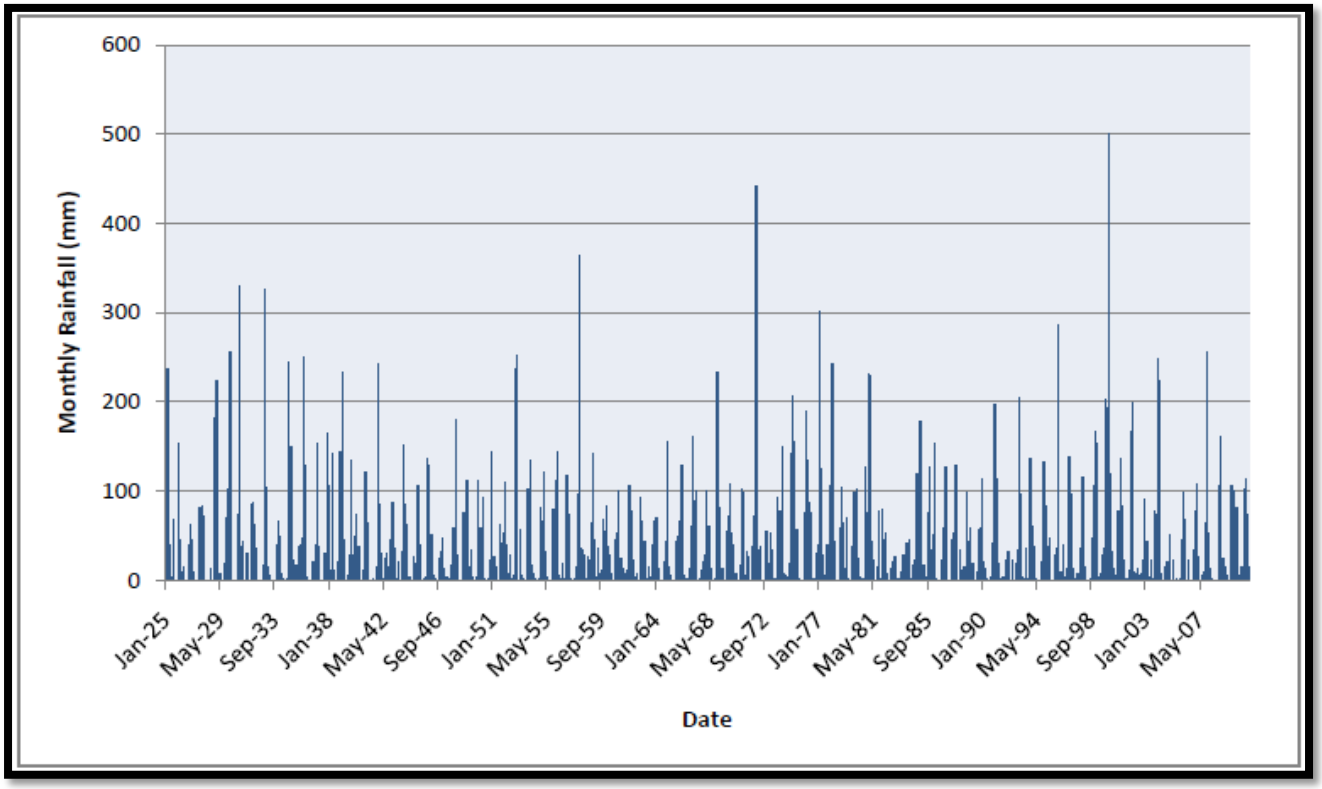


Figure 4.13: The monthly rainfall for the Pafuri area from January 1925 until April 2011 (Martin, 2011)

Tropical Cyclone Eline reached the coast of Mozambique and moved into the interior of southern Africa in the beginning of the year 2000; as a result February 2000 has the highest recorded rainfall in the Pafuri region at 500.9 mm (figure 4.15) which occurred during a La Niña period. January of 1972 shows the second highest monthly rainfall for the Pafuri region at 442.3 mm. February 1977 has a rainfall of 301.7 mm which makes it the third highest rainfall for the period in the graph above. January 1996 also has a high monthly rainfall of 286.4mm (Martin, 2011). The period between 1991-1992 the Pafuri region experiences a severe drought due to an El Niño event.

There is no overall trend of rainfall seen in the KNP, however there are coherent periods of above and below average rainfall, which have previously been called cycles (Du Toit et al., 2003). There is an aspect of non-randomness in these cycles as a result of the weather that El Niño Southern Oscillation (ENSO) brings to the East coast of South Africa. The predictability of this cycle when combined with climate change and its effects is

unclear. In previous years it has been noted that rainfall in the KNP is high (Martin, 2011). For example if Kamatipoort found in the South experiences a prolonged period of drought it is likely Punda Maria approximately 500 km North will experience below average rainfall in that period (Du Toit et al., 2003). This is because the climate in the Lowveld is governed by the same system. The wet and dry patterns experienced by southern Africa are consistent with an equator ward shift in the inter-tropical convergence zone (Ropelewski and Halpert, 1986).

4.8.1 El Nino and its Effects

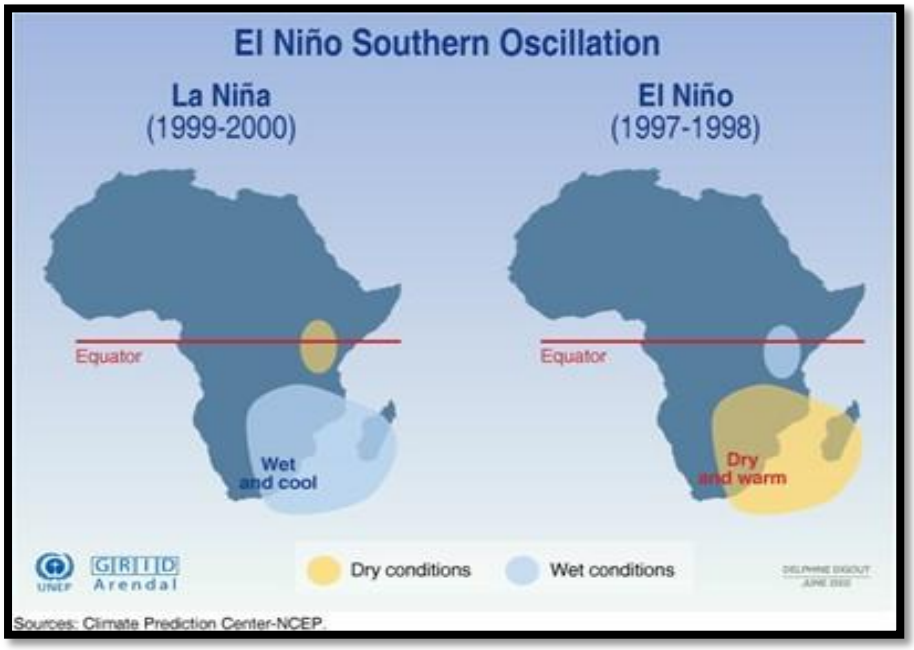


Figure 4.14: The El Niño and La Niña Southern Oscillation and the regions it affects (Digout, 2012)

El Niño Southern Oscillation has been described as a, "global coupled ocean-atmosphere phenomenon that is a primary driver of inter-annual variability in the rainfall and consequently the vegetation production of southern African rangelands" (Wessels and Dwyer, 2011). Evidence found in the KNP shows that droughts occur during an El Niño Southern Oscillation occurrence (figure 4.14) and high rainfall is experienced during La Niña periods. El Niño conditions have lead to the devastating droughts in 1991-92, 1997-98 and 2002-2003 while La Niña conditions (wet conditions) lead to very high vegetation production (1995-96 and 1998-99), but also flooding (1999-2000) (Wessels and Dwyer, 2011).

4.8.2 Rainfall in Northern KNP

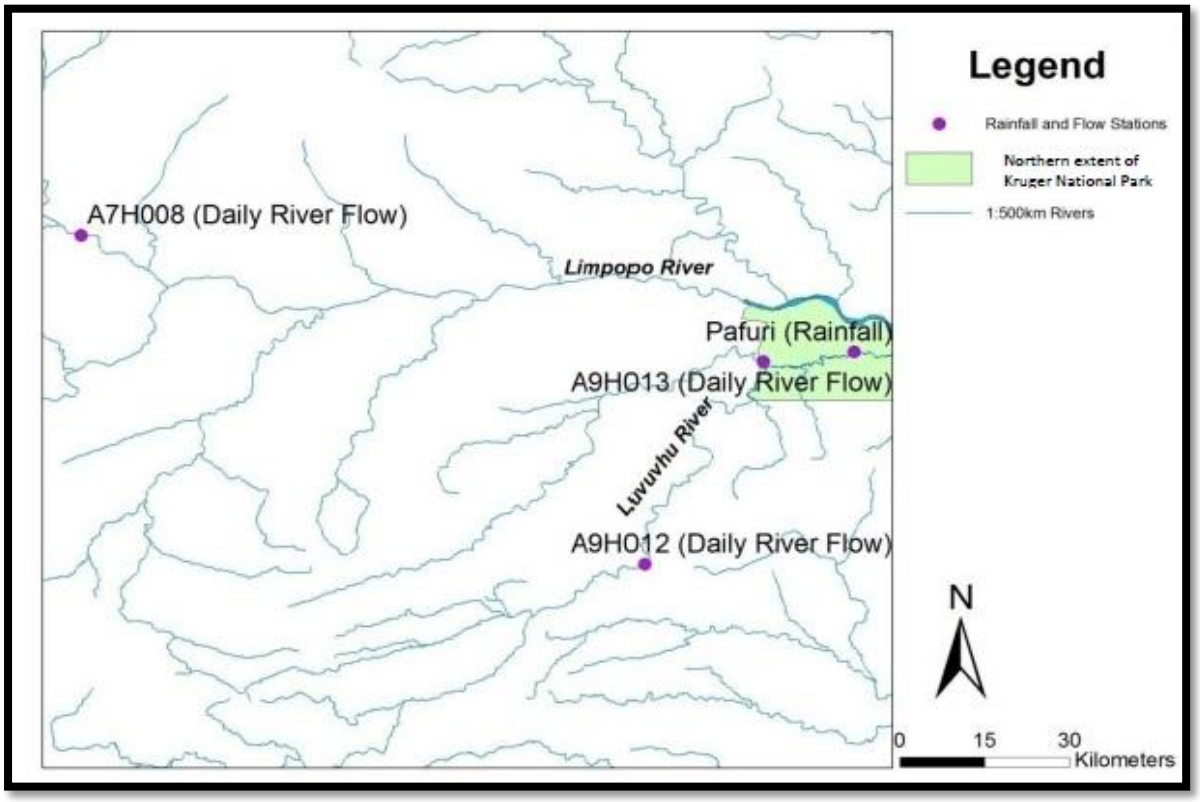


Figure 4.15: The locality of the Makuleke Concession in relation to the rainfall stations within the Luvuvhu Sub-basin and rivers with their respective flow stations (Martin, 2011)

As a result of the Limpopo basin's geographical position, the area's climate is influenced by the prevailing wind systems. The most significant of these winds being south-easterly wind systems that bring rainfall from the Indian Ocean. The ITCZ playes a role in influencing rainfall patterns in the northern parts of the basin, when it moves southwards (Ashton et al., 2001).

Air temperatures across the Olifants basin show a noticeable seasonal cycle, with hottest temperatures recorded during the early Austral Summer months and lowest temperatures during the cool, dry winter months. Rainfall is also highly seasonal, falling mainly as intense convective thunderstorms during the warmer summer months. Rainfalls vary from 400 mm per annum in the eastern parts of the Olifants basin, along the border with Mozambique, to over 1000 mm per annum on the Drakensberg (Ashton et al., 2001). Figure 4.16 indicates the four rainfall stations that are used to record rainfall data (figure 4.15) for the Makuleke region.

4.8.3 Flooding in the Makuleke Concession

Below is a summary of flood events in the Makuleke region as described in Deacon (2008): Bruwer (1987) states that there are two types of these flood events;

1. The first being the occurrence of high floods that overtop the banks of the Luvuvhu River as it enters the floodplain area. Another flood occurrence is when the lower floodplain floods and the rivers (Limpopo/Luvuvhu) break their banks at the confluence, this results in the back flooding of the Limpopo River. This is not subject to the Luvuvhu River being in flood. Regular flooding is important

to maintain the ecological integrity and functioning of the pan systems. High rainfall seasons are experienced every 8-10 years in this region.

2. The second type is the back flooding of the Limpopo River encompassing the pans between the Limpopo and Luvuvhu River systems. This type of inundation occurs more frequently averaging 2-3 year occurrence. This occurs whereby the Luvuvhu River is flowing strongly enough to flow over the embankments, however on condition the Limpopo River has a high flow simultaneously.

4.8.4 Evaporation Rates

South Africa has variable climatic conditions, ranging from sub-tropical humid to arid regions with summer and/or winter rainfall. Climatic conditions are important to understand as climate, among other factors, controls weathering. To account for the amount of evaporation in a meaningful way, the Weinert N value is used. The Weinert N value can simply be explained as a ratio of computed evaporation between the warmest month and annual precipitation (Weinert, 1984).

Evaporation rates across the Olifants basin are high and variable, ranging from some 2.4-2.6m yr^{-1} in the eastern areas of the basin to 1.7m yr^{-1} in the cooler, hilly regions in the south-western portion of the basin (Ashton et al., 2001). With the current evaporation rates and the quantity of rainfall received each year, numerous portions of the Olifants basin show clear evidence of the dominance of physical weathering processes (with Weinert N values greater than 5.0). These regions are located mainly in the eastern and north-eastern portions of the basin and along the lower reaches of the Olifants valley. Almost all of the rest of the Limpopo basin is subject to chemical weathering processes, either seasonally (Weinert N values below 4.0) or continually (Weinert N values below 2.0) (Weinert, 1964). Evaporation is mainly affected by temperature, humidity, rainfall, drought dispersion, solar radiation and wind. Evaporation increases in periods of hot, dry, windy days and decreases on days where there is cloud cover, the air is calm and it is humid. Evaporation is significant as the rate at which it occurs can drastically affect the aquatic invertebrates utilizing the water body in question. For example some organisms lay their eggs in the soil of depressions and wait for the rains before they hatch or spawn. If the seasonal rains fall but are less than the usual amount per annum and the evaporation rates are increased that year, the organisms relying on a filled water body to reproduce may not complete their life cycle.

4.9 KNP Ecology and Aquatic Invertebrates

To monitor an ecosystem effectively, indicator species selected for a particular ecosystem should be sensitive to disturbances and their response easily measured (Clark and Samways, 1996). These species are usually less resistant to change and are less likely to cope with change. Response can be determined if a known species has a small range of tolerance to one or several environmental variables. Therefore, its presence/absence, behaviour or abundance can measure the environmental conditions present in the wetland (Johnson et al., 1993). Macro invertebrates are useful in this regard as they occur widely across river habitats and are abundant. Other biota such as macrophytes, aquatic invertebrates, algae, amphibians, birds and fish are also used across the globe as environmental indicators (Adumus, 2002; Mack, 2001; Clark and Samways, 1996; Lane and Brown, 2007; Schulz et al., 1999; Sparling et al. 2002), Some researchers argue that invertebrates should not be used as indicators of environmental change (Helgen, 2002). This is because some aquatic invertebrate species are only present at the wetlands/pans for part of their life cycles and some are more resistant to environmental change

then others. Despite these particular concerns, their use as environmental indicators will benefit this research as they are almost always present in wetland/pan areas, display different sensitivity responses to different variables and display complete life cycles in the wetlands. Dragonflies (*Odenata)* have been used successfully in the Kruger National Park as indicators of biotope quality (Clark and Samways, 1996). It is important to obtain as much knowledge from a particular area and assess the factors that influence the distribution of organisms; this is because sometimes invasive species may place the wetland in question or species within it at risk from attack (Manel et al., 2001). This is because invasive species can often out-compete endemic flora and fauna for resources and habitat. In the ecology and conservation biology fields of study, models for predicting occurrence are common. It is important to note that these results can sometimes be misleading as ecosystems can go through periods of increased or decreased species numbers (Manel et al., 2001). The aquatic invertebrates collected in this study will be used to test the habitat/physical classification assigned to the wetland/pan areas. Here, the variables such as topography, hydrology and vegetation will be assessed.

4.10 Aquatic Macro Invertebrates and Substrate Properties

Many animals, birds and aquatic invertebrate species make use of the wetland/pan areas, some for parts of their life cycles whilst others rely on the area for basic needs (foraging, nesting and/or breeding). As a result these areas are high in biodiversity (Viljoen, In Prep). Aquatic invertebrate species are affected by clay sediment and suspended solids. In microhabitats aquatic invertebrates are found in different parts of the wetland/pan system, namely: at the surface (neuston), the water column (plankton and nekton), plant surfaces (epiphyton), and the substrate (benthos) (van der Valk, 2006). In freshwater systems benthic invertebrates are abundant (insects, molluscs and crustaceans) (Bilotta and Brazier, 2008; Covich et al., 1999). Material found on the bottom of the wetland/pan features consists of different depositional grain sizes, dead organisms, growing and dead roots, and faecal matter. Several benthic species occupy these areas at various depths and various times of the year (Cummins et al., 1989). Such spatial and temporal distributions indicate benthic species have different preferences for temperature, water velocity, pH and type of substrate (Covich et al., 1999). These determinants are related to preferred microhabitats. Disturbances of these microhabitats cause community structures to shift which often changes species composition. Understanding a species' preferred habitat allows the researcher to assess the reactions towards current conditions of the environment in the wetland/pan system by the aquatic invertebrate species.

An important physical variable that affects aquatic invertebrate distribution is suspended solids. Suspended solids are usually measured as solid content percentage to water volume. Variables such as concentration, duration of exposure, geochemical composition and particle-size distribution are important in understanding the role suspended solids play in wetland/pan formation and composition. Suspended solids can affect aquatic invertebrates by scouring or abrasion damaging respiratory organs. Suspended solids are associated with invertebrate drift, a study by Ryder (1989) stated that drift densities increased with suspended solids. Suspended solids also affect feeding efficiency of grazing on the algae and thus growth rates (Hynes, 1970). These variables ultimately lead to the distribution of the various species. Newcombe and MacDonald (1991) stated that when there is an increase in suspended solids there will be an increase effect on the biota. Duration of exposure tests yielded that long term exposure to concentrations of suspended solids caused filling of interstitial spaces and the contamination of food sources. The duration of exposure will also have a different effect on biota

depending on the seasonality and their life cycle i.e. summer months are more likely to yield breeding therefore more damage is seen with the increased abundance of species (Bilotta and Brazier, 2008). The geo-chemical composition of the suspended solids affects both physical (shape, particle-size and angularity) and chemical characteristics (pH, toxicity-agricultural chemicals and salinity) of the solids, which in turn has been shown in a study by Stephan (1953), to clog breathing apparatus and digestive organs. The study also shows that these symptoms are worse in suspensions of clay and less damage in sand. Particle size distribution is important as the size of the particle determines where it can be found in the wetland/pan system. Smaller particles, such as clays and silts, will be suspended in the water column for a longer period than that of the larger particles which are deposited on the bed (Greig et al., 2005). There are significant implications regarding particle-size structure and behaviour which have an influence on aquatic invertebrates and the water quality. It is important to note that each species responds differently to suspended solids depending on the stage in its life cycle and organism type.

Animals have been found to act as bio-indicators for the pollution of water, soil and air. For the correct monitoring of changes to take place a baseline status for a particular species in a particular area should be established (Webb et al., 2001). Soil concentrations of minerals are often a poor indicator of mineral uptake by plants and thus their availability to animals. A study by Webb et al. (2001), on African buffalo liver results yielded results of the highest concentrations of copper in the Northern and Central parts of the KNP. These parts of the park find themselves downstream of mining and refining activities. Tests for manganese, selenium and cobalt yielded insignificant results.

4.11 Mining near the KNP Region

Mining is one of the primary industries supporting the South Africa's economy (Ashton et al., 2001). There is a wide variety of mining operations and mineral processing taking place in the Limpopo basin, all of which have different affects on water sources and water quality. Evidence shows that particular mining operations that are located in low rainfall areas of the basin where physical weathering processes dominate result in relatively low impacts on water sources (Ashton et al., 2001). In contrast, mining operations found in wetter areas of the basin, where chemical weathering processes dominate, tend to have a wider-ranging impact on water quality. This is as a result of the excessive moisture within the soil profile which enables the continual chemical exchanges to take place. This allows for the available water to mobilize and transport respective contaminants that have become available. Such contaminants that can possibly be found in the Limpopo basin as a result of operating mining activities, their processing plants and closed but not cleared as environmentally friendly mines are: Copper, Vermiculite, Salt, Tin, Corundum, Gold minerals, Silicon, Coal, Lead, Phosphate, Vanadium, Dimension Stone, Clay minerals, Fluorspar, Chrome, Iron, Diamond Kimberlite, Chysotile Asbestos, Limestone, Dolomite, Glass Sand, Andalusite, Platinum, Silver, Manganese, Titanium, Illmenite, Chromium, Magnesite, Aventurine, Barytes, Cobalt, Feldspar, Flint Clay, Nickel, Tungsten, Arsenic, Pyrite, Pegmatite minerals and Graphite (Ashton et al. 2001). These minerals in their aqueous form can be categorized further as Anions (sulphate, phosphate, nitrite, nitrate, chlorine and sulphide), Cations (magnesium, aluminium, potassium, sodium and calcium) and Toxic minerals (chromium, zinc and arsenic). The above mentioned minerals have been selected for this study as they make up an important part of the mineralisation's process in a water system and have the ability to affect ecosystem viability (Ashton et al., 2001; Younger et al., 2002; Kelly, 1988).

In areas where mining activities occur, water availability is affected, generally as a result of water abstraction for mining operations (Ashton et al., 2001). The processes required to extract minerals from the ground require large amounts of water for the extraction of the desired minerals, maintenance of the equipment, cleaning of the minerals that have been extracted and cooling of the plants to name the major water uses on a mine (Salomons, 1995). Transportation of water to mining sites in the quantities required for the above processes is near impossible logistically and financially. This results in the decision to extract the required water for the production of the mines by means of diverting river courses past mines, building dams and the extraction of ground water. These changes to the "current" systems have dire consequences if the correct environmental course of action is not followed. If the water supply is decreased to insufficient amounts, lotic systems down-stream can be adversely affected. Annual flooding events which certain lotic system biota depend on for various life cycle periods will be affected, and floodplains which flood periodically, creating niche habitat for different species. Extraction of ground water occurs by the use of boreholes by mines. This water extraction method too has high impacts on the surrounding environment. This is because of the varying depth of bedrock and its porosity (aquifer). Many boreholes are used per site on any given mine, resulting in large amounts of water being brought up to the surface by pumps. Underground, this results in a drawdown of the water table level. This phenomenon results in the drying up of i.e. wetlands or disappearance of these systems, thus habitat loss for species that utilize them. Without the "regular" flow of rivers and expected depth of water tables, the ability of pan systems to flood annually seems improbable. Mines also affect water quality by illegal dumping of dirty/contaminated water (Strydom and King, 2009); spillages or water that is deemed safe for the environment but as a result of being utilized in the mining processes now contains extra metals and TSS. All of which eventually make their way down-stream into floodplains and pan systems affecting the ecosystem health (Gray, 1997). The most recent incident that occurred in the Mpumalanga and Limpopo Provinces was a toxic spillage from the Bosveld Phosphate Mine which flowed into the Kruger National Park for a week. Highly acidic water with a pH of 1.5 was detected at the discharge site. Fish species up to 12 Km away were said to have died as a result of exposure to the chemicals in the water (Crowley, 2014).

Aquatic invertebrates namely benthic invertebrates are considered good biomonitors of ecosystem heath. This is because these types of aquatic invertebrates are inactive and sensitive to low-level localized disturbances (Berkman, et al., 1986).

There is future scope in assessing the affects of mining operations on wetlands along the Limpopo River. This would be very useful in determining the extent to which they are impacted on.

Chapter 5 Methodology

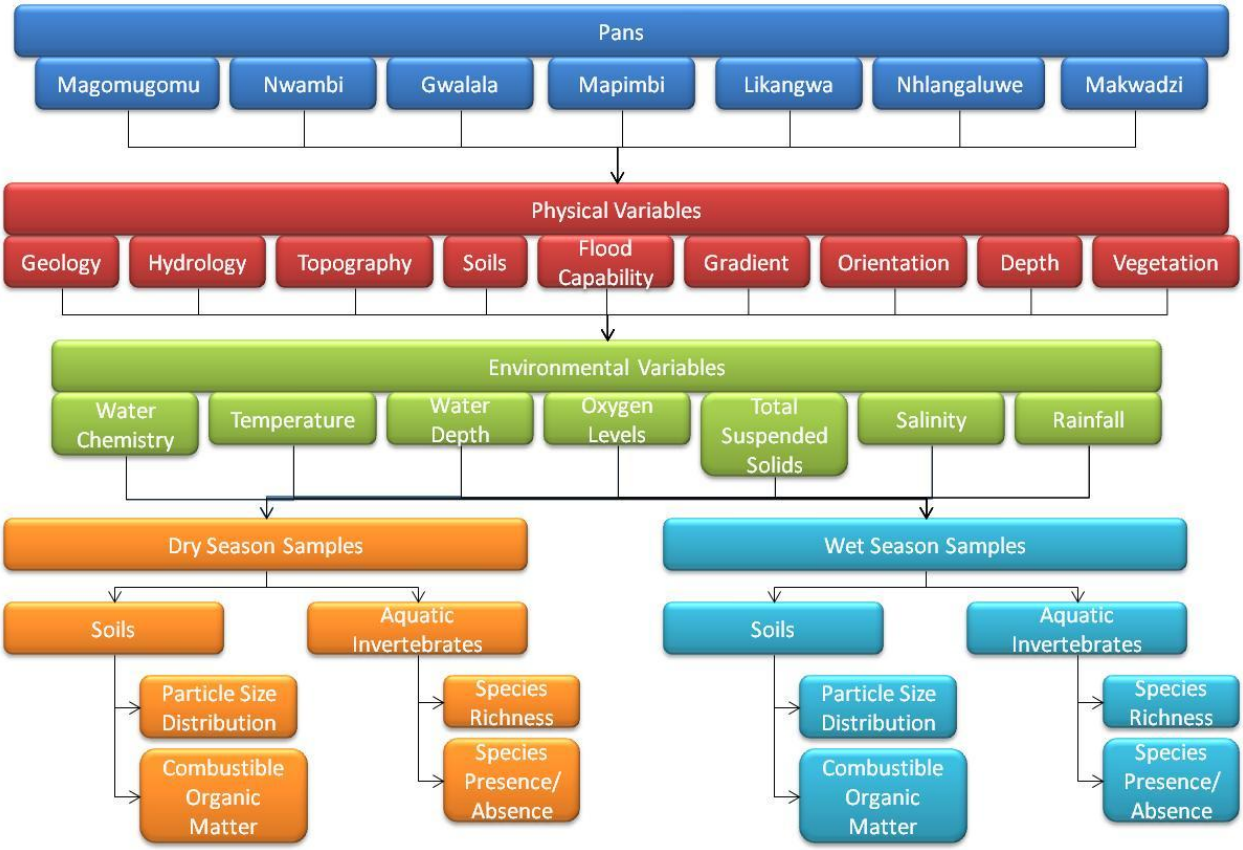


Figure 5.1: A concept map displaying the methodology used in this project



Figure 5.2: Magomugomu pan in March 2011 depicting the dense vegetation with fever trees and steep gradient on the Northern side with a rocky outcrop (photographs are researchers own)

5.1 Field Data Collection

An integrated methodology was used in this project whereby fieldwork was completed to collect relevant data required for this study and lab techniques were chosen that would best analyse and present the data collected. The seven pans were surveyed and their general characteristics noted. Items collected were: current weather conditions, stand-out features, the pans scale of flood, orientation of the individual pan systems, river source, the proposed flow, perennial/seasonal, background information on the area the pan is found in and dominant vegetation surrounding the pan. With respect to soil samples collected in the field, items noted were: the gradient of the pans sides (the slopes incline was measured and recorded for data analysis with the soils from their respective sample sites), description of the soil type/composition, site co-ordinates of the soil samples taken and the depth of the pan from the wetted buffer. These characteristics are elaborated on further in section 5.1.3. Aquatic invertebrates were also collected and sampled. Co-ordinates of sample sites were taken, why the site was chosen was noted (different biotopes) and general observations. These are discussed further in section 5.2.5. Vegetation surrounding the pans was assessed for an overall ecological perspective of the area. Also collected from each of the sites were soil, for particle size distribution analysis and the soils combustible organic matter percentage; including aquatic invertebrate samples, to be later analysed in the laboratory. GPS point data and pan extents were used for spatial data analysis. In the field, the equipment that was chosen was the most feasible for doing laborious fieldwork and hiking far distances to different sites with the equipment in hand. The gradients of the pans were measured along transects. The seven pans were selected based on their water flow, three annual and four perennial (see study area figure 4.2). Information regarding the background of the area

was obtained by local knowledge, previous studies in the area and literature on the topics and the Kruger National Park.

5.1.1 Pan Data Collection

Transects

Transects were made perpendicular to each pan (depending on the orientation of the pan, i.e. if the orientation is E-W transects will be made N-S up the embankment), see figure 5.3 and 5.4. The number of transects per pan was decided once the site was reached, depending on the pan size. Usually the number of transects chosen was 2 or 3 as the pans were relatively small. The transects were then mirrored on each side of the pan where possible, if not, they were continued as close to the original path as possible. At the start of each transect a GPS coordinate was taken (i.e. at the water's edge). Subsequent GPS coordinate points were taken along the transect at each gradient change in the topography, here a soil sample was taken for each site and its GPS coordinates recorded. The reason for this was to determine the depth of the system in terms of the system being more depression like or more likely to depict a flatter surface area. This process was repeated for each transect made. Sample sites differed from pan to pan due to dangerous animals and vegetative obstacles but where possible, direct line of sight for the transects was obtained. The gradient was also measured for each transect with a clinometer and the reading noted on the site sheet. Transect length varied due to differences in distances between gradient changes from the pans water edge outwards and due to the pans size. The exact measurements in (m) for the transects, are provided for each pan system in section 5.4.

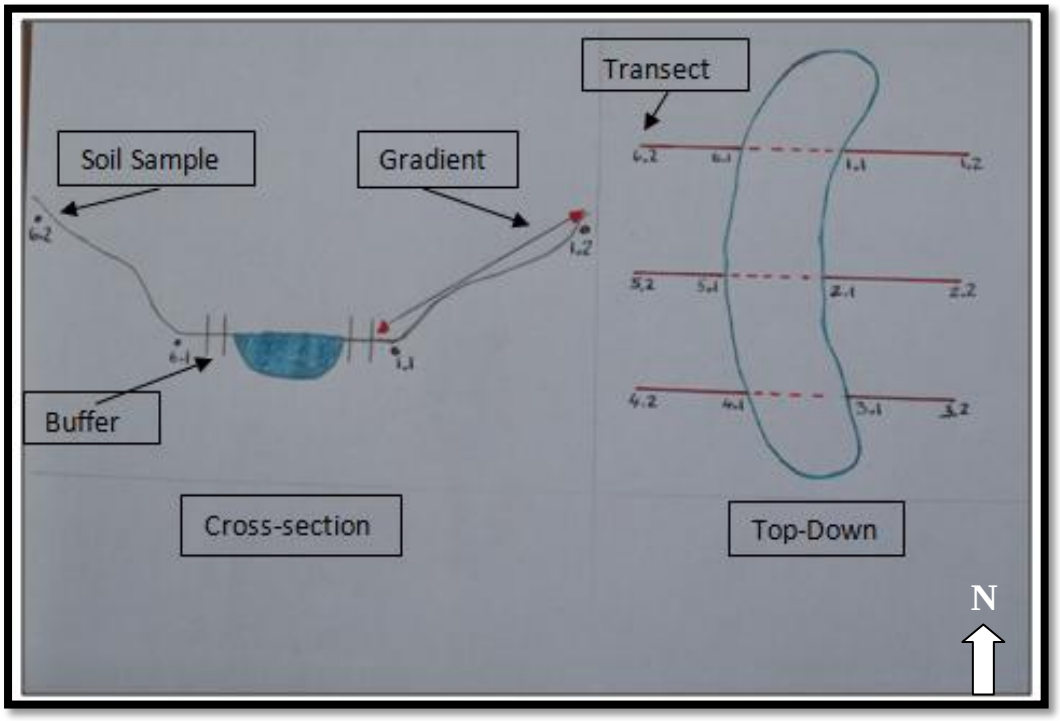


Figure 5.3: The figure depicts how the transects were conducted for the pan systems. The cross-section shows where soils were sampled from in terms of the gradient changes. The top down view of the transect illustrates that soil samples were conducted in a line on either side of the pan system. This transect uses Nwambi pan as an example as to how this was done



Figure 5.4: A figure depicting Gwalala pan. The red line indicates a transect that is drawn from one end of the pan directly across the body of water. The yellow lines represent the changes in gradient and the green dots are where soil samples were taken (photographs are researchers own)

Soil Sampling

At each coordinate or sample site a soil sample was taken (figure 5.4). Soil samples were taken at each change in gradient away from the body of water and outside of the wetted buffer, which resulted in either 2 or 3 samples on one side of the pan, therefore 4-6 soil samples per site. This is illustrated in figure 5.4 by the green dots. A soil auger was used to extract two auger measures up to 30cm deep from the sites chosen along the transect. A soil moisture probe (30cm deep) was used to determine the moisture of the samples at the sites. Each soil sample weighed approximately 1.5kg. Once extracted the samples were placed in a soil bag, sealed airlock tight so that moisture could not escape and labelled according to the respective pans name (i.e. NWA 2.1). Pictures of the sample sites were taken before and after the soil sampling at the study site (Brink et al., 1982).



Figure 5.5: A figure depicting a soil auger sample from Mapimbi pan show on the pan locality map in Figure 4.2 in March 2011 (photographs are researchers own)

Pan Characteristics

A site characteristics/field data capturing sheet (see appendix B) was used at all study sites for both wet and dry periods, the following information was captured in order:

- Background information of the area the pan is found in, i.e. history of the pan, prominent soil group and flooding characteristics,
- Current conditions were noted in case of rain the night before which could affect soil sampling results,
- The proposed water source, specifically the Limpopo or Luvuvhu Rivers,
- The approximate orientation of the pan, if possible, by cardinal points (N,S,E,W),
- Pan stand-out features such as, the colour of the water, smell and vegetation type,
- The scale of flood was designed by the head guide in the Makuleke area to determine the current water carrying capacity of the pans. The scale extends from 0-5, 0 indicating completely dried up, to 5 which is a pan that has flooded,
- The proposed river source flow was also established by the indication of its perennially or seasonality,
- The dominant vegetation was indicated on the site sheet, generally by which side of the pan it was found and whether it was woodland or grassland,
- Transect elevation or gradient was determined by an inclinometer to establish the steepness of the pans. At each change in steepness/gradient a soil sample was taken. Vegetation change was noted and related to gradient change,
- An approximate depth of the pans is also required to complete overall characteristic summary of the pans. Due to the inability to get a boat onto the pan surfaces, a measurement was obtained from the wetted buffer with the use of a long rod with a line which had measurements on and a weight attached to the end. The rod was then extended into the water (for further breakdown see figure 5.3),
- Soil probes were used to determine the moisture of the soil sample that was extracted at each site along the transect. The probe samples were used as a fieldwork aid in assessing the soils moisture content on site

before the soil moisture content test was conducted in the laboratory. Moisture samples are important in determining the wetted area of a pan system. Although wetted areas are subject to natural fluctuations in flow regime, it is important monitor any increases or decreases in these fluctuations, particularly in arid areas where water abstraction from the feeding river system and/or water table is taking place,

- A description of the soil type/composition was also noted to later be confirmed in the environmental lab and an assessment based on the Supergroup the soil sample was found in,
- Aquatic invertebrate information was also captured on this sheet in the form of: general observations made about the water surrounding aquatic invertebrate sample sites and "why was the site chosen", according to identified differences in biotopes (discussed in section 2.3.2).

These data were used to build up an understanding of the pan dynamics in the study areas. The general characteristics were provided by the Head Guide at Pafuri Wilderness Camp at the time, Walter Jubber.

Pan Depth



Figure 5.6: Sampling pan depth at Mapimbi pan March (photographs are researchers own)

The pan depth was also measured to cross reference the results with that of the Endorheic definition of a pan. A GPS coordinate was taken at the site chosen for the depth measurement. Systematically marked off points were made on a piece of gut. The marks were made at 3m and were marked off per meter, then at half a meter, then 10cm and finally 5cm marks were made. The line was weighted down to avoid the line not sinking and tied off onto a range rod. The range rod was then able to extend 2m and a human arm average 1m, therefore extending the rod 3m from the waters' edge over the surface of the water and then lowered into the water until the substrate stopped the descent of the line (see figure 5.6). This approach was taken as it was too dangerous to place a boat on the pans water and would require further permits from the KNP and more rangers. The line was lowered slowly then the depth read off of the appropriate cm/m marker and recorded. It is noted that this method

is not ideal to achieving sound results but due to the constraints at hand, this method was the only feasible option at the time.

Pan Extent Measuring

The spatial extent was measured around the pans by means of a cookie trail that was completed by the GPS around the pans to establish a record of their extent and distance/bearing measurements were also captured. This data capturing was completed once back at camp and was completed in Microsoft Excel, Windows 2007. To establish an exact extent of the pans a distometer and compass were utilized. One person was required to stand at a starting point (site 1) and another person walked the perimeter of the pan. A laser distance meter was pointed at the person walking around the pan and a point was shot every few metres and the distance/bearing read and captured, with the person carrying the distometer following in the previous persons' footsteps. Distance and bearing was measured at each change in direction around the pan (extent of pan- 2m wetted area buffer). This becomes the next starting point. This process was continued until the starting GPS point was reached. If the trails were interrupted, a GPS coordinate on each side of the interference was taken before continuing as above. These points were joined digitally in ArcGIS to create the pan extents. It is to be noted that the entire above pan extent mapping was completed two metres away from the water's edge to create a wetter buffer area and for a safety precaution for crocodiles and hippopotamus. In addition, the entire perimeter of some of the pans could not be walked. Below is a brief breakdown of the problems found at each pan during the GPS coordinating process and the laser distance meter recordings:

- Gwalala – The northern bank was accessible in portions, with the majority of the southern bank being inaccessible due to highly saturated clay soils;
- Likangwa – Only the southern bank was accessible due to the thick and tall reeds surrounding the rest of the pan. Dangerous game (*Syncerus caffer*) were utilizing this pan and as such the guide deemed a full perimeter walk not feasible due to safety precautions;
- Magomugomu – The entire perimeter was accessible barring a few thickets encountered. The coordinates and laser distance meter were used in the computation of the pan extent;
- Makwadzi – Makwadzi's extent is vast and irregular, its vegetation and saturated clay soils similar to that of Likangwa and Nhlangaluwe pan prevented on foot perimeter logging. Roads to this pan were greatly limited. There is one road which accesses the northern part of the pan and none for the southern region. Again due to the limited areas available for safety when on foot, only certain parts of the pan could be recorded.
- Mapimbi – Mapimbi is highly vegetated (thorn bushes and thickets), with steep slope sides and a tall canopy. The laser distance meter was used together with GPS where possible but the canopy cover limited satellite signal;
- Nhlangaluwe – GPS coordinates were recorded where possible together with the laser distance meter. The vegetation on the southern bank was very thick and required joining GPS coordinates in multiple areas along the bank; and
- Nwambi – The majority of this pan was accessible for GPS coordinate recording and the laser distance meter recordings, however, a vegetative canopy was present at the north western extent of the pan and thickets were scattered throughout.

Coordinates were logged where possible and the laser distance meter used where there were no interferences. It must be noted, two GPS satellite devices were used, and both showed limited ability for accuracy in areas with dense vegetation and/or a tall canopy layer.

5.1.2 Invertebrate Data Collection

Aquatic Invertebrate Sampling



Figure 5.7: The figure shows an area selected at Nwambi pan for aquatic invertebrate sampling (photographs are researchers own)

Aquatic invertebrates were collected from all the seven pan systems water body; if no water was present, a sample could not be completed. Sampling areas were determined by different ecological factors such as areas in shade, sunlight, vegetated/non- vegetated, accessible, muddy or rocky, all of which provide different micro habitats. Figure 5.7 shows an example of a non-vegetated, shady and muddy area chosen for sampling. A method called 'sweep net sampling' was used as it is the best method for shallow waters (Bird, 2010). A bottom sweep was obtained once the pole had been used to disturb the contents of the bottom of the pan. Samples were then bottled and brought back to the laboratory for identification at the family, genus or species level according to the use of the Aquatic Invertebrates of South African Rivers (Gerber and Gabriel, 2002).

Aquatic Invertebrate (Surface Sweep)

Sample sites were selected according to ecology or micro habitats around the pans. Once a sample site location was selected, a GPS location point was taken and the aquatic invertebrates were be sampled. Surface sweeps were collected by sweeping an aquatic net from left to right at a distance of 2m x 4 sweeps of the net. The samples collected in the net were then placed into a bottle with water from the pan and labelled (i.e. NWA 1.1). The samples were labelled 1.1 if they were surface sweeps and 1.2 if they were disturbed sweeps. The net was then cleaned and checked for any invertebrate accidentally still stuck in the net.

Aquatic Invertebrate (Disturbed Sweep)

Disturbed sweeps were collected in the same aquatic net by disturbing the saturated soil under the water in the sample site area with a rod. The sample area was a 2m x 2m area. The net sweeps were then taken again 2m x 4 sweeps, samples were then bottled and labelled (i.e. NWA 1.2).

5.1.3 Lab Storage

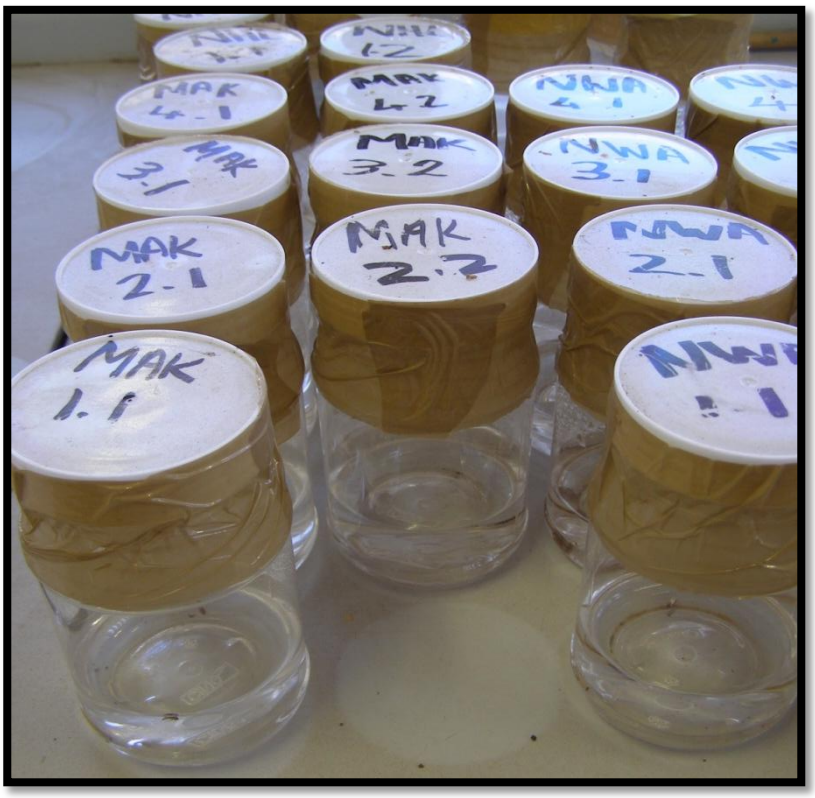


Figure 5.8: This figure shows the containers used to hold the aquatic invertebrates until they were taken to the laboratory together with the labelling technique and formalin inside to preserve the specimens (photographs are researchers own)

Once the samples had been collected they were placed in a sealed container with cooler bricks until camp was reached and the aquatic invertebrates could be identified and sorted. The samples were emptied out one by one into a sorting tray containing a 2cm layer of water, which was used to dilute the dark water to better identify the invertebrates. Distinguishing features were noted about the samples water conditions, smell, colour etc. Specimens found were sorted through with tweezers and collected. Representative sample species were collected for each species type and placed in a clean, formalin bottle labelled according to which pan it was found and which net sweep (see figure 5.8). Each species was then identified to their family and genus, if possible, by means of a SAS card. The samples from each study site were bottled again, placed in formalin and brought back to the University of the Witwatersrand for further classification of any unknown species.

5.2 Lab Data Analysis

Lab work and analysis was carried out at the University of the Witwatersrand. The soil analysis was completed in the Environmental lab of the Geography department and the aquatic invertebrate component of the lab analysis was completed in the Animals and Plants Sciences department. The soil sample analysis consisted of

four processes, initially calculating the moisture content of the soil by drying it in an oven, secondly calculating the combustible organic percentage in the soil by burning it in a kiln, thirdly calculating the percentage of average particle size of each sample by sieving and lastly analysing the particle size distribution by means of a statistical program called Gradistat to establish the mean, sorting, skewness and kurtosis properties of the soil and the overall sample type (Blott and Pye, 2001).

5.2.1 Soil Moisture Percentage

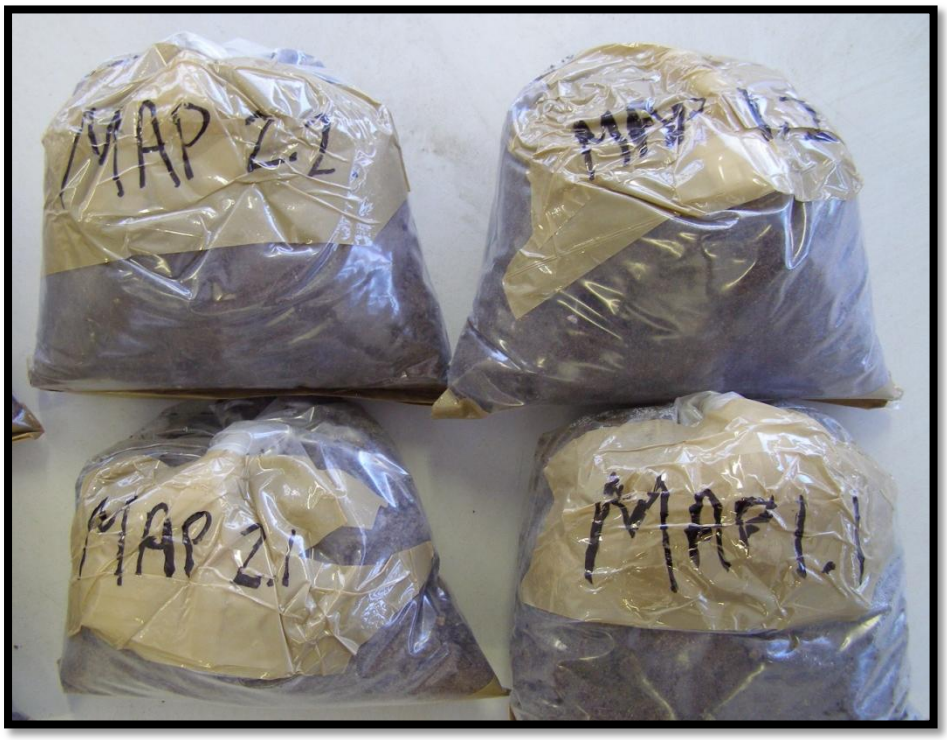


Figure 5.9: Shows soil samples in soil bags, taken from Mapimbi pan, with an air tight seal and appropriate labelling (photographs are researchers own)

To calculate the soil moisture, the samples (figure 5.9) were emptied out of the soil bags (air tight) onto a foil tray. Any large stones that could influence the soil particle size distribution tests were removed at this stage, but their composition noted. The foil tray's weight was removed and each soil sample was then weighed accordingly and the weight of the soil recorded. The trays, with the samples in them, were then placed in a sediment oven at 125 degrees Celsius (figure 5.10).



Figure 5.10: The oven in the Geography's environmental lab was used to dry the samples for the moisture testing of the samples (photographs are researchers own)

The samples were left overnight to dry out. Samples were then removed and placed into the desiccator for 12 hours to remove any moisture that might have been absorbed from the air in the lab. The samples were then removed from desiccator and reweighed to calculate moisture loss. This was achieved by the following calculation:

(Initial weight (wet) - Dry weight) ÷ Wet weight x 100 = % Relative Moisture

The samples were then stored again in soil bags if they were not being used immediately for combustible organic tests. The bags sites numbers were recorded in the same manner as in the fieldwork (i.e. NWA 1.1).

5.2.2 Combustible Organic Matter

Due to the moisture content needing to be calculated first, the soil samples became hard and compact. As a result, the peds needed to be crushed systematically so as to still keep the original particle size intact. This was achieved with the use of a ceramic mortar and pestle. Crucibles were heated then placed into the desiccator for 2 hours to make sure the crucibles themselves were not holding moisture which could influence the sample weight. A representative sample of the crushed soil (crucible size sample, average weight 30g) was used to represent the whole site sample. Once the crucibles were removed from the desiccator they were weighed and their weight recorded. The crushed soil samples were then placed into crucibles. Samples were then placed into a kiln at 500 degrees Celsius. This high temperature was chosen to make sure that all of the organic matter would be successfully burnt off. A diagram was drawn once the samples were placed into the kiln to ensure the correct identity of the samples for each pan site number. After 24 hours the samples were removed and place back into the desiccator for 12 hours. This was required again to ensure no moisture from the lab had been absorbed into the sample with the heat it held once removed from the kiln. The samples were removed and reweighed to calculate the organic content. This was calculated as follows:

(Original weight - burnt weight) ÷ Original weight x 100 = % Relative Organic Content

5.2.3 Average Particle Size Distribution



Figure 5.11: This figure shows the sieves that were used to sieve the soil in the environmental laboratory

Particle size distribution of soil samples was established with standard sieve techniques. The sieve sizes chosen were based on their ability to provide a rounded idea of the particle size distribution per sample acquired (figure 5.11). The larger sieves were positioned at the top and worked down in numerical value biggest to smallest. The samples were then placed into top sieve size and the lid set on top. The sieves were manually shaken for (20 min). After the first 10 minutes the samples top sieve was checked for any large peds that needed to be rubbed gently through the mess, a further 10 minutes of shaking was completed to ensure all the sample had been adequately sieved through. Thereafter the samples were left to stand for 15 minutes until all the fine silt had settled. Each sieve size was separated and the contents per aperture size poured into a foil tray (the trays weight was excluded) and the sample weighed. These weights were noted to determine the percentage of soil particle size distribution for each sample at a later stage with the Gradistat program figure 5.12 below.

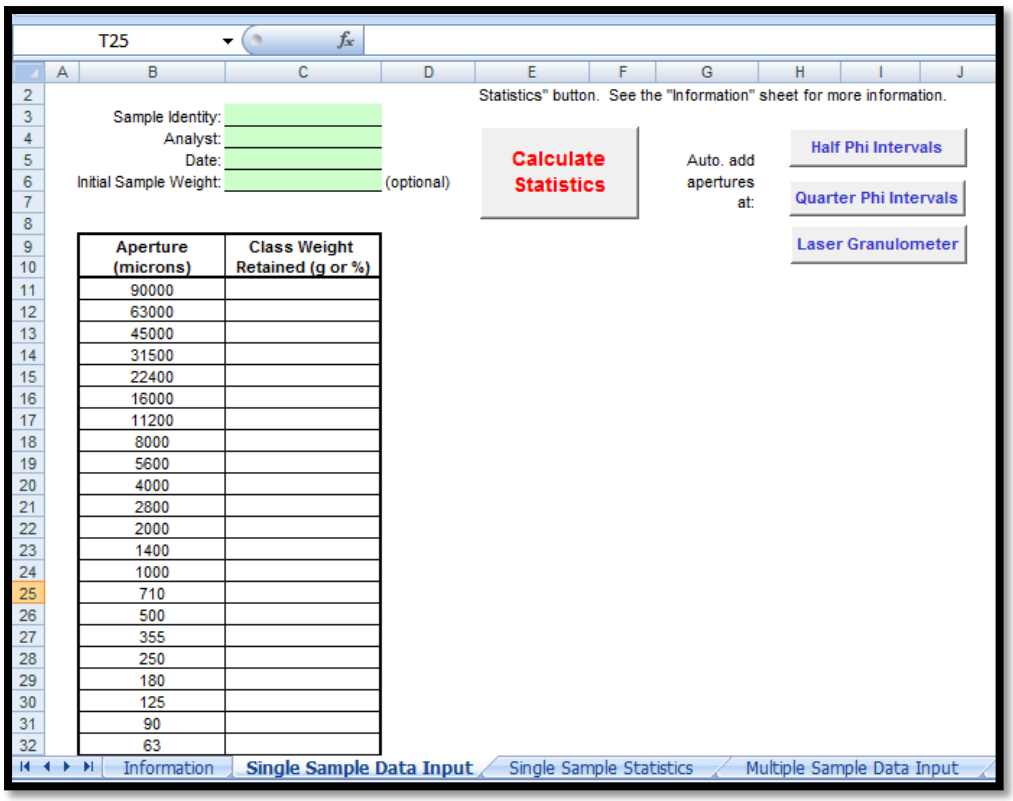


Figure 5.12: Screen shot of the Single Sample Data Input method used in from the Gradistat program. Aperture sizes 63 – 2000 were used

5.2.4 Statistical Analysis of Particle Size Distribution

The Gradistat Version 4.0 was chosen for its rapid analysis of sieve data (Blott and Pye, 2001). The program is best suited to analyse data obtained from sieve or laser granulometer analysis. The results recorded (values obtained) from the sieving of the soil samples were used and input into the intervals provided by the statistical analysis program. Quarter Phi Intervals were selected to compute the results. The single sample statistics were then calculated using the Method of Moments in Microsoft Visual Basic programming language; mean, mode, sorting, skewness and kurtosis. Physical descriptions such as, very coarse sand, moderately sorted and fine gravelly coarse sand was also calculated by Folk and Ward (1957) methods. A grain size distribution graph was also computed.

5.2.5 Aquatic Invertebrate Analysis



Figure 5.13: The figure below depicts a Fairy Shrimp, which was identified after analysis under the microscope used in the APES department at the University of the Witwatersrand (photographs are researchers own)

During the identification, various different references were used to establish the species found in each sample. Some aquatic invertebrates were unidentifiable on site with just the use of the naked eye and the database of references listed above (Astri and Leroy, 2000; Gerber and Gabriel, 2002; Picker et al., 2002). Their sample site was noted and they were brought back to the University of the Witwatersrand for further identification in the entomologist laboratory in the Animals, Plants and Environmental Studies department. The approach that was taken was to assume the prospective order of the aquatic invertebrate and work down to the species. To determine this, the structure or characteristics of the specimens body parts (similarities or differences) were assessed, i.e. eyes, mouthparts, segments, antennae and legs. Thus, by a process of reasonable deduction, the aquatic invertebrates could be identified. During this process the aquatic invertebrates were also photographed. A Fairy Shrimp can be seen in figure 5.13 with the use of a microscope to allow for archiving and to search for related articles of the different species at a later stage in the research. Species associations were also drawn between the different physical variables and the environmental variables at this point. This was completed by comparing species sensitivity to their types of surroundings and assessing their general characteristics/habitats and relating the literature to what was found on site.

5.3 GIS and Remote Sensing

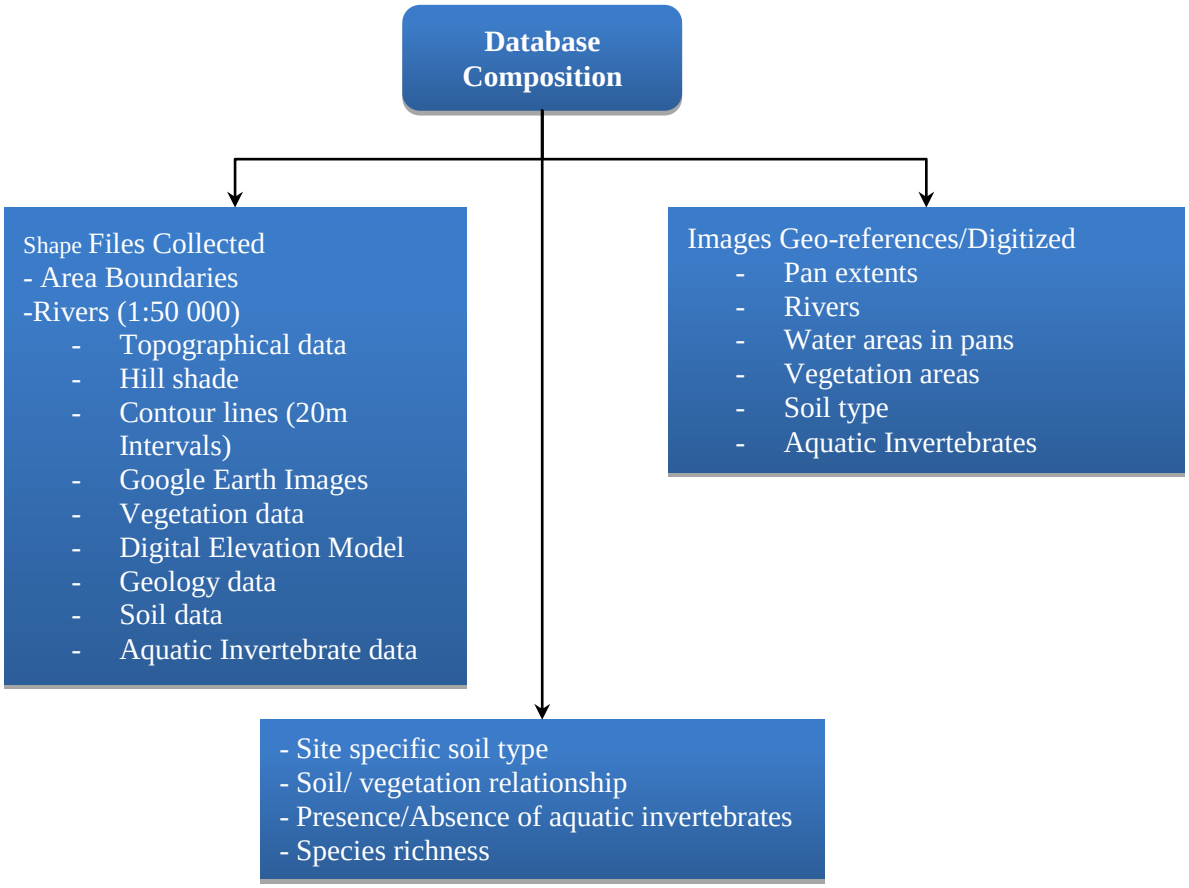


Figure 5.14: A diagram indicating the data used in the production of GIS figures/maps

Remote sensing, geo-referencing/digitization in conjunction with ground surveys, is an effective tool to rapidly survey large areas of land and water (Myers and Cowardin, 1974). These tools allows for the detection of details not apparent from field surveys. Remote sensing also allows for the detection of land cover (figure 4.13) and its change. It is important to monitor land cover change, because although fluctuations in local conditions do occur naturally over time they can also be unnatural and as a result detrimental to the ecosystems that find themselves caught in a period of land cover change and the relative consequences (Nagendra, 2001). GIS is beneficial for this research as not all the pans can be ground surveyed due to thick vegetation, increased wetted area (lack of solid ground) and danger created by wild animals present at some pans. Remote sensing is beneficial to wetland mapping and inventory as it allows for the identification of healthy plant species and vegetation change due to climatic changes by using infrared colours (Feddema et al., 2005). However, wetlands can be missed with the use of this method if they are dried up or are too small; to counteract this problem the area was compared with aerial photographs and digitization, seen below in figure 5.15.

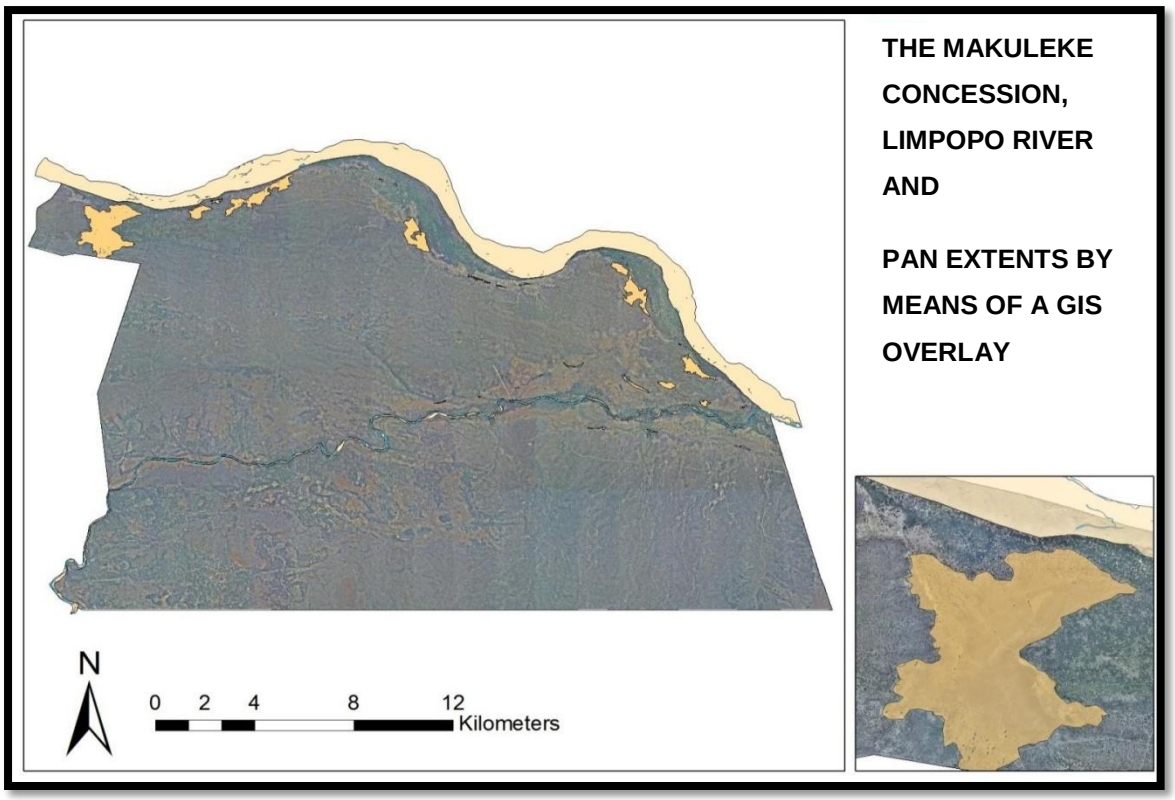


Figure 5.15: This figure was produced by Martin (2011), by using an aerial photograph and importing its shape file into ArcGIS then overlying the KNP boundary, rivers and pan extents. The aerial photograph is a figure from 2008 as that is the last updated reference

The extent shows how aerial photography together with remote sensing and pan extents can be identified, minimizing the chance of these wetland systems going undetected, even if they are not filled with water. This type of digitizing can, in this instance, be more valuable and used as a monitoring tool as the pan extents are more accurate. It is, however, more costly and time consuming and does not allow for an onsite evaluation of the systems which is always more informative. These types of digitized figures should be used in conjunction with fieldwork data to make the figure worthwhile. The Red, Green and Blue (RGB) bands are used during the overlay process to create depth in a figure and draw out features such as drainage lines.

This method serves to provide a qualitative assessment of the pan extents present in the Makuleke area. Changes in inland wetland areas can be identified by a number of methods, namely holding environmental variables as a constant, i.e. time of year (vegetation, size of water body) and using a change detection algorithm (Jensen et al., 1995). GIS has been used extensively in the conservation of geo-physical aspects of the world and has been found widely beneficial in classifying aquatic ecological systems which uses data on surficial geography, land surface elevation, lake-hydrology and other ecologically relevant information (Higgins et al., 2005). The use of these advanced technologies allows for a broader, more scientific understanding of the topographical and vegetation data, aiding in the identification of the pans and assessment of the ecosystems in and around them.

The following studies were drawn from to add value to this study as they were compiled around the same time and in the same study area.

- Pans and alluvial plains of northern Kruger (Viljoen, In Prep);

- An analysis of pans in the Makuleke contractual park, Kruger National Park, South Africa from 1963 – 2008. *Kruger National Park, Ramsar Wetlands site, GIS and Remote Sensing, Pan Inventories* (Martin, 2011);
- The influence of pan characteristics on their seasonal usage by mammals within the Makuleke Ramsar Wetland System (Antrobus, 2013);
- Land cover change between 2000 and 2010 in the Pafuri Triangle of the Makuleke contractual park in the Kruger National Park, South Africa (Knight, 2011);
- Avifaunal responses to vegetation characteristics around pans of the Makuleke Ramsar Wetland Site, Kruger National Park (Zoghby, 2011).

Table 5.1 was developed to identify the two sources, primary and secondary for this research with which valuable information was derived and compared to with the fieldwork component in this study.

Table 5-1: Sources for extracting GIS overlays

The table below states where the following information required for creating the GIS overlays was extracted from:

Information	**Primary/ Secondary Data**	**Source**
Geology	Secondary	Baseline geology was acquired from the South African national spatial biodiversity assessment report (Nel et al., 2004).
Soils	Secondary	Soil form literature and shape files were considered in relation to this study pans (Nortje et al., 2012).
	Primary	Soil samples extracted during the fieldwork portion of this study were allocated GPS points which were plotted on a map during the GIS section of this study.
	Primary	A new soil form map was then created in ArcGIS Version 10
Pans extents	Primary	Pan extents were measured via a distometer and GPS coordinates from ground truthing. The relevant maps in this study were then created in ArcGIS Version 10.
Vegetation (vegetation biomes and vegetation rasters and vectors)	Secondary	Shape files were obtained from Musina and Rutherford (2006) datasets, the data was then used in ArcGIS Version 10 to create the vegetation map seen in this study.
	Secondary	A list of the vegetative species cover list, surrounding some of the pans was obtained from Blair Zoghby.
Topography	Secondary	The topography shape files were obtained from a company called Environmental Impact Management

Information	Primary/ Secondary Data	Source
		Services.
	Primary	The topography shape files were then merged with the pan extent data and rivers to create the map seen in this study.
Hydrology (river overlays and endangered data)	Secondary	The hydrology data was acquired from Nel et al., (2004) Martin (2011).
	Secondary	The report provided the endangered river data (Nel et al. 2004).
River flow and rainfall	Secondary	The river flow and rainfall data stations was acquired from Martin (2011)
	Secondary	Rainfall data was acquired from the South African Weather Service for the duration of the study.
	Secondary	The rainfall graph illustrating rainfall patterns from 1963-2008 was acquired from Martin (2011)
Water quality data	Secondary	The raw water quality dataset was acquired from Antrobus (2013).
	Primary	An analysis of the water quality was then completed in this study in relation to the aquatic invertebrates.
Aquatic invertebrate data	Primary	A GPS coordinate was taken at each sample site during the fieldwork sampling. During the GIS section of this study these coordinates were utilized in creating a map to identify where the samples were undertaken in the pan system.

5.4 GIS Image Created for the Study Site

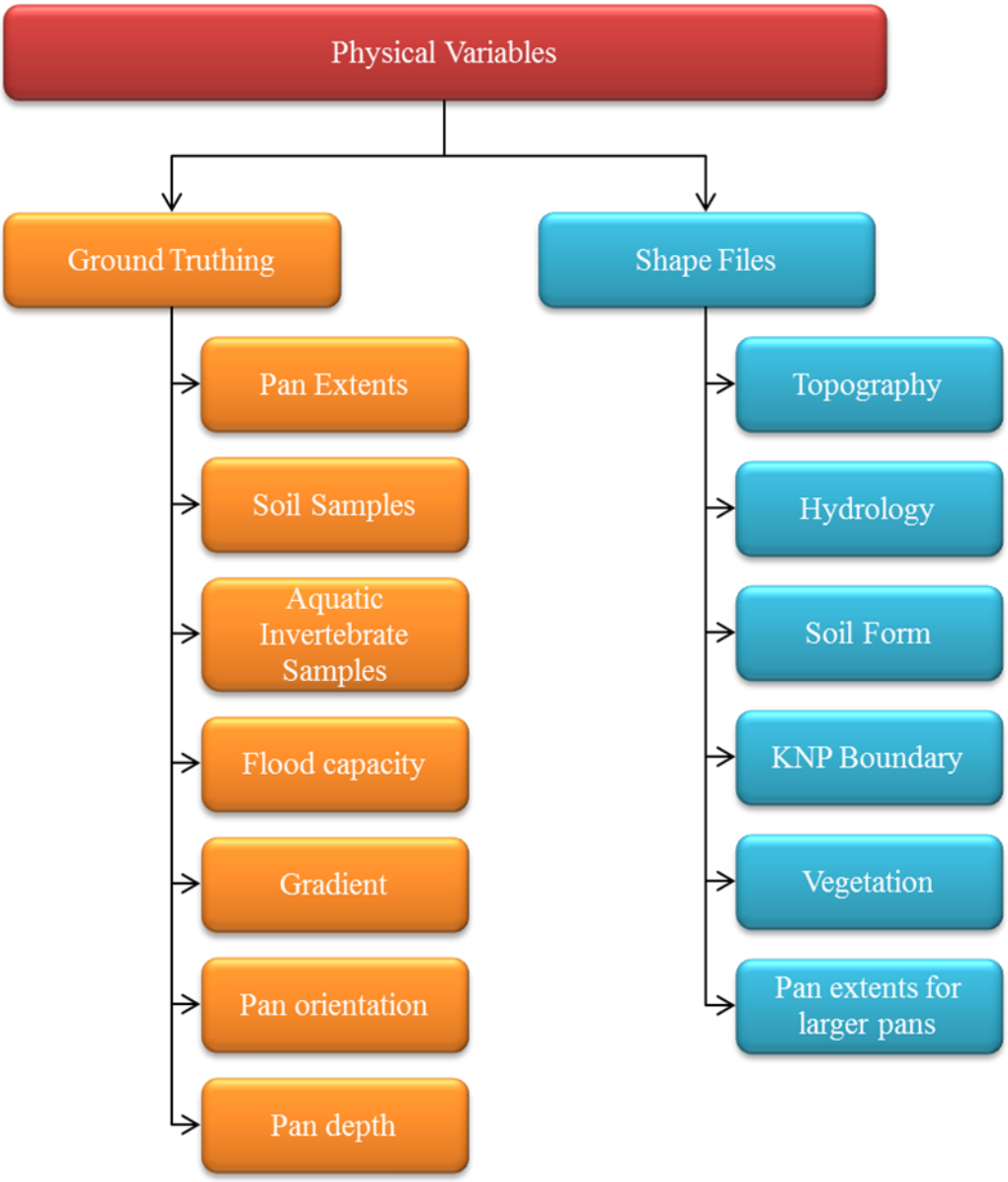


Figure 5.16: The physical variables acquired versus the shape files acquired to create the GIS maps

5.4.1 Digitized Maps in Previous Studies

Study Area

The study area is based inside the Makuleke concession which is an extension of the KNP and also a declared Ramsar site. To create the GIS figure, seen in figure 4.1, certain shape files were required (figure 5.16):

- The Kruger National Parks northern boundary,
- The main rivers in the Kruger National Park region and
- The roads within the Makuleke concession

Originally, the shape files and raster (classified) images incorporated the study area and areas surrounding the concession. As a result of this, the data were clipped in ArcGIS (Version 10) to simplify and condense the data

and aesthetics. The clipping tool is an analysis tool that allows the researcher to extract input features that overly the clip features therefore creating a new feature class or area of interest. For this to occur the clipped dataset must be a polygon, i.e. the Kruger National Park Boundary (Geographic Coordinate System: WGS_1984). Line features such as the main rivers in the study area (Geographic Coordinate System: WGS_1984) (the Limpopo and Luvuvhu) were clipped by the polygon feature class. Once the relevant shape files have been clipped, they can be utilized in the rest of the dataset's maps. For the study area to depict the rivers and the roads on the KNP boundary an overlay needed to be created. By using this tool the feature classes placed above the KNP boundary can be seen and analysed. This process also helps the researcher determine important features in a dataset.

Study Sites (Pans)

Figure 4.2 was created in the same manner, whereby utilizing the overlay tool for the KNP boundary, rivers and pan extents (polygons- Geographic Coordinate System: WGS_1984). The pan extents were created by plotting the GPS co-ordinates taken during the ground truthing part of this study. It is noted that during the GPS recording process an element of inaccuracy occurred. This generally occurred with cloud cover and heavily vegetated areas around the pans. The inaccuracy reached from 3 m – 60 m at times, as was established when the sample site coordinates were plotted on the maps with GIS. The pan extents were overlaid on top of the KNP boundary and rivers to provide analysis for possible relationships between their position and hydrology. Irregular coordinates which displayed large inaccuracies, e.g. 60 m, were removed from the pan extent dataset in GIS as to not skew the shape of the pans. The maps found in section 5.4.1 indicate some sample points within the pan extent area; this is due to two factors: 1) the inaccuracy of the satellite GPS coordinates during ground truthing and 2) due to parts of the pan being inaccessible, geo-referencing and digitization was required to join the extents as shown in figure 5.15.

Soil Form

The soil form map, figure 4.7, was created to illustrate the polygon classes – (Geographic Coordinate System: WGS_1984) that represented the different soil forms in the study area. From this map, pan locality, according to the GIS generated soil form from Viljoen (In Prep), and a cross-reference between the soil analyses in the environmental laboratory soil characteristics can be confirmed. Again the rivers were overlaid in this image to provide spatial reference and possible soil relationships and the KNP boundary to provide locality.

Proposed Method for Inundation

The figure 4.9 was created by Martin (2011) in ArcGIS (Version 9.3) to illustrate the potential method of inundation in the pans. Here, the image is clipped with various layers. The analysis for this image however, comes from the use of topographic feature classes such as DEMs, hill shades, and contour and hydrology data. Characteristics such as height, geology, levees and flood capabilities were assessed in combination.

Vegetation Map

Figure 4.12 depicts a map of the relevant vegetation found in the study area. This map was created with the information acquired from Mucina and Rutherford (2006) regarding the bio-regions in the study area. The layers required for this map to create relationships were the pan extent shape files, the vegetation units and the rivers. This map was then cross referenced with the soil form map in figure 4.6.

Soil and Aquatic Invertebrate Sample Sites

To create the series of images below the following methodology was followed:

The seven pans that were chosen were all ground truthed. GPS points for the pan extent dataset were only available as far as the vegetation would allow, in terms of accessibility. The rest of the 'pan extents' were geo-referenced in the manner seen in figure 5.15 with aerial photographs from 2008. The coordinates located inside the pan extent may also indicate a smaller water body that was present during the sampling period for Martin's research (2011-2012) (Martin, 2011). The GPS points were loaded into ArcCatalog 10 together with points from the geo-referenced images of the areas and overlapping or outlier data points were removed. The points were then saved as a shape file and imported into ArcGIS 10. In ArcGIS 10 the data points were joined together by lines to create a polygon image representing the pans extent, inclusive of wetted area. Once the pan extents were overlaid on the KNP boundary the soil sample data points were plotted. By the use of the same process, the soil GPS data was edited in ArcCatalog 10 before it was imported as a point data shape file into ArcGIS 10 for image production and analysis. The aquatic invertebrate data was digitized similarly, as the same baseline information was required for the maps. The GPS points input into ArcGIS illustrate the position of the aquatic invertebrate sample taken. There are fewer points digitized in this section as samples were chosen according to differences in biotopes in the pan systems and these often varied. The following maps indicate the data with the use of a main data frame and an extent indicator data frame. The main data frame was used to zoom into the pan to show its shape and the position of the sample sites corresponding to the pan. The extent indicator data frame was added to illustrate to the reader, where in the region the study site could be located. The study site is indicated by a red box around it. Closer inspection of the scale bars will also yield a difference from km to m, this is because the sizes of the pans vary greatly and as a result, require a different scale. During the ground truthing, the number of transects per pan was decided on by the differences in gradient surrounding the pan systems. For example, wherever significant changes in gradient were noted a transect was decided upon. In the GIS component, transects were measured in ArcGIS 10 with the measuring toolbar, the distances appear in decimal degrees, therefore the measurement needed to be changed to read in metres. The distance was read by selecting a point and dragging the ruler to the next location in the data source. Each transect distance was measured from each sample site at each gradient change. The gradient section for the pans systems indicates an increase or decrease in the slope. To indicate these gradient changes in this study the following notation has been provided: e.g. (+ values = increase in slope, - values = decrease in slope).

Gwalala Pan

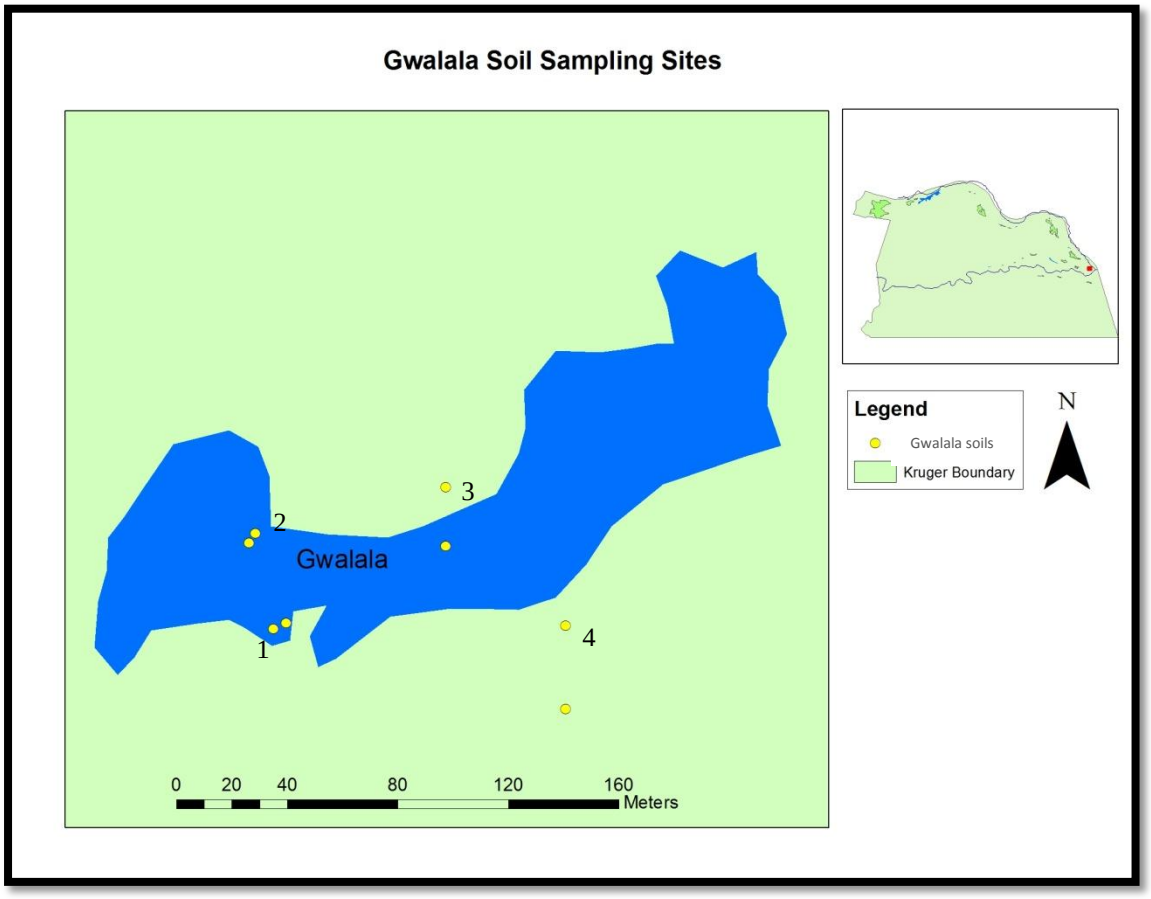


Figure 5.17: GIS figure of Gwalala soil sample sites

The Gwalala pans orientation runs from ENE to WSW. Gwalala is known to be the first pan in the area to flood in the rainy season. The pans northern side has a higher levee with a gradient of ($^{+}$10°) at site 2.1 and a gradient of ($^{+}$39°) at 3.1, with its southern side with a gradient of ($^{+}$2°) at 1.1 and ($^{+}$3°) at 4.1 exhibiting a generally lower gradient. The transect distance between the samples were the following sites 1.1-1.2= 12 m, sites 2.1-2.2= 4 m, sites 3.1-3.2 = 21 m and sites 4.1- 4.2 = 30 m. The widest part of the pan could be found west of sites 1 and 2 at 65 m.

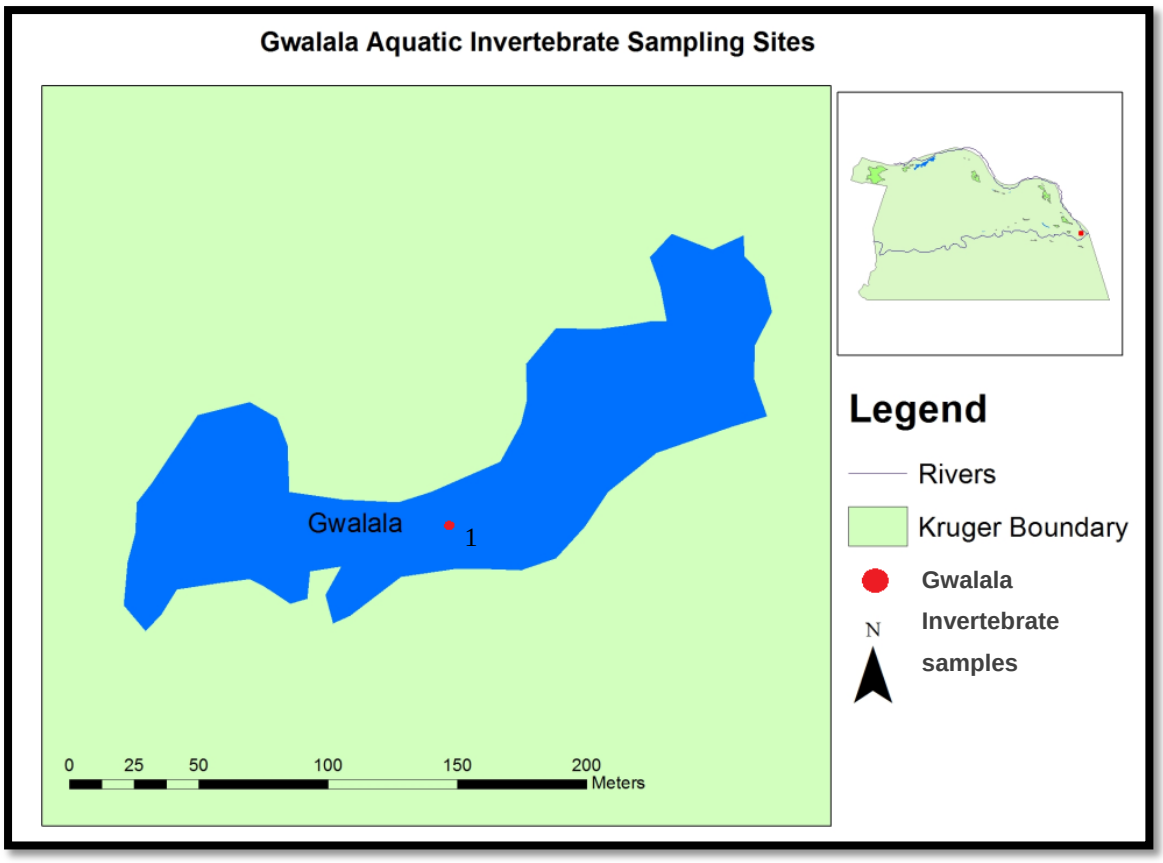


Figure 5.18: GIS figure of Gwalala aquatic invertebrate sample sites

This ArcGIS map illustrates the sample site of aquatic invertebrates for Gwalala. The pan extent was recorded in March 2011, during the soil sampling period. The reason the aquatic sampling GPS point appears in the centre of the pan, is as a result of the first set of sampling for aquatic invertebrates that commenced in the following sampling period of November 2011. Based on the lack of water availability in both the sample periods for this pan, the pans biotope characteristics were shallow, shady and disturbed sediment filled waters.

Likangwa Pan

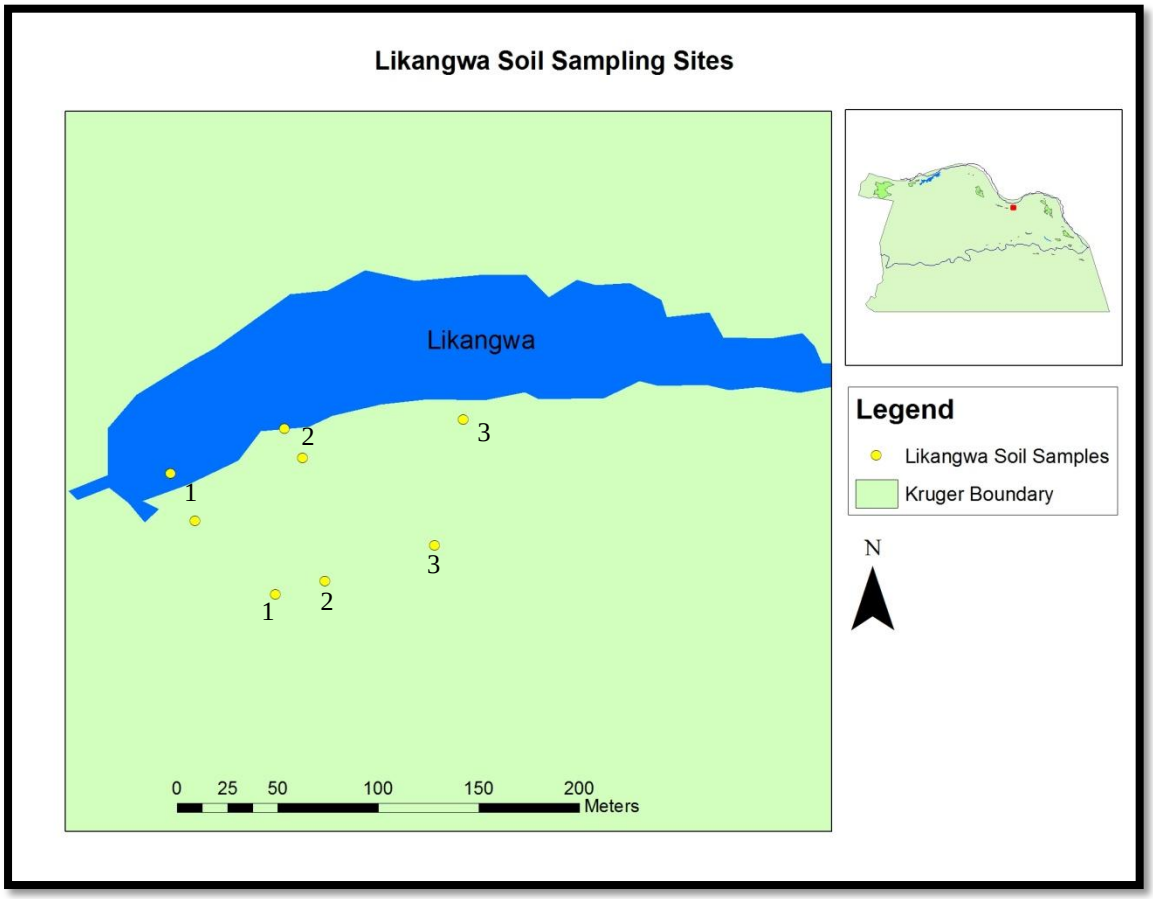


Figure 5.19: GIS figure of Likangwa's soil sample sites

Likangwa's orientation runs E to WSW. The pan is said to be on an ecotone with its northern side being Limpopo floodplain and its southern banks hosting a Baobab Mopane hillslope with a gradient of ($^{+}$22°) at site 1.1, a gradient of ($^{+}$15°) at site 1.2, site 2.1-2.2 had a gradient of ($^{+}$30°), sites 2.2-2.3 a gradient of ($^{-}$4°) and site 3.1 a gradient of ($^{+}$2°). The transect distance between the samples were the following: sites 1.1-1.2 = 27 m, sites 1.1-1.3 = 78 m, sites 2.1-2.2 = 17, sites 2.1-2.3 = 78 and sites 3.1-3.2 = 63. The pans widest part was 64 m between sites 2 and 3. As illustrated in figure 5.19, samples have only been taken from the southern side of the pan system. The reason for this is that the northern side of the pan system was not accessible due to dense vegetation and dangerous game. It was decided that even though not all the samples could be accessed, some data for the site would be valued and used to compare with the other pans located off the Limpopo River.

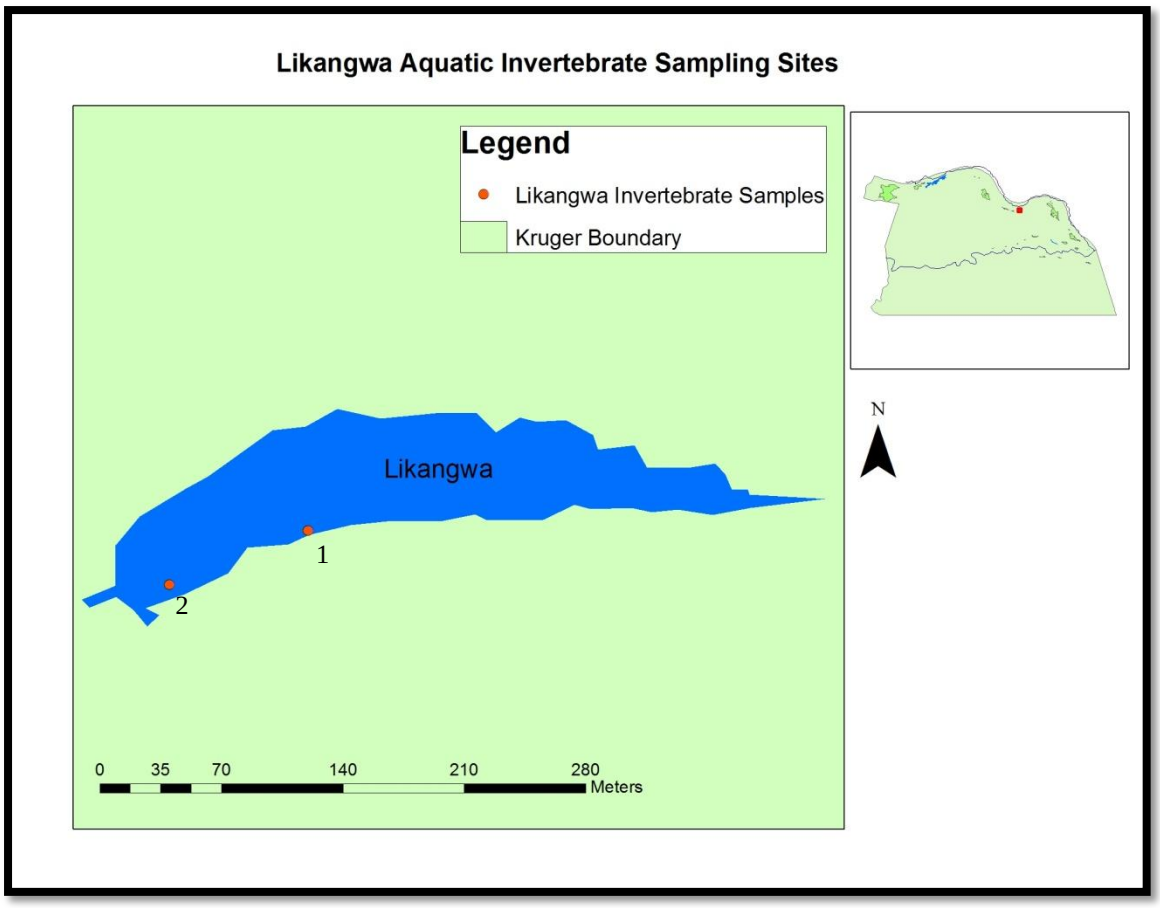


Figure 5.20: GIS figure of Likangwa's aquatic invertebrate sample sites

This ArcGIS map illustrates the sample site of aquatic invertebrates for Likangwa. Two sample sites were chosen here on the basis of accessibility as there was thick vegetation surrounding the pan, namely Elephant grass and soft clayey soils under foot. Sample site 1 was indicative of a rocky shallow biotope area with algae in the water. Sample site 2 differed in that it was associated with aquatic vegetation and deeper water.

Magomugomu Pan

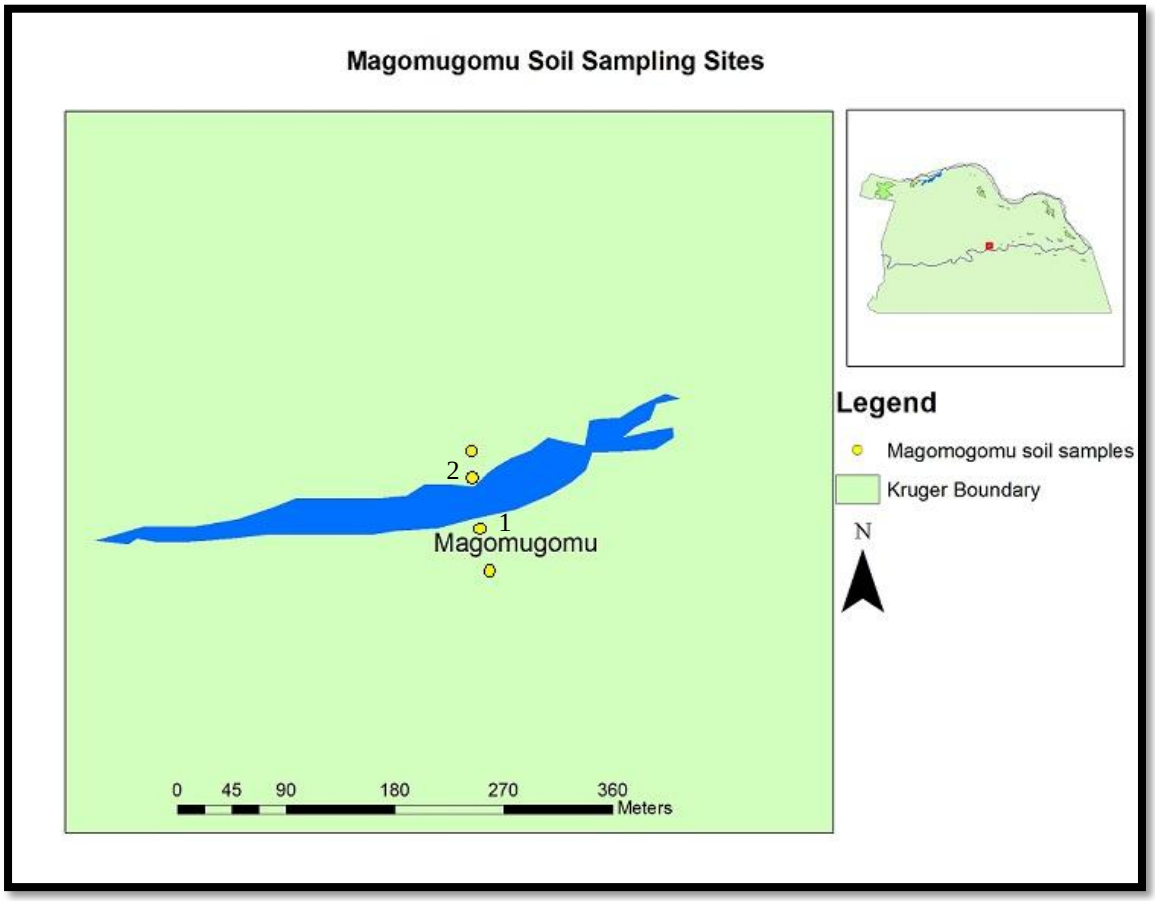


Figure 5.21: GIS figure of Magomugomu's soil sample sites

Magomugomu's orientation runs from ENE to W. On the northern side of the pan is a large rock outcrop almost kopje like, with a gradient of ($^{+}$7°) at site 2.1. The south of the pan opens onto an alluvial floodplain area with an elevation of ($^{+}$4°) at 1.1. The transect distance between samples were the following: sites 1.1- 1.2 = 47 m, sites 2.1- 2.2 = 21 m and the widest part of the water body of the pan was 41 m across. One transect was made use of at Magomugomu, this is because the transect is indicative of the gradient for the pan system.

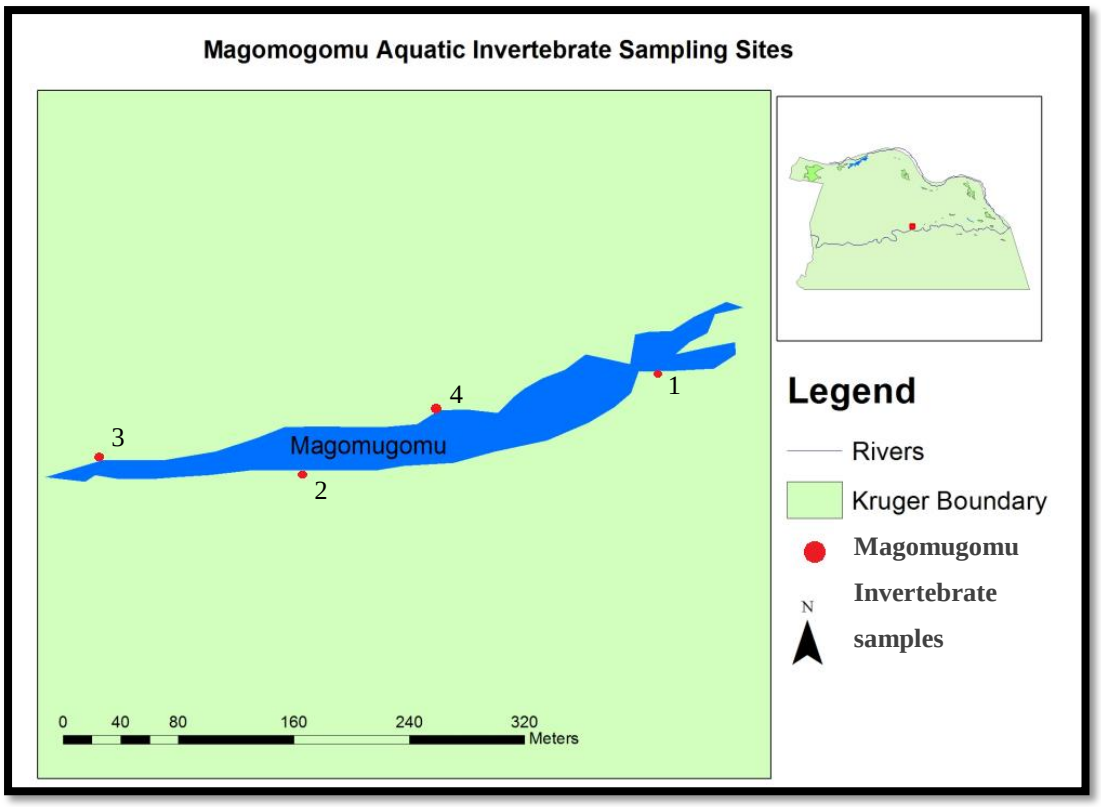


Figure 5.22: GIS figure of Magomugomu's aquatic invertebrate sample sites

This ArcGIS map illustrates the sample site of aquatic invertebrates for Magomugomu. Site 1 was chosen because it was directly in the sun all day and shallow. Site 2 is situated half way along the pan and is in open water. Site 3 is situated between the neck of the pan, where the south and north banks meet; the water here had suspended sediment and debris. Site 4 is located in an inlet with debris where there is a large tree and shade all day.

Makwadzi Pan

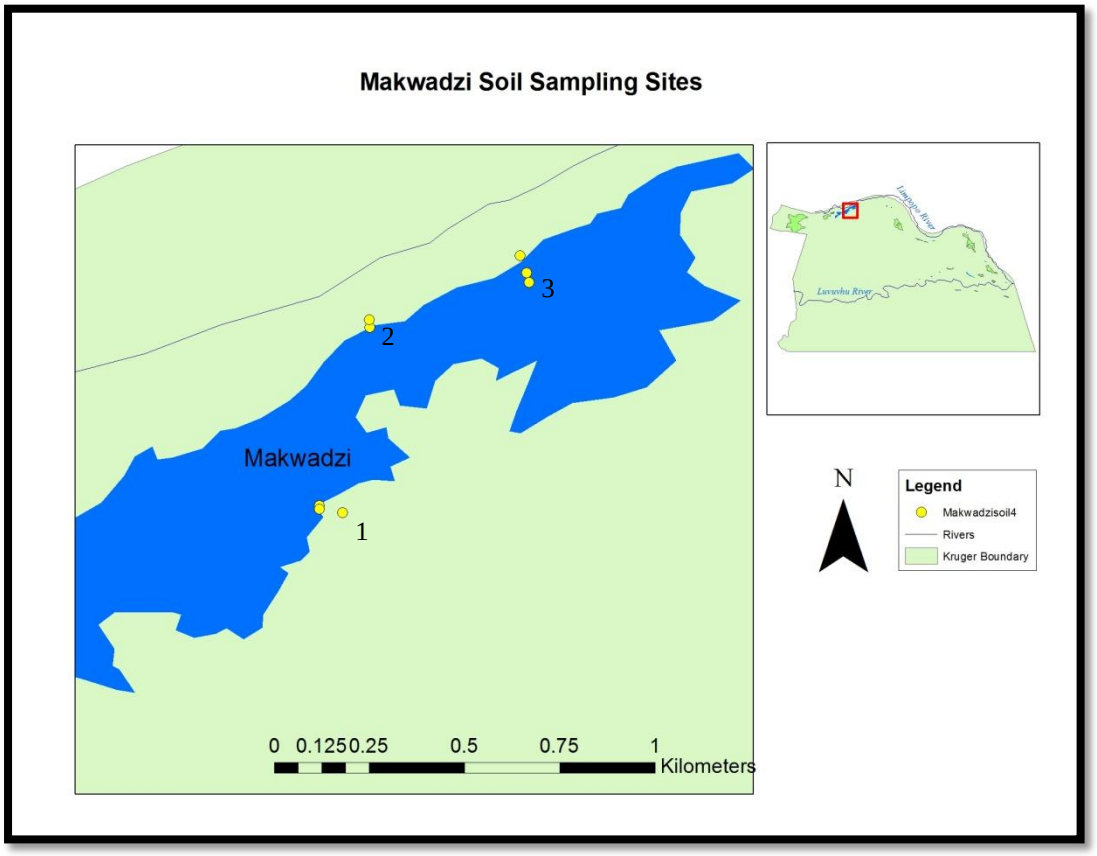


Figure 5.23: GIS figure of Makwadzi's soil sample sites

Makwadzi's pan extent was an imported shape file as the pan itself was too large and vegetated to ground truth. Makwadzi's orientation runs from NE to SW. The pan is very closely situated to the Limpopo River and as such exhibits prominent floodplain vegetation and characteristics. Makwadzi's east and western extents comprise of hill slopes. The southern side of the pan gradient is ($^{+}$13°) at site 1.1 and ($^{+}$20°) at site 1.2 and the northern side of the pans gradient is ($^{+}$10°) at site 2.1, ($^{+}$3°) at site 3.1 and ($^{+}$5°) at site 3.2. The transect distance between samples were the following: site 1.1 – 1.2 = 20 m, site 1.1 – 1.3 = 66 m, site 2.1 – 2.2 = 20 m, site 3.1 – 3.2 = 26 m and sites 3.1 – 3.3 = 73 m. The pans widest part was found west of point 1 at 535 m wide.

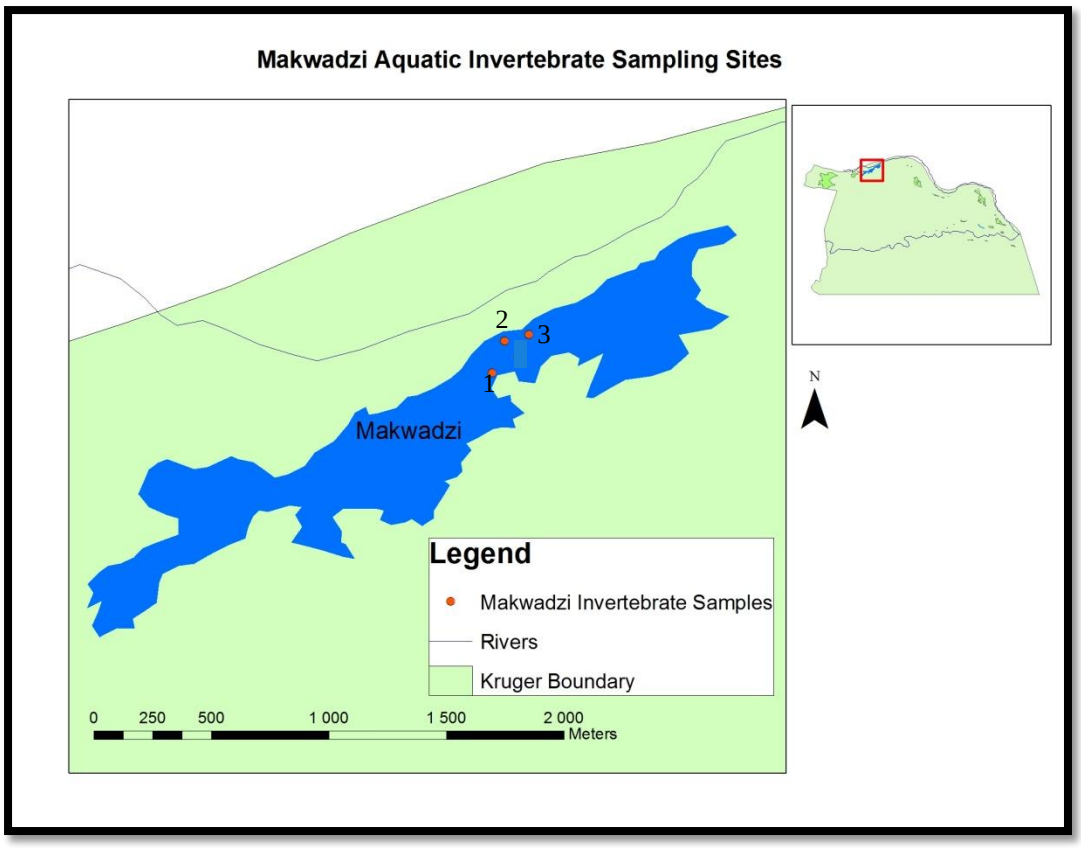


Figure 5.24: GIS figure of Makwadzi's aquatic invertebrate sample sites

Makwadzi's pans aquatic invertebrate samples were selected due to their accessibility owing to the vegetation and soft ground. Site 1 was associated with an area of rocky, clear water with some algae and partial shade. Site 2 was indicative of a very clayey area supporting reed vegetation exposed to sun all day. Site 3 was located in an inlet of the pan with hard dry clay banks with one side being vegetated and having algae present.

Mapimbi Pan

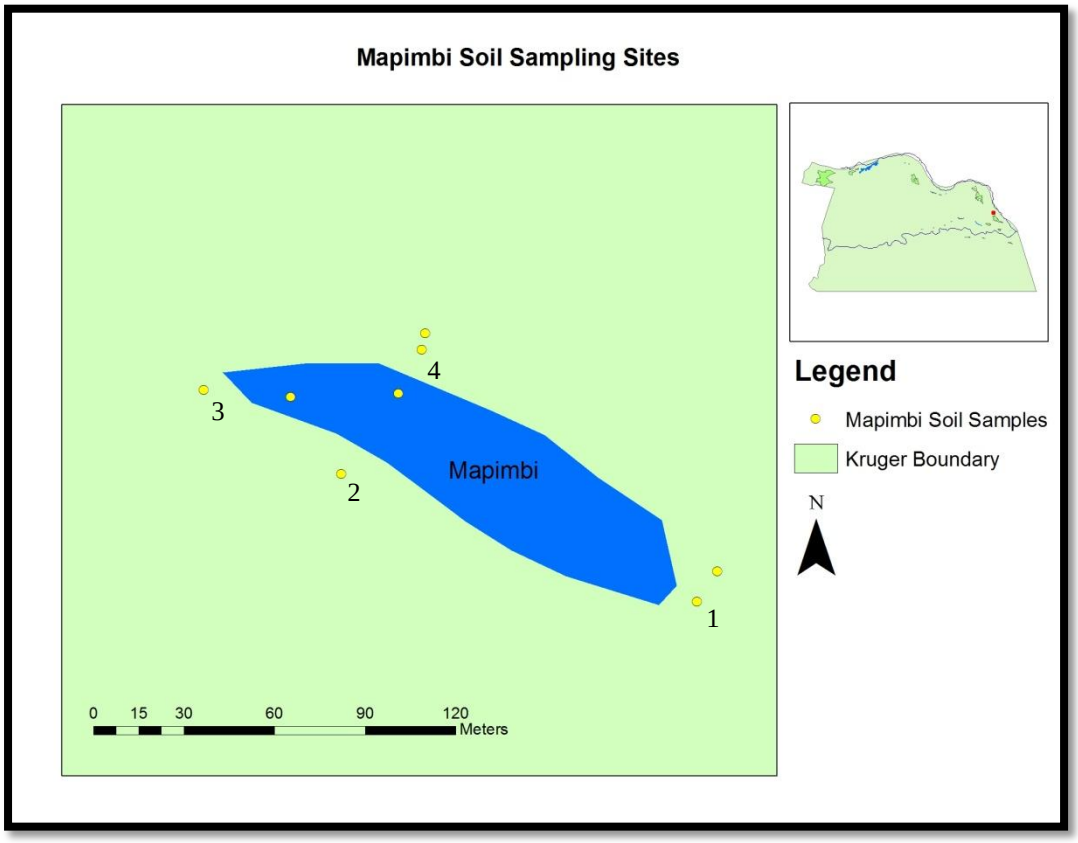


Figure 5.25: GIS figure of Mapimbi's soil sample sites

Point 2.1 appears in the pan itself, this is as a result of GPS inaccuracy caused by the dense vegetation surrounding the pan. Mapimbi pans orientation runs from ESE to WNW. The pan is characteristically basin like with steep levies. On the eastern bank of the pan the gradient at site 1.1 is ($^{+}$18°), the south is ($^{+}$16°) at site 2.1, west is ($^{+}$5°) at site 3.1 and the north is ($^{+}$11°) at site 4.1. The transect distance between samples sites was the following: site 1.1-1.2 = 12 m, site 2.1-2.2 = 11 m, site 3.1-3.2 = 27 m and site 4.1-4.2 = 6 m. The widest part of the pan was located between sample site 1 and 2 at 37 m.

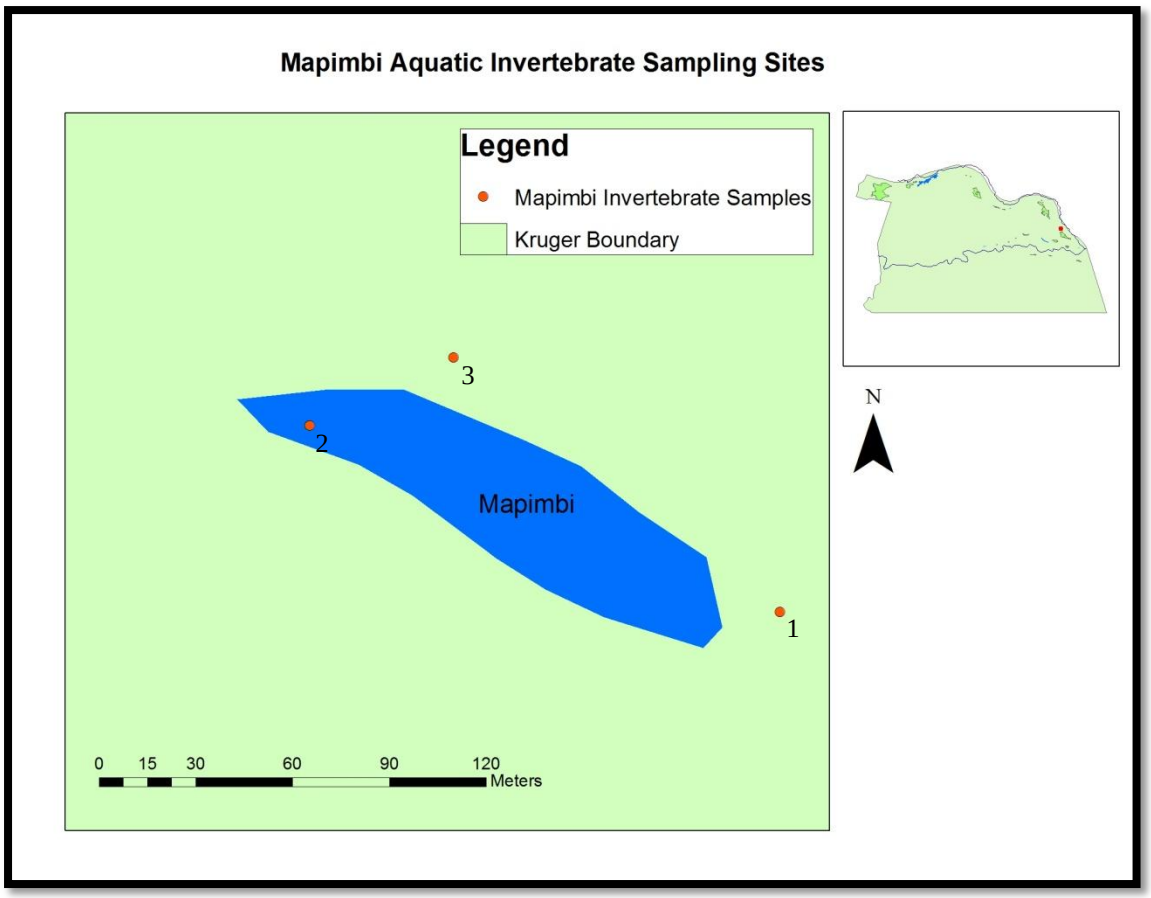


Figure 5.26: GIS figure of Mapimbi's aquatic invertebrate sample sites

This maps GPS point data was again affected by the dense vegetation, but serves to give an approximate zone for the aquatic invertebrate sampling. Site 1 was found in a shaded area with a steep slope into the water and debris on both the floor and surface of the water. Site 2 was located in a very rocky area with debris and a sunny surface. Site 3 was indicative of a sheer drop off, in a sunny area with vegetation and debris.

Nhlangaluwe Pan

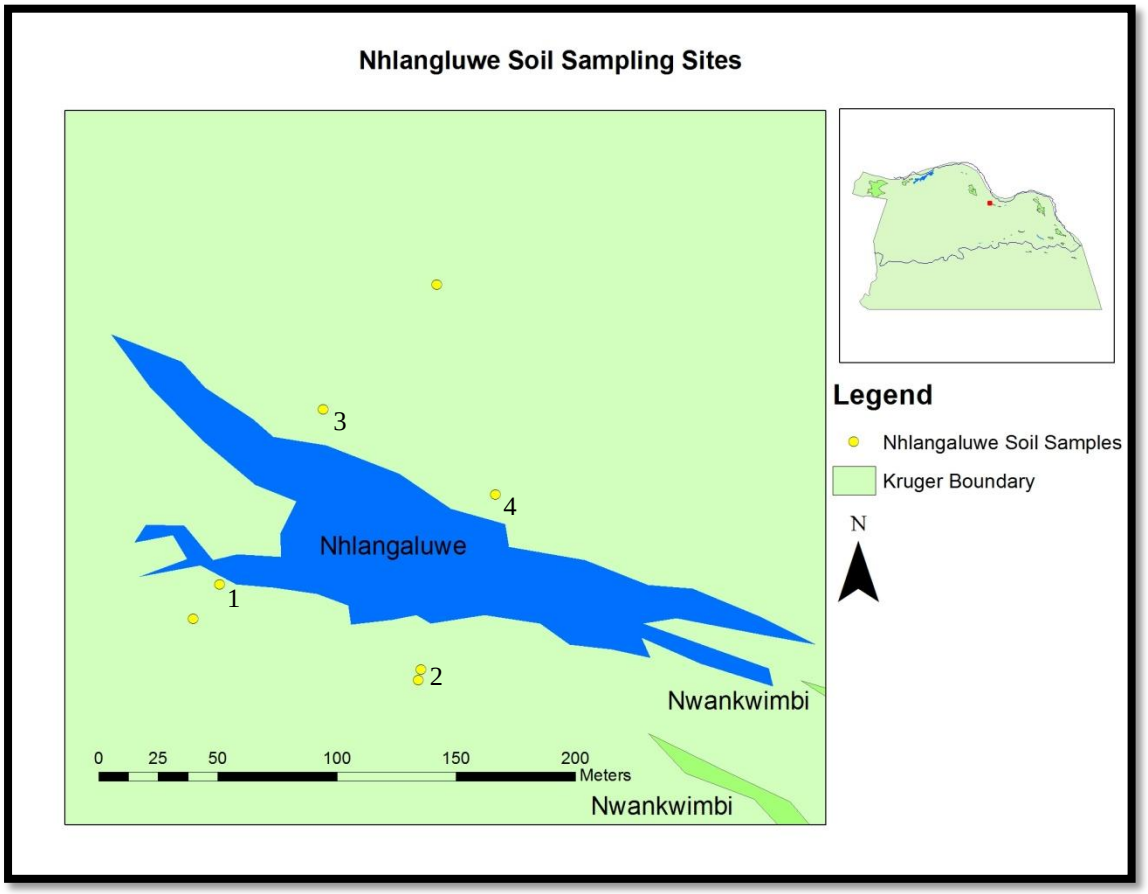


Figure 5.27: GIS figure of Nhlangaluwe's soil sample sites

Nhlangaluwe's pans orientation runs ESE to WNW. The pan is narrow and found between two kopjes with calcrete deposits. The pans eastern side has the ability during flood to join with its neighbouring pan Nwankwimbi. The northern side of the pan has a gradient of ($^{+}$44°) at site 1.1 a gradient of ($^{+}$33°) at site 2.1 and the southern side a gradient of ($^{+}$6°) at site 3.1. The transect distance between samples were the following sites: 1.1-1.2 = 12 m, sites 2.1-2.2 = 9 m and sites 3.1-3.2 = 68 m. The widest part of the pan is between sites 1 and 2 at 66 m.

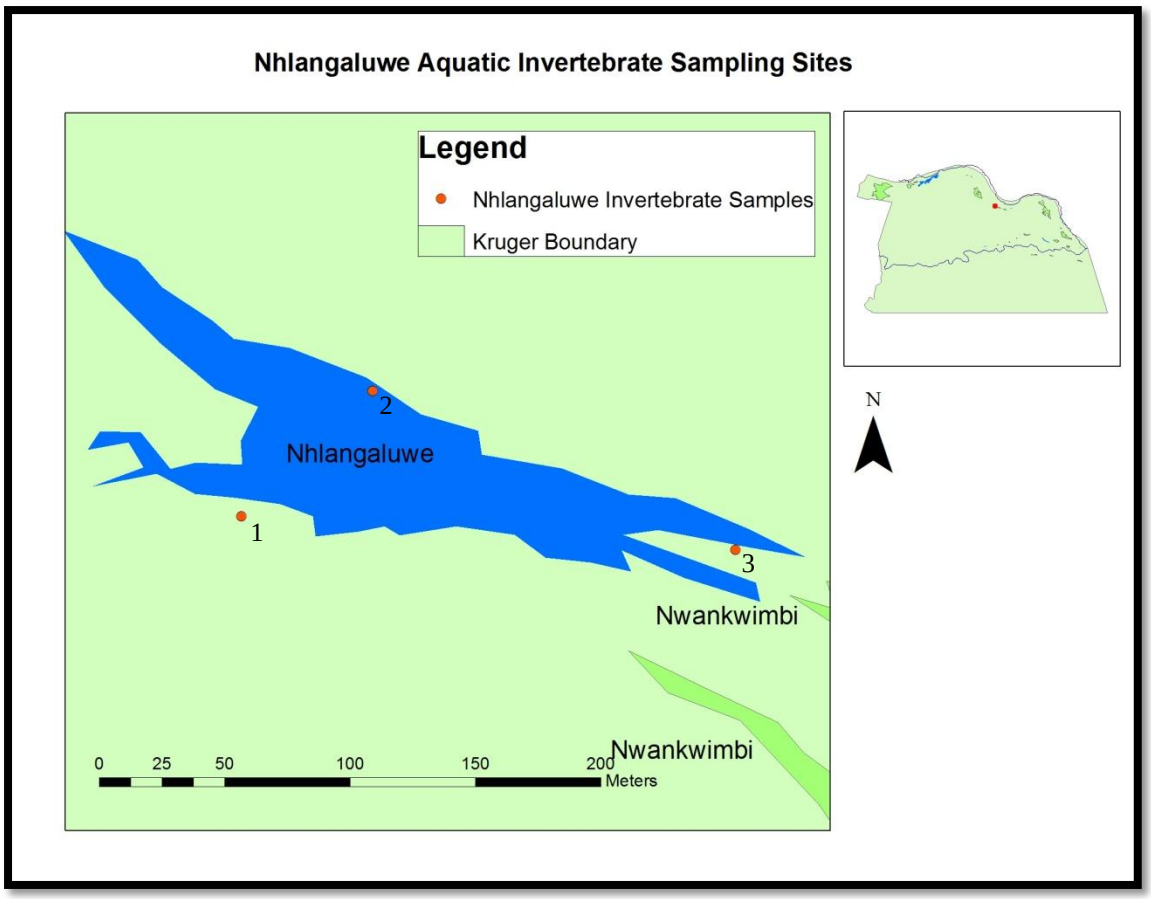


Figure 5.28: GIS figure of Nhlangaluwe's aquatic invertebrate sample sites

All the sites for Nhlangaluwe aquatic invertebrate sampling were exposed to sunlight. Site 1 had a suspended sediment load present and a rocky substrate. Site 2 was located in an inlet of the pan with elephant grass and reeds present. The water was also indicative of suspended sediment. Site 3 was an open area with no vegetation present; the water was lower in sediment at this site.

Nwambi Pan

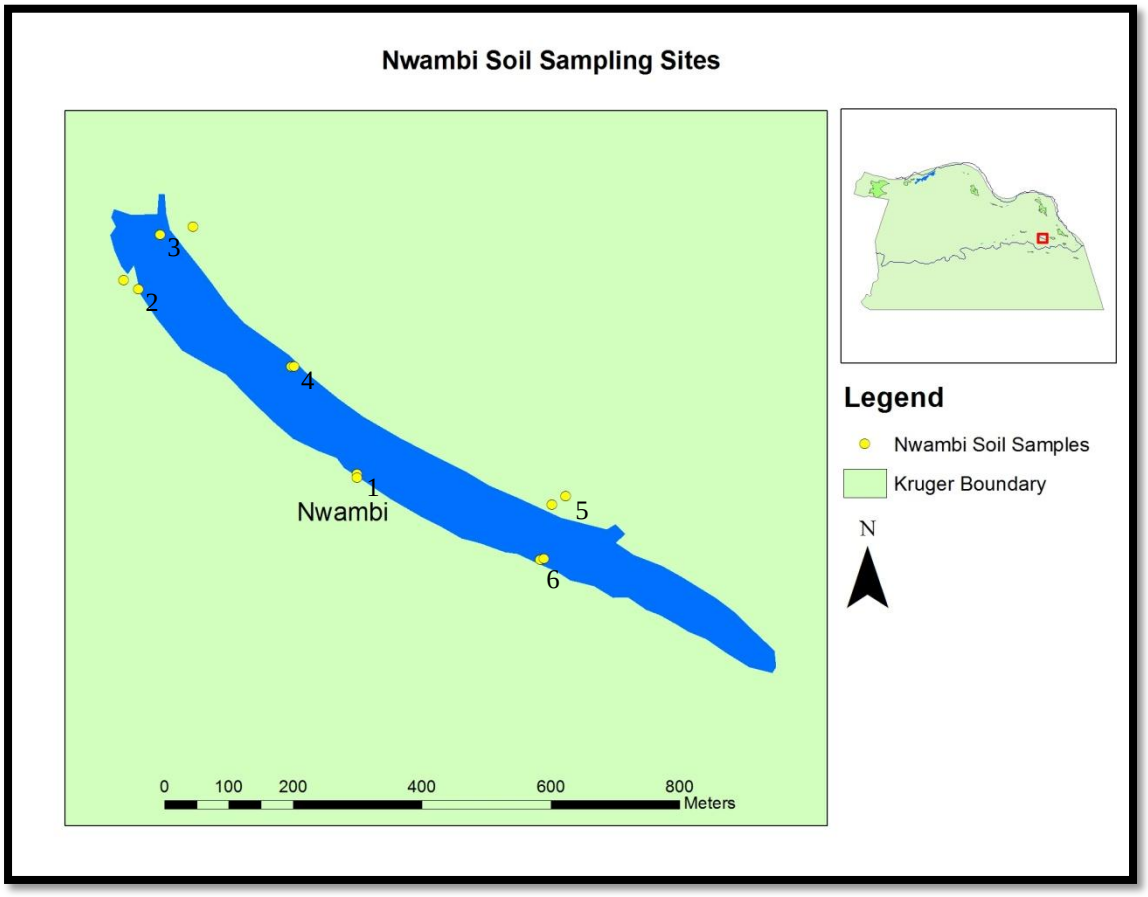


Figure 5.29: GIS figure of Nwambi's soil sample sites

Nwambi pans orientation runs from SE to NW. The pan is located in a relatively level topography although undulating at points leading to steep levees near the sides of the pan. The gradient around the pan was recorded as the following: on the west at site 1.1 ($^{+}$3°), north ($^{+}$41°) at site 2.1, north ($^{+}$20°) at site 3.1, east ($^{+}$25°) at site 4.1, south ($^{+}$11°) at site 5.1 and ($^{+}$16°) at site 6.1. The widest part of the pan was 95m found between sample sites 2 and 4.

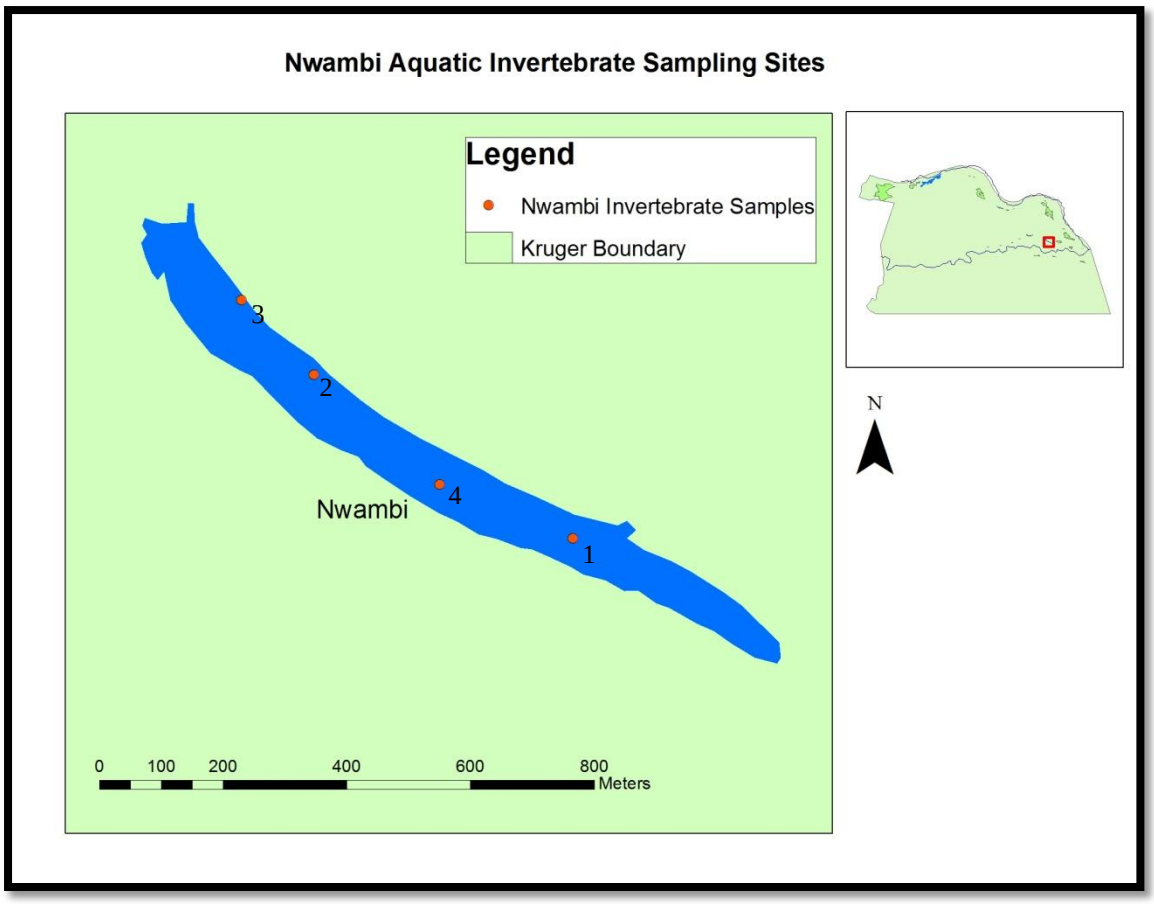


Figure 5.30: GIS figure of Nwambi's aquatic invertebrate sample sites

GPS point data level of accuracy was found again to be problematic as a result of the riverine vegetation around the pan. Sites 1, 2 and 3 in the map above were located on the south side of the pan and site 4 on the north. Site 1 was located below a shady bank in shallow vegetated water. Site 2 was chosen as it was a deep, shady inlet with little vegetation. Site 4 was located conversely in a sunny, shallow inlet with suspended sediment.

GIS and digitization of the study sites allowed for easier analysis and for a better overall understanding. Soil samples can be related to geology and topography and thus vegetation groups. The environments created by these characteristics give rise to the macro aquatic invertebrates utilizing the different biotopes found in and around the pan. These GIS techniques are an innovative way of sorting through large amounts of visual data sets more efficiently.

Chapter 6 Results

In this chapter the results of the fieldwork and laboratory data analysis are presented. The physical and environmental variables are considered individually and their relationships to the aquatic invertebrate species found in the study areas. The results have been tabulated and graphed for easy reference due to the large quantities of data acquired during this study. The results presented provide an enhanced overall understanding of the pan systems located along the Limpopo and Luvuvhu River systems. The order in which the results will be presented is, first the laboratory results for the soil moisture content and combustible organic carbon content will be compared. The grain size distribution will then be assessed in terms of its sediment size composition; here two examples will be drawn on. Pan characteristics will then be described to provide an overall representation of the study sites. Regional climate data will be discussed in connection to the water supply variability and quality present at the sites. The aquatic invertebrates found will be listed together with a habitat comparison and effects faced by different water quality levels of toxicity and environmental variables.

6.1 Pan Samples Laboratory Results

Section 6.1 presents both the soil moisture content (SMC) and the combustible organic carbon (COC) for the soil samples taken along the transects of the pans. The overall percentage losses experienced by each sample are represented in Table 6-1. It is important to remember the method explained in section 5.2 when analysing the table in terms of sample sites location vs. the distance from the pan and gradient changes along the transects.



Figure 6.1: The pan extent measurement processes being completed with a distometer and sample site 1.1 indicated with a yellow dot at Magomugomu pan

Table 6-1: Soil moisture content and combustible organic carbon content comparison for each soil sample site for both the wet and dry sampling period

Pan	Site	Soil moisture content (%) (Wet Period)	Soil moisture content (%) (Dry Period)	Combustible Organic Carbon (%) (Wet Period)	Combustible Organic Carbon (%) (Dry Period)
Magomugomu	1.1	15.08%	3.63%	5.57%	2.81%
	1.2	11.20%	2.39%	5.24%	2.55%
	2.1	29.43%	16.63%	5.42%	7.59%
	2.2	12.93%	12.92%	5.80%	6.87%
Nwambi	1.1	21.34%	11.68%	6.03%	6.21%
	1.2	9.96%	14.91%	5.19%	6.20%
	2.1	31.58%	15.69%	6.67%	7.76%
	2.2	12.57%	10.71%	5.17%	5.29%
	3.1	27.88%	14.80%	5.24%	6.77%
	3.2	14.42%	11.75%	5.71%	7.12%
	4.1	34.86%	11.01%	6.43%	7.17%
	4.2	17.79%	11.74%	6.16%	6.05%
	5.1	21.01%	11.02%	4.02%	7.64%
	5.2	6.41%	10.40%	3.62%	6.56%
	6.1	23.96%	10.60%	5.35%	6.33%
	6.2	10.36%	10.67%	6.15%	7.06%
Gwalala	1.1	30.28%	17.04%	6.81%	5.90%
	1.2	29.16%	11.92%	6.66%	4.70%
	2.1	29.03%	14.55%	5.03%	5.31%
	2.2	20.06%	14.39%	6.77%	6.40%
	3.1	25.43%	16.11%	6.10%	7.06%
	3.2	4.49%	6.27%	3.66%	3.40%
	4.1	30.96%	15.69%	7.16%	5.95%
	4.2	25.99%	14.69%	5.77%	5.04%
Makwadzi	1.1	30.23%	15.29%	7.10%	5.21%
	1.2	6.56%	15.13%	4.54%	6.03%
	1.3	5.01%	n/d	4.55%	n/d
	2.1	16.52%	13.59%	1.86%	5.48%
	2.2	7.66%	7.52%	2.92%	4.21%
	3.1	5.74%	6.83%	3.20%	2.71%
	3.2	6.56%	6.71%	3.47%	2.63%
	3.3	4.98%	7.03%	2.47%	2.94%
Likangwa	1.1	9.12%	10.06%	3.47%	5.64%
	1.2	6.33%	8.92%	4.84%	4.95%
	1.3	5.45%	7.05%	3.50%	3.00%
	2.1	5.92%	7.90%	4.00%	4.48%
	2.2	7.89%	7.17%	5.05%	3.68%

Pan	Site	Soil moisture content (%) (Wet Period)	Soil moisture content (%) (Dry Period)	Combustible Organic Carbon (%) (Wet Period)	Combustible Organic Carbon (%) (Dry Period)
	2.3	18.39%	7.94%	6.45%	2.98%
	3.1	25.35%	14.62%	4.76%	5.68%
	3.2	22.26%	7.60%	5.48%	5.10%
Mapimbi	1.1	20.45%	19.77%	3.75%	1.60%
	1.2	12.63%	9.40%	4.48%	2.26%
	2.1	15.55%	12.96%	0.90%	8.26%
	2.2	11.08%	7.26%	3.48%	10.66%
	3.1	16.97%	18.21%	4.94%	3.08%
	3.2	16.24%	9.96%	5.71%	4.68%
	4.1	16.69%	15.02%	7.70%	5.90%
	4.2	13.43%	18.25%	4.48%	4.76%
Nhlangaluwe	1.1	7.18%	7.85%	5.22%	4.11%
	1.2	7.54%	6.77%	5.35%	3.34%
	2.1	7.16%	4.29%	3.76%	3.21%
	2.2	3.87%	7.74%	3.77%	3.48%
	3.1	8.88%	11.42%	4.71%	3.96%
	3.2	10.38%	15.10%	4.84%	4.73%
	4.1	14.81%	13.89%	6.10%	5.25%
	4.2	11.62%	3.81%	5.26%	2.81%

6.1.1 Magomugomu Pan

Sample 2.1 for the wet period had the highest loss in soil moisture content for the Magomugomu sample. The site with the least moisture content percentage recorded for the wet period was sample site 1.2. The difference in soil moisture content between sites 2.1 and 1.2 for the wet period was 18.23%. Sample site 2.1 had the highest soil moisture content whereas sample site 1.2 also had the smallest loss in soil moisture content for the dry sample period. The difference here was 14.24%. Sample site 2.2 did not show any major differences in soil moisture content for both sample periods. The Magomugomu pan, as a whole, experienced a small percentage change in soil moisture content in its samples. The wet periods soil moisture content samples did not fall below 11% and 2% for the dry periods records for the pan.

Sample site 2.2 had the highest combustible organic carbon and sample site 1.2 had the smallest organic content in the wet period. The percentage difference between the wet periods samples were 0.56%. The highest percentage in combustible organic carbon for the dry period was recorded at sample site 2.1 and the lowest in the dry period at sample site 1.2. The percentage difference between the dry period samples highest and lowest was 5.04%. In both sample samples 1.1 and 1.2 vs. samples sites 2.1 and 2.2 the percentages were reversed, i.e. samples 1.1 and 1.2 experienced a greater loss of combustible organic carbon in the wetter months whereas 2.1 and 2.2 sample sites experienced a greater loss of combustible organic carbon in the dry months. The minimum percentage for combustible organic carbon across all the samples was 5% for the wet period and 2% for the dry

period. Both samples 1 and 2 were higher in organic content closer to the water's edge than at the gradient change further away from the water.

6.1.2 Nwambi Pan

The highest soil moisture content occurred at site 4.1 and the least soil moisture content was found at sample site 5.2 during the wet period, the difference between these two sites being 28.45%. The highest soil moisture content was recorded at sample site 2.1 for the dry period and the smallest soil moisture content was recorded at sample site 5.2, the difference between these sites being 9.28%. All the wet period sample sites soil moisture contents were above 6% and all dry period sample sites soil moisture contents were above 10% with relatively similar soil moisture content for both sets of sample sites that were tested at each gradient change along the transects. The wet period sample sites depict an erratic representation of the soil moisture content experienced by these sites.

In the wet period the highest combustible organic carbon is recorded at sample site 2.1 and the lowest at sample site 5.2, the difference here being 2.76%. In the dry period the highest combustible organic carbon is recorded at sample site 2.1 and the lowest at sample site 2.2 with the difference in combustible organic carbon percentage of 2.47%. All the sample sites for Nwambi's combustible organic carbon percentages are higher in the dry period samples than the wet period except for sample site 4.2 where the wet period sample is marginally higher by 0.11%. At the pan extent, high percentages of combustible organic carbon were found in samples 1, 2, 4 and 5. At the change in gradient of the pan, high percentages of combustible organic carbon were recorded at sites 3 and 6.

6.1.3 Gwalala Pan

The highest soil moisture content found at Gwalala was recorded during the wet period at sample site 4.1 and the lowest soil moisture content was also recorded during the wet period at sample site 3.2. The difference in soil moisture content was 26.47%. The highest soil moisture content during the dry period occurred at site 1.1 and the lowest at site 3.2, with the difference in soil moisture content being 10.77%. The average soil moisture content percentage for Gwalala during the wet period was 24.4% and the average soil moisture content for the dry sampling period was 13.8%. Overall sample site 3.2 yielded the lowest soil moisture content for Gwalala.

In the wet period the highest combustible organic carbon is recorded at sample site 4.1 and the lowest at sample site 3.2, the difference here being 3.5%. In the dry period the highest combustible organic carbon is recorded at sample site 3.1 and the lowest at sample site 3.2 with the difference in combustible organic carbon percentage of 3.66%. Sample site 3 holds both the highest recorded combustible organic carbon percentage and the lowest. Both sampling periods share a very similar trend in combustible organic carbon.

6.1.4 Makwadzi Pan

The highest soil moisture content occurred at sample site 1.1 and the lowest soil moisture content was recorded at sample site 1.3 during the wet period, the difference between these two sites being 25.22%. The highest soil moisture content recorded for the dry period was at sample site 1.1 and the lowest soil moisture content was recorded at sample site 3.2, the difference between these sites being 8.58%. There is a significant difference in sample site 1's soil moisture content from the wet to dry period and differences versus the other sample sites for

Makwadzi during the wet period with those sites having a percentage in soil moisture content less than 17%. Overall, sample site 1 has significantly higher soil moisture content than both 2 and 3 sample sites.

During the wet period the highest combustible organic carbon is recorded at sample site 1.1 and the lowest at sample site 2.1, the difference here being 5.24 %. In the dry sampling period the highest combustible organic carbon is recorded at sample site 1.2 and the lowest at sample site 3.2 with the difference in combustible organic carbon percentage of 3.32%. Sample site 1 experiences a reversal; whereby during the wet period the combustible organic carbon is low at 1.2 but high at 1.1 and during the dry period 1.1 is lower than 1.2.

6.1.5 Likangwa Pan

The highest soil moisture content occurred at site 3.1 and the lowest was recorded at sample site 1.3 during the wet period, the difference between these two sites being 19.9%. The highest soil moisture content that was recorded for the dry sampling period occurred at sample site 3.1 and the lowest soil moisture content was recorded at sample site 1.3, the difference between these sites being 7.57%. Sites 2.3, 3.1 and 3.2 stand out from the other samples as having high soil moisture content at their samples sites. Sample sites 1.1, 1.2, 1.3 and 2.1 in comparison have a smaller soil moisture content percentage.

During the wet period the highest combustible organic carbon is recorded at sample site 2.3 and the lowest at sample site 1.1, the difference here being 2.98%. In the dry period the highest combustible organic carbon is recorded at sample site 3.1 and the lowest at sample site 2.3 with the difference in combustible organic carbon percentage of 2.7%. All sample sites records for the wet and dry periods moisture losses are similar except for 2.3 which had a significant difference.

6.1.6 Mapimbi Pan

The highest soil moisture content occurred at site 1.1 and the lowest soil moisture content was recorded at sample site 2.2 during the wet period, the difference between these two sites being 9.37%. The highest soil moisture content recorded for the dry sampling period was seen at sample site 1.1 and the lowest soil moisture content was recorded at sample site 2.2, the difference between these sites being 12.51%. Mapimbi pan also depicts results showing increased soil moisture content at the extent of the pan and smaller soil moisture content percentages at the change of gradient. All the samples show higher soil moisture content in the wet period as apposed to the dry period except for sites 3.1 and 3.2 which have higher soil moisture content in the dry period.

During the wet period, the highest combustible organic carbon is recorded at sample site 4.1 and the lowest at sample site 2.1, the difference here being 6.8%. In the dry period the highest combustible organic carbon is recorded at sample site 2.2 and the lowest at sample site 1.1 with the difference in combustible organic carbon percentage of 9.06%. There is a significant percentage increase of combustible organic carbon present at sample site 2.1 and 2.2 for the dry sampling period results. Wet period samples indicate a steady increase from sample site 2.1 through to 4.1.

6.1.7 Nhlangaluwe Pan

The highest soil moisture content for the wet period occurred at site 4.1 and the lowest soil moisture content was recorded at sample site 2.2, the difference between these two sites being 10.94%. The greatest soil moisture

content that was recorded for the dry sampling period was sample site 3.2 and the lowest soil moisture content was recorded at sample site 4.2, the difference between these sites being 11.29%. Overall, sample sites 1.2, 2.1, 4.1 and 4.2 experienced higher soil moisture content during the wet period and sample sites 1.1, 2.2., 3.1 and 3.2 experienced a smaller soil moisture content during the dry period.

During the wet period the highest combustible organic carbon is recorded at sample site 4.1 and the lowest at sample site 2.1, the difference here being 2.34%. In the dry period the highest combustible organic carbon is recorded at sample site 4.2 and the lowest at sample site 4.1 with the difference in combustible organic carbon percentage of 2.43%. Nhlangaluwe's wet period samples for combustible organic carbon are all higher than that of the dry sampling period's results. Equally, sample sites (1.1 and 1.2), (2.1 and 2.2), (3.1 and 3.2) and (4.1 and 4.2) are similar in combustible organic carbon. In contrast to the general trend created by both the wet and dry periods, sample site 4.2 from the dry period is significantly lower than the wet period's records and the other combustible organic carbon results for Nhlangaluwe.

6.1.8 Pan Comparisons

Table 6-2: The average soil moisture content and combustible organic carbon content loss for each pan for the wet and dry sampling period, for site specific percentage refer to table 6-1

Pan	Soil moisture content (%) (Wet Period)	Soil moisture content (%) (Dry Period)	Combustible Organic Carbon (%) (Wet Period)	Combustible Organic Carbon (%) (Dry Period)
Magomugomu	17.16%	5.51%	8.89%	8.89%
Nwambi	19.35%	5.48%	12.08%	12.08%
Gwalala	24.43%	6.00%	13.83%	13.83%
Makwadzi	10.41%	3.76%	10.30%	10.30%
Likangwa	12.59%	4.69%	8.91%	8.91%
Mapimbi	15.38%	4.43%	13.85%	13.85%
Nhlangaluwe	8.93%	4.88%	8.86%	8.86%

The average soil moisture content for all the study areas has been tabulated in table 6-2 to show the overall percentages from all the sample sites within each individual pan for the wet and dry periods. The wet period percentages for soil moisture content were all higher than the dry periods. Nhlangaluwe showed the smallest difference in soil moisture content between sample periods with only 0.07% and so did Makwadzi with 0.11%. Mapimbi too, showed nominal results with a difference of 1.53% and Likangwa with 3.68%. The three pans with the highest soil moisture content between sample periods were Nwambi with 7.27%, Magomugomu with 8.27% and Gwalala with 10.6%. Table 6-2 indicates that the wet period samples that were collected were wetter than the dry period samples collected for at the same sample sites.

An average for combustible organic carbon for all the pan study areas has been tabulated to indicate overall percentages from all the sample sites within each individual pan for both wet and dry periods. The results for the greatest percentage of combustible organic carbon fluctuate between the wet and dry periods, the majority being the wet period however. Minimal differences in percentage occurred in Likangwa with 0.25%, Makwadzi with 0.41%, Gwalala with 0.53% and Magomugomu with 0.55%. A larger percentage was found with pans Mapimbi with 0.72%, Nhlangaluwe with 1.02% and Nwambi with 1.2%.

6.1.9 Correlation Graph for Carbon and Moisture Loss

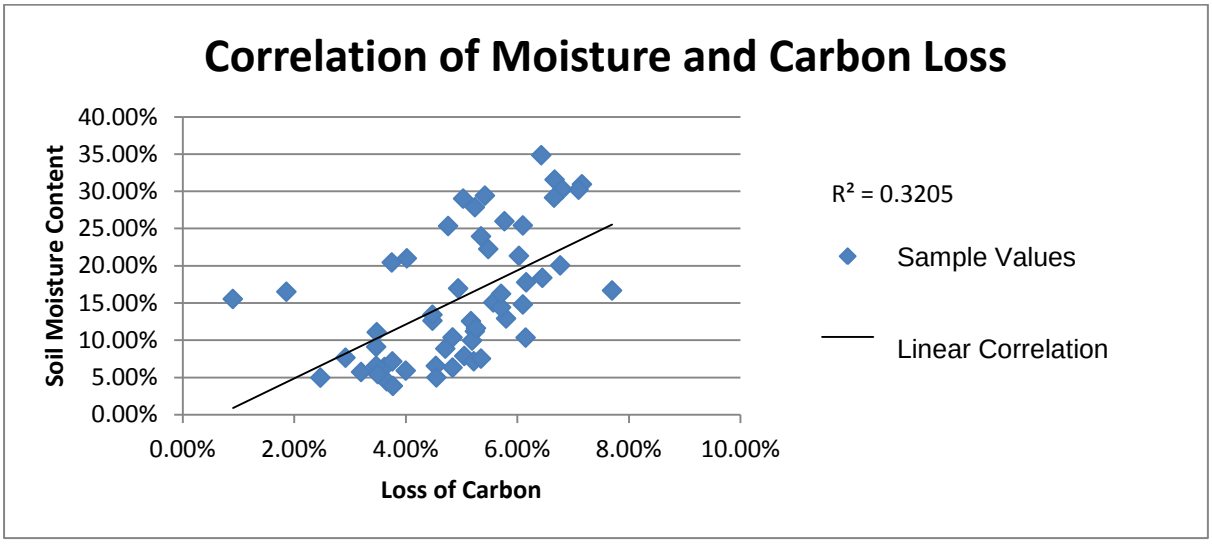


Figure 6.2: Wet and dry period combustible organic carbon (%) and soil moisture content (%) correlation for all pan sites

Figure 6.2 shows a positive correlation, this means that as the percentage loss in combustible organic carbon increases so too does the soil moisture content. The correlation coefficient (r) was calculated at 0.3205 indicating that there is a positive correlation between soil moisture content and combustible organic carbon loss tested at the sample sites. Correlations between the soil moisture content and the combustible organic content show that a high organic content is equal to high soil moisture content that is found in the samples.

6.2 Grain Size Distribution

Grain size distribution is important as soil structure and texture influence the size of the pores where air and water are stored (Araya, 2007). Both nutrient uptake by roots from the soil and the rate of vegetative growth are related to grain size distribution. Different soil forms have different characteristics, each with their own ability to hold water for certain periods of time. The types of soils that are found in wetland/pan systems are generally more clay-like, and those systems that are supported by a water table are more sandy.

Table 6-3: The table below lists the results for the soil particle size analysis in Gradistat

Pan	Sample #	Wet Period Mean (*um*)	Wet Period Sorting (σ)	Wet Period Skewness (*Sk*)	Wet Period Kurtosis (*K*)	Dry Period Mean (*um*)	Dry Period Sorting (σ)	Dry Period Skewness (*Sk*)	Dry Period Kurtosis (*K*)
Magomugomu	1.1	689	529.1	0.99	2.771	313.173	278.743	2.955	13.882
	1.2	608.585	448.205	1.481	4.372	227.496	239.069	3.389	17.462
	2.1	745.6	512.426	0.925	2.607	609.759	492.9	1.116	3.227
	2.2	702.616	489.891	1.036	3.037	646.511	552.709	0.871	2.553
Nwambi	1.1	732.991	521.048	0.873	2.584	713.608	527.862	0.901	2.667
	1.2	501.297	483.857	1.39	4.054	700.896	521.29	0.88	2.734
	2.1	755.431	508.758	0.87	2.598	717.549	509.462	0.744	2.553
	2.2	616.664	510.58	1.201	3.34	566.438	547.617	1.041	2.881
	3.1	657.408	468.862	1.192	3.48	583.365	482.834	1.126	3.432
	3.2	666.433	481.764	1.287	3.547	597.839	531.374	1.112	3.107
	4.1	767.397	549.463	0.758	2.315	660.32	513.355	0.854	2.692
	4.2	725.137	500.043	1.003	2.919	606.237	531.002	0.924	2.765
	5.1	691.502	520.022	0.986	2.854	590.981	532.769	1.07	2.967
	5.2	604.98	483.285	1.307	3.753	550.545	503.931	1.226	3.516
	6.1	731.329	559.084	0.71	2.302	521.455	548.512	1.218	3.281
	6.2	620.093	547.395	0.975	2.761	617.242	526.586	0.92	2.801
Gwalala	1.1	808.432	508.015	0.768	2.298	733.313	520.105	0.71	2.405
	1.2	905.716	465.789	0.749	2.344	790.723	551.235	0.497	2.049
	2.1	860.734	466.014	0.807	2.673	651.353	486.853	0.907	2.907
	2.2	801.361	450.696	0.953	2.929	721.629	495.478	0.738	2.588
	3.1	920.663	481.312	0.498	2.29	832.458	529.496	0.449	2.082

	3.2	888.737	431.195	0.685	2.795	651.206	480.547	0.902	2.941
	4.1	856.182	430.564	0.879	2.947	715.298	502.427	0.742	2.561
	4.2	793.984	457.771	0.674	3.016	713.181	548.114	0.653	2.263
Makwadzi	1.1	996.984	415.781	0.739	2.794	936.113	599.464	0.156	1.661
	1.2	1330.662	558.45	-0.346	1.389	876.639	542.447	0.353	1.969
	1.3	838.323	438.207	0.88	3.068	n/d	n/d	n/d	n/d
	2.1	563.354	322.226	2.163	9.121	853.805	549.293	0.351	1.943
	2.2	520.167	290.928	2.588	11.197	750.213	522.645	0.665	2.353
	3.1	544.496	449.739	1.621	4.889	290.069	430.45	2.562	8.4
	3.2	610.762	441.068	1.554	4.524	334.36	450.981	2.136	6.501
	3.3	447.723	325.374	2.585	10.9	354.82	483.308	1.924	5.493
Likangwa	1.1	970.153	495.755	0.302	2.081	970.998	535.073	0.19	1.885
	1.2	958.944	385.066	0.736	3.301	764.985	525.382	0.611	2.318
	1.3	1034.497	359.619	0.565	3.171	575.501	488.291	0.985	2.902
	2.1	1044.243	484.112	0.158	2.006	876.16	495.281	0.404	2.303
	2.2	991.534	400.784	0.633	2.761	817.837	511.804	0.584	2.28
	2.3	943.232	461.953	0.586	2.369	517.012	481.054	1.225	3.519
	3.1	999.743	467.766	0.465	2.099	671.763	518.821	0.979	2.834
	3.2	1046.775	479.675	0.303	2.001	640.885	498.351	1.01	3.005
Mapimbi	1.1	627.774	398.639	1.729	5.252	518.462	387.832	1.696	5.602
	1.2	595.016	368.074	1.779	6.098	589.979	418.074	1.341	4.281
	2.1	358.267	253.546	2.558	10.653	420.098	458.159	1.79	5.25
	2.2	645.449	471.141	1.151	3.394	459.647	490.088	1.611	4.411
	3.1	n/d	n/d	n/d	n/d	592.744	541.06	1.013	2.78

	3.2	n/d	n/d	n/d	n/d	617.672	480.672	1.054	3.224
	4.1	n/d	n/d	n/d	n/d	683.996	472.42	0.962	3.043
	4.2	n/d	n/d	n/d	n/d	649.491	470.425	1.049	3.281
Nhlangaluwe	1.1	879.148	530.38	0.459	2.021	839.109	561.171	0.439	1.939
	1.2	913.03	531.313	0.392	1.902	869.754	569.688	0.348	1.836
	2.1	866.121	447.464	0.845	2.712	740.731	504.898	0.608	2.46
	2.2	919.201	461.815	0.668	2.478	797.992	523.043	0.486	2.189
	3.1	760.569	414.36	1.011	3.578	945.955	499.325	0.363	2.063
	3.2	855.822	421.68	0.956	3.018	645.383	441.652	1.126	3.596
	4.1	985.165	495.9	0.071	2.249	883.417	520.624	0.453	2.12
	4.2	1109.593	379.006	0.379	2.73	929.782	439.156	0.431	2.532

The graphs below utilize soil particle size distribution from both wet and dry periods. To clarify, although the samples are associated with wet and dry periods, this simply indicates the frequency of sampling related to section 6.1. Section 6.2 however, concentrates on the spatial differences associated between the sites closest to the wetland/pan edge and those furthest away.

6.2.1 Magomugomu Pan

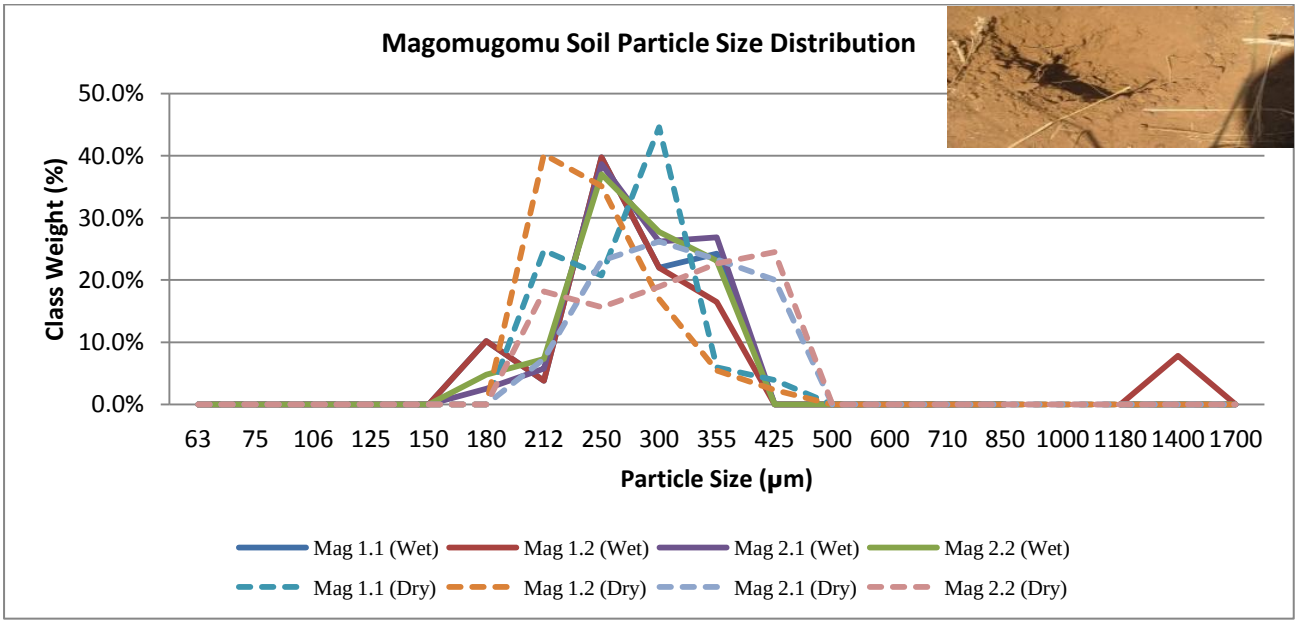


Figure 6.3: Illustrates the soil sample sites and the related particle size distribution for Magomugomu and a figure of the related soil

The solid lines depict a similar trend throughout the dataset; this indicates that the soil particle size distribution is similar among the pan. Therefore, indicating similar spatial properties within the pan systems soils. The dotted lines depict dissimilar properties in the data. There are clear differences between the wet samples versus the dry period samples. The dry period's medium-coarse sand is dissimilar to that of the wet periods samples, in that wet periods samples are more indicative of medium particle size. There is a higher percentage of finer particles in the dry period than in the wet period's soil particle size distribution samples.

6.2.2 Nwambi Pan

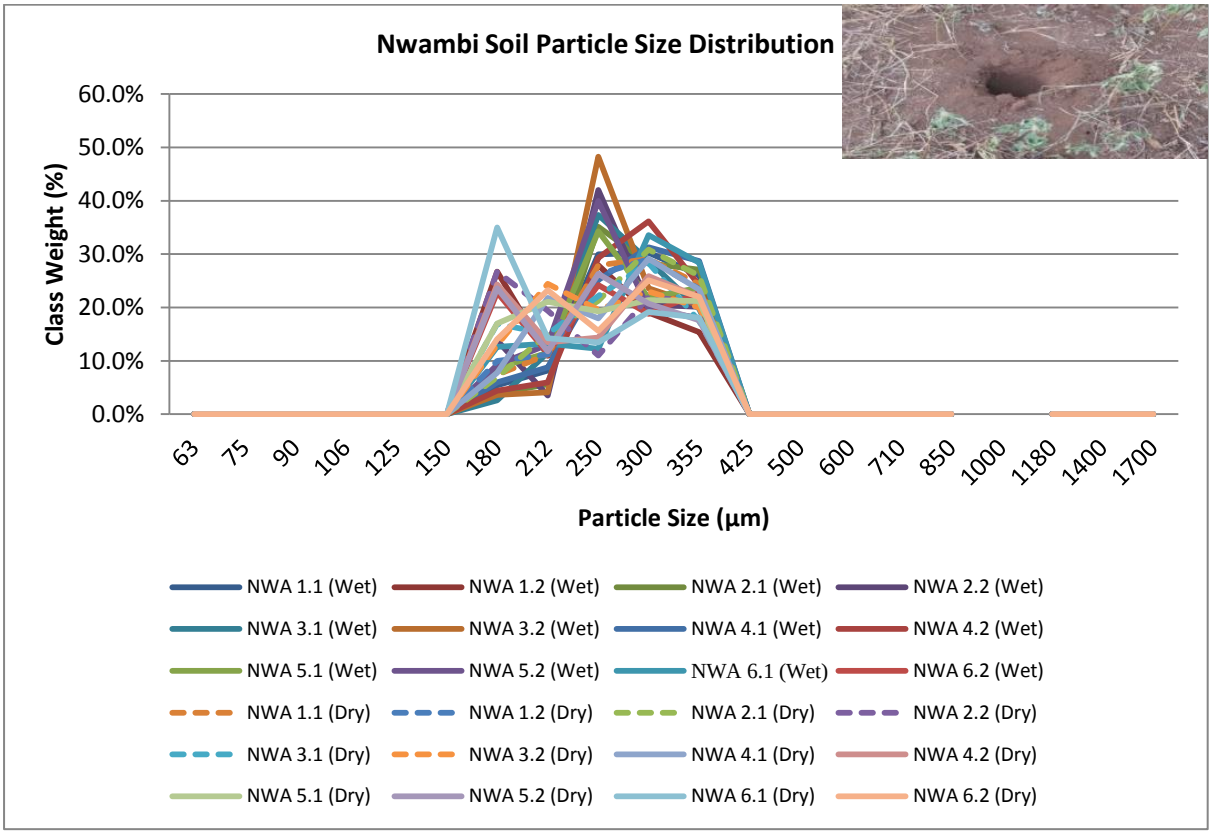


Figure 6.4: Illustrates the soil sample sites and the related particle size distribution for Nwambi and a figure of the related soil

Both datasets for Nwambi are similar, indicating that the soil particle size distribution around the wetland/pan system is similar. The graph indicates that the soil particle size distribution is well sorted. Both wet and dry periods of the samples indicate a similar percentage of medium sand particle size. However, the wet period has a higher percentage of fine sand particles than in the dry sampling period. The wet period samples also have a significantly increased percentage of medium sized sand particles than that of the dry period's samples.

6.2.3 Gwalala Pan

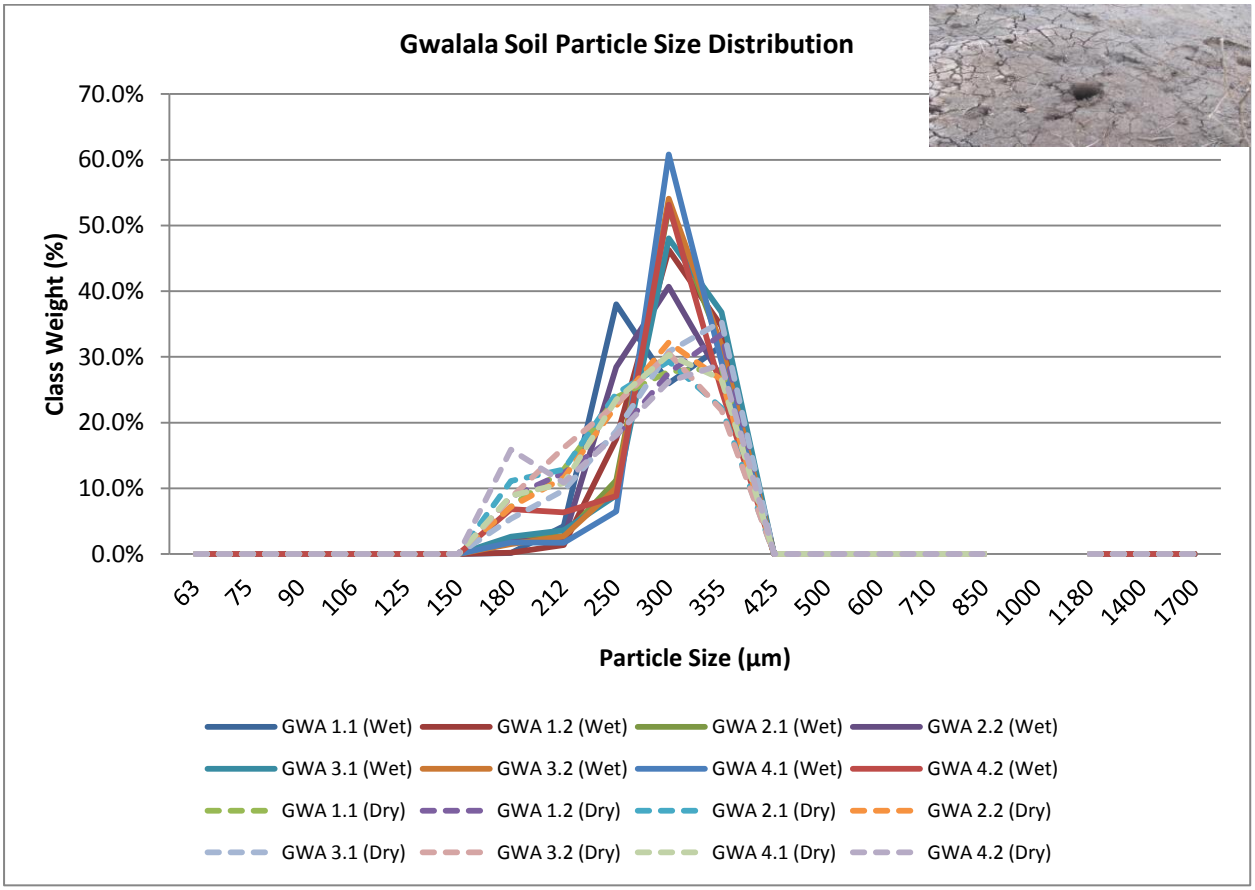


Figure 6.5: Illustrates the soil sample sites and the related particle size distribution for Gwalala and a figure of the related soil

The solid lines follow a similar trend, with the majority of the soil particle size falling into the 300µm (medium sand) category. The dotted lines likewise follow a trend indicating similarity among the sample series. The majority of the particle size distribution falls between 150µm (fine) and 425µm (medium). The solid line samples indicate a higher percentage of particle size distribution around 300µm (medium) but the dotted lined data appears to have more evenly distributed sediment. Gwalala has a higher percentage of finer sediment during the dry period than wet period. Both data sets follow the same trends, this is indicative of consistency in the topography surrounding the system for both periods.

6.2.4 Makwadzi Pan

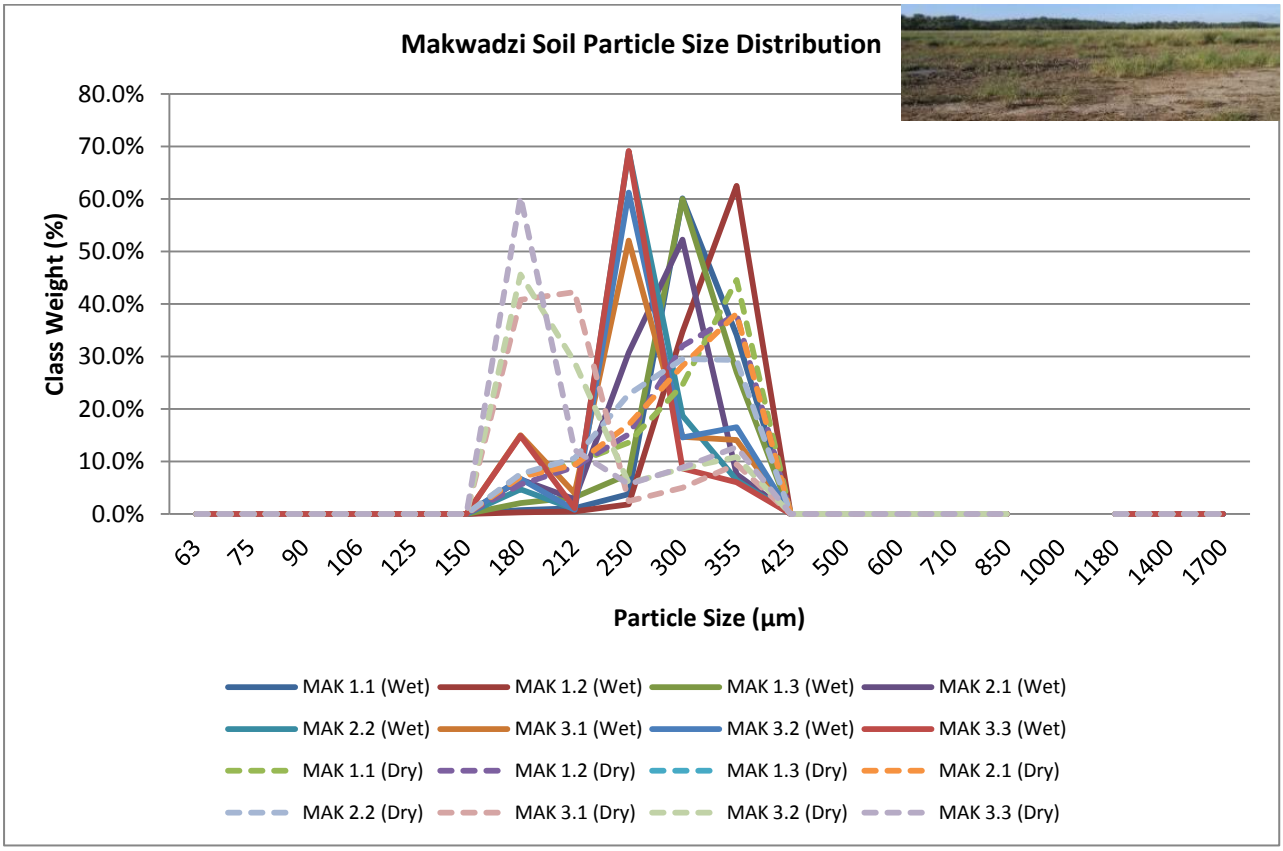


Figure 6.6: Illustrates the soil sample sites and the related particle size distribution for Makwadzi and a figure of the related soil

Both datasets indicate higher percentages of particle size distribution between 150µm (fine) and 425µm (medium). However, the solid lines percentages are predominantly between 212µm and 425µm, whereas the dotted lined particle size is located between 150µm (fine) - 250µm (fine-medium) and 355µm (medium) - 425µm (medium). Both datasets show variance between sample periods and site/topographical differences. This variance can be attributed to the area being flooded and depositing different sized sediment load into the wetland/pan and constant disturbance by large herbivores utilizing the systems.

6.2.5 Likangwa

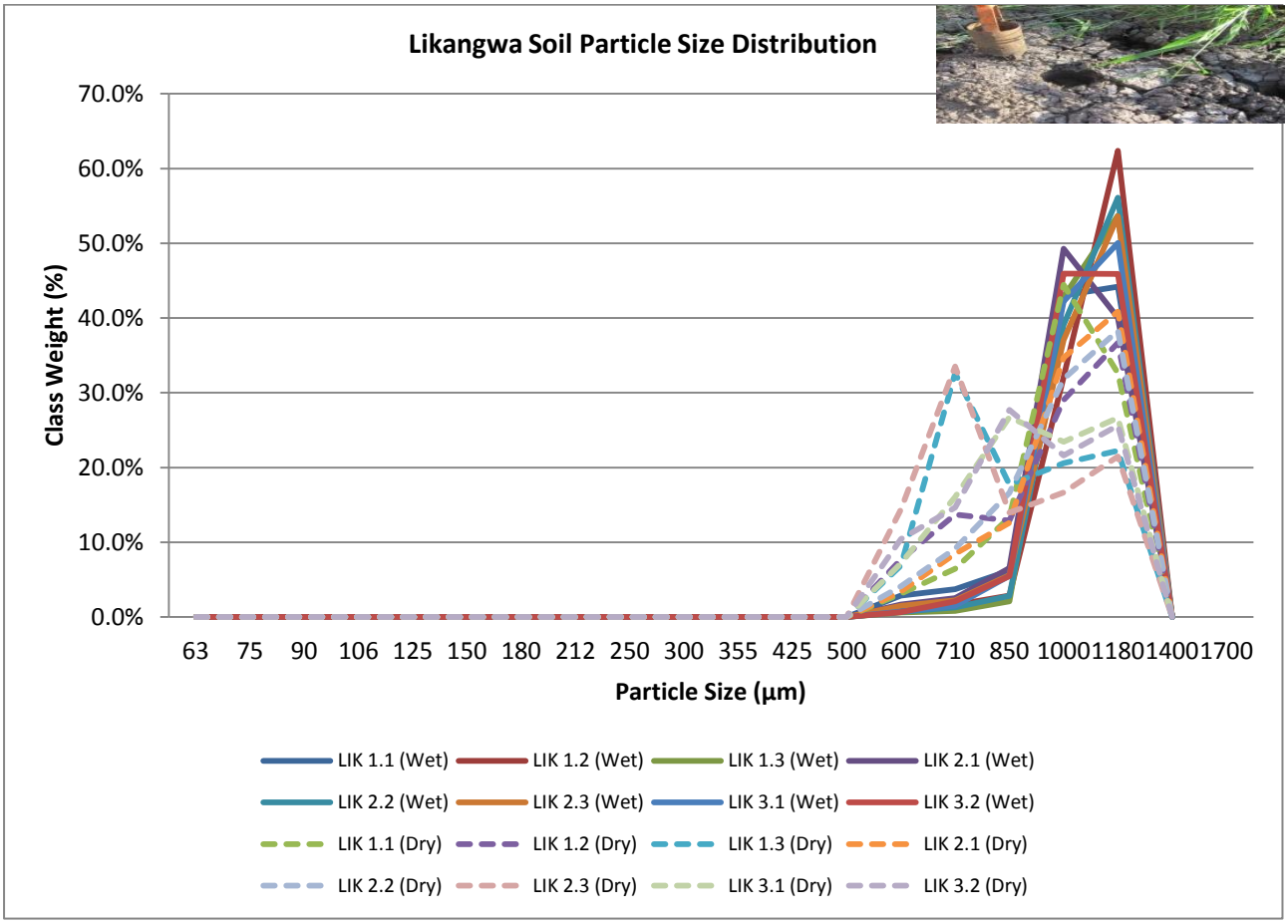


Figure 6.7: Illustrates the soil sample sites and the related particle size distribution for Likangwa and a figure of the related soil

Both datasets have the majority of their weight class in the larger particle size distribution regions at the end of the graph. The solid lines data series is dominant between 850µm (coarse) and 1400µm (very coarse). The dotted line however, has a more evenly spread dataset between 500µm (medium-coarse) and 140µm (fine). The differences seen between both the wet and dry periods can be attributed to flood events seen generally during the summer rainfall season. It is well known that floods carry a sediment load downstream with them and are deposited into areas such as a wetland. This action therefore explains the dissimilarity between the two soil particle size distribution datasets.

6.2.6 Mapimbi Pan

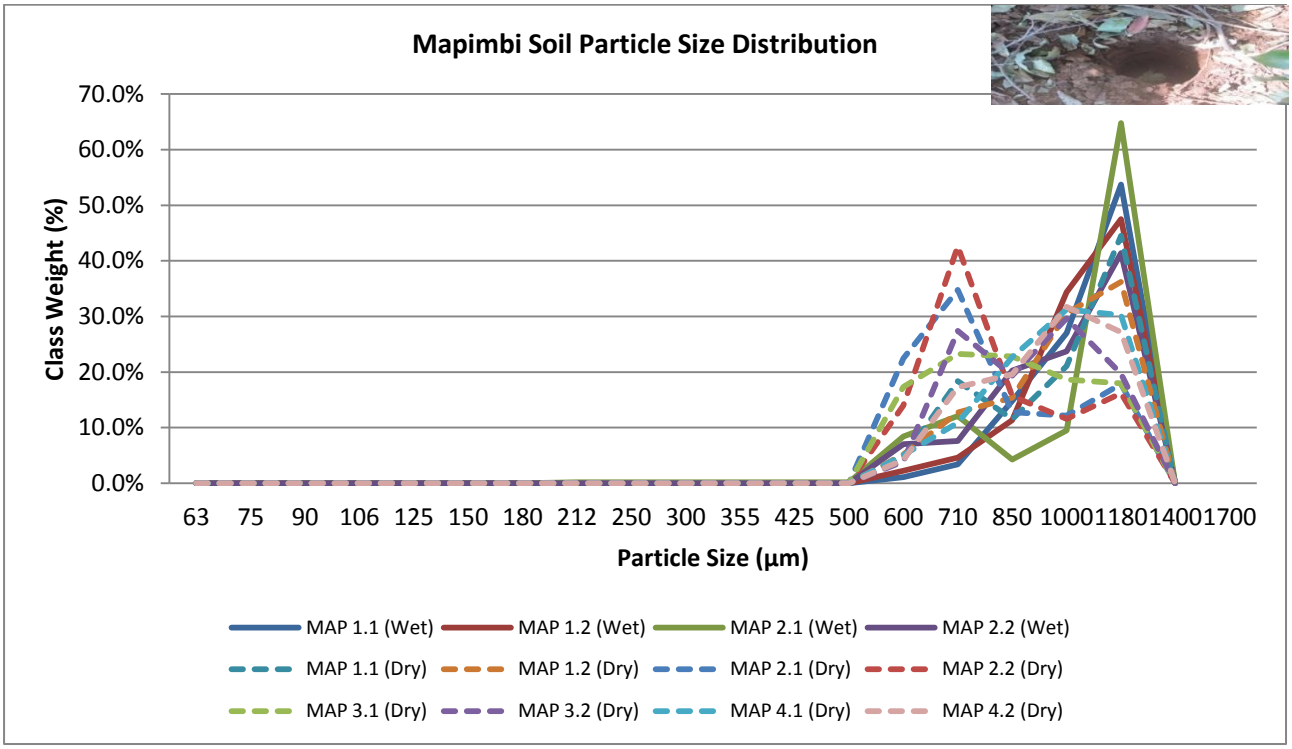


Figure 6.8: Illustrates the soil sample sites and the related particle size distribution for Mapimbi and a figure of the related soil

Both datasets have the majority class weight percentage between 500µm (medium-coarse) and 1400µm (very coarse). The wet period samples are predominantly found between 1000µm (coarse- coarse-very) and 1400µm (very coarse), whereas the dry period samples are distributed between 600µm (coarse) and 1180µm (very coarse) predominantly. The dry period has an increased small particle size distribution percentage than that of the wet period samples. The wet period samples indicate a higher percentage of larger sediment than that of dry period. Samples indicate dissimilarity between sample sites. This is not attributed to a new sediment load being deposited as the system does not receive water by a means of flooding but by the water table. Sample sites 1 and 3 differ more than sites 2 and 4, this could be attributed to animal movement around the pan as sample sites 1 and 3 are located in areas where animals utilize the wetland/pan system and sites 2 and 4 are located in areas of the wetland/pan where less animal disturbance may occur.

6.2.7 Nhlangaluwe Pan

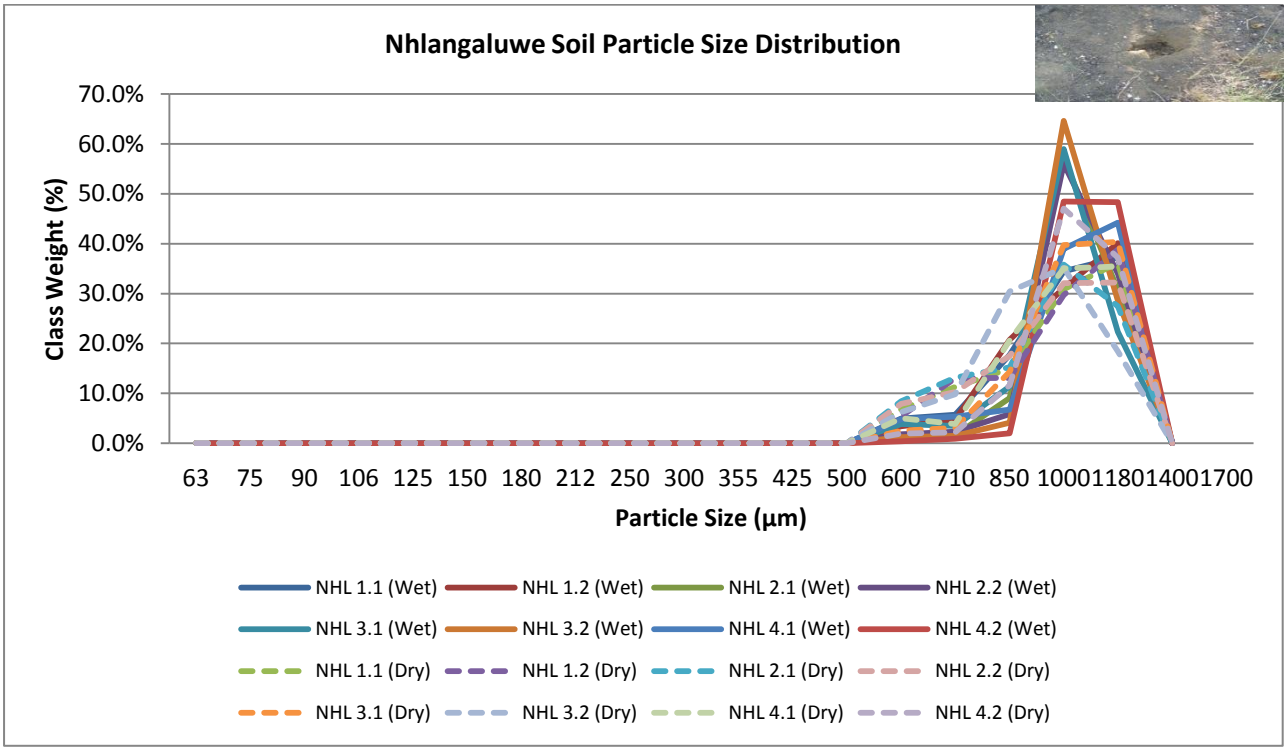
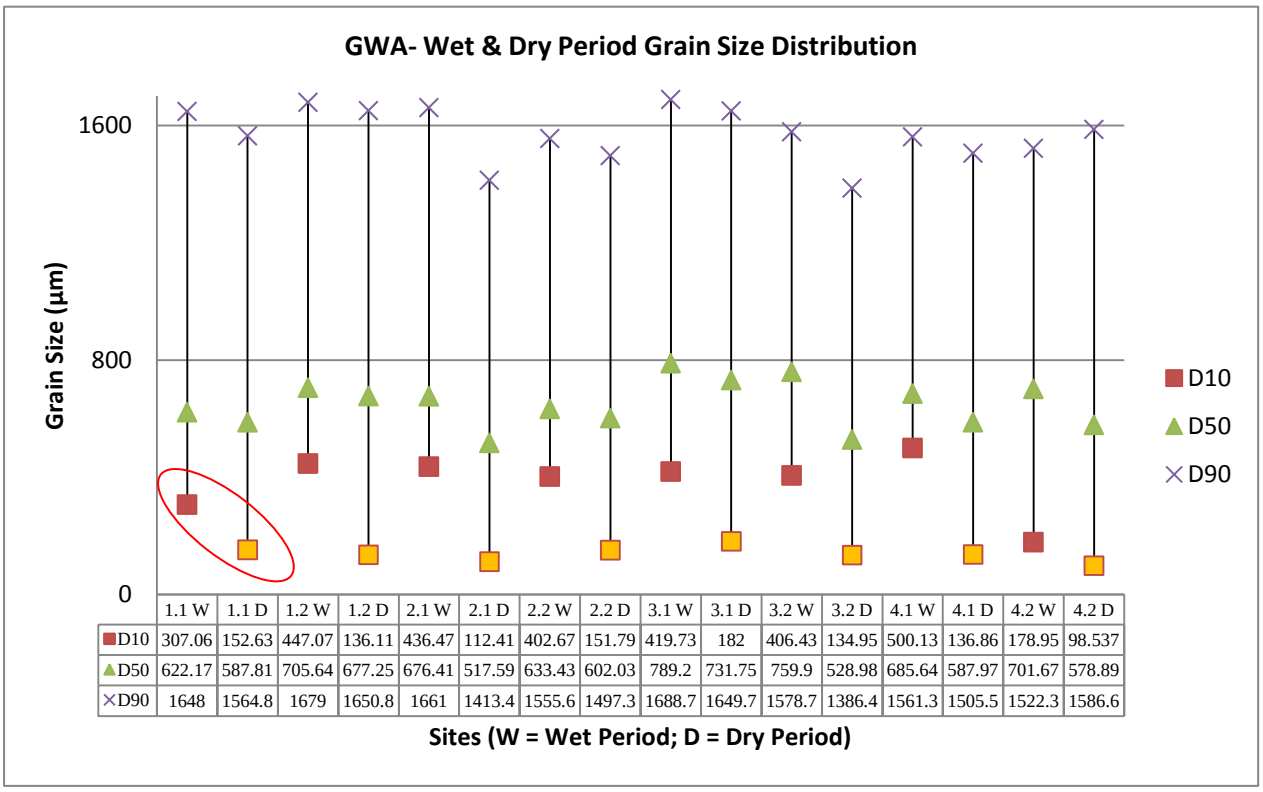


Figure 6.9: Illustrates the soil sample sites and the related particle size distribution for Nhlangaluwe and a figure of the related soil

Both the wet and dry period samples have a similar trend, where both dataset's larger percentages of particle size are distributed between 850µm (coarse) and 1400µm (very coarse). The wet period samples have a higher class weight percentage than the wet period samples. Both datasets too have a similar lower class weight percentage between 500µm and 850µm. However the dry period samples have a higher percentage of finer sediment than that of the wet period samples. Nhlangaluwe is also situated on the banks of the Limpopo River and is inundated during the summer months; this would affect the sediment trends seen.

The three graphs in section 6.2.8, 6.2.9 and 6.2.10 respectively illustrate the above soil particle size analysis results. The differences between the wet and dry period grain size distribution patterns are shown. The three graphs also highlight the differences in trends seen between the samples taken close to the wetland/pans edge lower down the hill and samples taken further away higher up the hill. The graph data plots the mean grain size (D50) and the D10 and D90 values respectively (D50 = mean grain size, D10 and D90 = the 10th and 90th percentile respectively, meaning 10% or 90% of the data fall below these percentiles) to show this.

6.2.8 Grain Size Distribution for Gwalala

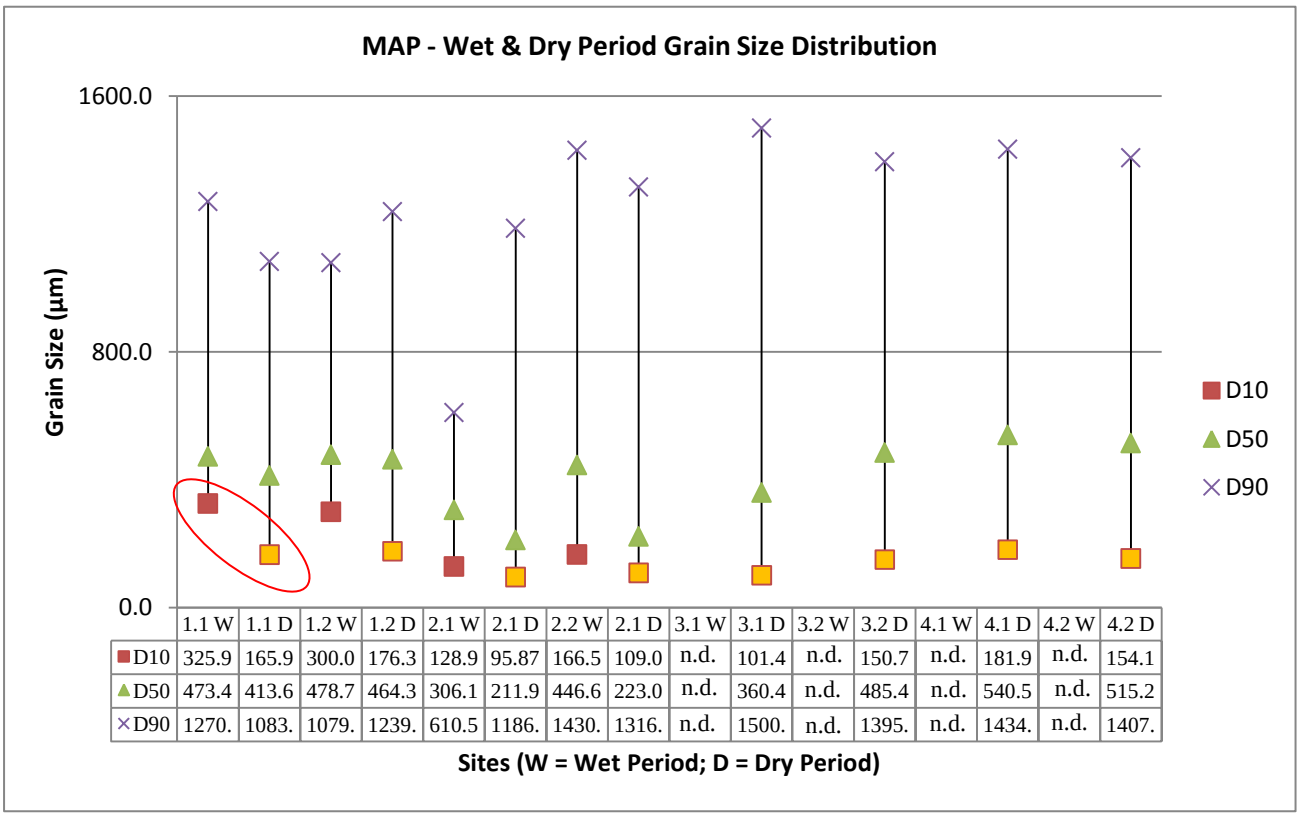


	1.1 W	1.1 D	1.2 W	1.2 D	2.1 W	2.1 D	2.2 W	2.2 D	3.1 W	3.1 D	3.2 W	3.2 D	4.1 W	4.1 D	4.2 W	4.2 D
D10	307.06	152.63	447.07	136.11	436.47	112.41	402.67	151.79	419.73	182	406.43	134.95	500.13	136.86	178.95	98.537
D50	622.17	587.81	705.64	677.25	676.41	517.59	633.43	602.03	789.2	731.75	759.9	528.98	685.64	587.97	701.67	578.89
D90	1648	1564.8	1679	1650.8	1661	1413.4	1555.6	1497.3	1688.7	1649.7	1578.7	1386.4	1561.3	1505.5	1522.3	1586.6

Figure 6.10: Distribution of Gwalala's grain size (µm) for wet and dry Periods

In figure 6.26 it can be see that all the sediment samples taken during the dry period are finer than that of the summer samples. This is indicated with the dry periods samples being coloured orange, the red line around the first sediment indicates the trend that the sample follows with larger sediment in the wet period vs. smaller sediment in the dry period. The larger sediment in the sample series is consistent in both wet and dry periods and the same can be said for the mean (D50) in the samples. The wet period, samples 1.1 is moderately sorted medium sand, samples 1.2, 2.1, 2.2, 3.1, 3.1, 3.2 is moderately sorted coarse sand, 4.1 is moderately well sorted coarse sand and 4.2 is poorly sorted coarse sand. During the dry period, samples 1.1, 1.2, 3.1 and 4.2 are poorly sorted very coarse sand, 2.1, 2.1, 3.2 and 4.1 are poorly sorted coarse sand.

6.2.9 Grain Size Distribution for Mapimbi

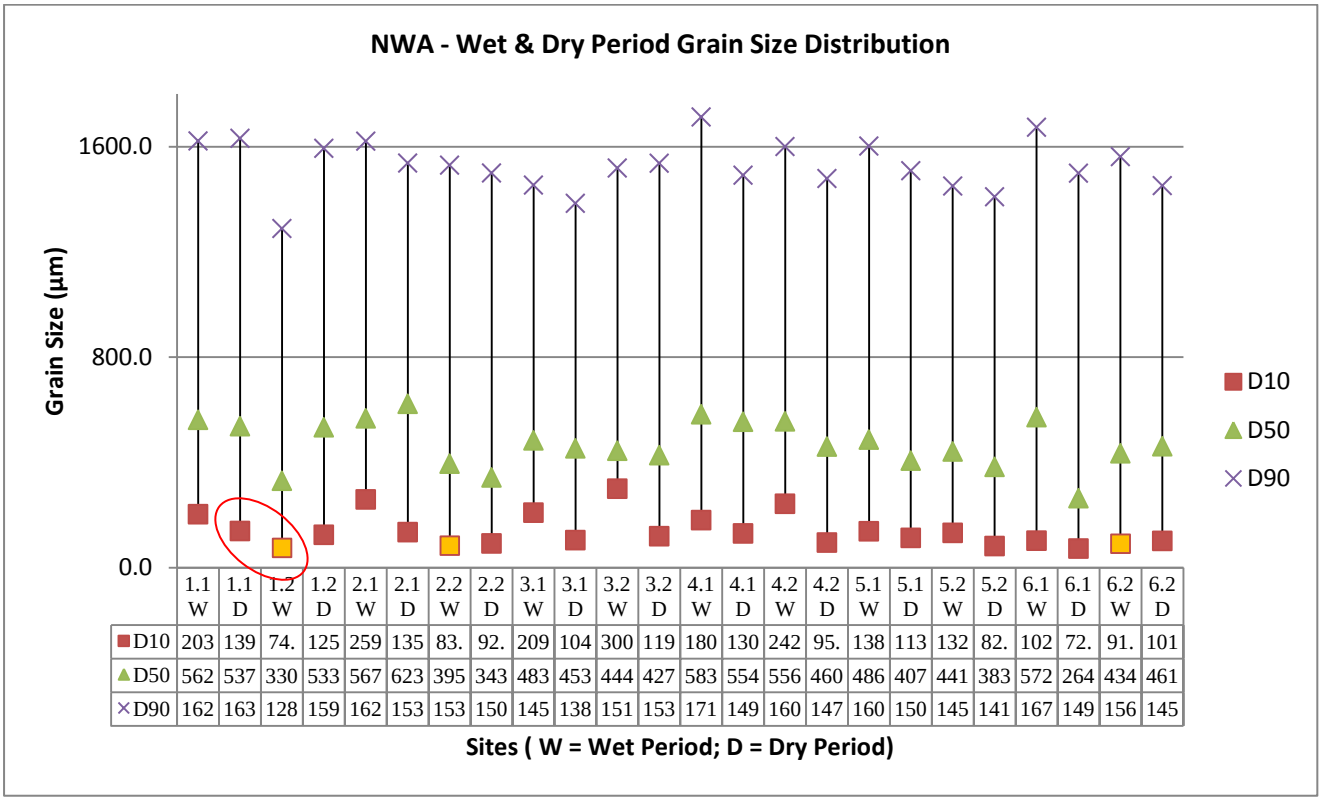


	1.1 W	1.1 D	1.2 W	1.2 D	2.1 W	2.1 D	2.2 W	2.1 D	3.1 W	3.1 D	3.2 W	3.2 D	4.1 W	4.1 D	4.2 W	4.2 D
D10	325.9	165.9	300.0	176.3	128.9	95.87	166.5	109.0	n.d.	101.4	n.d.	150.7	n.d.	181.9	n.d.	154.1
D50	473.4	413.6	478.7	464.3	306.1	211.9	446.6	223.0	n.d.	360.4	n.d.	485.4	n.d.	540.5	n.d.	515.2
D90	1270.	1083.	1079.	1239.	610.5	1186.	1430.	1316.	n.d.	1500.	n.d.	1395.	n.d.	1434.	n.d.	1407.

Figure 6.11: Distribution of Mapimbi's grain size (µm) for wet and dry periods (n.d. = no sample taken) (D50 = mean grain size, D10 and D90 = the 10th and 90th percentile respectively, meaning 10% or 90% of the data fall below these percentiles)

In figure 6.27 can be seen that Mapimbi's dry sampling period sediments follow the same trend, in that the dry periods sediment samples are finer than the wet period sediment samples. This is indicated with the dry period samples being coloured orange, the red line around the first sediment indicates the trend that the sample follows with larger sediment in the wet period vs. smaller sediment in the dry period. The mean (D50) for this sample varies from one site to another and between sample periods. The same variability can be seen in the larger sediment sizes. Mapimbi's textural group for both the wet and dry period samples was sand. In the wet period, the majority of Mapimbi's grain size distribution was medium sand and it was moderately sorted. Sample 2.2 was poorly sorted medium sand. During the dry period, samples 1.1 and 1.2 were poorly sorted medium sand, 2.1 and 2.2 were poorly sorted fine sand, 3.1 was poorly sorted fine sand, 3.2 poorly sorted course sand, 4.1 and 4.2 poorly sorted coarse sand.

6.2.10 Grain Size Distribution for Nwambi



	1.1 W	1.1 D	1.2 W	1.2 D	2.1 W	2.1 D	2.2 W	2.2 D	3.1 W	3.1 D	3.2 W	3.2 D	4.1 W	4.1 D	4.2 W	4.2 D	5.1 W	5.1 D	5.2 W	5.2 D	6.1 W	6.1 D	6.2 W	6.2 D
D10	203	139	74.	125	259	135	83.	92.	209	104	300	119	180	130	242	95.	138	113	132	82.	102	72.	91.	101
D50	562	537	330	533	567	623	395	343	483	453	444	427	583	554	556	460	486	407	441	383	572	264	434	461
D90	162	163	128	159	162	153	153	150	145	138	151	153	171	149	160	147	160	150	145	141	167	149	156	145

Figure 6.12: Distribution of Nwambi's grain size (µm) for the wet and dry period (D50 = mean grain size, D10 and D90 = the 10th and 90th percentile respectively, meaning 10% or 90% of the data fall below these percentiles)

Figure 6.28 indicates that not all the samples follow the same tendency as the above two examples, here sample sites 1.2 wet and dry period, 2.2 wet and dry period and 6.2 wet and dry period have finer sediments in the wet period and coarser sediment in the dry period. This is indicated with the wet period samples being coloured yellow, the red line around the sediment indicates the inconsistencies in the sample series. Nwambi's samples 1.2, 2.1, 2.2, 3.1, 3.2, 5.1, 5.2 and 6.2 sediment is considered to be poorly sorted medium sand and 1.1, 4.1, 4.4 and 6.6 is poorly sorted course sand for the wet period. The dry period sediment samples 5.2 was considered poorly sorted medium sand, 1.1, 1.2, 2.1, 3.1, 4.1, 4.2, 5.1 and 6.2, samples 2.2 and 6.1 were poorly sorted very fine sand and sample 3.2 was poorly sorted fine sand.

6.2.11 Concluding Discussion

Soil particle size distribution is significant because of its ability to retain water and moisture for an extended period of time. Smaller grain sizes are also known to contain and/or hold increased minerals that have settled on the bottom sediment. The analysis of the above soil particle size distribution graphs indicates that; the grain size of the soils studied at Magomugomu, Makwadzi, Likangwa, Nhlangaluwe and Mapimbi systems would not be able to support a body of water for a long period of time even though the samples held a percentage of smaller sediment. This therefore indicates that dead organic matter (DOM) found in soil samples and the related COC (Section 6.1) are important variables that assist in water retention within wetland environments. Particle size distribution and COC cannot be assessed separately when determining the water retention potential of soils as the presence of DOM supports infiltration and absorption and/or in its absence allows for well drained soils to dominate. Wetland features in particular hold increased amounts of vegetative matter which may contribute to

water retention within the system. Generally, pan systems are seen to rely more on a higher percentage of smaller sediment which has stronger water retention capabilities.

6.3 Pan Characteristics

Table 6-4: Background information acquired during the ground truthing part of the study

Pans	Point Coordinates °S	Point Coordinates °E	Water Source	Orientation	Perennial/ Seasonal	Scale of Flood (Wet Period)	Scale of Flood (Dry Period)
Magomugomu	22.42328	31.19056	Luvuvhu River	ENE to W	Annual	4	3
Gwalala	22.42495	31.13001	Luvuvhu River	ENE to WSW	Annual	5	0/1
Likangwa	22.37947	31.2199	Limpopo River	E to WSW	Perennial (potential to dry out, but has been wet for the past 3 years)	4	2
Nwambi	22.41566	31.26037	Luvuvhu River	SE to NW	Perennial	4	3
Nhlangaluwe	22.37625	31.20095	Limpopo River	ESE to WNW	Perennial	4	3
Makwadzi	22.34651	31.12721	Limpopo River	NE to SW	Annual but becoming more perennial	5	2
Mapimbi	22.40286	31.28006	Limpopo River	ESE to WNW	Perennial	3	3

The point coordinates shown can be input into a GIS and the relevant pan located. The water source refers to where the pans greatest potential lies to receive water. This is significant as the Limpopo River, as previously discussed, is a weak perennial river where flows frequently cease. The orientation of the pan refers to direction according to the cardinal points and possible geological relations to the drainage and the topography. Perennial vs. seasonal is indicative of the status of the rivers that the pans may be associated with. This is important, as the hydrology is a key factor in the functioning of these systems. The values given for the relative scale of flood refer to the individual pans ability to fill/drain per sampling period in this study, with (5) being excessively flooded, (4) being flooded, (1) a small pool of water and (0) being dry.

The method of inundation for the respective pans has been discussed in section 4.4 earlier in this study. The proposed water source and method of inundation are linked. The source provides the information for which river system is responsible for the pans inundation or presence of water. The proposed water source for Magomugomu is flooding from the Luvuvhu River by inundation over the levees. However, Magomugomu is located below a hill on its northern banks with the pan itself situated east to west. As a result, Magomugomu would receive excess run-off from the hill slope and store it in the pan as well. The Luvuvhu River area is associated with quartzite from the Soutpansberg Group, which has low infiltration; this contributes to the increase in runoff into the pan. Magomugomu is inundated annually and when full, it supports a large ecosystem for a period of time. During this study the pan registered a 4 scale of flood in the wet period (March 2011),

meaning that it was full and during the dry period the scale of flood was 0 (November 2011), which meant it was dry. However, in March 2012, the pan had a scale of 0 meaning it was completely dry and had not been inundated as in the previous year.

Gwalala's proposed water source is the Luvuvhu River, with its method of inundation based on rivers flooding of the pan and rainfall. Gwalala's northern bank is consistent with that of a levee and its southern bank a floodplain, the pans orientation is east to west between these two geological features. The flooding events have resulted in the deposition of alluvium and clay/silt sediments in the pan forming an impermeable and muddy base. Gwalala's inundation is also recorded as annual, with the pans scale of flood for the wet period (March 2011) being rated as 5 which means the pan was flooded and during the dry period (November 2011) Gwalala's scale of flood was 0/1 where a pool of 1.5m x 1.5m was found. The wet period (March 2012) presented the same results as the dry period (November 2011).

Likangwa's proposed water source is the Limpopo River system. Likangwa is found in an alluvial floodplain, with its orientation being east to west parallel to the Limpopo River and its formation being controlled by basaltic outcrops, this pan also has a well developed levee present. Likangwa is a perennial pan but is starting to dry out, it is recharged with rainwater and run-off and when the Limpopo floods and inundates it. The scale of flood assigned to Likangwa for the wet period (March 2011) was 4 as the pan was full. During the dry period (November 2011), the pan's scale of flood was 2 as it was very low from the previous sampling season.

Nwambi pan's proposed water source is the Luvuvhu River system. The pan is controlled by levees and sandy deposits from the river. Nwambi's method of filling up is by rainfall events and run-off events due to the nature of the depression being the gradient of its banks and located near a hill slope. The pan is therefore, as a result, perennial. Its orientation is north to south facing with a scale of flood for the wet period (March 2011) of 4, being flooded, and 3 for the dry period (November 2011), still very full.

Nhlangaluwe's proposed water source is the Limpopo River. In the same manner as Likangwa, it is also found in the alluvial floodplain with its orientation being east to west and parallel to the Limpopo River. Nhlangaluwe is also influenced by the Limpopo River's prominent levee and controlled geologically by basalt outcrops. In comparison to Likangwa, Nhlangaluwe is still considered perennial even though both pans are in close proximity. The pan is recharged by rainfall and run-off due to the pan being located at the bottom of a steep slope and inundation from the Limpopo when it breaks its banks in flood. Nhlangaluwe's orientation is north to south and its scale of flood during the wet period (March 2011) was 4, being full, and 3 in during the dry period (November 2011), still holding a relatively large amount of water.

Makwadzi pan's proposed water source is the Limpopo River and is controlled geologically. Makwadzi is recharged during the rainy summer months when the Limpopo spills its banks. The pan has a north to south orientation and is considered an annual pan but is becoming perennial. During the wet period (March 2011), Makwadzi's scale of flood was 5 indicating that it was flooded and in the dry period (November 2011), the scale of flood was at 2 indicating it had lost a lot of water over the year but was still retaining a large amount.

Mapimbi pan's proposed water source is the Limpopo River and has different geological controls to the other pans located on the Limpopo River. Mapimbi receives its water earlier in the year as a result of its location close

to the water table. Fluctuations in the level of the water table provide water perennially to this pan system. The pan is however, also located in a low lying topographical setting with higher banks allowing for surface run-off collection during rainy seasons. Mapimbi's orientation is east to west and its scale of flood during the wet period (March 2011) and the dry period (November 2011) was 3. The wet periods (March 2012) site visit for aquatic invertebrates observed the same scale of flood for Mapimbi, its scale of flood had remained constant.

6.3.1 Tabulated Physical Pan Data

The table below depicts the soil probe percentages showing the changes in moisture of the soil on site the further away one moves from the pans wetted area along the transects where the soil samples were taken from. The soil probe readings were recorded during the dry period before the rainy season begun (November 2011). The moisture probe percentage readings are represent the following categories (10% - 30% = Dry; 40% - 70% = Moist; 80% - 100% = Wet). (* Sample site not reached, No Data (n.d.) due to site inaccessibility)

Table 6-5: Soil probe readings

Pan	Site Number	Soil Probe Percentage of Moisture (%) (Dry Period 2011)
Magomugomu	1.1	95
	1.2	15
	2.1	90
	2.2	20
	3.1	n.d.
	3.2	n.d.
	4.1	n.d.
	4.2	n.d.
Gwalala	1.1	50
	1.2	10
	2.1	20
	2.2	10
	3.1	20
	3.2	30
	4.1	20
	4.2	10
Likangwa	1.1	50
	1.2	20
	1.3	10
	2.1	40
	2.2	20
	2.3	10

Pan	Site Number	Soil Probe Percentage of Moisture (%) (Dry Period 2011)
	3.1	100
	3.2	90
Nwambi	1.1	n.d.
	1.2	20
	2.1	n.d.
	2.2	30
	3.1	n.d.
	3.2	20
	4.1	n.d.
	4.2	20
	5.1	20
	5.2	10
	6.1	15
	6.2	15
Nhlangaluwe	1.1	30
	1.2	10
	2.1	30
	2.2	10
	3.1	30
	3.2	10
Makwadzi	1.1	30
	1.2	10
	1.3	100
	2.1	100
	2.2	30
	3.1	10
	3.2	*
	3.3	*
Mapimbi	1.1	100
	1.2	30
	2.1	100
	2.2	25
	3.1	50
	3.2	20
	4.1	100

Pan	Site Number	Soil Probe Percentage of Moisture (%) (Dry Period 2011)
	4.2	15

6.3.2 Soil Probe Analysis

Magomugomu's soil probe readings were recorded as wet for sample sites 1.1 (95%) and 2.1 (90%) These results were to be expected as they were sampled near the pan edge. The soil at these sites was dry and fine but compacted. Sample sites 1.2 (15%) was surrounded by leaf litter with the soils being dry and sandy and 2.2 (20%) found at the next gradient change along the transect were considered as dry with large peds, sandy soil and leaf litter. Gwalala's results were more constant with sample site 1.1 (50%) being moist and 1.2 (10%), 2.1 (20%), 2.2 (10%), 3.1 (20%), 3.2 (30%), 4.1 (20%) and 4.2 (10%) reading dry. Sample sites 1 and 4 were indicative of a clay/sandy nature. Sample sites 2 and 3 were finer soils. Likangwa's soil moisture ranged from dry to wet. Site 1.1 (50%) was considered moist and rocky with small peds and had a grass vegetation type. Sample site 1.2 (20%) was very rocky, site 1.3 (10%) was also very rocky but the soil was fine and dry, site 2.2 (20%) had a few rocks in the sample with sandy type characteristics and site 2.3 (10%) was rocky with fine soils which were considered dry and site 3.1 (100%) and site 3.2 (90%) was wet. The soils depicted were fine soils with vegetative cover. Data collected for Nwambi at site 1.2 (20%), 2.2 (30%) had fine and dry soils with peds, site 3.2 (20%) was also dry with soft fine soils, site 4.2 (20%) was consistent with hard, fine dry soils, site 5.1 (20%) and 5.2 (10%) were fine dry soils with vegetation, site 6.1 (15%) and 6.2 (15%) had dry and fine soil. Nhlangaluwe is also distinctive of dry soils as all the samples taken were found to have a moisture percentage of 30% or under and were fine sandy soils. Soils found in Makwadzi at sites 1.1 (30%) and 1.2 (10%) were very dry compact clay peds and a thick layer of grass covering it. Sample site 2.2 (30%) had smaller dry clay peds but the sample was mixed with sandy sediment and pebbles as well; the sample site also showed signs of fissuring and 3.1 (10%) had fine soil with a few peds and was classed as dry. Soils tested at site 1.3 and 2.1 were classified as wet. Mapimbi sample site 1.1 (100%) was wet with its soil being soft, site 2.1 (100%) and 4.1 (100%) were also wet, sample site 3.1 (50%) was considered moist and sample sites 1.2 (30%) which was sandy, 2.2 (25%), which was very fine and dry, site 3.2 (20%) and 4.2 (15%) were dry.

6.3.3 Pan Depth Analysis

Table 6-6: Wet and Dry period pan depth readings

(No Data (n.d.) due to site inaccessibility)

Pan	Site	Pan Depth (cm) (Dry period 2011)	Average Depth for Dry period (cm)	Pan Depth (cm) (Wet period 2012)	Average Depth for Wet period (cm)
Magomugomu	1	n.d.	n.d.	10	11.75
	2	n.d.		18	

Pan	Site	Pan Depth (cm) (Dry period 2011)	Average Depth for Dry period (cm)	Pan Depth (cm) (Wet period 2012)	Average Depth for Wet period (cm)
	3	n.d.		4	
	4	n.d.		15	
Gwalala	1	n.d.	n.d.	2	2
Likangwa	1	9.5	21.75	15	21.50
	2	34		28	
Nwambi	1	8.5	5.75	17	12.75
	2	3.5		5	
	3	5		22	
	4	6		7	
Nhlangaluwe	1	3	8.66	7	5
	2	14		3	
	3	9		n.d.	
Makwadzi	1	4	8	10	5
	2	9		5	
	3	15		5	
	4	4		n.d.	
Mapimbi	1	7	12.33	33	41
	2	20		37	
	3	10		53	

The differences in the depth of the pan were read at each aquatic invertebrate sampling site to acquire further knowledge of the different biotopes that the species were found inhabiting. Pan depth sampling was undertaken in November 2011 and March 2012. These characteristics are important for the analysis of the physical composition of the pans as a whole. However, the sampling is limited due to the fact that the sampling was undertaken on shore and not in the centre of the pan.

The pan depth data provided is that of the depth measured from the wetted area of the pan. At times measurements were difficult as the sand developed a rippling effect beneath the water creating an uneven surface; as a result a few measurements were required to locate a flat part of the pan floor. The mean average was calculated for the entire study sites as a whole to determine an overall depth for the pans individually. General site observations influencing aquatic invertebrates as well the average depth in the wet period at the sample sites are listed below:

- Magomugomu: Had an average depth of 11.75cm in the wet period. The pans water was full of sediment but the surface overall was debris free. There is no data for the dry period depth as the pan was dry,
- Gwalala: Had an average depth of 2cm in the wet period, the site was very murky with evidence of suspended sediment and animal activity as well as debris and algae on the surface. The floor of the pan was also covered with vegetation. There is no data for the dry period as the pan was dry,
- Likangwa: Had a wet period average of 21.50cm in depth, and an average depth in the dry period of 21.75cm. The difference being 25mm deeper in the dry period. This minimal difference can be attributed to inconsistencies with the bottom of the pan. Overall, Likangwa showed no significant changes between the periods. Its substrate was consistent of rocks and large sandy sediment,
- Nwambi: The pan average depth in the wet period was 12.75cm; in the dry period the water level showed a sign of dropping as the average pan depth was 5.75cm. The water in the pan was cloudy and red containing suspended solids,
- Nhlangaluwe: In the wet period the average depth was 5cm and in the dry period 8.66cm. Considering there was no data for site 4 in the wet period, the average is lower however, this taken into consideration, the pan depth did not change significantly during the periods of sampling. The substrate was consistent with thick, grey clay sediment, clouding the water,
- Makwadzi: The wet period average pan depth was 5cm and the dry period average pan depth was 8cm, like Nhlangaluwe there was no data for site 4 so the wet period average is lowered. Overall, no considerable depth differences occurred. During the dry period the water was green, had a sulphurous smell and was very cloudy and;
- Mapimbi: The wet period average depth for Mapimbi was 41cm and 12.33cm in the dry period. There is a marked difference in depth for this pan in comparison to the other study sites. The water was generally clear with algae on the surface.

6.3.4 Soil Type and Dominant Vegetation Immediately Surrounding the Pans

Table 6.5 compares soil form literature for the Makuleke region. The first column, “Proposed soil type during ground truthing", is by the Environmental Officer and Senior Trails Guide for the area, Walter Jubber. The field guides soil identification was then clarified by the latest soil literature for the Makuleke by Nortje et al. (2012). An additional column was added for the comparison of proposed soil forms by Tinley (1978) and Venter (1990).

Each study site is listed below with a fieldwork summary of an onsite analysis of the soils, dominant vegetation and general pan information. This section of results compares three different sources of which research has been completed in the study areas and assesses the individual pans soil properties. The analysis below divides the comparison into two, 1) a comparison of the different literatures, and 2) a soil characteristics comparison. The full soil form descriptions can be found in section 4.2.

Table 6-7: Soil composition and dominant vegetation

Pan Name	Proposed Soil Type during ground truthing (Nortje et al. 2012)	Proposed soil type (Tinley, 1978; Venter 1990)	Soil Composition	Dominant Vegetation	General Notes
Magomugomu	Oakleaf soil form	Deep to moderately deep, red and brown, paraduplex, calcareous clay Valsrivier form.	Reddish Dark Brown	*(Acacia xanthophloea)* Fever Trees and Riverine Forest	Alluvial floodplains, The north side of the pan has a stone outcrop
Gwalala	Oakleaf soil form	Deep to moderately deep, red and brown, paraduplex, calcareous clay Valsrivier form.	High clay content Soil presented fissures and pebbling effect in drying areas	*(Acacia xanthophloea)* Fever trees and (*Acacia albida)* Ana Trees	First Pan to flood
Nwambi	Oakleaf and Arcadia soil forms	Deep red, neocutanic clay of the Oakleaf form	Red, fine sandy soils with peds	Riverine vegetation northern side of pan: (*Acacia albida)*Ana trees and *(Acacia xanthophloea)* Fever trees east-west: (*Diospyros mespiliformu)* Jackal berry and (*Xanthocercis zambesiaca)* Nyala trees south: *(Acacia xanthophloea)* Fever trees	Silt is deposited in this pan by back flooding of the Limpopo and Luvuvhu Rivers
Likangwa	Valsrivier soil form	Very deep, brown, calcareous and sodic, neocutanic and paraduplex clay Oakleaf and Valsrivier forms	Shallow bedrock with leached soils. Hard fissured crust but moist below	*(Acacia xanthophloea)* Fever trees dominate lower northern bank, Knob thorn (*Acacia nigrescens*) dominate south side. Lala palms (*Hyphaene coriacea*)	On an ecotone separating Limpopo floodplains and Baobab Mopane hillslopes

Pan Name	Proposed Soil Type during ground truthing (Nortje et al. 2012)	Proposed soil type (Tinley, 1978; Venter 1990)	Soil Composition	Dominant Vegetation	General Notes
				were also present.	
Nhlangaluwe	Arcadi and Valsrivier form	Very deep, brown, calcareous and sodic, neocutanic and paraduplex clay Oakleaf and Valsrivier forms	Mispa with basaltic rocks on the north and south slopes; Arcadi cotton soil on east and west banks	Giant rat's tail (*Sporabolus pyradimalis*) on east and west lower banks; Knob thorn *(Acacia nigrescens)* on north and south banks. Lala palms (*Hyphaene coriacea*) were also present.	Nhlangaluwe has the ability to merge with 2 neighbouring pans (Kwankwinbi and Vendabenda) to form one large pan in the wetter periods. The 3 joined pans stay this way as they are on a drainage line
Makwadzi	Willowbrook soil form	Very deep, brown, calcareous and sodic, neocutanic and paraduplex clay Oakleaf and Valsrivier forms	Fine, dry loam/sandy soil	Giant rat's tail (*Sporabolus pyradimalis)* is dominant immediately surrounding the pan; Knob thorn *(Acacia nigrescens)* and (*Colophospermum mopane)* mopane trees can be found on the western and eastern hill slopes. There is also prominent floodplain vegetation, particularly emergent macrophytes.	Annual but becoming more perennial Found on a drainage line and in an individual catchment area
Mapimbi	Mispah and Dundee soil form	Very deep brown, neocutanic and stratified, loam or fine sand Oakleaf.	Loose soils, big peds, organic composition	*(Acacia xanthophloea)* Fever trees and Knob thorn *(Acacia nigrescens)* surround the pan.	Appears to have a constant source of water (Possible seepage from the Limpopo River) but is also filled during

Pan Name	Proposed Soil Type during ground truthing (Nortje et al. 2012)	Proposed soil type (Tinley, 1978; Venter 1990)	Soil Composition	Dominant Vegetation	General Notes
					flood seasons from surface run-off. Found on a drainage line and in an individual catchment area

Magomugomu Pan

1. The soil form identified by Walter Jubber from the field work portion of this study (2011-2012) proposed that Magomugomu's soil form was Oakleaf. Soil analysis performed by Nortje et al. (2012), stated that the soils for Magomugomu were also of the Oakleaf soil form. Earlier literature on the areas soil forms stated that Magomugomu's soil form was Valsrivier (Tinley, 1978; Venter 1990).
2. Similar soil characteristics for the Oakleaf and Valsrivier forms are as follows: the surface horizon does not qualify as organic, humic, melanic or vertic topsoil although it may have been darkened by organic matter and both forms experience underlying material that is unconsolidated.

Gwalala Pan

1. The soil form identified by Walter Jubber from the field work portion of this study (2011-2012) proposed that Gwalala's soil form was Oakleaf. Soil analysis performed by Nortje et al. (2012), stated that the soils for Gwalala were Dundee soil form. Earlier literature on the areas soil forms stated that Gwalala's soil form was Valsrivier (Tinley, 1978; Venter, 1990).
2. Similar characteristics are noted with the Oakleaf and Valsrivier forms as in Magomugomu however, the Dundee soil form does differ. Dundee soil forms have an underlying material that is not specified and is generally stratified alluvium varying in organic and mineral content.

Nwambi Pan

1. The soil form identified by Walter Jubber from the field work portion of this study (2011-2012) proposed that Nwambi's soil forms were Oakleaf and Arcadia. Soil analysis performed by Nortje et al. (2012) stated that the soils for Nwambi were Arcadia soil form. Earlier literature on the areas soil forms stated that Nwambi's soil form was Oakleaf (Tinley, 1978; Venter, 1990).
2. Arcadia soils in comparison to Oakleaf soil forms are very high in clay content and have underlying material that is unspecified.

Likangwa Pan

1. The soil form identified Walter Jubber from the field work portion of this study (2011-2012) proposed that Likangwa's soil form was Valsrivier. Soil analysis performed by Nortje et al. (2012), stated that the soils for Likangwa were Valsrivier soil form. Earlier literature on the areas soil forms stated that Likangwa's soil form was Oakleaf/Valsrivier (Tinley, 1978; Venter 1990).
2. Valsrivier soils are associated with the swartland form and underlying saporlite or hard rock.

Nhlangaluwe Pan

1. The soil form identified by Walter Jubber from the field work portion of this study (2011-2012) proposed that Nhlangaluwe's soil forms were Arcadia and Valsrivier soils around the pans. Soil analysis performed by Nortje et al. (2012) stated that the soils for Nhlangaluwe were Valsrivier soil form. Earlier literature on the areas soil forms stated that Nhlangaluwe's soil form was Oakleaf/Valsrivier (Tinley, 1978; Venter 1990).
2. Similarities can be seen throughout all of these suggested soil forms for Nhlangaluwe. For example, Arcadia soils and Valsrivier soils are dark soils associated with hard rock sediments. Valsrivier and Oakleaf soils share underlying unconsolidated material.

Makwadzi Pan

1. The soil form identified by Walter Jubber from the field work portion of this study (2011-2012) proposed that Makwadzi's soil form was Willowbrook. Soil analysis performed by Nortje et al. (2012), stated that the soils for Makwadzi were Willowbrook soil form. Earlier literature on the areas soil forms stated that Makwadzi's soil form was Oakleaf/Valsrivier (Tinley, 1978; Venter 1990).
2. Similar soil characteristics between these forms can be seen with Valsrivier and Willowbrook soils which are both dark. Also, the soil forms Willowbrook and Valsrivier have high organic contents.

Mapimbi Pan

1. The soil form identified by Walter Jubber from the field work portion of this study (2011-2012) proposed that Mapimbi's soil form was Mispah and Dundee. Soil analysis performed by Nortje et al. (2012) stated that the soils for Mapimbi were Dundee soil form. Earlier literature by Tinley (1978) and Venter (1990) on the areas soil forms stated that Mapimbi's soil form was Oakleaf.
2. Mispah, Oakleaf and Dundee have few similarities but mainly vary. The underlying material in the Dundee soil form is not specified and is dominated by stratified alluvium, whereas Mispah is consistent with calcrete sediment and Oakleaf is unconsolidated.

Across all three sources there is a discrepancy in the soil form named in the immediate area of the pans location. The reason for this is most likely due to extreme flooding events that frequent the areas every few years. These extreme flood events have the ability to distribute soils around the systems often changing the soil forms in the immediate surroundings. Tinley (1978), and Venter's (1990), research is 10 years apart, Nortje et al. (2012), is a further 20 years apart from Venter (1990). A year before Tinley (1978) completed his research, Cyclone Emily passed through the Pafuri region, followed by another cyclonic event in 1984, and 6 years before Venter (1990) would complete his research on soils in the area. Since then the area has been exposed to cyclone Demoina in 1984, a drought in 1991-1992 and Cyclone Eline in 2000. This study's research has assessed the Makuleke

regions soil forms for the period of 2011-2012, however since the completion of the fieldwork another extreme flood event occurred in the region January 2013. These extreme weather events have the ability to wash soils further downstream and move different soil types into areas. These natural flooding events could be the cause of soil changes within the Makuleke area.

6.4 Climatic Results

Climate is discussed in this study because it has an impact on water chemistry and thus affects aquatic invertebrates. The use of the rainfall data was also used in determining the wet and dry periods, presence or absence of water and the potential impacts caused by flood events.

6.4.1 Rainfall

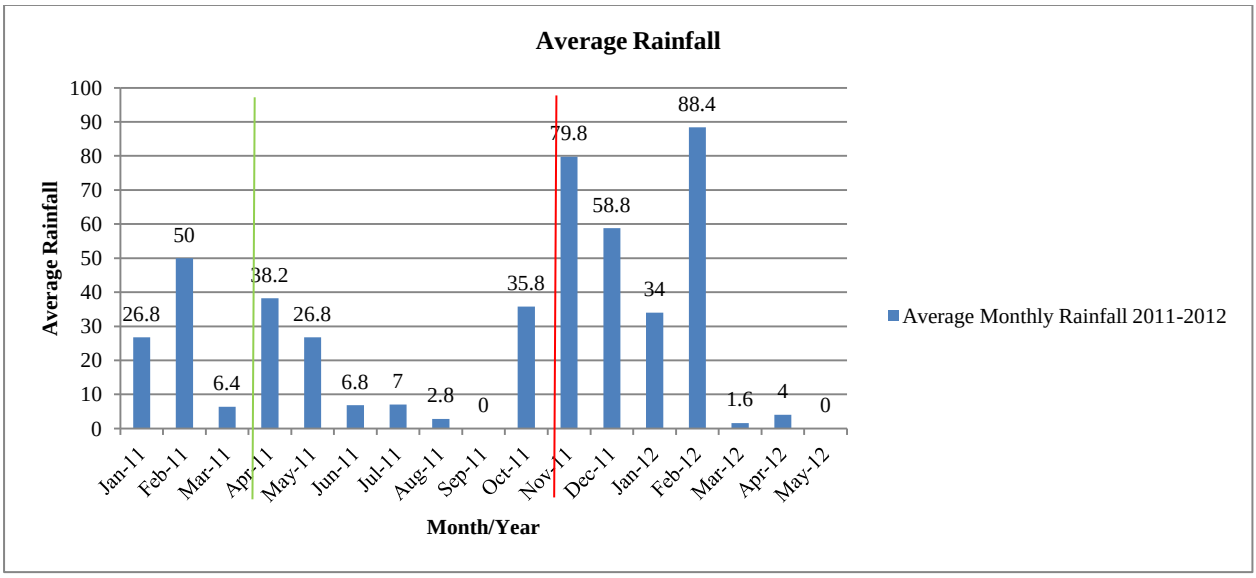


Figure 6.13: A histogram depicting the average rainfall in the northern KNP Punda Maria region for the duration of the study period (Martin, 2011). The green line seen within the graph indicates the end of the wet period when sampling took place and the redline indicates the dry sampling period that took place before the first rains.

The Southern hemisphere, particularly South Africa does not experience four distinct seasons, spring and autumn are very short. Although one cannot adequately state a start and end point of the different seasons the following divisions are commonly accepted: autumn = 1 March – 31st May; winter = 1 June – 31 August; spring = 1 September – 30 November and summer = 1 December – 28/29 February.

Using the average data for rainfall for the study area from January 2011 to May 2012, low rainfall periods and peaks in rainfall can be identified. Low rainfall months can be seen in from June to September 2011 with rainfall below 20mm. October 2011 sees the rainfall average begin to increase. In October the area received just less than 40mm of rainfall. From October to November, rainfall doubled with 80mm. From November 2011 to January 2012, however, there is a decline to less than 40mm of rainfall. January 2012 to February 2012 depicts another peak in rainfall for the area, the highest rainfall in the average dataset of over 80mm. From February 2012 to May 2012 rainfall drops to just above 0mm. March 2011 to May 2011 of the rainfall data indicate higher rainfall in 2011 over this period than in March 2012 to May 2012. It is important to note however, that this data set displays rainfall that is below average in comparison to previous years (see section 4.8) according to the seasonal rainfall for the area. The months of September – November usually display rainfall data averaging

150-200mm during this three month period. The figure above also indicated rainfall was late in 2011-2012, receiving the first peak in rainfall only in late November with a higher rainfall at the end of summer in March 2012. The rainfall however was significantly higher over the three months with approximately 460mm of rain received.

6.4.2 Average Maximum and Minimum Temperature

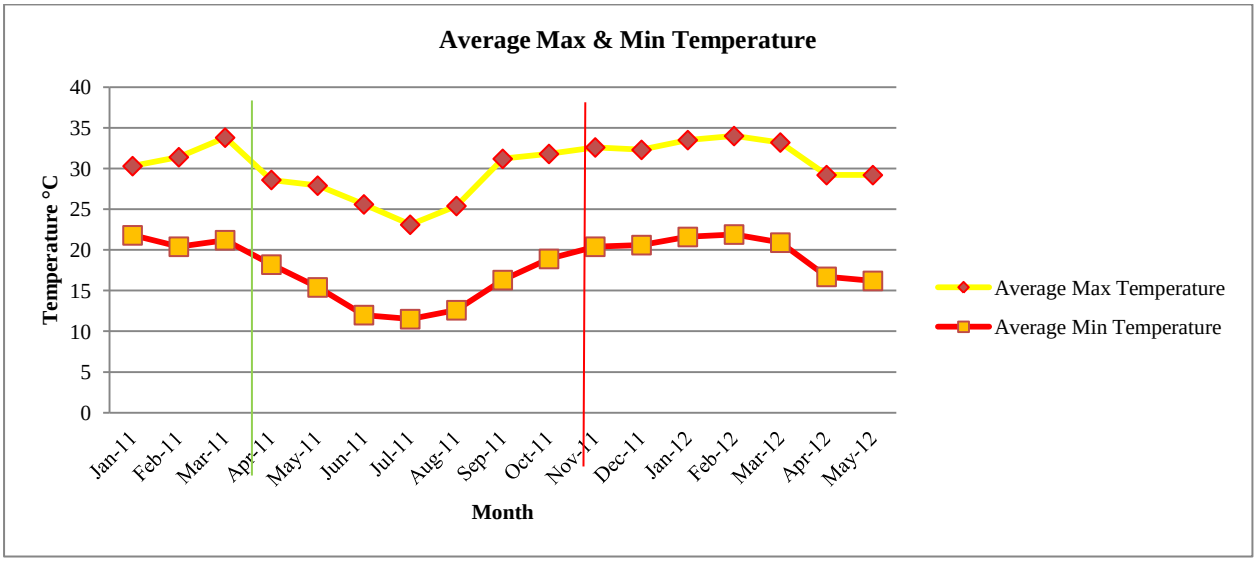


Figure 6.14: A line graph depicting the average monthly maximum and minimum temperatures for northern KNP Punda Maria weather station over the study period (2011-2012). The green line seen within the graph indicates the end of the wet period when sampling took place and the redline indicates the dry sampling period that took place before the first rains.

Using the above average maximum and minimum temperature for the study area, deductions can be made about the trends in temperature and evaporation. Both the maximum and minimum temperature lines are indicative of the same temperature trends. The wet period, January 2011-March 2011 and January 2012-March 2012, have very similar temperatures with their maximum temperatures ranging between 30-35°C and their minimum temperatures between 20-25°C. The dry period seen in this graph, April 2011-August 2011 and April 2012-May 2012, see drops in both maximum and minimum temperatures. The maximum temperature decreases to between 20°C and 30°C and the minimum decreasing to between 20°C and 10°C. There is a peak in both maximum and minimum seen in March 2011.

Rainfall versus temperature yielded the following results, during the dry period (April-August) of 2011 both the rainfall and temperatures were low. January 2011- March 2011 saw a spike in the temperature soon after which a decline in the rainfall in the area can be seen. During this time it is possible that the regions evaporation rates could have increased, thus resulting in a decrease in the water in the pans and an adverse effect of minerals increasing in the pan systems.

6.5 Water Chemistry Results

Pan systems in terms of geo-chemistry are seen as nutrient sinks. This is because they are depressions that will inevitably collect water through various means and as result of this collect, whatever has accumulated in a sediment load during transportation. The minerals collected in the pan systems is then stored in the sediment

itself and utilized when converted into organic and/or inorganic forms. These minerals are essential to aquatic ecosystems. However, due to the nature of pan systems, because of the amount of water they hold and their evaporation rates, minerals in these systems can increase. The following aspects can be affected by irregular occurrences of mineralisation in aquatic environments: trophic levels, change species abundance displace species and influence species richness.

The water quality data in section 6.5 below has been sourced from Antrobus (2012). The data sets ionic values have subsequently been analysed against the South African Water Quality Guidelines Volume 7 Aquatic Ecosystems, 1996, the "Resource Water Quality Objectives for the Upper and Lower Orange Water Management Areas (WMA's)", 2009. The WMA's report has been modified from DWAF 1996, 2006 and 2008, **Canadian Guidelines 1987, cited by South African Water Quality Guidelines (Department of Water Affairs and Forestry, 1996) and the *USA Guidelines 1987 cited by (Department of Water Affairs and Forestry, 1996). For simple comprehension of the data set at a glance value, an "effects key" has been developed. Here, the use of the above literature allowed for an effective significance to be placed onto the particular ions found in the pans and rivers. These effects are categorized by 3 main categories (Target Water Quality Range, Chronic Effect Value and Acute Effect Value) and sub-categories (where the values either meet or fail the subsequent main category given) with a corresponding colour of significance or importance. Instances where values contain a "<" sign in front of them indicate detection limits for that ion. During the water quality testing, some samples were too small to obtain a reading from, in these instances detection limit ranges were used. These detection limit ranges, together with the inability to obtain an accurate and exact figure, are the reason for differences in the detection limit values.

6.5.1 Cations

Table 6-8: Indicates the cations found and their concentrations for the Limpopo River and its associated pans (Likangwa, Mapimbi and Nhlangaluwe) and the Luvuvhu Rivers and its associated pan Nwambi. The effects key categories are as follows: Target Water Quality Range (TWQR), Chronic Effect Value (CEV) and Acute Effect Value (AEV)

Period Sampled	Pan/ Water Sources	Cations				
		Units (mg/l)				
		Magnesium	Aluminium	Potassium	Sodium	Calcium
March 2011 (Wet Period)	Likangwa	16.16	3.64	8.84	138.26	19.21
	Limpopo River	14.20	0.23	4.98	46.83	29.54
	Luvuvhu River	3.33	0.25	0.80	6.31	6.02
	Mapimbi	30.46	0.89	8.47	103.95	44.43
	Nhlangaluwe	16.23	0.79	10.11	86.06	22.18
	Nwambi	5.69	3.77	8.61	7.32	9.10
November 2011 (Dry Period)	Likangwa	23.57	6.98	10.14	499.13	2.24
	Limpopo River	21.10	0.02	3.28	52.97	39.40
	Luvuvhu River	7.36	0.24	1.34	11.34	9.76
	Mapimbi	59.89	2.70	15.45	188.39	51.93
	Nhlangaluwe	34.90	4.78	12.70	312.72	30.78
	Nwambi	12.17	9.96	12.26	12.62	15.00

Key
Limpopo Drainage
Luvuvhu Drainage
Meets (TWQR)
Fails (TWQR)
Meets (CEV)
Fails (CEV)
Meets (AEV)
Fails (AEV)

The magnesium concentration found for the rivers and the pans is very low overall. The Limpopo Rivers concentration at 14.20mg/l in the wet period, 21.10mg/l in the dry period, is higher than that of the Luvuvhu River at 3.33mg/l in the wet period and 7.36mg/l during the dry period. All the samples were of higher concentration in the dry period sampling. Mapimbi had the highest concentrations for both wet and dry samples and Nwambi had the lowest concentrations for both wet and dry samples. Both Mapimbi and Nhlangaluwe almost doubled in concentration during the dry period. All concentrations were higher in the pans along the Limpopo River.

The aluminium concentrations found for the rivers and the pans varies from meeting the TWQR to failing the AEV. The Limpopo Rivers concentration in the wet period is 0.23mg/l and 0.02mg/l in the dry period. The Luvuvhu Rivers concentrations are higher, at 0.25mg/l in the wet periods and 0.24mg/l in the dry periods. All the samples concentrations of aluminium increase in the dry sampling period except for the Limpopo River which sees a drop to 0.02mg/l. Nwambi had the highest concentration in both the wet and dry periods with both concentrations failing the AEV. Nwambi pan's concentration increased three times from wet to dry periods. Concentrations of aluminium were commonly higher for pans along the Limpopo River.

All the concentrations for potassium in the wet and dry period were found to meet the TWQR. The Limpopo Rivers concentration in the wet period is 4.98mg/l and 3.28mg/l in the dry period. The Luvuvhu Rivers concentrations are lower, at 0.80mg/l in the wet period and 1.34mg/l in the dry period. There is a general increase in potassium concentrations during the dry period. The highest concentration of potassium found was found in the dry period in Mapimbi at 15.45mg/l. The lowest concentration was the Luvuvhu River in the wet period with 0.80mg/l. Concentrations of potassium were commonly higher for pans along the Limpopo River.

Sodium concentrations vary through both sampling periods. The Limpopo Rivers concentration at in the wet period is 46.38mg/l and 52.97mg/l in the dry period. The Luvuvhu Rivers concentrations are lower, at 6.31mg/l in the wet period and 11.34mg/l in the dry period. All the sodium concentrations increase in the dry period. Two higher values for sodium appear in the wet period, Likangwa 138.26mg/l meets CEV and Mapimbi 103.95mg/l fails TWQR. In the dry period three higher values stand out, Likangwa 499.13mg/l fails AEV, Mapimbi 188.39mg/l fails CEV and Nhlangaluwe 312.72mg/l meets AEV. All concentrations for sodium were higher in the pans along the Limpopo River.

Concentrations of calcium for both the wet and dry sample periods meet the TWQR. The Limpopo Rivers concentration is 29.54mg/l in the wet period and 39.40mg/l in the dry period. These concentrations are higher than that of the Luvuvhu River at 9.76mg/l in the wet period6.02mg/l in the dry periods. The pan with the highest concentration was Mapimbi with 51.9 mg/l in the dry period and the pan with the lowest concentration was Likangwa with 2.24mg/l in the dry period. Significantly, Likangwa's concentration dropped in the dry period for sampling whilst the rest of the samples increased in concentration. All concentrations for calcium were higher in the pans located along the Limpopo River.

6.5.2 Anions

Table 6-9: Indicates the anions found and their concentrations for the Limpopo River and its associated pans (Likangwa, Mapimbi and Nhlangaluwe) and the Luvuvhu Rivers and its associated pan Nwambi

Period Sampled	Pan/ Water Sources	Anions				
		Units mg/l				
		Sulphate**	Phosphate	Nitrite*	Nitrate	Chloride
March 2011 (Wet Period)	Likangwa	3.67	3.14	< 0.05	< 0.07	49.38
	Limpopo River	28.49	< 0.2	< 0.05	< 0.07	66.95
	Luvuvhu River	< 0.1	< 0.2	< 0.05	< 0.07	6.75
	Mapimbi	23.21	< 0.2	< 0.05	2.87	123.30
	Nhlangaluwe	2.07	4.47	< 0.05	< 0.07	27.95
	Nwambi	1.71	< 0.2	< 0.05	2.21	4.92
November 2011 (Dry Period)	Likangwa	19.38	11.5	2.5	3.45	186.94
	Limpopo River	31.93	3.22	0.7	0.97	74.48
	Luvuvhu River	0.69	1.61	0.35	0.48	13.41
	Mapimbi	16.37	11.5	2.5	15.83	242.54
	Nhlangaluwe	7.41	11.5	2.5	14.27	119.76
	Nwambi	5.42	1.61	0.35	3.08	13.90

Key
Limpopo Drainage
Luvuvhu Drainage
Meets (TWQR)
Fails (TWQR)
Meets (CEV)
Fails (CEV)
Meets (AEV)
Fails (AEV)

Sulphate has both high and low concentrations in both sample periods, however they still all meet the TWQR. The Limpopo Rivers concentration at 28.49mg/l in the wet period and 31.93mg/l in the dry period is higher than that of the Luvuvhu River at <0.1mg/l in wet period and <0.69mg/l in the dry period. All samples increase in concentration from wet 23.21mg/l to dry 16.37mg/l periods, except for Mapimbi which decreases in concentration. The Limpopo River had the highest concentrations in both the wet (28.49mg/l) and dry (31.93mg/l) periods. All concentrations for sulphate were higher in the pans located along the Limpopo River.

All of the samples taken in the wet period for phosphate met the TWQR. Of the samples taken in the dry period, Likangwa, Nhlangaluwe and Mapimbi moved up to fail TWQR. The Limpopo Rivers concentration at <0.2mg/l in the wet period and 3.22mg/l in the dry period is higher than that of the Luvuvhu River at <0.2mg/l in the dry period and 1.61mg/l in the dry period. The highest concentrations (11.5 mg/l) were found in the pan's Likangwa, Nhlangaluwe and Mapimbi in the dry period of sampling. The lowest also with reference to detection limit was <0.2mg/l sampled at the Limpopo River, Luvuvhu River, Mapimbi and Nwambi in the wet period. All concentrations for phosphate were higher in the pans located along the Limpopo River.

The concentrations of nitrite in the wet period samples all failed the TWQR and in dry period the concentrations increased, with the Limpopo and Luvuvhu River and Nwambi meeting the CEV and Likangwa, Mapimbi and Nhlangaluwe failing the CEV. The Limpopo Rivers concentration at <0.05mg/l in the wet period 3.22mg/l in the dry period is higher than that of the Luvuvhu River at <0.05mg/l in wet period 0.35mg/l in the dry period.

The highest concentrations were found in the Limpopo and Luvuvhu River and Nwambi in the dry period of sampling with 2.5mg/l. The lowest concentrations were found in the wet period for all the samples at <0.5mg/l. All concentrations for nitrite were higher in the pans located along the Limpopo River.

The concentration of nitrate varied over the wet and dry sample periods. The Limpopo River's concentration at <0.07mg/l in the wet period and 0.97mg/l in the dry period is higher than that of the Luvuvhu River at <0.07mg/l in the wet period and 0.48mg/l in the dry period. The dry periods concentrations of nitrate increased, this is clearly seen in Mapimbi 15.83mg/l which was the highest concentration in both wet and dry periods and Nhlangaluwe 14.27mg/l second highest in the dry period. The lowest concentration was found in the wet period samples for Limpopo and Luvuvhu Rivers, Likangwa and Nhlangaluwe with a detection limit of <0.07mg/l. Nhlangaluwe went from being one of the lowest concentrations in the wet period to the second highest in the dry period. All concentrations for nitrate were higher in the pans along the Limpopo River.

Chloride concentrations for the wet period and the dry period have a baseline of TWQR and meets CEV. The Limpopo Rivers concentration at 66.95mg/l in the wet period and 74.48mg/l in the dry period is much higher than that of the Luvuvhu River at 6.75mg/l in the wet period and 13.41mg/l in the dry period. Many of the samples have a general increase in their dry period samples; however, large increases can be seen at sample sites Likangwa, Mapimbi and Nhlangaluwe. Mapimbi holds the highest concentration for both periods of sampling at 242.54mg/l and Nwambi was found to have the lowest at 4.92mg/l in the wet period. All concentrations for chloride were higher in the pans located along Limpopo River.

6.5.3 Toxic Metals

Table 6-10: Indicates the toxic metals found and their concentrations for the Limpopo River and its associated pans (Likangwa, Mapimbi and Nhlangaluwe) and the Luvuvhu Rivers and its associated pan Nwambi

Period Sampled	Pan/ Water Sources	Toxic Metals		
		Units (mg/l)		
		Chromium	Zinc	Arsenic
March 2011 (Wet Period)	Likangwa	0.022	< 0.060	0.008
	Limpopo River	0.002	< 0.060	< 0.004
	Luvuvhu River	0.001	< 0.060	< 0.004
	Mapimbi	0.004	< 0.060	< 0.004
	Nhlangaluwe	0.005	< 0.060	0.008
	Nwambi	0.018	< 0.060	< 0.004
November 2011 (Dry Period)	Likangwa	0.037	< 0.060	0.023
	Limpopo River	0.002	< 0.060	< 0.004
	Luvuvhu River	0.002	< 0.060	< 0.004
	Mapimbi	0.012	< 0.060	< 0.004
	Nhlangaluwe	0.028	< 0.060	0.013
	Nwambi	0.046	0.066	< 0.004

Key	
	Limpopo Drainage
	Luvuvhu Drainage
	Meets (TWQR)
	Fails (TWQR)
	Meets (CEV)
	Fails (CEV)
	Meets (AEV)
	Fails (AEV)

Chromium concentrations for the wet sampling period all met the TWQR. In the dry period however, three pans failed the TWQR, namely Likangwa, Nhlangaluwe and Nwambi. Likangwa's increase was small but

Nhlangaluwe and Nwambi's concentrations increased substantially. The Limpopo Rivers concentration at 0.022mg/l in both sample periods wet and dry was slightly higher than that of the Luvuvhu River at 0.001mg/l in the wet period 0.002mg/l and in the dry period. The highest concentration measured was at Nwambi in the dry period at 0.046mg/l. The lowest concentration was recorded at the Luvuvhu in the wet period at 0.001mg/l. Changes in increased concentration are seen in Nwambi from wet to dry sampling periods. It is interesting to note that the Luvuvhu River (Nwambi's source) has the lowest concentration. Concentrations were relatively similar when compared to possible increases in proposed water sources.

The zinc detection limit has been indicated as <0.060mg/l. All sample sites for the wet period and the dry period hold this value except for Nwambi's dry period sample which is 0.066mg/l. The detection limits indicate that the toxic metal zinc was too low to be recorded. Thus, zinc has been considered to meet TWQR for all samples except for Nwambi's sample taken in the dry sampling period.

Arsenic concentrations samples meet the TWQR except for Likangwa in the dry sample periods. The Limpopo Rivers concentration was at <0.004mg/l in the wet period and dry period, and the same was seen for the Luvuvhu River at <0.004mg/l in the wet and dry period. There is a significant increase in Likangwa's concentrations from 0.008mg/l in the wet period to 0.023mg/l in the dry period. A slight increase from wet to dry period was also seen in Nhlangaluwe.

6.5.4 Environmental Variables

The pH of closed water systems is important because, depending on the level of pH, certain ions can be released into the system making it toxic. The electric conductivity refers to the ability to pass an electric current. This electric current is affected by inorganic minerals as they conduct the electricity. Temperature has the ability to increase electric conductivity. The total dissolved solids are connected to the environmental variable electrical conductivity in that the TDS increases the conductivity due to the amount of ions dissolved in the water. It is important to remember that in clay systems, such as that of the study sites, there will be a higher conductivity because of the materials that have ionized in the water.

Table 6-11: Important environmental variables in aquatic ecosystems

Period Sampled	Pan/ Water Sources	Variables			
		pH	EC (mS/cm)	Temp (°C)	TSS (mg/l)
March 2011 (Wet Period)	Likangwa	8.546	0.727	31	224
	Limpopo River	8.713	0.589	31.8	290
	Luvuvhu River	7.97	0.114	32	30
	Mapimbi	8.6	1.08	31.8	78
	Nhlangaluwe	7.663	0.571	34.4	76
	Nwambi	7.033	0.1302	29	337
October 2011 (Dry Period)	Likangwa	8.623	0.231	34.3	576
	Limpopo River	7.31	0.646	23.6	3
	Luvuvhu River	7.34	0.171	28.9	3
	Mapimbi	7.74	1.555	30	250
	Nhlangaluwe	8.356	1.617	23.4	355

Key	
	Limpopo Drainage
	Luvuvhu Drainage
	Meets (TWQR)
	Fails (TWQR)
	Meets (CEV)
	Fails (CEV)
	Meets (AEV)

	Nwambi	7.66	0.206	23.3	1205	Fails (AEV)

Possible effects due to pH variance was calculated according to the method used in the SAS guidelines, whereby if the pH value varies from its previous background value for a specific site and time of day by >0.5 of a pH unit or by >5% overall, effects could occur. Temperature effects on aquatic invertebrates are calculated in a similar way. The water temperature should not be allowed to vary from the background average daily water temperature considered to be normal for that specific site and the time of day by >2°C or by 10%. Variables also assessed in this table are electrical conductivity and total suspended solids.

The pH of a water system is very important due to its ability to affect ecosystems. According to the definition above, pH should not change by >0.5. However, these changes in >0.5are seen in table 6.9 for both the wet and dry periods. At first glance the change in pH values seem high, however this is considered normal as it represents sampling period changes. The Limpopo Rivers pH was 8.713 in the wet period and 7.31 in the dry period, the Luvuvhu River was 7.97 in the wet period and 7.34 in the dry period with both rivers acidity increased slightly. During the wet period, Likangwa, the Limpopo River and Mapimbi were more alkaline than the Luvuvhu River and Nhlangaluwe. In the dry period Likangwa's, Nhlangaluwe's and Nwambi's alkalinity increased. In Table 6.9, pH is considered to meet the TWQR. This is because it is recognised that these pH changes are seen as normal given the long time period between sampling. However, if the values indicated in Table 6.9 represented pH changes in a short timeframe (i.e. 2-3 days) harmful consequences could result. Frequency of sampling is a limitation of assessing pH values, a large data set of frequent sampling would be required in to provide meaningful statistics.

The electrical conductivity was found in low concentrations across the sample sites. The higher values were found in the pans located along the Limpopo River. The highest EC was found in the wet sample period was at Mapimbi with 1.08mS/cm and in the dry period with Mapimbi 1.555mS/cm and Nhlangaluwe with 1.617mS/cm.

For the aquatic ecosystem to remain stable, the environmental variable temperature also needs to remain within >2°C of variance. Water temperatures are likely to change over seasonal periods naturally. This change is usually slow, allowing species to adapt; as a result the changes in temperature seen in the table are not acute changes. Two temperatures stand out in the dataset, these being Likangwa; as this pans temperature increased from summer (wet period) to (dry period) from 31°C to 34°C and Mapimbi; as this pans temperature was the most constant for both periods of sampling.

Total suspended solids are important as they provide the baseline potential for total dissolved solids to increase in the water system, thus increasing mineral levels in the water. The results for TSS vary drastically in both wet and dry periods. Increases in levels and decreases in levels were great. Likangwa, Mapimbi, Nhlangaluwe and Nwambi all increased considerably from the wet to dry period. In contrast, a decrease was seen for the Limpopo and Luvuvhu Rivers.

6.6 Aquatic Invertebrate Taxa Abundance and Richness Table

Taxa were caught by the SASS method of a surface (S) and disturbed (D) sweep for each sample site. Samples were standardized and made as quantifiable as possible by capturing data for the number of different taxa per samples identified and then placing an abundance value to that individual taxon, therefore identifying the qualified taxa richness for each sample. The abundance of taxa was given a range value which represents the number of individual taxon identified per sample. Sensitivity of taxa is referred to in this section 6.6 and section 6.7. The use of the term sensitivity in this study will refer to individual taxon tolerances to pollution as used by the South African Scoring System (SASS5) (Dickens and Graham, 2001).

Table 6-12: Represents the taxa found per sample site and the biotopes they were found in

Pan	Site #	Site Description for surface (S) and disturbed (D) sweep	Taxa	Taxa Abundance (Number of individuals) (*=1-5) (**=6-10) (***=11+)	Taxa	Taxa Abundance (Number of individuals) (*=1-5) (**=6-10) (***=11+)
			Dry Period (November 2011)		**Wet Period (March 2012)**	
Mapimbi	1.1	(S) Shade, debris	*Notonectidae anisops* *Annelida hirudinae* *Diptera culicidae* *Mollusca thiaridae* *Annelida oligochaeta* *Mollusca physidae* *Anisoptera libellulidae* *Corixidae enithares*	** ** ** ** * * * *	*Notonectidae anisops* *Anisoptera libellulidae* *Mollusca thiaridae* *Diperta psychodidae*	*** * ** *
		Total # of taxa identified	**8**		**4**	
	1.2	(D)	*Notonectidae anisops* *Diptera chironomidae* *Annelida oligochaeta* *Mollusca thiaridae* *Annelida hirudinae* *Desis formidabilis* *Anisoptera libellulidae* *Corixidae enithares*	** * * *** * * * **	*Mollusca thiaridae* *Unio cafer*	*** *
		Total # of taxa identified	**8**		**2**	
	2.1	(S) Rocky, debris, sunny surface	*Notonectidae anisops* *Annelida oligochaeta* *Diptera culicidae* *Anisoptera libellulidae* *Corixidae enithares*	** * ** * *	*Anisoptera corduliidae* *Notonectidae anisops* *Corixidae enithares*	* ** **
		Total # of taxa identified	**6**		**3**	

Pan	Site #	Site Description for surface (S) and disturbed (D) sweep	Taxa Dry Period (November 2011)	Taxa Abundance (Number of individuals) (*=1-5) (**=6-10) (***=11+)	Taxa Wet Period (March 2012)	Taxa Abundance (Number of individuals) (*=1-5) (**=6-10) (***=11+)
	2.2	(D)	*Annelida oligochaeta* *Annelida hirudinae* *Corixidae enithares* *Diptera ephydridae* *Mollusca thiaridae* *Diptera culicidae* *Notonectidae anisops*	* * ** * * * *	*Coleoptera hydrophilidae Adult* *Mollusca physidae* *Mollusca thiaridae* *Hydracarina hydrachnellae* *Hemiptera belostomatidae* *Anisoptera corduliidae*	** *** * * * *
		Total # of taxa identified	**7**		**6**	
	3.1	(S) Deep waters, vegetated, debris, sunny	*Annelida oligochaeta* *Annelida hirudinae* *Diptera ephydridae* *Notonectidae anisops* *Corixidae enithares* *Hemiptera belostomatidae*	* * ** ** * *	*Hemiptera belostomatidae* *Notonectidae anisops*	* **
		Total # of taxa identified	**6**		**2**	
	3.2	(D)	*Annelida oligochaeta* *Annelida hirudinae* *Diptera ephydridae*	* * *	*Mollusca thiaridae* *Diperta psychodidae*	* *
		Total # of taxa identified	**3**		**2**	
Makwadzi	1.1	(S) Rocky/pebbly, clear water with a bits of algae, shady	*Diptera chironomidae* *Corixidae enithares* *Diptera ceratopogonidae chironomidae* *Notonectidae anisops*	* * * **	No species found	
		Total # of taxa identified	**4**		**0**	
	1.2	(D)	*Coleoptera hydrophilidae* *P. piccanina* *Corixidae enithares* *Diptera ceratopogonidae chironomidae*	* ** * **	No species found	
		Total # of taxa identified	**4**		**0**	
	2.1	(S) very clay like, reed vegetation, sunny bank	*Corixidae enithares* *Diptera chironomidae* *Diptera ceratopogonidae chironomidae*	* * *	*Notonectidae anisops* *Corixidae enithares* *Hydracarina hydrachnellae* *Diptera culicidae* *Anisoptera libellulidae*	** ** * *** *

Pan	Site #	Site Description for surface (S) and disturbed (D) sweep	Taxa Dry Period (November 2011)	Taxa Abundance (Number of individuals) (*=1-5) (**=6-10) (***=11+)	Taxa Wet Period (March 2012)	Taxa Abundance (Number of individuals) (*=1-5) (**=6-10) (***=11+)
		Total # of taxa identified	**3**		**5**	
	2.2	(D)	*Corixidae enithares* *Diptera chironomidae* *Diptera ceratopogonidae chironomidae*	* * *	*Coleoptera hydrophilidae Adult* *Notonectidae anisops* *Corixidae enithares* *Coleoptera dytiscidae* *Hydracarina hydrachnellae* *Ochthebius dilatatus*	** * ** ** ** *
		Total # of taxa identified	**3**		**6**	
	3.1	(S) One side vegetated, dry clay, algae, inlet	*Corixidae enithares* *Notonectidae anisops*	** **	*Corixidae enithares* *Coleoptera dytiscidae* *Diptera culicidae larvae* *Coleoptera dytiscidae Larvae*	* ** * *
		Total # of taxa identified	**2**		**4**	
	3.2	(D)	*Corixidae enithares* *Notonectidae anisops* *Diptera ceratopogonidae chironomidae* *Gomphidae*	* * * *	*Diptera culicidae larvae* *Corixidae enithares* *Notonectidae anisops* *Coleoptera dytiscidae* *Hydracarina hydrachnellae* *Coleoptera dytiscidae Larvae*	** * * ** * ***
		Total # of taxa identified	**4**		**6**	
	4.1	(S) Sunny, suspended sediment, area utilized by animals	*Corixidae enithares* *Notonectidae anisops* *Diptera chironomidae* *Diptera ceratopogonidae chironomidae* *Diptera culicidae larvae* *Coleoptera dytiscidae*	** ** ** * ** *	Too vegetated to access sampling site	
		Total # of taxa identified	**6**		**n.d.**	
	4.2	(D)	*Diptera chironomidae* *Corixidae enithares*	* *	Too vegetated to access sampling site	
		Total # of taxa identified	**2**		**n.d.**	
Nwambi	1.1	(S) Vegetated, shady bank and shallow	Notonectidae anisops Corixidae enithares	** **	*Mesocnemis singularis* *Hydracarina hydrachnellae*	** ***

Pan	Site #	Site Description for surface (S) and disturbed (D) sweep	Taxa	Taxa Abundance (Number of individuals) (*=1-5) (**=6-10) (***=11+)	Taxa	Taxa Abundance (Number of individuals) (*=1-5) (**=6-10) (***=11+)
			Dry Period (November 2011)		**Wet Period (March 2012)**	
		Total # of taxa identified	**2**		**2**	
	1.2	(D)	*Corixidae enithares* *Diptera ceratopogonidae chironomidae* *Diptera culicidaees* *Notonectidae anisops*	** * * *	*Diptera chironomidae* *Corixidae enithares* *Coleoptera elmidae* *Diptera ceratopogonidae chironomidae*	* * * *
		Total # of taxa identified	**4**		**4**	
	2.1	(S) Vegetated, inlet, debris	*Anisoptera corduliidae* *Gomphidae* *Diptera culicidae larvae* *Corixidae enithares*	* * * **	*Anisoptera libellulidae*	*
		Total # of taxa identified	**4**		**1**	
	2.2		*Diptera culicidae larvae* *Corixidae enithares*	* *	*Coleoptera hydrophilidae Adult* *Hydracarina hydrachnellae* *Mollusca physidae*	* * *
		Total # of taxa identified	**2**		**3**	
	3.1	(S) Inlet, deep, little vegetation	*Corixidae enithares* *Diptera ceratopogonidae chironomidae*	* *	*Notonectidae anisops* *Corixidae enithares* *Diptera chironomidae*	* * *
		Total # of taxa identified	**2**		**3**	
	3.2	(D)	*Diptera culicidaees* *Anisoptera libellulidae*	* *	*Anisoptera libellulidae* *Diptera chironomidae* *Notonectidae anisops* *Corixidae enithares*	* *** ** *
		Total # of taxa identified	**2**		**4**	
	4.1	(S) Muddy, sunny, inlet, debris, in an erosion path, possible increase in silt	*Notonectidae anisops* *Corixidae enithares* *Anisoptera corduliidae*	* * *	*Diptera chironomidae* *Notonectidae anisops* *Mesocnemis singularis* *Coleoptera elmidae* *Mollusca physidae* *Hydracarina hydrachnellae*	* ** ** *** * ***
		Total # of taxa identified	**3**		**6**	

Pan	Site #	Site Description for surface (S) and disturbed (D) sweep	Taxa	Taxa Abundance (Number of individuals) (*=1-5) (**=6-10) (***=11+)	Taxa	Taxa Abundance (Number of individuals) (*=1-5) (**=6-10) (***=11+)
			Dry Period (November 2011)		**Wet Period (March 2012)**	
	4.2	(D)	*Diptera culicidae larvae* *Diptera chironomidae*	* *	*Diptera chironomidae* *Corixidae enithares* *Mollusca physidae* *Diptera ephydridae*	** *** * **
		Total # of taxa identified	**2**		**4**	
Likangwa	1.1	(S) Rocky, shallow, vegetated and suspended sediment	*Diptera ceratopogonidae chironomidae* *Tabanus giguttatus* *Corixidae enithares* *Notonectidae anisops*	** * * *	*Diperta psychodidae* *Notonectidae anisops* *Coleoptera dytiscidae Larvae* *Corixidae enithares* *Anisoptera libellulidae* *Diptera culicidae*	** * ** * * **
		Total # of taxa identified	**4**		**6**	
	1.2	(D)	*Corixidae enithares* *Diptera ceratopogonidae chironomidae*	* *	*Notonectidae anisops* *Corixidae enithares* *Anisoptera libellulidae* *Hydracarina hydrachnellae* *Annelida oligochaetas* *Diptera culicidae larvae* *Anisoptera corduliidae*	** * * ** ** ** *
		Total # of taxa identified	**2**		**7**	
	2.1	(S) Vegetated, deep water	*Diptera ceratopogonidae chironomidae* *Anisoptera libellulidae*	* *	*Notonectidae anisops* *Zygoptera lestidae* *Coleoptera hydrophilidae Adult* *Diptera culicidae* *Hemiptera belostomatidae* *Desis formidabilis*	* * ** * * *
		Total # of taxa identified	**2**		**6**	
	2.2	(D)	*Corixidae enithares*	*	*Notonectidae anisops* *Corixidae enithares* *Zygoptera chlorolestidae* *Diptera culicidae* *Hemiptera belostomatidae* *Zygoptera lestidae*	* ** * ** * *
		Total # of taxa identified	**1**		**6**	

Pan	Site #	Site Description for surface (S) and disturbed (D) sweep	Taxa Dry Period (November 2011)	Taxa Abundance (Number of individuals) (*=1-5) (**=6-10) (***=11+)	Taxa Wet Period (March 2012)	Taxa Abundance (Number of individuals) (*=1-5) (**=6-10) (***=11+)
Nhlangaluwe	1.1	(S) Suspended sediment and rocky	*Corixidae enithares* *Diptera ceratopogonidae chironomidae*	** *	*Corixidae enithares* *Anisoptera libellulidae* *Coleoptera dytiscidae* *Zygoptera Ceriagrion glabrum* *Cheumatopsyche hydropsychidae* *Diptera culicidae* *Anisoptera corduliidae*	*** * *** * * * **
		Total # of taxa identified	**2**		**7**	
	1.2	(D)	*Corixidae enithares*	*	*Corixidae enithares* *Notonectidae anisops* *Annelida oligochaetas* *Diperta psychodidae*	** ** ** *
		Total # of taxa identified	**1**		**4**	
	2.1	(S) Suspended sediment, algae, inlet, vegetated reeds	*Diptera culicidae larvae* *Diptera ceratopogonidae chironomidae*	* *	*Corixidae enithares* *Notonectidae anisops* *Cheumatopsyche hydropsychidae* *Mollusca thiaridae* *Annelida oligochaetas*	*** * * * **
		Total # of taxa identified	**2**		**5**	
	2.2	(D)	*Diptera culicidae larvae* *Diptera chironomidae*	* *	*Notonectidae anisops* *Coleoptera dytiscidae* *Annelida oligochaetas* *Coleoptera hydrophilidae Adult* *Mollusca thiaridae* *Cheumatopsyche hydropsychidae*	** * ** * ** **
		Total # of taxa identified	**2**		**6**	
	3.1	(S) Suspended sediment, no vegetation, shallow waters	*Corixidae enithares* *Notonectidae anisops*	* *	Could not access site due to hippos	
		Total # of taxa identified	**2**		**n.d.**	
	3.2	(D)	*Tabanus giguttatus* *Diptera ceratopogonidae chironomidae* *Notonectidae anisops* *Mollusca Sphaeriidae*	* * * *	Could not access site due to hippos	

Pan	Site #	Site Description for surface (S) and disturbed (D) sweep	Taxa Dry Period (November 2011)	Taxa Abundance (Number of individuals) (*=1-5) (**=6-10) (***=11+)	Taxa Wet Period (March 2012)	Taxa Abundance (Number of individuals) (*=1-5) (**=6-10) (***=11+)
		Total # of taxa identified	**4**		**n.d.**	
Magomugomu	1.1	(S) Shallow, sun	Pan had no water		*Notonectidae anisops* *Coleoptera dytiscidae* *Diptera culicidae*	* * *
		Total # of taxa identified	**0**		**3**	
	1.2	(D)	Pan had no water		*Notonectidae anisops* *Coleoptera dytiscidae* *Annelida hirudinae* *Diptera culicidae* *Corixidae enithares*	** ** * * *
		Total # of taxa identified	**0**		**5**	
	2.1	(S) Open water, sunny, shallow half way of pan	Pan had no water		*Notonectidae anisops* *Artemia salina*	* **
		Total # of taxa identified	**0**		**2**	
	2.2	(D)	Pan had no water		*Coleoptera dytiscidae Larvae* *Corixidae enithares* *Diptera culicidae* *Coleoptera hydrophilidae Adult* *Zygoptera Ceriagrion glabrum* *Anisoptera libellulidae*	* ** ** *** * *
		Total # of taxa identified	**0**		**6**	
	3.1	(S) Shallow, neck of the pan (south and north banks meeting), suspended sediment, debris	Pan had no water		*Corixidae enithares* *Coleoptera dytiscidae* *Coleoptera hydrophilidae Larva* *Coleoptera hydrophilidae Adult*	* ** ** **
		Total # of taxa identified	**0**		**4**	
	3.2	(D)	Pan had no water		*Notonectidae anisops* *Corixidae enithares* *Diptera culicidae* *Coleoptera hydrophilidae Adult*	* * ** *
		Total # of taxa identified	**0**		**4**	

Pan	Site #	Site Description for surface (S) and disturbed (D) sweep	Taxa Dry Period (November 2011)	Taxa Abundance (Number of individuals) (*=1-5) (**=6-10) (***=11+)	Taxa Wet Period (March 2012)	Taxa Abundance (Number of individuals) (*=1-5) (**=6-10) (***=11+)
	4.1	(S) Debris, shaded inlet	Pan had no water		*Notonectidae anisops*	*
		Total # of taxa identified	**0**		**1**	
	4.2	(D)	Pan had no water		*Hemiptera nepidae* *Corixidae enithares* *Coleoptera hydrophilidae* *Adult*	* ** **
		Total # of taxa identified	**0**		**3**	
Gwalala	1.1	(S) Shallow, shade, suspended sediment and dirty	Pan had no water		*Mollusca ancylidae* *Coleoptera dytiscidae*	* *
		Total # of taxa identified	**0**		**2**	
	2.1	(D)	Pan had no water		*Coleoptera dytiscidae* *Mollusca ancylidae*	* *
			0		**2**	

6.6.1 Mapimbi Pan

Mapimbi displays a higher taxa richness in the dry period as apposed to the wet period and a higher overall abundance. The taxon with the highest number of individuals seen at Mapimbi was the *Notonectidae anisops*, however in terms of abundance *Mollusca thiaridae* held a higher value. Mapimbi also has both the most and least sensitive taxa present; the least sensitive taxa being *Annelida hirudinae* and *Diptera culicidae* and the most sensitive taxon being *Anisoptera corduliidae*.

6.6.2 Makwadzi Pan

Makwadzi too displays a higher taxa richness in the dry period as apposed to the wet period and a higher overall abundance. The taxa with the highest number of individuals seen at Makwadzi were *Corixidae enithares* with *Notonectidae anisops* and *Diptera ceratopogonidae chironomidae* also with a high richness value. In terms of abundance *Corixidae enithares* had the largest amount. Taxa present in Makwadzi are neither least sensitive nor most sensitive.

6.6.3 Nwambi Pan

Nwambi displays higher taxa richness in the wet period as apposed to the dry period, and a higher overall abundance in the wet period of sampling. The taxon with the highest number of individuals seen at Nwambi was

Corixidae enithares with high presence of *Diptera culicidaees*, *Diptera ceratopogonidae chironomidae, Notonectidae anisops* and *Anisoptera libellulidae*. *Corixidae enithares* had the highest abundance with *Notonectidae anisops* as the second highest. Nwambi supports both least sensitive and most sensitive species. The dominant least sensitive taxa are *Diptera chironomidae* and *Diptera culicidae larvae*. However, Nwambi's sensitive taxa found are highly sensitive namely *Mesocnemis singularis* and *Coleoptera elmidae*. Both of which occur in two separate sites. *Anisoptera corduliidae*, also sensitive, appears at two different sites.

6.6.4 Likangwa Pan

Likangwa displays higher taxa richness in the wet sample period as apposed to the dry period, and a higher overall abundance in the wet period. The taxa with the highest number of individuals seen at Likangwa were; they were *Anisoptera (corduliidae and Libellulidae)*, *Corixidae enithares*, *Notonectidae anisops* and *Diptera ceratopogonidae chironomidae*. *Corixidae enithares* had a greater abundance. Likangwa's presence of taxa in terms of sensitivity also varies, this is because taxa like *Annelida oligochaetas*, *Diperta psychodidae* and *Diptera culicidae* occur here and have a very high tolerance for toxic waters. Also present are taxa with a low tolerance such as the *Anisoptera corduliidae* and *Zygoptera chlorolestidae* and *Zygoptera lestidae*.

6.6.5 Nhlangaluwe Pan

Nhlangaluwe displays higher taxa richness in the wet period, and a higher overall abundance in the wet sample period. The taxon with the highest number of individuals seen at Nhlangaluwe was *Notonectidae anisops*; however *Corixidae enithares* was the most abundant. Nhlangaluwe taxa also varied from most tolerant (*Annelida oligochaeta* and *Diperta psychodidae*) to tolerant (*Anisoptera corduliidae*).

6.6.6 Magomugomu Pan

Magomugomu displays higher taxa richness in the wet period as apposed to the dry periods, and a higher overall abundance is seen in the wet sample period. This is because the pan was dry during the dry sample period in winter and therefore no aquatic invertebrates could be sampled. The wet sampling period indicated that *Corixidae enithares* had the highest number of individual's seen at Magomugomu; however, *Coleoptera hydrophilidae* was the most abundant. The taxa found in Magomugomu are relatively tolerant species.

6.6.7 Gwalala Pan

Gwalala displays higher taxa richness during the wet sample period as apposed to the dry sample period and a higher overall abundance in the wet period of sampling. This is because the pan was dry during the winter months and therefore no aquatic invertebrates could be sampled. The wet period samples indicated that both *Mollusca ancylidae* and *Coleoptera dytiscidae* held the highest number of individuals that occurred in the pan together with a similar abundance. Like Magomugomu, Gwalala's aquatic invertebrates present are relatively tolerant species.

There are a few taxa that do not occur frequently namely; *Unio cafer* (Mapimbi- summer), *Desis formidabilis* (Mapimbi- dry period and Likangwa-wet period), *P. piccanina* (Makwadzi-winter), *Ochthebius dilatatus* (Makwadzi- wet period), *Coleoptera elmidae* (Nwambi- wet period), *Cheumatopsyche hydropsychidae* (Nhlangaluwe- wet period), *Mollusca Sphaeriidae* (Nhlangaluwe- dry period), *Artemia salina* (Magomugomu- wet period) and *Hemiptera nepidaes* (Magomugomu- wet period).

6.7 Aquatic Invertebrate Matrix with Tolerance to Environmental Changes and Habitat Relationships

Section 6.7 tabulates data for both the wet and dry sample periods results for the aquatic invertebrate section of this study. The tables list the taxa that were found during the study period together with their common habitat that they are generally associated with. The habitat within which taxa were located during this study is also noted for comparison in the table. The habitat characteristics sampled in this study were (shade, sunny, rocky, debris, emergent vegetation, deep waters, shallow waters, clear water, algae, inlet and suspended sediment or clouded water). The reason these biotopes were selected is that each pan had similar characteristics to some extent of the pans perimeter where samples could be achieved. This sampling also allowed for more qualitative and quantitative data collection to understand the use of the pan by the associated aquatic invertebrate taxa. The numerical values used in the habitat section of the tables represent the number of times that taxa were recorded utilizing a biotopes or preferred habitat. The tables also provide a SASS value derived from, also found in South African Water Quality Guidelines (Department of Water Affairs and Forestry, 1996; Dickens and Graham, 2001). This value is representative of the aquatic invertebrates' tolerance to pollution. The sliding scale and its values can be defined in the following manner: 1-5 highly tolerant to pollution, 6-10 moderately tolerant to pollution and 11-15 a very low tolerance to pollution. This SASS is indicative of flowing waters; therefore it is possible that taxa located in the pans have higher tolerances than that of species utilizing running water.

6.7.1 Wet Period Comparison

Table 6-13: Aquatic invertebrates found in the wet period and their related pan habitat (See appendix C for list of common names and related taxon morphology). A sliding scale was used to describe the taxa tolerance to pollution in the following way, 1-5 highly tolerant to pollution, 6-10 moderately tolerant to pollution and 11-15 a very low tolerance to pollution (Department of Water Affairs and Forestry, 2006)

Scientific name	SASS Sensitivity Value	Habitat	Shade	Sunny	Rocky	Debris	Emergent Vegetated	Deep Waters	Shallow Waters	Clear water	Algae	Inlet	Suspended sediment
Annelida hirudinae	3.5	Under stones, vegetation or debris, shallow pools or quiet areas of river		1					1				
Annelida oligochaeta	1	Mud or bottom substrate, pools or quiet areas of streams			2		3		1		2	2	4
Coleoptera dytiscidae (Adult)	5	Amongst plants on the edges of ponds/pools, Back water areas of streams	2	3	1	1	4		5		3	3	5
Coleoptera dytiscidae (Larva)	5	Amongst plants on the edges of ponds/pools, Back water areas of streams		1	1		3		2		2	2	1
Coleoptera elmidae (Adult)	8.5	Stones or any solid substrate, fast streams	1	1		1	1		1			1	1
Ochthebius dilatatus	8	Stagnant pools, wet rocks around waterfalls, amongst plants on the edge of the streams		1			1						1

Scientific name	SASS Sensitivity Value	Habitat	Shade	Sunny	Rocky	Debris	Emergent Vegetated	Deep Waters	Shallow Waters	Clear water	Algae	Inlet	Suspended sediment
Coleoptera hydrophilidae (Adult)	5	Amongst vegetation, in muddy patches along river banks, quiet shallow pools or slow edges of the streams	1	3	1	4	4	1	2		1	3	2
Coleoptera hydrophilidae (Larvae)	5	Pools, quiet shallow edges of streams				1			1				1
Diptera ceratopogonidae chironomidae	5	Sand, mud, edges of streams					1		1				
Diptera chironomidae	2	Silk tubes on any type of substrate, pools, streams and any container filled with water	1	2		2	3	2	1			4	2
Diptera culicidae (Larvae)	1	Pools and any temporary puddle			1		2		1		1	1	1
Diptera culicidae	1	Pools and any temporary puddle		4	2	1	4	2	5				3
Diptera ephydridae	6	Margin of dams, pans and other water bodies		1		1						1	1
Diperta psychodidae	1	Streams, stagnant puddles with decaying organic matter (certain species only)	1	1	2	2	2	1	1				2
Hemiptera belostomatidae	3	Bottom of shallow pools, backwater areas or quiet areas of streams		2	1	2	3	3					
Corixidae enithares	3.5	Shallow pools, quiet muddy areas of the streams	2	6	5	5	11	3	7		3	7	8
Hemiptera nepidae	3.5	Vegetation, trash or mud, shallow pools or slow streams	1			1						1	
Notonectidae anisops	3	Pools, backwaters of streams	2	8	4	6	12	5	6		3	7	7
P. piccanina	4	Clinging to vegetation in still waters											
Hydracarina hydrachnellae	8.5	Submerged vegetation or bottom debris, slow streams or quiet pools	1	3	2	3	6		2		1	3	4
Artemia salina	4	Temporary pond or salt pans		1					1				
Mollusca ancylidae	5.5	On rocks or and solid submerged substrate, all streams country-wide	4	2	1	4	3	1	2		2	2	4
Mollusca physidae	3.5	Gravel beds, or on aquatic vegetation		3	1	4	1					3	2
Mollusca Sphaeriidae	3	Sand or gravel beds											
Mollusca thiaridae	3.5	Gravel in flowing streams and silt substrate in pools	2	2	1	4	3	1			2	2	2

Scientific name	SASS Sensitivity Value	Habitat	Shade	Sunny	Rocky	Debris	Emergent Vegetated	Deep Waters	Shallow Waters	Clear water	Algae	Inlet	Suspended sediment
Unio cafer	5.5	Deep muddy substrate	1			1							
Anisoptera corduliidae	7.5	Stones, slower areas of stream		2	4	2	1		1				2
Anisoptera libellulidae	5	Stones, muddy patches, backwater areas, very slow streams		2	3	1	5	1	3			2	3
Gomphidae	4	Pools with extensive reed beds or rocks					1				1	1	
Cheumatopsyche hydropsychidae	4	Under stones, living in shelters made of sand grains and fast flowing rivers			1		2				2	2	3
Mesocnemis singularis	10	Under stones, on vegetation, headwaters of streams	1	1		1	1		1			1	1
Ceriagrion glabrum	4	Vegetation, edges of slow streams		1	1				1				1
Chlorolestidae zygoptera	7.5	Vegetation, edges of slow streams					1	1					
Zygoptera lestidae	7.5	Vegetation, backwater areas, pools					2	2					
Tabancmorpha tabanidae	5	Widespread, concentrated near pan areas											
Desis formidabilis	5	Water bodies rocks or vegetation					1	1					

The majority of aquatic invertebrates found in the wet period sampling are utilizing the pan biotope areas in the same manner they would in a stream environment, there are however additional areas that have increased usage. Due to the nature of pan systems, sediment is higher and more concentrated as apposed to flowing water systems. This is important as increased sediment can affect the condition of organisms. Adaptations can be seen with aquatic invertebrates utilizing emergent vegetation as a supplement for stones or rocks at the bottom of streams, for example, *Mesocnemis singularis*, *Zygoptera chlorolestidae* and Gomphidae, of which the two damselflies taxa have a high sensitivity rating of 10 and 7.5. Aquatic invertebrate taxa that utilize a muddy habitat in streams or the back waters of streams have been found in inlet areas in the pans; the areas here are very muddy and disturbed, for example, *Corixidae enithares* (sensitivity 3.5), *Mollusca physidae* (sensitivity 3.5) and *Gomphidae* (sensitivity 4). There is increased animal activity at pans in general but more so in these areas and thus increased suspended sediment. Closed drainage systems also result in a build-up of debris, this has lead to the increase use of debris as apposed to living vegetation for movement from one place to another, i.e. *Mollusca physidae* (sensitivity 3.5) and *Anisoptera corduliidae* (sensitivity 7.5). *Coleoptera elmidae*

(sensitivity 8.5), is known to live in flowing streams, but was found in Nwambi 1.2 in still water conditions. It is also related to habitats of solid substrate or stones; whereas in the study site the *Coleoptera elmidae* has been found to utilize habitats with, debris, emergent vegetation and an inlet which has a very soft substrate.

6.7.2 Dry Period Comparison

Table 6-14: Aquatic invertebrates found in the dry period sampling and their related pan habitat. A sliding scale was used to describe the taxa tolerance to pollution in the following way, 1-5 highly tolerant to pollution, 6-10 moderately tolerant to pollution and 11-15 a very low tolerance to pollution (Department of Water Affairs and Forestry, 1996)

Common name/ Scientific name	SASS Sensitivity Value	Habitat	Shade	Sunny	Rocky	Debris	Emergent Vegetated	Deep Waters	Shallow Waters	Clear water	Algae	Inlet	Suspended sediment
Annelida hirudinae	3.5	Under stones, vegetation or debris, shallow pools or quiet areas of river	2	3	1	5	2	2					
Annelida oligochaeta	1	Mud or bottom substrate, pools or quiet areas of streams	4	4		6	2	2					
Coleoptera dytiscidae (Adult)	5	Amongst plants on the edges of ponds/pools, Back water areas of streams		1									1
Coleoptera dytiscidae (Larvae)	5	Amongst plants on the edges of ponds/pools, Back water areas of streams											
Coleoptera elmidae (Adult)	8.5	Stones or any solid substrate, fast streams											
Hydraenida	8	Stagnant pools, wet rocks around waterfalls, amongst plants on the edge of the streams											
Coleoptera hydrophilidae (Adult)	5	Amongst vegetation, in muddy patches along river banks, quiet shallow pools or slow edges of the streams	1		1					1	1		
Coleoptera hydrophilidae (Larvae)	5	Pools, quiet shallow edges of streams											
Diptera ceratopogonidae	5	Sand, mud, edges of streams	3	3	6		9	2	3	2	4	3	8
Diptera chironomidae	2	Silk tubes on any type of substrate, pools, streams and any container filled with water	2	5	1	2	2		1	1	1	1	5
Diptera culicidae (Larvae)	1	Pools and any temporary puddle	1	1		3	6	1	1		2	6	4
Diptera culicidae	1	Pools and any temporary puddle	1	2	2	3							
Diptera ephydridae	6	Margin of dams, pans and other water bodies		2	1	2	1	1					

Common name/ Scientific name	SASS Sensitivity Value	Habitat	Shade	Sunny	Rocky	Debris	Emergent Vegetated	Deep Waters	Shallow Waters	Clear water	Algae	Inlet	Suspended sediment
Diperta psychodidae	1	Streams, stagnant puddles with decaying organic matter (certain species only)											
Hemiptera belostomatidae	3	Bottom of shallow pools, backwater areas or quiet areas of streams		1		1	1	1					
Corixidae enithares	3.5	Shallow pools, quiet muddy areas of the streams	7	8	8	8	13	3	5	1	4	7	11
Hemiptera nepidae	3.5	Vegetation, trash or mud, shallow pools or slow streams											
Notonectidae anisops	3	Pools, backwaters of streams	5	5	4	6	6	1	5	1	3	3	5
P. piccanina	4	Clinging to vegetation in still waters	1		1						1		
Hydracarina hydrachnellae	8.5	Submerged vegetation or bottom debris, slow streams or quiet pools											
Artemia salina	4	Temporary pond or salt pans											
Mollusca ancylidae	5.5	On rocks or and solid submerged substrate, all streams country-wide	2	1	1	3							
Mollusca physidae	3.5	Gravel beds, or on aquatic vegetation	1			1							
Mollusca *Sphaeriidae*	3	Sand or gravel beds							1				1
Mollusca thiaridae	3.5	Gravel in flowing streams and silt substrate in pools	2	1	1	3							
Unio cafer	5.5	Deep muddy substrate											
Anisoptera corduliidae	7.5	Stones, slower areas of stream				2	2					2	
Anisoptera libellulidae	5	Stones, muddy patches, backwater areas, very slow streams	2	1	1	2	4	4				2	
Gomphidae	4	Pools with extensive reed beds or rocks		2		4	4				2	6	2
Cheumatopsyche hydropsychidae	4	Under stones, living in shelters made of sand grains and fast flowing rivers											
Mesocnemis singularis	10	Under stones, on vegetation, headwaters of streams											
Ceriagrion glabrum	4	Vegetation, edges of slow streams											

Common name/ Scientific name	SASS Sensitivity Value	Habitat	Shade	Sunny	Rocky	Debris	Emergent Vegetated	Deep Waters	Shallow Waters	Clear water	Algae	Inlet	Suspended sediment
Chlorolestidae zygoptera	7.5	Vegetation, edges of slow streams											
Zygoptera lestidae	7.5	Vegetation, backwater areas, pools											
Tabancmorpha tabanidae	5	Widespread, concentrated near pan areas			1		1		2				2
Desis formidabilis	5	Water bodies rocks or vegetation	1			1							

The majority of aquatic invertebrates found in the dry period are utilizing the pan biotope areas in the same manner they would in a stream environment. The aquatic invertebrates that are utilizing the pan systems are tolerant taxa. In the wet period the *Desis formidabilis* (sensitivity 5) utilized emergent vegetation as per its prescribed habitat, in the dry period *Desis formidabilis* is seen to utilize the debris in the pan. *Mollusca sphaeriidaes* (sensitivity 3), commonly found in sandy or gravely beds is found in thick muddy sediment. *Piccanina* (sensitivity 4), known to cling to vegetation has been found utilizing debris and algae in the pans.

Through the species assemblages present it is deduced that the study sites hold increasingly more tolerant aquatic invertebrate species. It is also noted that the systems that potentially have access to the water table such as Mapimbi and Nwambi are the only pans able to support sensitive species.

6.8 Water Quality and Effects on Aquatic Invertebrates

The literature used to compile the table in Appendix G describes the minerals found in the pans and river sources and their effects on aquatic ecosystems were: The Target Water Quality Range for South African ecosystems according to Department of Water Affairs and Forestry (1996), and Ramollo (2008). This table lends itself to the relationship between minerals and the effects they have on aquatic invertebrates.

The ions listen in Appendix G occur naturally in small amounts to provide the relevant minerals to aquatic ecosystems for them to survive. Inorganic minerals can directly or indirectly affect the rapid increase in primary producers. Eutrophic and hyper-eutrophic processes can also be affected, especially in areas such as pans where the inflow of water is limited, often causing a decline in oxygen which in turn, results in an increase in the reduction of compounds and higher toxicity levels. There is still a great deal that is uncertain with regards to the actual effects of these minerals on aquatic invertebrates in high levels (Ramollo, 2008). It is important to remember that high concentrations of these minerals can be harmful to the aquatic invertebrates.

Minerals that are essential for the sufficient functioning of aquatic invertebrates are magnesium, zinc (a micro-nutrient or cation), sulphate (essential to providing species with proteins) and calcium (a vital cation in species

with bony skeletons). Aluminium, sodium and chromium are toxic minerals in large quantities. Potassium is non-toxic and is a scarce ion in natural waters. The effects of arsenic on aquatic invertebrates are unknown.

Organic compounds have different types of effects on aquatic organisms such as: i) phosphate- increased levels can decrease the metabolism of organisms present, ii) nitrate, becomes toxic to aquatic invertebrates in large quantities because it decreases the amount of oxygen available in the water, iii) chloride increases if there is an increase in total dissolved solids and affects the growth of aquatic invertebrates. When nitrate levels increase algae increases which in turn, has adverse effects on the aquatic organisms (Karouna-Renier and Sparling, 2001).

6.9 Distance from River Source

Table 6-15: Tabulates the pan systems and their respective river source. Distances were measured from the edge of the pan system to the nearest outer edge of the river source using Google Earth 2012

Wetland/ Pan	River Source	Method of Inundation	Distance (m)
Mapimbi	Limpopo River	Subterranean seepage	188.03
Makwadzi	Limpopo River	Flooding	267.69
Nhlangaluwe	Limpopo River	Geological control	768.52
Likangwa	Limpopo River	Geological control	179.65
Gwalala	Luvuvhu River	Controlled by levees	441.58
Nwambi	Luvuvhu River	Controlled by levees	1243.14
Magomugomu	Luvuvhu River	Controlled by levees	382.39

Nwambi pan is seen to be the furthest away from its river source the Luvuvhu River at 1243.14m. The pan that was found to be the closest to its river source was Likangwa at 179.65m. On average, the Limpopo pans are closer to their river sources as apposed to the Luvuvhu pan systems. A wetlands distance from a river source is important as wetlands are often recharged by means of flooding. A pan by definition is recharged by rainfall and as such in this study the pans distance from the rivers is an important aspect to assess in determining the systems means of inundation. Likewise, the method of inundation can influence or predetermine the type of system.

Chapter 7 Discussion

Chapter seven discusses how the physical and environmental variables are interlinked and their impact on aquatic invertebrates. In the results section, a relationship between the vegetation, soil moisture loss and the combustible organic carbon was shown and the discussion section develops an argument as to why these relationships occur and their overall effects. Differences in grain size distribution, sediment characteristics and the soil capacity to hold water are also discussed. In addition to the above physical variables, chapter six, presented data for water quality that, in this section, will be compared to the aquatic invertebrates present or absent, and their responses to water quality. The physical and environmental variables addressed in this study will be compared to the previous classification given to the study sites wetlands using the Ramsar Scheme. Pan characteristics are also analysed to further define and classify the pans in this study.

7.1 Dominant Vegetation Types

Vegetation is a very important part of wetland ecosystems. Different types of vegetation play different roles in wetland ecosystems. The vegetation surrounding these types of water bodies is known to trap sediment and pollutants found in it (Johnston, et al., 1984).

Here, direct chemical uptake and denitrification can occur. The vegetation, whether riparian, grasses or reed bed has the ability to slow and dissipate waters that flood the system during flood events. The vegetative cover also provides a place for animals to rest, nest and feed during the different seasons. Vegetative canopies associated with riparian vegetation have the ability to create large amounts of shaded areas, thus minimizing/slowing the rate of evaporation from the wetland. Vegetation is also a source of food, particularly to aquatic invertebrates as most feed on dead leaf and woody material that has fallen into the water body (Dosskey, et al., 2010).

Section 4.7, broadly assessed the vegetative types present in the study area. Appendix F listed data obtained from Zoghby (2011), for some of the wetland/pan systems. The following vegetative taxa were found at all the wetland/pan systems **Grasses**; *Panicum maximum, Tragus berteronianus, Aristida congesta, Eragrostis lehmanniana, Sporobolus niten, Urochloa mosambicensis, Enneapogon cenchroides* and *Panicum deustum.* **Trees and shrubs**; *Albizia forbesii, Acacia albida, Acacia xanthophloea, Cassia abbreviate, Spirostachys africana, Grewia flavescens, Diospyros mespiliformis* and *Anisotes formosissimus* (Zoghby, 2011).

By assessing the vegetative taxa list, dominant vegetation for the afore-mentioned wetland/pan systems can be provided. Nwambi and Nhlangaluwe have the highest grass taxa diversity, followed by Likangwa and Mapimbi. Nwambi has the highest taxa diversity of shrubs and tree taxa and Nhlangaluwe with the second most diverse vegetation, followed by Likangwa and then Mapimbi with the least diversity in shrub/tree taxa. Nwambi has the most vegetative taxa according to Zoghby (2011). The second highest diversity in vegetation is Nhlangaluwe, third is Likangwa and the wetland with the least diverse vegetation was Mapimbi.

7. 2 Pan Soil Properties

Section 7.2 will discuss the relationship between the soil moisture content (SMC) and the combustible organic content (COC). Soil moisture testing of wetland or pan areas is important for environmental monitoring. Therefore, testing for moisture may be used to establish a wetted area around a water body. COC can be described as the dead organic matter (DOM) that has settled on the surface. Over time, the DOM begins to

incorporate into the top layer of the soil profile or A horizon. This process is significant as the decayed matter and the amount of moisture present in the soil are interrelated. DOM has the ability to absorb and hold water, as a result, increased COC in the soil increases soil moisture content. DOM, together with surface vegetation, promotes infiltration and the development of a thicker A horizon. The thicker the A horizon, the longer soil moisture or water can be retained. This relationship is important to consider in wetland systems as they are both water and vegetative dominated.

Section 7.2 discussion addresses soil moisture measurements that are point samples along the transects across the wetland/pan systems. These samples are therefore time and site specific. As a result, broader generalizations about the systems are difficult to formulate. It is expected that the sample sites lower down the slopes would have a higher soil moisture content as a result of being closer to the water table and being less well drained. Vegetative taxa and different soil types and their respective characteristics also have the ability to affect COC and moisture content in the soils.

7.2.1 Magomugomu Pan

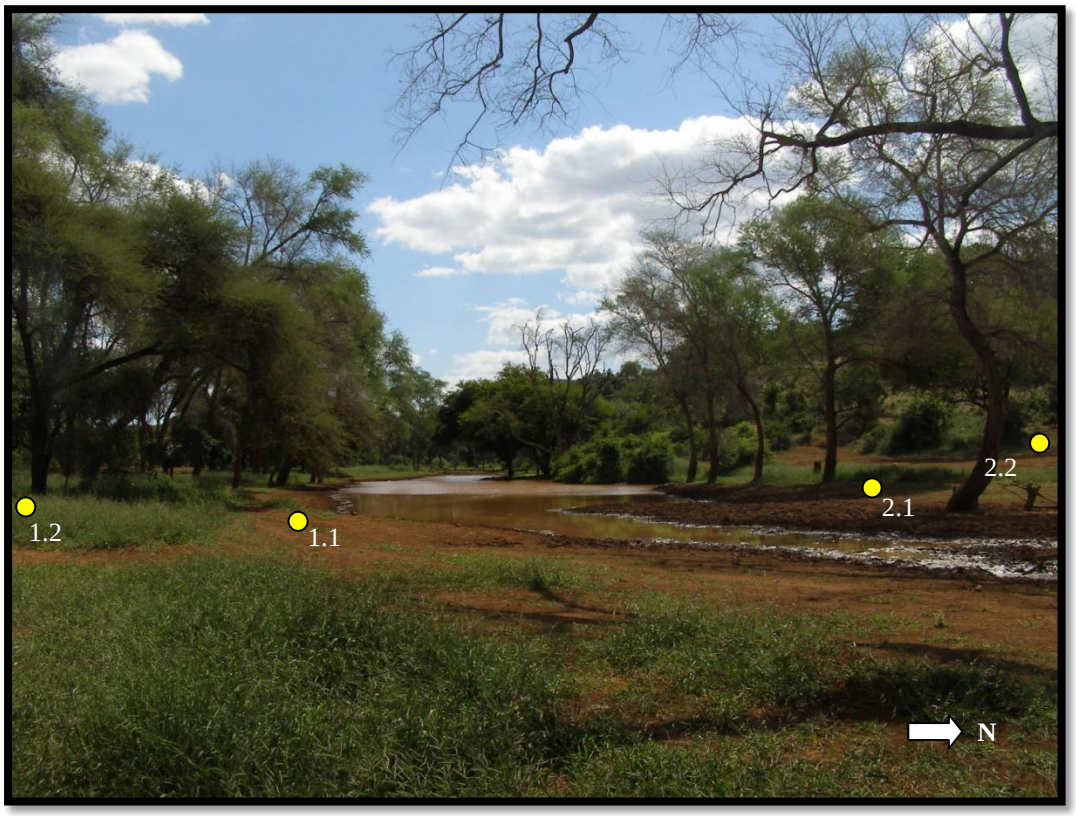


Figure 7.1: Magomugomu pan showing the locations of soil samples (photographs are researchers own)

Magomugomu's sample sites 1.1 and 1.2 are lower in SMC than that of sample site 2.1 and 2.2. The COC of these sites complement this finding in that the COC for site 1.1 and 1.2 is also lower than sites 2.1 and 2.2. Here, spatial differences can be seen between the opposite sides of the pan along the transect. Sites 2.1 and 2.2 have the highest COC for both the wet and dry samples; the increased COC % corresponds to the increased soil moisture content seen for samples 2.1 and 2.2. Sites 1.1 and 2.1 hold more moisture because they are at a lower

gradient on the slope and therefore closer to the water table and wetted area. The soil type associated with this pan is Oakleaf. The soil type is considered to contain unconsolidated material and is characterised by waterlogged soils. However, in comparison to the other study sites the SMC and COC, Magomugomu does not have a strong ability to retain water over long periods. Significant differences are seen between the wet and dry period samples, indicating a fluctuation in the wetted area around the pan.

7.2.2 Nwambi Pan



Figure 7.2: Nwambi Pan sample site 5 cannot be seen in this figure as it is behind dense vegetation (photographs are researchers own)

Nwambi falls into two bioregions, the sub-tropical alluvial vegetation to its north and south and Lowveld riverine vegetation to its east and west. Section 6.1.2 discussed that site 4.1 held the largest amount of moisture. However assessing sites 2.1 and 4.1 as the two highest SMC for the wet period, this can be attributed to their topographical location and the bioregion they fall in; samples sites 1.1, 2.1 and 4.1 fall into the Lowveld riverine vegetation and sites 5.1, 5.2 and 6.1, 6.2 into the sub-tropical alluvial vegetation zone. The sites found in the Lowveld riverine vegetation are associated with tall forest fringes and shrub areas on levees. The trees located here were *Diospyros mespiliformis* and *Xanthocercis zambesiaca*. *Diospyros mespiliformis* require heavy aerated soils with lots of moisture and the *Xanthocercis zambesiaca* have deep roots which are able to tap into underground water systems. Between these sites, soil sediment type varied between poorly sorted, coarse or very fine soil therefore allowing enhanced water retention. The fact that both of these trees types are present indicates that the soil moisture is high and regularly available. Sites 3.2, 5.2 and 6.2 begin to taper off into sub-tropical alluvial vegetation where the soils become poorly sorted medium-coarse sand. Here the area is dominated by erosion gullies, open areas of sand and *Faidherbia albida* and *Vachellia xanthoploea*. *Faidherbia*

albida have extensive root systems and are known to grow in waterlogged soils along rivers; however the trees in the study were located further away from the body of water in a very dry area with a fissured surface indicating that a water body or extension of Nwambi had not been present for some time. The high presence of COC in both wet and dry periods indicate year round organic matter, indicating the presence of water is extremely high and constant allowing the vegetation types around Nwambi to thrive. The sites 1, 2 and 4 are indicative of high combustible organic carbon this is attributed to the Lowveld riverine bioregion.

Sample sites 1.1, 2.1, 3.1, 4.1, 5.1 and 6.1 are noticeably moister, like Magomugomu, this is because these samples are on a lower gradient and closer to the wetted area. Four out of the 6 sample sites (sample sites 1, 2, 4 and 5) along the transects have a higher COC at their first respective samples (1.1, 2.1, 4.1 and 5.1) indicating spatial homogeneity. Nwambi's soil displays characteristics from both Arcadia and Oakleaf soil forms. The Arcadia soil form possesses the ability to shrink and swell with moisture increases and decreases. These soils types together with the percentage of COC present between both sampling periods indicate that Nwambi's ability to hold water year round is strong. Although these samples indicate a strong annual presence of water in the pan, the wetted areas are seen to have significant differences between sampling periods which indicate fluctuations in the water levels. This can be seen in the samples 1.1, 2.1, 3.1, 4.1, 5.1 and 6.1.

7.2.3 Gwalala Pan



Figure 7.3: Gwalala Pan (photographs are researchers own)

Gwalala's northern bank is a levee which has been built up from annual flooding over time. The bioregion is the sub-tropical alluvial vegetation. Figure 7.3 indicates emergent vegetation and submerged vegetation which is

visible due to the low water level in the pan. Background information on the pan indicated that Gwalala is the first pan in the area to flood annually. Gwalala's soils are unconsolidated and poorly sorted. The sample site with the highest SMC during the wet period was 1.2. Site 4.1 has the highest wet period value. Both sites 1.1, 1.2 and 4.1, 4.2 are located on the southern side of the pan where the area is flatter and under trees. The southern side is the part of the pan closest to the Luvuvhu River and thus closer to the source of water. Sample site 3.2 had the lowest wet sampling period value and dry sampling period value for SMC, this is because the site was located on the upper side of the levee where it was elevated a distance away from the pans water body and water table. It is to be noted that by November 2011, Gwalala was dry and in the following year of March 2012 there was only a pool of water 2cm deep after there had been 88.4 mm of rain in February 2012, indicating that the manner in which Gwalala receives and maintains its water body is by annual flooding of the Luvuvhu River together with rainfall. Gwalala has a significant amount of vegetation; this could also contribute to water loss through evapo-transpiration in the soils. The increased COC seen at sample site 3.1 in the dry period can be attributed to being at the bottom of the levee banks; here materials can fall down the steep levee and wash into the area as a result of the previous inundation flooding. Wet period sample 4.1 has the highest COC, this site is directly beneath a vegetation canopy, surrounded by shrub vegetation and was possibly, at some stage, part of the pan and thus was accompanied by remnants of emergent vegetation.

Spatial differences can be seen at sample site 3.2 of Gwalala. The low SMC percentage corresponds to the low COC percentage found at 3.2. The other sample sites trends are similar. Gwalala's soils are also considered Oakleaf, such as that of Nwambi and Magomugomu, and have been darkened by the organic material present in the soil. The sediment is unconsolidated and does not have the ability to hold water moisture for long periods of time. Significant differences in wetted area can also be seen between the samples indicating large sampling period fluctuations.

7.2.4 Makwadzi Pan



Figure 7.4: Makwadzi Pan (photographs are researchers own)

Makwadzi is located between the Limpopo-ridge Bushveld to the south of the wetland and Lowveld riverine forest to the north. Makwadzi's soils were moderately sorted coarse sand in the wet period samples and very fine poorly sorted sand in the dry period samples. The highest SMC came from sample site 1.1 in the wet period, where the soils, as seen in figure 7.4, were fissured, moist and clay-like when sampling was completed. Sample 1.3 for the wet period held the least SMC, this is because the sample was located on top of the ridge with a gradient of 20° and coarse sandy soil with calcrete, and as a result the ridge creates an area of run-off and remains dry. The northern side of the pan is comprised of alluvial floodplain exposed to flooding by the Limpopo River and possible seepage from groundwater. The combustible organic carbon for Makwadzi on average is high in both the wet and dry period; this is because the pan is surrounded by dense grass vegetation, predominantly Giant rats tail. The generally lower trend of COC for sample sites 3.1, 3.2 and 3.3 is because the vegetation decreases away from the pan before it becomes the riverine forest. Sample sites 3.1, 3.2 and 3.3 are exposed to direct sunlight decreasing soil moisture through evaporation.

Makwadzi's samples sites display spatial similarities between them. This can be seen between sites 1, 2 and 3. Here SMC and COC differ significantly. Strong similarities can however be seen in sites 2.1 and 2.2, 3.1, 3.2 and 3.3. Literature states that Makwadzi's soils are of the Willowbrook form and are known for their high clay content; this was supported by the fieldwork portion of the study as there was visual evidence of shrinking and swelling (fissures in the soil). Makwadzi's wetted area appears to have remained constant and clear fluctuations are present as a result of sampling period differences but the amount of change is minor.

7.2.5 Likangwa Pan



Figure 7.5: Likangwa Pan, sample sites are not visible on this figure (photographs are researchers own)

Likangwa is also located between the Limpopo River (north) and a ridge (south) and falls into the sub-tropical alluvial vegetation category. Sample sites 1.1, 1.2, 1.3, 2.1 and 2.2 for SMC are indicative of soils that are coarse sand and well sorted as they are observed to have a reduced capacity to retain moisture. These sites, located on the southern ridge, were shallow soils and when samples were taken with the auger, bedrock was hit. Sample sites 2.3, 3.1 and 3.2 were located at higher gradients along the ridge, in the wet period their location could result in higher SMC due to run-off from the drainage line they were located in. The COC for dry period displays a trend whereby as you move away from the pans edge and up the slope the COC percentage decreases, indicating that there is less organic matter present on the ridge.

Likangwa's SMC percentage corresponds to the COC percentage available for the sample sites; this indicates there is a strong relationship between the amount of water present in the samples and the vegetation present. All the sample sites SMC and COC samples are similar indicating spatial similarities. This is likely, because all the samples are from the same site of the wetland system. Samples 1.1 and 2.1 showed that their wetted areas stayed relatively similar for both wet and dry periods with sample 3.1 showing a significant change in its wetted area.

7.2.6 Mapimbi Pan



Figure 7.6: Mapimbi Pan, sample sites 1 and 4 cannot be seen due to the vegetation surrounding the pan (photographs are researchers own)

Mapimbi's bio-region is the Lowveld riverine forest; this is illustrated in the figure above whereby around three quarters of the water body is surrounded by tall, dense forest and dense shrub layer. Mapimbi's SMC was high all year round, the percentages remained high even in the sample taken at the change of gradient, and this could be related to the proximity of the pan to the water table. Sample sites 1.1, 1.2 and 3.2 were taken on opposite sides of the pan in tapered off levees with a low gradient and also yielded the highest SMC for both the wet and dry period. The Mapimbi systems ability to hold a large amount of water all year round has resulted in substantial vegetation growth. *Vachellia xanthoploea* occur here as their preferred habitat is where underground water is present. The significant increase in COC at Mapimbi 2.1 and 2.2 is attributed to the increased amount of leaf litter present in the dry sampling period, particularly on the northern bank which is denser than the southern bank. SMC has no correlation with COC for this pan as there is water readily available all year round. Therefore, there is no significant change between the wet and dry period values of moisture.

Spatial differences however can be seen throughout the SMC samples closest to the wetted area 1.1, 2.1, 3.1 and 4.1, which indicates sampling period fluctuations in the water level. There are no significant correlations between the SMC and the COC. Mapimbi has both Dundee and Mispah soil forms present. Both soils have high organic properties with the Dundee soils demonstrating stratified alluvium soils. Although these soils are not dominated by clay properties the samples still indicate significant SMC year round. This is indicative of a high water table at Mapimbi.

7.2.7 Nhlangaluwe Pan

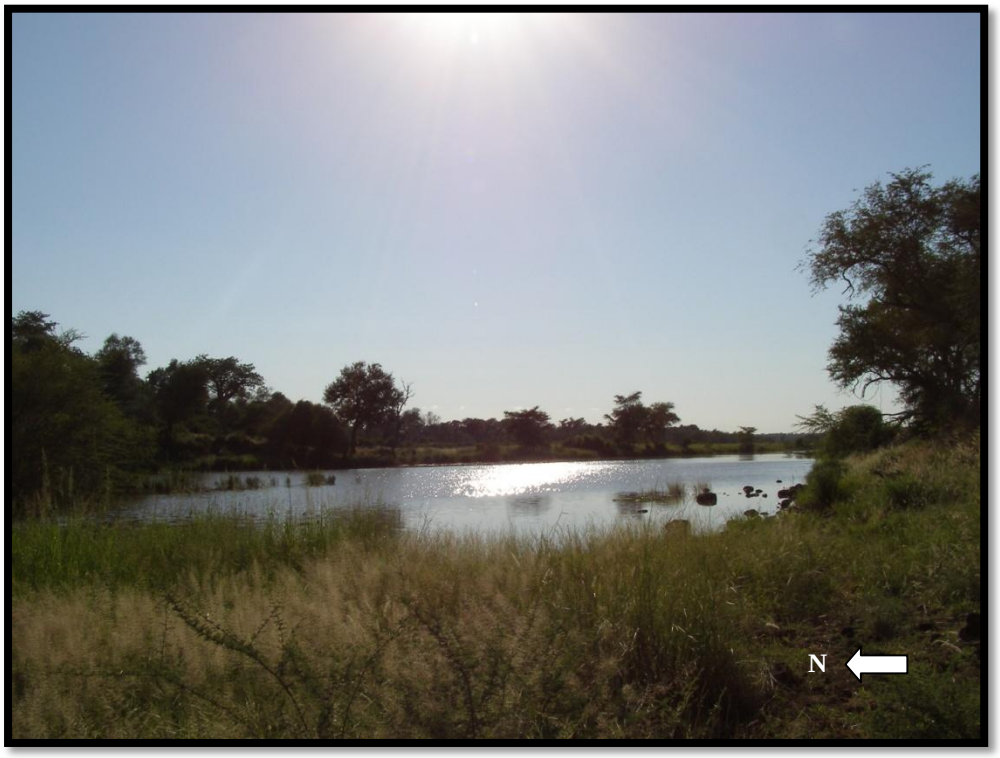


Figure 7.7: Nhlangaluwe Pan, the sample sites cannot be seen here in this figure as they are on the southern bank of the pan (photographs are researchers own)

Figure 7.7 above illustrates the sub-tropical alluvial vegetation bio-region that Nhlangaluwe is found in. To the north, a riverine terrace can be seen, to the east and west alluvial flats with flooded grasslands and to the south a ridge. The alluvial flats are synonymous with wet soils that can support macrophytic vegetation. This characteristic supports the results found in moisture tests completed on Nhlangaluwe in that due to the presence of DOM, Nhlangaluwe is able to retain moisture for longer in its soil. Sample sites 1.1, 1.2 and 2.1, 2.2 were located on the side of the pan where the ridge is found and sites 3.1, 3.2 on the opposite ridge and 4.1 in the alluvial flats area. The southern bank was dryer than the northern bank. Sample site 4.1's high COC is related to fertile soils with grassland vegetation. Sample site 3.1 and 3.2 is consistent with riparian thicket. The overall higher percentage in COC during the wet period samples is attributed to the year round vegetation but is obviously higher during the rainy season when the vegetation is growing.

Like Makwadzi and Likangwa, Nhlangaluwe's SMC and COC percentages at the sample sites indicate a strong relationship between the amount of water in the soil and the amount of DOM. Nhlangaluwe's sample sites around the wetland indicate that the area surrounding the wetland is uniform. Both Likangwa and Nhlangaluwe are characterised by the Valsrivier soil form with diagnostically unconsolidated material. Nhlangaluwe's wetted area has also remained relatively constant during both sampling period changes indicating good water retention.

Within the seven study areas, underlying patterns have emerged as a result of the SMC and COC analysis. The main reasons for notable differences are relief surrounding the wetland/pan systems and the vegetation composition around the wetlands/pans due to the relief and the water retention capabilities in the soil to support

this vegetation. Study areas Makwadzi, Likangwa, Nhlangaluwe and Magomugomu show similar traits and Nwambi, Gwalala and Mapimbi also show similar traits. Of these two distinctive differences in characteristic compositions of the wetlands/pans, overlaps are seen in particular sites, for example wetlands/pans that share a high relief and low relief displays both characteristics. In terms of wetland/pans with low relief characteristics, Makwadzi experienced low SMC in the wet period and a higher SMC in the dry period with a relatively similar trend in the wet and dry period for COC. The presence of dense ground layer of grasses namely; *Pennistum purpureum* and *Typha latifolia* traps moisture in the soils during the wet period preventing excessive evaporation as the vegetation creates a humid environment within the vegetation and thus retaining soil moisture. However, in the dry period when the vegetation shortens and thins due to less rainfall and these now sparse areas are exposed to more sunlight, less rainfall and increased evaporation thus decreasing the SMC. The COC content in these types of environments remains relatively constant; this is because of the type of vegetation present and its quantities. The vegetation described above remains present in the soil all year round. Likangwa's sample sites were completed on the southern ridge; here there is a significant increase in relief which affected both the SMC and COC. Sample sites 2.1, 2.2 and 3.1, 3.2 were located on a steep gradient that consisted of Mopane vegetation and sites 1.1 and 1.2 consisted of a low relief and grass/reed vegetation cover. The SMC, again in the lower relief area with grass/reeds, was low in comparison to the higher relief area with taller vegetation, providing a means of increased COC in the dry period as a result of leaf litter. Nhlangaluwe shares the same properties as Likangwa whereby they both have an area of their wetland/pan with ridge characteristics and open flat areas. Again, the losses in SMC and COC are indicative of relief and vegetation type. Sample sites 1.1, 1.2, 2.1, 2.2, 3.1 and 3.2 are located on a ridge, whereas 4.1 and 4.2 are on a low lying relief area. However, Nhlangaluwe displays a greater loss of COC across all sites in the wet period; this could be because although the dry period is inclined to have increased levels of organic matter in the soils due to DOM, the wet period also provides an environment whereby moisture levels and increased heat continues to break down organic matter, increasing its percentages in the soil. Sites 3.1, 3.2 (steep gradient) and 4.1, 4.2 (low relief) although in different relief areas, both experienced a large amount of water loss; this is because sample sites 3.1 and 3.2 were covered with thicker vegetation and rockier outcrops creating a cooler shaded area. Sample sites 4.1 and 4.2 were covered with grass vegetation but with a much more shaded area of *Hyphaene coriacea*. Similarly, Magomugomu's northern ridge had the highest SMC and COC as apposed to the southern alluvial plains. The ridge consisted of a mixture of tall trees with both shrubs and grasses, whereas the southern side of the pan had vast open areas with Acacias, taller trees such as *Acacia xanthophloea* and patches of grasses. Like Nhlangaluwe, Magomugomu's pan extent found in the alluvial areas had higher COC in the wet than the dry period, indicative of the vegetation seen there. The sites found on the ridge experienced had high SMC attributed to the thick, dense shaded area.

The other three wetland/pans, in contrast, are dominated by dense shrubby areas, woodland thickets and tall trees. Nwambi has a wet/dry period correlation between SMC and COC, and correlations between sites. The topography surrounding Nwambi is generally of the same relief with a slight undulation to the north eastern side with an increased gradient. Otherwise, Nwambi has a distinctive u-shaped depression to it. Sites 2.1, 3.1 and 4.1 had significant SMC in the wet period; this is because the samples were taken in areas where shade was present all day as a result of the large dense tree canopy. Differences in the SMC of sites in the wet period is significant, the sites on the elevated parts of the depression, sites 1.2, 2.2, 3.2, 4.2, 5.2 and 6.2 were significantly dryer.

Their distance from the tree canopy also meant that they were exposed to sunlight at different times of the day. The overall observation for Nwambi's COC is that there is an observable increase in the dry period over the wet period; this is attributed to the large amount of leaf litter deposited onto the ground around the wetland/pan. Mapimbi, like Nwambi, is a u-shaped depression with very steep sides, however, the vegetation surrounding Mapimbi has a considerably thicker shrub layer but it also had a canopy layer of trees. Most of the sample sites were heavily shaded, except for samples 3.1 and 3.2 which were semi-shaded and had a tapered gradient. There is a considerable peak in the dry period samples of COC, this is a result of site 2.1 and 2.2 having higher grasses presence beneath the shrub layer, this side of the pan was also absent of a tall tree canopy. The SMC remained constant for Mapimbi over the sampling period with sites 1.1, 1.2 and 4.1, 4.2 showing high SMC. These sites were located in heavily shaded and humid areas. Gwalala is unlike Nwambi and Mapimbi in this grouping, although it shares the same characteristics in vegetation and moisture, its relief is entirely different, in this way site 3.2 has a significantly lower SMC and COC overall. This is because sample site 3.2 is located on the levee created by the annual flood events. The rest of the sites show considerable similarity in vegetation and SMC, the relief of the rest of the pan is relatively low and supports a tall canopy layer and shrubbery; the dominant vegetation surrounding this pan being the shrubs. This vegetation is constant year round contributing to the constant values of COC present.

Consequently, wetlands/pans with a higher grass component (Makwadzi, Likangwa and Nhlangaluwe) surrounding them had a year round high COC and SMC related to the vegetation growth patterns per sampling period. Wetlands/pans that consisted of trees with a taller canopy and shrubbery layer (Nwambi, Gwalala and Mapimbi) had significant sampling period (wet vs. dry) differences in COC and the SMC found at these types of wetlands/pans were higher than that of the previous group of wetlands/pans mentioned. Relief analysis yielded mixed results, if a ridge was consistent with a barer surface of vegetation with few grasses and Mopane, the soils were generally coarse sand allowing run-off to occur, decreasing SMC. Areas on ridges with rocky outcrops where trees and shrubs were growing, the soil tended to be a medium sand type and were found to be moister. The relief located on lower topography on top of the u-shaped pans (generally sites 1.2, 2.2, 3.2 etc.) indicated soils of a much drier nature, regardless of their textural group.

Spatial analysis supports a slightly different suggestion as to how the wetland/pan systems should be grouped as a result of the SMC and COC analysis. This being that the systems Makwadzi, Nhlangaluwe and Likangwa held similar properties with a strong link between SMC and COC indicating that of the samples analysed along the transect DOM within the soils A horizon has assisted infiltration into these systems and allowed for water to be held for longer periods of time than that of the other systems. However, Magomugomu and Gwalala's samples have a high variance in SMC and COC. These trends indicated that the wetland/pan systems that depicted uniformity in sample sites were unable to hold water for a long period of time. Nwambi however, depicts characteristics from groups of spatial differences; COC links to SMC in a homogeneous manner however, the wetland/pans soil type is also indicative of clay properties inferring that the soil type may be contributing, more meaningfully, to holding the water for longer periods of time. Mapimbi also has no significant correlation between COC and SMC, nor is it characterised by clay soils. However, its SMC is still very high, indicating close proximity to the water table. SMC and COC together with the identification of a fluctuating wetted area

can be used to begin to assess the current classification (floodplain vlei) provided to the Makuleke Ramsar Wetlands.

7.4 Water Quality and Implications for Aquatic Invertebrates

In section 6, the water chemistry results were divided into cations, anions and toxic metals to represent the water chemistry composition and to establish potential toxicity of the wetland or pan systems. This type of analysis is important, as explained in section 1.1 and section 2.3.2, because aquatic ecosystems are threatened by anthropogenic factors and according to the CSIR (2010) the main factors placing these systems under stress are usually toxic ions and anion contamination together with nutrient enrichment from agricultural areas upstream. Water quality is governed by sediment type, grain size and concentrations of pollutants such as organic carbon content (Berkman et al., 1986; Hellawell, 1986; Walling and Moorehead, 1989). Wetland/pan systems carry significantly high concentrations of these ions within the water bodies themselves and are hydrogeomorphically comprised of these components due to their exposure to annual flooding events. These ions affect water quality and adversely affect aquatic ecosystems, influencing the aquatic ecosystems integrity and distribution of aquatic invertebrates (Dallas and Day, 1993).

Within the wetland/pans, the cations magnesium, potassium and calcium all met the TWQR; however aluminium and sodium both displayed high levels, failing the AEV. Different water sources tested showed that concentrations of aluminium and sodium were higher in Likangwa, Mapimbi and Nwambi wetlands/pans in the wet period. During the dry period, these high concentrations remained for Likangwa, Mapimbi and Nwambi wetlands/pans, with Nhlangaluwe also displaying higher concentrations. The Limpopo wetlands/pans and River displayed higher concentrations in cations as apposed to Luvuvhu water sourced wetlands/pans, with the exception of Nwambi pan which had the highest aluminium for the dry sampling period. In contrast, Likangwa had the highest sodium concentrations present during the dry period. There is a definitive increase in concentration and salinity of nutrients from the wet period compared to that of the dry period due to the decrease in water present.

According to the water quality and effects (table 6.14) magnesium's effects on aquatic invertebrates are not well documented but are present in high quantities in water systems. Aluminium found in high concentrations in water systems can be harmful to aquatic invertebrates but as discussed in the pH section below, these ions do occur naturally in low concentrations which benefit the environment and its organisms (Department of Water Affairs and Forestry, 1996). The cation potassium is not harmful to aquatic ecosystems but is very scarce. Calcium is very important for aquatic invertebrates as it provides organisms present in the water with important nutrients for exoskeletons. The high concentrations found in Mapimbi correlated to the high abundance of snails and limpets found there, indicating good water quality for them to survive and thrive. The cation sodium can also have chronic effects in high concentrations in water, but in natural instances sodium are essential for the maintenance of physiological functions within organisms and thus essential requirement (Department of Water Affairs and Forestry, 1996).

The anions water quality results showed that the levels of anions found in this class were significantly lower than the cations. Sulphate and phosphate had the lowest concentrations overall with nitrate having the highest concentrations which decreased in the dry period samples. Many of the samples were lower than their detection

limits, thus indicating a decrease in possible toxicity levels. Higher concentrations of nitrite, nitrate and chloride were seen in Mapimbi in the dry period. Similarly, Nhlangaluwe showed an increase in these anions over the sampling periods. Nitrate (AEV) was the highest anion found in both sampling periods.

The Department of Water Affairs and Forestry (1996) and Ramollo (2008) stated that chloride is a non-toxic ion, however in the case of increased total dissolved solids; toxic effects can develop stunting growth of aquatic invertebrates. All wetland/pan systems had low concentrations except for Mapimbi which met the CEV. Both sulphate and phosphate are important for aquatic ecosystems; sulphate is responsible for a protein component and phosphate for organisms metabolism functioning of which meet the TWQR (Department of Water Affairs and Forestry, 1996) both. Nitrite and nitrate work together performing different functions within the aquatic ecosystem. Nitrite being responsible for bacterially mediated processes of inorganic oxidation, nitrification and dentrification and nitrate is the by-product of the oxidation of ammonia to nitrate. Excessive amounts of nitrate leads to algae blooms and decreased oxygen in the water system. It is important to note that although the value concentrations of these ions are low, a combination of their presence has the ability to make the water toxic for aquatic invertebrates.

The toxic ions chromium and arsenic appeared in very low concentrations with a slight increase seen in Likangwa, Nwambi and Nhlangaluwe during the dry period. The values represented for zinc however, are consistent throughout the water samples with the detection limit being <0.060mg/l, except for Nwambi in the dry period with 0.066mg/l. The values recorded are very high and fail the AEV, and in short term exposure can do much damage to an aquatic ecosystem (Department of Water Affairs and Forestry, 1996).

Chromium is an ion which is seldom found in aquatic ecosystems, when it is; it is generally associated with industrial activities and the presence of organic matter. In the samples taken, Likangwa, the Limpopo River and Nwambi all failed the TWQR with Nwambi having the highest chromium concentration in the dry period. The higher concentrations in the Limpopo River and Likangwa can be associated with the rivers drainage being exposed to mining activities and different industrial sectors dumping waste products into the river system, however Nwambi's high concentration is unexpected. Nwambi's COC was higher than Likangwa and this could indicate why there was an increase in chromium levels found at Nwambi. Zinc is considered an important ion to aquatic ecosystems as it contains the enzyme metalloenzymes which links to a protein creating a bond (Department of Water Affairs and Forestry, 1996). However, Nwambi's water quality for zinc failed the AEV with 0.066mg/l. Short term exposure of zinc will cause death in aquatic invertebrate taxa. The affects of arsenic on aquatic invertebrates is uncertain and highly dependent on the life stage of the organism when it comes into contact with it (Department of Water Affairs and Forestry, 1996).

The environmental variables that have been assessed in the results section are significant as their interaction with specific ions and the aquatic ecosystem is delicate, as each is interlinked and has considerable affects. For example, electric conductivity is an important variable as it is required to transport ions within the water body and to make them available for the aquatic ecosystem. Electric conductivity may affect a system by making too many ions readily available or under producing ions leaving the aquatic ecosystem deficient of the required ions.

The amount of suspended solids in the water body is determined by the hydrology and geology of the area. Suspended solids are more readily available in the wet period due to the rainy season and increase in transport load into the study area particularly due to flood events. On the Limpopo River, anthropogenic materials are dispensed into the water column by agriculture and mining activities. The high concentrations of TSS can lead to a decrease in light in the water, decrease in temperature due to sunlight being blocked out and decreased dissolved oxygen which in turn affects aquatic ecosystems. The effect of TSS was calculated by determining if there had been an increase in the values from wet to dry period samples by <10%. Increases above the CEV <10% change were seen for the Limpopo River, Likangwa and the Luvuvhu River, and increases of TSS increase above AEV was seen for Mapimbi and Nhlangaluwe respectively. The greatest increase over the sampling periods that failed the AEV was Nwambi. Although the values for TSS were high, natural variation occurs within this environmental variable. Even though the data shows a large increase in the sediment for Nwambi, the limitation of the data is that it was only based on wet vs. dry period sampling, meaning that the values may be high but the aquatic invertebrates utilizing the water may be tolerant to these changes.

The temperature of wetlands/pans water is very important for aquatic ecosystems and aquatic invertebrates alike, as it has the ability to affect the body temperature of invertebrates and the solubility of gasses within the water column. Again, like in TSS, changes were calculated by a threshold change of 2°C. These changes depicted in table 6.9 are wet vs. dry period changes and this limits the data interpretation. However, significant abrupt shifts in short term (diurnal) temperature can affect aquatic organisms. Abnormal changes, for example by an increase in TSS which may decrease the temperature of the water body by blocking out sunlight, can have adverse effects on the aquatic ecosystem. These effects can include the disruption of organisms frequenting these wetlands during migration or during parts of their life cycles when certain wetlands are utilized. Exposure to affected wetlands can result in physical abnormalities such as stunted growth. Data indicates that the Limpopo River sourced wetlands/pans have a higher in temperature than the Luvuvhu River sourced wetlands/pans. Temperature in water bodies is important as temperature has the ability to determine if a species thrives (increases abundance) or not. On average, the Limpopo River wetlands have a higher abundance and species richness, indicating that the temperature found in the Limpopo River has the ability to support aquatic invertebrates.

Temperature affects pH levels and is thus important as it determines the rate of solubility and thus accessibility of ions to aquatic organisms. Typically freshwater in South Africa ranges between a pH of 6 and 8 and the surface pH ranges between 4 and 11 (Department of Water Affairs and Forestry, 1996). The Limpopo River has the most alkaline pH of the dataset during the wet period with 8.713 and Nwambi with 7.033, also in summer. All samples were alkaline for both wet and dry periods. The pH values were assigned their water quality significance (as per section 6.5) if a change of > 0.5 was seen in the samples. However, due to the nature of the environment and its natural fluctuations, this process is only indicative of possible pH fluctuations that could pose threats to aquatic organisms health. Therefore, pH values have been assessed as they are and their affect to ecosystems in their sampled state. The ion aluminium acts like a buffer in water bodies that have a more acidic pH allowing organisms to tolerate these changes in pH until they adapt. Likangwa, Nwambi and Mapimbi all have high concentrations of aluminium. In contrast sodium-chloride has a poor buffering effect during the pH changes in water, making aquatic invertebrates more vulnerable.

Aquatic invertebrates rely on the ionic levels in the water body with which they live or utilize for a period of their life cycle. Thus it is important to understand their tolerance of these concentrations and the effects as a result of changes occurring. Grain size distribution and ions located within the sediment also effect aquatic invertebrates. The "smaller the grain size, the higher the surface area of the specific sediment particle, thus increasing its ability to absorb various contaminants such as ions" (ANZECC and ARMCANZ, 2000). This is more significant in wetland/pan systems with higher clay content. The water quality results showed that Nwambi had the highest overall concentration of ions. Mapimbi, Likangwa, Nhlangaluwe, the Luvuvhu River and then the Limpopo River yielded the lowest concentrations. The range of ions found in the pans studied is indicative of the array of natural ions accessible to aquatic organisms. Based on the properties discussed above with regards to the positive effects of ions, those ions that have positive impacts on aquatic ecosystems aid the following: increased levels of sodium (aids biological functioning), calcium (aids the development of the exoskeleton), aluminium (buffers acidic water making it more tolerable), sulphate (adds protein into the aquatic ecosystem for the organisms to utilize) and phosphate (aids in the metabolism of aquatic invertebrates). The wetland/pan systems found with two or more of these nutrients are, Likangwa, Mapimbi, Nhlangaluwe, and Nwambi. These ions found in the environmental serve as an indicator of the wetland/pan systems environment at the time of sampling but are subject to frequent changes due to external factors such as climate, flow regime and sediment. Frequent sampling periods of the water quality would provide an in-depth understanding of the toxicity levels of these systems and the possible changes to increasing anthropogenic influences outside of the KNP.

7.5 Sampling Period Variation of Aquatic Invertebrate Taxa Richness and Abundance in Relation to Taxa Sensitivity

As discussed previously in section 7.4, water quality is important as this plays a significant role in taxa richness and abundance. The amount and type of nutrients in the water determines the health of the system and the types of aquatic invertebrates utilizing the wetland/pan. Depending on the conditions suited to the individual taxon, taxa richness, total number of taxon, may be higher than taxa abundance, total number of individuals of a certain taxon, in the areas or vice versa. Certain taxa which are adapted to poor water quality such as *Annelida oligochaeta, Annelida hirudinae, Diptera culicidae, Notonectidae anisops* and *Diptera chironomidae* generally thrive in pans where there are concentrated amount of nutrients present in the water column and sediment at the bottom of the pan. More sensitive taxa such as the *Coleoptera elmidae*, *Ochthebius dilatatus, Hydracarina hydrachnellae, Anisoptera corduliidaes* and *Latycnemidae* cannot thrive in poor water quality and prefer fresher waters with lower nutrient concentrations, often preferring moving water in streams and rivers (Department of Water Affairs and Forestry, 1996).

The assessment of macro aquatic invertebrates' responses to water quality is important because by understanding an organisms response, a greater understanding of its surrounding environment and its health can be established, aiding conservation and management. Aquatic invertebrates are particularly sensitive in that they are directly exposed to water conditions because they live in the water. Aquatic invertebrates complete their life cycles in wetlands/pans and are therefore exposed directly to physical, chemical and biological sensors within that wetland/pan system (United States Environmental Protection Agency, 2002). Aquatic invertebrates play an integral part in the food web and are highly sensitive to pollution and as such are significant indicators of pan

health. Habitat is another important attribute to assess when analysing the health of a wetland/pan system. This is because many of the aquatic invertebrates, especially the benthic invertebrates, are largely immobile and are therefore continuously exposed to constituents in the water body. The inability to move away from poor conditions makes aquatic invertebrates and the habitats they are associated with ideal for identifying sources of pollution.

During sampling analysis, if a decrease is seen in taxa richness and abundance from one sample period to the next, this may indicate a change in habitat conditions or that the sampling in this study could have coincided with the larval stage of their life cycle. Due to the nature of this study, sampling depicts wet vs. dry period sampling differences and water quality effects on taxa (tolerance or vulnerability). This can also be indicated by taxa presence or absence from wet and dry period sampling.

The relationship between water quality found in the wetlands/pans and aquatic invertebrates found is discussed below:

7.5.1 Mapimbi Pan

During the wet period of sampling, Mapimbi's taxa richness was lower than that of the dry period sampling period (section 6.6.1). This could be attributed to the lower nutrient levels experienced in the wet period due to higher dilution of the water from the inflow of ground water and less taxa utilizing the wetland/pan during the wet period during the larval stages. In the wet period, *Notonectidae anisops*, *Mollusca thiaridae*/*Mollusca ancylidae* and *Mollusca physidae* were the most abundant taxa, with *Notonectidae anisops* being the most prominent taxa. The results from the water quality showed that Mapimbi has the highest calcium concentrations out of the samples taken. The high concentration of calcium has a positive effect on *Mollusca ancylidae/Mollusca thiaridae* found in the wetland/pan as calcium is important for exoskeletons and shells. In the dry period, the taxa richness for Mapimbi was high indicating favourable living conditions for a wider variety of taxa. This could also be attributed to the decrease in water sources in the area and aquatic invertebrates requiring a constant water source for part of their life-cycle. The toxic metals found in Mapimbi met the TWQR and show no visible effect on the aquatic invertebrates. Mapimbi shows the ability to support taxa that are very tolerant of poor water quality such as *Diperta psychodidae*, which have a sensitivity value of 1. The use of this wetland/pan by tolerant taxa does not relate to isolation from fresh water sooner than the other wetlands/pans during the wet sampling period, as Mapimbi are fed by ground water. However, taxa such as *Anisoptera corduliidae* have a low tolerance and sensitivity value of 7.5, being relatively sensitive to poor water quality. Overall, Mapimbi pan has the ability to support aquatic invertebrates with poor to moderately high sensitivity levels to water quality (section 6.8). This could be a result of Mapimbi's link to the water table, thereby introducing fresher water into the system on a regular basis. This fresh water received from the ground water inflow provides the sensitive taxa with the toxicity reprieve enabling the organisms to live in the wetland/pan.

7.5.2 Makwadzi Pan

Makwadzi showed that taxa richness was higher during wet period sampling rather than in the dry period, with the average abundance also being higher in the wet period. The wet period sample site 1 yielded no taxa at all. The prominent taxon found in sample sites at Makwadzi in the dry period were *Diptera ceratopogonidae* which

have a sensitivity value of 5, and in the dry period *Corixidae enithares* with a sensitivity value of 3.5. The majority of the taxa sampled, held a sensitivity value of 5 or below, meaning that the water was not suitable for sensitive taxa. However, sample site 2.2 held two taxa with a low tolerance, the *Ochthebius dilatatus* with a sensitivity value of 8 and the *Ochthebius dilatatus* with a sensitivity value of 8.5. Makwadzi's water quality was inferred from the Limpopo River's results because this is the source of the wetlands/pans water. Levels of Sulphur and Chloride were higher in the Limpopo River samples than in the Luvuvhu River samples. The higher level of Chloride found in the river could indicate high levels in the wetland/pan which would indicate faecal material contamination. This is highly likely to be as a result of human activities along the Limpopo River, but due to the elevated level of Makwadzi it is likely that concentrations would be less, however during a flood event the pan could be inundated with higher concentrations of nutrients collected and transported by the river system. The concentrations of sulphur on the other hand, indicate essential proteins present for aquatic invertebrates. However, as previously mentioned, increased levels after flood events could result in a reduction of pH which would affect the aquatic ecosystem. Makwadzi's ability to sustain least-highly sensitive taxa can be attributed to its proximity to and regular flushing from the Limpopo River, its flowing water introducing both harmful nutrients and nutrients of value to aquatic ecosystems within the pan.

7.5.3 Nwambi Pan

Both the taxa richness and taxa abundance for Nwambi is higher in the wet sample period. Nwambi pan displayed a variety of aquatic invertebrates sampled. In the wet period *Corixidae enithares* were more prominent in the samples but in the dry period both *Corixidae enithares* and *Diptera chironomidae* had a greater abundance. Very tolerant taxa such as *Corixidae enithares* with a sensitivity value of 3.5, *Diptera culicidae* with a sensitivity value of 1, *Notonectidae anisops* with a sensitivity value 3 and *Diptera chironomidae* with a sensitivity value of 2 makes up three quarters of the taxa abundance during the dry period. There are also moderately tolerant taxa such as the *Anisoptera libellulidae* with a sensitivity value of 5, the *Gomphidae* and *Diptera ephydridae* with a sensitivity value of 6. During the wet period, this range of tolerance in aquatic invertebrate taxa is increased, with tolerant taxa such as *Diptera chironomidae* and *Corixidae enithares* and less sensitive taxa such as *Hydracarina hydrachnellaes* with a sensitivity value of 8.5, *Coleoptera elmidaes* with a sensitivity value of 8.5 and *Mesocnemis singularis* with a sensitivity value of 10. The *Mesocnemis singularis* are not concentrated at one site but occur at two different sites, sites 1 and 4, with an abundance range of between 6 and 10 individuals for both sites indicating that the water quality is acceptable for the taxa to utilize. This is surprising as Nwambi has the highest concentration of aluminium in the wet and dry periods, high nitrite and nitrate content, and failed TWQR for chromium. Sampling period changes indicate higher concentrations in dry periods and can explain the taxa richness comprising of taxa that can tolerate poor conditions. The volume of water received in the wet sampling period in the pan indicates that the water present at Nwambi, although highly concentrated, is utilized by sensitive taxa indicating that the water in the wetland/pan is still unaffected by anthropogenic influences.

7.5.4 Likangwa Pan

Likangwa shows a marked difference in taxa richness and abundance between sampling periods. The wet period has high taxa richness with highly tolerant taxa such as *Diperta psychodidae* with a sensitivity value of 1, and *Diptera culicidae* with a sensitivity value of 1 to highly moderately sensitive taxa such as the *Zygoptera lestidae*

with a sensitivity value of 7.5 and the *Zygoptera chlorolestidae* with a sensitivity value of 7.5. *Ochthebius dilatatus* with a sensitivity value of 8.5 was, however, sampled from site 1.2. *Corixidae enithares, Diptera culicidae* and *Notonectidae anisops* were the most prolific taxa present during the wet period of sampling. The sensitivity range was least moderate in the dry period and ranged from 3 (*Notonectidae anisops*) to 5 (*Anisoptera libellulidae*). Likangwa's abundance of taxa differs drastically by sampling period, with a much higher number of individuals sampled during the wet period indicating more favourable conditions for aquatic invertebrates. These extreme changes in taxa richness and taxa abundance indicate a clear difference in water quality per sampling period. In The dry sampling period, Likangwa's nutrient levels were the following: sodium which meets the AEV, aluminium fails AEV, nitrate and nitrite fails CEV and chromium and arsenic fail the TWQR. Likangwa is also a storage floodplain location with a higher clay content, contributing to its ability to retain water and nutrients received by inundation during the wet period.

7.5.5 Nhlangaluwe Pan

Nhlangaluwe shared similar results to Likangwa whereby there was a significant difference in taxa richness and abundance between sampling periods. Dry period samples indicated the presence of *Diptera culicidae, Diptera ceratopogonidae, Notonectidae anisops, Diptera chironomidae and Corixidae enithares,* of which *Diptera ceratopogonidae, Diptera chironomidae* and *Diptera culicidae* did not appear in the wet period site samples. This is most likely due to the fact that these taxa were not utilising the pan at that stage for part of their life cycle. All of the taxa found in the dry period samples have a high tolerance to poor water quality. In the wet sampling period aquatic invertebrate taxa that were found at Nhlangaluwe hold a high water quality tolerance (e.g. *Diperta psychodidae, Notonectidae anisops* and *Annelida oligochaeta*) and moderate tolerance (e.g. *Cheumatopsyche hydropsychidae, Coleoptera dytiscidaeand* and *Anisoptera corduliidae*). There were no highly sensitive taxa sampled, indicating a poorer water quality such as that of Likangwa. The dry period samples indicated that the samples had a higher abundance of *Corixidae enithares* and *Diptera ceratopogonidae* indicating poorer water quality present at this time. In the wet period, the sensitivity value range of aquatic invertebrates was the most tolerant, ranging from 3-5. Nhlangaluwe's water quality shows that like Likangwa its aluminium failed the AEV and the sodium content met the AEV level. Nhlangaluwe also has higher levels of phosphate, nitrite, nitrate (Meets AEV) and chloride. A high concentration of these nutrients generally affects systems in the following ways: nitrate and nitrite imbalances can lead to a decrease in oxygen transported to organisms; chloride could impair the growth of organisms (Department of Water Affairs and Forestry, 1996). It is suggested that these types of effects can occur in Nhlangaluwe based on the high concentrations sampled and the fact that only aquatic invertebrates with a high tolerance particularly during the dry period can utilize the water. The presence of phosphate in pan systems is due to the presence of animals utilizing an area for water and defecating in the water, lower concentrations can benefit aquatic organisms (by producing nutrient hot-spots) by aiding their metabolism; large concentrations found in the water body will lead to poorer water quality conditions. Nhlangaluwe has a higher presence of phosphate in the dry period. The higher phosphate content could be attributed to herds of buffalo and elephant that frequent the pan due to its geographic location as it is easy to access, has a flat gradient. These large animals inadvertently mix sediment into the water column by trampling in the mud making the water turbid. This in turn also affects aquatic invertebrates as some cannot tolerate the high levels of suspended sediment as it effects their body functioning. Nhlangaluwe is also a storage floodplain with a higher clay content making its soils more likely to store nutrients for longer periods after flood

events from the Limpopo River, therefore increasing nutrient content and overall nutrient concentrations. As a result Nhlangaluwe is also vulnerable to higher values of pollutants that may make their way into the river system adversely affecting pan ecosystem.

7.5.6 Magomugomu Pan

Magomugomu had no water in the dry period and as a result taxa richness and taxa abundance can only be discussed for the wet sample period. The taxa found in Magomugomu are adapted to poor water quality conditions, this can be seen by assessing their sensitivity value between the taxa, when this was completed all the taxa sampled ranged from 1 (*Diptera culicidae*) to 5.5 (*Mollusca ancylidae*). The most abundant taxon found was the *Coleoptera hydrophilidae* larva with a sensitivity value of 5. Magomugomu was also the only pan that had a *Hemiptera nepidae* with a sensitivity value of 3.5. As there are no water quality data available for Magomugomu specifically, the data for the Luvuvhu River was adapted to it. However, when assessed in this manner it is evident that the Luvuvhu River's water quality is high and this does not account for the types of taxa utilizing the pan which have a high tolerance to poor water quality. These highly tolerant taxa are unlike those seen in the other pans, which is attributed to the fact that this pan is occasionally flooded but receives a lot of water from rainfall. This contributes to a stagnated water body with higher nutrient concentrations and a lack of oxygen. The taxa sampled are also taxa that predominantly utilize the substrate for their habitat, therefore exposing them to these higher quantities of nutrients, which means that they need to be adapted to poor water conditions.

7.5.7 Gwalala Pan

Like Magomugomu, Gwalala was dried up during the dry sample period and during the wet sample period sampling only held a pool of water approximately 2m x 2m. In contrast, in previous years Gwalala has held a large body of water. Based on one sample taken (surface sweep and disturbed sweep) only two taxa were found, *Mollusca ancylidae* with a sensitivity value of 5.5 and *Coleoptera dytiscidae* with a sensitivity value of 5. Water quality is not available for Gwalala but is related to samples from the Luvuvhu River. Gwalala has been classified as a Riparian Inundation forest receiving its water from the Luvuvhu during the rainy months when flooding occurs; thereafter Gwalala would only receive water by rainfall. The lack of regular inundation in this instance for Gwalala has attributed to the distribution of aquatic invertebrates, meaning that its ability to support a wider range of aquatic invertebrates when inundated have now been forced these to utilize other water bodies for parts of their life-cycles as Gwalala did not support a body of water during both sampling periods. Both taxa found in these samples utilise the clayey substrate and have a moderate sensitivity to water quality. This indicates that although the water body is the lowest in volume in comparison to the other pans, the water quality is not contaminated or concentrated with nutrients.

In general all the wetland/pan systems in this study shared a common denominator with tolerant taxa being present. Noticeable differences in taxa richness and abundance can be grouped in the following manner, Limpopo wetland/pans vs. Luvuvhu wetlands/pans, Longitudinal Zonation/ landform (section 7.6) and drainage inflow, all of which contributed to aquatic invertebrate sensitivity to water quality and their utilisation of the pan systems.

The Limpopo wetlands/pans (Makwadzi, Nhlangaluwe, Likangwa and Mapimbi) have very different characteristics to the Luvuvhu wetlands/pans (Gwalala, Magomugomu and Nwambi), Mapimbi and Nwambi are discussed separately later in this section.

The Limpopo wetlands/pans are associated with Floodplain Storage and Depression areas. These areas are noticeably flatter, wider and characterised by open grassland areas which extend from the waters' edge a few hundred meters outwards before any Riparian fringe vegetation is seen. Differences in the longitudinal zonation of these pans, means that these areas will support different taxa to that of the Luvuvhu wetlands/pans. The longitudinal zonation/landform occurs as a result of the hydrological regime supporting the pan system. The drainage inflow of these Limpopo wetlands/pans is by seasonal river flooding, which supports the longitudinal zonation classification in terms of how the water is received and dealt with in the systems.

7.6 Pan Characteristics and Proposed Classification

Identifying and understanding the characteristics of pan systems is very important. Wetland and pan systems are unique and although they are classified by the current Ramsar classification a local/regional classification of the systems can assistance in their understanding. The better a system is understood the easier it is to manage these systems in terms of ecosystem conservation. Previous classification systems have addressed hydrology, geomorphology and ecological factors. As such, a localized classification scheme for the study sites utilizing similar properties is provided in this section using the skeleton of the National Wetland Classification System provided by Ollis et al. (2009), chapter 1.1 and chapter 2.1. The physical variables assessed in the study that also contributed to the localized classification system are; soil particle size distribution, soil moisture content and combustible organic carbon.

The ecological variables assessed in this study provided a means for the systems condition to be assessed concurrently with its physical variables. The water quality assessment was compared to the presence or absence of macro-aquatic invertebrates samples within these systems. It is well known that wetland/pan systems are considered nutrient sinks; this was also taken into consideration during the analysis of the water quality data as to not automatically assume that the wetlands/pans held a high toxicity or were of poor health. An approach was taken to assess these systems with the aquatic invertebrates used as bio-indicators for a systems health. It is important to remember that aquatic invertebrates are adaptable to their systems quality and are simply used as bio-indicators in this study. As such, a qualitative scoring system has been developed for each wetland/pan. The method undertaken to develop the score was achieved by assessing the number of times a taxon appeared in a wetland/pan system together with its water quality sensitivity ranking provided in table 6.11. The following qualitative scores were used: healthy, moderate-healthy, moderate-poor and poor. For example, if the majority of the aquatic invertebrates sampled in a system had a low sensitivity and the water quality was identified as poor the system was ranked, poor.

7.6.1 Magomugomu Pan

Magomugomu is classified as an annually flooding pan. During this study period the pan was recorded to have a scale of flood of (4) being full during the wet period (2011) and during the dry period (2011) the pan had completely dried out, indicating sporadic water permanence. This annual filling event coincides with low and high rainfall in the area. Magomugomu's location immediately below a hillslope as discussed in section 6.3

provides this pan with a second method to receive water. Not only does the pan receive water from the Luvuvhu River when it floods but rainfall feeds the pan as well and therefore has a closed drainage. The rocky hillslope increases run-off and the depression with its poorly sorted medium sand provides an impermeable base to collect the water. The grain size distribution analysis and COC yielded that the reason Magomugomu is only able to hold water for a short period of time is as a result of the limited COC available in the samples even though the sediment is fine-medium. Soil probe samples at the base of the pan indicated a wet sample, however 1m upslope the soil sample read dry, indicating a difference between lowland soils and upland soils. Magomugomu's depth measurements were the fourth deepest measurements averaging at 11.75cm deep in during the wet sampling period and completely dry during the dry sampling period indicates that the pan is shallow. The alluvial soils and proximity to the Luvuvhu River enable the pan to support vegetation such as *Acacia xanthophloea* which require large amounts of water and have therefore adapted to the irregularity of this pan system. Magomugomu's shape is oval like (flat) and consistent with Cowardin et al. (1979) classification guideline.

Based on the above description, Magomugomu's regional characteristics are as follows:

Table 7-1: Magomugomu's regional characteristics

Pan	System	Regional Setting	Landscape Unit	HGM Type	Longitudinal Zonation/ landform	Drainage Outflow	Drainage Inflow	Inundation Periodicity	Saturation Periodicity	Systems Condition
Magomugomu	Inland	Subtropical Alluvial Vegetation	Slope	Depression	Floodplain vlei	None	River Flooding/ Rainfall	Intermittently Inundated	Seasonally Saturated	Poor

7.6.2 Nwambi Pan

Nwambi has a constant presence of water depicting a closed drainage system. The wet sampling periods scale of flood indicated full (4) and during the dry period Nwambi registered at (3) three quarters full. When compared to the rainfall over the study period, Nwambi retained a large amount of water despite lower rainfall experienced in the area during the sampling periods. At the immediate top of the banks, the pan was identified as dry. The grain size distribution analysis and COC yielded that the reason Nwambi is able to hold water year round is as a result of the increased COC available in the samples together with well sorted sediment. Pan depth indicated that during the dry period the average depth was 5.75cm and in the wet period 12.75cm. The pan is still considered comparatively shallow and supports Arcadian soils. Nwambi is located in a sunken depression in the sand with levees. Nwambi's ability to support large/dense vegetation such as *Faidherbia albida*, *Vachellia xanthoploea*, *Xanthocercis zambesiaca* and *Diospyros mespiliformis* trees is evidence of a regular, large source of water availability. Nwambi's immediate vegetation is riparian thereafter the vegetation density decreases. Nwambi is bow shaped in length, but largely U-shaped (basin like) in depth.

Based on the above description, Nwambi's regional characteristics are as follows:

Table 7-2: Nwambi's characteristics

Pan	System	Regional Setting	Landscape Unit	HGM Type	Longitudinal Zonation/ landform	Drainage Outflow	Drainage Inflow	Inundation Periodicity	Saturation Periodicity	Systems Condition
Nwambi	Inland	Limpopo Ridge Busveld/Sub-tropical Alluvial Vegetation and Lowveld Riverine forest	Plain	Depression	Riparian fringe	None	Ground water/ River Flooding	Permanently Inundated	Not Applicable	Healthy

7.6.3 Gwalala Pan

Gwalala is annually flooded, according to the wet sample period in (2011) the pan had a scale of (5), being over flowing and during the dry period (0/1) showing minimal water present, consistent with being controlled by rainfall patterns. All but one sample site (4.2) registered as wet when the soil probe analysis was completed for the pan. Gwalala's alluvial soils that fissure and crack when dry support *Acacia xanthophloea* and small shrub vegetation. Hydrophytic vegetation was also identified as being present. The grain size distribution analysis and COC yielded that the reason Gwalala is only able to hold water for a short period of time is as a result of the limited COC available in the soils, therefore limiting the rate of infiltration of water and its ability to hold moisture even though the sediment is fine-medium. The depth measurements for Gwalala (2011) was 0cm in the dry sampling period as the pan was dried up and 2cm in the following wet sampling period in (2012) demonstrating that the pan is shallow and flat. Gwalala is known to be the first pan in the area to be filled but does not hold its water for long according to the head guide of the Makuleke concession. Gwalala's shape is inconsistent to that of an endorheic system proposed by Cowardin et al. (1979). However, Gwalala's other characteristics according to the NWCS still consider the system a pan.

Based on the above description, Gwalala's regional characteristics are as follows:

Table 7-3: Gwalala's characteristics

Pan	System	Regional Setting	Landscape Unit	HGM Type	Longitudinal Zonation/ landform	Drainage Outflow	Drainage Inflow	Inundation Periodicity	Saturation Periodicity	Systems Condition
Gwalala	Inland	Sub-tropical Alluvial Vegetation	Plain	Flat	Riparian inundation forest	None	River Flooding	Intermittently Inundated	Seasonally Saturated	Moderate-Poor

7.6.4 Makwadzi Pan

Makwadzi pan has been going through a period of transition over the past 4 years from annual flooded to being continually inundated with water. Makwadzi's scale of flood for the wet sample period was (5) overflowing and in the dry sampling period was (2) which is very low, however Makwadzi still holds water all year round. This transition however may cease if rainfall for the region or flooding from the Limpopo River decreases. Sample sites 1.3 and 2.1 were the only samples that were classified as wet, the rest read dry on the soil probe meter. Makwadzi covers a vast surface area, however when the depth analysis was completed the results were unexpectedly shallow. The wet sampling period registered at an average of 5cm and the dry period 8cm. Makwadzi's large surface water is linked to the fact that it lies on a drainage line and forms its own catchment. The grain size distribution analysis and COC yielded that the reason Makwadzi is able to hold water all year round is as a result of the increased COC available in the samples together with fine-medium sediment. Makwadzi supports vegetation such as *Acacia nigrescens* and *Perotis patens* in its immediate surroundings, indicating that the fluctuations in water levels cannot support larger tree taxa.

Based on the above description, Makwadzi's regional characteristics are as follows:

Table 7-4: Makwadzi's characteristics

Pan	System	Regional Setting	Landscape Unit	HGM Type	Longitudinal Zonation/ landform	Drainage Outflow	Drainage Inflow	Inundation Periodicity	Saturation Periodicity	Systems Condition
Makwadzi	Inland	Limpopo Ridge Bushveld vegetation/ Subtropical Alluvial Vegetation and Lowveld Riverine Forest	Plain	Un-channelled Valley-bottom wetland	Valley bottom flat/ Floodplain storage	None	River Flooding	Seasonally Inundated	Permanently Saturated	Moderate-Poor

7.6.5 Likangwa Pan

Likangwa is a perennial pan but does have the potential to dry out, especially if Nhlangaluwe (Limpopo River dries out as Likangwa is dependent on Nhlangaluwe overflowing to recharge it. Both Likangwa and Nhlangaluwe are dependant of the Limpopo River for their recharge. The scale of flood during the wet sample period was (4) full and in the dry period was (2) which was very low. Likangwa's southern side provides a means for excess run-off from the above slope to make its way into the pan from rainfall; the soils are sandy and have shallow bedrock. The soil probe analysis saw site 1.1 being moist, site 2 being dry and sites 3 were wet. This could have been as a result of the water funnelling its way down the ridge into the pan area on the eastern side, as there is a drainage indent in it. The grain size distribution analysis and COC yielded that the reason Likangwa is able to hold water for long periods, sometimes annually is as a result of the increased COC available in the samples. The site is dominated at its edges by grass taxa that are present year round. The sediment samples yielded that the soils at Likangwa are medium-coarse which is less likely to support a water body for a sustained period of time. Likangwa's depth remained constant through the wet period at 21.50cm and in the dry period was 21.75cm even though there was a substantial loss overall seen in the scale of flood inundation, indicating that the floor of the pan is more V-shaped than flat. Likangwa soils have the ability to support a variety of vegetation, those requiring deep soils such as *Acacia xanthophloea* and those requiring shallow soils such as *Acacia nigrescens* and *Hyphaene Coriacea*.

Based on the above description, Likangwa's regional characteristics are as follows:

Table 7-5: Likangwa's characteristics

Pan	System	Regional Setting	Landscape Unit	HGM Type	Longitudinal Zonation/ landform	Drainage Outflow	Drainage Inflow	Inundation Periodicity	Saturation Periodicity	Systems Condition
Likangwa	Inland	Subtropical Alluvial Vegetation	Plain	Floodplain wetland	Floodplain depression/ Floodplain storage	None	River Flooding	Seasonally Inundated	Permanently Saturated	Moderate-Healthy

7.6.6 Mapimbi Pan

Mapimbi pan's scale of flood was determined at (3) three quarters full for both wet and dry sample periods, thus displaying signs of a stable/ perennial system. Mapimbi is located close to the water table. The depth measurements that were taken for Mapimbi indicated that it has the deepest depth of all the pans in the wet period with an average of 41cm and a depth of 12.33cm in the dry period. Mapimbi's fine soils are able to support large trees and a dense shrub layer. The grain size distribution and COC shows that Mapimbi is able to sustain its water body year round as a result of the increased COC available in the samples. Mapimbi is dominated by a shrub layer and tall canopy of trees; as a result a dense vegetative layer is available around three quarters of the wetland/pan system. The sediment sampled for Mapimbi yielded that the soils are well drained which does not contribute to the constant amount of water present, this further enforces the notion that this system is supported by the water table and COC which aids the infiltration of water.

Based on the above description, Mapimbi's regional characteristics are as follows:

Table 7-6: Mapimbi's characteristics

Pan	System	Regional Setting	Landscape Unit	HGM Type	Longitudinal Zonation/ landform	Drainage Outflow	Drainage Inflow	Inundation Periodicity	Saturation Periodicity	Systems Condition
Mapimbi	Inland	Lowveld Riverine Forest	Plain	Un-channelled valley bottom wetland	Valley bottom depression/ Riparian fringe	None	Ground water	Permanently Inundated	N/A	Healthy

7.6.7 Nhlangaluwe Pan

Nhlangaluwe is a perennial pan that experienced a scale of flood of (4) in the wet sampling period representing a full pan and (3) during the dry sampling period indicating a large amount of water. Nhlangaluwe's ability to merge with its surrounding wetlands/pans suggests that it is also found on a drainage line. All soil probe analyses completed at the pan was dry indicating well drained soils. The dry results from the probe analyse were not a result of a lack of water as the depth measurements indicated that the average depth during the wet periods was 5cm (this figure has been lowered due to n.d. for one sample) and 8.66cm in the dry period. The grain size distribution analysis and COC yielded that the reason Nhlangaluwe is able to hold for long periods of time as a result of the increased COC available in the samples. The sediment for Nhlangaluwe was medium-coarse which does not assist with the retention of soil moisture, however like Likangwa and Makwadzi, Nhlangaluwe has a dense grass vegetation surrounding the water's edge which has the ability to trap the soil moisture in for long periods of time. The soil type present supports vegetation requiring shallow soils such as *Acacia nigrescens* and *Hyphaene Coriacea*.

Based on the above description, Nhlangaluwe's regional characteristics are as follows:

Table 7-7: Nhlangaluwe's regional characteristics

Pan	System	Regional Setting	Landscape Unit	HGM Type	Longitudinal Zonation/ landform	Drainage Outflow	Drainage Inflow	Inundation Periodicity	Saturation Periodicity	Systems Condition
Nhlangaluwe	Inland	Subtropical Alluvial Vegetation	Plain	Floodplain wetland	Floodplain depression/ Floodplain storage	None (However, in times of severe flooding can become exorheic	River Flooding	Seasonally Inundated	Permanently Saturated	Moderate-Healthy

Chapter 7.6 aims to provide detailed localized characteristics for the Makuleke wetlands. The Ramsar, Convention on Wetlands of International Importance came into force for South Africa in December 1975 with the aim of protecting pristine wetland areas of importance (Ollis, et al., 2009). The Ramsar convention identified the Limpopo River Makuleke wetlands/pans as Floodplain vlei and the Luvuvhu River Makuleke wetlands/pans as storage floodplain type. These conventional wetland listings are well suited for other international wetland types but struggle to accurately characterize the wetland/pan types within an increasingly arid region such as northern KNP. This study suggests that the use of a local classification method such as the Proposed National Wetland Classification System (NWCS) (section 2.2) or the localized characteristics laid out in section 7.6 would be more useful in understanding the regions wetland systems. The NWCS provides a top down approach to classifying by identifying primary discriminators (system, regional setting, landscape unit and HGM unit) and secondary discriminators (hydrological regime and wetland characteristics). This classification is strongly influenced by a hydrogeomorphic approach which is well suited to these arid systems that are driven by flow regime and sediment composition. The secondary discriminators cater for the assessment of wetland characteristics such as geology, natural vs. artificial, vegetation cover, substratum, salinity and acidity/alkalinity. These characteristics can be quantified by fieldwork research and used to reinforce that local characteristics like those suggested in section 7.6 should be used alongside the Ramsar classification. The units selected for the additional localised classification system were selected on their basis to contribute meaningfully to the areas systems by providing units that correctly assessed their characteristics and define the systems as being unique to each other. The nine units decided upon (systems, regional setting, landscape unit, HGM type, longitudinal zonation/landform, drainage outflow, drainage inflow, inundation periodicity and saturation periodicity) were quantified by the field and lab work portions of this study. The data collected in the field and laboratory tests served to provide confirmation that a local classification unit could assist the current classification and become beneficial when assessing and managing these systems in the future.

The Ramsar classification for the Makuleke wetlands does not consider wetland functioning or biological assessment. The localized classification presented provides a qualitative biological assessment for each wetland/pan system in which aquatic invertebrates were used as bio-indicators for system health. Aquatic invertebrates were chosen for a number of reasons namely, benthic invertebrates specifically have little mobility, aquatic invertebrates are generally abundant, and they are the primary food source for fish and are good indicators of localized conditions. By providing a system condition to a classification, the classification becomes more useful as it addresses both the physical variables and the environmental variables in a system, providing a clearer picture of the systems overall health and functioning. Baseline information such as this can then be built on in the future to assess how a system is changing. It must be noted that the January 2013 flood event could have changed the dynamics of these systems during the time of this studies fieldwork (see appendix E), however this would allow for more research to be conducted on these individual system to assess how the food event has affected the systems.

Many classification methods applied to wetland/pan systems are broad with overarching categories and/or vague and are not applicable to the systems they have been linked to. Section 7.6 proposes the basis from which local characteristics further define these systems into more precise individual pan systems. Due to climate change, systems are constantly changing, and to maintain an understanding of these systems, classification methods need

to adapt with them to consider physical and environmental scale changes, thus correctly managing the ecosystems within the pans, and those that utilize them. A deeper understanding of these pans as individuals has been provided above in this section. This has been achieved through the use of the hydrological and geomorphic controls according to the Hydrogeomorphic Classification (HGM) System, which in terms of pan systems are the two most important local/regional contributing factors.

A comparison of the seven pans indicates that at first glance the pans located on the Limpopo River look very similar, even possibly wetlands, and the pans on the Luvuvhu River look like similar depressions, however the pans on both these systems show differences in drainage inflow, landforms and inundation periodicity when compared with the HGM. These factors contribute to the types of aquatic ecosystems present.

All the pans found on both the Limpopo and Luvuvhu Rivers experienced recharge by at least one method of drainage inflow (flooding), except for Mapimbi which gains its water from the water table. Nhlangaluwe is the only pan to have both a drainage inflow and drainage outflow when the Limpopo pans burst their banks. Mapimbi and Nwambi receive water from the water table through seepage, however due to Nwambi's relief; it is a natural depression and will collect and water around it from higher areas. Similarly, Nhlangaluwe is located on a drainage line and as a result it receives a large supply of water in this manner. Gwalala, Makwadzi and Likangwa receive major inundations from their specific river systems although only Makwadzi and Likangwa share storage floodplains. Gwalala's longitudinal landform differs in that it is a riparian inundated forest which is similar to Nwambi and Mapimbi's riparian fringe vegetation. Likangwa also shares similar properties to Magomugomu in that it receives water as a result of its immediate location to a hillslope. The pans on the Limpopo River although present at the bottom of a catchment area by and large surrounded by hillslopes to the south. This contributes to the occurrence of colluvial movement into these systems. Gwalala is the only pan to support a floodplain vlei longitudinal landform type.

7.7 Concluding Discussion

The physical variables selected for this study were assessed in a top down method. For a more unique perceptive on the individuality of these pan systems a bottom up approach was used in collecting soil sediment for grain size distribution analysis, soil moisture content and combustible organic carbon from specific sites, providing site specific attributes so that the study was ecologically meaningful. With the use of both a broad scale approach to the study area and an acute approach to the study sites, a more accurate classification can be achieved, which will enable better environmental management.

A local/regional classification structure has been developed in this section for each pan. The aim is to provide additional site specific information which may be used in assisting the Ramsar classification in further differentiating between the unique systems.

The Luvuvhu pans are associated with Floodplain Vlei and Riparian areas. These areas tend to be more isolated from the river source and more depression like. They do receive water by flooding but their water retention abilities differ greatly. This difference is seen in the soils, the soils of the Limpopo were much more coarse like as apposed to the soils of the Luvuvhu River system which were slightly clay and more loam like. Due to the nature of alluvial floodplains both Limpopo and Luvuvhu pans did hold a percentage of clay enabling them to

retain water but to different degrees. The Limpopo River pans were supported in their ability to maintain a water body by the degree of dead organic matter that was found within the samples which added to the combustible organic matter tested for in the laboratory. Much of the dead organic matter associated with the Limpopo River pans was grasses. The Luvuvhu River pans ability to maintain a water body was assisted by dead organic matter which aided the infiltration of water into the system; however the sediment associated with the Luvuvhu Rivers had a stronger capability of holding moisture for longer than that of the Limpopo River pans. The longitudinal zonation/landform (section 7.6) again contributed to differences in the system's ability to support taxa. Vegetation associated with these riparian/riparian forest areas was considered very dense, with a scrub/shrub layer and tall trees right at the edge of the pan systems. A few meters away the landscape reverts back to arid areas with few grasses and sporadic Acacias. The drainage inflow for Gwalala and Magomugomu as indicated above is flooded. Both of these pans receive water by rainfall as well but due to their isolation they usually dry up over the dry sampling period, resulting in these areas supporting aquatic taxa during periods of good rainfall.

Nwambi (Luvuvhu River) and Mapimbi (Limpopo River) have both been associated with ground water. This is because their water levels remained constant both are indicative of the Riparian Fringe longitudinal zonation/landform and have similar depression like characteristics. These pans too have Riparian vegetation surrounding them immediately on the gradient change. However, their uniqueness is as a result of their drainage inflow being ground water. These pans are able to support sensitive taxa year round as a result of the constant inflow of fresh water.

Below is a breakdown of how the wetlands/pans look at a local/regional classification according to their observable and examined characteristics.

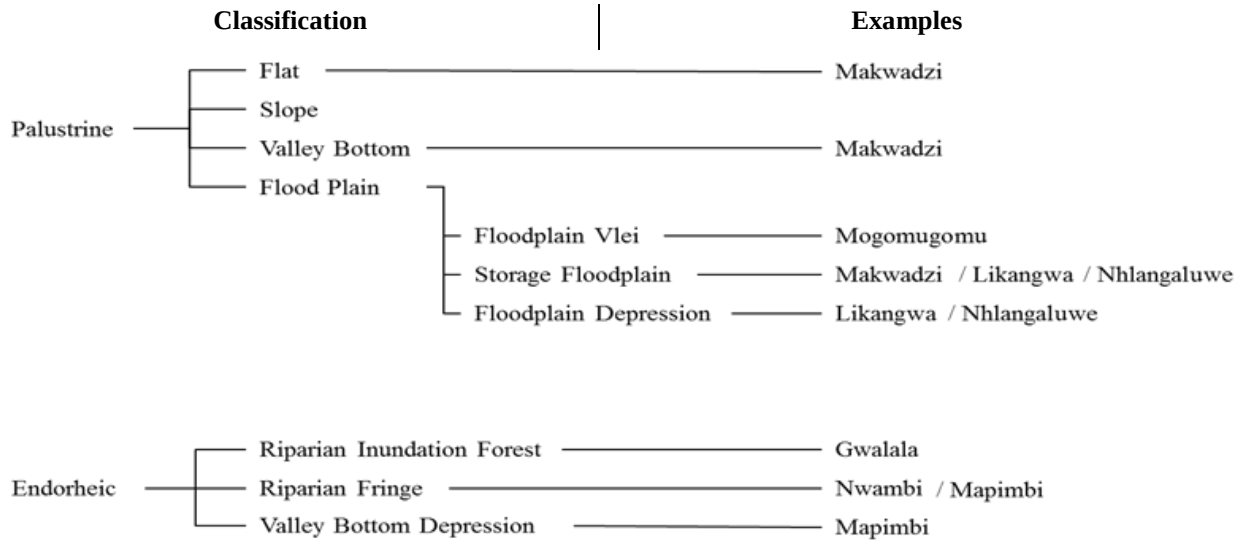


Figure 7.8: The local/regional classification of the Makuleke wetlands/pan study sites

The wetland/pans in the study area can be classified as palustrine or endorheic based on their differences between their sub-systems and classes. Figure 2.1 used the literature provided by Cowardin et al. (1979) classification system and Dini et al. (1998) proposed wetland classification for South Africa to develop a regional understanding (figure 7.8) for the Makuleke wetland/pan systems. With the use these two classification systems a better basic understanding of the study sites is revealed. It is important to remember that these pan

systems do not fall under one specific classification as there are multiple classifications that they could fall under as the systems are constantly changing in nature due to geomorphic and hydrological processes. These changes that occur are predominantly seen between wet and dry periods however long term changes must also be considered. Therefore figure 7.8 is an outline of where these systems can be found in terms of a regional classification scheme.

Both Nwambi and Mapimbi shared similar properties in that they both receive groundwater inflow, Nwambi also experiencing flood inundation and riparian fringes. Year round vegetation contributed heavily to the high combustible organic carbon content found at each of these sites, increasing nutrient levels in the water and causing these pans to hold the highest nutrient content values. In the other pans this high nutrient content saw very tolerant aquatic invertebrates utilizing its water column and substrate, however due to the ground water inflow sensitive aquatic invertebrates are able to use both these pans systems as there is a steady inflow of cleaner water into their pan system. Aquatic invertebrates with a moderate tolerance to water quality were found in Gwalala even in a small stagnant water body. This indicates that when inundated Gwalala has the potential to support more sensitive taxa. The Limpopo River pans Likangwa and Nhlangaluwe showed similar results in that there were major sampling period differences in taxa richness and abundance, and are both storage floodplains. The commonality between the diagnostically unconsolidated soils shows their ability to retain nutrients received by flooding during the wet sampling periods and into the dry sample periods, increasing their concentrations and thus effects on ecosystems. As a result Nhlangaluwe's taxa were all highly tolerant, whereas Likangwa showed sampling period differences with the dry period displaying tolerant taxa and the wet period both tolerant and sensitive taxa. Like Likangwa, Makwadzi held tolerant taxa and sensitive taxa. The Limpopo River pan systems are regularly exposed to anthropogenic affects, particularly mining and agriculture, therefore exposing them on a regular basis to irregular variations in nutrient levels. However at the time of sampling, these pans are able to support a variety of sensitive aquatic invertebrate taxa. The Luvuvhu Rivers' water quality was better than that of the Limpopo River, but not by a large margin. Magomugomu being a pan that is flooded by the Luvuvhu River however displayed only taxa with high tolerance to poor water quality. During the sensitivity analysis of the taxa found in the pans, variables such as grain size, combustible carbon content and nutrient levels contributed to taxa richness, taxa abundance and their distribution in each pan.

The biological assessment attached to the regional classifications for the pans allows for a constant functional/biological assessment of the systems. This is because living organisms such as aquatic invertebrates act as an early warning system for wetland condition. Even though aquatic invertebrates may only utilize the pan system for parts of their life cycles and can adapt to varying conditions, certain taxa are generally suited to specific habitats and water quality. When these taxa begin to change, noticeable differences within systems are likely to have changed to. The system condition indicated in the local/regional classification provided in section 7.6 allows for a baseline environment to be established indicating that currently the systems appear to be remaining constant.

Chapter 8 Conclusion

The aim of this study was to use field evidence such as soil particle size distribution, combustible organic carbon, soil moisture content, vegetation type, water quality and aquatic invertebrates and their associated habitat to provide additional local/regional wetland classifications. The seven wetland/pan systems within the Makuleke concession in the northern Kruger National Park (KNP) are classified as floodplain vlei and storage floodplain according to Ramsar. This study evaluated the physical and environmental variables that are associated with the systems. The current Ramsar based classification used for the Makuleke wetlands is a prominent internationally used classification. However in arid areas like that of the northern KNP, the Ramsar classification lacks local/regional characteristics which are able to further define systems as being unique to one another. For example, the individual systems occasionally join during the wetter periods but by and large they remain disconnected systems which have different physical and environmental features with which they can be defined. The Ramsar classification does not consider local/regional characteristics in its classification scheme, which renders the Makuleke pans improperly classified. Therefore, it is proposed that the use of the local/regional characteristics outlined in section 7.6 be utilized alongside the Ramsar classification as another classification tier. Soil particle size distribution, combustible organic carbon, soil moisture content, water quality, aquatic invertebrate habitat variables were measured during the field and lab work on these wetland/pans and considered more important than others from a classification perspective in that the variables assisted in determining where a wetland/pan system fell in the localized/regional classification proposed for the study sites and identified wetland functioning. The proposed localized/regional classification that has developed out of this study assesses both the physical aspects of the systems as well as the systems condition. The biological component used to assess the systems condition was aquatic invertebrates because they are highly sensitive to the environment within which they live.

Pans that have fine grain sizes also show higher nutrient content within the water. When the grain size is larger, nutrient content was lower as the sediment was unable to hold nutrients for a period of time. An assessment of the longitudinal zonation/landform from ground truthing facilitated a better understanding of the combustible organic carbon located at each site and its combined contribution with sediment size to nutrient levels and pan dynamics. Results showed that the pans with coarse sediment, namely Makwadzi, Likangwa and Nhlangaluwe, were able to retain water for longer due to the amount of organic matter present in the soil. Whereas the Luvuvhu River pans, were associated with finer sediment and retained moisture based on the smaller pores available in the sediment relying less on organic matter. Pan depth analysis showed that the depth of a system is a significant variable which affects aquatic invertebrates. This is because it reflects those taxa that utilize the substrate or water column. Water quality also determined spatial distribution of the aquatic invertebrates together with the different habitats within the systems. The TSS did not have a critical effect on the aquatic invertebrates. Site differences in TSS showed that although Nwambi had high levels of TSS the pan was still able to support sensitive species, whereas Nhlangaluwe, which held the second highest TSS, supported highly tolerant species. Temperature is a significant environmental variable that affects aquatic ecosystems, in this study however the temperatures seen did not display significant changes that would be detrimental to the environment. The changes seen are considered normal due to water temperature change in accordance with seasonal change. The wetland/pan temperatures differ slightly from one another with the flatter, shallower pans

depicting slightly higher water temperatures. The above mentioned variables are important components to wetland/pan systems and all play a particular role in aquatic ecosystems.

System variables outside of the immediate wetland/pan areas, such as flood events (flow regime), are a natural part of the cycle in the environment. These events are known to bring life back into the area by stimulating the growth of vegetation and the population growth of aquatic invertebrates by increasing the waters' surface and habitat availability. However, extreme events provide strong natural disturbances capable of essentially resetting aquatic and floodplain communities (Elwood and Walters, 1969, Friedman et al. 1996). This is a significant element to understanding wetland functioning and system condition and that they are continually changing as a result of these natural cycles indicating that these systems are vulnerable to major environmental events such as climate change.

Aquatic invertebrates found in wetland/pan systems are known to play an integral part in the food web as they consume excess plant matter (Hickey and Salas, 1995) and in turn are also predated on by birds and other animals who utilize the wetland/pan system. Disturbances, such as extreme events, can introduce new taxa and change geomorphic processes therefore changing current conditions in an ecosystem which drastically affect the overall wetland/pan system. Vegetation has also been identified as a key unit in the landscape to prevent damage during flood inundation and reduce erosion processes. Increases in anthropogenic contributions upstream could eventually affect the flow regime and water quality, changing the natural geomorphic processes and taxa in the area therefore affecting the wetland/pan inflow, creating adverse effects on the aquatic invertebrate taxa utilizing the water bodies.

The wetland/pan systems in the Makuleke region are highly dependent on seasonal hydrology and geomorphic processes. These processes are seen in this study to affect macro aquatic invertebrate populations, both positively and negatively, as the pan systems support aquatic invertebrates for part of their life cycles. However, these systems are highly susceptible to disturbances from natural influences and anthropogenic influences due to their nature of purifying water, acting as flood barriers, recharging groundwater and providing natural species habitat. It is vital to remember that these water-based landscape features, although protected and managed in the KNP, are still at risk of disappearing or becoming highly toxic due to their location and system function being found downstream of activities that have, in the past, proven detrimental to wetland/pan systems. These wetlands are also facing future damage from climate change as a result of changes in hydrological regimes where increased flood events or droughts for long periods of time are seen. Moreover, changes in temperature experienced by these systems will also begin to affect the evaporation rate of the water body, which in turn can affect the aquatic invertebrate's usage of the pan system.

Aquatic invertebrate taxa richness and abundance is related to the physical and environmental variables. The relative importance of these variables was assessed in terms of their relevance to describing the nature of the pan systems and assessing the classification for the wetland/pan areas based upon classification schemes used in the literature. During this assessment, local/regional classification tiers for the wetland/pan systems were assigned to the systems based on the proposed National Wetland Classification System provided by Ollis et al. (2009). When addressing the physical variables in this study, hydrology was a significant variable as it determined the presence of drainage inflow or outflow (flood events from the Limpopo and Luvuvhu River) in these systems

and the rate of ground water recharge. Topography as a physical variable was significant in determining where wetlands/pans were located within the landscape unit, for example with respect to hills, where run-off could be received and/or situated on drainage lines. The vegetation assessment of the region was useful in understanding the presence of combustible organic content found in the samples and their relationship with sediment size and soil moisture content. The sediments properties in the study, obtained from the area around wetland/pan systems, played a valuable part in the understanding of the wetland/pan area's ability to retain water after inundation events. Other environmental variables were also determined during ground truthing, such as slope gradient and pan geometry.

Significant environmental variables were determined by their ability to affect aquatic invertebrates positively or negatively. The water chemistry section of this research was important in determining aquatic invertebrate usage of the water due to healthy environmental levels in the wetlands/pans or their distribution/intolerance as a result of unfavourable water conditions due to the environmental variables. These effects varied according to individual pans regardless of their river source. The Limpopo River and its associated wetland/pans saw higher levels of anthropogenic induced ions. Unexpectedly though, Nwambi, with its source from the Luvuvhu River/ground water, also saw similar high nutrient levels. These effects of nutrient levels in the wetlands/pans caused variations with aquatic invertebrate taxa richness and abundance. Wetlands/pans that displayed relatively unfavourable conditions for aquatic invertebrate taxa that were located closer to the river system were Likangwa and Nhlangaluwe. These systems showed an increased abundance in the tolerant taxa with fewer intolerant taxa present, whereas Magomugomu also displayed unfavourable water conditions and only supported highly tolerant aquatic invertebrate taxa. Magomugomu's attributes could be due to its seasonal inundation and distance from the river, thereafter receiving only rainfall and hill slope runoff. The two pans were assumed to receive water by flooding and ground water, Mapimbi and Nwambi, both displayed the highest overall nutrient content and were seen to support both the most tolerant aquatic invertebrate taxa and the most sensitive taxa in this study, indicating that although the nutrient levels were high, the aquatic invertebrates had access to fresh water. The environmental variables; aquatic invertebrates, their surrounding habitats and the water quality of each of the wetland/pan systems, provided the system condition portion of the local classification with the means to consider overall system condition for each wetland. The use of aquatic invertebrates in this manner is very useful as they act as an early warning of wetland condition.

In conclusion, the different classifications provided in previous literature reviewed of different wetlands/pan systems has not adequately described the Makuleke pan systems on a local/regional level. The pans in the region are classified as Floodplain vlei or Storage floodplains. To better understand these systems, this study has provided further local tiers of classification for each pan as described in section 7 together with a qualitative understanding of the systems condition. Each wetland/pan systems characteristics were analysed individually and as a result has received its own local/regional classification to be used in conjunction with the Ramsar classification. The following units were selected based on their importance in determining a system type; system, regional setting, landscape unit, HGM type, longitudinal zonation, drainage outflow/inflow. The following units; inundation periodicity and saturation periodicity were identified as additional important units to include, further defining a wetland system on its ability to retain water and maintain a water body. To fully understand these systems the aquatic invertebrate data, water quality and the utilization of micro habitats by

these organisms was assessed. A system condition unit has also been included in the classification which allows for the ecological functioning of the system to be monitored simultaneously to the physiological changes seen in the systems. The Ramsar classification on its own does not provide a means by which physical changes can be individually monitored within a system together with biological changes in the system. As such, a proposed definition for the Makuleke pan systems is given. An aquatic system that is earthbound, less than 6m deep, can be temporary or permanent, are near the water table, are ephemerally inundated with fresh water which is retained by under drained hydric soils and supports hydrophytic vegetation. The conservation of these systems is very important, particularly due to their location in an arid area. This study's results will prove useful in understanding current wetland/pan dynamics and the relationship between the aquatic invertebrates that utilize them. The study has also provided a local/regional classification scheme that will prove useful for environmental management of these systems within the KNP. The January 2013 flood event experienced by the area however, is likely to have changed the current pan dynamics examined in this study (see Appendix E). A future study of these sites could determine changes in pan dynamics and the effects that extreme flood events have on the aquatic invertebrates utilizing the wetlands/pans.

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Appendix

Appendix A

Aquatic Invertebrates Photographed Under Microscope



Figure A.1: Predacious Diving Beetle Larvae



Figure A.2: Anisoptera Libellulidae

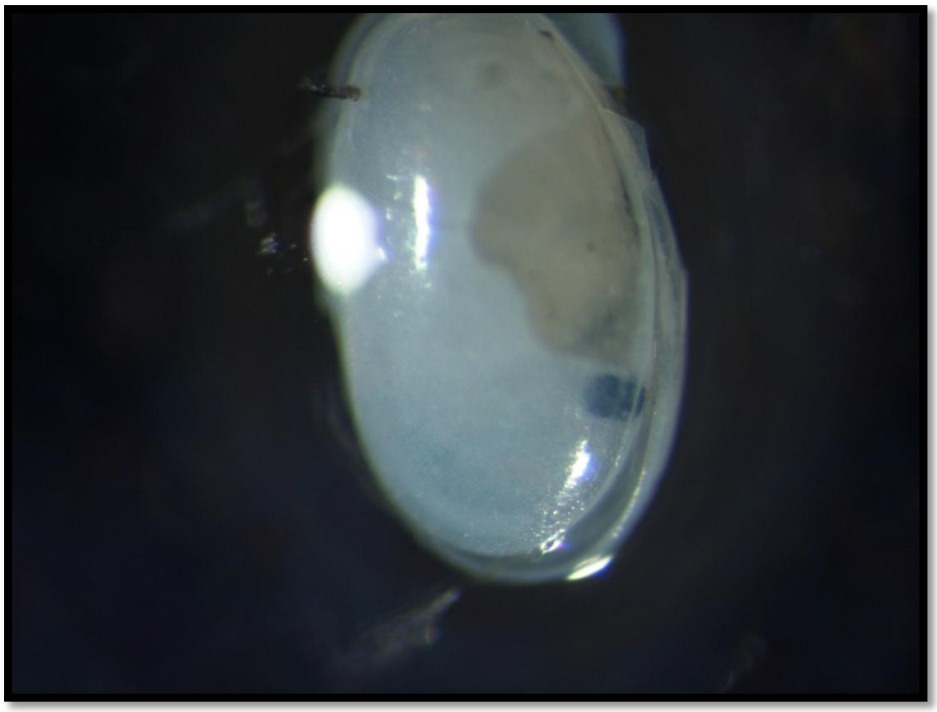

Figure A.3: Clam with Brine shrimp



Figure A.4: Water scavenger beetle

Appendix B

Field Worksheet

PAN NAME	
DATE	
TIME	
DAILY CONDITIONS	
RIVER SOURCE	
SCALE OF FLOOD	
ORIONTATION	
ANNUAL/SEASONAL	
OUTSTANDING PAN FEATURES	
SOIL PROBE READING	
PAN DEPTH	
DOMINANT VEGETATION	

Pan	Soil sample#	Coordinates	Site description	Pan depth	Pan gradient	Aquatic invertebrate site #	Coordinates	Biotope	Site observations

General Notes:

Figure B.1: Fieldwork Sheet

Appendix C

Aquatic invertebrates found during the study and their related morphology

Common name/ Latin name	Morphology	Behaviour	Colour
Leeches/ ***Annelida hirudinae***	Flattened, with rear slightly wider than front, no legs or tentacles, suckers at both ends of body	Move in creeping, looping fashion, swim with side-to-side motion, with body stretched out	Pale with bright spots or stripes, brown or black
Aquatic Earthworms/ ***Annelida oligochaeta***	Long, thin, soft and muscular, thin translucent body wall, no legs or tentacles, bundles of hair close to the surface	Crawling about in the muddy substrate, inactive in a coiled up position	Pink
Predacious Diving Beetles Adult/ ***Coleoptera dytiscidae***	Oval shaped bodies, rounded backs, elongated hind legs with last segment flattened and fringed	Fast swimming/diving using hind legs together like oars, resting just below the water's surface, head down and tip of abdomen pushing through surface film	Black or Brown, some species carry yellow markings
Predacious Diving Beetles Larva/ ***Coleoptera dytiscidae***	Streamlined spindle-shaped bodies, large heads, well developed mouthparts and fringed swimming legs	Swims slowly with alternative rowing of the legs	Pale, light brown or dark brown
Riffle Beetle Adult/ ***Coleoptera elmidae***	Very small, slender antennae, last segment widened in some species, sharp claws on the feet	Very slow moving, walking/crawling whilst clinging to substrate with long claws	Black, some species with red tones
Minute Moss Beetle/ *Ochthebius dilatatus*	Minute in size, mouthparts longer than antennae, antennae club-shaped	Active swimmers	Dark brown, shiny
Water Scavenger Beetle Adult/ ***Coleoptera hydrophilidae***	Oval body with rounded back, short clubbed antenna, mostly hidden, mouthparts much longer than antenna	Active swimming, using hind legs alternately, they come to the surface with head first to break the surface film with the tip of the antenna	Brownish or black
Water Scavenger Beetle Larvae/ ***Coleoptera hydrophilidae***	Soft, worm-like, well developed mouthparts	Slow moving, Creeping/crawling with head tilted upwards	Pale brown

Biting Midges/ *Diptera ceratopogonidae*	Very thin, hair-like, all body segments equal in diameter, no pro-legs and no respiratory tube on abdomen	Swim with curved body, like a snake	Pale or brown
Midges/ *Diptera chironomidae*	Slender, elongated, cylindrical, small heads, pro-legs and gill appendages on the tip of abdomen	Back and forth flicking of entire body	Yellow, brown, green and red
Mosquito Larvae/ *Diptera culicidae*	Elongated, covered with tufts of hair, large heads, segment behind head noticeably enlarged and respiratory tube on tip of abdomen	Floats under surface slanted with respiratory tube in contact with the air, wriggles away when disturbed	Yellow, brownish
Mosquito Pupae/ *Diptera culicidae*	Large heads, abdomen curved around head, two paddle-like structures on tip of abdomen, two ear-like structures on head	Floats under the surface, curled up into a comma shape	Brown
Brineflies/ *Diptera ephydridae*	Wingspan 10 mm, stocky, forelegs enormously enlarged and raptorial-grasping prey, mottled wings and hairy antennae	Feed on aquatic insects, larvae generally aquatic, use forelegs to walk over wet algal crusts	Grey and black
Moth Flies/ *Diperta psychodidae*	Slender, cylindrical, covered with fine hair, small hardened head, dark hardened plates on all segments, single tube and tuft of hair on tip of abdomen	Active creeping, crawling motion	Grey and black
Giant water Bugs/ *Hemiptera belostomatidae*	Large, robust nymphs, prominent eyes and forelegs adapted to seize and hold prey	Swim with forelegs stretched forward, cling to submerged substrate with the tip of abdomen in contact with the air	Brown, or dull green
Water Boatmen/ *Corixidae enithares*	Small cigar-shaped, middle legs long, ending with two claws for anchoring purposes, hind legs long, fringed for swimming, no extended beak, mouthparts fused with the head	Swim in a quick darting fashion, rowing with the hind legs	Dark grey, mottled yellow, brown or black
Water Scorpions/ *Hemiptera nepidae*	Body shapes varied according to species, forelegs modified for seizing prey, long respiratory tube on tip of the abdomen	Swim slowly with alternating strokes of middle and hind legs, sit quietly amongst vegetation with forelegs in striking position	Pale brown to dark brown or black
Backswimmers / *Notonectidae anisops*	Unusually large eyes, long hind legs	Swim on their backs using only their hind legs, rests with body at an angle with tip of abdomen in contact with the air, produce a burning sting when handled carelessly	Patterns of white, pearl, yellow, brown and black

Pygmy backswimmer/ *P. piccanina*	Very small, body length at 2 mm, broad and short with their backs being keel-shaped.	Similarly to the *Notonectidae*, the Pygmy backswimmer swims on its back	Seen under microscope are pit-like depressions on the body. Shiny/brown
Water Mite/ *Hydracarina hydrachnellae*	Minute, round shape, soft body with translucent skin, eight legs, body not divided into separate segments	Swimming, using all eight legs	Brown, green or red
Fairy or Brine Shrimp/ *Artemia salina*	Numerous pairs of flattened, leaf-like thoracic limbs, usually 10 mm long	Planktonic, filter feeders, swimming on their backs using their limbs to filter edible particles from the water	Opaque bodies, Black eyes and line along back with orange tail
Fresh water Lipets/ *Mollusca ancylidae*	Shells flattened limpet-like, base of shell wide round or oval, resembles a sand dune when viewed from the side	slow gliding movement	Brown or black
Pouch Snails/ *Mollusca physidae*	Shell opening to the left, shell smooth and glossy, slender tentacles	slow gliding movement	Brown
Pill clams/ *Mollusca Sphaeriidae*	Small, fragile shells, smooth without grow rings	Inactive	Whitish, brown with dark speckles
Snails/ *Mollusca thiaridae*	Strong thick shell, well developed spiral, tubercles more pronounced in some individuals	Slow moving on the foot	Cream with brown markings, brown
Mussels/ *Unio cafer*	Large elongated shells, prominent growth rings, erosion of the outer layer visible	Inactive, two halves open slightly when filtering water	Dark brown with pearly eroded patches
Green-eyed Skimmers Dragonflies/ *Anisoptera corduliidae*	Oval bodies, rounded heads, very long legs	Walking, swims with legs stretched out backwards	Pale brown, speckled
Skimmers Dragonflies/ *Anisoptera libellulidae*	Oval bodies, triangular heads, bulging eyes and legs not as long as with Corduliidae	Walking, Swims in short bursts, legs are held in one position	Pale, speckled or dark brown
Club Tails Dragonflies/ Gomphidae	Robust, approximately 40 mm in length with a wedge-shaped head and large bulbous eyes and thick antennae	Nymph's crawl on the substrate or propel themselves through the water by sucking water into their gills and pushing it out	Shades of black and light green
Caseless Caddisflies/ *Cheumatopsyche hydropsychidae*	Long slender body, tufts of gills on both sides of the body, two claws on last body segment and distinctive patterns or colorations on the head are useful for identification purposes	Crawling, using legs and claws on the last segment, float about in vertical position while abdomen is flicked from side to side	Pale, green or brown

River Jack Damselflies/ *Mesocnemis singularis*	Short, stout bodies, strong legs, three short gills with dark band across, gills swollen, hollow on the inside	Climbs on rocks or vegetation	Brown
Common Citril/ *Zygoptera Ceriagrion glabrum*	Slender bodies, three leaf-like gills, pointed tips and certain jointed gills	Slow moving amongst vegetation	Pale, green or brown
Malachites Damselflies/ *Zygoptera chlorolestidae*	Long, slim bodies, long antennae, three gills with rounded tips and a single dark band across each gill	Slow moving amongst vegetation	Pale brown
Spread winged Damselflies/ *Zygoptera lestidae*	Very long, very slim bodies, large wide heads, long very thin legs, three long gills and rounded tips curved	Slow moving amongst vegetation	Brown
Hippo Fly/ *Tabanus giguttatus*	Very large, one of the biggest horse flies	Flies from place to place using its wings to locate pan areas to lay its eggs in	Black body, sulphur yellow thorax with back wings and clear tips to them
Long-Jawed Spider/ *Desis formidabilis*	18-22 mm long, chelicerae 1/3 of body length, head smooth and shiny, abdomen covered in water repellent hair used to trap air bubbles legs long and strong	Rest in silk retreats in limpet shells or rock crevices	Head-dark red-brown, abdomen-grey

Figure C.1: Aquatic invertebrates found during the study and their related morphology

Appendix D

Google Earth Images

Gwalala



Figure D.1: Gwalala (6-4-2007)



Figure D.2: Gwalala (2-1-2010)

Likangwa



Figure D.3: Likangwa (8-15-2005)



Figure D.4: Likangwa (1-1-2008)

Magomugomu

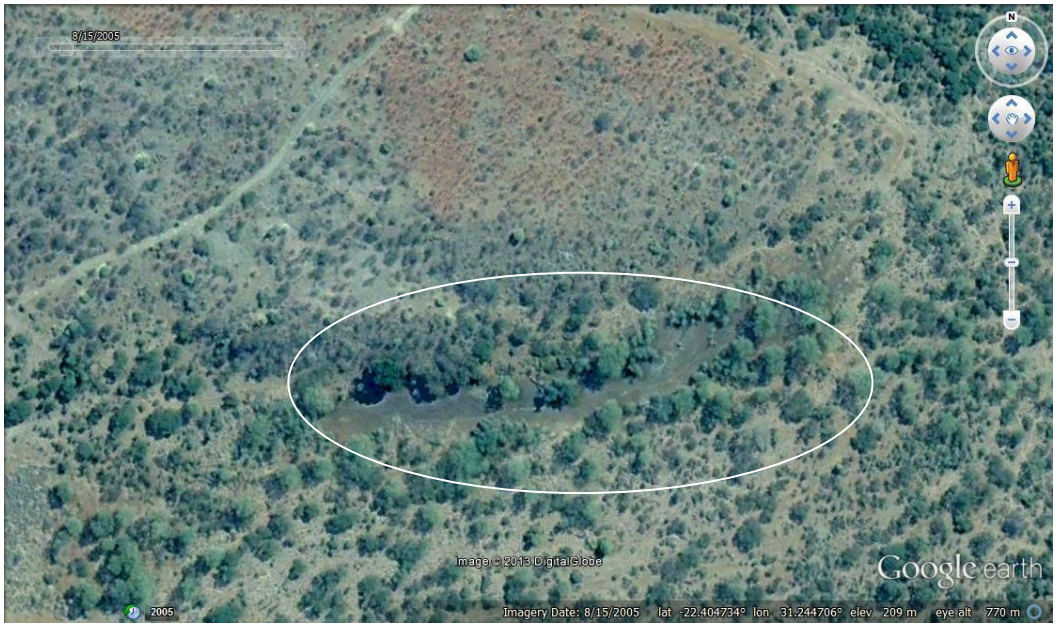

Figure D.5: Magomugomu (8-15-2005)



Figure D.6: Magomugomu (1-1-2008)

Makwadzi



Figure D.7: Makwadzi (5-14-2006)

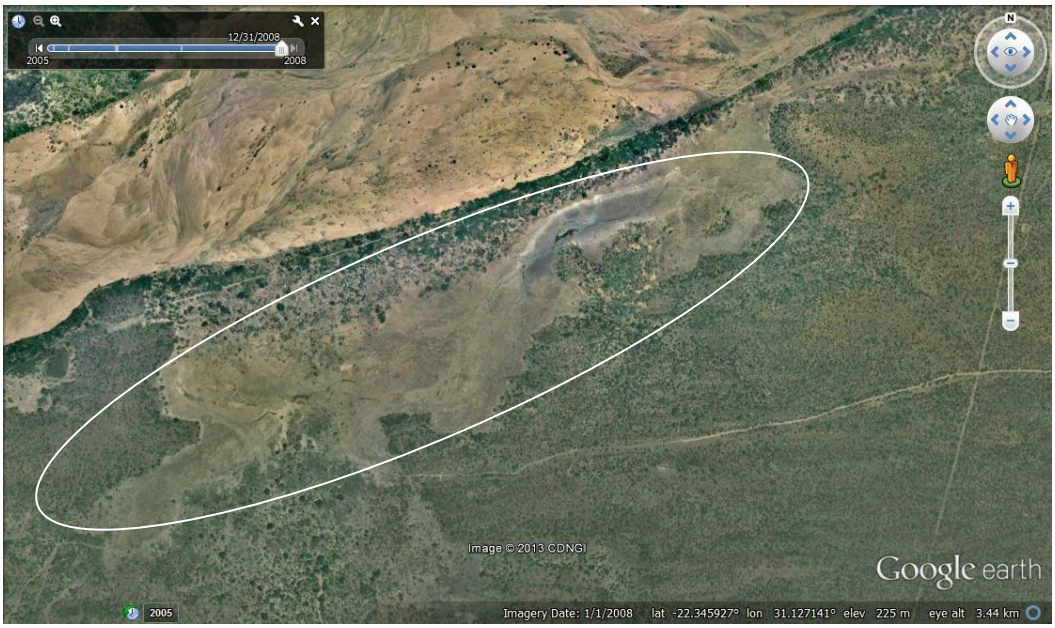

Figure D.8: Makwadzi (1-1-2008)

Mapimbi



Figure D.9: Mapimbi (8-15-2005)

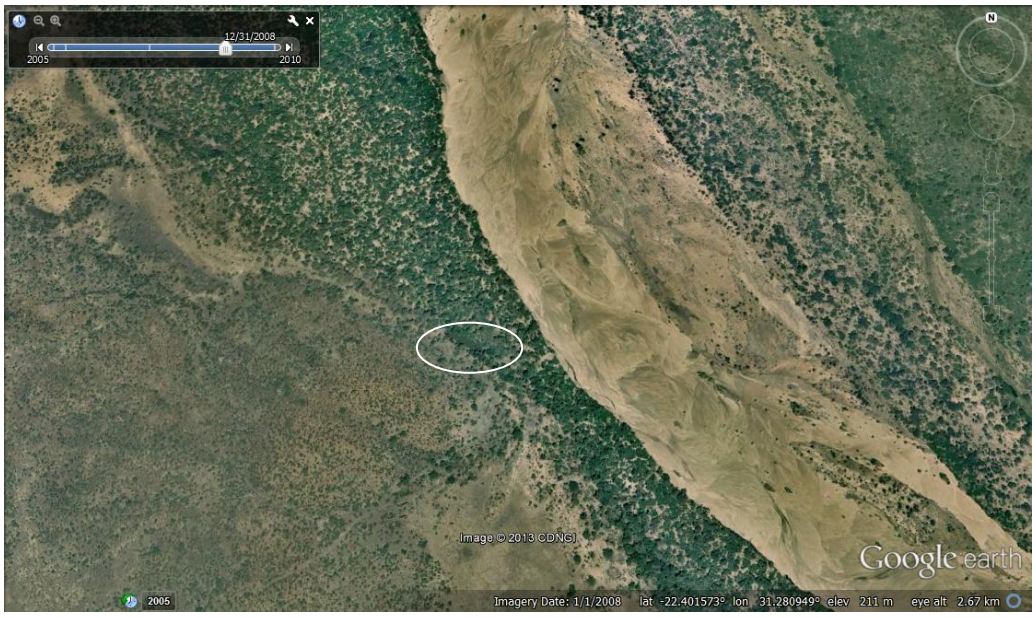

Figure D.10: Mapimbi (1-1-2008)

Nhlangaluwe



Figure D.11: Nhlangaluwe (8-15-2005)



Figure D.12: Nhlangaluwe (1-1-2008)

Nwambi



Figure D.13: Nwambi (6-04-2007)



Figure D.14: Nwambi (1-1-2008)

Appendix E

January 2013 Floods



Figure E.1: Makwadzi (January 2013)



Figure E.5: Nwambi (January 2013)

Appendix F

Table F-1: Tabulates the vegetation types found in March 2011 transects during ground truthing of the pans, Nwambi, Likangwa, Nhlangaluwe and Mapimbi by Zoghby (2011). Vegetation species that appear at all the pan systems listen in the table are identifiable by a grey shaded block

VEGETATION SPECIES LIST				
VEGETATION TYPE	**PANS**			
	NWAMBI	**LIKANGWA**	**NHLANGALUWE**	**MAPIMBI**
Guinea Grass *(Panicum maximum)*	**X**	**X**	**X**	**X**
Red Grass *(Themeda triandra)*		**X**	**X**	
Yellow Thatching Grass *(Hyperthelia dissoluta)*	**X**			
Spear Grass *(Heteropogon conturtus)*	**X**		**X**	**X**
Mopane Grass *(Enteropogon macrostachyus)*	**X**	**X**	**X**	
Carrot-seed Grass *(Tragus berteronianus)*	**X**	**X**	**X**	**X**
Cat's Tail *(Perotis patens)*	**X**		**X**	
Golden Bristle Grass *(Setaria sphacelata)*			**X**	**X**
Tassel Three-awn *(Aristida congesta)*	**X**	**X**	**X**	**X**
Ratstail Dropseed *(Sporobolus africanus)*	**X**	**X**	**X**	
Saw-tooth Love Grass *(Eragrostis superba)*	**X**	**X**		
Sand Quick *(Schmidtia pappophoroides)*	**X**			**X**

VEGETATION SPECIES LIST				
VEGETATION TYPE	**PANS**			
	NWAMBI	**LIKANGWA**	**NHLANGALUWE**	**MAPIMBI**
Gum Grass *(Eragrostis gummiflua)*			**X**	**X**
Blue-seed Grass *(Tricholaena monachne)*		**X**	**X**	
Lehmann's Love Grass *(Eragrostis lehmanniana)*	**X**	**X**	**X**	**X**
Common Reed *(Phragmites australis)*		**X**	**X**	
Broad-leaved Bristle Grass *(Setaria megaphylla)*		**X**	**X**	
Catstail Dropseed *(Sporobolus pyramidalis)*	**X**			
Curly-leaved Dropseed *(Sporobolus nitens)*	**X**	**X**	**X**	**X**
Pinhole Grass *(Bothriochloa insculpta)*	**X**		**X**	**X**
Stinking Grass *(Bothriochloa radicans)*	**X**			**X**
Finger Grass *(Digitaria eriantha)*	**X**	**X**	**X**	**X**
Feather-top Chloris *(Chloris virgata)*	**X**			
Bushveld Signal Grass *(Urochloa*	**X**	**X**	**X**	**X**

VEGETATION SPECIES LIST				
VEGETATION TYPE	**PANS**			
	NWAMBI	**LIKANGWA**	**NHLANGALUWE**	**MAPIMBI**
mosambicensis)				
Common Cluster Fig *(Ficus sycomorus)*	**X**			**X**
Shepherds-tree *(Boscia albitrunca)*	**X**			
Bushveld Albizia *(Albizia harveyi)*			**X**	
Broad-pod Albizia *(Albizia forbesii)*	**X**	**X**	**X**	**X**
Ana Tree *(Acacia albida)*	**X**	**X**	**X**	**X**
Umbrella Thorn *(Acacia tortilis)*		**X**	**X**	
Horned Thorn *(Acacia grandicornuta)*	**X**		**X**	
Knob Thorn *(Acacia nigrescens)*	**X**	**X**	**X**	**X**
Fever Tree *(Acacia xanthophloea)*	**X**	**X**	**X**	**X**
Sickle Bush *(Dichrostachys cinerea)*	**X**	**X**		
Mopane *(Colophospermum mopane)*	**X**		**X**	
Weeping Boer-bean *(Schotia brachypetala)*	**X**	**X**		**X**
Long-tailed Cassia *(Cassia abbreviata)*	**X**	**X**	**X**	**X**
African Wattle *(Peltophorum africanum)*		**X**	**X**	

VEGETATION SPECIES LIST				
VEGETATION TYPE	**PANS**			
	NWAMBI	**LIKANGWA**	**NHLANGALUWE**	**MAPIMBI**
Round-leaved Teak *(Pterocarpus rotundifolia)*	**X**	**X**	**X**	
Apple-leaf *(Philenoptera violacea)*	**X**	**X**	**X**	**X**
Nyala-tree *(Xanthocercis zambesiaca)*	**X**			**X**
Green Thorn *(Balanites maughamii)*			**X**	
Cape Ash *(Ekebergia capensis)*	**X**			
Natal Mahogany *(Trichilia emetic)*	**X**		**X**	**X**
Lembombo Ironwood *(Androstachys johnsonii)*			**X**	
Large Fever Berry (*Croton megalobotrys)*	**X**			
Tamboti *(Spirostachys africana)*	**X**	**X**	**X**	**X**
Angular-stemmed Spikethorn *(Gymnosporia heterophylla)*		**X**		
Buffalo Thorn *(Ziziphus mucronata)*	**X**			
White-leaved Raisin *(Grewia bicolor)*		**X**	**X**	
Sandpaper Raisin *(Grewia flavescens)*	**X**	**X**	**X**	**X**

VEGETATION SPECIES LIST				
VEGETATION TYPE	**PANS**			
	NWAMBI	**LIKANGWA**	**NHLANGALUWE**	**MAPIMBI**
Baobab *(Adansonia digitata)*			**X**	
Red Bushwillow *(Combretum apiculatum)*	**X**		**X**	
Russet Bushwillow *(Combretum hereroense)*	**X**			**X**
Leadwood *(Combretum imberbe)*	**X**			
Purple-pod Cluster-leaf *(Terminalia prunioides)*	**X**	**X**	**X**	
Magic Guarri *(Euclea divinorum)*			**X**	
Jackal-berry *(Diospyros mespiliformis)*	**X**	**X**	**X**	**X**
Sausage Tree *(Kigelia africana)*	**X**			**X**
Bushveld Gardenia *(Gardenia volkensii)*	**X**			
(Anisotes formosissimus)	**X**	**X**	**X**	**X**
(Anisotes rogersii)		**X**		**X**
Elephant's Ear *(Abutilon angulatum)*	**X**	**X**		**X**
Red Spikethorn *(Gymnosporia senegalensis)*	**X**	**X**		**X**
Woolly Caper-bush *(Capparis tomentosa)*				**X**

VEGETATION SPECIES LIST				
VEGETATION TYPE	**PANS**			
	NWAMBI	**LIKANGWA**	**NHLANGALUWE**	**MAPIMBI**
Tall Firethorn Corkwood *(Commiphora glandulosa)*	**X**			
Nine-awn Grass *(Enneapogon cenchroides)*	**X**	**X**	**X**	**X**
(Sporobolus consimilis)		**X**		
Broad-leaved Panicum *(Panicum deustum)*	**X**	**X**	**X**	**X**
Total	**51**	**38**	**44**	**35**

Appendix G

Table G-1: Representing minerals and ions effects on aquatic invertebrates

Minerals	Background Information	Occurrence	Effects on aquatic ecosystems	Organic	Inorganic
Mg (24) Magnesium	Magnesium is a product of the weathering of ferro-magnesium containing rocks and carbonate rocks. The solubility of magnesium is determined by pH, it is soluble at a pH level of 7.	Magnesium is a common cation in natural waters.	Little is currently know about the exact effects that magnesium has on aquatic invertebrates. It is found in high concentrations and is an essential nutritional ion to these organisms.		✓
Al (27) Aluminium	Aluminium is the third most abundant cation in the earth's crust. The cation is generally insoluble in the neutral pH range. Aluminium is considered a non-critical ion however; in larger quantities it can be harmful.	Aluminium can be found in soils and sediments by natural weathering and accelerated acidification processes. It can be found in surface waters and found naturally in waters made acidic by humic and fulvic acids. This ion is commonly emitted from coal.	Bio-available Aluminium in chronic/acute concentrations is toxic to aquatic organisms. However, the effects are uncertain and dependent on the organism and its life stage.		✓
K (39) Potassium	Potassium is released by the weathering of most common silicate materials and is commonly found in clay material. Potassium concentrations increase in the presence of run-off from agricultural lands using fertilizers.	Potassium is a naturally occurring ion in waters	Potassium is a scarce compound in most natural waters. This main metal is generally non-toxic to aquatic invertebrates.		✓

Minerals	Background Information	Occurrence	Effects on aquatic ecosystems	Organic	Inorganic
Ca (43) Calcium	Calcium is found in all waters as Ca^{2+} found dissolved in calcium mineral rich rocks.	Calcium occurs naturally in most water bodies together with magnesium, which is one of the main components of water hardness.	Calcium is vital in living systems as it provides organisms with important constituents for bony type skeletons.		✓
Cr (52) Chromium	Chromium is a scarce metal; as such the amounts found in aquatic ecosystems are very low. It appears as a yellow colour in an alkaline state and orange in an acidic state.	Elevated levels of chromium are due to industrial activity. Chromos compounds can be oxidized into chromic forms and by heat and the presence of organic matter.	Effects from Chromium are based on chronic and acute exposure. It can be toxic at different concentrations in different groups of aquatic organisms. Daphniidae or Water fleas are sensitive to chromium.		✓
Zn (66) Zinc	Zinc is a metallic mineral and an important micronutrient or cation for organisms as it forms part of various metalloenzymes. Zinc (II) is toxic to aquatic organisms in low concentrations.	Zinc occurs naturally in nature and can enter the aquatic ecosystem by weathering and erosion processes and industrial processes. Greatest concentrations occur in waters with a low pH, low alkalinity and a high ionic strength.	Zinc is an anion and is beneficial as a micronutrient however, in severe imbalances will cause death, i.e. Chronic and acute toxic effects.		✓
As (75) Arsenic	Arsenic is a metalloid cation which is toxic to marine and freshwater aquatic life. It is insoluble in water but many of its compounds are highly soluble. It can occur in many different states depending on the pH.	Arsenic occurs mostly in nature from the weathering of arsenic-containing rocks. Arsenic is readily absorbed onto sediments and suspended solids. Industrial pollution is also a cause of arsenic	The effects of Arsenic are uncertain and dependent on the organism and its life stage.		✓

Minerals	Background Information	Occurrence	Effects on aquatic ecosystems	Organic	Inorganic
	When arsenic combines with arsenide salts it becomes toxic to organisms.	being present in nature.			
Chloride	Chloride is generally associated with faecal contamination. In pristine water conditions chloride is lower than 10mg/l, with concentrations. Chloride is an essential component of living systems.	Chloride can occur in systems as a result of agricultural run-off, industrial sewage overflows and from the weathering of sedimentary rocks (rock salt deposits).	There are no toxic effects as a result of chloride ions on living systems. However, if there is an increase in TDS toxic effects could develop and growth can surface if the amount of chloride in the soil falls below 2ppm.	✓	
Nitrate	Nitrate is the bi-product of the oxidation of ammonia to nitrate. Nitrites are converted to nitrates by aerobic autotrophic bacteria. Nitrates are common in aquatic environments	Nitrates occur everywhere in soils particularly associated in areas with the breakdown of organic matter and eutrophic conditions. Increased levels of nitrate are associated with shallow ground water and agricultural run-off.	Increased nitrate levels result in excessive growth of algae. Increased algae lead to toxic conditions. Nitrate is otherwise not toxic.	✓	
Sulphate	Sulphate is the third most abundant anion. It is relatively soluble in water however; they do tend to have an accumulative effect.	Sulphate naturally occurs in surface waters as SO_4^{2-} ions. It is a result of the leaching process from sedimentary rock.	Sulphate is an essential anion for proteins. Sulphate is not toxic in low concentrations, however, in high concentrations if forms sulphuric acid, reducing pH levels affecting aquatic ecosystems.		✓
Nitrite	Nitrite is involved in the bacterially mediated process of	Nitrite can occur in inland waters in high concentrations where	Toxic effects occur as a result of impairment in the transport of oxygen to	✓	

Minerals	Background Information	Occurrence	Effects on aquatic ecosystems	Organic	Inorganic
	inorganic oxidation, nitrification and denitrification. Inland water concentrations are usually less than 0.1mg/l.	waters are exposed to polluted waters with nitrogen-containing wastes.	organisms. Exposure at low levels to nitrite can result in increased stress responses, lower growth, productivity and poor health.		
Phosphate	Orthophosphate are utilized widely by plants and converted into cellular structures. Phosphate is also the principle anion concerned with controlling eutrophication in aquatic ecosystems.	In nature, phosphate occurs mostly as inorganic. Phosphate is immediately available to aquatic invertebrates as orthophosphate. It also occurs on ions when absorbed onto suspended solids.	Phosphate is important in organisms for metabolism and is seldom found in high concentrations.	✓	
Sodium	Sodium is an alkali metal which reacts with water and is highly soluble. Sodium is essential for the maintenance of physiological functions.	Sodium occurs in an ionic form in plant and animal matter and is generally found in the environment as sodium chloride. Sodium concentrations found in water bodies in low rainfall areas are high.	In high concentrations, sodium can be highly toxic to aquatic invertebrates.		✓