Assessing water quality status by means of the Driver-Pressure-State-Impact-Response (DPSIR) model around Mapungubwe National Park, Limpopo Province, South Africa

by

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submitted in accordance with the requirements
for the degree of

MASTER OF SCIENCE

in the subject

ENVIRONMENTAL MANAGEMENT

at the

UNIVERSITY OF SOUTH AFRICA

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DECEMBER 2015

DECLARATION

Student Number**: 41228197**

I declare that **"ASSESSING WATER QUALITY STATUS BY MEANS OF THE DRIVER-PRESSURE-STATE-IMPACT-RESPONSE (DPSIR) MODEL AROUND MAPUNGUBWE NATIONAL PARK, LIMPOPO PROVINCE, SOUTH AFRICA"** is my own original work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references. I further declare that I have not previously submitted this work, or part of it, for examination at UNISA for another qualification or at any other higher education institution in South Africa.

________________________ _____________________

SIGNATURE **DATE**

(Mr. SM MATHETSA)

ACKNOWLEDGEMENTS

I am very much grateful to God the Almighty for providing me with strength and wisdom to conduct this study. Furthermore, I would like to acknowledge the positive role and contribution that was received from the following people and institutions.

- My Supervisor, Dr. Isaac T. Rampedi, thank you for the guidance, patience, and encouragement you provided during the course of the study;
- My Co-supervisor, Dr. Thomas Gyedu-Ababio, thank you for the comments and the contribution you have made during this research project;
- To my wife, Mbhoni and children, Tumelo and Nsuku. You have missed my company when my attention was on this research project and I thank you for your patience and understanding;
- Mapungubwe National Parks and Heritage Site for granting permission for the study to be undertaken at the site. In particular, Mr. Reckson Mashaba, I am very grateful for your patience and assistance during data collection, and the information sharing sessions;
- My friends (Tlhagala Ngoasheng, Dikeledi Baloyi, Nthoko Tlebjane, Sam Mahladisa, and Badidzi Mathetsa), for assistance during data collection;
- Mr. Matome Sekiba and Dr. Abel Ramoelo, thank you for your time and knowledge in assisting with maps;
- Agricultural Research Council – Institute for Soil, Climate and Water (ARC-ISCW) for conducting water analysis as well as providing rainfall data; and
- All participants and stakeholders who took their time to complete the questionnaire and share valuable information during this study.

DEDICATIONS

I dedicate this research to my late father, Johannes Mathetsa and mother Florah Mathetsa. Your inspirational words and the support you provided me with from my childhood have groomed me into the person I am today. This would not have been possible without your positive contribution.

ABSTRACT

Freshwater resources play an important role in the integrity of natural ecosystems as well as livelihoods of communities. However, South Africa has limited freshwater resources and many of this country's inland water streams are polluted as a result of human activities. Various legislations such as the National Water Act (Act No. 36 of 1998) were promulgated in order to address the issue of sustainable management of these resources. In this study, the Driver-Pressure-State-Impact-Response (DPSIR) model was applied to determine water quality challenges and threats in and around the Mapungubwe National Park and Heritage Site (MNPHS). This study area was declared as a heritage site by the United Nations Educational, Scientific and Cultural Organisation (UNESCO) and is also a national park.

Several research objectives were formulated and various methodologies were used to address the research aim. In determining land uses around the study area, site visits, visual inspections, literature reviews as well as the analysis of the national land use data were undertaken. Various land uses that have potential to negatively impact water quality were identified. In order to determine the status of water quality in the study area, water samples were analysed *in-situ* and in the laboratory. The results obtained showed that water quality was generally compliant with a few exceptions. For example, the concentrations of nitrates, microbes, and few metals such as mercury and beryllium were not complying with water quality guidelines and standards. Finally, in formulating the DPSIR framework for the MNPHS, a participatory approach was used where stakeholders were interviewed by means of a questionnaire. One of the most salient finding of the DPSIR modelling in this study was institutional weaknesses associated with the poor implementation of existing water related laws and regulations. The study also highlighted a few recommendations for further action and research.

Keywords: DPSIR, freshwater resources, water quality, land use, UNESCO, Mapungubwe National Park and Heritage Site.

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ARC - Agricultural Research Council

ARC - ISCW - Agricultural Research Council-Institute of Soil, Climate, and Water

CALS - Center for Applied Legal Studies at University of the Witwatersrand

CGS - Council for Geoscience

CSIR - Council for Scientific and Industrial Research

DEA - Department of Environmental Affairs

DEAT - Department of Environmental Affairs and Tourism

DWA - Department of Water Affairs

DWAF - Department of Water Affairs and Tourism

DWS - Department of Water and Sanitation

DPSIR - Drivers-Pressure-State-Impact-Responses

IDP - Integrated Development Plan

km - kilometres

km^2 – square kilometers

LEDET - Limpopo Department of Economic Development, Environment, and Tourism

mm - millimeters

MNPHS - Mapungubwe National Park and Heritage Site

SAHRA – South African Heritage Resources Agency

SANBI – South African Biodiversity Institute

SANParks – South African National Parks

SANS – South African National Standards

UNESCO – United Nations Educational, Scientific and Cultural Organisation

CHAPTER 1
INTRODUCTION AND RESEARCH BACKGROUND

1.1. INTRODUCTION AND BACKGROUND

The water system is one of the most essential components of all natural ecosystems and is indispensable in various economic sectors such as agriculture, mining, and domestic use. Without water, neither social and economic development nor ecological processes are sustainable (Fuggle and Rabie, 2009). South Africa is a semi-arid country with limited freshwater resources, as the mean annual precipitation is 497 mm, and is thus below the world average of 860 mm (Ashton *et al*., 2001; Germs *et al.*, 2004; van Rensburg *et al.*, 2011).

Despite such limitations, water resources in South Africa, whether surface or groundwater, are subjected to massive amounts of pollution as a result of human activities such as agriculture, mining, poor sanitation measures and industries. This creates an environmental problem which threatens water quality, water security and long-term water sustainability (Department of Water Affairs and Forestry [DWAF], 2000; Department of Environmental Affairs and Tourism [DEAT], 2006; Centre for Scientific and Industrial Research [CSIR], 2010; Dabrowsky and de Klerk, 2013). The pollution can further extend across states where there are internationally shared water resources such as the Limpopo, Orange and Crocodile Rivers. The impact could also affect areas of ecological importance such as wetlands, national parks, heritage sites and protected areas (Vos *et al.*, 2010).

One way to understand the ramifications of environmental problems associated with water pollution in ecologically sensitive areas is to make use of the so-called Driver-Pressure-State-Impact-Response (DPSIR) model. This model emerged around the late 1990s with the goal of assisting in determining environment-related indicators in a coherent manner (Marsili-Libelli *et al*., 2004; Borja *et al*., 2006; Tscherning *et al*., 2012). Neves (2007) indicates that the DPSIR model can be used as a basis for analysis of ecosystem–society interactions, allowing for the main drivers to be determined for a specific area.

As shown in Figure 1.1, the DPSIR framework provides an analysis of indicators needed to enable feedback to policy-makers on environmental quality and the resulting impact of political choices made or to be made in future (Kristensen, 2004). In many studies, this framework has been applied to characterise and improve an understanding of cause–effect relationships between environmental and human activities (Elliot, 2002; Borja *et al*., 2006; Meybeck *et al*., 2007; Odontsetseg *et al*., 2009; Benini *et al*., 2010; Pinto *et al*., 2011; Kagalou *et al*., 2012; Tscherning *et al*., 2012).

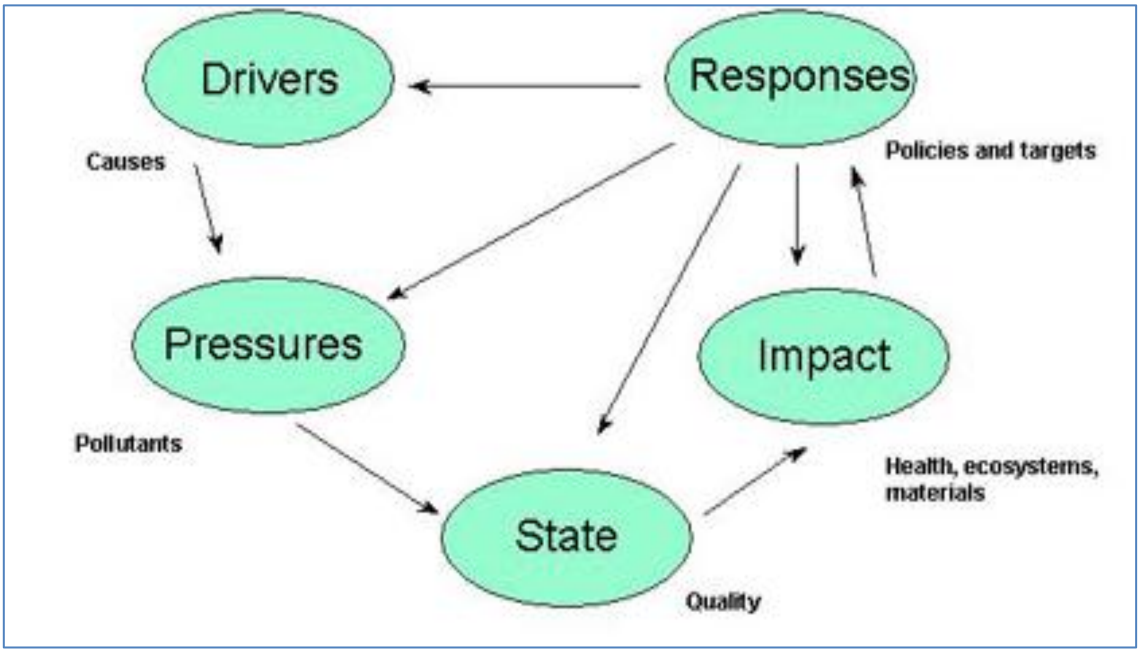


Figure 1.1: The DPSIR linkage.

Source: Kristensen *(*2004).

Specifically, DPSIR model is comprised of five different components. ‘D’ represents driving forces comprised by socio-economic needs that require the existence of a given economic activity. ‘P’ stands for the various pressures whose intensity depends on nature and extent of driving forces and also on other factors which shape human interaction with ecological systems. ‘S’ highlights the state of environment as pressure is exerted on it. ‘I’ is for impact related to ecosystems and human health affected by state modifications. ‘R’ stands for responses which lead to changes in the DPSIR chain (Caiero *et al*., 2004).

Studies which have used DPSIR have shown that this model can provide a vital tool for determining specific land uses within catchments, their socio-economic and environmental interactions, guidance and suggestions for sustainable land use and environment-friendly measures for policy adoption (Bidone and Lacerda, 2004; Karaogernis *et al.*, 2004; Marques *et al.*, 2009).

1.2. RESEARCH AIM AND OBJECTIVES

The main aim of this study was to apply the DPSIR model in identifying and characterising cause–effect relationships involved in the quality of surface water systems in and around the Mapungubwe National Park and Heritage Site (MNPHS) in the Limpopo Province. In order to address the aim of this study, the following research objectives were formulated:

- To determine land uses that can potentially influence water quality changes in and around the MNPHS;
- To assess the current water quality status in the streams around the study area relative to several water quality standards and guidelines;
- To provide an outline within a DPSIR framework that summarises the physio-geographical conditions impacting receiving river systems, the socio-economic drivers and related pressures that negatively affect the hydro-physio-chemical regimes in and around the MNPHS; and
- Proposes measures that can be taken in order to ensure freshwater resource protection around the study area.

1.3. RESEARCH QUESTIONS

Few questions arise with regard to applying the DPSIR modelling at the MNPHS and assessing the impact that various land uses may have on the water quality. The research was guided by these key questions. The first question is centred on the identification and the determination of specific land use activities that may potentially lead to changes in the quality of surface water in the study area. This question is crucial in addressing the first objective of the study. The second question is: what is the current status of water quality in and around the chosen study area? The second objective addresses this question. The third question, which is addressed by objective three, can be stated as follows: can the DPSIR model assist in the assessment of water quality of various water resources in the study area?

1.4. RATIONALE, MOTIVATION AND SIGNIFICANCE OF THE STUDY

In South Africa, there are 8 protected areas declared as heritage sites. Such designation is based on their historical, natural or cultural value and consequently their management is a top priority (DEAT, 2006). Mapungubwe National Park (MNP) is one of these United Nations Educational, Scientific and Cultural Organisation (UNESCO)-declared heritage sites. The National Heritage Resource Act (Act No.25 of 1999) was established in order to formulate priorities in managing heritage sites. This has led to the formation of the South African Heritage Resources Agency (SAHRA) whose main mandate is to promote and coordinate the protection of such sites and related heritage resources.

Not only is the MNP a national heritage site because of its ecological characteristics and natural landscape, but the study area is also defined as a national park and is managed in terms of the National Environmental Management: Protected Areas Act (NEMPAA) (Act No.57 of 2003) and the National Environmental Management: Biodiversity Act (NEMBA) (Act No.10 of 2004). NEMPAA's main objective is to ensure that the areas described as such are fully conserved or protected against any human activity that might interfere with their unique characteristics. On the other hand, NEMBA aims at ensuring that there is adequate management, conservation, and sustainability of the country's biophysical characteristics.

As shown in Figure 2, the park is located along the Limpopo River at the confluence of the Shashe and Limpopo Rivers (Götze *et al.*, 2008). The Limpopo River drains an area of nearly 413,000 km^2 and is the main border between South Africa, Botswana, Zimbabwe and Mozambique (Food and Agricultural Organization of the United States [FAO], 2004). It is an internationally shared water resource, with its system starting further away upstream from the Kruger National Park (KNP) into Mozambique.

As a result of limited availability of freshwater resources and the role water plays in the natural and human environment, South Africa has introduced a number of legislations and regulations in order to improve and optimise the management and protection of water resources. While the Water Services Act (WSA) (Act No. 108 of 1997) focuses on the access to basic water supply and the right to basic sanitation and an environment that is not detrimental to human health, the National Water Act (NWA) (Act No.36 of 1998) recognises water scarcity in South Africa and seeks to promote the management of water resources in an equitable and sustainable manner.

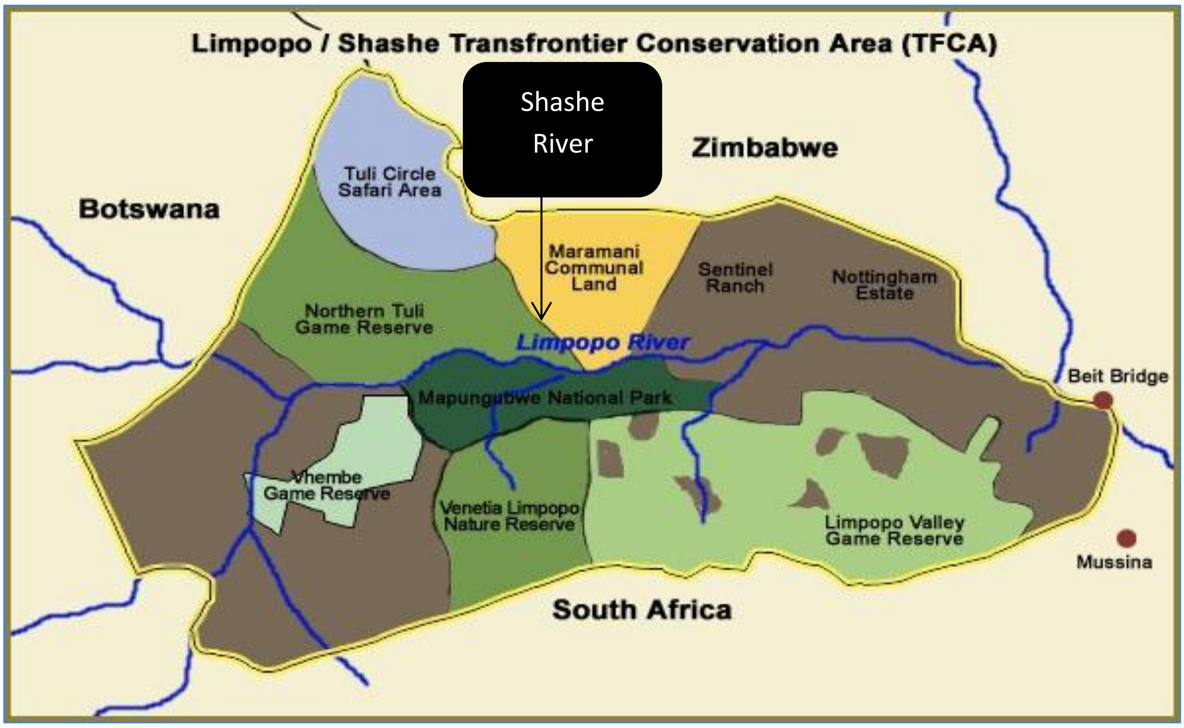


Figure 1.2: Locality of the Mapungubwe National Park along the Limpopo River.

Source: SANParks (2015).

Due to its ecological state and cultural importance, sustainable management of the park and its surrounding rest upon compliance with various international treaties, legislations, regulations and by-laws. The surrounding area of the MNP is open to different land uses such as human settlements, agriculture, tourism and mining (Ashton *et al.*, 2001; Carruthers, 2006; Sinthumule, 2014; South African National

Parks [SANParks], 2015). The recent development pertaining to the issuance of a mining permit and commissioning of the operation adjacent to the park was very controversial. Hence, it was criticised by adjacent landowners, conservation authorities, Non-Governmental Organisation (NGO)'s, and certain government entities – primarily because such activities are known to generate highly significant environmental impacts with great potential for environmental degradation (Berry and Cadman, 2007; Sievers, 2011; Henning and Beater, 2014; Peace-Park, 2015; Centre for Applied Legal Studies [CALS], 2015). Because of these environmental management concerns, a movement called Save Mapungubwe Coalition was eventually formed in an attempt to prevent the mining activity from taking place. While mining is regarded as an important activity in terms of promoting socio-economic development, the movement maintained that the area would be environmentally degraded as the mining activities progress (Save Mapungubwe, 2012; CALS, 2015). Thus, these concerns prompted the need for an understanding of the human–environmental interactions in this ecologically sensitive and culturally important area.

According to Kristensen (2004), the determination of water quality may help in the identification of possible interactions between man and the environment, and also assist in providing appropriate management plans and interventions that have the potential to promote sustainable development. Some studies have applied the DPSIR framework to promote an understanding of the environmental state of river systems, along with associated human pressures and impacts (Skoulidikis, 2009; Kagalou *et al*., 2012). DEAT (2006) has applied the DPSIR model on its State of Environmental Report (SOER). Walmsley *et al.* (2001) explain that, in South Africa, there is limited research regarding the identification and characterisation of socio-economic drivers, anthropogenic pressures and impacts on the environmental state of vulnerable river systems as well as associated management responses using the DPSIR model. Using the ecologically sensitive MNPHS as the focus area, this study applies the DPSIR model in trying to understand stresses and possible impacts on the quality of surface water resources.

1.5. LIMITATIONS OF THE STUDY

Although there is linkage between water quality and water flow, only the quality of water was considered in order to fulfil the objectives of this study. The streams around the study area only flows during the rainfall season, therefore water quality monitoring was limited to only Limpopo River. There was no sufficient baseline (or previous) information available on the water quality of the study area that could be used to compare with the current water quality. Focus groups discussions were limited to only three governmental departments owing to the unavailability of different stakeholders at the same time and place. The conflicts that emerged between various stakeholders around the study area due to commissioning of the mining activity had also prevented various stakeholders from taking part in the study.

1.6. STRUCTURE OF THE DISSERTATION

This dissertation is organised into eight chapters. Chapter 1 provides an introduction to the research aim and objectives. The chapter also gives the rationale for the study as well as motivation for the selection of the study area. Lastly, limitations for the study are explained.

Chapter 2 reviews the literature relevant to the research aim. The review covers sustainability concepts, integrated water resource management, the DPSIR model and its application towards a better understanding of the causes of environmental degradation. In addition, water resource management and legal requirements are examined. Chapter 3 describes and characterises the study area. This includes the bio-physio-chemical characteristics of the Mapungubwe National Park and the surrounding environment, land uses and socio-economic interactions with the park.

The methodology applied in addressing the research aim and research objectives is discussed in Chapter 4. The results of the research are presented in Chapters 5, 6 and 7. The same chapters also provide discussions of the results. Chapter 8 entail conclusions and recommendations for further studies.

CHAPTER 2
LITERATURE REVIEW

2.1. INTRODUCTION

This chapter provides a literature review of aspects that are related to the research aim and objectives. It includes an overview of the concepts of sustainability, sustainable water resource management, and principles of water quality management. Furthermore, a review of South Africa's environmental legislation associated with management of various activities surrounding the study area, and the application of the Driver-Pressure-State-Impact-Response (DPSIR) model in addressing water quality management in a sustainable manner are also examined.

2.2. THE CONCEPT OF SUSTAINABILITY

The exponential increase in the world's population, growing sophistication of its needs, activities for the maintenance of present-day lifestyles, and the process of industrialisation, have not only resulted in increased pressure on and depletion of the earth's natural resources, but have also caused increased generation of enormous quantities of waste (DWAF, 2001; Chilundo *et al.*, 2008; Fuggle and Rabie, 2009). This has, therefore, called for an increased focus on conserving and protecting natural resources in a sustainable manner. The concept of sustainability, which is a state of equilibrium between social, economic and environmental factors, was introduced in this regard. As indicated in Figure 2.1, the aim of sustainable development is to integrate and maintain balance between social, economic and environmental goals. This concept was adopted and further promoted in 1992 at a United Nations Conference held in Rio de Janeiro, Brazil (DWAF, 2004). In this Conference, 27 Principles, which are known as the Rio Declarations, were adopted in order to promote sustainable balance between the demands of human beings and the carrying capacity of the environment without compromising each other. Principle 4 of the Rio Declarations states that sustainable development should be achieved in such a manner that environmental protection forms an integral part of the development processes and cannot be considered in isolation from them (United

Nations [UN], 1992; Kubiszewski and Cleveland 2012). DWAF (2000) further explained that the overriding objective of sustainability is to infuse and integrate environmental protection goals into planning, implementation and decision-making processes of socio-economic development. Equilibrium can be achieved when, through economic development, there is improvement in the social wellbeing of human beings without further degrading the already pressurised natural resources such as water, biodiversity and land.

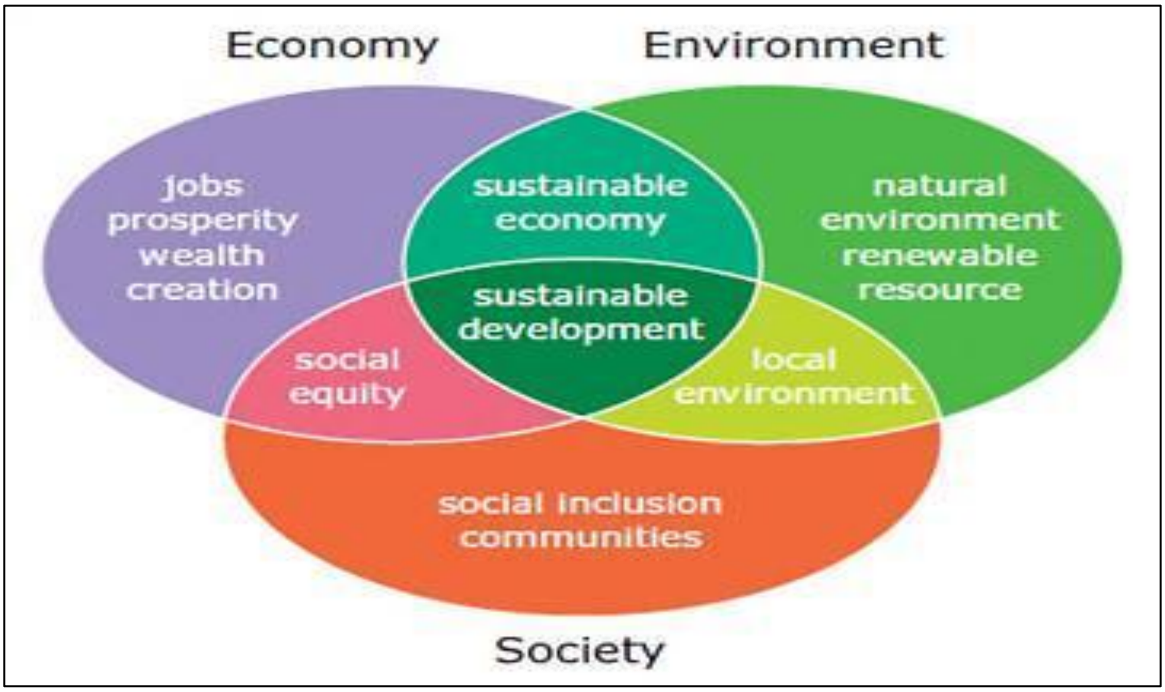


Figure 2.1: The three pillars of sustainability.

Source: Jivanji (2013).

In promoting sustainable development, implementation of effective environmental management plays a crucial role in meeting socio-economic and ecological needs. This includes proper management of water resources, air, land, and soil. According to Walmsley *et al.* (2001) and as advocated by Chapter 18 of Agenda 21, sound water resource management remains one of the key components of sustainable development. Knüppe (2011) maintains that sustainability in water resource management is attained when water resource systems are managed in a way that satisfies the changing demands put on them, now and in the future, without degradation.

2.3. WATER RESOURCE MANAGEMENT IN SOUTH AFRICA

2.3.1. Brief overview of water resources in South Africa

South Africa has limited availability of freshwater resources (DEAT, 2006; Knüppe, 2011). Several factors such as a semi-arid climate, water pollution and international obligations, limit the amount of water that this country has at its disposal (CSIR, 2010). This is further worsened by the pressure that long-term population growth, high evaporation rates that exceeds rainfall and economic development are placing on the country's water resources (Hedden and Cilliers*,* 2014). The financial, human and ecological impacts of global and local changes to climate are already evident in South Africa, particularly where water resources constraints are experienced either in quality, quantity, or both (Knüppe, 2011).

The challenge surrounding water resources is not only experienced in South Africa but extends to other African countries. Hughes *et al.* (2011) indicates that current stress on water in many areas of Africa is likely to be enhanced by climate variability and change. Increases in runoff in East Africa (possibly floods) and decreases in runoff, possibly with the risk of increased droughts) are projected by the 2050s. As previously mentioned, current water stresses cannot be linked only to climate variations. Issues of water governance and water-basin management must also be considered in any assessment of water resource management in Africa, especially in areas where shared water resources are of environmental management concern. South Africa shares various water resources such as the Limpopo and Orange Rivers basins with other African countries. The Limpopo River Basin is impacted by various anthropogenic factors such as mining and lack of proper governance from any of the four countries sharing this basin (Botswana, South Africa, Zimbabwe, and Mozambique). This could significantly have cumulative impacts on other users and on aquatic ecosystem health and integrity (Ashton *et al.*, 2001).

2.3.2. Water resource quality

In recent decades, there has been growth in water resource impairments in many parts of the world due to demand and degradation in water quality (Mahumani, 2009;

Song and Frostell, 2012). Chilundo *et al.* (2008) further explain that surface water pollution with toxic chemicals and excessive nutrients, resulting from a combination of transboundary transport, storm water runoff, point and non-point leaching and groundwater discharges has become an issue of environmental concern worldwide. Increased urbanisation and industrialization has been one of the main drivers of these pollution challenges.

This has also been the case even in South Africa where water resource quality is negatively impacted to the point of irreversible deterioration (DWAF, 2004; DEAT, 2006, Walsh and Wepener, 2009; CSIR, 2010; van der Laan *et al.*, 2012). Such deterioration does not only limit freshwater availability but has a harmful impact on aquatic ecosystems and ecologically important resources such as wetlands and aquifers. It also has the potential to affect the future sustainability of economic developments. According to DWAF (2004), there should be sufficient water of suitable quality to meet South Africa's goal of promoting economic development and poverty alleviation as well as protecting the integrity of aquatic ecosystems. In this manner, water resource quality may also be used as an indicator reflecting progress towards the achievement of sustainable development within catchment management areas (Walmsley *et al.*, 2001). Chilundo *et al.* (2008) contend that the measurement of physical, chemical, and biological parameters play a vital role in characterising the status of the streams or rivers in a particular region.

Even though water quality deterioration could be attributed to natural causes such as underlying geology, biological processes, atmospheric deposits and evaporation losses, anthropogenic activities such as agriculture, mining, industrialisation, and urbanisation may significantly alter the water quality of streams (DEAT, 2006; Dabrowsky and de Klerk, 2013, Hedden *et al.*, 2014). Water quality deterioration has been widely noted in some parts of the country's major resources where a range of manmade activities are widely practised. An example is the Highveld region in the Mpumalanga province where studies conducted by Dabrowsky and de Klerk (2013) and Hedden *et al.* (2014) further indicate that multiple impacts of activities such as agriculture, mining and power generation exposes the natural environment and water quality resources to environmental degradation and severe pressure. Similarly, the

Vaal, Lephalale and Waterberg areas also experience challenges in water quality due to the effects of these multiple practices.

Challenges such as reduced water supply due to water pollution, inefficiencies in water management practices, poor governance, having water unaccounted for as well as lack of infrastructure maintenance, have to be addressed effectively (Palmer *et al.*, 2004; DWA, 2013). As a result, there is a need for applying an integrated water resource management approach. With integrated water resource management, all factors or activities that have potential to influence water quality in a catchment should be taken into consideration when assessing and managing the water quality status. This involves a practice-based understanding of policy, the role of leadership and communication, effective governance, collective action and regulation, self-regulatory measures and feedback to all involved (Pollard and du Toit, 2011).

2.3.3. Principles of water quality management

Water quality may be regarded as the concentrations of desirable or undesirable constituents in water. It includes physical (temperature, turbidity, total suspended solids, suspended particulate organic matter), chemical (pH, electrical conductivity, sulphates, nitrates, and heavy metals such as potassium and mercury) and biological (bacteria such as *E. coli*, *coliform*,) parameters in water, of which variable levels will decide fitness for its intended purpose (DWAF, 1996a; Palmer *et al.*, 2004; WHO, 2008; Chilundo *et al.*, 2008; Matowanyika, 2010). For example, the quality of water required for drinking purposes will not be the same as the quality of water required for irrigation. Similarly, the required quality of water used industrially cannot be the same as the quality required for recreational purposes. In the National Water Act (Act No. 36 of 1998), South Africa has defined the country's main water users as agricultural, domestic, recreational, industrial, and aquatic ecosystems. Poor water quality could directly or indirectly have impacts on various water users in a negative manner. Poor water quality does not only influence users, but it can also have financial implications in the form of treatment costs to make it suitable for a particular use.

Human factors and natural processes could influence water quality of freshwater resources. In South Africa, some of the anthropogenic activities that impact water quality negatively include mining, power generation, agriculture, and poor management of wastewater treatment infrastructure (CSIR; 2010; Matowanyika, 2010; DWA, 2012; Dabrowsky and de Klerk, 2013). Also, pollution processes such as acidification, eutrophication, salinisation, metal contamination and sedimentation all contribute towards water pollution (DWAF, 2001; CSIR, 2010). Apart from manmade activities, water quality could be affected by natural factors such as geology, soil erosion, rock weathering, and atmospheric precipitation (Germs *et al.*, 2004). Pollution transportation mechanisms such as runoff, transboundary pathways, point and non-point discharges are likely to dispense pollutants from one point to another.

Water chemistry takes three forms namely, physical, chemical, and biological – in which abundances or lacks in any parameter can change the state of water quality sources. These are further defined as follows:

2.3.3.1. Physical characteristics

- *Temperature*

According to Palmer *et al.* (2004), various hydrological, climatic and structural features of a particular region, catchment or river determines the thermal characteristics of surface water. All water users have their preferences in terms of temperature requirements which are defined as how hot or how cold the water is. Palmer *et al.* (2004) further mentions that high temperature reduces oxygen solubility which may cause certain chemicals in water to be toxic. This could have a negative impact on most aquatic ecosystems. Some of the anthropogenic activities that could have influence on increased water temperatures include discharges from thermal activities, removal of riparian vegetation covers, inter-basin transfers, and heated return flow of irrigated water (DWA, 1996a).

- *Turbidity, total suspended solids (TSS), and suspended particulate organic matter*

Turbidity refers to the scattering of light in a liquid medium due to suspended liquid matter (Porteous, 2000). The amount of suspended solids or materials in water has an impact on the transparency of water and this could affect the penetration of light. Lack of sufficient light can influence the survival of aquatic organisms such as fish and plants (Palmer *et al.*, 2004; DWAF, 1996a). Manmade activities such as industrial processes, discharges from sewage treatment facilities and construction processes have the potential to increase the concentrations of TSS.

2.3.3.2. Chemical characteristics

- *pH*

The state of acidity or alkalinity of water depends on the presence of hydrogen (H^+) and hydroxyl (OH^-) ions. A pH value below 7 indicates that water is acidic, therefore, high concentration of H^+ can be expected meanwhile a pH value of above 7 represents alkaline water with high concentrations of OH^- . According to DWAF (1996a), when pH is 7, the presence of hydrogen and hydroxyl ions is equal, making water electrochemically neutral. Palmer *et al.* (2004) comment that even though geological and atmospheric influences determine the pH of natural water, pH may be low due to acidification from acid mine drainage (AMD), industrial discharges and precipitation. Unbalanced pH in water does have a negative influence on aquatic species and other users depending on that particular water resource.

- *Electrical conductivity (EC), salinity, and total dissolved solids (TDS*)

EC is the ability of water to conduct electricity while TDS indicates the amount of materials that are dissolved in water and these can be organic or inorganic, ironized or unionized (Palmer *et al.*, 2004). Salinity indicates the saltiness of water. Matowanyika (2010) notes that EC increases as the presence of ions such as bicarbonate, calcium, chlorides, sulphates, carbonates and magnesium increases, thus giving water a salty taste and having a negative impact on all water consumers. Pollution sources such as industrial discharges, mining, and agricultural activities could lead to high TDS and EC in water.

- *Dissolved oxygen*

The maintenance of adequate dissolved oxygen concentrations is critical for the survival and functioning of aquatic biota as it is required for respiration processes (Palmer *et al.*, 2004; WHO, 2008). While its presence in water can be through natural diffusion of atmospheric oxygen, its depletion can be caused by factors such as amount of suspended materials in water, presence of oxidable organic matter, resuspension of anoxic materials through floods or dredging, and these can lead to an increase in toxic materials such as ammonia, cadmium, cyanide, and zinc (DWAF, 1996a).

- *Nutrients*

Three main nutrient types found in water are nitrogen, phosphorus, and potassium. Although these nutrients produce algae which provides food for aquatic ecosystems like fish, excess amount of nitrogen (in the form of nitrate or ammonium) or phosphorous (in the form of phosphate) in water can result in the over-production of plankton. Planktons are known to be consumers of large amounts of oxygen in water, leaving other oxygen-dependent organisms stressed (Palmer *et al.*, 2004). Sewage effluent is regarded as the biggest carrier of nitrogen in water.

- *Biocides, herbicides or pesticides*

Biocides (commonly referred to as agro-chemicals) are used in agricultural activities, mainly to regulate the presence of insects in crops. They are commonly known by having long chains of chemical structures which are not easily breakable. Their presence in water becomes hazardous to aquatic ecosystems. Organochlorine insecticides (such as dichlorodiphenyltrichloroethane [DDT] and dieldrin) are the most hazardous with respect to the natural environment and their use has been banned in many countries (Palmer *et al.*, 2004; Shabalala and Combrinck, 2012).

- *Trace metals*

Metals such as iron, magnesium, zinc, copper, chromium, nickel, arsenic, cobalt and selenium are present at low concentrations in water and play a role in metabolic processes of living organisms. However, their presence in high concentrations could lead to toxicity. Sources of trace metals include geological weathering, atmospheric sources, industrial effluents, agricultural runoff and AMD (Palmer *et al.*, 2004).

2.3.3.3. Biological characteristics

Human and animal wastes from the sewage discharges can be carried to water resources and they are sources of pathogenic or disease-causing bacteria and viruses (du Plessis *et al.*, 2014). The disease-causing organisms are accompanied by other common types of non-pathogenic bacteria found in animal intestines, such as faecal coliform bacteria, *Enterococci* bacteria, and *Escherichia coli, or E. coli* bacteria. These are not usually disease-causing agents themselves but their high concentrations in water suggest the presence of disease-causing organisms. *Faecal coliform*, *Enterococci*, and *E. coli* bacteria are used as indicator organisms highlighting the probability of finding pathogenic organisms in water resources (Germs *et al.*, 2004; Netshiendeulu and Motebe, 2012).

2.3.4. Status of water quality in South Africa

Various studies have indicated that water quality around some major rivers in the country has significantly deteriorated due to impact of different development activities (Vos *et al.*, 2010; Pollard and du Toit, 2011). This poses serious health risks to human beings and ecosystems while decreasing the water's ability to be used in different sectors such as agriculture, recreational, and industrial settings. An example could be drawn from a study by Durand *et al*. (2010) which highlights recent water quality challenges associated with AMD around the Witwatersrand basin as a result of the adverse effects of gold mining on nearby communities and on the ecologically sensitive RAMSAR site, Blesbokspruit. These impacts also threaten the survival of the UNESCO heritage site known as the Cradle to Humankind situated near Krugersdorp on the borders of Gauteng and the North West provinces (as indicated in Figure 3.1). Similarly, significant water quality deteriorations are currently being experienced on the Olifants River, located at the Highveld region upstream of the Kruger National Park where activities such as mining, agriculture, and sewage wastewater treatment are taking place (CSIR, 2010). Dabrowsky and de Klerk (2013) further explains that this river, despite supporting key sectors such as agriculture and power generation, remains one of the most polluted rivers in the country. South Africa has developed different water quality guidelines as per sector use where water quality targets ranges were set for different parameters.

2.3.5. Water quality of the study area

In terms of water management, the study area for the current research forms part of Limpopo River basin. A study conducted by Ashton *et al.* (2001) along this river basin indicates that water quality is relatively good and is usually fit for most designated uses throughout the length of the Limpopo River and its tributaries. However, there are limited water quality studies or information available on the specific study area. The available water quality results obtained from DWAF are relevant for the 1993 - 2007 periods and are shown in Table 2.1. These results were compared with drinking water quality standards as recommended by SANS 241 (2011).

Table 2.1: Water quality results upstream and downstream of the study area.

Parameter	Drinking water quality standards	P1	P2	P3
Ca (mg\L)	<150	16.4	23.45	32.21
Cl (mg\L)	<200	9.6	21.05	80.6
DMS		141	204	411
EC (mS\	<150	19	31	59
F (mg\L)	<1	0.33	0.26	0.32
K (mg\L)	<50	3.68	3.27	4.9
Mg (mg\L)	<70	5.26	9.9	20.16
Na (mg\L)	<200	9.12	16.83	57.88
NH4 (mg\L)	<1	0.03	0.04	0.07
PO4 (mg\L)		0.05	0.03	0.04
SAR		0.51	0.75	1.76
Si (mg\L)		5.36	7.33	4.55
SO4 (mg\L)	<400	10.08	13.27	36.41
Talk		70.08	242.4	145.4
Turbidity	<1	183	92.98	89.56
NO3+NO2	<0.9	0.18	0.53	0.23
pH	5.0-9.5	8.02	7.21	8.1

Source: DWA (2015).

The following results were produced by DWA on the following points and times:

- Point 1: Limpopo River at PontDrift (1994)
- Point 2: Limpopo River at Beit Bridge (1980–1993)
- Point 3: Limpopo River Downstream of Beit Bridge (1993–2004)

The results indicate that the water quality measured upstream and downstream of the study area does comply with most parameters as recommended by SANS 241 (2011) drinking water quality standards. Although these results show generally acceptable water quality, it could not be concluded that the water quality is fine because there have been land uses changes and developments around the MNPHS.

2.4. LEGISLATION INVOLVED IN INTEGRATED ENVIRONMENTAL MANAGEMENT IN MAPUNGUBWE NATIONAL PARK

The MNPHS has both natural and anthropogenic activities taking place in its surroundings. Among its various natural features are unique cultural landscapes, variety of plants and animals, and a shared water resource between four countries

(South Africa, Botswana, Zimbabwe, and Mozambique). Human activities such as mining, agriculture, and tourism are being practiced around this site (Götze *et al.*, 2008; Jivanji, 2013; Sinthumule, 2014; CALS, 2015). The site is governed by different legislations in the country due to its national importance and unique characteristics. Table 2.2 shows major characteristics of the site together with the legislation that regulates it. The park has also subscribed to the Greater Mapungubwe Transfrontier Conservation Area (GMTCA). This treaty was formed in order to promote conservation and sustainable use of natural resources between the areas that are bordered by the Limpopo River. These countries are Botswana, Zimbabwe, and South Africa (Peace-Park, 2015).

Table 2.2: Characteristics and different environmental legislations involved in management of the park.

Characteristics	**Legislation**
UNESCO-declared heritage site owing to its cultural landscapes	South African Heritage Resources Act (Act No.25 of 1999)
Protected area owing to its significance in biodiversity	National Environmental Management Act (Act No.107 of 1998); National Environmental Management: Biodiversity Act (Act No.10 of 2004); National Environmental Management: Protected Areas Act (Act No.57 of 2003)
Water management	National Water Act (Act No.36 of 1998)
Various agricultural activities taking place along the Limpopo River and control of alien species	Conservation of Agricultural Resources Act (Act No.43 of 1983)
Mining activities occurring along the park	Minerals and Petroleum Resources Development Act (Act No.28 of 2002)

2.4.1. The Constitution of South Africa (Act No.108 of 1996)

Over the years, various international initiatives aimed at protecting the ecology against further degradation while promoting socio-economic developments have emerged. Agreements such as the Convention on Wetlands (known as RAMSAR) in 1975, the World Conservation Strategy in 1980, the Brundtland Report in 1987, the Rio Declaration (1992), and the Kyoto Protocol (1997) are some of these initiatives. Taking into consideration the international agreements and changes in the demand for integrated environmental management, environmental governance in South Africa was then structured from a human rights and ecological protection point of view. Section 24 of the Constitution of South Africa (1996) stipulates that it is the constitutional right of every human being to an environment that is not harmful to their health and wellbeing and also that it is their responsibility to ensure that the environment is protected to benefit both current and future generations. In ensuring this, reasonable legislative or other matters such as pollution prevention measures, promotion of conservation, and proper usage of natural resources shall be applied.

Section 27 of the Constitution also gives provision to the right to sufficient water of a good quality (Constitution (Act No.108 of 1996). In order to give effect to these constitutional mandates, different environmental legislations were developed and promulgated.

2.4.2. National Environmental Management Act (Act No.107 of 1998)

National Environmental Management Act (NEMA, Act No.107 of 1998) was promulgated in 1998 and it repeals the greater part of the Environmental Conservation Act (Act No.73 of 1989). NEMA is regarded as the framework legislation in South Africa as it provide guidance in decision-making and administration of all South African legislations related to the environment. Under NEMA, various institutions and obligations to ensure that cooperative governance between the three spheres of government (national, provincial, and local government) are created and promoted.

With its core principle being promotion of ecologically sustainable development, NEMA provides several principles as the following ones (National Environmental Management Act (Act No.107 of 1998) :

- Provision for fair decision-making, conciliation and arbitration of conflicts in environmental matters;
- General duty of care in preventing, controlling, and rehabilitating the effect of significant pollution or environmental degradation;
- Enforcement of compliance with environmental legislation and instituting prosecutions and fines related to environmental crimes;
- Addressing of environmental emergency incidents;
- Giving power to employees to refuse to conduct work that may cause environmental pollution and protection to whistle-blowers;
- Recognition and adherence to international or global responsibilities;
- Opportunity for the public to decide on environmental matters; and
- Framework for conducting EIAs for activities that might have a significant impact on the environment.

2.4.3. National Water Act (Act No.36 of 1998)

The National Water Act (NWA, Act No. 36 of 1998) replaced the Water Act (Act No.54 of 1956). In NWA, a holistic approach in making sure that water resources are protected, used, developed, conserved, managed, and controlled in a sustainable manner is promoted. The Act also requires that the following be taken into consideration when promoting sustainable management of water resources:

- Consider water as a basic human need for both present and future generations;
- The need to protect water resources;
- Some water resources are shared with other countries such as in the case of the Limpopo River;
- Social and economic development shall be promoted through the proper use of water; and
- Establish suitable institutions such as Water Use Associations (WUAs).

By taking into consideration the purpose of the Act, the NWA further gives effect to development of measures that will assist in ensuring that the constitutional mandate is being implemented. These include:

- Ensuring that water management strategies such as National Water Resources Strategies (NWRS) and Catchment Management Strategies (CMS) are possible;
- Establishment of water management institutes, for example, Water Management Areas (as indicated in Figure 2.2) Catchment Management Agencies (CMAs) such as Inkomati-Usuthu CMA and WUAs;
- Development of water resource protection measures such as water resource classifications systems, resource quality objectives, reserve determination, pollution prevention measures such as polluter pays principle, and addressing of emergency incidents;
- Authorisation of water uses by issuing of water use permits and licences to water users as stipulated in Section 21 of the Act;
- Provision of access to and right over land where water resources such as dams could be situated;
- Monitoring of water resources, assessment and consolidation of information related to water resources such as water quality data; and
- Enforcement of penalties and remedies related to water crimes.

The NWA also makes provision for the definition of water resource quality in South Africa which means quality of all aspects of a water resource including:

- The quantity, pattern, timing, water level, and assurance of stream flow;
- The quality in terms of the chemical, physical, and biological characteristics;
- Characteristics and conditions of the in–stream and riparian habitat, and
- The characteristics, conditions and the distribution of the aquatic biota.

Different regulations were established in order to effectively implement the protection of water resources. These include regulations such as General Notice Regulation 704 (1999) which enforces mining and related industries to effectively implement water management, and General Notice Regulation 1160 (1999) which gives effect to establishment of water management areas and their boundaries as shown in Figure 2.2.

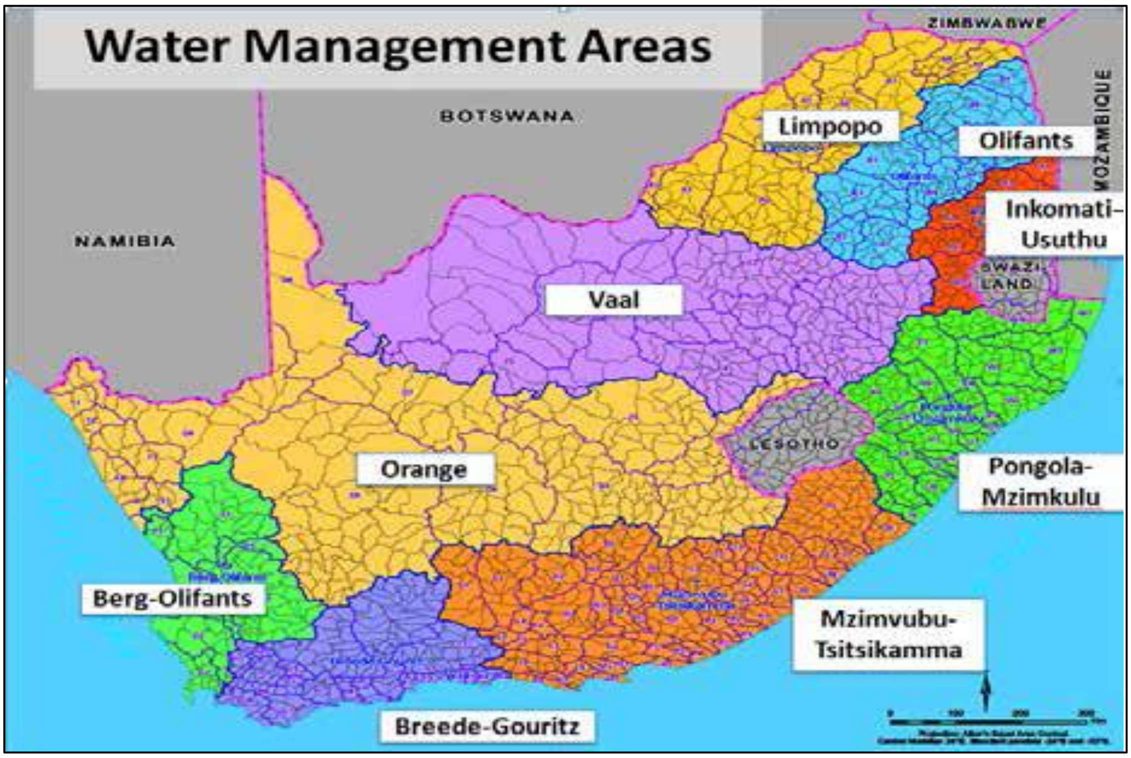


Figure 2.2: South Africa's nine water management areas established based on the drainage system.

Source: DWA (2013).

In support of NWA, the Water Services Act (Act No. 108 of 1997) was promulgated in 1997 to provide for matters related to right of access to basic water supply and basic sanitation, a regulatory framework for the institution of water services and intermediaries such as municipalities and water boards (Hodgson and Manus, 2006).

2.4.4. National Environmental Management: Biodiversity Act (Act No.10 of 2004)

South Africa's biodiversity plays a role in both socio-economic growth and development such as tourism, fishing, horticulture, medicinal plants, commercial or non-commercial of indigenous species, recreational, cultural, aesthetic and spiritual activities. It also plays a role in ensuring that there is provision of ecosystem services such as production of clean water in a catchment, prevention of erosion, carbon storage, and clean air (DEAT, 2006). Biodiversity includes terrestrial, aquatic or costal plants and animal species.

The National Environmental Management: Biodiversity Act (NEMBA, Act No.10 of 2004) was promulgated in order to ensure that the country's biodiversity is protected and effectively managed. It provides for protection of species and ecosystems, sustainable use of indigenous biological activities, equity in bioprospecting, and giving effect to the establishment of a regulatory body called the South African Biodiversity Institute (SANBI). According to this Act, some of the critical principles associated with the study area include biodiversity planning and monitoring, management of threatened or protected ecosystem and species, management of ecosystem or species causing threat to biodiversity such as invader species, and permitting of activities related to biodiversity.

2.4.5. National Environmental Management: Protected Areas Act (Act No.57 of 2003)

Protected areas are defined in the Act as areas that are declared and regulated as a buffer zone for the protection of special nature reserves, national parks, world heritage sites or nature reserves. The National Environmental Management: Protected Areas Act (Act No.57 of 2003) was established in order to provide for the protection and conservation of ecologically viable areas representative of South Africa's biological diversity and its natural landscapes and seascapes. The Act also gives provision to the establishment of a national register of protected areas, their management, cooperative governance, public participations and matters related to protected areas.

2.4.6. Conservation of Agricultural Resources Act (Act No.43 of 1983)

This legislation covers the management and control of over-utilisation of natural agricultural resources in order to promote soil conservation, water sources, and vegetation (including wetlands). It also aims at promoting management of weeds and elimination of invader species (CARA, 1983).

2.4.7. South African Heritage Resources Act (Act No. 25 of 1999)

The South African Heritage Resource Act (Act No. 25 of 1999) gives provision to an integrated system involved in management of national heritage resources. It also provides for the establishment of a national heritage resources agency which is involved in identification, protection, and management of heritage resources around the country (SAHRA, 1999).

2.4.8. Minerals and Petroleum Resources Development Act (Act No. 28 of 2002)

The Minerals and Petroleum Resources Development Act (Act No. 28 of 2002) addresses the equitable access to and sustainable development of the minerals and petroleum resources in the country. Through section 38 of Chapter 4, the Act does provide for environmental protection and rehabilitation of mines during the operational and closure phases.

2.5. DPSIR MODEL

2.5.1. Background on DPSIR model

The DPSIR model was first introduced by the European Environmental Agency (EEA) in 1999 and was adopted by the EEA as a framework for conducting environmental assessments. Its objective is to provide a structure within which indicators are identified and provide feedback to policymakers and conservation managers on the quality of the environment and the resulting impacts on the political choices made or to be made in the future. This framework has, in many cases, been used in understanding the cause–effect relationships that exists between human beings and their interactions with the environment (Vazquez, 2003; Kristensen, 2004; Diab and Motha*,* 2007; Carr *et al.*, 2007 Odontsetseg *et al.*, 2009). Gabrielsen and Bosch (2003) also mention that the framework focuses on using indicators to communicate the most relevant features of the environment and other issues included in the assessments and policy analyses. As shown in Figure 2.3, Kristensen (2004) also explains that this framework is useful in describing the origin and consequences of environmental problems and understanding their dynamics through linkages between the components of the framework.

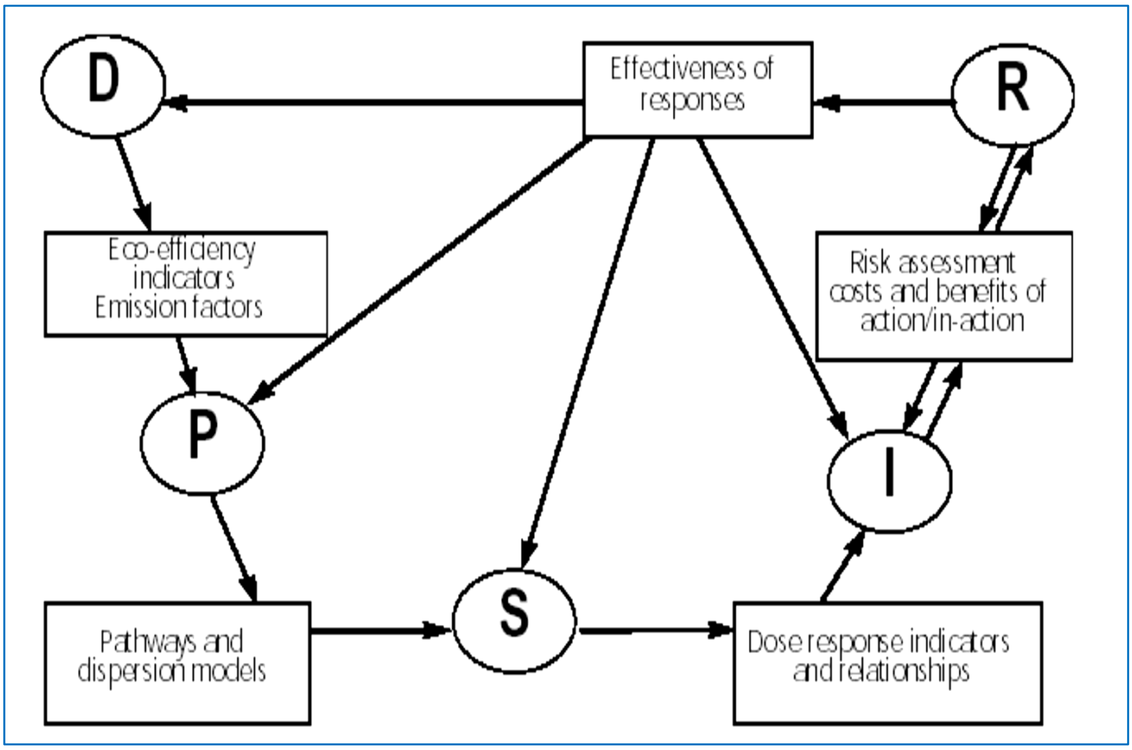


Figure 2.3: Indicators and information linking the DPSIR framework.
Source: Kristensen (2004).

The DPSIR model consists of 5 components which are linked together. These components are defined in the following section.

2.5.1.1. Drivers

Driving forces are human influences and activities that can positively or negatively impact on the environment. These may include social, demographic and economic developments in societies and the corresponding changes in lifestyle, overall levels of consumption and production patterns are examples of the driving forces (Diab and Motha, 2007; Tsai *et al.*, 2009). Drivers may be socio-economic sectors where human needs such as the provision of food, water, shelter, health, security, culture, and jobs are fulfilled. Natural activities such as climate change and floods can also act as drivers.

2.5.1.2. Pressure

The intentional or unintentional forces that various natural drivers exert on the environment are defined as pressure/s (Odontsetseg *et al.*, 2009; Kelble *et al.*, 2013). Changes in the land use, consumption of natural resources such as coal and water, releases of pollutants or substances that negatively impact on the environment such as greenhouse gases, AMD or salinised water, waste pollutants, and physical damages through direct contact such as cutting of trees and land clearances, and destruction of river banks are examples of pressures exerted on the environment.

2.5.1.3. State

The state defines currently measured environmental quality and how it is influenced by environmental pressures. These changes tend to be negative most of the time and cause damage or degrade the environment. Changes in state could be of physical parameters such as temperature and turbidity, chemical variables such as levels of carbon dioxide in the atmosphere, pH or phosphates levels in water, increased levels of chemicals in the soil, and increases in levels of *E-coli* and coliform, indicating the presence of biological agents (Neves, 2007; Diab and Motha, 2007).

2.5.1.4. Impacts

According to Kristensen (2004), negative effects of environmental changes on ecosystems such as loss of terrestrial biodiversity, water pollution, and air pollution are described as the impacts that emanates from the change in the state. The changes in the state of ecosystem not only affect human beings but may impact on flora and fauna as well. The impacts can be positive for human beings in terms of improvement in socio-economic developments, provision of food, jobs, and basic needs such as water and electricity. On the other hand, changes may cause human health problems, destruction of biodiversity, as well as changes in the recreational value of any specific environment (Zhang and Fujiwara, 2007; Tsai *et al.*, 2009).

2.5.1.5. Responses

Responses are the societal actions taken in order to address a certain environmental impacts (Agyemang *et al.*, 2007). For example, legislative initiatives to protect native vegetation could be a response to an impact on loss of terrestrial biodiversity. Responses are the actions that are taken in order to prevent, mitigate, avoid, compensate, ameliorate, or adapt to changes in the state of the environment. Responses could be made or initiated by government (provincial, national or local), society or community, NGOs or even scientists with the intention of controlling the drivers or pressure through regulation, prevention or mitigation, to maintain or restore the state of environment. This can be in the form of drafting and implementing legislations, scientific approaches such as technologies and best practices (Kristensen, 2004; Agyemang *et al.*, 2007; Tsai *et al.*, 2009).

2.5.2. The DPSIR model in water resource management

Integrated Water Resource Management (IWRM) can be defined as taking a holistic approach to the management of water resources in a particular catchment (Rasi Nezami *et al.*, 2013). This process includes identifying land uses and users, catchment regimes and flows, institutional arrangements and coordination of water resource management, state of water resources around the catchment, and socio-economic interaction around the particular catchment.

Kristensen (2004) highlights the importance of quantifying and identifying the current state and impacts on water environment and how these are changing with time at a global, regional, and national level, and even at catchment level. In Italy, studies by Libelli *et al.* (2004) and Benini *et al.* (2010) made reference to the European Water Framework Directive and guidelines which have identified the need for a cause–response approach towards the evaluation of pressure on the environment caused by human-related activities and their associated impacts, to promote sustainable water use, enhance the protection and improvement of the quality of the aquatic environment. These studies have called for integration of the DPSIR model in water resource management. A further example is indicated in Figure 2.4.

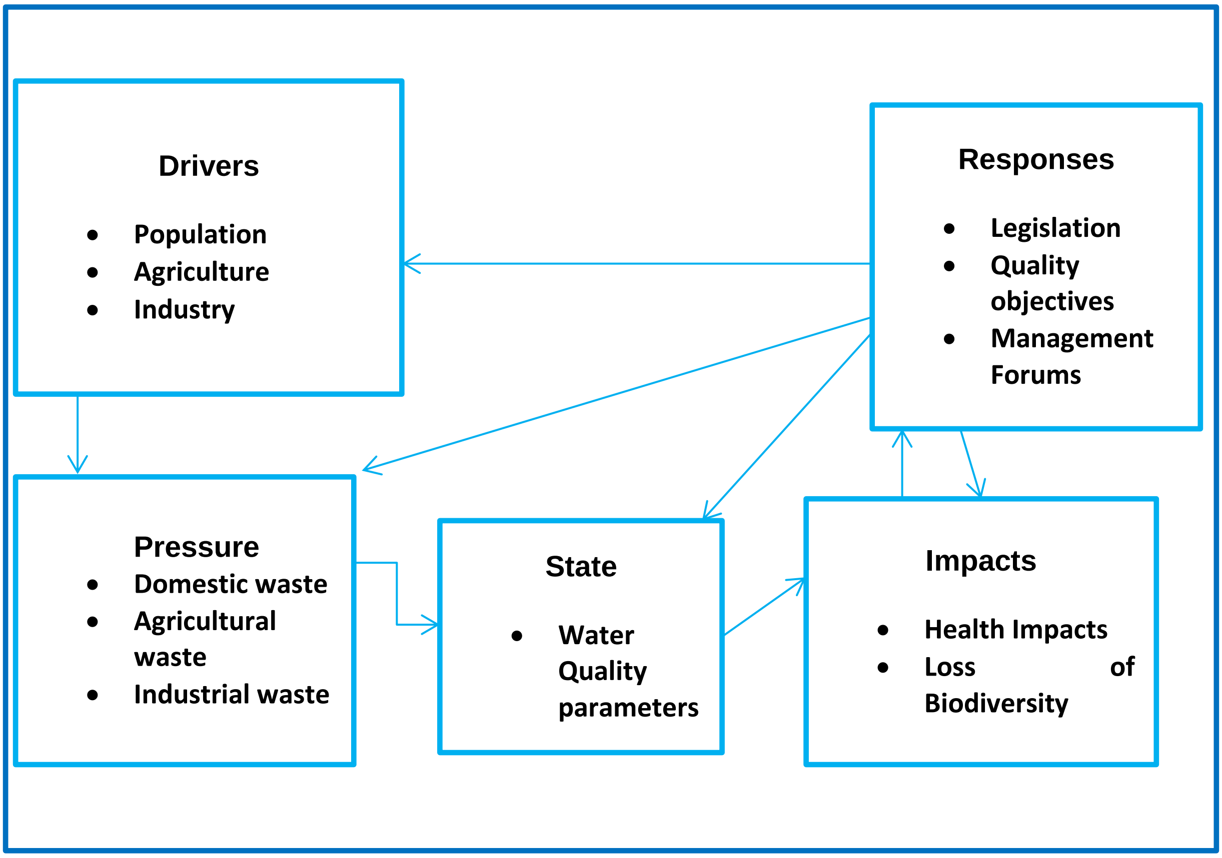


Figure 2.4: Integration of water quality in the DPSIR framework.
Source: Libelli *et al.* (2004) (edited).

Several studies were conducted in various countries applying this model, namely Europe, Asia, South and North America and Australasia. The studies highlight successes in the application and yielding of desired results in assessing the status of water resource types such as coastal water, surface water, groundwater, wetlands and watershed areas, basins, and the impacts on them of various factors (Bidone and Lacerda, 2004; Rekolainen, 2003; Karaogernis *et al.*, 2004; Borja *et al.,* 2006; Pirrone *et al.,* 2005; Carr *et al.*, 2007; Odontsetseg *et al.,* 2009; El Sawah *et al.*, 2011; Kagalou *et al.*, 2012; Song and Frostell, 2012; Rasi Nezami *et al.*, 2013).

In Africa, this model was applied in Ethiopia where integrated environmental management was determined using the model in Simen Mountain National Parks which is a UNESCO-declared heritage site (Essayas, 2010). To further indicate the importance of this model, Agyemang *et al.* (2007) also applied it in determining various indicators of environmental degradation in northern Ghana.

However, the application of this model has been criticised in some studies (Diab and Motha, 2007). Song and Frostell (2012) cite some typical criticisms of the model, which include:

- Formation of static indicators and its inability to take into account the dynamics of the system being discussed;
- It provides unclear cause–effect relationships of complex environmental problems and a limited understanding of drivers for environmental changes;
- Linear unidirectional causal chains of environmental problems are suggested by this model; and
- It analyses environmental trends only by repeating the indicator reports at regular intervals.

2.5.3. DPSIR applications in South Africa

According to Walmsley *et al.* (2001), there has been limited application of the DPSIR model in South Africa. Agyemang *et al*. (2007) also noted that in many parts of the world, this model is still new and in a development stage in many regions in Africa, South Africa included. However, a few studies exist where the model has been applied in analysing key institutional factors in air quality in the south Durban basin (Diab and Motha, 2007) and also in mapping land degradation and conservation (Lindeque, 2009). This model was also applied in determining the main drivers involved in the management of inland water resources in the country and these are mentioned in Figure 2.5 (Kristensen, 2004). The figure shows that both climate and anthropogenic activities could be the main drivers in inland water quality to different states of water management.

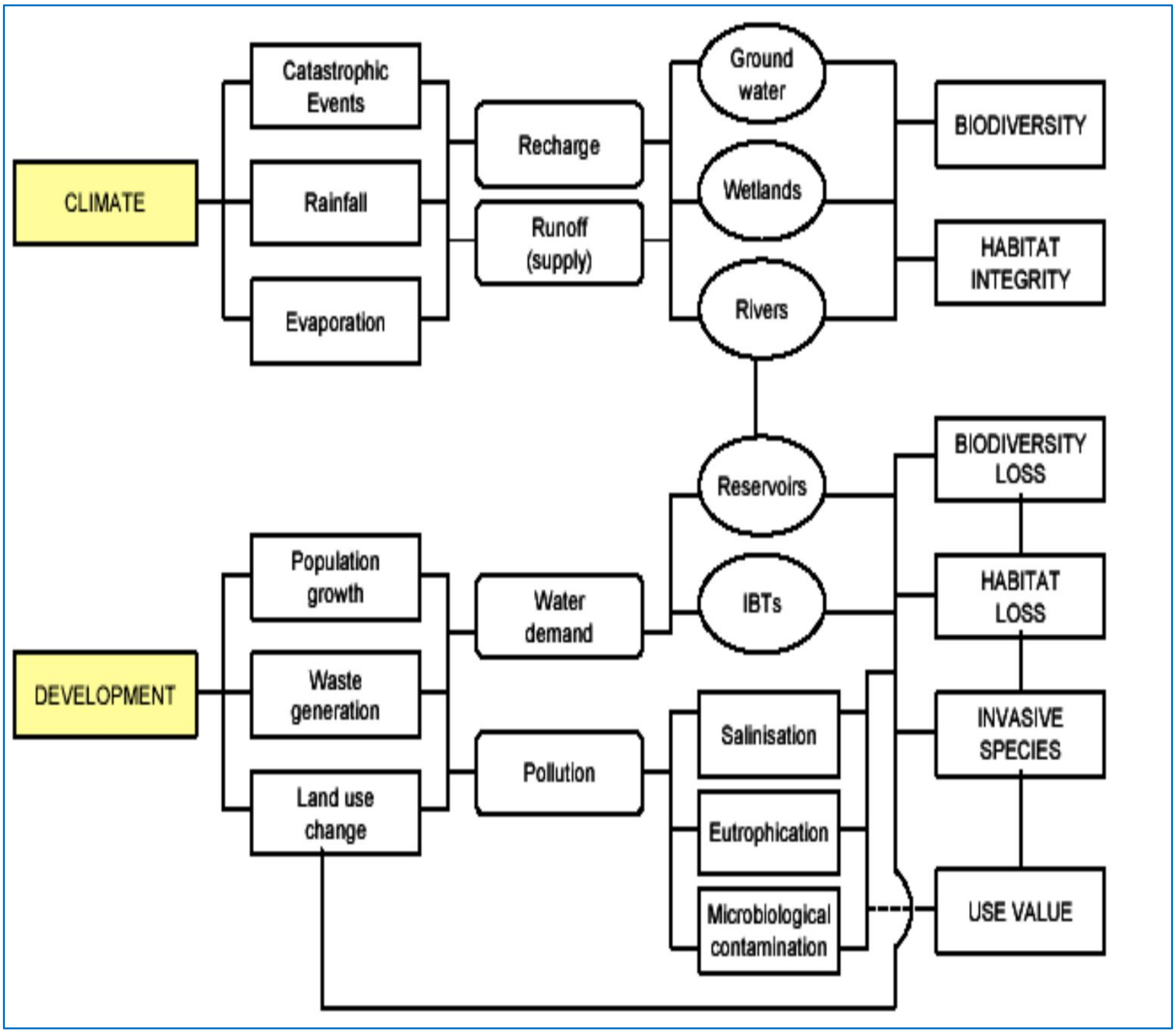


Figure 2.5: Diagram showing the main driving forces affecting South Africa's inland water resources.

Source: Kristensen (2004).

CHAPTER 3
DESCRIPTION OF THE STUDY AREA

3.1. INTRODUCTION

This chapter describes the geographical and human characteristics of the study area. This includes the biophysical features (climate, topography, geology, soil and hydrology), and features of cultural, ecological and archaeological importance. The human environment (population demographics and socio-economic characteristics) and a brief overview of land uses are also described in this chapter.

3.2. GEOGRAPHICAL LOCATION

Figure 3.1 shows the geographical location of the Limpopo Province, which is one of the nine provinces in South Africa. The province covers an area of approximately 125 755 km^2 and is located in the northern-most part of the country (South African Yearbook, 2010). The province is also regarded as one of the poorest in the country and is characterised mostly by rural communities, mining and agricultural activities (such as crop and cattle farming). The Limpopo province is separated from the countries of Botswana and Zimbabwe by the Limpopo River (South African Yearbook, 2010). Typical of the situation in South Africa, freshwater resources are limited in this region, with socio-economic development and industrial activities such as mining, agriculture, human settlement, and wastewater treatment contributing to water quality and quantity challenges (Ashton *et al.*, 2001; CSIR, 2010; Nekhavhambe *et al.,* 2014).

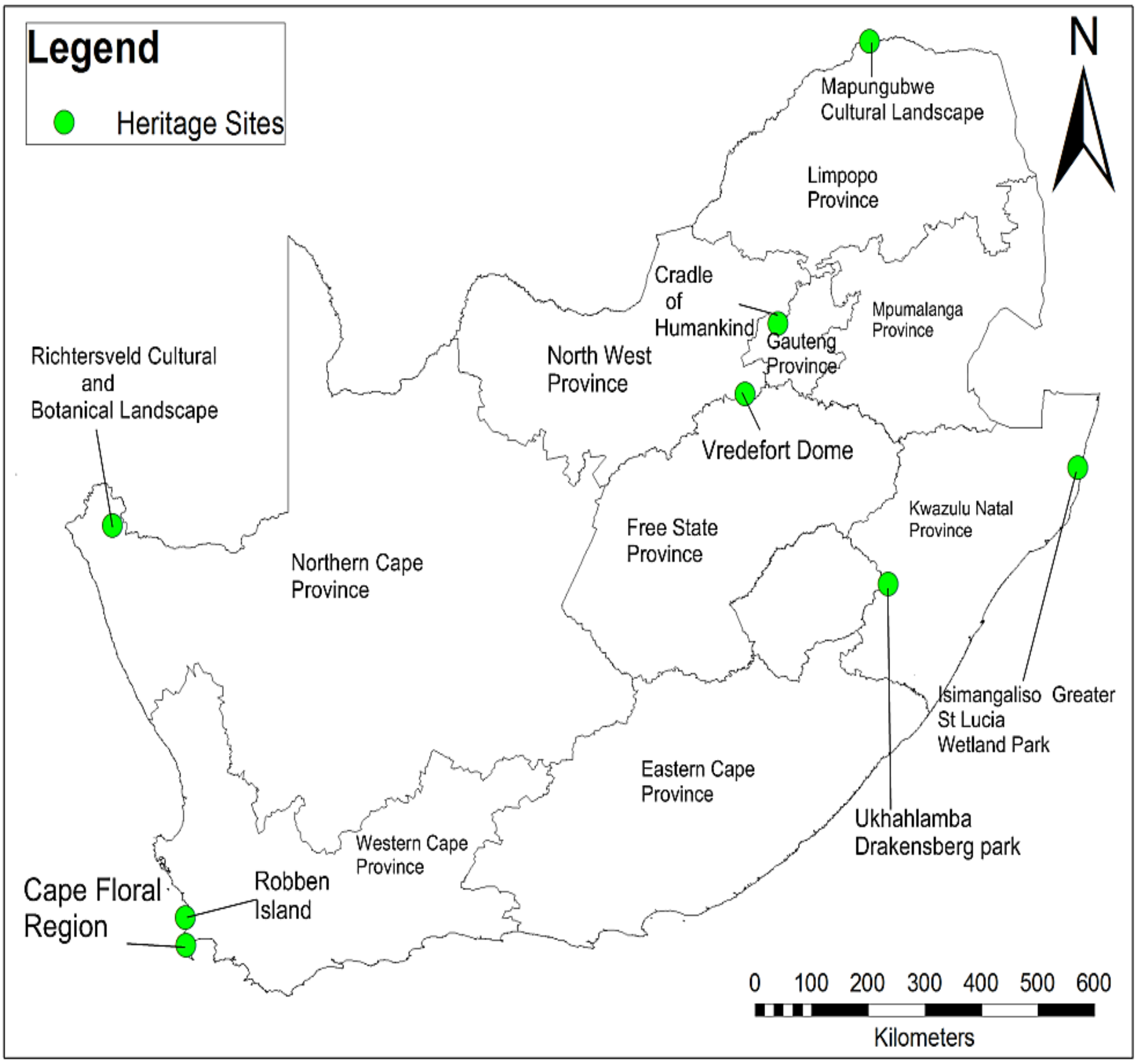


Figure 3.1: Republic of South Africa's nine provinces together with locations of UNESCO-declared world heritage sites.

The study area is located in and around the MNPHS, situated in the Vhembe District Municipality (VDM) of the Limpopo Province. Together with Isimangaliso Wetland Park, Richteveld Cultural and Botanical Gardens, Cradle of Humankind Dome, uKhahlamba\Drakensberg Park, Robben Island, Vredefort Dome, and Cape Floral Region Protected Area, the MNPHS is one of South Africa's eight world heritage sites (as shown in Figure 3.1) as designated by the UNESCO. MNPHS is located on the South African side of the confluence of Shashe and Limpopo Rivers and covers an estimated 28 000 hectares (Peace-Parks Foundation, 2015). The park boundaries stretches from Pondrift in the west for about 35 km to Schroda in the east, and stretches from the Limpopo River in the north to the tarred road (R572) linking Pondrift and Musina in the south (SANParks, 2013; Henning and Beater, 2014; Sinthumule, 2014). The Limpopo River forms the northern boundary of the park while the road R572 forms the southern boundary. Government Notice Number 71 of 30th April 2009 (GN 31832) defined the four corners of the boundary of MNPHS as follows:

NW corner 22°12’ 56”S 29°08’22”E
NE corner 22°10’ 10”S 29°29’04”E
SE corner 22°14’ 15”S 29°31’35”E
SW corner 22°17’ 40”S 29°12’ 00”E

The MNPHS is a major tourism attraction in the country and was home to the famous golden rhino, a symbol of the power of the King of the Mapungubwe people who inhabited the Limpopo River valley between 900 AD and 1300 AD (Huffman, 2007; Peace-Parks Foundation, 2015).

3.3. DESCRIPTION OF THE BIO-PHYSICAL COMPONENTS

3.3.1. Landscape

MNPHS was declared a heritage site by UNESCO in July 2003. According to UNESCO (2015), the landscape of this site contains evidence of an important interchange of human values that led to far-reaching cultural and social changes in southern Africa between 900 AD and 1300 AD. According to Jivanji (2013), the importance of this site arises from its pre-colonial development as a thriving kingdom and it was home to an array of people who drew religious, artistic and cultural associations with this natural landscape. Within the park are archaeological sites such as Mapungubwe, K2, and Zhizo and their existence dates back from the early Stone Age. Figure 3.2 indicates the K2 archaeological site. Murimbika (2006) further explains that many of these archaeological sites concentrated on the area where the Shashe-Limpopo confluence is found, while the Zhizo site (700–900 AD) is situated on the farm Schroda. Mapungubwe Hill and the adjoining Bambandyanalo (1100–1250 AD) have a particular scientific interest and value (Carruthers, 2006; Berry and Cadman, 2007; SANParks, 2013; DEA, 2015; UNESCO, 2015).

According to Götze *et al.* (2008), Mapungubwe site is considered to be one of the most important archaeological sites in sub-Saharan Africa and is the most remarkable Iron Age site in South Africa. Additional features of importance are the numerous rock paintings and petroglyphs found in the area. It is renowned for the golden rhino and is believed to be the precursor of Great Zimbabwe, the most remarkable Iron Age site in southern Africa (Murimbika, 2006; Huffman, 2007; DEA, 2015).

Figure 3.2: K2 archaeological site.
Source: Murimbika (2006).

3.3.2. Hydrology

The study area falls within the Limpopo Water Management Area (WMA)'s sub-catchment A71L, with the total quaternary catchment estimated to be 1 765 km^2 (Ashton *et al.*, 2001; Limpopo Coal Company, 2014). This quaternary catchment area falls under the Limpopo basin. It has the lowest rainfall and highest mean annual evaporation of all of the catchments in the tertiary catchment area (SANParks, 2013; Henning and Beater, 2014). The hydrological feature of the site is dominated by the confluence of the Shashe and Limpopo Rivers (as shown in Figure

3.3) which are seasonal and primary rivers of the study area. The surface drainage of the area occurs mostly in a northerly direction towards the Limpopo River in a drainage basin known as Setoka-Sandsloot sub-catchment (Götze *et al.*, 2008). The sub-catchment consists of the area drained by several small seasonal and episodic streams which all flow northwards to discharge into the Limpopo River. These secondary rivers located on the South African side are Kolope, Mapedu, Upper Sand, and Mogalakwena Rivers. Low and unpredictable rainfall (average 375 millimetres) characterises this sub-catchment and the streams normally only contain surface water immediately after rainfall during the summer months (Boroto and Görgens, 1999; Ashton *et al*., 2001; Huffman, 2007).

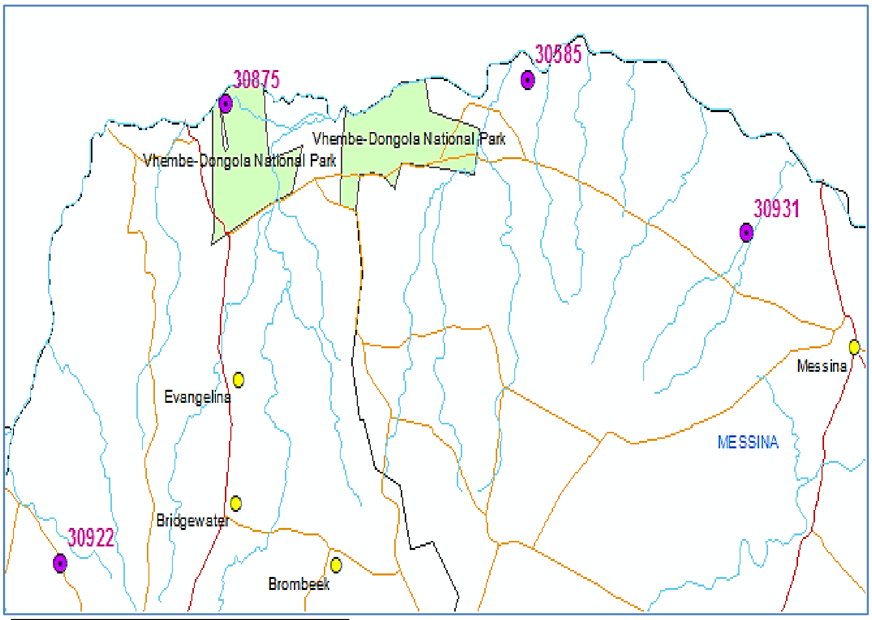
Kolope/Maluotswa wetland is found upstream of the confluence. According to SANParks (2013), though the Limpopo and Kolope floodplains are the dominating wetland type in the park, other smaller, steeper gradient and seasonal tributaries occur in the park and mostly mouth onto the Limpopo floodplain. These two floodplains ultimately form one system towards the confluence in the Samaria section of the park. Groundwater supply in this area is known to be generally poor with weathered sandstones, weathered contacts and fault zones providing for excellent aquifers (Henning and Beater, 2014). Weirs upstream of the river are used to store water, but downstream, farmers draw water from large sand aquifers and riverbeds (SANParks, 2013; DWA, 2013). Schroda Dam is a notable surface water storage area found within the park. This dam is utilised by De Beer’s Venetia Diamond Mine to store water abstracted from the river and pump it to the mine.

Figure 3.3: View of the Limpopo and Shashe Rivers within MNPHS.

3.3.3. Climate

The climate is semi-arid with mean annual rainfall ranging from 350 to 400 millimetres (Huffman, 2007; Sinthumule, 2014). Rainfall is highly variable and usually falls during the summer months. Extended periods of below average rainfall also occur in the area with the driest months being from May to September, when less than 7 mm of rain per month may be experienced. Rainfall is also highly seasonal, falling predominantly as intense convective thunderstorms during the warmer summer months. The area receives an average of approximately 10 rainy days per annum with rainy season predominantly from November to March when about 83% of the total annual rainfall occurs. There were severe droughts observed during the early 1990s and exceptional floods during 2000 in the Limpopo valley, and this illustrates the extreme variability of rainfall and runoff in the basin. This variation has significant effects on aquifer recharge (Huffman, 2007; SANParks 2013; CALS, 2015).

Temperatures across the study area have marked seasonal cycles where the highest temperatures can be recorded during the early summer months and lowest temperatures during the cool, dry winter months. In summer, temperatures sometimes can rise to 45°C, while winters are relatively mild (Ashton *et al.*, 2001; Berry and Cadman, 2007; SANParks, 2013; Henning and Beater, 2014). Figures, 3.5, 3.6, 3.7 and 3.8 indicate monthly average temperature and rainfall upstream (Pondrift) and downstream (Messina Noordgrens) of the park obtained from ARC-ISCW's monitoring stations. Locations of these monitoring stations in relation to the park are shown in Figure 3.4. The figures indicate that highest rainfall in the region is experienced in the months of January and December; it is also in these months that high temperatures are experienced.



Point Identity	Description
30585	Musina Noordgrens
30875	Pondrift
30922	Seldeomgesien
30931	Musina PP

Figure 3.4: Location of weather stations at MNPHS (previously called Vhembe-Dongola National Parks).

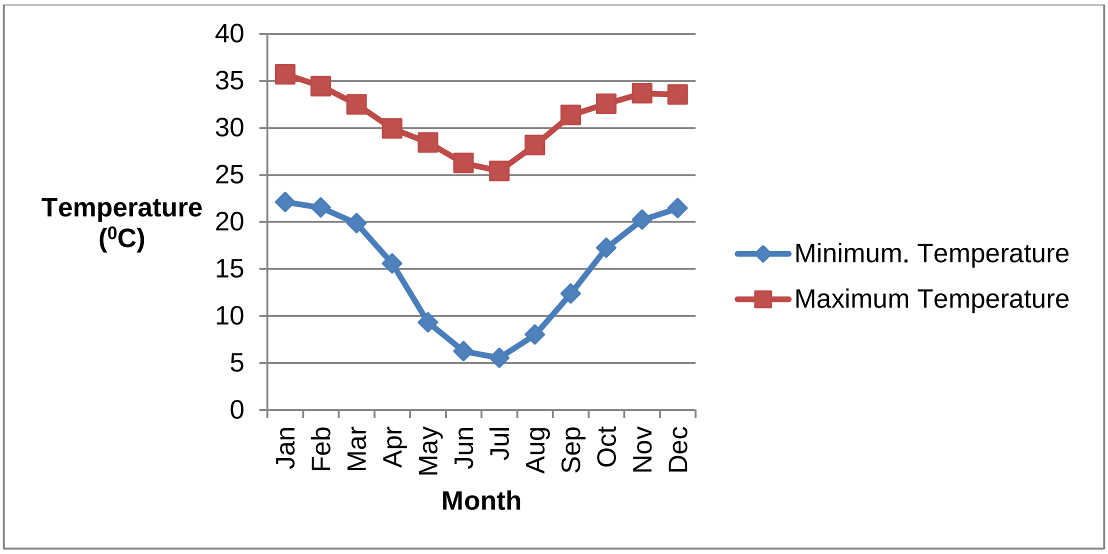


Figure 3.5: Average monthly temperature at Musina (Noordgrens weather station) recorded between 8 January 2003 and 8 March 2015.

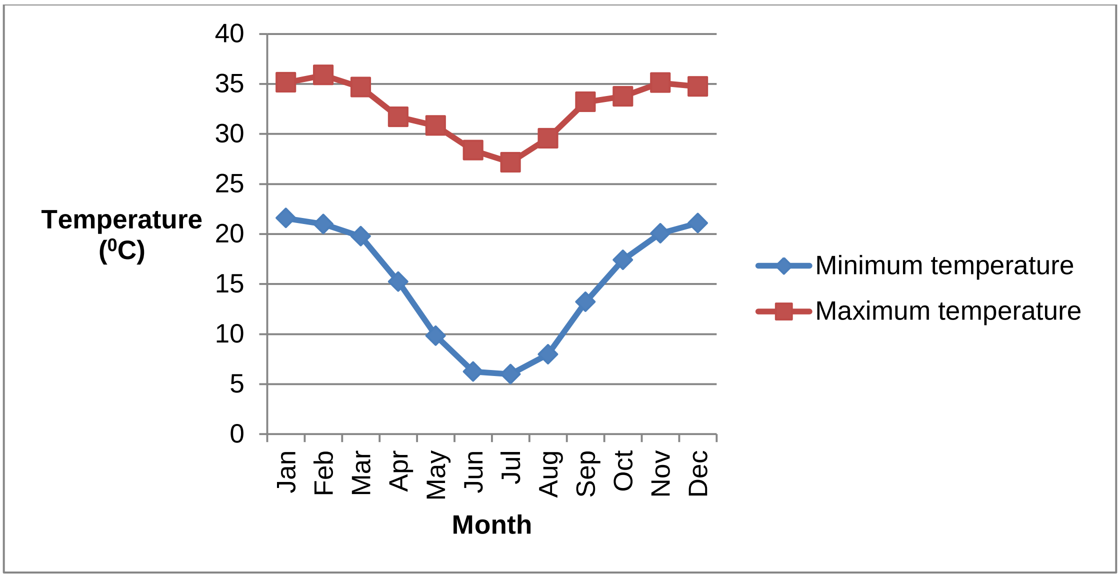


Figure 3.6: Average monthly temperature at Pondrift weather station recorded from 6 August 2010 to 8 March 2015.

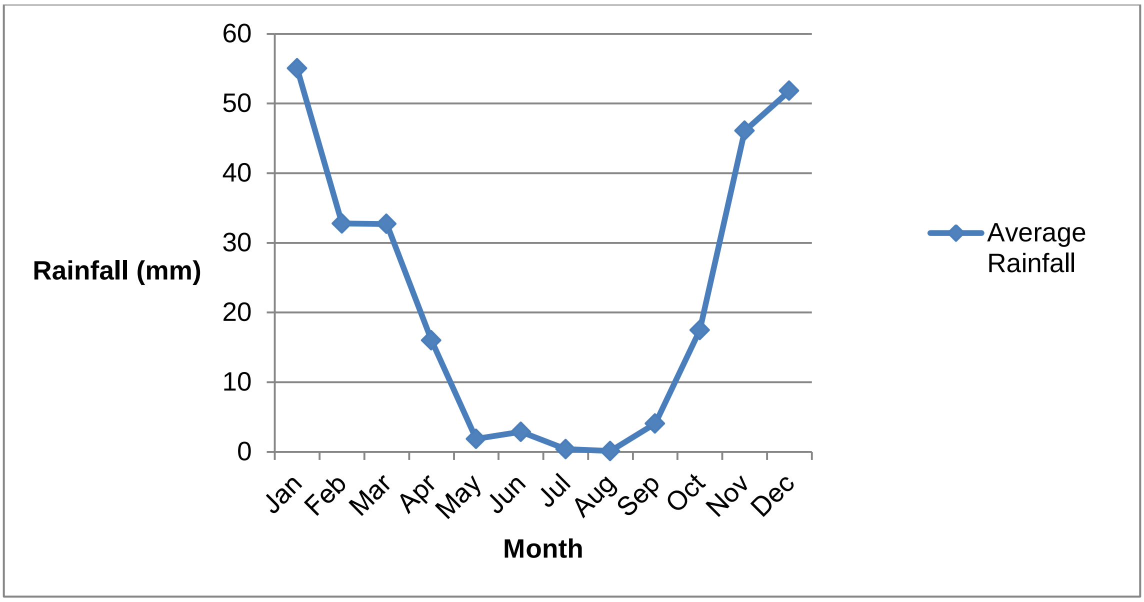


Figure 3.7: Average monthly rainfall at Musina (Noordgrens weather station) recorded between 8 January 2003 and 8 March 2015.

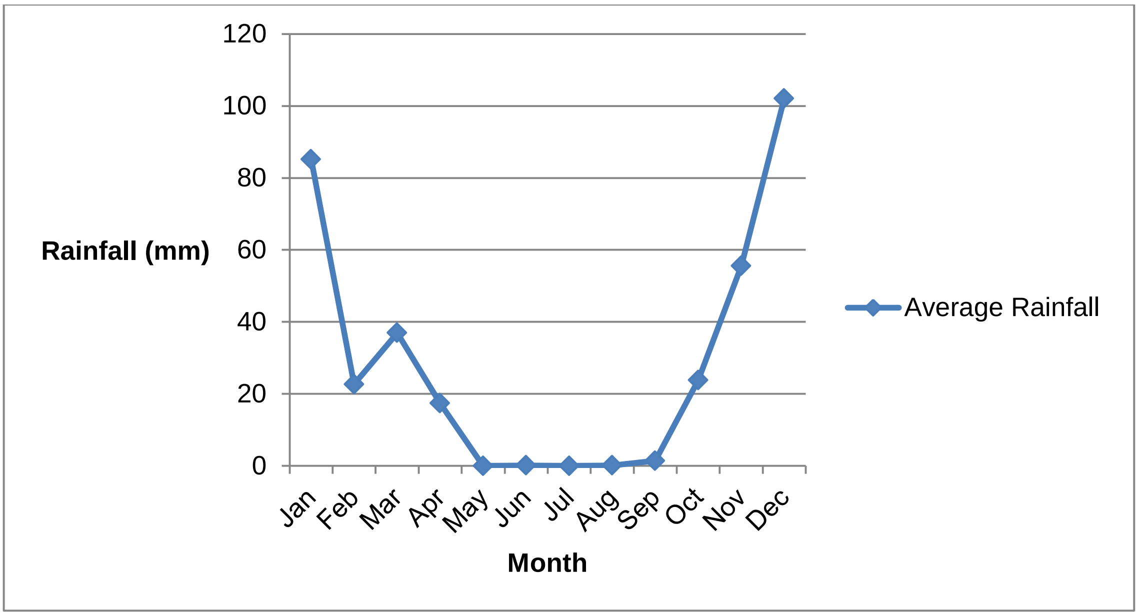


Figure 3.8: Average monthly rainfall recorded at Pondrift weather station from 6 August 2010 to 8 March 2015.

3.3.4. Topography and soil types

The topography of the study area is characterised by a semi-arid flat mopane veld and the altitude varies from 300 m to 780 m above sea level (Sinthumule, 2014). Sandstone, conglomerate ridges and koppies defines the landscape south of the

Limpopo River which changes into rugged, hilly terrain closer to the river (Götze *et al.*, 2008). As previously mentioned, various mountainous formations, also known as archaeological sites, can be observed within the park.

The soil formation on the Limpopo basin is largely influenced by climatic features, biological activities and underlying parent rock material found around the region (Henning and Beater, 2014). According to Ashton *et al.* (2001), soils in the sub-catchment can be divided into two main groups. These are the moderately deep sandy soils on the sloping and undulating terrain in the upper reaches of the sub-catchment, and relatively shallow, coarse-grained sandy soils and silt deposits in flat and undulating terrain in the lower reaches of the sub-catchment, particularly along the flood terraces of streams. Despite having various agricultural activities being practised along the study area, soil types found in this region are generally known to have low agricultural potential (SANParks, 2013; Sinthumule, 2014).

3.3.5. Geology

Various geological formations indicated in Figure 3.9 are found in the vicinity of the study area. MNPHS comprises an attractive semi-arid landscape with varied geology, including extremely old Archaean rocks, metamorphic of intermediate age, Karoo sandstone/conglomerate uplands that are about 200 million years' old, and recent alluvium and sands (SANParks, 2013; CALS, 2015). The area is underlain by a sequence of silicified sandstones and quartzites, accompanied by minor carbon-rich mudstones and shales, and then basalts, of the Karoo sequence. The sandstones are resistant to weathering and remain as harder outcropping rock formations that stand clear of the surrounding terrain to form small, steep-sided ranges of hills (Ashton *et al*., 2001; Henning and Beater, 2014). The large areas of this sub-catchment consist of quaternary deposits of unconsolidated or poorly consolidated sandy material. Two mining operations are being undertaken on the South African side of the basin. De Beer's Venetia Diamond Mine, which is located 20 km from the park, currently mines the diamondiferous kimberlite located in the area. Coal reserves were discovered within the vicinity of the area, and Coal of Africa's Vele Colliery currently mines coking coal.

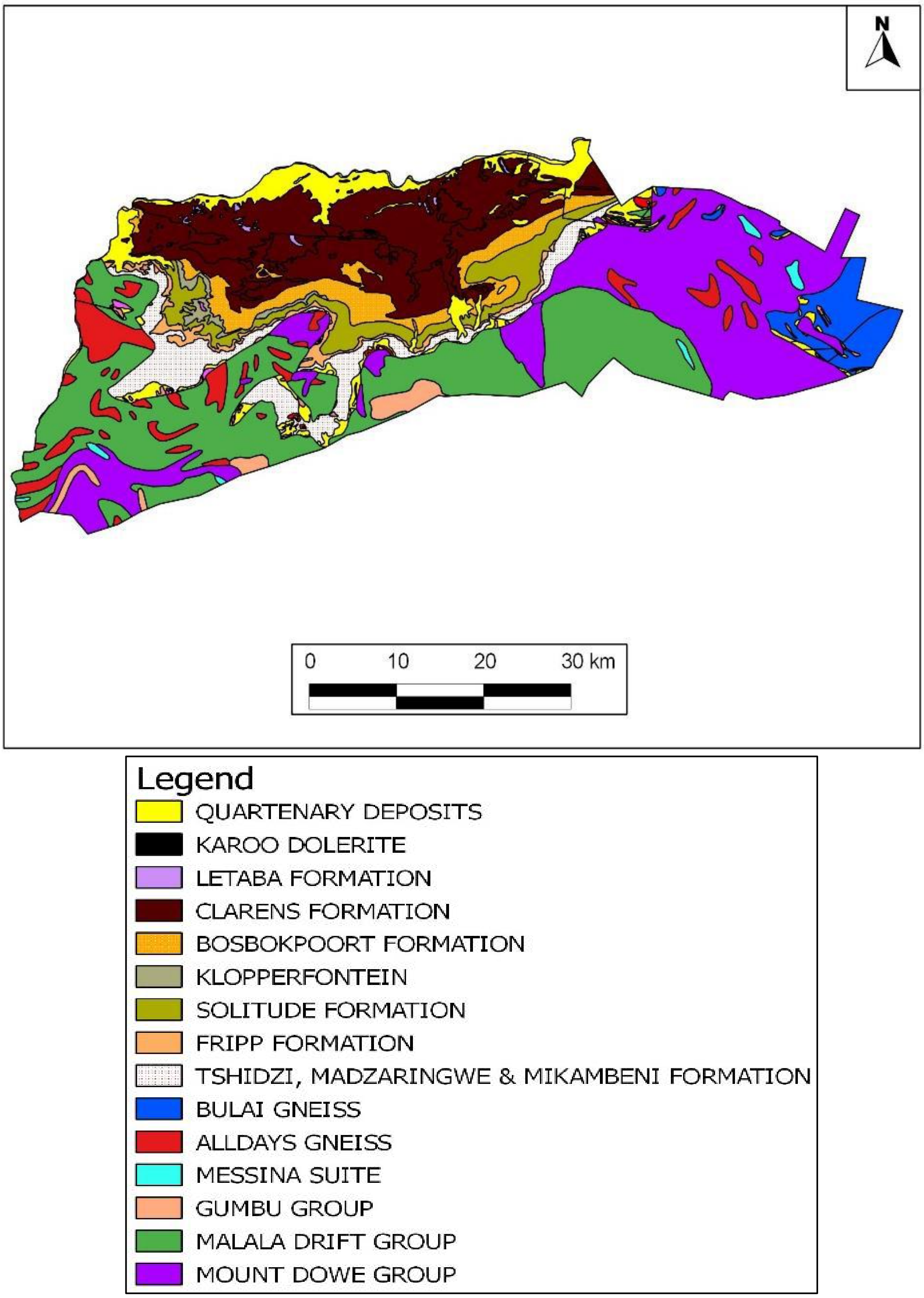


Figure 3.9: Geological formations around MNPHS.

Source: Henning and Beater (2014).

3.3.6. Flora

One of the most common characteristics of the study area is the existence of a variety of plant species ranging from invader species (as indicated in Figure 3.10) to protected trees. The vegetation around the area is mostly low, open mopane veld (*Colophospermum mopane*) with *Commiphora* (8 species) and *Combretum* species, with very attractive *Acacia* woodlands (24 species) occurring on riparian fringes and areas of alluvial soils (Sinthumule, 2014). Huffman (2007) further explains that the Limpopo drainage basin consists of dry-land natural vegetation such as mopane shrubs and grasses which are mostly consumed by elephants. Mopane trees are a home for the well-known mopani worms which are a source of protein and a traditional South African food for local communities. Henning and Beater (2014) explain that grass species like *A. congesta*, *E. cenchroides* and *B. deflexa* are river and floodplain-associated vegetation found within the park. Götze *et al.* (2008) discovered that with 219 species identified, the *Ib* land type has the second highest plant diversity of all the land types in the park. Although a large portion of the study area adjacent to the Limpopo River has been transformed through agricultural practices, limited areas (majority cleared) of riverine forest still occur along the Limpopo River. The area is also a home to one of the most famous tree species in the country, the Baobab tree (*Adansonia digitata* species) (indicated in Figure 3.11).

Figure 3.10: Invasive alien species found in MNPHS.

Source: SANParks (2013).

Figure 3.11: The *Adansonia digitata* tree species observed in the park.

3.3.7. Fauna

As part of the park's mandate of conserving the animals, the animals are enclosed in the park and are protected against any form of harm. In a report by SANParks (2013), it was mentioned that most of the animal populations have variable growth rates within the park due to the park forming part of a larger region over which species roam. No immediate threats to the environment are foreseen – with the exception of elephant effects – but their movement is constrained by water distributions and fences in the Mapungubwe area. The park also has game reserves surrounding its vicinity which house medium-sized herbivores such as eland, gemsbok, impala, kudu, waterbuck, wildebeest and zebra (Jivanji, 2013). Some of the most endangered mammals, such as the black rhinoceros and the African wild dog, are sanctioned in the park and are also found in the privately owned farms situated adjacent to the park (Götze *et al.*, 2008). Threatened reptiles, birds, insects, carnivores, and herbivores are found within the park.

Mega-herbivores such as elephants and white rhinos, as well as different carnivores such as lions and wildcats, form part of the animal species found in the park. Figure 3.12 shows some of the animals spotted in the park during various site visits by the author during the year 2014, while Table 3.1 lists the most notable animal species existing in MNPHS. Different types of reptiles such as pythons and black mambas are also found in the park.

Table 3.1: Some of the animals found in MNPHS.

Eland (common)	Kudu (common)
Blue Wildebeest (common)	Zebra (common)
Waterbuck (common)	Impala (common)
Bushbuck (common)	Klipspringer (common)
Duiker (common)	Steenbok (common)
Red Hartebeest (rare)	Gemsbok (common)
Giraffe (common)	Bush pig (common)
Warthog (common)	Baboon (common)
Elephant (common)	White rhino (rare)
Lion (rare)	Leopard (common)
Cheetah (rare)	Hyena, spotted and brown (rare)
Wild dog (rare)	Aardvark (common)

Source: SANParks (2015).

Figure 3.12: Some of the mammals found in MNPHS.

3.4. HUMAN ENVIRONMENT

3.4.1. Locality

MNPHS forms part of Musina Local Municipality (MLM) which falls under Vhembe District Municipality (VDM). VDM covers estimated 21 407 km^2 of which the MLM covers area of approximately 757 829 hectares (Vhembe, 2014). Figure 3.13 indicates that a portion of the study area also falls within the Blouberg Local Municipality (BLM) which is situated approximately 95 km from Polokwane towards far northern part of the Capricorn District Municipality (Blouberg, 2011).

Figure 3.13: Map of VDM and BLM, both of which form part of MNPHS.

Source: Blouberg (2011).

3.4.2. Population demographics

VDM has population of over 1.1 million, living in 297 753 households. Of these, 292 508 are black households, 4 236 are white, 321 are coloured and 689 are Asian (Vhembe, 2014). In 2001, the population in MLM stood at 39 310 and in 2011, the population had increased to 68 359, showing a population growth of 29 049 during this period. This growth was the second highest compared to the other municipalities in the district's population growth of 96 666 (Musina, 2014). These growth trends are illustrated in Table 3.2.

Table 3.2: Population growth trends in MLM.

Census	**VDM**	**MLM**
2001	11 98056	39 310
2011	1 294 722	68 359
Population growth	96 666	29 049

Source: Musina (2014).

Musina (2014) notes that the highest population group of people in MLM is black African at 64 285 followed by whites at 3 284 and Indians or Asians at 329, with coloured being the least populated group at 229. The higher population growth could be linked directly to the large influx of people being experienced from neighbouring countries such as Zimbabwe. This could cause challenges in terms of service delivery, unemployment rate and socio-economic impact. According to a report by Limpopo Coal Company (2012), population growth is, however, affected by the HIV/AIDS prevalence in the area. Approximately 12% of the total population in the MLM is HIV-positive or has AIDS, with the dominant age group being 16 to 64 years of age, which is the economically active age group. The report further states that the HIV/AIDS prevalence rate in the 15 to 64 age category (17%) is also shown to be higher than the Municipality's overall total (12%). The HIV/AIDS prevalence started to rise speedily from 1997 to 2004.

As explained earlier, a portion of the study area also falls within the BLM. Alldays, a portion of BLM, located at the far northern part of the Capricorn District Municipal, is the nearest town to the MNPHS. It has a population of 8 848 residents (Blouberg, 2014). According to Henning and Beater (2014), a population of 5 751 people reside in the park. Table 3.3 shows the population of the study area by age and gender.

Table 3.3: Population, age and gender of residents around MNPHS.

Age group	Male	Female	Total
0 – 14	489	519	**1 008**
15 – 34	1 596	1 536	**3 132**
35 – 64	771	702	**1 473**
65+	78	60	**138**
Total	**2 934**	**2 817**	**5 751**
0 – 14	17%	18%	**18%**
15 – 34	54%	55%	**54%**
35 – 64	26%	25%	**26%**
65+	3%	2%	**2%**
Total	**100%**	**100%**	**100%**

Source: Henning and Beater (2014).

3.4.3. Socio-economic interactions

MLM contributes an estimated 11% of gross domestic product (GDP) to the VDM (Vhembe, 2014). Musina (2014) reports that – with an unemployment rate of 25%, where the highest percentage is among the youth aged between 15 to 19 years and declining with age – the main contributors to the economy of this municipality can be broken down as follows:

- Agriculture, forestry and fishing (35%),
- Mining (30%),
- Transportation and communication (15%),
- Manufacturing (11%),
- Finance and business services (9%),
- Wholesale and retail trade, catering and accommodation (6%),
- Community, social, personal services (6%),
- Government services (5%), and
- Construction (5%).

Within the study area, where the majority of the residents are farmworkers, agriculture is the main source of employment (Sinthumule, 2014). The area houses one of the country's most well-known crop-farming industries called ZZ2. According to the local economic analyses conducted for VDM (Vhembe, 2014\15), MNPHS plays a major role in economic development around the area because of its ability to attract tourists from across the world (Henning and Beater, 2014). As a result of its location across the borders of three countries combined with its wildlife variety and cultural uniqueness, the park attracts a great deal of ecotourism and hunting lodge activities. Accommodation catering either for tourists or for staff is offered by the park.

3.4.4. Overview of land use

Land use activities around the study area include tourism mostly in the form of game reserves and privately owned lodges, agricultural activities (such as citrus, maize, tomato, cotton, and lucerne on moderately deep and coarse-grained sandy soils, and mining (diamond and recently coal) activities. Residential areas (mostly occupied by farmworkers and land claimants such as Machete community) are found on the perimeters of the park. Job opportunities have been created for communities surrounding the study area through tourism (such as game reserves and eco-lodges), crop and cattle farming, and mining (diamond and coal) (Jivanji, 2013; Sinthumule, 2014; CALS; 2015).

De Beer’s Venetia Diamond Mine and Coal of Africa’s Vele Colliery are the biggest industrial activities adjacent to the park. The towns of Musina and Alldays are both located approximately 50 km from the park in an easterly and westerly direction respectively. The combination of these different land use activities could constitute conflict in land uses between mining, agriculture, tourism and conservation (Sinthumule, 2014, CALS, 2015).

3.5. GREATER MAPUNGUBWE TRANSFORMATION CONSERVATION AREA

The study area forms part of the Greater Mapungubwe Transfrontier Conservation Area (GMTCA) which was formally established in 2006 by Botswana, South Africa and Zimbabwe. The GMTCA‘s objective is to ensure that conservation of the biodiversity and cultural landscapes of the area is promoted between these three countries (Jivanji, 2013; Sinthumule, 2014; Peace-Parks Foundation, 2015). As indicated in Figure 3.14, various privately owned game reserves and national parks forms part of GMTCA. Peace-Parks Foundation (2015) further mentions that MNPHS, Venetia Limpopo Game Reserve, Northern Tuli Game Reserve (NOTUGRE), Tuli Circle Safari Area (TCSA), portions of wildlife management areas in Zimbabwe, Sentinel Ranch, Nottingham Estate and River Ranch, form the core of GMTCA.

Figure 3.14: Map of the GMTFA.

Source: Peace-Parks Foundation (2015).

CHAPTER 4
RESEARCH METHODOLOGY

4.1. INTRODUCTION

This chapter provides an elucidation of data collection methods applied in this study. A multidisciplinary approach was undertaken in this study as both quantitative and qualitative research approaches were applied. The chapter also detail the process of obtaining ethical approval and how the collected data was analysed. Systematic participatory approaches, water samples collection and analysis, and determination of land use activities around MNPHS are elaborated on in this chapter.

4.2. OBTAINING ETHICAL APPROVAL

As per the requirements of the University of South Africa (UNISA)'s College of Agriculture and Environmental Science (CAES), an ethical approval was obtained prior to conducting any data collection process. This ethical clearance was an indication that any form of data collection will be undertaken using guidelines provided by the institution.

The ethics guidelines further stipulate that consent shall be obtained from anyone required to participate in the study. A consent form was used in order to obtain consent from various stakeholders. The form was provided either separately prior to the research or as part of the research questionnaire. The consent form explained to participants the purpose and methodologies to be applied in this study. It also highlighted the role they are required to play and confirmed that their identities would be kept confidential regarding the information they would share for the purpose of this study. By completing the consent form, stakeholders indicated that they were willing to provide any necessary assistance or information in order to make this study a success.

4.3. DETERMINATION OF LAND USES AND IMPACTS

In order to determine the type of land uses around the MNPHS, three approaches were applied. Firstly, two site visits were conducted specifically for site assessment of activities taking place around the park. The first site visit was conducted on 22nd June 2014 while the second one was conducted on 3rd June 2015. During these site visits, the location and type of various land uses such as mining, agriculture, tourism and conservation was observed and assessed.

Secondly, different studies highlighting land uses around the study area were reviewed in order to determine the types of activities taking place. This includes the review of studies conducted around the area, as well as topographical maps (obtained from Department of Rural Development and Land Reform), and Google Maps using Google Earth software.

And lastly, a land cover analysis was conducted. The 2013-2014 national land cover data developed to establish the land cover for the whole of South Africa was obtained from DEA and it was used to identify land cover pattern for the area surrounding the MNPHS. Land covers were grouped into five classes in order to determine the relationship between land use and water quality. The land cover classes that were used are water bodies, agricultural, mining, urban industrial and residential areas.

4.4. WATER QUALITY SAMPLING AND ANALYSIS

4.4.1. Sampling site selection and frequency of sampling

Different water quality sampling sites were set along the Limpopo River and were named as P1, P2, P3, P4, P5 and P6 (indicated in Figures 4.1 and 4.2). These sites are described in more detail in Table 4.1. Selection of these sites was based on their accessibility, safety, and capacity of each site to accurately represent water quality upstream and downstream of the study area (DWAF, 2004; Chilundo *et al.*, 2008). Monitoring points were only placed along the Limpopo River. As previously mentioned, the other streams around the area only have water after periods of rain.

Water samples were collected over a period of five-month intervals. The first sample collection was conducted on 9th August 2014, the second was on 9th January 2015, and the last sampling period took place on 4th June 2015.

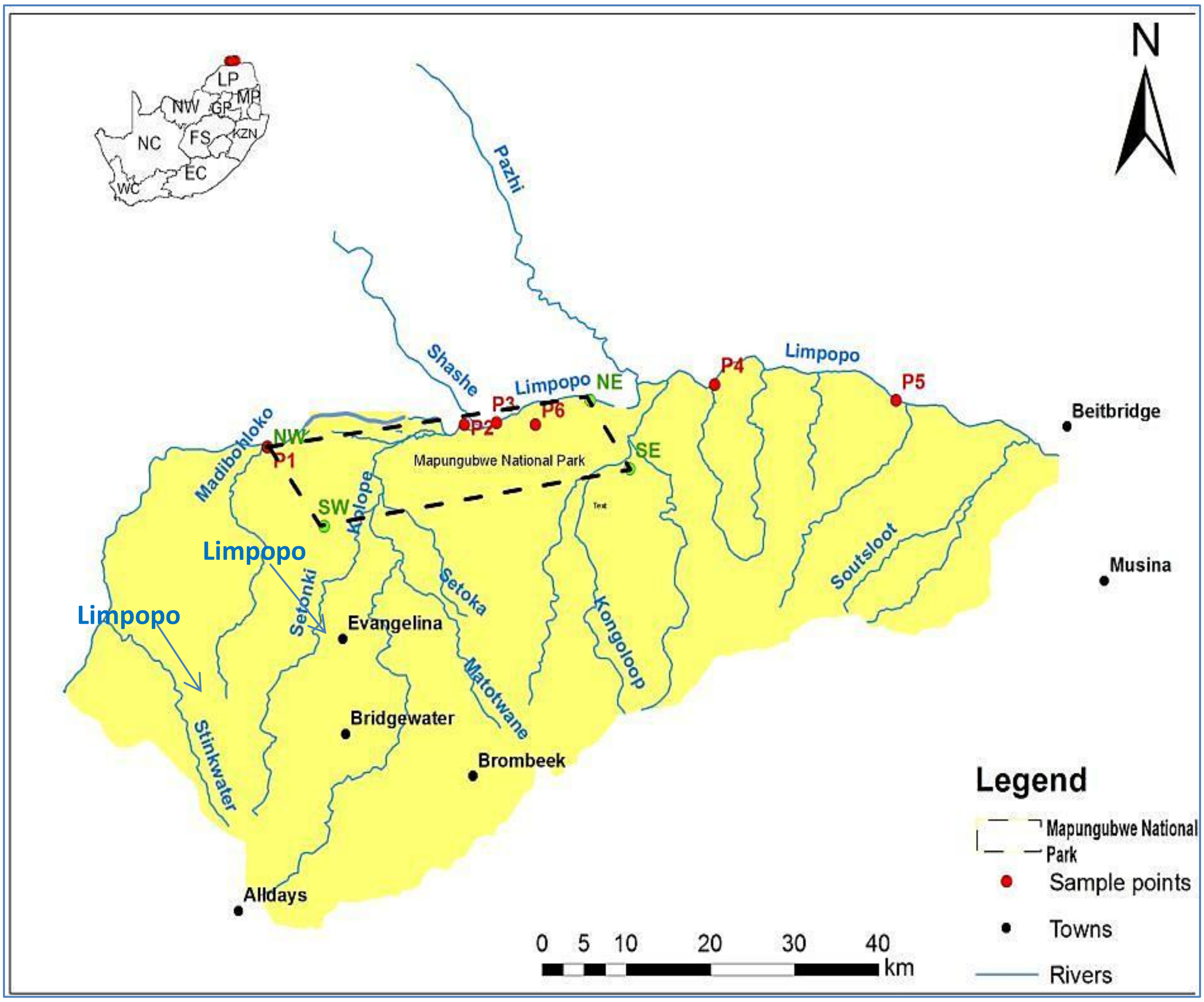


Figure 4.1: The location of water quality sampling points across the park.

Table 4.1: Descriptions of water quality sampling sites of the study area.

Sampling point identification	Description	GPS Coordinates	
		Latitude	Longitude
Point 1	This point is located on the Pondrift border on the Limpopo River. The border is located upstream of the park and the point is regarded as an indicator of the quality of the water entering the park. This point is located just before the border of the park.	$22^0$12.953’	029^0 08.369’
Point 2	This point is located within the park before the Limpopo-Shashe River confluence. It is used as an indicator of the quality of water within the park before the Shashe River discharges into the Limpopo River.	22^0 11.585’	029^0 21.015’
Point 3	Located after the Limpopo-Shashe River confluence, the point indicates the status of water quality after the two rivers have combined. It is also located within the boundaries of the park.	22^0 11.504’	029^0 23.050’
Point 4	The point indicates the water quality of the Limpopo River outside the boundaries of the park but upstream of the newly established Vele Colliery.	22^0 09.206’	029^0 37.056’
Point 5	Water quality of the Limpopo River after the Vele Colliery is indicated in this point. It is also located outside of the boundaries of the park towards the Beitbridge border.	$22^0$10.160’	029^0 48.673’
Point 6	Located within the boundaries of the park on Farm Schroda, the Schroda dam holds water used by the mine. The water is harvested during the rainy season and is abstracted from Limpopo River via wells.	$22^0$11.584’	029^0 25.563’

Figure 4.2: Pictures of the sampling points during sample collection at different intervals.

4.4.2. Sampling methodology

The concentrations of pH, TDS, turbidity, salinity, temperature, and EC were measured *in-situ*. A portable ExStik EC500 pH\Conductivity meter (indicated in Figure 4.3) was used. Concentrations of these parameters were obtained by dipping the instrument into the stream and recording the readings for each physical property from the instrument.

Figure 4.3: The portable ExStik EC500 pH\Conductivity meter.

Samples were also collected to determine concentrations of the other parameters in water. One grab sample of water was collected from each site on each monitoring date. Time, location and date were recorded for each sample collected. In order to avoid contamination, a set of new rubber hand gloves were worn for each sample collected. As elaborated in Figure 4.4, one-litre acid-washed opaque plastic bottles supplied by the laboratory (ARC-ISCW) were used to collect the water samples by dipping the bottle into the stream and dam until it was full. Samples for microbial analysis were collected for each sampling point at the same time with chemical samples. Sterile 250 millimetre bottles supplied by the laboratory were used to collect these samples. After collection, samples were stored in a cooler box with ice. Because of the distance between sampling location and the laboratory, the samples were stored in a refrigerator overnight and were placed into the cooler box with ice the following morning before being delivered to the ARC-ISCW laboratory for analysis.

Figure 4.4: Sequence of water sample collection (A-D).

4.4.3. Analytical procedure

Sample analysis was conducted by the Agricultural Research Council-Institute for Soil, Climate and Water (ACR-ISCW) laboratory in Pretoria. The following analytical procedures were applied in determining the concentrations of the parameters in the water samples.

4.4.3.1. pH, electrical conductivity and alkalinity

The pH, EC, carbonate and bicarbonate concentrations were determined sequentially using the ManTech Auto-titrator method. pH was measured after calibration with buffers 4, 7 and 10. EC was measured after calibration with an EC standard solution. Alkalinity refers to the acid-neutralising or buffering capacity of a solution. This method also measured the concentrations of hydroxide, carbonate, and bicarbonate, and total alkalinity in water. It was calculated as the sum of their values, and expressed as milligram of calcium carbonate per litre.

4.4.3.2. Anions (Fluoride, Chloride, Nitrate, Nitrite, Sulphate and Phosphate)

Ion chromatography was used for determining the amount of fluorides, nitrite, nitrate, chloride, sulphates, and phosphates in water samples. A filtered aliquot of the sample was injected into a flowing carbonate/bicarbonate eluent and carried through a series of ion exchange columns and into a conductivity detector. The first column has a guard column and it protects the analytical column by removing particulate and organic matter. The analytical column separated the anions by their relative affinities for a low-capacity, strongly basic anion exchanger. The last column, which is the suppressor column, provides continuous suppression of background conductivity of the eluent and enhances response of the target analytes by acidification. The separated anions in their acid form were measured by conductivity detection. The anions were identified based on their retention times and quantified by conductivity relative to standard response. The conditions of the instrument during analysis are stated in Table 4.2.

Table 4.2: Instrument conditions during analysis of anions.

Columns	Eluent	Flowrate	Column temperature	Detection	System back-pressure
Dionex ION pack AS22, 4x250 ml	4.5mM Sodium Carbonate,1.4mM Sodium Carbonate	1.2ml/min	$30^{o}C$	Suppressed Conductivity	1800psi

4.4.3.3. Cations (Calcium, Potassium, Magnesium, Sodium, and Boron)

This method describes the elemental determinations by Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) on calcium, potassium, magnesium, sodium, and boron. A sequential optical systems and radial viewing of the plasma was used. The instrument measures characteristic emission spectra by optical spectrometry. Samples were nebulized and the resulting aerosol was transported to the plasma torch. Element-specific emission spectra were produced by radio-frequency inductively coupled plasma. The spectra were dispersed by a grating spectrometer, and the intensities of the emission lines were monitored by the detector. The conditions of the instrument are indicated in Table 4.3.

The water samples were filtered using 0.5 micron filters and put on the auto-sampler vials. The calibration working range was from 1part per million to 100 part per million. The samples were run after the calibration was done and quantitated against the calibration for each cation.

Table 4.3: Conditions of the instrument during analysis of the cations.

Medium	Generator power	Peristaltic pump speed	Plasma gas flow	Auxiliary gas flow rate	Sheath gas flow rate
Aqueous very low salt content	1000W	20	PL1 = 12	0	0.2

4.4.3.4. Microbial analysis

Coliform bacteria were identified in water either as total coliforms or *E. coli.* Total coliforms can be present in water without *E. coli* being present but *E. coli* cannot be present in water without total coliforms also being present. The presence of total coliforms and *E.coli* in water samples were detected using Eosin Methylene Blue agar (EMB). These resulted in colonies of different colours, namely metallic green *(E.coli)* and pink (*coliforms*).

In preparing serial dilution water, nine millimetres of distilled water (dH_2O) were transferred into a McCartney Bottle and sterilized at 121 degrees Celsius. In preparing the media, appropriate grams of agar were weighed and dissolved into the distilled water (dH_2O). It was also sterilised at 121 degrees Celsius for 15 minutes. After sterilisation, the media was poured in the petri dishes (plates) and allowed to settle under the lamina flow. One hundred micrograms per litre (mg\µl) of diluted samples were pipetted in the appropriate plate. The glass spreader was removed from the alcohol and passed through a bunsen burner flame to ignite the alcohol. Once the alcohol was burned away, the spreader was air-cooled. Once cooled, the petri dish was opened and the sample was distributed over the entire surface of the plate. The glass rod was returned to alcohol and incubate plates were incubated for approximately three hours at 37^{o}C. After incubation the total number of colonies was counted from the plates that were countable. Colonies that were formed on EMB were counted and represented as colony-forming units per milliliter (CFU\ml). For the growth of heterotrophic bacteria in water samples, the standard method agar (a non-selective media) was used for the detection of total cultivable bacterial count.

Colonies that were formed on standard method agar were counted and represented as colony-forming units per millilitre (CFU\ml).

Generally, results were obtained by averaging the number of colonies on all plates from the same undiluted or diluted sample volume, and multiplying by a dilution factor. For example:

(89 colonies +103 colonies) / 2 plates= 96 colonies

96 colonies x 10 (dilution factor) =960CFU/ml

The dilution factor is the reciprocal of the volume of original, undiluted sample plated, and was used to standardise the results according to the sample volume. For example, if 1 millilitre of original sample was used, the dilution factor would be 1. If 0.1 millilitre of original sample was used, the dilution factor would be 10. The dilution factor for 1 millilitre of diluted sample (0.01 mL of original sample) is 100, and the dilution factor for 0.1 millilitre of diluted sample (0.001 mL of original sample) is 1000.

4.4.3.5. Trace metals

Inductively coupled plasma-mass spectrometry (ICP-MS) combines the sample introduction of ICP technology with low level detection of a mass spectrometer. The analysis process was separated into four main stages which are sample introduction, aerosol generation, ionization by argon plasma source, mass discrimination and detection system. The sample in solution was introduced by pneumatic nebulization into argon plasma at very high temperatures causing desolvation, ionization and atomization. The ions were extracted from the plasma through a differentially pumped vacuum interface and separated on the basis of their mass to charge ratio by a quadrupole mass spectrometer. The ions transmitted through the quadrupole were detected by an electron multiplier detector and the ion information processed by a data handling system. The interferences relating to the technique were recognized and corrected. The corrections include compensation for isobaric interferences and interferences from polyatomic ions derived from the plasma gas, reagents or sample matrix. The instrumental drift as well as suppressions or enhancements of instrument response caused by the sample matrix were corrected for by the use of internal standards. The samples were filtered using 0.45 micron filters and diluted ten times with an acidic diluent containing the internal standard. The calibration standards ranged from 5 parts per billion to 50 parts per billion. The samples are run with blanks and a quality control after calibration. The samples were run using the external calibration method.

4.5. PARTICIPATORY APPROACH

This method involves data collection in the form of a stakeholder participatory approach. Various stakeholders playing a role in the governance of the MNPHS and its surroundings were identified and interviewed using a structured questionnaire, and the data obtained was analyzed in order to understand the interaction between DPSIR factors in the study area (Carr *et al.*, 2007; Agyemang *et al*., 2007; el Sawah *et al.*, 2011).

4.5.1. Identification of participants

Participants were identified based on their role or involvement in management of socio-economic and environmental activities in and around the study area. A database of stakeholders was developed. Identified participants were mining industries, adjacent landowners (farming and tourism), research and academic institutions, NGOs, local communities and organs of state in all three spheres (local, provincial, and national government). Identified stakeholders were notified about the research and their participation was requested.

4.5.2. Design of a questionnaire

A draft questionnaire, guided by the components of the DPSIR model, is indicated in in Appendix A. It underlined the concepts raised by the model and their interaction with water quality around the study area. It aimed at obtaining the perceptions and knowledge of different stakeholders in relation to components of the model, land use activities, and understanding of water quality concerns around the MNPHS. The questionnaire allowed for broad-based data collection and had guidelines in explaining each concept of the model. The stakeholders were given five options per question in order to determine their extent of agreement, namely:

1-Strongly disagree

2-Disagree

3-Neutral or no opinion

4-Agree

5-Strongly agree

4.5.3. Collection of data

In gathering information from various participants, the following approaches were used:

- **Email** - An email, with the questionnaire and consent form attached, was sent to participants who were not available in person during data collection. These participants were requested to sign and complete the consent form and questionnaire and to return them via email. Some participants were reminded via telephone calls to complete the questionnaire after they indicated their willingness to participate.

- **One-on-one interviews and discussions** - Other participants were visited at their workplaces and farms for interview, discussion and completion of the questionnaire. These participants were also requested to give consent prior to participation.

- **Focus group discussions** – Three separate focus group discussions were held with participants from DWS (Limpopo region), Limpopo Economic Development, Environment and Tourism (LEDET), and the Department of Mineral Resources (Limpopo Province). Special attention was given to discussions around the socio-economic and environmental interactions around MNPHS and completion of the questionnaire by participants. The reason behind not having a multi-stakeholder focus group was the unavailability of different participants and the distances between their locations.

4.5.4. Analysis of the data

Once all completed questionnaires were received back from various participants, counting was done in order to determine the statistical proportion of answers to each question. Participant’s completed questionnaires were first grouped according to the sectors they represent (such as farming, government, NGO, tourism, academic and research institutions). The questions were then grouped into their relevance as per general environmental knowledge and the DPSIR model aspects. For example, main drivers of water quality changes such as economic, ecological or natural, and social factors were grouped together while sub-drivers of each main driver such as tourism, agriculture and industries were also grouped together. Assessment was done based on the proportion of responses from stakeholders or respondents. Utilising these responses, land use activities taking place around the study area, and the state of water quality, the DPSIR model was developed for the study area.

CHAPTER 5
RESULTS AND DISCUSSION: LAND USE IMPACTS

5.1. INTRODUCTION

The Mapungubwe National Park and Heritage Site (MNPHS) is surrounded by various land use activities that could possibly lead to negative impacts on water quality. According to du Plessis *et al.* (2014), most water quality challenges are associated with land use types surrounding water resources. This chapter identifies major land uses and discusses possible water resource pollution associated with them. Identified land uses are discussed in sections 5.2.1, 5.2.2, 5.2.3, and 5.2.4 while the summary of findings is presented in section 5.3.

5.2. ANALYSIS OF LAND USES AND IMPACTS

5.2.1. Conservation and tourism

The MNPHS was declared a national park in 1995 by the then Northern Province (now Limpopo province) when it was known as the Vhembe-Dongola National Park. The park is home to various types of animals such as herbivores, carnivores, omnivores, birds, and reptiles (Hermann *et al.*, 2015). Owing to its cultural landscape and the existence of a variety of animals, the conservation scope of the park was further expanded in 2004. A year earlier, the park was declared a heritage site by UNESCO, as shown in Figure 5.1 A. In the same year, it was renamed Mapungubwe National Park and World Heritage Site (Berry and Cadman, 2007; SANParks, 2013; Peace-Park, 2015). The presence of wildlife diversity coupled with its cultural landscape and state of the art museum (see Figure 5.1 B) became a tourist attraction for the area. According to SANParks (2013), apart from providing visitors with opportunity for animal viewing and educational facilities in the form of research and museum, the park also offers camping sites and accommodation to tourists. In 2011, 136 tourists and 67 employees could be accommodated by the park at any given time (SANParks, 2013; Sinthumule, 2014).

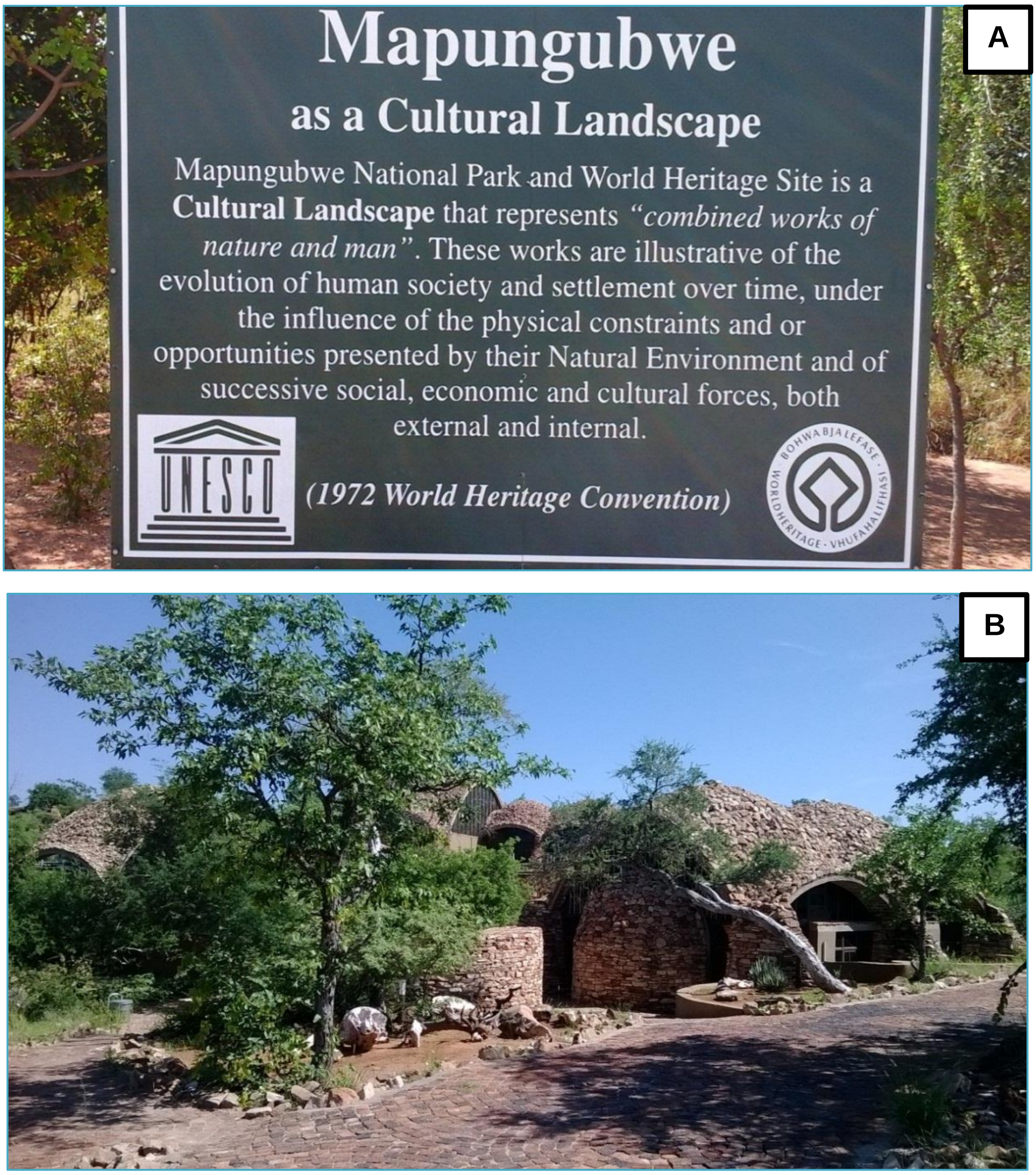


Figure 5.1: The UNESCO sign at the entrance of the MNPHS (A) and the museum within the park (B).

Several privately owned farms and nature reserves such as Vhembe, Venetia, and Limpopo Valley are found around the park on the South African side. Some of these privately owned lands are indicated in Figure 5.2. In addition to wildlife viewing, activities such as research, trophy hunting, and camping are provided in these areas. These game farms also provide accommodation in the form of camps and lodges for tourists (Jivanji, 2013; Henning and Beater, 2014).

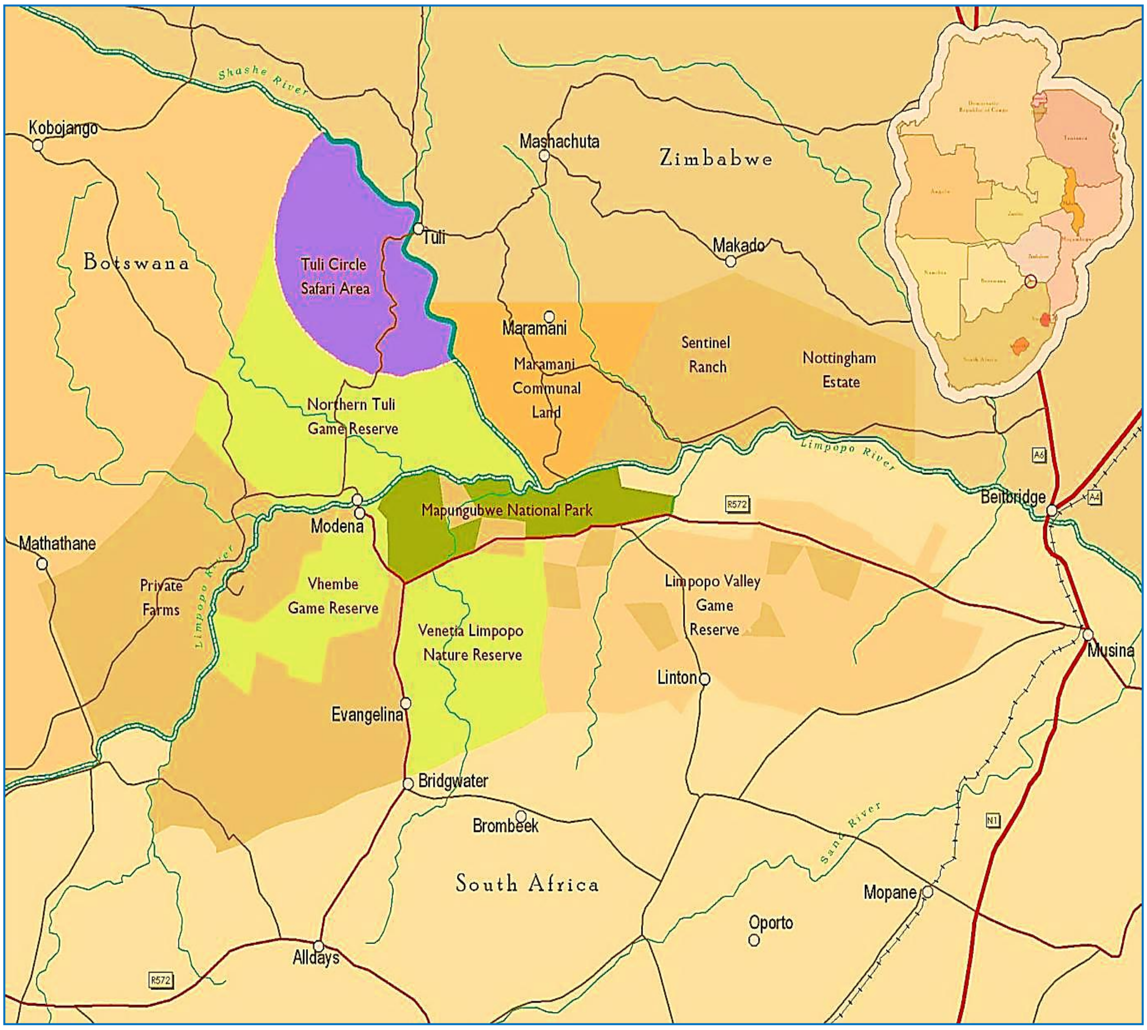


Figure 5.2: MNPHS and adjacent privately owned game reserves.

Source: Jivanji (2013).

On the socio-economic side, the presence of conservation activities and the tourism sector in the area contributes towards job creation. For example, Sinthumule (2014) notes that the MNPHS and the surrounding game reserves have directly led to nearly 73 employment opportunities. However, there are potentially water polluting activities that are associated with conservation and tourism occurring within and around the study area. The latter activities are discussed further.

5.2.1.1. Maintenance of wildlife and livestock

Diverse wildlife as well as livestock such as cattle and donkeys are found in and around the MNPHS. Figure 5.3 indicates some cattle which were spotted in the vicinity of the park. The movement of these animals could lead to overgrazing which could prompt and trigger the occurrence of soil erosion as reported in a related study in and around the Pilanesburg Nature Reserve in the Northwest province of South Africa (Rampedi, 1995). With accelerated soil erosion, sediments can be washed into the surrounding surface water resources during rainfall events, thus increasing the turbidity of receiving water resources (DEAT, 2006, Matowanyika, 2010).

The existence of animals is also linked with the prevalence of various microbial organisms in water, which may lead to the formation and dissemination of certain pathogens. When livestock and wildlife release faecal deposits directly into the water medium, microorganisms such as faecal coliforms and *E.coli* may be the end result (DEAT, 2006; Netshiendeulu and Motebe, 2012).

Figure 5.3: Cattle found in MNPHS.
Source: Hermann *et al.* (2015).

5.2.1.2. Impacts of human settlements

Densely populated residential areas such as Alldays and Musina are found approximately 50 kilometres away from the study area (Jivanji, 2013). The location of these towns is indicated in Figure 5.4. The park itself contains tourist camping sites and accommodation facilities for both tourists and staff. Privately owned game reserves also offer these facilities. Small populations of farmworkers and land claimants such as the Sematla and Machete communities also reside next to the study area (SANParks, 2013; Sinthumule, 2014).

Figure 5.4: Map indicating the towns of Musina and Alldays.

Human settlements are by their very nature environmentally degrading, as waste of all types is generated. With such settlements, the problem of solid waste mismanagement, littering and illegal waste disposal may result (Matowanyika, 2010). Such waste may contribute towards the turbidity of receiving water bodies. With human settlements, it is also necessary to establish wastewater treatment plants for the proper disposal of human excreta and the treatment of associated wastewaters. According to Henning and Beater (2014), a large number of households around the study area do not have access to proper sanitation services. While wastewater treatment plants in settlements such as Musina, Nancefield, and Alldays are operating optimally, the informal settlements rely on sanitation systems such as pit latrines, septic tank systems, and bucket toilets. Inevitably, such systems would lead to environmental impacts such as long-term and large-scale groundwater pollution.

Furthermore, wastewater treatment facilities may contribute towards the build-up of microorganisms as treated effluent is discharged into water resources (Germs *et al.*, 2004; Oberholster and Ashton, 2008). Similarly, phosphates and other nutrients can also enter water resources. With more water pollution and accelerated eutrophication, downstream human communities who consume or use such polluted water may suffer diseases such as diarrhea and malaria (Du Plessis *et al.*, 2014).

5.2.2. Impacts of agriculture

Several agricultural activities, mainly crop farming, are taking place upstream and downstream of the MNPHS (Carruthers, 2006; Berry and Cadman, 2007; CALS, 2015). Various products such as cotton, oranges, potatoes, maize, pumpkins and tomatoes are cultivated and harvested in this area. The produce supplies national and international markets. Henning and Beater (2014) report that, of the agricultural land found around the park, 1 286 hectares lie fallow, citrus farms take about 715 hectares, maize covers about 523 hectares, while tomato crops take about 351 hectares. Cotton covers about 46 hectares and the rest goes to other crops including planted pastures, perennial crops, lucerne, medics, and weeds. Some of the crop farming land uses are indicated in Figure 5.4.

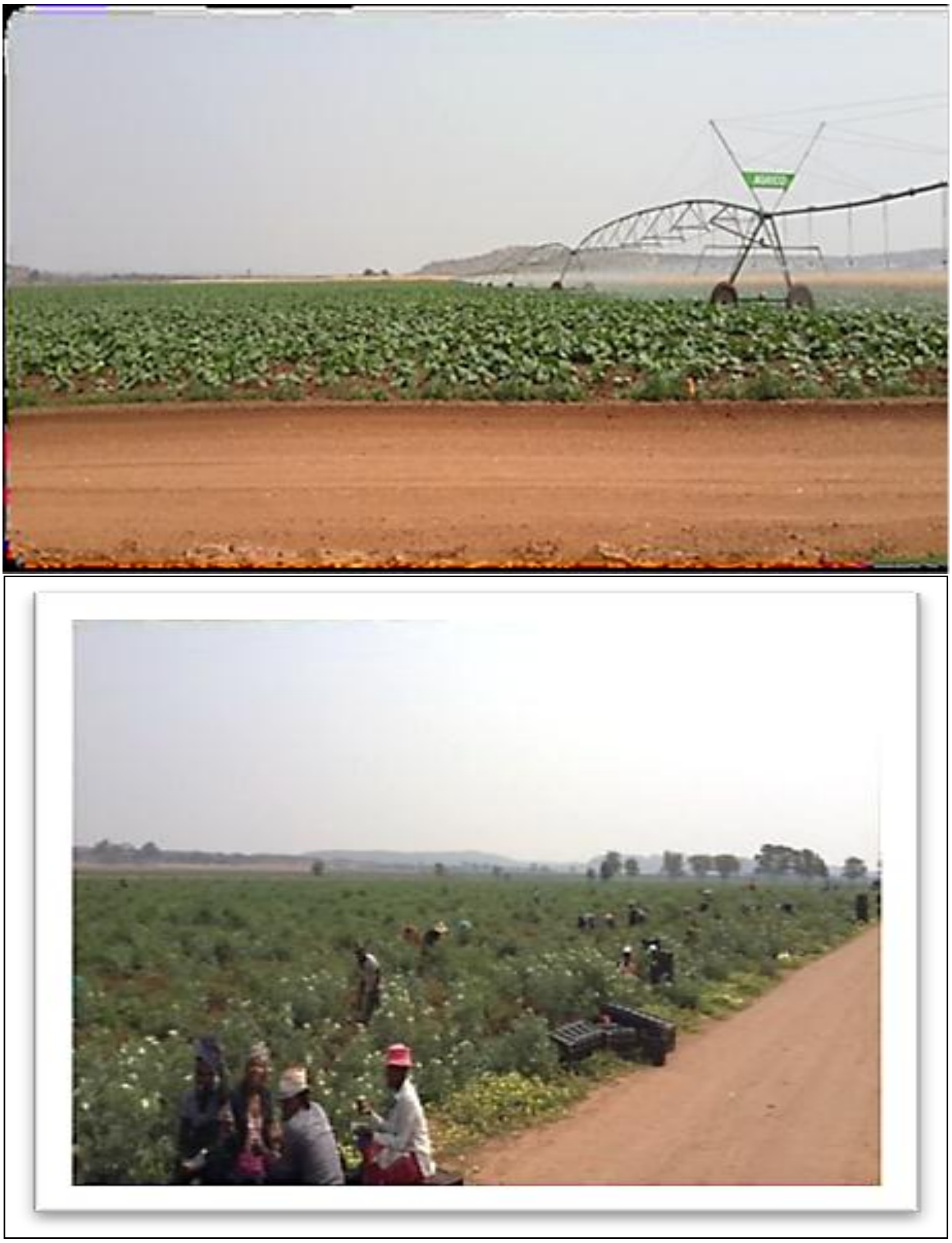


Figure 5.4: Agricultural activities occurring around MNPHS.

Source: Henning and Beater (2014).

Agriculture is one of the main sources of employment around MNPHS. Sinthumule (2014) estimates that 1 099 workers are permanently employed in the citrus and vegetation farming enterprises. Furthermore, approximately 3 080 temporary jobs are generated in the same agricultural industry during harvesting season of three to six months (Sinthumule, 2014). However, in spite of the socio-economic value of the agricultural practices, potential water quality degradation of the surrounding water resources can also emerge. Some of the critical water quality impacts include pollution caused by the following sources:

- **Sedimentation**

Erosion of the topsoil and agricultural waste such as leaves and weeds could lead to formation of sediments in the river. This will have an impact on the turbidity of the receiving water resources. Pollutants emanating from the use of nutrients and pesticides during crop farming can also be elevated in the receiving river channels. Sedimentation could have negative impacts on other water users such as mining and could affect the aquatic ecosystems health negatively (DWAF, 2004; DEAT, 2006; Shabalala and Combrinck, 2012; Dabrowsky and de Klerk, 2013).

- **Agro-chemicals**

In order to control weeds and insects that could damage crops, the utilisation of herbicides and pesticides such as Dichlorodiphenyltrichloroethane (DDT) is commonly practised in agriculture (Shabalala and Combrinck, 2012). Once applied to crops in the vicinity of the MNPHS, such persistent pollutants can be washed onto water resources through runoffs which could lead to their bioaccumulation, death of other organisms and making the water unsuitable for use by other water users in the catchment (Walsh and Wepener, 2009; DEAT, 2006).

- **Fertilisers**

Fertilisers are used to enrich soil in order to enhance crop growth with one or more nutrients. The use of fertilisers could lead to these nutrients being transported into receiving or nearby water resources through runoffs, especially during rainy season and irrigation. This could therefore elevate the concentrations of nutrients such as phosphorus, nitrogen, and potassium in the water. As a result, eutrophication will occur. The process of eutrophication can render water unusable for other water users (Germs *et al.*, 2004; Shabalala and Combrinck, 2012; Dabrowsky and de Klerk, 2013).

5.2.3. Mining

Two mining sites are found within a 50 km radius of the park. The Venetia diamond mine is located approximately 15 kilometres south-west of the MNPHS. The mine started operating in 1992 as an opencast mine and it is currently being developed into an underground mine (Venetia, 2015). Vele Colliery, which started operating in 2011, is located approximately seven kilometres east of the park (Limpopo Coal Company, 2014). The location of these two mining operations is illustrated in Figure 5.6. Through its cooperate social investment projects, the Venetia mine has assisted in building educational facilities such as schools and crèches, as well as the construction of roads, thus contributing towards social development in the communities living in the Blouberg and Musina municipalities (Blouberg, 2011; Musina, 2014). Various direct and indirect jobs were created through this mining operation. Similarly, once fully operational, the Vele colliery is also expected to play a significant role in employment and community development projects around the two local municipalities (Limpopo Coal Company, 2014). Henning and Beater (2014) indicate that several mining companies were issued with rights to prospect around MNPHS. This makes the area a potential mining hub in the near future.

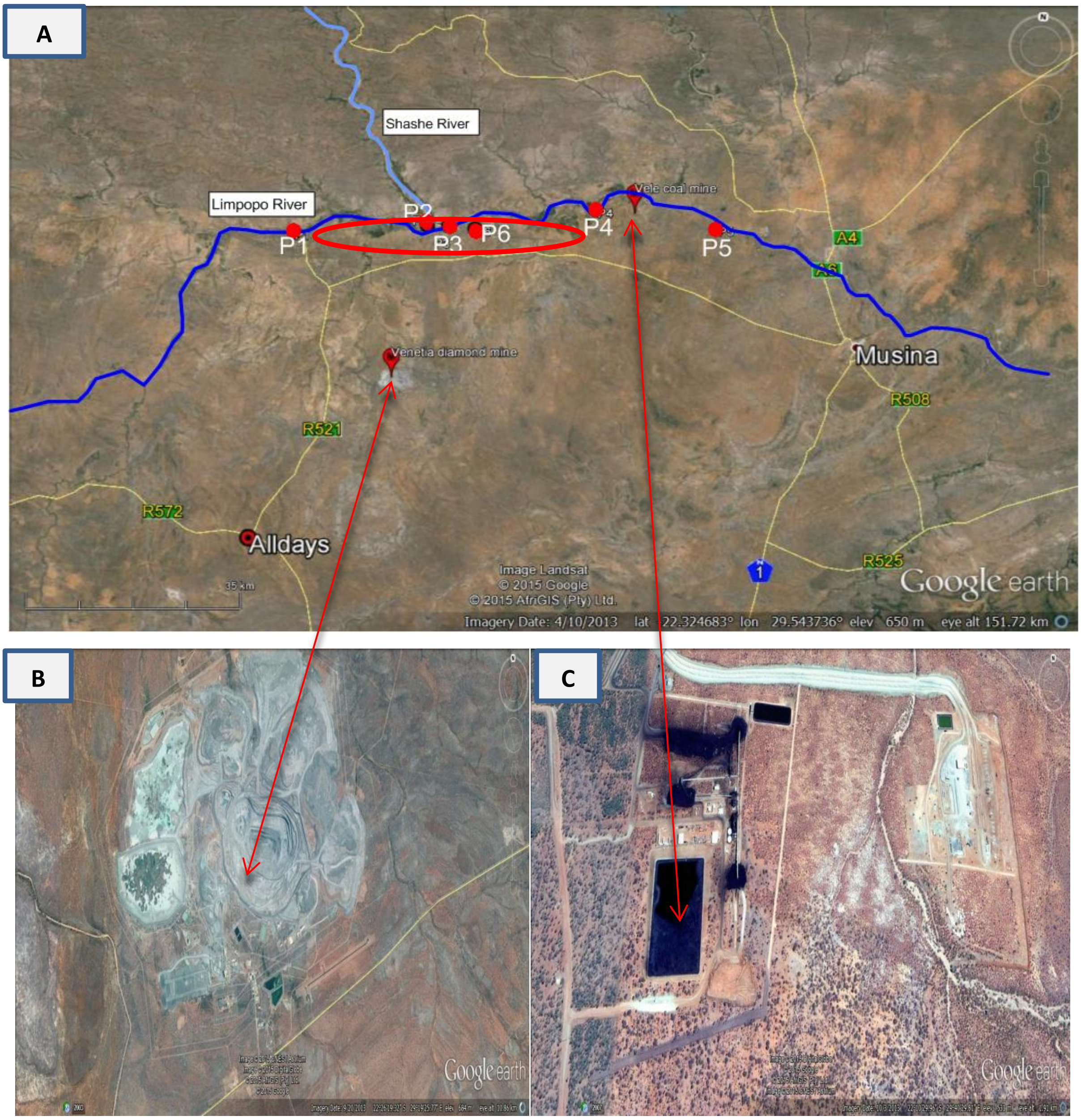


Figure 5.6: Location of two mines (A) adjacent to MNPHS and some mining activities (B-Venetia diamond mine, C-Coal of Africa coal stockyard) adjacent to MNPHS.

Water quality impacts associated with mining include sediments from poorly built roads during exploration and the disturbance of groundwater during mine or shaft construction. Water pollution from direct discharges of polluted water, seepage and runoffs from uncontrolled waste rock dumps could lead to the elevation of pollutants in the nearby water resources. Acid mine drainage (AMD) is the most common pollutant associated with coal mining. It is a very toxic pollutant which has the potential to accelerate oxidation and acidification processes, and the release of trace metals in water (Durand, 2010). The presence of AMD in water may lead to loss of aquatic life and can render affected water unusable by other water users such as agriculture (DWAF, 2004; CSIR, 2010). While diamond mines are associated mostly with pollutants such as nitrates, the impact of coal mines on water quality is regarded as one of the most significant due to acid mine drainage. This is already being experienced in coal mining towns such as in the Highveld region in Mpumalanga (CSIR, 2010; Dabrowsky and de Klerk, 2013).

5.3. SUMMARY OF FINDINGS ON LAND USE IMPACTS

The MNPHS is surrounded by various land users playing a significant role in socio-economic improvement and the promotion of environmental conservation in the study area. Figure 5.7 illustrates major land cover patterns around the MNPHS in 2014. Environmental conservation, tourism, agricultural, mining, and residential (both urban and rural settlements) activities have been identified as some of the major land uses in this region.

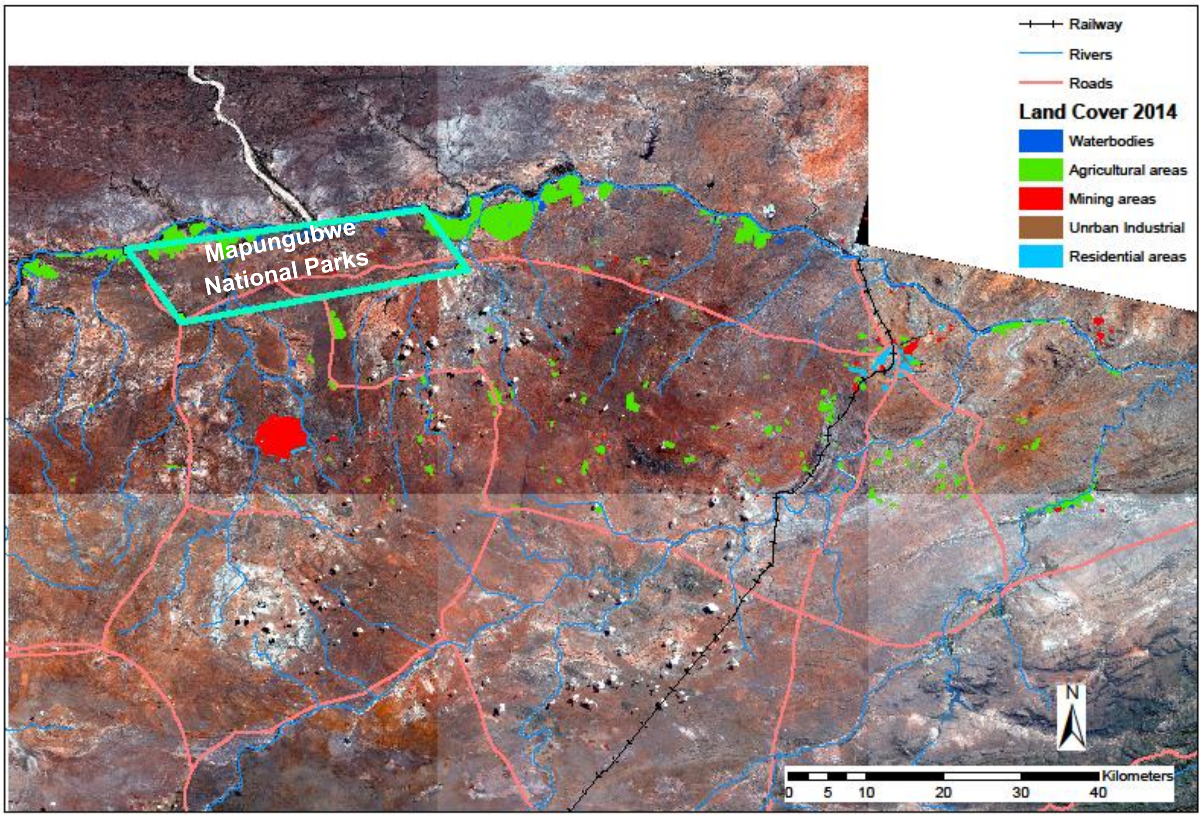


Figure 5.7: Land cover pattern around the MNPHS.

These activities are located either adjacent to or along the streams which are tributaries of the internationally shared Limpopo River. Apart from their socio-economic and ecological importance, each of the land uses can be associated with the contribution they can make as threats to water quality around the park, of which the Limpopo River is the main environmental receptor medium (SANParks, 2013; CALS, 2015). Changes in water quality resulting from any land use in this region can make water unsuitable for other uses. For example, changes in sulphate concentrations due to mining activities can make the water unsuitable for domestic usage (DWAF, 2004; DEAT, 2006).

Based on the 2014 land cover map (as indicated in Figure 5.7), the larger portion of the land is used for environmental conservation and tourism activities in this area. Although land use activities such as agriculture, mining, and human settlement are practised in smaller portions of the land and contribute positively towards socio-economic development of the area, various water pollutants are also associated with them. Pollution processes such as sedimentation, salinisation, AMD, eutrophication, and soil erosion could emanate from these activities (Germs *et al.*, 2004; CSIR, 2010; Shabalala and Combrinck, 2012; Dabrowsky and de Klerk, 2013; Henning and Beater, 2014). Water quality deterioration could prompt undesirable consequences such as negative human health impacts, loss of biodiversity, species migration, decrease in tourism attraction, and could also affect socio-economic interactions around the Limpopo province. However, based on the findings discussed in this chapter it appears pollution from these activities is not very strong under the prevailing settings. In the next chapter, the water quality status in the MNHPS is presented and discussed with more specific details.

CHAPTER 6

RESULTS AND DISCUSSION: WATER QUALITY

6.1. INTRODUCTION

This chapter presents and discusses research findings based on the water quality data obtained in and around the study area. Selected water quality parameters from various monitoring points were measured *in situ* and in the laboratory. Samples were collected on 9th August 2014, 9th January 2015, and 4th June 2015. The levels of these parameters were compared with drinking water quality standards and water quality guidelines currently being utilised in South Africa. Results from selected water quality characteristics are discussed in sections 6.2, 6.3, and 6.4 of this chapter, while a summary of findings is provided in section 6.5.

6.2. PHYSICO-CHEMICAL CHARACTERISTICS

The physical and chemical characteristics of water are collectively known as its physico-chemistry (Porteous, 2000). It highlights the physical properties of the particular water body as well as the concentrations of various chemicals. The levels of all of these properties in water determine its suitability for a particular use. The results of the selected physico-chemical properties of surface water around the study area are discussed in the subsections below.

6.2.1. Temperature

Temperature can exert control over aquatic ecosystems whereby its alteration can lead to shifts in the distribution and occurrence of aquatic species. Plants such as plankton flourish under different water temperatures while green algae and cyano-bacteria prefer temperatures of 30^{0}C and above (Palmer *et al.*, 2004; DWAF, 1996a). But according to DWAF (1996b), the temperature of inland surface waters in South Africa should range between 5^{o}C and 30^{o}C. The target water quality range (TWQR) of water temperature should not be allowed to vary from the background daily average water temperature considered to be normal for that specific site and time of day, by >2°C or by >10% (DWAF, 1996b). Using a portable meter, water temperatures were recorded *in situ* at different monitoring points during monitoring periods. The results are indicated in Figure 6.1.

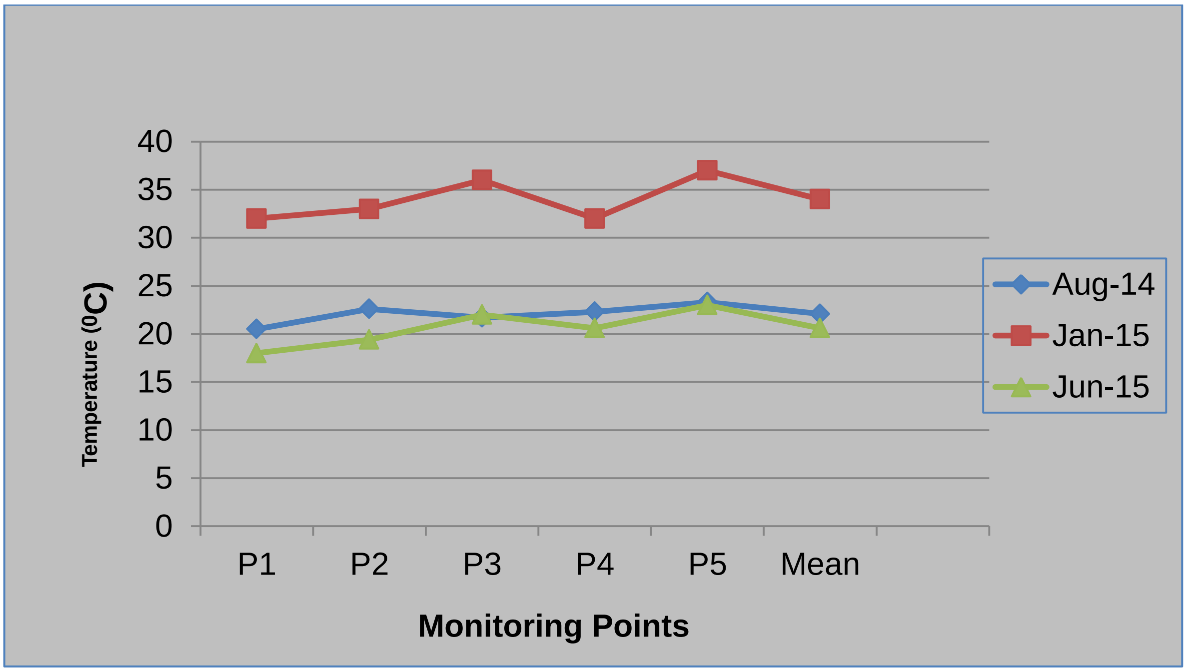


Figure 6.1: Water temperatures recorded at different monitoring sites between August 2014 and June 2015.

Natural factors such as climate could influence temperature of water (Oberholster and Ashton, 2008). The study area experiences high temperatures for most part of the year, with the highest temperature estimated to be 45ºC during the summer months (Ashton *et al.*, 2001; Götze *et al.*, 2008). To that extent, the highest water temperature of 37ºC was recorded during the summer monitoring period of January at sampling point P5. The variations in temperature could influence the presence of various chemical parameters in water systems in and around the study area.

6.2.2. pH

The level of pH is measured as a logarithm of between 1 and 14 whereby <7 indicates the acidity and >7 indicated alkalinity of the water (DWAF, 1996a). With a mathematical expression of - log [H+]; where [H+] is the hydrogen ion activity, a pH of 7 normally occurs at a temperature of 25^{o}C and it is regarded as neutral pH

(Palmer *et al.*, 2004). DWAF (1996a) indicates that for surface water, pH should typically range between 4 and 11 while geological and atmospheric conditions easily influence the pH for neutral water. pH is an important variable in water quality assessment as it influences many biological and chemical processes within a water body (Palmer *et al.*, 2004, WHO, 2008). Changes in pH influence the availability of important plant nutrients such as phosphate and ammonium (Matowanyika, 2010).

In this section, two sets of results are presented in Table 6.1. These are pH measured *in situ* and analysed in the laboratory. The results are then compared with the drinking water quality standard in Figures 6.2 and 6.3.

Table 6.1: pH values of different samples measured *in situ* and in the laboratory.

	August 2014		January 2015		June 2015	
Location	***In situ***	**Lab**	***In situ***	**Lab**	***In situ***	**Lab**
P1	8.3	8.2	7.8	8.1	7.9	8.8
P2	8.7	8.6	8.0	8.0	8.4	8.5
P3	8.9	8.8	8.1	8.3	9.1	9.2
P4	8.7	9.0	7.8	8.2	8.5	8.7
P5	8.8	8.7	8.3	8.2	8.7	8.8

There were no major differences observed between *in situ* and laboratory measured pH. For example, during the August monitoring period, an *in situ* pH of 8.3 was recorded at monitoring point P1 while a slightly lower pH of 8.2 was measured in the laboratory for the same monitoring point. The lowest pH recorded *in situ* was 7.8 on points P1 and P4 during the January monitoring period, while the highest was at point P3 at 9.1 during the monitoring period of June. The laboratory measured pH of the samples ranged between 8.0 and 9.2. The recorded mean pH across all monitoring points ranged between 8.0 and 8.8.

Figures 6.2 and 6.3 indicate the pH values at monitoring points as compared to South African National Standard (SANS 241 of 2011), also regarded as drinking water quality standards. This standard recommends that a pH ranging between 5.0 and 9.7 indicates that water is suitable for drinking purposes. The pH level outside this range can affect human health if consumed. The pH levels recorded *in situ* and in the laboratory indicate that pH was within the requirements of this standard. Therefore, it is unlikely that human health will be affected due to pH levels in the water if it is consumed.

Figure 6.2: *In situ* pH at monitoring sites measured against drinking water quality standard.

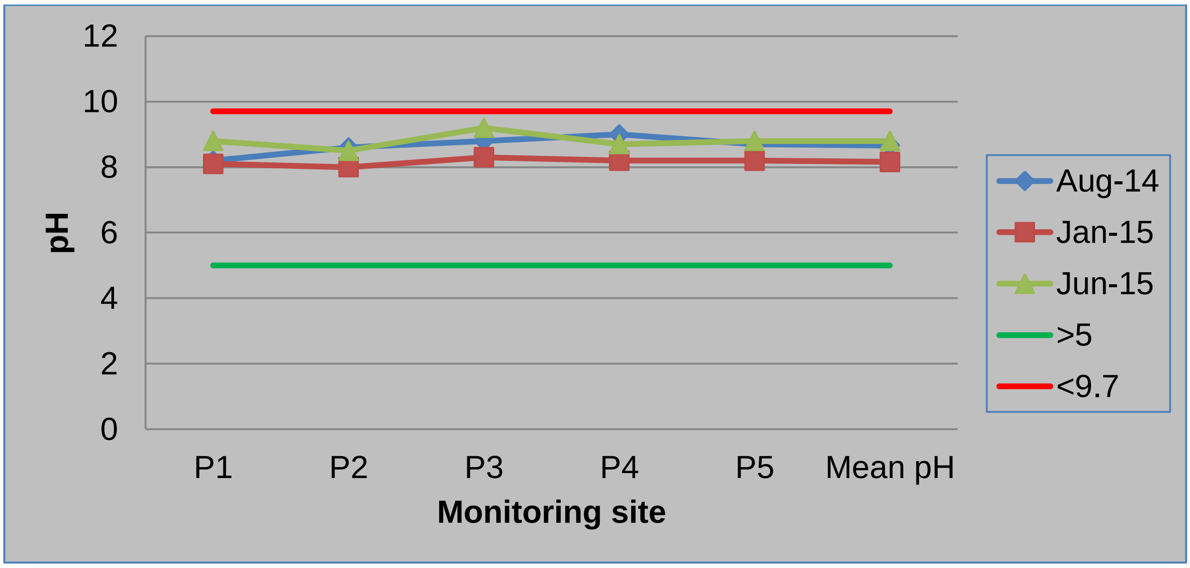


Figure 6.3: Laboratory pH at monitoring sites measured against drinking water quality standard.

The acceptable pH level for water used for irrigation-related purposes should range from 6.5 to 8.4 (DWAF, 1996b). A pH slightly higher than the recommended threshold was detected at some monitoring points. However, agricultural activities being practised in and around the study area utilised water abstracted from the Limpopo River (SANParks, 2013). Most aquatic ecosystems thrive under pH ranging between 6.5 and 8.0. None of the sites had a pH of below 6.5. However, at some monitoring points, a pH above 8.0 was recorded. In that sense, some aquatic species might struggle to adapt to these pH conditions and this could lead to species deaths or migrations (DWAF, 1996c; Oberholster and Ashton, 2008).

Direct discharges of wastewater from various industrial sectors such as mining, pulp and paper manufacturing, and domestic sewage management could influence pH levels in water. The use of calcium-based fertilisers and additives such as agricultural lime could also have an impact on elevated values of pH (Walsh and Wepener, 2009; Shabalala and Combrinck, 2012; Dabrowsky and de Klerk, 2013). Although high pH levels could also occur naturally, anthropogenic activities being practised around the study area such as agriculture and mining could potentially elevate the pH levels beyond acceptable limits (CSIR, 2010).

6.2.3. Electrical conductivity (EC)

Measured in micro siemens per metre (mS\m), electrical conductivity (EC) is the indication of the presence of ions in water and these highlight the capability of water to conduct electricity (DWAF, 1996a). EC does not identify the specific ions present in water. However, significant increases in conductivity may be an indicator that pollutants with ions are present in the particular water system. Electrical conductivity is also most commonly used as an indicator of salinity (van der Laan *et al.*, 2012). According to Matowanyika (2010), EC levels in water are usually elevated due to anthropogenic processes such as industrial discharges, salinity and leaching from waste-related activities. In this study, the levels of EC in water samples were determined *in situ* and using laboratory analysis methods. The results of both methods are indicated in Table 6.2.

Table 6.2: *In situ* and laboratory levels of EC (mS\m) in water during monitoring period.

	August 2014		January 2015		June 2015	
Location	***In situ***	**Lab**	***In situ***	**Lab**	***In situ***	**Lab**
P1	56.1	49	30.6	34	59.2	60
P2	57.3	49	29.2	31	75.3	81
P3	56.7	48	39.7	49	48	50
P4	71.9	60	27	30	86.5	828
P5	73.6	60	26.7	30	145.2	159

When comparing the levels of EC obtained using these two methods, the only significant variation in the levels was recorded during the monitoring period of June at sampling point P4. At this point, 86.5 mS\m was recorded *in situ* while 828 mS\m was analysed in the laboratory. This rapid increase in EC has been noted. EC levels of below 200 mS\m were recorded across all monitoring points using these two methods.

In Figures 6.4 and 6.5, the levels of EC obtained during monitoring periods were compared with the TWQR for drinking water quality standards. The standard recommends that the EC levels of water suitable for drinking purposes should be below 170 mS\m. At all monitoring points, *in situ* measured EC levels were below the stipulated threshold. There was a notable increase between points P4 and P5 during monitoring period of June. Levels measured in the laboratory also indicated conformance with the standard except for point P4 in June. Points P1, P2, and P3 are situated more upstream where activities that could potentially lead to elevated levels of EC are minimal, while P4 and P5 are situated downstream of park-related activities and agriculture. Therefore, it could be suggested that the rapid increase in EC is associated with upstream activities (Walsh and Wepener, 2009; van der Laan *et al*., 2012; Shabalala and Combrinck, 2012).

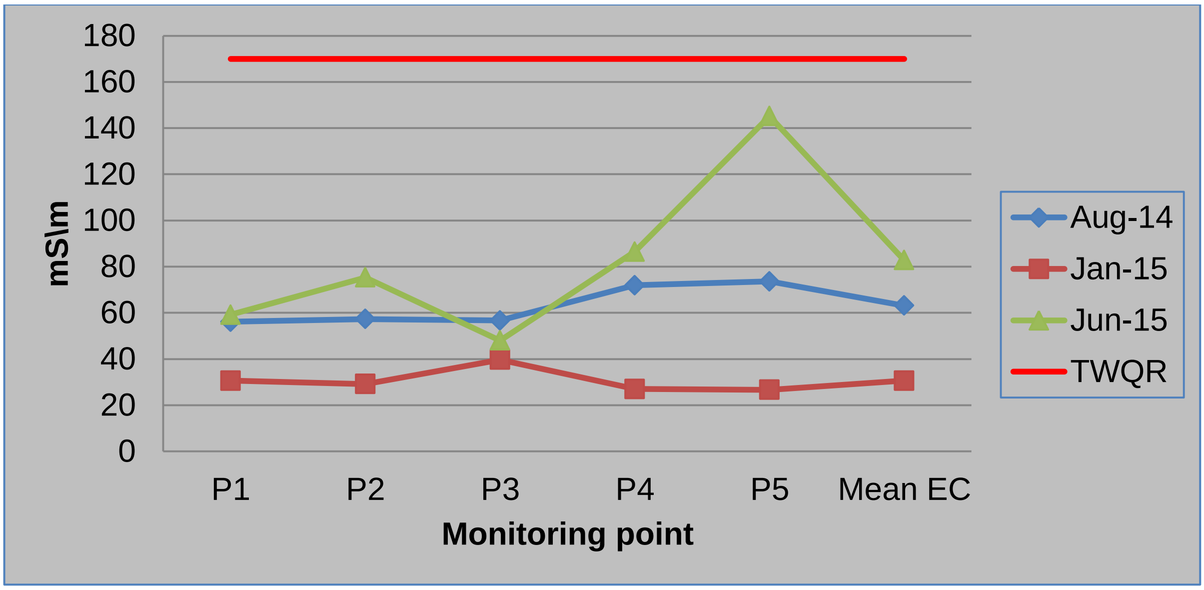


Figure 6.4: *In situ* EC at monitoring sites measured against drinking water quality standard.

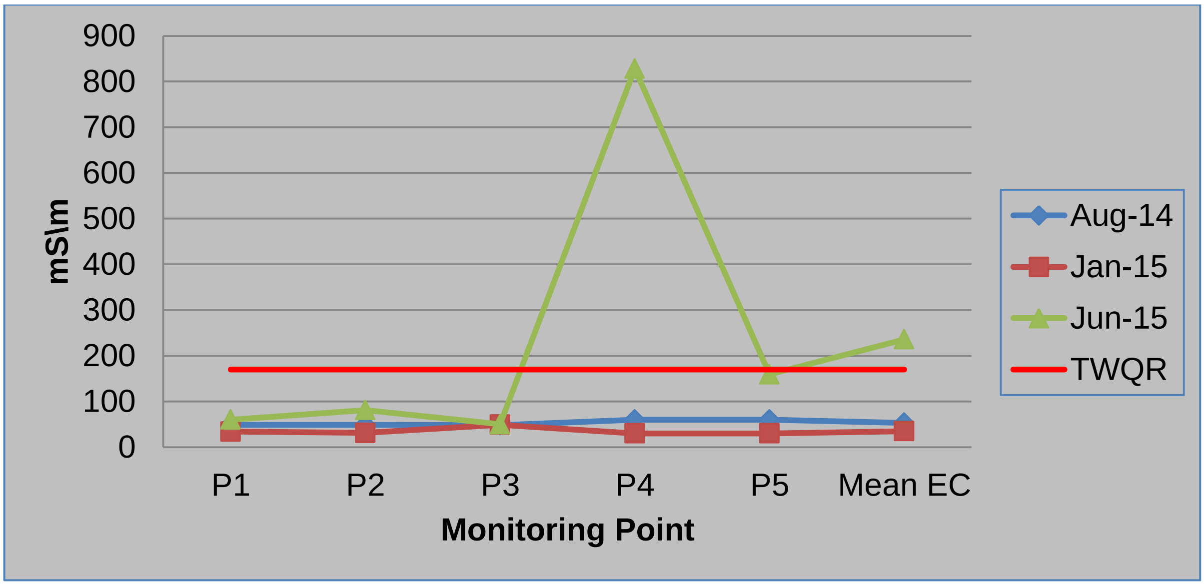


Figure 6.5: Laboratory EC for the monitoring sites measured against drinking water quality standard.

6.2.4. Total dissolved solids (TDS)

The availability of inorganic salts such as carbonates, chlorides, sulphates, nitrates, potassium, magnesium, calcium, sodium and dissolved materials in water is indicated by total dissolved solids (TDS). The level of TDS is measured in milligrams per litre (mg\L). These substances occur in water either due to natural activities such as evaporation or anthropogenic activities such as industrial discharges, urban runoff, domestic and agricultural activities (Palmer *et al.*, 2004; Oberholster and Ashton, 2008). According to DWA (1996c), the TDS level is directly proportional to the EC of water and since most dissolved substances in water carry an electrical charge, the EC level is usually used as an estimate of the level of TDS in the water.

In situ and laboratory-measured TDS levels are indicated in Table 6.3. Major differences are noted at most monitoring points when comparing the TDS levels recorded using these two methods. The results indicate that at all points, the TDS level measured *in situ* were slightly higher than the laboratory-analysed TDS. The only exception was at monitoring point P4 during June, where high TDS levels of 5148 mg\L were measured in the laboratory as compared to the 593 mg\L measured *in situ*. This discrepancy has been noted. The lowest TDS level measured *in situ* was at monitoring location P5 obtained in January at 183 mg\L, while the highest measured *in situ* was at point P5 at 5148 mg\L obtained in June. The laboratory-measured TDS ranged from 183 mg\L at point P2 in January to 873 mg\L at P5 in June.

Table 6.3: *In situ* and laboratory levels of TDS (mg\L) in water at monitoring sites.

	August 2014		**January 2015**		**June 2015**	
Location	***In situ***	**Lab**	***In situ***	**Lab**	***In situ***	**Lab**
P1	402	283	214	209	421	344
P2	392	278	279	183	525	433.2
P3	393	339	280	273	480	271.5
P4	509	415	189	171	593	5148
P5	504	418	183	169	907	873.4

The amount of TDS recorded during various monitoring periods was compared with the drinking water quality standards. The comparisons are further illustrated in Figures 6.6 and 6.7. This standard recommends that the TWQR for TDS should be below 1200 mg\L to consider the water suitable for drinking purposes. The TDS values measured *in situ* indicated that during all monitoring periods, the levels of TDS at various monitoring points conformed to the TWQR. The laboratory-determined TDS levels were also below the TWQR except at point P4 in June. TDS levels in this point were 5148 mg\L. It could also be noted that at this point, EC was high. This monitoring point is located downstream of several agricultural activities and the park. During monitoring, the water was stagnant and this could have contributed to a buildup in salts, resulting in high TDS (Shabalala and Combrinck, 2012).

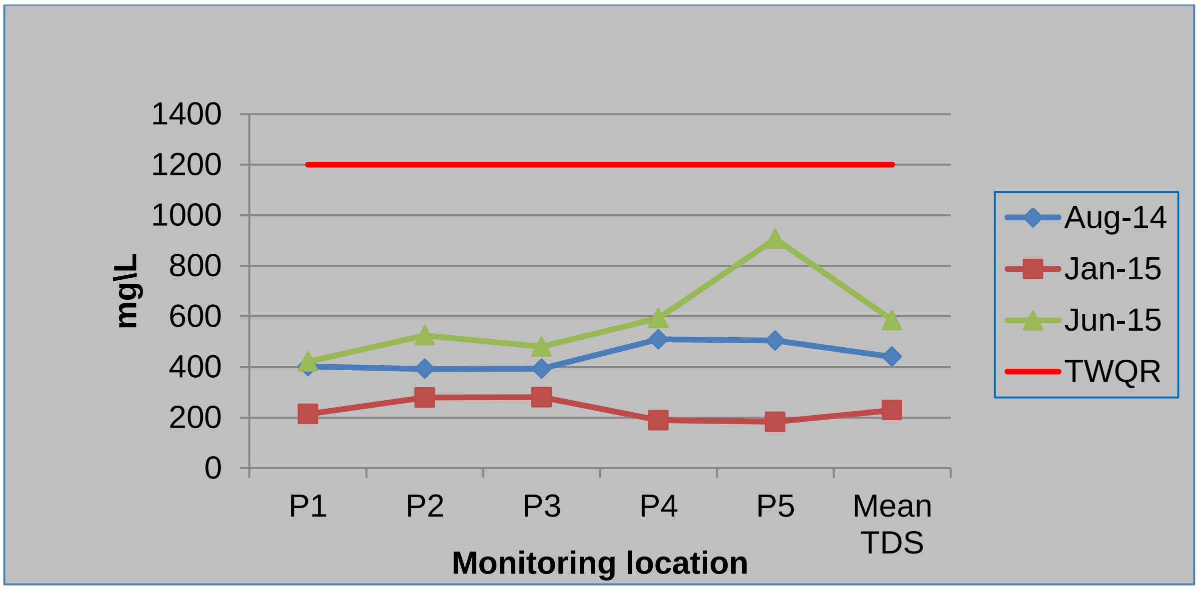


Figure 6.6: *In situ* TDS measured against drinking water quality standards.

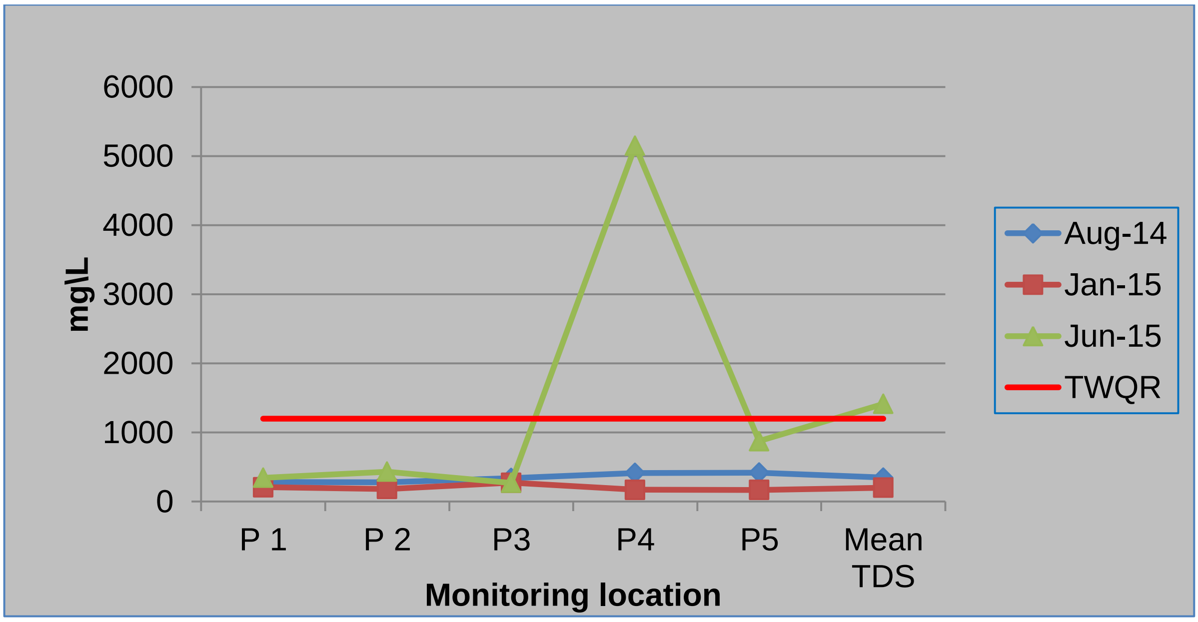


Figure 6.7: Laboratory TDS measured against drinking water quality standards.

The presence of TDS in water can be used for predicting the availability of inorganic salts. DWAF (1996b) further indicates that the TWQR for irrigation should be 540 mg\L. It was only in monitoring points P4 and P5 (for both *in situ* and laboratory measurements) that these limits were exceeded. DWAF's aquatic water quality guidelines (1996c) recommend that the TWQR of TDS in water should be below 110 mg\L. According to the research results, the levels of TDS were above the TWQR for the aquatic ecosystem in all monitoring sites at all monitoring periods. Therefore this high TDS levels might drive large scale changes to affected aquatic ecosystems (Oberholster and Ashton, 2008).

6.2.5. Salinity

The level of salts such as sodium chlorides (NaCl), sodium bi-carbonates ($NaCO_3$), magnesium sulphates ($MgSO_4$) are presented in water by salinity (Matowanyika, 2010). Salinity in water could be the result of natural processes such as rock weathering or anthropogenic activities such as land use change (Palmer *et al.*, 2004). DWAF (1996c) notes that high salt content may interfere with aquatic ecosystem growth. For the purpose of this study, the salinity of the water in the area was only measured *in situ*. The results are presented in Figure 6.8.

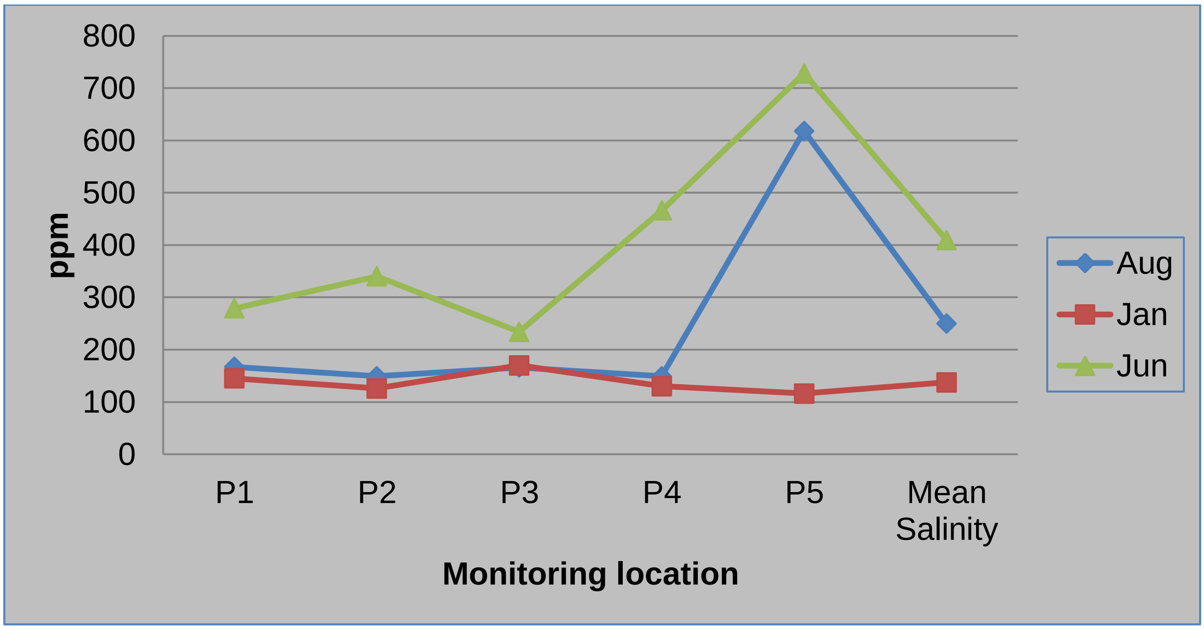


Figure 6.8: Salinity measured at monitoring sites.

The highest salinity levels in water were measured during the monitoring period of June while the lowest levels were recorded during the January monitoring period. This could be attributed to the fact that high flows were experienced during January, therefore no buildup of salts occurred. According to Palmer *et al.* (2004), elevated levels of EC could be experienced as a result of high salinity levels in water. The high salinity levels were recorded at monitoring point P5 in August (728 ppm) and June (618 ppm). This could be because water was stagnant at this monitoring site, thus contributing to the buildup of salts in water. There is currently no TWQR on salinity stipulated in South Africa's water quality guidelines or drinking water quality standards.

6.2.6. Sulphates (SO_4)

Sulphates (SO_4) are a common constituent of water and arise from the dissolution of mineral sulphates in soil and rock, particularly calcium sulphate (gypsum) and other partially soluble sulphate minerals (DWAF, 1996a). One of the most common water quality challenges emanating from mining activities is the formation of acid mine drainage (AMD). AMD has the potential to elevate levels of sulphates in water (CSIR, 2010). Industrial activities using sulphuric acids in their processes could also lead to the elevated levels (Durand, 2010). DWAF (1996a) explains that high levels of sulphates could cause diarrhea and give a bitter taste if the water is consumed. The levels of SO_4 obtained during monitoring periods are highlighted in Table 6.4.

Table 6.4: Sulphates (mg\L) levels at monitoring sites.

Location	August 2014	January 2015	June 2015
P1	51	31.02	41.59
P2	48.09	29.28	29.27
P3	48.01	31.08	20.52
P4	64.87	25.35	1258.51
P5	64.27	24.79	127.21

Laboratory analysis was used in determining the levels of SO_4 over different monitoring periods. In Figure 6.9, these measurements were compared with aesthetic (<250 mg\L) and acute health (<500 mg\L) TWQR as recommended by SANS 241(2011). The level of SO_4 ranged between 20.52 mg\L and 1258.51 mg\L across the monitoring points. The obtained levels conformed to the TWQR required by the standard in all the monitoring points during the monitoring periods, except for rapid elevated levels of 1258 mg\L at P4 recorded during June. Low levels of SO_4 in most monitoring points highlight that there are currently no signs of discharge from anthropogenic activities with the potential to cause increases in SO_4 levels. Mining, particularly of coal and gold, is the most common activity in this regard (Dabrowsky and de Klerk, 2013). The results below TWQR further highlight that, if consumed, diseases such as diarrhea are unlikely to be experienced due to SO_4 levels (DWAF, 1996a). There is currently no TWQR specified by DWAF's water quality guidelines for irrigation and aquatic uses.

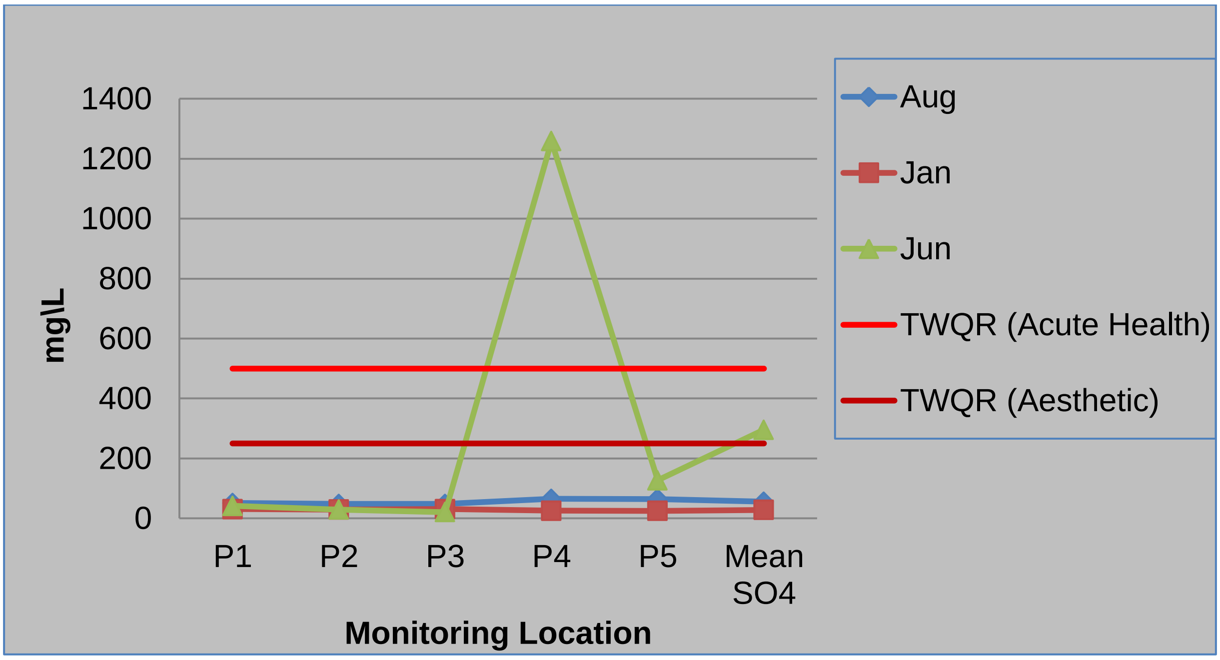


Figure 6.9: Sulphates at monitoring sites measured against drinking water quality standard.

6.2.7. Chlorides (Cl^-)

According to DWAF (1996b), chlorine occurs in water as chloride (Cl^-) and is deposited in water through atmospheric deposition of oceanic aerosols, weathering of some sedimentary rocks (mostly rock salt deposits) and from anthropogenic activities such as industrial, sewage effluents, agricultural and road runoffs. DWAF (1996a) states that Cl^- is very soluble, and their elevated levels impart a salty taste to water, accelerate the corrosion rate of metals and can also be detrimental to chloride-sensitive garden plants. The Cl^- levels for different monitoring points measured are presented in Table 6.5.

Table 6.5: Chlorides (mg\L) levels at monitoring sites.

Location	August 2014	January 2015	June 2015
P1	46	48.32	86.52
P2	46.23	42.92	116.58
P3	46.09	75.5	67.84
P4	79.28	39.68	2133.59
P5	75.14	38.18	344.76

Figure 6.10 indicates the levels of Cl^- measured against TWQR for drinking water of 300 mg\L at various monitoring sites and periods. The Cl^- levels ranged between 38.18 mg\L and 2133 mg\L over the monitoring periods. It was only during the month of June that levels of the Cl^- did not comply with the required TWQR of the drinking water quality standards (P4 at 2133 mg\L and P5 at 344.76 mg\L). During this period when Cl^- levels are high, high TDS (indicated in Figure 6.7) was also obtained. High levels of TDS highlight the presence of ions such as Cl^- in water (DWAF, 1996a). Activities such as agriculture and mining could contribute to elevated levels of Cl^- in water through discharges and runoffs of contaminants (Dabrowsky and de Klerk, 2013).

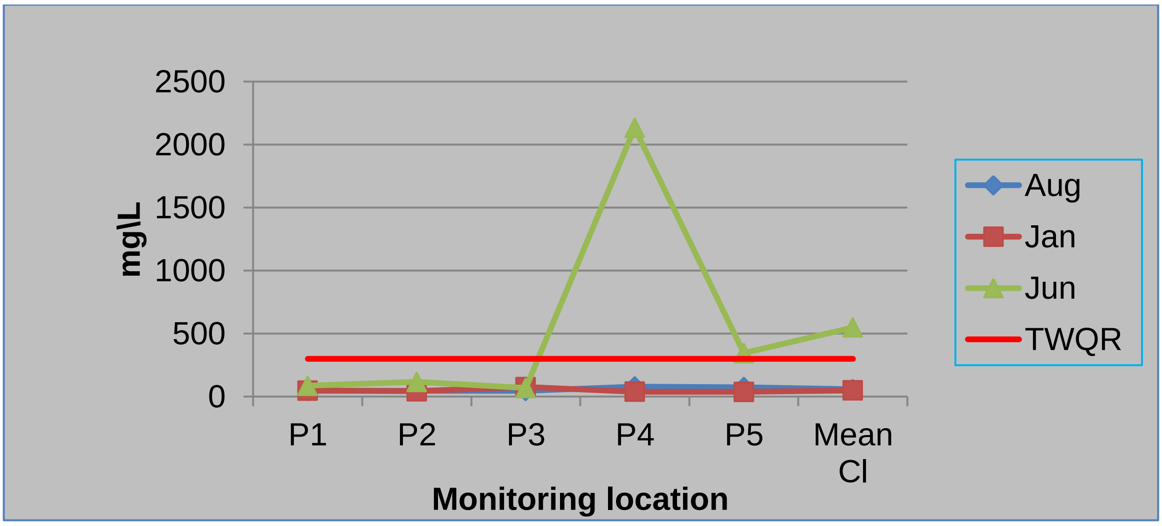


Figure 6.10: Chlorides at monitoring sites measured against drinking water quality standards.

6.2.8. Fluorides (F^-)

Fluoride (F^-) is the most electronegative member of the halogens and has a strong affinity for positive ions while it readily forms complexes with many metals (DWAF, 1996a). In water, F^- occurs due to anthropogenic activities such as industrial and agricultural pollution, while natural factors and geological variables such as composition of the soils and rocks as well as climatic conditions also lead to the formation of fluorides in natural water (Palmer *et al.*, 2004). The presence of F^- in drinking water reduces the occurrence of dental caries in adults and children while skeletal fluorosis may occur if exposure to intermediate F^- levels occurs over long periods (DWAF, 1996a; DWAF, 1996c). The F^- levels obtained at various monitoring points are indicated in Table 6.6.

Table 6.6: Fluorides (mg\L) at monitoring sites.

Location	**August 2014**	**January 2015**	**June 2015**
P1	0.46	0.3	0.43
P2	0.37	0.31	0.45
P3	0.26	0.34	0.25
P4	0.3	0.29	2.17
P5	0.29	0.27	0.61

The TWQR for F^- in drinking water should be below 1.5 mg\L as per recommended drinking water quality standards. Measured levels of F^- ranged between 0.25 mg\L and 2.17 mg\L over different monitoring periods. Although the mean F^- shows compliance with the TWQR for drinking water, high levels were noted on monitoring point P4 during the month of June. It is therefore suggested that no health impacts could be expected from the presence of F^- in the water systems around the study area, as the levels were conforming to the TWQR.

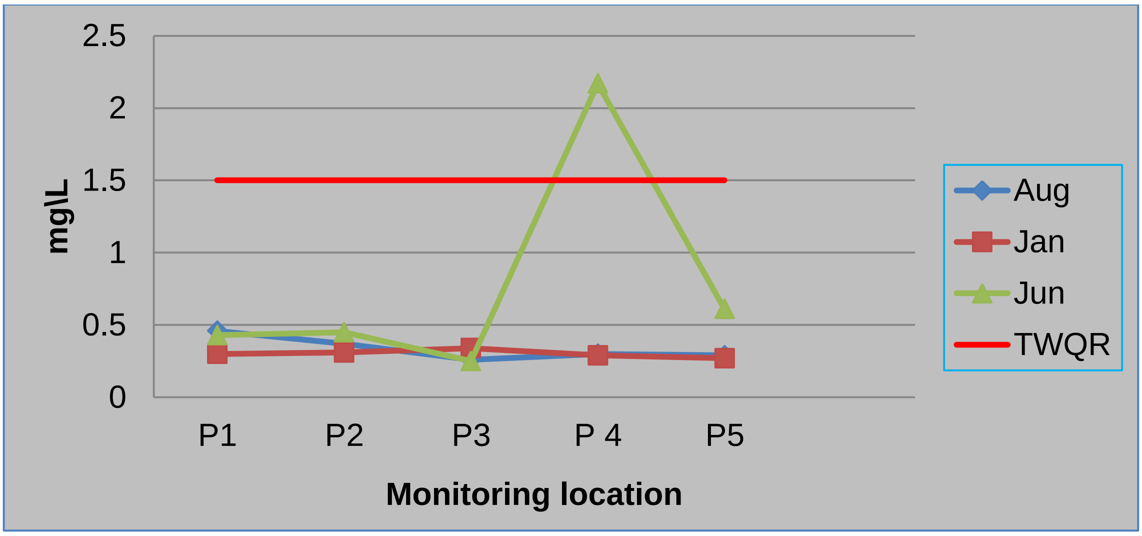


Figure 6.11: Fluorides at monitoring sites measured against drinking water quality standards.

6.2.9. Nitrates (as N)

Nutrients such as nitrates stimulate the growth of macrophytes (aquatic plants) and phytoplankton (algae) in water through the eutrophication process (Oberholster and Ashton, 2008; van der Laan *et al.*, 2012). The presence of phosphorus in water allows for the assimilation of more nitrogen before phosphorus is depleted. Usage of fertilisers along water bodies and urban runoffs from dense settlements increase the presence of nitrates in water (Matowanyika, 2010). Upon absorption by human beings, nitrates combines with the oxygen-carrying red blood pigment, haemoglobin, to form methaemoglobin, which is incapable of carrying oxygen, and this condition is termed methaemoglobinaemia (DWAF, 1996a). Reaction of nitrate with haemoglobin can be particularly hazardous in infants under three months of age and is compounded when the intake of Vitamin C is inadequate. Table 6.7 indicates the levels of nitrates in water samples.

Table 6.7: Nitrates (mg\L) levels at monitoring sites.

Location	August 2014	January 2015	June 2015
P1	7.28	0.23	1.47
P2	2.99	0.2	1.69
P3	0.77	1.83	1.12
P4	2.34	0.08	12.76
P5	0.46	0.11	2.31

The nitrate level of the monitored water points ranges from 0.1 mg\L to 12.76 mg\L. When measured against the TWQR for drinking water quality standards, few monitoring points indicated that nitrate values were higher than the recommended levels of 0.9 mg\L. The mean levels of this variable were also above this range for the monitoring periods of June and August. Anthropogenic activities such as usage of fertilisers, animal manure, cattle farming, and sewage effluent could lead to elevated levels of nitrate (Netshiendeulu and Motebe, 2012). Shabalala and Combrinck (2012) suggest that low flow of water could also contribute to these high levels, especially when the surrounding land uses have potential to cause high levels of nitrates. This can have a negative impact on human health, especially causing diseases such as methaemoglobinaemia (DWAF, 1996a).

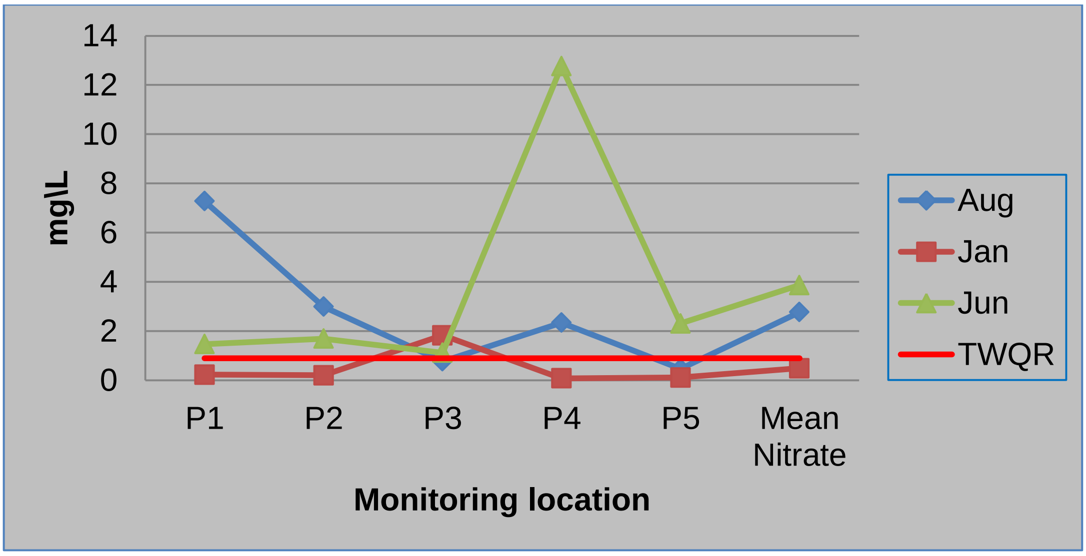


Figure 6.12: Nitrates at monitoring sites measured against drinking water quality standards.

The aquatic and irrigation water quality guidelines recommend the nitrate TWQR for these water uses to be 10 mg\L and 30 mg\L, respectively (DWAF, 1996b; DWAF, 1996c). The nitrate levels at all monitored sites conformed to the irrigation TWQR while only the June water sample showed elevated levels at P4. At high levels of nitrates, eutrophication conditions are likely to occur. DEAT (2006) explains that high levels of nitrates in water could lead to low levels of species diversity, nuisance growth of aquatic plants and blooms of blue-green algae. Algal blooms may include species which are toxic to man, livestock and wildlife (DWAF, 1996c).

6.2.10. Sodium (Na)

Sodium (Na) is an alkali metal which is very soluble in water to form sodium ions (DWAF, 1996a). According to DWAF (1996c), Na is ubiquitous in the environment and usually occurs as sodium chloride (NaCl), but sometimes as sodium sulphate, bicarbonate or even nitrate. Formations of Na in water could be caused by deposition of industrial wastes, especially from processes that give rise to brine or contain elevated levels of sodium (DWAF, 1996c; Palmer *et al*., 2004). Na is also present at high levels in domestic wastewater due to the addition of table salt (sodium chloride) to foods. Furthermore, with re-use or recycling of water, the sodium levels will tend to increase with each cycle or addition of sodium to the water. For this reason, sodium levels are elevated in runoffs or leachates from irrigated soils (DWAF, 1996a). Na also occurs in water naturally from geological formations such as rock weathering (Palmer *et al.*, 2004). The Na results obtained from various monitoring periods are presented in Table 6.8.

Table 6.8: Sodium (mg\L) levels at monitoring sites.

Location	August 2014	January 2015	June 2015
P1	44	29.49	57.57
P2	45.75	27.76	61.18
P3	44.67	38.02	42.18
P4	64.33	24.84	1222.1
P5	65.83	24.2	170.07

The levels of Na obtained at all monitoring points over the monitoring period were compared with the drinking water quality standards and are indicated in Figure 6.13. The drinking water quality standards recommend that the acceptable levels of Na be below 200 mg\L in drinking water. The levels ranged from 24.2 mg\L to 1222.1 mg\L respectively (see Figure 6.13). The highest level of Na measured was at monitoring location P4 in June at 1222.1 mg\L. The Na levels generally conform to drinking water quality standards.

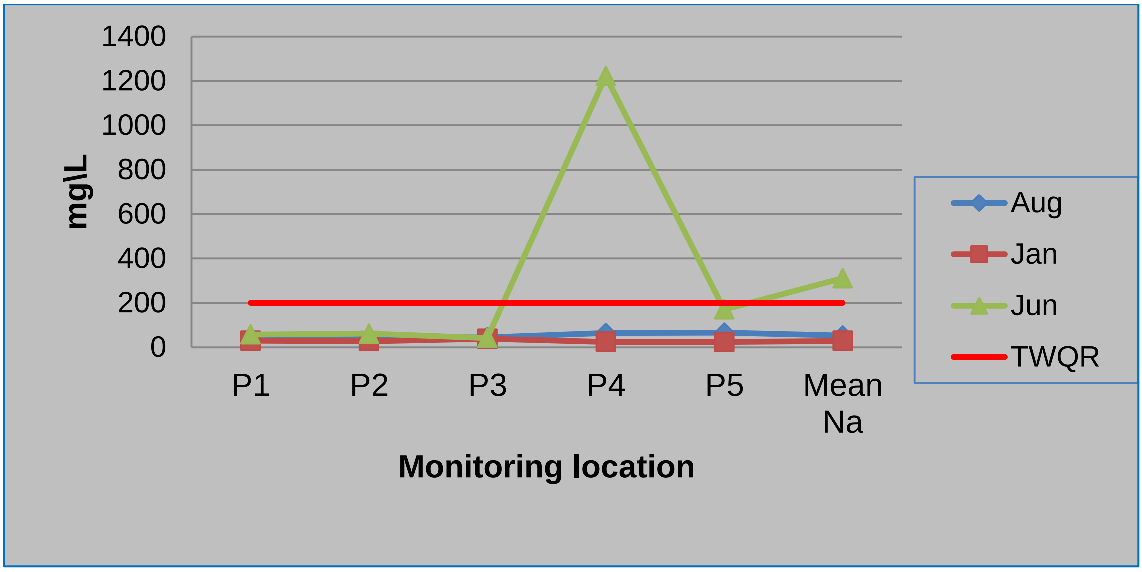


Figure 6.13: Sodium at monitoring sites measured against drinking water quality standards.

6.2.11. Potassium (K)

Just like Na, potassium (K) is also an alkali metal which is very soluble in water, forming potassium ions, but unlike Na, low levels of K are found in wastes and brines. This is because sodium salt is cheaper than potassium salt (DWAF, 1996a) and is more utilised in water treatments and recycling methodologies. Furthermore, K also does occur naturally in minerals and from soil. High levels of K may occur in runoff from irrigated lands, fertiliser production and domestic wastes (and Combrinck, 2012). Levels of K obtained over monitoring points in the study area are indicated in Table 6.9.

Table 6.9: Potassium (mg\L) levels at monitoring sites.

Location	August 2014	January 2015	June 2015
P1	5.05	4.67	4.95
P2	4.92	4.32	4.29
P3	4.99	5.35	3.36
P4	4.87	4.36	9.95
P5	5.49	4.02	6.04

The levels of K obtained during monitoring periods ranges between 3.36 mg\L and 9.95 mg\L. When compared with the recommended TWQR of 50 mg\L, all monitoring points conformed to the drinking water quality standards. Therefore, health effects are unlikely to be experienced due to the presence of low K levels in water around the study area. There is no specified TWQR for water utilised for aquatic ecosystems or irrigation in South Africa.

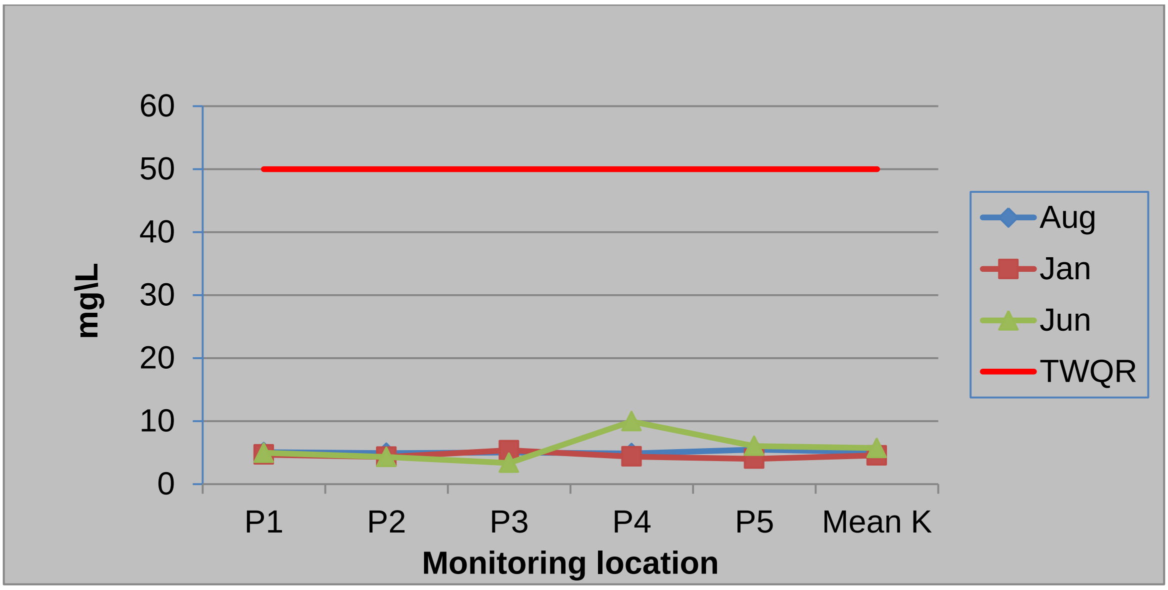


Figure 6.14: Potassium at monitoring sites measured against drinking water quality standards.

6.2.12. Calcium (Ca)

Calcium (Ca) occurs naturally in varying levels in most water and, together with magnesium, is one of the main components of water hardness (Palmer *et al.*, 2004). Soft water contains low levels of Ca, while hard water contains high levels of Ca (DWAF, 1996b). Calcium is an essential element for all living organisms and is an important constituent of the bony skeleton of mammals, while its solubility is influenced by pH and temperature (DWAF, 1996a). In Table 10, the levels of Ca obtained during various monitoring periods are shown.

Table 6.10: Calcium (mg\L) levels at monitoring sites.

Location	August 2014	January 2015	June 2015
P1	28.4	29.3	44.15
P2	30.08	21.32	61.15
P3	29.9	38.48	33.41
P4	31.33	23.21	203.19
P5	32.43	23.67	59.78

When compared with the recommended TWQR of less than 150 mg\L in drinking water, all monitoring sites indicated conformance except site P4 in June (shown in Figure 6.15). There is no TWQR available for Ca for freshwater aquatic ecosystems but calcium levels up to 250 mg\L are acceptable for all water users (DWAF, 1996c).

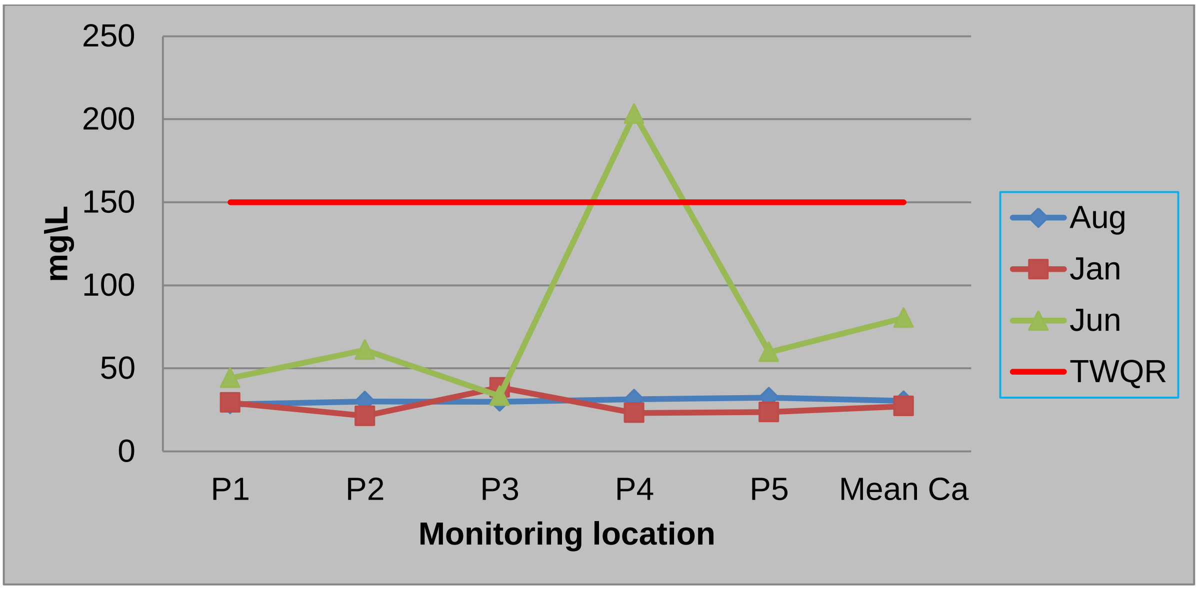


Figure 6.15: Calcium at monitoring sites measured against drinking water quality standards.

6.2.13. Magnesium (Mg)

Like calcium, magnesium (Mg) represents the hardness of water. The solubility of Mg in water is governed by the carbonate/bicarbonate equilibrium and hence, the pH. Common minerals of Mg are magnesium carbonate and various magnesium silicates (DWAF, 1996a). It is also regarded as an essential nutritional element. Mg is also a basic, essential element for plants (the central metallic ion in chlorophyll) and most other living organisms, since it is a component of important enzyme co-factors (DWAF, 1996a). Table 6.11 indicates the levels of Mg obtained during monitoring period.

Table 6.11: Magnesium (mg\L) levels at monitoring sites.

Location	August 2014	January 2015	June 2015
P1	19.34	12.48	22.93
P2	20.01	10.22	31.78
P3	19.57	15.51	22.47
P4	20.74	9.34	179.71
P5	21.29	9.12	51.44

The levels of magnesium in the water samples ranged between 9.12 mg\L to 179 mg\L over the monitoring period. When compared with the recommended TWQR of below 70 mg\L, only point P4 in the monitoring period of June was above the drinking water quality standards. However, the mean levels indicate overall compliance to the standards as they were all below the 70 mg\L (as shown in Figure 6.16).

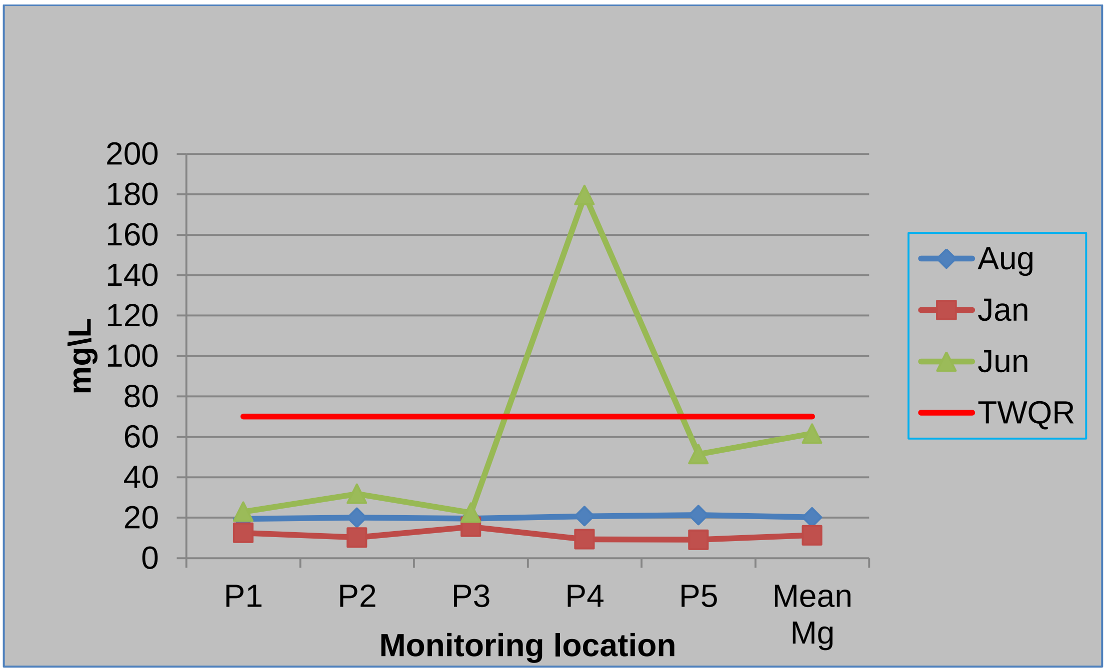


Figure 6.16: Magnesium at monitoring sites measured against drinking water quality standards.

6.2.14. Trace metals

Measured in micrograms per litre (ug\L), trace metals in water evolve due to natural factors such as geological weathering, atmospheric sources, and anthropogenic factors such as AMD, agricultural runoffs, and industrial effluents (Walsh and Wepener, 2009; Chilundo *et al.*, 2008). They occur in small levels in water whereby elevated levels indicate that the water is toxic. In this study, levels of trace metals were determined in water only during June. The results thereof are presented in Table 6.12 where the levels of various trace metals were compared with drinking water quality standards.

Table 6.12: Trace metals (ug\L) analysed for the month of June 2015 and compared with drinking water quality standards.

Parameter	Drinking water quality standards	P1	P2	P3	P4	P5
Cobalt as Co	<500	0.165	0.191	0.153	1.109	0.219
Selenium as Se	<10	3.211	2.796	6.022	30	5.247
Arsenic as As	<10	1.432	0.204	1.865	6.907	2.486
Zinc as Zn	<5	0	344.1	0.688	0	0
Nickel as Ni	<70	2.313	1.948	1.171	6.722	1.962
Manganese as Mn	<500	0	0	0	51.92	0
Chromium as Cr	<50	0.832	1.647	0.719	3.69	1.615
Vanadium as V	<200	4.695	10.51	7.104	34.19	16.94
Beryllium as B	<1.5	20.48	6.968	13.99	242.8	52.68
Copper as Cu	<2000	0.762	4.104	2.679	3.455	1.348
Lead as Pb	<10	0	0	0.176	0.677	4
Mercury as Hg	<6	2.481	1.761	2.26	3.602	8.949
Uranium as U	<15	1.162	4.308	20.44	112	159.7
Antimony as Sb	<20	0.036	0.053	0.041	0.181	0.046
Cadmium as Cd	<3	0.276	0.173	0.179	0.424	0.102

Analysis of the trace metals revealed that beryllium levels detected were above their recommended drinking water quality standards of 1.5 ug\L at all monitoring sites. Mercury levels detected at all monitoring sites were within the recommended TWQR of below 6 ug\L, except at site P5 where levels were found to be 8.9 ug\L. DWAF (1996a) explains that the occurrence of mercury contaminants in water is predominantly site-specific and related to identifiable site specific discharges. Intake by human beings may occur via air, food or water. Food, particularly fish and fish products, are usually the major source of exposure to mercury. Mercury is a major concern for the health of aquatic ecosystems due to its toxicity and ability to bio-accumulate in food chains (DWAF, 1996c). Other variables where levels above their recommended TWQR were detected are selenium and zinc. The drinking water quality standards recommend that the selenium levels for drinking water are below 10 ug\L. However, levels exceeding 30 ug\L were detected at point P4. At point P2, 344 ug\L levels of zinc were detected and this is above the recommended drinking water TWQR of 5 ug\L. Problems with water taste and toxicity challenges could occur where there are elevated levels of trace metals in water (Chilundo *et al.*, 2008).

6.3. MICROBIOLOGICAL POLLUTANTS

Various types of micro-organisms such as bacteria, viruses and protozoa can be found in water (Germs *et al.*, 2004). Consumption of or exposure to water polluted with these micro-organisms could lead to diseases such as gastroenteritis, giardiasis, hepatitis, typhoid fever, cholera, salmonellosis, dysentery and eye, ear, nose and skin infections, which have been associated with polluted water worldwide (DWAF, 1996a; du Plessis *et al.*, 2014). *E-coli*, *coliform* and total bacteria are referred to as indicators used to monitor presence of micro-organisms in water. Germs *et al.* (2004) further explain that the level of microbial pollutants entering the water could change independently through various processes such as their growth, settling on sediments, chemical reactions and decay.

For this study, as indicated in Table 6.13, microbiological analysis in water was determined for 2 monitoring periods. The samples were analysed for *E-coli* and faecal coliform for the months of August 2014 and January 2015 while total bacterial levels were only analysed across all monitoring points only during monitoring period of January 2015. The results were compared with drinking water quality standard recommendations.

Table 6.13: Microbial parameters at monitoring sites.

Point	***E-Coli*** **(cfu\1mL)**		**Faecal Coliforms (cfu\1mL)**		**Total bacteria (cfu\1mL)**
	TWQR-0cfu\100mL		**TWQR-10cfu\100mL**		**TWQR-1000cfu\100mL**
	August 2014	**January 2015**	**Aug 2014**	**Jan 2015**	**Jan 2015**
P1	0	6	6	135	60775
P2	0	9	3	100	31502
P3	0	0	0	10	65275
P4	0	0	13	31	31818
P5	0	0	20	105	13667
Mean	0	3	8.4	76.2	40607.4

Drinking water quality standards recommend that 0 cfu\100mL *E-coli* should be detected in drinking water. The results of this study indicate that no *E-coli* were detected in the water samples during monitoring period of August. However, *E-coli* were found to be present at two monitoring points (P1 and P2) during monitoring period of January. Levels of faecal coliform were also detected in all but monitoring point P3 for the monitoring period of August, and in all monitoring points in January. These levels were found to be above the recommended TWQR of 10 cfu\100mL at points P4 and P5. For the monitoring period of January, total bacteria were detected in all monitoring points and these levels were above TWQR of 1000 cfu\100mL.

While man-made activities such as feedlots and dairy runoffs, runoff from broad acre farming, stormwater, and livestock defecating directly into the water contribute to the presence of micro-organisms in water systems, human waste also contributes to presence of *faecal coliforms* in water (DEAT, 2006; Matowanyika, 2010). According to du Plessis *et al.* (2014), deposition of human waste in water bodies lead to the enrichment of the nutrients in the water, the growth of algae and the stimulation of other aquatic biota. This has negative impact on aquatic species such as fish because algae will use all the oxygen in the water. With reference to the study area, it is suggested that, owing to the presence of a variety of animals, defecation into the water by animals could be the main reason for the high content of these microbial components indicators.

6.4. WATER QUALITY AT SCHRODA DAM

Water quality was also determined for selected parameters at Schroda Dam, which is the largest water-holding facility in the vicinity of the study area (SANParks, 2013). The dam is used by De Beers' Venetia mine to store water utilised for mining and related activities at its operation. Table 6.14 shows the quality of the water in the dam analysed in January. *In situ* measurements were done for certain variables. These results were compared with recommended drinking water quality standards.

Table 6.14: Water quality of certain parameters in the Schroda Dam.

Parameter	Drinking water quality standards	*In situ*	Laboratory
Temperature(^{o}C)		34	
pH	5-9.7	8.8	8.97
EC (mS\m)	<170	856	94
SAR			3.19
Salinity (ppm)		420	
Fluoride (mg\L)	<1.5		1.24
Nitrite (mg\L)	<11		2.53
Nitrate(mg\L)	<0.9		0.96
Chloride (mg\L)	<300		130.56
Sulphates(mg\L)	<250		47.1
Phosphates(mg\L)			0
Carbonate (mg\L)			26.4
Bicarbonate(mg\L)			259.25
Sodium(mg\L)	<200		110.84
Potassium(mg\L)	<50		8.71
Calcium (mg\L)	<150		25.36
Magnesium(mg\L)	<70		40.15
Boron(mg\L)			0.16
TDS (mg\L)	<1200	592	523.38
E Coli (per 1ml)	0cfu\100mL		0
Faecal Coliform(per 1ml)	10cfu\100ml		440
Total Bacteria (cfu\1ml)	1000cfu\100mL		6668

The water quality of the Schroda Dam indicates that all analysed parameters were within the standard's TWQR, except for nitrates and microbiological pollutants. Nitrate levels measured were slightly above the TWQR of 0.9 mg\L at 0.96 mg\L.

Faecal coliform and total bacteria were also detected in the water samples. This indicates that the only health impacts are likely to be caused by the elevated levels of nitrates and microbial organisms.

6.5. SUMMARY OF FINDINGS ON WATER QUALITY

Water quality represents levels of constituents at desirable amounts. At given levels, water can be suitable for specific uses such as domestic, recreational, agriculture, industrial, and aquatic ecosystems. A particular use or process will have certain requirements for the physical, chemical, or biological characteristics of water. For example, drinking water will have a different threshold for the levels of pH when compared to pH ranges for water that supports invertebrate communities. Natural factors such as geology, geomorphology, soils, climate, vegetation, rock weathering, atmospheric precipitation, evaporation, vegetation, and crystallisation around the particular surface water could affect water quality (Germs *et al.*, 2004, DEAT, 2006; Oberholster and Ashton, 2008). However, land use activities such as industrial activities, mining, agriculture, decline in management of wastewater treatment infrastructure like sewage works, and urbanisation add to changes or deterioration in the quality of water (CSIR, 2010; DWA, 2012; van der Laan *et al.*, 2012; Dabrowsky and de Klerk, 2013).

A range of variables may limit suitability of water usage by comparing the physical, chemical and microbial characteristics of particular water with water quality guidelines or standards. Although many uses have some requirements in common for certain variables, each use will have its own demands and influences on water quality. Presence of these variables may also indicate possible sources. Ashton *et al.* (2001) indicate that the water quality in the Limpopo basis is relatively good for various uses. In this section, the mean levels of selected variables were compared with various water use guidelines and standards in order to identify possible threats to different water uses.

6.5.1. Drinking water quality

Table 6.15 details the mean value of selected parameters from the monitored points as compared with the drinking water standards. Hodgson and Manus (2006) point out that drinking water which complies with the drinking water quality standards will not pose a significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages (babies and infants, the immuno-compromised and the elderly).

Table 6.15: Mean levels of water quality parameters across various monitoring points compared with drinking water quality standards.

		Mean levels				
Parameter	**Drinking water quality standards**	**P1**	**P2**	**P3**	**P4**	**P5**
pH	5-9.7	8.37	8.37	8.77	8.63	8.57
EC (mS\m)	<170	47.7	53.7	49	306	83
TDS (mg\L)	<1200	279	298	295	1911	487
Salinity (ppm)		197	205	190	248	487
Fluoride (mg\L)	<1.5	0.4	0.38	0.28	0.92	0.39
Nitrate(mg\L)	<0.9	3	1.63	1.24	5.06	0.96
Chloride (mg\L)	<300	60.3	68.6	63.1	751	153
Sulphates(mg\L)	<250	41.2	35.5	33.2	450	72.1
Sulphates(mg\L)	<500	41.2	35.5	33.2	450	72.1
Sodium(mg\L)	200	43.7	44.9	41.6	437	86.7
Potassium(mg\L)	<50	4.89	4.51	4.57	6.39	5.18
Calcium(mg\L)	<150	34	37.5	33.9	85.9	38.6
Magnesium(mg\L)	<70	18.3	20.7	19.2	69.9	27.3

The mean levels of selected water quality variables across the monitoring streams complied with the recommended drinking water quality standards. However, mean nitrate levels of all monitoring points did not conform to the threshold. Consuming water that has nitrate levels above the threshold could lead to diseases such as methaemoglobinaemia. At point P4, mean levels of EC, TDS, chlorides, sulphate (acute), sodium, and magnesium also exceeded the drinking water quality standards TWQR. The study area is surrounded by crop farming activities (Henning and Beater, 2014). Crop farming potentially contributes to physical and chemical impacts on water quality because of an increase in contaminants, and in particular nutrient runoff, which leads to high level of nitrates (Walsh and Wepener, 2009;

Netshiendeulu and Motebe, 2012, Shabalala and Combrinck, 2012). DWA monitoring results indicates that the nitrate levels around the catchment complied with the requirements of drinking water quality standards (DWA, 2015). However, the elevated concentrations of these nitrates are observed from the monitoring results. The increase in nitrates concentrations does highlight consistent agricultural land use and modernized fertilization methods which could have developed over time (Walsh and Wepener, 2009).

6.5.2. Aquatic water quality

Aquatic water quality guidelines provide water quality limits recommended for aquatic species to survive in that particular water (DWAF, 1996c). Only pH was assessed against TWQR guidelines which recommend that it should range between 6.0 and 8.0. The mean pH at all points was above 8.0. Although this does not necessarily indicate poor water quality for the survival of aquatic ecosystems, it could potentially suggest that some animals might struggle to survive at this pH level.

6.5.3. Irrigation water quality

Different types of irrigation activities require water of a certain quality (DWAF, 1996b). TWQRs were set for various levels of parameters of which, exceeding the threshold could potentially affect growth and production if such water is used for irrigation. For the purpose of this study, mean levels for analysed parameters were compared with the TWQR as defined in the guidelines. The results are presented in Table 6.16.

Table 6.16: Comparison between water quality guidelines and mean levels obtained from monitoring points.

		Mean levels				
Parameter	**TWQR (irrigation)**	**P1**	**P2**	**P3**	**P4**	**P5**
pH	6.5-8.4	8.37	8.37	8.77	8.63	8.57
TDS (mg\L)	40	279	298	295	1911	487
Fluoride (mg\L)	2	0.4	0.38	0.28	0.92	0.39
Nitrate(mg\L)	5	3	1.63	1.24	5.06	0.96
Chloride (mg\L)	100	60.3	68.6	63.1	751	153
Sodium(mg\L)	70	43.7	44.9	41.6	437	86.7

The results indicate that the mean levels of TDS obtained during monitoring periods were above the TWQR of 40 mg\L. When irrigating with water of a high salt content and little or no leaching of salt takes place or the soil drainage is poor, the effect is that salt accumulates and a saline soil is formed, thus reducing growth yield of crops (DWAF, 1996b; van der Laan *et al.*, 2012). However, this does not necessarily mean poor water quality, since agricultural activities around the area utilise water directly from the Limpopo River (SANParks, 2013; Henning and Beater, 2014). With a knowledge on the actual water quality patterns as determined from the data already analysed, and possible land uses that may be responsible for such a status, the next chapter is based on the formulation of the DPSIR model for understanding the water management problematics in the study area.

CHAPTER 7

RESULTS AND DISCUSSION: THE DEVELOPMENT OF DPSIR FRAMEWORK OF THE STUDY AREA

7.1. INTRODUCTION

This chapter deals with the formulation of the Driver-Pressure-State-Impact-Response (DPSIR) model relevant to the study area. The modelling is based on land use analysis and the state of water quality, as well as the results of the feedback received from different respondents who were regarded as stakeholders in and around the MNPHS were utilised. The proportion of stakeholders per sector is outlined and thereafter their extent of environmental awareness and state of water quality is provided. The views of various stakeholders concerning individual drivers of water quality change, the pressures they exert, the state of water quality, and the effects of water quality changes are then discussed. In conclusion, the responses which may be appropriate for the protection of the ecological state of freshwater resources in the study area are examined.

7.2. BACKGROUND OF THE RESPONDENTS

Evaluation of the different factors involved in the DPSIR modelling around the catchment was aided by following a participatory approach. Views, perceptions and opinions of various stakeholders were considered, and these assisted in defining the factors involved in this model. In similar and related studies, such an approach enabled stakeholders to share their knowledge of environmental challenges regarding the study area (Agyemang *et al.*, 2007; Walz *et al*., 2007).

An analysis of the type of stakeholders who participated in this study is provided in Figure 7.1. A total of 29 stakeholders were consulted to shed light on the significance of the various components of the DPSIR model. The majority (52%) of the respondents represented stakeholders in the government sector who are mainly responsible for the implementation of various legislative and regulatory measures in the study area. These stakeholders comprised representatives of the Department of

Mineral Resources (DMR), Department of Water and Sanitation (DWS), Department of Agriculture, Fishery and Forestry (DAFF), Department of Environmental Affairs, and the Department of Cooperative Governance and Traditional Affairs (COGTA). While consultation with DMR, DAFF and COGTA was limited to provincial representatives, participation by the DEA and DWS was extended to a national level. The reason for this extension is that some of the functions involving legislation implementation extend beyond the provincial level. For example, provision of certain environmental authorisations such as water use licences could only be effected at a national level. The DMR is responsible for implementation of the Minerals and Petroleum Resources Development Act (MPRDA) (Act No.49 of 2008) and associated regulations. This includes issuance of prospecting rights, mining permits and mining rights, as well as approval of environmental management plans of mining related activities. Through the National Water Act (NWA) (Act No.36 of 1998), the implementation of water resource protection measures such as the national water resource and catchment management strategies is mandated to DWS. The DEA oversees implementation of various specific environmental management acts such as the National Environmental Management Act (Act No.107 of 1998), National Environmental Management: Biodiversity Act (NEMBAA, Act No.10 of 2004), and the National Environmental Management: Protected Areas Act (NEMPAA, Act No.15 of 2009). These acts are involved in addressing various management options in their specific environmental management fields. Through local government, COGTA is involved in implementing the socio-economic development and basic services provisions of the study area.

Twenty-one per cent (21%) of the other stakeholders are land users, who are land owners or occupants conducting various activities such as game farming, crop farming, and tourism-related activities around the MNPHS (Henning and Beater, 2014). The NGOs and research institutes constitute another 10% of the respondents. NGOs are involved in the promotion of environmental justice and sustainable development whereas research institutes conduct further studies that will enable the enhancement of environmental protection (CALS, 2015). Fourteen per cent (14%) of the stakeholders are communities residing within 50 kilometres in the vicinity of MNPHS. The towns of Musina and Alldays are the closest urban settlements whereas farm dwellers and land claimants such as the Machete and Sematla communities reside around the park (Jivanji, 2013). The remaining three per cent (3%) of stakeholders are industries such as mining. Apart from job creation, industries are involved in promotion of socio-economic development around the study area and in the country as a whole.

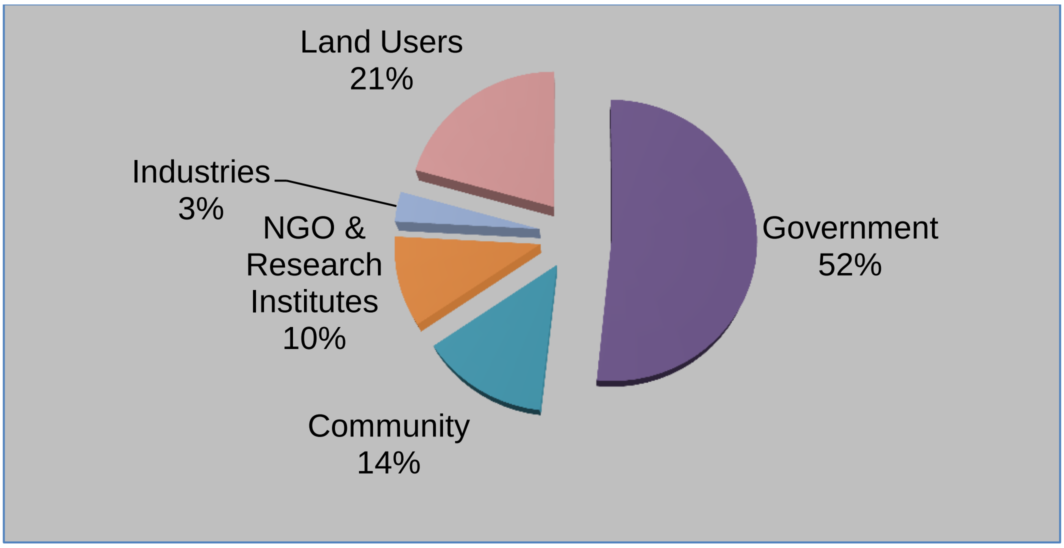


Figure 7.1: Proportions of respondents per sector.

7.3. ENVIRONMENTAL KNOWLEDGE AND AWARENESS AMONGST RESPONDENTS

DEAT (2006) describes environmental management as a multidisciplinary process whereby environmental resources are managed by applying careful preparation, planning, and administration of environmental policies and standards. All concerns pertaining to environmental management should be considered at all stages such as planning and execution in a manner that the carrying capacity of the environment of a particular area is not exceeded. This is important for the study area where all land use activities and environmental demands should be taken into consideration in order to ensure that degradation of environmental processes is prevented.

Environmental awareness is one of the critical instruments of environmental management (2009; Seroka-Stolka *et al.*, 2013). Agyemang *et al.* (2007) indicate that lack of environmental education and awareness could pose environmental challenges. This is because people who are environmentally aware tend to have proenvironmental behaviour which can lead to positive attitudes towards environmental conservation. The majority of stakeholders (86%) participating in this study indicated that they have sufficient knowledge of environmental issues, which suggests that stakeholders may be aware of pertinent issues that affect environmental degradation and the integrity of associated streams in this catchment. The remaining fourteen per cent (14%) of the stakeholders appears to lack environmental knowledge or can be regarded as ignorant on environmental issues surrounding the study area. Environmental knowledge will not in itself directly contribute to sound environmental management but it is an important prerequisite for such a goal.

The stakeholders' environmental awareness of the study area was assessed in terms of water quality, ecological state, and socio-economic-environmental interactions. The following results emerged. About 30 per cent (30%) of the respondents indicated that they have no opinion about these three factors, thus highlighting their lack of environmental awareness. The number of stakeholders believing that the water quality of surface resources was pristine balanced the number of those who disagreed. On the other hand, the majority of respondents indicated that they are not satisfied with socio-economic-environmental interactions surrounding the MNPHS. The reasons for these variations in patterns may be related to the point that freshwater ecology and associated factors are a specialist discipline requiring a deeper understanding and an appreciation of ecological aspects and processes. Water is a medium in which inorganic and organic components are integrated, and their functioning affects the maintenance and survival of both terrestrial and aquatic organisms in terms of both quality and quantity (Palmer *et al.*, 2004).

7.4. ANALYSIS OF THE DPSIR MODEL IN THE STUDY AREA

7.4.1. Drivers

Drivers of water quality changes are processes and man-made activities that can lead to changes in water quality (Odontsetseg *et al.*, 2009; Kagalou *et al.*, 2012). These can be regarded as contributing to water pollution. Although these threats can occur naturally, activities related to social and economic developments hugely increase pressure on the environment and its associated water resources (Kristensen, 2004; Agyemang *et al.*, 2007). Natural factors are activities that occur as a result of the biophysical characteristics of the area. Aspects such as the topographical and geological configuration of the study area, climate change and rainfall patterns are regarded as natural processes. However, social and economic factors are man-made processes undertaken to address a certain human-related demand in a particular region or area (Karageorgis *et al.*, 2005). According to Walmsley *et al.* (2001), some of the socio-economic activities that drive water variations in a catchment include population growth and demographic changes, economic growth which is closely related to industrialisation, and the need for basic services such as the provision of energy.

Regarding the nature of drivers in the study area, the majority of stakeholders have acknowledged all three factors (economic, natural, and social) as the drivers of water quality changes. Man-made activities in this catchment linked to economic developments include agriculture, tourism and hospitality, as well as mining (Henning and Beater, 2014).

Fifty eight per cent (58%) of the respondents appear to agree that social drivers of water quality variations in this study area can be demographic changes. Forty one per cent (41%) thinks that demand for basic human needs such as sanitation provision is also a social driver. Musina (2015) indicates that there has been an influx of people from neighbouring countries such as Botswana and Zimbabwe. This, together with the presence of local residents, brings about changes in the demographics of the study area. Demographic changes and population growth tend to accelerate the demand for basic services.

It was noted that respondents agree with the statement that climatic variations and rainfall patterns are the natural drivers of water quality changes in this catchment. The study area is subjected to extremes in climate and weather patterns (Carruthers, 2006). In Australia, Holland *et al.* (2015) observed that annual and seasonal variations in weather could lead to pollution processes such as salinisation and erosion.

7.4.2. Pressure

Diab and Motha (2007) describe pressure in the context of the DPSIR model as the outcomes of the drivers and cause for environmental concern. As various activities described as drivers are being practised in a catchment, they exert pressure on the environment through the release of various pollutants which impair air and water quality. With regard to freshwater, release of pollutants by these activities leads to changes in freshwater quality which can make the water unsuitable for various applications. Rasi Nezami *et al.* (2013) comment that as the quality of water resources deteriorates due to drivers, pressure is exerted on domestic, agricultural, and industrial water needs. Pollutants such as nutrients, harmful microbes, and sediments could all link to the occurrence of various negative drivers in this study area (Oberholster and Ashton, 2008).

In terms of stakeholder involvement, the respondents highlighted their awareness of pressures resulting from the occurrence of various socio-economic and natural drivers. This was indicated by the proportions of various stakeholders who acknowledged this observation by pinpointing population demographics (92%), conservation efforts (89%), as well as man-made activities such as tourism (78%) and other land uses (79%). In response to some of these pressures, pollutants may be released into freshwater resources in the study area and affect these activities.

7.4.3. State

The state is defined as the quality of the environmental media such as air, water, and land (Borja *et al.*, 2006; Odontsetseg *et al.*, 2009). In the context of the DPSIR model, the state is further defined by Holland *et al.* (2015) as an indicator of abiotic conditions of water as well as the biotic conditions at habitat, community, species, and genetic level. In terms of water quality, its state is represented by the levels or concentration of physical, chemical, and microbial parameters (Chilundo *et al.*, 2008). The state is affected as a result of pressure exerted on freshwater resources. Various processes such as sedimentation in water may lead to changes in state of a particular water resource. Chilundo *et al.* (2008) conclude that it is extremely important to monitor water quality in order to determine its state and associated impacts.

In order to determine the physical, chemical and microbial characteristics of the water resources in the study area, stakeholders were also engaged in terms of indicating their level of awareness. Thirty-seven per cent (37%) of the stakeholders were of opinion that the state of water quality around the MNPHS has been determined, while sixty-three per cent (63%) were not aware of this being the case. However, recent records of water quality status of this region were not available in water management system databases. Further engagements indicated that limited monitoring is also done on this quaternary catchment. Vele Colliery recently established an environmental management committee which includes oversight monitoring of water related issues.

Seventy-six per cent (76%) of the respondents disagreed that the water quality might be in compliance with drinking water quality standards or aquatic water quality guidelines respectively. A study by Ashton *et al.* (2001) on this basin indicates that the state of water quality in this region is satisfactory. However, land use changes, establishments of anthropogenic activities such as mining, and population demographic factors may have influenced the changes in water quality between 2001 and 2015. The results of water quality monitoring conducted between August 2014 and June 2015 indicate that the majority of water quality constituents do comply with various South African standards and guidelines. It can therefore be indicated that despite existing pressures on the water resources in and around the study area, water quality is still in a relatively satisfactory state.

7.4.4. Impacts

In the DPSIR model, impacts are defined as changes in human health and environmental consequences as a result of environmental degradations (Borja *et al.*, 2006; Diab and Motha, 2007; Kagalou *et al*., 2012). Agyemang *et al.* (2007) suggest that environmental impact could take the form of either physical impairment or social damages. Deterioration in water quality can have an impact on the functioning of the natural ecosystems, human health, and the availability of water resources to other water users in and around this catchment. The study area is characterised by various activities depending on the state of water quality. Deterioration in water quality could negatively affect these activities.

Stakeholders have indicated they are aware of various impacts that could occur due to change in the state of water quality in this region. The respondents agreed with each of the following impacts in the percentage indicated - aquatic impacts (82%), changes in land use (79%), and climate variations (72%). Aquatic ecosystems such as presence of fish and planktons depend on good water quality. Oberholster and Ashton (2008) have indicated that deterioration in water quality leads to the mortality and migration of aquatic species. Climatic variations are already being experienced in this catchment with extremely high temperatures and low rainfall characterising the area (Huffman, 2007).

The respondents further acknowledged that economic development factors such as tourism, agriculture, and industrialisation will be affected by deteriorating water quality. The MNPHS is surrounded by conservation and tourism activities such as game viewing and trophy hunting. These activities depend hugely on the presence of a variety of animals, requiring water of a good quality for their survival. Deteriorating water quality could impact on the presence of these animals, thus reducing activities such as animal viewing which is one of the tourism attraction facilities in the park. Furthermore, agricultural activities in this catchment use water directly from the Limpopo River (Henning and Beater, 2014). To be utilised for this purpose, the water quality should be of a certain standard. Deterioration could thus minimise production rates of various types of food produced in these crop-farming areas. With regard to social impacts, diseases such as diarrhea and cholera are linked with consumption of polluted water by human beings (DWA, 1996a). If the water quality does not meet drinking water quality standards, it will escalate treatment costs, limit supply, and potentially cause health-related diseases for consumers.

7.4.5. Responses

In order to mitigate or minimise the impact on environmental degradation, certain responses are necessary and must be implemented in the affected area. Kristensen

(2004) describes responses as decisions or actions that are taken in order to address the resulting impacts from deterioration. In addressing the impacts, Diab and Motha (2007) indicate that responses can be formulated to directly address the state, or to modify drivers and pressures. According to Holland *et al.*, (2015), a response in the form of a policy directive or change in management can be formulated in addressing the impact at the same time as maximising the positive drivers.

The MNPHS is a multi-purpose site with a unique characteristic such as its cultural composition. Various management responses in the form of compliance with international protocols and legislation requirements need to be adopted in order to effectively promote conservation and protect the cultural landscape of the site. Internationally recognised protocols such as the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and Kyoto protocols further regulate management of this site and its surroundings. In order to strengthen recognition of and compliance with such requirements and to promote conservation, a memorandum of agreement between the countries of Botswana, South Africa, and Zimbabwe was signed and adopted in 2006 (Jivanji, 2013; Peace-Park, 2015). This initiative was termed Greater Mapungubwe Transformation Conservation Area. Furthermore, South African legislations such as NEMBAA (Act No. 10 of 2004), NHRA (Act No. 25 of 1999) and NEMPAA (Act No. 15 of 2009) specifically address the promotion of biodiversity, cultural resources and further protection of declared areas such as the MNPHS.

In order to protect freshwater resources against degradation, various South African legislative requirements has have been put in place. The NWA (1998) is the primary legislation that addresses promotion, conservation and sustainable use of water resources. Strategies such as national water resource strategy, water users associations, and catchment management strategies were developed in order to addresses the requirements of the act. DWS also developed regulations such as the General Notice 704 of 2009 (GN704) which regulates water uses and protection in mining and related industries. Under the NWA (1998), various guidelines that can be implemented by water users were also developed in order to promote compliance with this act. The Water Services Act (Act No. 108 of 1997) and local by-laws also promote provision of services such as water of good quality for human consumption.

Stakeholders were engaged with regard to their awareness on these legislative requirements and their implementation. The majority (48%) showed indecisiveness and a lack of awareness. Those who were aware of these legislations could have been representatives of regulatory institutions as it is their mandate to implement these regulations. Lack of awareness of legislation across various stakeholders and land users could compromise compliance with required legislations and best practices associated with activities related to their water uses.

Involvement of stakeholders could be regarded as one of the effective tools in addressing the state of environmental degradation or changes in environmental quality (Agyemang *et al.*, 2007). The NEMA (Act No. 107 of 1998) Act makes provision for public involvement in decision-making on environmental-related issues. Regarding water management issues, DWS requires that a stakeholder involvement process be carried out prior to the compilation of plans such as integrated water and waste management plans. Stakeholders were given an opportunity to share their knowledge and experience regarding water quality issues and land uses in the catchment

About 34% of respondents were indecisive on such involvement; meanwhile, 44% were dissatisfied with the extent of openness and transparency regarding water quality issues around the catchment. With regard to participation in decision-making on environmental issues, 41% were still indecisive while only 21% agreed that this is happening. These percentages illustrate that there is not enough involvement of stakeholders, judging from respondents consulted for this study. This could provide barriers to the achievement of integrated freshwater management strategies as well as sound environmental management decision-making processes (Walz *et al.*, 2007). Principle 10 of the Rio Declaration also comments on the importance of addressing environmental issues with the involvement of concerned participants.

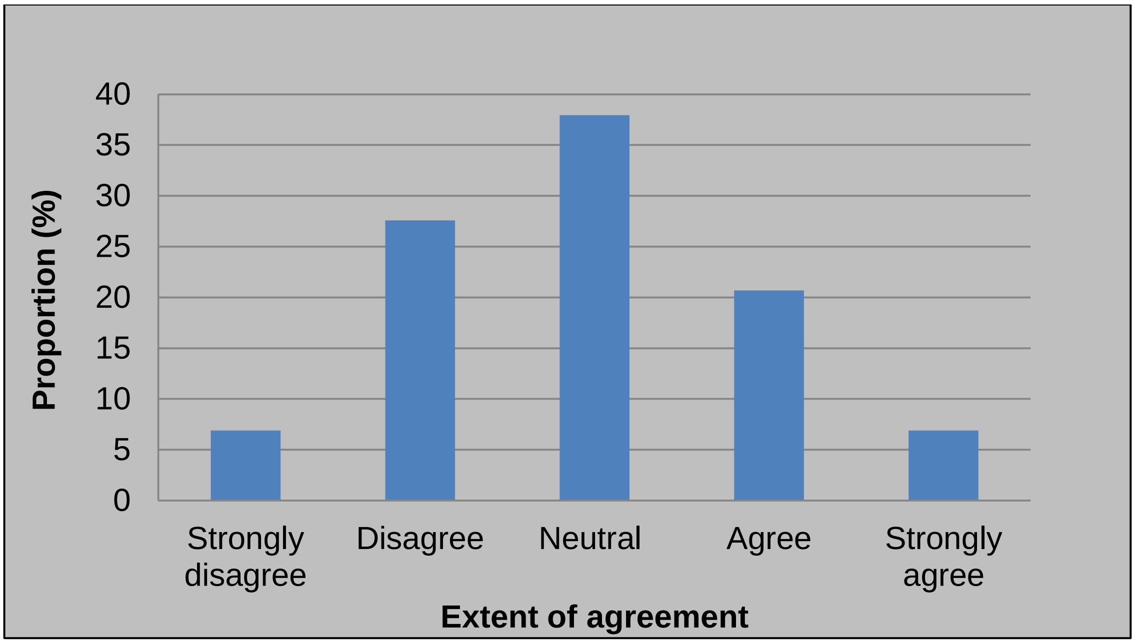


Figure 7.2: Participants responses regarding overall effectiveness of responses to water quality changes and challenges in the study area.

The implementation of relevant responses in an effective manner can promote the protection of water resources against long term decline. However, the overall view of various stakeholders consulted for the current study indicates that such responses – in the form of legislation, self-regulatory mechanisms, environmental monitoring programmes – or merely the involvement of public representatives, are not effective. These patterns are illustrated by Figure 7.2, which shows the way in which participants responded regarding their perceptions of overall effectiveness of responses to water quality changes and challenges in the study area.

7.5. SUMMARY OF FINDINGS ON DPSIR

In applying the DPSIR model, indicators arising from the analyses may provide important feedback to land use planners and policymakers on the state of environment and associated impacts on environmental quality (Kristensen, 2004; Borja *et al.*, 2006; Odontsetseg *et al.*, 2009). The model has been applied mostly in European countries and has proved to be an effective tool in addressing environmental challenges such as the management of coastal and inland water resources (Rekolainen, 2003; Rasi Nezami *et al.*, 2013). When applying the model to water quality management, various factors that could lead to water quality degradation such as economic drivers are identified. The pressures that these drivers exert on water resources, for example the release of pollutants, are then analysed. Due to pressures exerted on water resources, the state of water quality changes, which has various consequences such as health impacts and ecosystem vulnerability. Responses are measures that are being applied in order to combat or address water quality deterioration.

Land use mapping and geographical information system tools are examples of approaches which have implemented this model in water resource management. Another approach seen as an effective tool in applying the DPSIR model is that of participation involving various stakeholders in a particular catchment or study area (Walz *et al.*, 2007; Agyemang *et al*., 2007). With this methodology, interviews, questionnaires, and focus groups may be used in order to obtain perceptions, opinions and knowledge of stakeholders with regard to water quality concerns. Stakeholders may have a specific knowledge of certain dynamics prevailing in the study area.

In and around the MNPHS, stakeholders such as land users, landowners, government regulators (national and local), and land occupants such as communities were identified and involved in this study. A questionnaire guided by land uses identified in the study catchment was used in order to analyse the existing degree or level of awareness and perceptions of stakeholders regarding various DPSIR factors. The options presented to stakeholders were guided on land uses around the catchment. Taking into consideration the participatory approach, land uses and the determined state of water quality, Figure 7.3 indicates the most pertinent outcomes of the DPSIR model on this catchment.

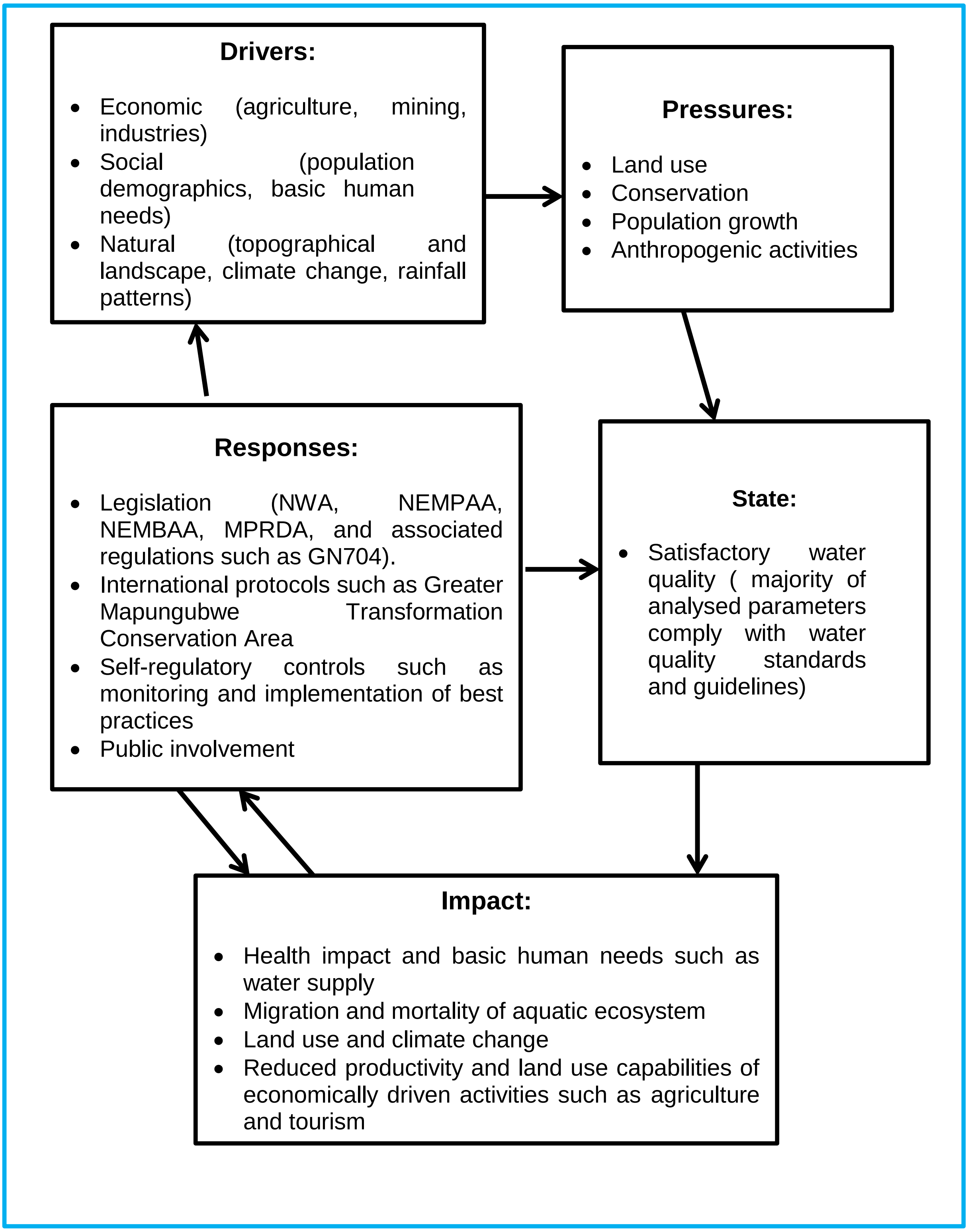


Figure 7.3: Summary of the DPSIR framework for the water quality management of the MNPHS.

CHAPTER 8
CONCLUSIONS AND RECOMMENDATIONS

8.1. INTRODUCTION

The main aim of this study was to apply the DPSIR model in identifying and characterising cause–effect relationships involved in the quality of surface water systems in and around the MNPHS in the Limpopo Province. In this chapter, conclusions on the research conducted are provided. These conclusions are based on the research findings associated with each research objective. In addition, recommendations for further studies are outlined.

8.2. CONCLUSIONS

8.2.1. Major land uses

The first objective of this study was to determine the land uses that have the potential to affect the quality of the surrounding surface water around the MNPHS. Various studies have been conducted on the extent to which land uses impact on the quality of freshwater resources in different catchments in South Africa. These studies have confirmed that there is an association or relationship between pollutants released from these land uses and the quality of water in those catchments (Oberholster and Ashton, 2008; Dabrowsky and de Klerk, 2013; Ogden *et al.,* 2013; du Plessis *et al.,* 2014).

The present study has revealed an array of different land uses in and around the area of MNPHS. Most of these activities are conducted to meet socio-economic imperatives in this region as well as addressing environmental conservation. Table 8.1 summarises major land uses that were determined for the study area as well as their impact on the quality of receiving water bodies and their role in socio-economic development.

Table 8.1: Major land uses around MNPHS, their impacts on freshwater resources and socio-economic contributions.

Land use	Socio-economic impact	Impact on water quality
Agriculture	• Improve food security; • Improve job creation; • Enhance local economic development.	• Accumulation of nutrients and other agrochemicals in water; • Soil erosion as a result of crop cultivation activities; • Excessive water utilisation which may impact on water quality.
Mining	• Improves job creation; • Enhances local economic development.	• Release of acid mine drainage and other heavy metals into water resources; • Air pollution which may contribute to acid rain; • Excessive water utilisation which may lead to reduced flow regime thus affecting water.
Tourism	• Improves job creation; • Enhances local economic development.	• Solid waste mismanagement and littering by tourists which could lead to waste being washed into water resources thus lead to turbidity challenges; • Water utilisation which may impact on water quality; • Release of microbial pathogens from sanitation facilities;
Nature conservation	• Enhances environmental protection.	• Release of faecal matter from wildlife and livestock.
Residential	• Improvement in quality of life through provision of housing.	• Waste generation and littering by residents; • Release of microbial pathogens from sanitation facilities.

8.2.2. Water quality of the study area

The second objective of the study was to examine the status of the water quality in few monitoring points along the course of the Limpopo River. The monitoring points were located in the river system upstream of MNPHS, within the park, and downstream of the park where various land uses exist. Generally, there were few water quality problems observed as majority of the constituents analysed complied with the South Africa's drinking water quality standards, and water quality guidelines for both agricultural and aquatic ecosystem as recommended by DWA. The following parameters are of environmental concern as they were above the drinking water quality standards:

- Nitrates – nitrate levels in the water systems around this catchment were above the drinking water quality standards. Vos *et al.* (2010) indicate that high contents of nitrates in water could lead to eutrophication. Eutrophication will lead to a decrease of oxygen in the water, thus negatively affecting the aquatic ecosystem. Furthermore, DWA (1996a) explains that, if consumed by human beings, water containing high nitrates levels may lead to a blood disorder disease called methaemoglobinaemia. According to Walsh and Wepener (2009), modern fertilisation methods in agriculture lead to high levels of nitrates in water as a result of nutrients runoffs.
- Microbial pollutants – during monitoring periods, water systems were found to contain faecal coliform, *E.coli*, and bacteria above the threshold recommended by drinking water quality standards. The presence of wildlife and livestock together with poor sanitation facilities add to the presence of these microbial pollutants. This is further supported by studies conducted by Netshiendeulu and Motebe (2012), van der Laan *et al.* (2012), and Shabalala and Combrinck (2012), which highlight similar findings. These may contribute negatively to health issues, and diseases such as diarrhea and cholera could be experienced by humans when consuming water containing such pollutants. Health problems could also be experienced when edible crops which are irrigated with this water, are eaten raw.

- Heavy metals – heavy metals such as beryllium, mercury, uranium, zinc were found to be occurring at concentrations slightly higher than the drinking water quality standards. Mining-related activities are mostly associated with the presence of these metals.

Parameters such as the electrical conductivity, total dissolved solids, chlorides, sulphates, and sodium were found to be above the drinking water quality standards at monitoring point 4. This point was located downstream of the park but upstream of the newly formed coal mine.

8.2.3. The DPSIR model of the study area

The DPSIR model in this study area indicates the presence of socio-economic and natural processes that may affect water quality. Activities stemming from these processes include agriculture, mining, environmental conservation, and tourism. In addition, population demographics and basic human needs were identified as social drivers in this study area. Given the unique landscape of this area, drivers that can influence water quality are its topography and landscape, climate change and rainfall patterns. These findings are similar as those expressed by other researchers (Agyemang *et al*., 2007; Kagalou *et al.,* 2012; Holland *et al.,* 2015).

The existence of these drivers may lead to the deterioration of water quality, in that they release various pollutants which cause processes such as eutrophication, salinisation and sedimentation. The study also established the state of water quality around MNPHS. It was found that, although there are areas where the constituents are not in compliance with various guidelines and standards, the water quality is generally satisfactory. If water quality in this study area is to deteriorate further from the existing baseline however, serious environmental and health consequences can be experienced. For example, the aquatic ecosystem can be negatively affected, which can contribute to ecological stress and loss of biodiversity.

Various responses have been put in place in order to promote sustainable water resource management of this study area. International legislations and treaties such as Greater Mapungubwe Transformation and Conservation Area agreement have been drafted in order to promote protection of natural resources in this catchment. Nationally, various legislative requirements such as NEMA, NWA, NEMBAA, MPRDA and NEMWA are in place, and therefore management of this area should be aligned with their requirements. However, it could be concluded that these mechanisms are not being fully implemented. This is evidenced from the differing opinions and legal battles that emerged when mining activity was commissioned next to this conservation area. The formation of a coalition movement called “Save Mapungubwe Coalition” highlighted the fact that, although these legislations are in place, protection of water resources and other environmental needs to be given top priority (CALS, 2015). Feedback from stakeholders also illustrates minimal enforcement of compliance with these legislative requirements. Furthermore, the study has found that there is lack of proper involvement of the public or interested and affected stakeholders. Public and stakeholder involvement is regarded as one of the effective tools of environmental management.

8.3. RECOMMENDATIONS FOR FURTHER STUDIES

Based on the findings of this study, the following recommendations for further action and studies are suggested:

- ✓ Prioritisation of environmental conservation in this particular area;
- ✓ Effective regulation of other land uses that may significantly hinder protection of natural resources and the cultural landscape by strengthening monitoring and compliance enforcement;
- ✓ Effective implementation of relevant legislations and treaties such as the GMTCA in order to further promote sustainable protection of the environment;
- ✓ The need to conduct regular monitoring of water resources around this catchment;
- ✓ Increase the degree of stakeholder involvement in the catchment management strategy;
- ✓ Conduct further studies to determine effective ways of implementing socio-economic activities without compromising environmental protection.

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APPENDIX A: STAKEHOLDERS QUESTIONNAIRE

This questionnaire is designed for the research project dealing with water quality status around the Mapungubwe National Park in the Limpopo Province, South Africa. The research project seeks to examine not only the prevailing water quality of affected streams but also factors and issues that are likely to influence water quality variations in the study area. For this reason, the Drive-Pressure-State-Impact-Response (DPSIR) model has been selected to help identify all the relevant factors that could influence water quality changes around the Park. Consequently, the questionnaire has been divided into various sections, the goals being to address the different aspects raised by the DPSIR Model.

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As proof of prior informed consent, please sign at the appropriate space to indicate to the University of South Africa of your willingness to be interviewed.

Organization	
Role (community/government/ NGO, Industry, etc.)	
Position occupied	
Contact Details	
Signature	
Date	

Brief background of DPSIR

DPSIR (Drive-Pressure-State-Impact-Response) is a model that can be applied as a way of structuring environmental information concerning specific environmental problems and to reveal existing causes, consequences, effective responses & trends and the dynamic relationships between these components. This systematic approach enables the identification of the full range of empirical factors involved and prospective assessment of the direction, nature and strength of their interconnections. Indicators play a valuable role in terms of building the necessary knowledge, communication and awareness for integrated scientific, political and public input into effective decision-making processes for sustainability or other key societal objectives.

Driving forces refers to the forces of changes caused by human activities. They put pressure on natural systems indirectly and can be of demographic, economic, social, political, scientific, technological, or spiritual nature (e.g. the demand for energy, economic growth, the demand for food and housing, population growth).

Pressure refers to stress points that impact systems and manifest themselves as changed environmental conditions (e.g. greenhouse gas emissions, contaminated sites, noise, water pollution, land degradation, etc.).

State refers to the quantitative and qualitative condition of a system (e.g. lake water quality, average global temperature, number of species in a forest).

Impacts are specific effect of a pressure on ecosystems functioning and thus also on humans and their quality of life (e.g. health problems, species extinction, eutrophication, air pollution, land degradation).

Responses are political and societal reactions (e.g. taxes, laws, migration) that reduce the driving forces and the pressures or make adaptation to the changed condition and its impact possible.

Guidelines for responding to the questionnaire

- Each question is guided by the DPSIR aspects and generic knowledge. Please read & understand the DPSIR guidelines provided. Feel free to ask the researcher/supervisors should you not understand any question.
- Only **one answer is required per question**, and the survey will not take more than 20 minutes to complete.
- Please indicate to what extent you agree with the questions asked: **(1) Strongly disagree, (2) Disagree, (3) Neutral or No opinion, (4) Agree, (5) Strongly agree.**
- Please mark your selection with an (x).

No	**Statement**	**Extend of agreement**				
1	My knowledge of environmental management is good	1☐	2☐	3☐	4☐	5☐
2	I have limited environmental knowledge	1☐	2☐	3☐	4☐	5☐
3	The catchment is pristine n water fit for human consumption & sustaining natural ecosystems	1☐	2☐	3☐	4☐	5☐
4	The ecological state of the area is satisfactory	1☐	2☐	3☐	4☐	5☐
5	I am satisfied with the current socio-economic-environmental interactions on the catchment	1☐	2☐	3☐	4☐	5☐
6	Natural factors are the key primary drivers of water quality state in the study area	1☐	2☐	3☐	4☐	5☐
7	Economic factors are the key primary drivers of the ecological state in the study area	1☐	2☐	3☐	4☐	5☐
8	Social issues are the key drivers of ecological state in the study area	1☐	2☐	3☐	4☐	5☐
9	The ecological state around the park is highly influenced by demographic factors	1☐	2☐	3☐	4☐	5☐
10	Agricultural activities surrounding the catchment highly influence the ecological state	1☐	2☐	3☐	4☐	5☐
11	Tourism & related activities around the study area impact the state of water quality adversely	1☐	2☐	3☐	4☐	5☐
12	Increased demand for basic human needs and poverty alleviation on the catchment plays a vital role in water quality changes	1☐	2☐	3☐	4☐	5☐
13	Industrialization (mining & associated) around the catchment does influence the water quality state on the catchment	1☐	2☐	3☐	4☐	5☐
14	The change in ecology is influenced highly by the topography and geological appearances	1☐	2☐	3☐	4☐	5☐
15	Climate changes and changes in rainfall patterns influences the changes in water quality on the catchment	1☐	2☐	3☐	4☐	5☐

16	Land use changes in the catchment area are adversely impacting water quality	1☐	2☐	3☐	4☐	5☐
17	The human activities around the catchment could lead to physical, chemical, and microbial impacts on the quality of receiving waters water resources	1☐	2☐	3☐	4☐	5☐
18	Change in water qualities could exert pressure on conservation occurring around the area	1☐	2☐	3☐	4☐	5☐
19	Change in water quality could lead to pressure on source of livelihoods	1☐	2☐	3☐	4☐	5☐
20	Conservation of the area will be highly pressurised due to change in water quality	1☐	2☐	3☐	4☐	5☐
22	The state of water quality in the catchment is well known	1☐	2☐	3☐	4☐	5☐
23	The water quality on the study area is in a pristine state and without human disturbances	1☐	2☐	3☐	4☐	5☐
24	The water quality does comply with the drinking water quality status as required by South African water quality guidelines and standards	1☐	2☐	3☐	4☐	5☐
25	The state of water quality does comply with the aquatic water quality standards	1☐	2☐	3☐	4☐	5☐
26	The water quality on the catchment is deteriorating	1☐	2☐	3☐	4☐	5☐
27	The water quality deterioration could lead to species, habitat and biodiversity loss around the area	1☐	2☐	3☐	4☐	5☐
28	Water supply (locally and internationally) will be affected due to changes in water quality	1☐	2☐	3☐	4☐	5☐
29	Tourism is likely to be negatively impacted as the quality of water deteriorates	1☐	2☐	3☐	4☐	5☐
30	Water quality deterioration could lead to low agricultural productions	1☐	2☐	3☐	4☐	5☐
31	Health impacts could be experienced due to poor water quality	1☐	2☐	3☐	4☐	5☐
32	Industrialization is likely to be affected due to poor water quality	1☐	2☐	3☐	4☐	5☐
33	Negative changes in water quality could lead to land degradation and land use capabilities.	1☐	2☐	3☐	4☐	5☐
34	Climate change, floods, and changes in rain patterns could have an impact on water quality deterioration	1☐	2☐	3☐	4☐	5☐
35	International protocols & agreements are in place and implemented in ensuring water quality deterioration is prevented	1☐	2☐	3☐	4☐	5☐
36	Effective monitoring is being conducted on water quality	1☐	2☐	3☐	4☐	5☐
37	The South African legislation and associated regulations are in place and are being efficiently applied in and around the catchment	1☐	2☐	3☐	4☐	5☐
38	Best practice guidelines, strategies and policies in water resource management have been implemented in addressing water quality challenges in the study area	1☐	2☐	3☐	4☐	5☐
39	Local government policies (e.g. IDP) are being effectively applied around the catchment	1☐	2☐	3☐	4☐	5☐

40	Interested & affected parties do effectively participate in decision making and ensuring protection of the water resources on the area	1☐	2☐	3☐	4☐	5☐
41	There is effective communication with relevant stakeholders	1☐	2☐	3☐	4☐	5☐
42	The current responses are sufficient and effectively applied to prevent water quality deterioration	1☐	2☐	3☐	4☐	5☐