Assessment of the surface water quality of the main rivers feeding the Katse Dam, Lesotho

by

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Declaration

I, Tiyani Beaulla Mathebula, declare that the dissertation, which I hereby submit for the degree Masters of Science in Water Resource Management at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

Signed this 9th day of December 2015

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Assessment of the surface water quality of the main rivers feeding the Katse Dam, Lesotho

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SUMMARY

Water quality is an essential and critical aspect in meeting basic human and environmental needs. The scarcity of rainfall and water in South Africa prompted the need to augment water supply by transferring water from other catchment areas through inter-basin transfers, such as the transfer of water through the Vaal River system from the Lesotho Highlands. The Katse Dam is the main dam in the Lesotho highlands feeding water into the Vaal Dam, through the Ash River. Five rivers, namely the Malibamatso, Bokong, Pelaneng, Liphofung and Mokhoulane, feed into the Katse Dam. Surface water resources are susceptible to chemical, physical and microbiological contamination, either through human or natural activities. It became important that the raw water flowing from the five rivers into the Katse Dam be monitored to ensure that the dam water be preserved.

The aim of the study was to investigate the surface water quality of the five rivers feeding the Katse Dam in Lesotho. The approach was to determine the activities occurring in the catchment area and whether these activities have any effects on surface water resources, and consequently, on the users of the water resources. Also, to examine the historic (2000 to 2011) and current (2012 to July 2014) water quality data to establish if the water quality has changed. To determine the surface water quality, samples were taken from the five rivers respectively. Samples were

taken once a month for Study Period A (2000 to 2005), every second month for Study Period B (2006 to 2011) and four times a year for Study Period C (2012 to July 2014). Physical determinants such as temperature, dissolved oxygen, pH and turbidity were measured in situ. Selected chemical, physical and microbiological determinants were analysed at the Rand Water Analytical Services Laboratory.

The water quality of the five rivers was relatively good, influenced mainly by both natural processes and human activities occurring within the Katse Dam catchment area. The water quality varied between rivers and over the study periods. The historic water quality data was not compliant with most water quality guidelines whilst current water quality data showed improved water quality. The Bokong River had the highest number of non-compliant determinants with water quality guidelines, especially for the World Health Organisation (WHO) and Department of Water Affairs & Sanitation (DWS) Aquaculture guidelines indicating that the water quality might have been compromised. The Pelaneng River had the least number of non-compliant determinants, thus indicating even better water quality when compared to other rivers.

Natural processes such as rock weathering and geological composition of the catchment area influenced chemical determinants such as aluminium, copper, manganese and zinc, as well as physical determinants such as turbidity, total dissolved solids, water hardness, pH and suspended solids being non-compliant with most of the guidelines. Chemical determinants could have been influenced by the mining activities occurring in the catchment area. However, this requires further investigation. Agriculture and human settlements were to a large extent the most influential activities impacting the water quality.

Chemical determinants such as ammonium, nitrates, nitrites and microbiological determinants such as *Escherichia coli*, coliphage bacteria, faecal coliform, *Giardia* and *Cryptosporidium* were linked to the application of manure and other agricultural inputs to crop fields, the lack of proper sanitation, and extensive livestock farming. The concentrations of these microbial determinants far exceeded the WHO, South African National Standard (SANS) drinking water and DWS guidelines. The surface water in this catchment area is used for domestic, livestock and farming purposes, therefore a compromise in the quality could have health and environmental effects

on the communities living within the catchment area and the aquatic ecosystem at large.

On the basis of these findings and conclusions, it is recommended that a long-term continuous monitoring programme be implemented, especially in areas where increased human activities have been observed. Monitoring should be strengthened for the Bokong and Liphofung Rivers since these rivers showed the highest number of non-compliances and microbial contamination. All anthropogenic activities in the catchment areas of these rivers must be monitored and strictly managed to prevent and mitigate their possible impacts. Specific emphasis should be placed on agricultural development, which should be controlled to ensure sustainable livestock and cropping practices. Sanitation facilities, systems and community programmes should be put in place to minimise faecal contamination. It would be beneficial for the Lesotho Highlands Development Authority (LHDA) to establish a central database for all information that will be accessible to both South African and Lesotho citizens.

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- Rand Water and LHDA for providing access to the water quality monitoring data of the rivers.

DEDICATION

To my Lord and saviour Jesus Christ who is the very reason for my being, I owe it all to you.

To my husband Vunene Mathebula, thank you for your constant love, support and inspiration.

To my two boys, Yinhla and Nthavela Mathebula, you make it all worthwhile.

To my parents, Gladys Nkuna and Swart Nkuna, thank you for always praying for me and being my pillar of strength.

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LIST OF ACRONYMS

ART	-	Average Residence Time
AMD	-	Acid Mine Drainage
BOD	-	Biochemical Oxygen Demand
COD	-	Chemical Oxygen Demand
CFU	-	Colony Forming Unit
DAPI	-	Diamidino-2-Phenylindone
DIC	-	Differential Interference Contrast
DNA	-	Deoxyribonucleic Acid
DWS	-	Department of Water and Sanitation
DWAF	-	Department Of Water Affairs and Forestry
FC	-	Faecal Coliform
LHDA	-	Lesotho Highlands Development Authority
LHWP	-	Lesotho Highlands Water Project
MAV	-	Maximum Allowable Value
MPN	-	Most Probable Number
MPS	-	Multi Parameter System
NTU	-	Nephelometric Turbidity Units
ONPG	-	O-Nitrophenyl-β-D-galactopyranoside
RNA	-	Ribonucleic Acid
SANS	-	South African National Standard
TDS	-	Total Dissolved Solids
TWQR	-	Target Water Quality Range
US EPA	-	United States Environmental Protection Agency
WHO	-	World Health Organisation
WWTP	-	Waste Water Treatment Plant
YSI	-	Yellow Spring Instrumentation

CHAPTER 1

1. INTRODUCTION

1.1. Water supply and reserves in South Africa

It has been well documented in literature that South Africa is a water scarce country with erratic and unpredictable rainfall patterns, with an average annual rainfall of 465mm compared with the world average of 860 mm annually (Pitman, 2011). This has a direct impact on river flow and availability of water supply to the ever-increasing population and economic activities especially in the Gauteng region of South Africa (Government Communication and Information Systems, 2004; Muller *et al*., 2009), where water is used for example for general domestic use, industrial development, power generation, mining operations, agriculture and tourism (Oelefse & Strydom, 2010).

The scarcity is attributed to the high pressure systems which dominate a major part of the country, making it unfavourable for rain to form (Van Rooyen *et al*., 2010). The topography of South Africa also influences rainfall patterns because the surface land tends to rise steeply from the Eastern and Southern coastline to mountains, forming the rim of the interior plateau and falling gradually to the north and west. About 65% of the country receives less than 500 mm of rainfall per year on average and 20% of the country receives less that 500mm per year leading to large variations in river flows. High evaporation rates of 1500mm per year have been detected in the southern and eastern regions and 3000mm evaporation rates along the western regions (Van Rooyen *et al*., 2010).

In addition to these physical and hydrological conditions, water shortages are aggravated by the increased competition between water users, a high demand for fresh water, decreasing water supply levels and the location of major industrial developments being far from water courses, thus requiring large scale transfer of water across catchment areas (Crafford, 2006; Walter *et al.,* 2011).

In view of the challenges raised above, it became necessary to explore ways of augmenting water supply to the Gauteng region of South Africa. A need to then transfer water from other catchment areas via inter-basin transfer schemes to the Vaal River System was therefore identified and implemented. The aim of the

schemes was primarily to enhance the semi-arid lands south and west of the country, and encourage the development of some mining towns (Johannesburg for gold mining and Kimberley for diamond mining) (Lustenberger, 2010).

1.2. Description of the water supply network

The transfer schemes include the (1) Tugela-Vaal transfer scheme, where the water is transferred through the Drakensberg pump storage scheme into the Sterkfontein dam (2) the Zaaihoek scheme through Majuba power station and Grootdraai Dam into the Vaal catchment area; (3) the Mooi-Mgeni scheme through Midmar Dam in the Mngeni River, (4) the Thukela-Mhlatuze scheme through Goedetrouw and (5) the Lesotho Highlands Scheme from the Lesotho highlands to the Ash River (DWAF, 1994; Snaddon *et al.,* 1998; Muller, 2009).The most ambitious of the projects is the augmentation of water supplies to the Vaal River over long distances from the Lesotho highlands (Lesotho Highlands Project-LHWP).

In the Lesotho Highland Scheme, the Katse Dam is the main dam (highest dam: height of 185m) feeding the water to the Ash River and eventually into the Vaal Dam. The water from the Katse Dam is drawn into a tunnel through the intake tower that is located upstream of the Katse Dam wall. The water travels along an underground pipe which is about 75 km long, through the Muela Hydroelectric Power Station and into the Muela Dam, producing electricity for Lesotho using hydroelectric turbines. The water from the Muela Dam then travels along a 33,27 km-long underground pipe and finally flows into the Ash River near Clarens in South Africa. The Ash River then flows into the Saulspoort Dam (Figure 1.1). Thereafter the water flows into the Liebenbergsvlei River, the Wilge River and then into the Vaal Dam (Rand Water, 2014).

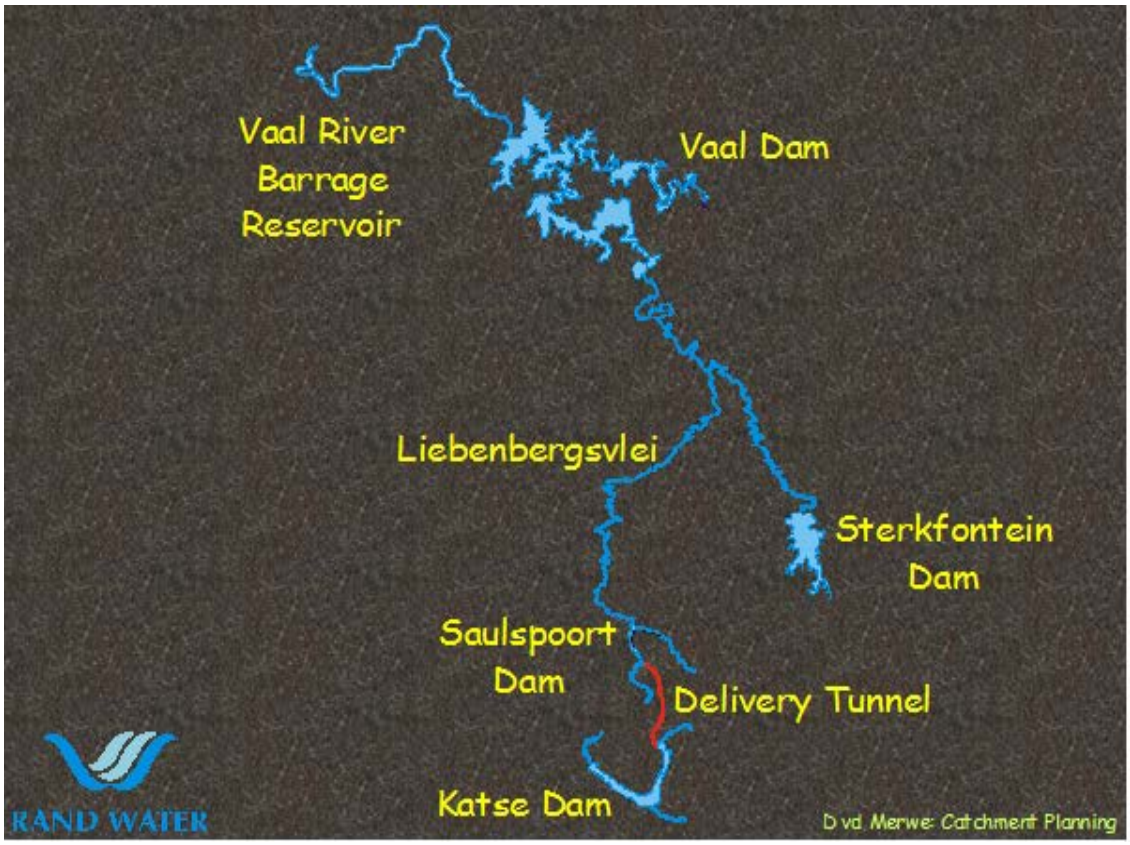

Figure 1.1: The transfer and flow of water from the Katse Dam to the Vaal Dam (Rand Water, 2014)

There are five main feeder rivers within the Katse Dam catchment area, namely the Bokong, Liphofung, Malibamatso, Mokhoulane and Pelaneng Rivers (Figure 1.2). The Katse Dam is situated approximately 2 km downstream of the confluence of the Bokong and Malibamatso Rivers (Pretorius *et al.,* 2001). The Bokong River also originates in this area. The Liphofung, Mokhoulane and Pelaneng Rivers are tributaries to the Malibamatso River (Letšela *et al*., 2003). It has a surface area of 37,6 square kilometres; average depth of 180 meters and total storage capacity of 1,95 billion cubic meters (Rand Water, 2014).

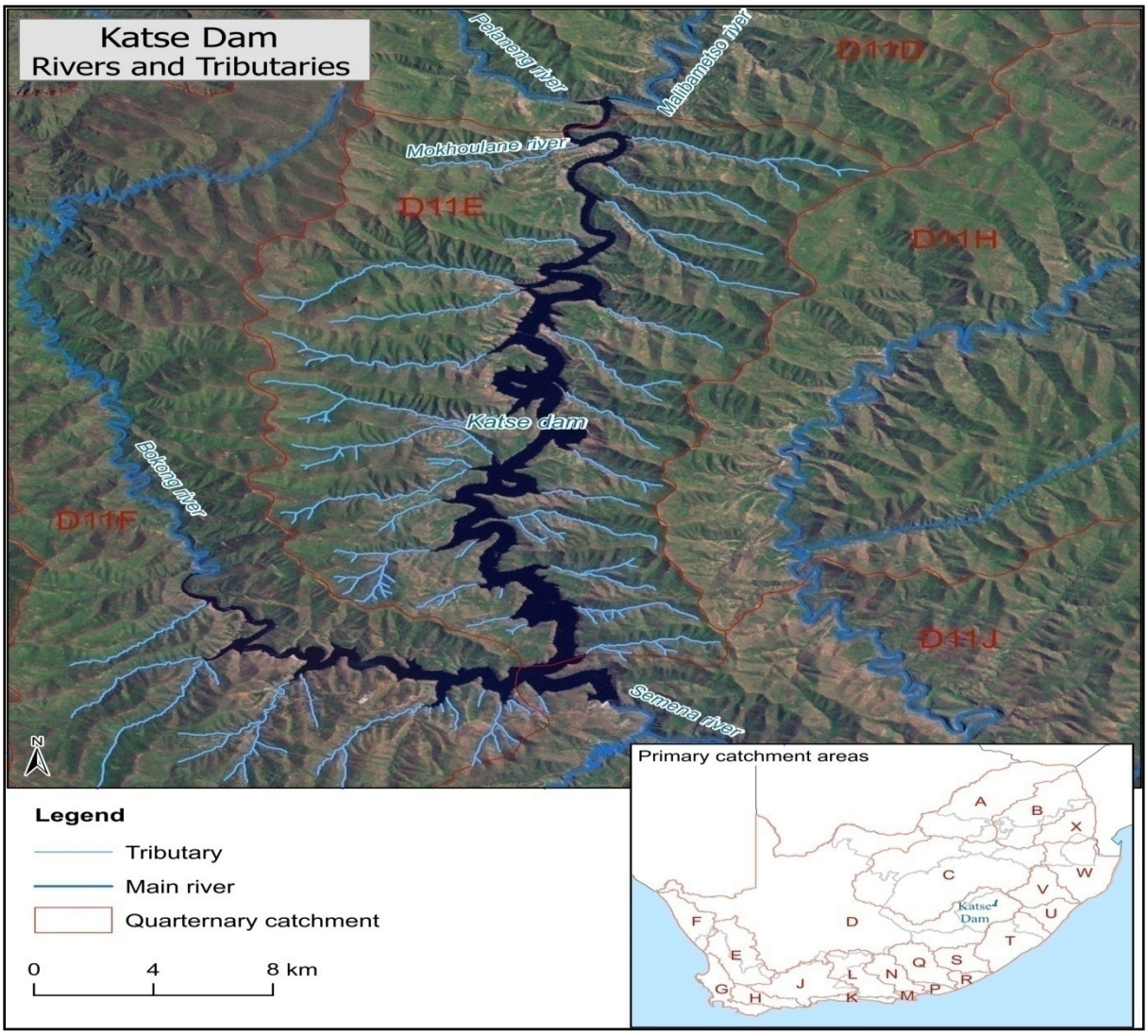

Figure 1.2: Main rivers feeding into the Katse Dam catchment area (created by Ingrid Booysen, University of Pretoria, 2014)

1.3. Need for good quality water in these schemes

Rivers and streams are very susceptible to both microbial and chemical contamination when compared with groundwater reservoirs. If the river is dammed, then the quality of the dam water will be affected. This is attributed to the absence of natural filtration and soil protection, as well as shorter distances between where the contamination occurs and where the water is extracted. This leads to increased microbial load within running river or surface water and the microbes reaching water reservoirs and water extraction points very quickly (Kistemann *et al*., 2002).

It is therefore important that the raw water flowing from the five rivers into the Katse dam catchment area be monitored for microbial quality and chemical quality as a

strategic move to protect the reservoir, and the aquatic environment in general within the catchment. Even though the water from the Lesotho Highlands is considered to be of good quality (Lepono *et al*., 2003), it would be important to monitor the water quality so that the status can be maintained. In the catchment area, there maybe be anthropogenic activities that result in point and diffuse sources of pollution that could have an impact on the water quality of the rivers (Okoh *et al*., 2012).

Within this catchment area, there are human settlement areas which have been established on scarce arable land. The human activities that are taking place in this area include cultivating on marginal land, without employing any conservation measures and overgrazing, leaving the soil bare and susceptible to soil erosion, run-off, poor drainage and sedimentation. The surface waters around these areas are not well protected and are easily accessible to human beings and animals, making them susceptible to contamination (Kravitz *et al*., 1999). There are also approximately 20 000 people residing around the Katse Dam catchment area i.e. the Ha Lejone and Motebong Villages which depend on and utilise surface water resources such as rivers and streams for household water use, drinking and irrigation on a small scale (Kravitz *et al*., 1999). Sanitation is also a major issue since less than 5% of the villagers use toilets or pit-latrines. The majority use the bush or riverside to relieve themselves, therefore increasing faecal contamination on surface water (Kravitz *et al*., 1999).

The valley side of the Katse Dam is used mostly for farming and grazing purposes by villagers, leading to unsustainable practices such as overgrazing and leaving the soil susceptible to erosion and degradation (Mwangi, 2008). The community also uses the river water to wash clothes using detergents. This causes an increase in phosphorus levels within the water (Ramsingh *et al.*, 1998). When ingested, the high phosphorus levels in water can cause health problems such as bone disease and hardening of tissue in humans (Heaney, 2000).

High phosphorus levels in the water could cause nutrient enrichment or eutrophication. This promotes the growth of algae e.g. Cyanobacteria such as *Microcystis aeruginosa* and macrophyte growth which leads to oxygen depletion in the water body causing fish kills and death of other benthic organisms (Paerl, 2014). Eutrophication has some detrimental effects on the environment such as degradation

of water quality for human and animal consumption, decrease in the aesthetic value or scenery of the water surface and causes a decline in wild and cultured aquatic resources (Ansari & Sarvajeet, 2013). This would also increase the cost of treating the water to remove the growth of algae (Kleinman *et al*., 2011; Ansari & Sarvajeet, 2013). In addition, the villagers would not be able to bear this cost due to poverty and lack of resources and infrastructure to treat the water to the point of usability.

It is therefore necessary to determine the water quality of each contributing system to the dam. For example, there is a commercial aquaculture project at the Katse Dam which produces rainbow trout fish in a cage culture system. The Bokong River feeds the Katse Dam close to this trout fish farm (Figure 1.3). The aim of the project is to act as a hatchery and fish processing facility to produce about 300 tonnes of fish per annum. This will require careful monitoring of water quality parameters to ensure that the dam water maintains its integrity since this kind of fish requires fully oxygenated waters (Food and Agriculture Organisation, 1995; Eilertsen, 2013). Another fish farming activity occurs at the Malibamatso River which is located close to Ha-Lejone village. Contamination of the water would lessen the aesthetic value especially for some people who practise recreational fishing around this area (LHDA, 2000).

Figure 1.3: The rainbow trout farming cages in the Katse Dam (taken from Eilertsen, 2013)

Mining is also taking place in some parts of the catchment area, for example diamond mining activities close to the Malibamatso River. (Pottinger, 1997). Waste

water produced during mining activities contains high levels of salt and other minerals, which renders the water unsuitable for discharge directly into river systems. If discharged onto the ground, mineral content may cause both point-source and more dispersed pollution problems, which can impact the water quality negatively (Rahm *et al*., 2006).

As stated, the water quality from the Lesotho highlands is of 'good quality' which could also be attributed to the existence of wetlands in the area which provides clean water to the dam as well as the surrounding community areas (Letšela *et al*., 2003). A comparison study of the Katse Dam, Vaal Dam water and Sterkfontein Dam water was conducted (Table 1.1). The findings were that the water from the Lesotho Highlands is of a better quality in comparison with the Vaal Dam and Sterkfontein Dam water (Table 1.1). This is evident as indicated by the lower concentrations of the selected physical and chemical constituents (Table 1.1). However, the general physical, chemical and microbiological water quality constituents from the Vaal Dam were found to be of lower quality than that of the Sterkfontein Dam. In terms of water quality status, this supports the findings of Lepono *et al*., (2003) that in general, water from the Lesotho highlands is of a better quality.

Table 1.1: Data comparing the water quality of the Katse Dam, Vaal Dam and Sterkfontein dam (Ramsingh *et al*., 1998)

Parameter	Katse Dam	Vaal Dam	Sterkfontein Dam
Temperature (˚C)	2.93-22.6	9-25	9-26
Conductivity (mS/m)	7-9.8	14-21	7.8-9.0
Hardness (mg/$CaCO_3$/l)	30-110	50-73	26-33
Turbidity (NTU)	0.32-13	7.1-340	0.55-39
pH	7.3-8.4	7.4-8.3	6.9-7.8
Alkalinity (mg $CaCO_3$/l)	29-41	51-74	30-33
Total Dissolved Solids (mg/l)	37-94	94-140	52-60
Magnesium(mg/l)	3-6	4.8-8.3	2.3-2.8
Calcium (mg/l)	6.6-38	69.7-18	6.5-8.8
Sulfate (mg/l)	0.75-15	10-23	10-12
Chloride (mg/l)	1.2-5	10-13	<10

Previously, water quality has been monitored in the Malibamatso, Bokong, Pelaneng, Liphofung and Mokhoulane Rivers. Results have shown the presence of faecal coliform bacteria with *Cryptosporidium* detected only at Pelaneng and Mokhoulane rivers (Ramsingh *et al*., 1998). An assessment of the water quality of the rivers will bring insight into the water quality status of the rivers just before feeding into the Katse Dam as well as the 'fitness for uses' by the various users. Data for the water quality will be compared to the DWS guidelines, the SANS for Drinking water and international guidelines such as those of the World Health Organisation (WHO).

1.4. The impact of steep terrain on surface water quality of streams

Since Lesotho is a mountainous area, the high altitude and steep topography, and snowfall in the winter months may have an impact on the water quality. In highland catchment areas, rainfall is of high intensity with thunderstorms and often in a short period of time (Van der Merwe *et al*., 2002).

The surface water in steep terrain is dominated by particulate organic carbon which consists of mainly soil particles and organic debris (Shanley & Wemple, 2002). In the northern mountainous areas of Asia, the winter months are cold and dominated by snow with fluctuations in temperature, precipitation and stream discharge (Park *et al*., 2010). Dilution of surface waters by snowmelt is a major driving factor affecting the concentration and fluxes of major solutes, especially nitrates and dissolved organic carbon (DOC). The melting of snowpacks influences the movement of water and the transport of various solutes from soils to surface water. The snowmelt affects the surface water biogeochemistry because it flushes out solutes from the forest floor and mineral soil, thus contributing to acidification and nutrient concentration in surface waters. Acidification however, will also depend on the parent rock and the weathering rates of the steep terrain (Park *et al*., 2010).

Prolonged and heavy rainfall events can erode steep slopes and clog streams with sediments. Hence sediment loading is a major contributor to stream water quality degradation (Rickenmann *et al*., 2015). Mountain streams have a low concentration of dissolved substances in general. However, the dissolved substances accumulate downstream over time and as they react with dissolved soil particles (Shanley & Wemple, 2002).

1.5. Hypothesis

The surface water quality of the five main rivers feeding the Katse Dam is not significantly being impacted by possible anthropogenic activities taking place in the catchment area.

1.6. Aim of the study

The aim of this study is to investigate the surface water quality of the five rivers feeding the Katse Dam in Lesotho to assess if the surface water quality is being impacted by anthropogenic activities.

1.7. Objectives

- Literature review focusing on (a) the activities in the catchment areas of the five rivers under investigation and (b) the effects of these activities on water sources and the users of the water resource;
- Determine the current surface water quality of the Bokong, Liphofung, Malibamatso, Mokhoulane and Pelaneng rivers by performing water quality analyses on collected surface water samples;
- Compare the data obtained with historical data to establish if the water quality of these rivers has changed and;
- Determine if the current water quality complies with the requirements for use by different users.

1.8 Organisation of Report

The document is laid out as follows:

Chapter 2 discusses the natural factors affecting the water quality of surface waters as well as the anthropogenic activities such as agriculture, mining, industries, human settlements and waste disposal methods. Descriptions of the microbiological, chemical and physical determinants and their sources from the environment are also discussed, and how these compare to water quality requirements for different users as well as international best practice.

Chapter 3 discusses the domain and the methodology employed in this study. The climate, geology, hydrology and land use activities around the main rivers feeding into the Katse Dam are discussed. The locations of the various sites where samples were taken are also discussed. Sampling procedures and the analysis of physical, chemical, and microbiological determinants are discussed.

Chapter 4 discusses the results obtained from the sampling conducted in the five main rivers feeding the Katse Dam. The physical, chemical, and microbiological determinants were compared to various guidelines, as well as historical data.

Chapter 5 provides the data that was compared to the various user requirements in order to determine the fit for purpose of the water coming from the five rivers, the general discussions, observations and conclusions.

Chapter 6 provides recommendations from this study.

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CHAPTER 2

2. LITERATURE REVIEW

2.1. Factors affecting the water quality of rivers

Water quality is a critical aspect in meeting basic environmental and human needs (Gleick & Ajami, 2014). Water quality is the suitability of water to sustain certain uses or processes and can be defined by a range of certain Determinants with certain influences on the quality of water. The quality of water is affected by both natural and human influences, with geological, hydrological and climatic factors being the most important of the natural influences (Palaniappan *et al*., 2010; WHO, 2011).

Human activities negatively impacting the water quality are industrial, urban and agricultural activities. These activities make surface water unsuitable for the intended uses, e.g. agricultural activities are a major source of nitrogen and phosphorus pollution in surface water bodies (Ansari & Sarvajeet, 2013; Carpenter *et al*., 1998; Simeonov *et al*., 2003). The human population is increasing, thus causing an increase in the usage and demand of water resources. This increased usage of water resources exerts pressure on the built water infrastructure, compromising the water quality. Ecosystems which rely on freshwater, degrade as human need for water increases because water courses are altered in order to cater for the growing human population (Gleick & Ajami, 2014).

2.1.1. Natural Influences

2.1.1.1. Geology

The types of rocks in an area are composed of different chemical determinants. As the rock weathers, different proportions of metal, ions and nutrients are released as the water flows through the rocks (Alloway, 2013). Primary and sedimentary rocks occur in varying thicknesses and depths. As hydrological processes occur, the dissolved solutes enter the upper layers of the rocks either through irrigation, flood water, upward ground water flow in seepage zones, rising groundwater levels or capillary rise. The solutes reaching the upper rock layer then affect the water quality in that area (Singh & Schulze, 2015; WHO, 2011).

A stream's water quality reflects the geology of a catchment area, especially if there are limited or no anthropogenic impacts. The geology also affects water hardness

and alkalinity of the surface water (Wirmver *et al*., 2013). Water hardness is based on the amount of calcium per litre. In this instance, dissolved polyvalent metallic ions from sedimentary rocks are natural sources of water hardness. Both calcium and magnesium are present in many sedimentary rocks such as limestone and chalk (WHO, 2011).

Water from gypsum rock formations is high in both calcium and magnesium. By contrast, crystalline igneous and metamorphic rocks undergo slow weathering of silicates and release low concentrations of calcium, magnesium and sodium in the infiltrating water, which would then have less impact on the water quality (Selinus *et al.,* 2013).

The occurrence of fluoride in water has been linked to the geology of that area. High grade metamorphic rocks have high fluoride content with streams in the area having high fluoride content. Iron is an important component of water. It is found in groundwater that has come into contact with iron-rich crystalline rocks. High iron content can be detected in surface water flowing in soils with high iron content, thus contributing to the quality of water in an area (US Geological Survey, 2014; Selinus *et al.,* 2013).

2.1.1.2. Climatic and hydrological conditions

The most important and immediate reaction to a change in climate is observed in river or lake temperature (European Environment Agency, 2007a). There is a close equilibrium between river water temperature and air temperature. This implies that as air temperature rises, river temperature will also rise (European Environment Agency, 2007a). A substantial rise in water temperature can have an impact on the flora and fauna of aquatic habitats because most biological and chemical processes accelerate with increasing temperature. Water temperature has an impact on the behaviour of certain aquatic organisms, e.g. fish migration and sustenance of different life stages of some insect populations. High water temperatures cause extensive growth of phytoplankton, macrophytes and epiphytes which leads to low dissolved oxygen (DO) in the water body, thus causing the organisms to suffocate (Davidson & Hazelwood, 2005; Durance & Ormerod, 2007).

The climate of an area is directly linked with the flow velocity, water levels, residence times and hydraulic characteristics of the rivers and streams in that area (Whitehead

et al., 2009; Brown *et al*., 2007). For example, if an area experiences heavy rainfall and flooding, there will be an increased load of suspended sediments and solids, as well as microbial fluxes e.g. *Escherichia coli.* Contamination in soils will be observed as well as an increase in metal fluxes due to the transport of fine sediment from surface soils (Longfield & Macklin, 1999). Prevailing climatic conditions also have an effect on residence time and determine whether a pollutant will have a short or long residence time (WHO, 2011).

Average residence time (ART) or flushing time is defined as the total time it takes for a substance or pollutant to stay in a given water body (Delhez, 2004). It quantifies the time water stays in semi-enclosed water bodies, therefore being used as an indicator of pollution and in ecological assessments procedures as well as in understanding eutrophication problems in enclosed water bodies. A water system with a short residence time is able to flush out or export pollutants entering the system upstream in a much faster manner e.g. a pond can flush out inorganic nitrogen that enters the system through groundwater discharge, runoff or rainfall, thus maintaining the water quality (Delhez *et al*., 2004; Chapman *et al*., 2013).

Changing climatic conditions can also influence flow velocity, e.g. an extensive study of the Spanish Ebro river basin was conducted with regard to the hydrology, and behaviour of environmental pollutants with changing climatic conditions. In this study, persistent organic pollutants such as DDT were found to be most prevalent during periods of low water flow. This is due to the lack of dilution, whereas in high flow periods, there's sufficient dilution of pollutants with very low detection levels of pollutants. The degradation, turnover, sorption and transport of persistent organic pollutants in the water are strongly influenced by changing climatic conditions (Bovolo *et al*., 2011). Eventually, these factors have an effect on sediment transfer and channel morphology, all which can have an impact on the water quality and alter the ecosystem at habitat level and catchment area level (Verdonschot, 2000).

2.1.2. Anthropogenic activities

Some of the anthropogenic activities which might affect surface water quality include agriculture, mining, industrial, human settlements and waste disposal methods (Yadav & Kumar, 2011; Rashid & Ramshoo, 2013). Agriculture and urban activities are non-point sources of pollutants such as phosphorus and nitrogen and other

nutrients in surface water. Within the environment, the sources of these nutrients are varied and dispersed over large areas (Carpenter *et al*., 1998). The application of inorganic chemical fertilizers on agricultural land is an example of a non-point source of contamination (Chigor *et al*., 2012). An assessment of the surface water quality of water sources used for drinking and irrigation was conducted in Zaria, Nigeria. The main sources of pollution varied from municipal waste water, storm water runoff, abattoir effluents and irrigation runoff from farms using fertilizers (Chigor *et al*., 2012). In a similar study in northern Greece conducted by Simeonov *et al*., (2003), the municipal and industrial effluents as well as agricultural runoff were the main contributors to organic and nutrients parameters and contributed to high concentrations of lead (Pb), zinc (Zn) and cadmium (Cd). This indicates that sources of pollution can be diverse and dispersed, depending on the human activities or influences around the area.

Urbanization, human settlements and an increase in human population have caused sewage from industry and households to increase (Wang, 2009; Engel *et al*., 2011). If sewage is discharged into a river, it will increase the organic content of the rivers. The organic input causes dissolved oxygen levels to decrease, indicating that, the aquatic system is degrading (Wang *et al*., 2007). Municipal waste water treatment plants (WWTP) are point sources of nutrient and faecal contamination. For example, high bacteriological quantities e.g. faeces-indicating bacteria such as *E. coli* were detected in the Buffalo River and the surrounding dams, giving indications that sewage was being dumped at some point in the river (Chigor *et al*., 2013). This was due to the fact that some of the WWTP in the surrounding areas were overloaded and being directly discharged into the river (Chigor *et al*., 2013).

In the USA nutrient input from WWTPs to aquatic systems contributes almost 50% of the total nutrient load in aquatic systems. Annually, the nutrient input can be up to 90% of the nutrient load (Haggard *et al*., 2005). This shows that the contribution of waste water treatment plants to nutrient load is considerable. WWTP effluents input into streams causes the nutrient concentration to become elevated beyond saturating concentration because of the high nutrient input concentration. The impact of high nutrient input includes an increment in sediment deoxygenation downstream. The phosphate buffering ability of benthic sediments is also decreased quite substantially (Haggard *et al.,* 2003b). Stream nutrient load and transformation

is affected negatively and the effects persist several kilometers downstream, having a long-term effect on the stream composition (Haggard *et al.,* 2003b, 2005).

The water quality in densely populated areas and large metropolitan areas is poor and contaminated compared to the water quality of upstream dwellers living in more environmentally attractive surroundings. Densely populated areas are often inhabited by poor, low-income people, e.g. informal settlements and squatter camps, which do not have access to treated water and proper sanitation infrastructure. These informal settlements have open sewers and drains where garbage waste, dead animals and waste water is deposited directly and these then discharges into rivers and streams in that polluted state. Due to lack of proper sanitation facilities such as toilets, people defecate in the bush, next to sewage pipes, and alongside roads. During heavy rainfall seasons, these drains and sewers overflow into the surrounding environment, increasing faecal contamination into surrounding water bodies (Van den Berg *et al*., 2003; United Nations World Water Development Report, 2006).

An example is in the Eastern Cape Province of South Africa around the Buffalo River, where there is not sufficient sanitation infrastructure for the highly populated rural communities. The communities draw water from the river and use it without any treatment, posing a serious health risk. The water quality of the Buffalo River is of a poor quality, with high levels of bacteria because of the faecal contamination from the source, and increasing through the rural areas and downstream of the river (Chigor *et al*., 2013). The same situation exists in many developing countries, such as in the Bukoba region of Tanzania, where only 63% of the residents receive water services from the Bukoba water service authorities (UN-Habitat, 2004b). The residents utilize pit latrines and septic tanks resulting in septic tank effluent being discharged into storm water drains which then contaminate Lake Victoria. This lake is the town's main source of water (UN-Habitat, 2004b).

Industries utilize water in many ways, e.g. for heating and cooling, cleaning, for generating steam, as a raw material, as a solvent and as a constituent part of the product and in the process generate solid waste and by-products (United Nations World Water Development Report, 2006). The balance is then discharged as waste water or effluent either as direct disposal into a stream or river or routed to the nearest municipal sewage treatment plant. Treatment by an on-site wastewater

treatment plant results in discharge of effluent into a series of open ponds. The concern is that the contaminated water is returned directly to the water cycle without any treatment or adequate treatment. The discharged water might be contaminated with heavy metals, organic matter, chemicals or particulates and affects the quality of the receiving water body. These contaminants are directly toxic to organisms in the water and the high levels also affect oxygen availability and destroy aquatic life downstream. Industrial discharge can also have direct human impact if industrial discharge is located upstream of recreational swimming areas or subsistence fishing grounds or at a point where farmers and local people extract water for crop irrigation and domestic use. There are also indirect ways in which industries negatively affect the water quality. This can occur through the leaching of chemicals from solid waste and atmospheric deposition of chemicals distributed by rain and air pollution. The chemicals leach out of industrial dumpsites and landfill sites and eventually reach streams and groundwater. Industries also release sulphur and nitrogen compounds into the atmosphere. These compounds transform and dissolve into raindrops and fall as acid rain, which causes streams to have acidic waters and affecting aquatic life (United Nations World Water Development Report, 2006).

Water quality may also be compromised by present and past mining activities at a given area. In South Africa, like other countries throughout the world, acid mine drainage (AMD), generation weathering and generation of sulphides are major environmental problems associated with mining (Tutu, 2012). Abandoned mines are likely sources of heavy metal pollution e.g. mining activities have increased the generation of AMD and increased levels of metals such as arsenic (As), copper (Cu), and iron (Fe) on the surface waters of the Andean tributaries in North Central Chile long after the mine had closed (Parra *et al*., 2011).

The presence of these metals in water above tolerable concentrations has negative effects on ecosystems and human health (Hudson-Edwards *et al*., 2011). AMD is formed when there is a breakdown of pyrite and other sulphides by water or air which releases acid, sulphate and metals into the environment. AMD causes the water to be very acidic and the high concentration of dissolved metals and salts change the water chemistry. Coal mining activities in the Witbank and Highveld coal fields, South Africa, have altered the water chemistry of water bodies 200km downstream (Ashton *et al*., 2001). A direct impact is the conversion of carbonates

and bicarbonates into carbonic acid, which then dissociates into water and carbon dioxide, thus removing the buffering system in the water which functions to control the water acidity. Most photosynthetic organisms need bicarbonate as a source of inorganic carbon and if all bicarbonate has dissociated, the organisms lose their ability to photosynthesise (Ashton *et al*., 2001). The ionic balances in the water are altered, leading to cell components and carbonate exoskeletons of certain organisms being destroyed. Sulphates and sulphide products lead to increased suspended solids and dissolved solids which lead to salination and decrease the dissolved oxygen content of the water system (Ashton *et al*., 2001).

2.2. Water quality requirements for different users

The purpose of water quality standards is to safeguard water quality and prevent pollution for the protection of public health and welfare for assigned water uses. This is in accordance with the public interest for drinking water supplies, agricultural, industrial, recreational, wildlife and aquatic life to maintain and improve the biological integrity of water (U.S. Environmental Protection Agency, 2012).

2.2.1. World Health Organisation drinking water guidelines

At an international level, the World Health Organisation (WHO) water quality guidelines are the international reference points for drinking water quality criteria. However, countries have a sovereign right to develop their own water quality standards and regulations at national level (US Environmental Protection Agency, 2012).

Water quality criteria are based on determinants that characterize the water quality. The criteria are set at a maximum level for the concentration of a substance in the water which would not cause any harm when the water is used continuously for a single specific purpose. There are, however, some determinants which are set at a minimum acceptable concentration to ensure the maintenance and sustenance of biological functions e.g. dissolved oxygen. Not all determinants have been assigned a recommended or guideline value e.g. ammonium has no guideline value because it occurs in drinking water at concentrations that are well below those that can cause of health concerns. Iron also has no guideline value for the same reason as ammonium (WHO, 2011).

The WHO has been very active in developing guidelines, however, of late; a more preventative approach which includes the development of Water Safety Plans (WSPs) has advanced. WSPs take cognizance of all factors that can endanger the quality of potable water from source to tap water when the consumer uses the water instead of just monitoring the final drinking water quality (Figueras & Borrego, 2010). Thus, WSPs are based on an integrated risk assessment approcach for ensuring the delivery of safe drinking water (Dunn *et al*., 2014).

2.2.2. Department of Water and Sanitation (DWS) water guidelines

In South Africa, the Department of Water and Sanitation is the national agency responsible for formulating and implementing water policy. Thus, the DWS has formulated the South African Water Quality guidelines. The guidelines are divided into four broad categories according to the water use i.e. domestic (which includes drinking, cooking, bathing, washing of clothes and gardening), industrial, agricultural (Irrigation, Aquaculture, Livestock & watering), Aquatic Ecosystems and recreational guidelines. Under these categories, the fitness for use is either ideal, meaning that it's 100% fit for use, acceptable, tolerable (for a limited period), unacceptable or completely unfit for use. The ideal fitness category is the desirable water quality or target water quality range (TWQR).

Therefore it is best to use water whose determinants concentrations are above the TWQR of the DWS Domestic water guideline (DWAF, 1996a). The DWS water guidelines for selected microbiological, physical and chemical determinants are indicated in Table 2.1. However, these guidelines do not have values for chemical determinants such as boron, phosphorus and nickel but the WHO does have these guideline values. In some instances, the values of the WHO and DWAF are very different e.g. the WHO has a sodium guideline value of 50mg/l whereas DWAF has a guideline value of 100 mg/l.

Table 2.1: Water quality guidelines (DWAF, 1996a, 1996b, 1996c, 1996d, 1996e); SANS, 2015; WHO, 2011

Guideline/Standard Determinants	Unit	WHO 2011	SANS 241:2015	DWAF Domestic 1996a	DWAF Irrigation 1996b	DWAF Livestock & Watering 1996c	DWAF Aquaculture 1996d	DWAF Aquatic Ecosystems 1996e
Chemical determinants								
Aluminium	$mg.l^{-1}$	0 - 0.9	0 - 0.3	-	0 – 5.0	0 – 5.0	<0.03	0 - 0.005/0.01
Ammonia	$mg.l^{-1}$	-	0 - 1.5	-	-	-	0.0-0.025	-
Arsenic	$mg.l^{-1}$	0 - 0.01	0 - 0.01	-	0 - 0.1	0 – 1.0	-	0 - 0.01
Cadmium	$mg.l^{-1}$	0 - 0.003	0 - 0.003	-	0 - 0.01	0 - 0.01	0.2 for soft waters	0 - 0.00035/0.0004
Calcium	$mg.l^{-1}$	-	-	-	-	0-1000.0	-	-
Fluoride	$mg.l^{-1}$	0 - 1.5	0 - 1.5	-	0 – 2.0	0 – 2.0	-	Background value must not differ by more than 10%
Iron	$mg.l^{-1}$	0 – 2.0	0 - 2.0	-	0 – 5.0	0 – 10.0	0-0.01	0 - 0.001/0.0012
Lead	$mg.l^{-1}$	0 - 0.01	0 - 0.01	0-0.01	0 - 0.2	0 - 0.1	0-0.01	-
Magnesium	$mg.l^{-1}$	-	-	-	-	0 – 500.0	-	-
Nitrate	$mg.l^{-1}$	0 – 50.0	0 – 11.0	-	-	0 – 100.0	<300	-
Nickel	$mg.l^{-1}$	0 - 0.07	0 - 0.07	-	0 - 0.2	0-1	0-0.05	-
Nitrite	$mg.l^{-1}$	0 – 3.0	0 - 0.9	-	-	-	0.05	-
Selenium	$mg.l^{-1}$	0-0.04	0-0.02	0-0.02	0-0.02	0-0.05	0-0.3	0-0.0002
Sodium	$mg.l^{-1}$	0 – 200.0	0 – 200.0	-	0 – 70.0	0 – 2000.0	-	-
Sulphate	$mg.l^{-1}$	0 – 500.0	0 – 500.0	-	-	0 – 1000.0	-	-
Total Silica	$mg.l^{-1}$	-	-	-	-	-	-	-
Total Organic Carbon	$mg.l^{-1}$	-	-	-	-	-	-	-
Zinc	$mg.l^{-1}$	0-3.0	0-5.0	-	0-1.0	0-20.0	0-10.0	0-0.002

Table 2.1 (Continued) Water quality guidelines (DWAF, 1996a, 1996b, 1996c, 1996d, 1996e); SANS, 2015; WHO, 2011

Guideline/Standard Determinants	Unit	WHO 2011	SANS 241:2015	DWAF Domestic 1996a	DWAF Irrigation 1996b	DWAF Livestock & Watering 1996c	DWAF Aquaculture 1996d	DWAF Aquatic Ecosystems 1996e
Microbiological determinants								
E.coli	MPN.100ml^{-1}	0.0	0.0	-	0-10	0-200.0	0-10	-
Giardia and Cryptosporidium		-	-	0	-	-	-	-
Coliphage bacteria	CFU/100ml	0	-	0-1	-	-	-	-
Faecal coliform	FC/100 ml	0	0	0	0-10 000	-	-	-
Physical Determinants								
Chemical Oxygen Demand	mg.l^{-1}	-	-	-	-	-	-	-
Conductivity	mS.m^{-1}	-	0 – 170.0	-	0 – 40.0	0 – 154.0	-	-
Dissolved Oxygen	%	-	-	-	-	-	60-90 % saturation	80-120 % saturation
pH	N/A	-	5.0 - 9.7	-	6.5 - 8.4	-	6.5-9.0	Background value must not differ by more than 0.5 or 5%
Temperature	°C	-	-	-	-	-	-	Background value must not differ by more than 2ºC or 10%
Total Dissolved Solids	mg.l^{-1}	-	0 – 1200.0	-	0 – 260.0	0 – 1000.0	-	Background value must not differ by more than +/- 15%
Turbidity	NTU	-	0 – 1.0	-	-	-	-	Background value must not differ by more than 10%
Water Hardness	mg/l	-	-	50-100	-	-	20-100	-

Many countries do not have specific water quality guidelines for *Cryptosporidium* and *Giardia* but rather follow the world health organization (WHO) guidelines (WHO, 2011) which recommend the development of Water Safety Plans. These are control measures that can be applied to manage potential risk from *Cryptosporidium* and *Giardia.* These should include prevention of source water contamination by human and animal waste, followed by adequate treatment, disinfection and protection of water during distribution. For example, there is no specific standard for *Cryptosporidium* in the European Union (EU) and United Kingdom (UK) drinking water directive (McLauchlin *et al*., 2012). However, a treatment standard of less than 1 oocyst per 10 litres of water in a sample taken over a 24 hour period is required (US EPA, 2011). These countries prefer a risk based approach to the management of *Cryptosporidium* rather than prescribing specific limits on numbers of oocysts (US EPA, 2011).

Similarly, Sigudu *et al*., (2014) developed a preventative strategy to reduce the risks associated with exposure to these protozoa and non-compliance to guidelines or standards. The strategy involves ten detailed steps, grouped into four major phases. Phase 1 is the undertaking of a desktop study or survey of the monitoring requirements followed by phase 2, which involves a situational analysis of the water source, type of water purification plant as well as the epidemiology. Phase 3 covers information management in the form of sample collection, analysis and storage of data. Phase 4 is the review of the efficiency of the monitoring process.

The United States of America (USA) has the interim enhanced surface water treatment rule which requires that treatment systems servicing populations of more than 10 000 people must achieve a 2- log removal of *Cryptosporidium.* This means that treatment works should target producing water with turbidity of 0.3 NTU (nephelometric turbidity unit) in 95% of daily samples in any one month. A 99% removal of *Cryptosporidium* through filtration systems combined with regular monitoring. The South African standard for *Cryptosporidium* and *Giardia* should be less than 1 oocyst per 10 litres in drinking water (SANS 241: 2015). For Australia, no guideline value was set for *Cryptosporidium* in the 2004 Australian drinking water guidelines. On the contrary, the guidelines emphasize the use of risk assessment, risk management, the use of multiple barriers and monitoring (US EPA, 2011). This

is attributed to the fact that there is no method to identify infectious strains in drinking water and large volumes of water would need testing (US EPA, 2011).

2.2.3. South African National Standard 241-2: 2015 for drinking water

Water quality assurance for domestic consumption in South Africa is safeguarded by the South African National Standards (SANS) 241 for drinking water. SANS (241-2: 2015) specifies acceptable drinking water in terms of microbiological, physical, aesthetic and chemical determinants. The water that complies with the standard is regarded to pose an acceptable health risk to consumers for life time use. The risk of the various determinants is further defined in terms of 1) acute health, 2) chronic health, 3) aesthetic, and 4) operational (SANS 241:2015).

2.2.4. Ecosystem function

Ecosystem health is determined largely by the effective functioning of the natural background conditions. An ecosystem that is fully functional would support various organisms at different trophic levels i.e. primary producers and all consumers (United Nations Global Environmental Monitoring System [UN-GEMS] Water Programme, 2008). In general, changes in aquatic ecosystems are not easily detectable because the effects on composition and function are not immediately apparent. Change is often gradual over time until a dramatic shift occurs. Other ecosystems however, are sensitive to physical and chemical changes on a small scale but with eventual loss of biodiversity and ecosystem degradation (United Nations Global Environmental Monitoring System [UN-GEMS] Water Programme, 2008).

There are ecosystems which have received input of nutrient gradually. Due to the impact of the nutrient input, such ecosystems shifted from being dominated by rooted aquatic plant species to an ecosystem dominated by algae suspended in the water column (Scheffer *et al*., 2001). Aquatic ecosystems are designed to assimilate, dilute and transport waste (Palmer *et al*., 2002). If the capacity of these processes is no longer viable, then pollution occurs, since the system can no longer perform its functions and there is loss of ecosystem services on a broader scale (Palmer *et al*., 2002).

Ecosystems vary in composition because each zone is determined by the quality of water dominating the habitat type, the degree of water flow as well as the distribution of species (UN-GEMS Water Programme, 2008). The physical, chemical and

microbial determinants can either have a beneficial effect or a negative effect on ecosystem functioning when two or more determinants act synergistically or antagonistically or when acting as individual determinants or Determinants (Palmer *et al*., 2004; Lewis *et al*., 2015). The monitoring of the chemical, physical and microbiological determinants of ecosystems is necessary and important in order to detect extreme changes over time to mitigate and ensure that the normal state is not stretched beyond its limit (UN-GEMS Water Programme, 2008).

The DWS guidelines for selected determinants in aquatic ecosystems are listed in Table 2.1, which compares the guidelines for domestic, agriculture and the WHO. The TWQR for aquatic ecosystems, specifically for heavy metals, are the lowest i.e. they are required in very low concentrations in the ecosystem compared to TWQR for domestic and agricultural, SANS, WHO guidelines. This includes lead, with a concentration of 0.0012 mg/l and selenium with 0.0002 mg/l concentration. This shows the sensitivity of aquatic ecosystems to heavy metal pollution. However, for some physical determinants, there are no guideline values but the requirement is that background value must not differ by more than 0.5 or 5% e.g. pH or temperature (DWAF, 1996e).

2.2.5. Agriculture

Agricultural activities are known to disrupt all freshwater systems from their pristine states (Moss, 2008). This is attributed to the fact that the entire land surface which is mostly agricultural, forms the catchment area for one or another river system. Therefore, all activities happening in the catchment area have an effect on the freshwater systems (Moss, 2008). As the largest user of freshwater resources, agriculture uses an average of 70% of all surface water supplies globally and is therefore a major cause of degradation of both surface and groundwater (Gössling *et al*., 2012).

The aquaculture industry has since relied on a wide variety of synthetic and natural chemical and biological treatments, to prevent and treat disease outbreaks, for the enhancement of the health status of the cultured species and to improve the overall environmental conditions of the aquaculture production systems. These include antibiotics, disinfectants, pesticides, fertilizers and water and soil treatment compounds. However, this becomes a challenge because aquaculture production

systems including freshwater and brackish water systems, inland cages and ponds, are hydrologically interconnected with the surrounding water bodies, with the potential to produce continuous or intermittent wastewater discharges into them (Rico *et al*., 2012). The natural structure and functioning of these surrounding water bodies is impacted negatively, due to the addition of these chemicals (Rico *et al*., 2012). For example, copper is used as an algaecide to remove ecto-parasites in aquaculture industries (Tom-Peterson *et al*., 2011). It is effective but affects the microbial degradation of organic matter, lowering organic matter in aquatic systems. This is because copper inhibits bacterial growth even at concentrations as low as 0.1 µM (Tom-Peterson *et al*., 2011).

In terms of guidelines, the DWS water quality guidelines for agriculture also include livestock, irrigation and aquaculture. The guidelines for aquaculture are more stringent in comparison with those guidelines for irrigation and livestock (Table 2.1). It is a clear indication that within agriculture, aquaculture is a more sensitive environment (DWAF, 1996b; 1996c; 1996d).

2.3. Descriptions of the microbiological, chemical and physical determinants and their sources from the environment

There are microbiological, physical and chemical determinants which indicate the water quality status in any given water body. Examples of chemical determinants are given in Table 2.1 i.e.iron, lead and copper which impact water distribution and treatment systems. Some physical determinants such as turbidity and total dissolved solids impact the aesthetic value of water systems. These determinants play an important role in effective ecosystem functioning (WHO, 2011).

Even though these determinants are essential for life for survival of most organisms, they can be problematic as pollutants (WHO, 2011). These determinants are highlighted as pollutants of concern in the WHO (2011), SANS (2015) and the DWAF water quality guidelines which are currently being revised by the DWS. Therefore, it is important to focus on their sources or occurrence in the environment, either natural or anthropogenic, their impacts on the ecosystem, humans and animals and what the target water quality ranges are, according to the different water quality guidelines.

2.3.1. Selected microbiological determinants

2.3.1.1. *Cryptosporidium sp.* and *Giardia sp.*

Cryptosporidium and *Giardia* are microorganisms classified as protozoa belonging to the phylum Apicomplexa. They develop within the gastrointestinal tract of vertebrates throughout their entire life cycles. Protozoa are motile, microscopic and eukaryotic, that is, usually single celled organisms. A majority of the protozoa are aerobic heterotrophs, some are aero tolerant and a few are anaerobic (Striebig *et al*., 2015). They are generally larger than bacteria and sometimes consume bacteria as a source of energy. They act as polishers of effluents from biological and municipal waste water treatment processes by consuming particulate matter and bacteria. Specifically *Cryptosporidium parvum* and *Giardia lamblia* are very important and significant microorganisms because of their pathogenicity or impact on individuals whose immune system have been compromised and are implicated in many diseases associated with protozoa worldwide. They also infect birds, fish and reptiles (Metcalf & Eddy, 2004; Sigudu *et al*., 2014).

The oocyts of *G. lamblia and C. parvum* can survive in the environment for extended periods of time, depending on the characteristics of the water (Aljanahi and Khan, 2014). The two species can withstand a variety of environmental stresses, including freezing and exposure to seawater (Health Canada, 2012). The cysts are also resistant to chlorine, therefore prevention and control of treatment of community water supplies is very important (Prescott *et al*., 2002).

Consequently, a multi-barrier approach must be taken such as a combination of watershed or wellhead protection, appropriate treatment, optimized filtration for effective fine particle removal and disinfection, a well-maintained distribution system and monitoring the effectiveness of treatment (e.g., turbidity, disinfectant residuals). This approach has been the best approach in reducing protozoa and other waterborne pathogens in drinking water (Health Canada, 2012). In general, all water supplies should be disinfected, and an adequate concentration of disinfectant residual should be maintained throughout the distribution system at all times. When it comes to chemical treatment, a combination of ozone and chlorine dioxide is the most effective disinfectant against *Cryptosporidium* and *Giardia* (Health Canada, 2008). This is because ozone (O_3) is a very strong oxidant which is capable of

effectively inactivating *Cryptosporidium* and *Giardia*. The disadvantage is that both ozone and chlorine dioxide are typically more expensive and complicated to implement, especially in small treatment systems. It also decay rapidly after being applied during treatment and thus cannot be used to provide a secondary disinfectant residual (Health Canada, 2008).

2.3.1.2. *Escherichia coli*

There is a wide range of faecal bacteria in the faeces of humans and animals that are commonly found in water bodies e.g. the coliform group, streptococcus, campylobacter. Even though some of the faecal bacteria are not pathogenic or disease-causing, some bacteria of importance are *Escherichia coli* and Enterococci which are preferred bacterial indicators, of recent faecal contamination and a high risk of pathogens being present (Edberg *et al*., 2000).

A specific strain of *E. coli* 0157:H7 is a highly infectious pathogen, gram negative bacterium causing severe diarrhoea, gastroenteritis and dehydration in children and known to cause bloody diarrhea or what is known as hemolytic uremic syndrome (HUS). It has been implicated in multiple food and waterborne outbreaks of diarrhea and/or hemorrhagic colitis (HC) worldwide (National Nonpoint Source Monitoring Program, 2013; Lin *et al.*, 2012). Shiga toxin (Stx), a potent cytotoxin, is the major virulence factor linked to HUS and HC (Mohawk & O'Brien, 2011).

E. coli can survive in drinking water for periods between four and twelve weeks, depending on environmental conditions such as temperature and the presence of other microflora available (Edberg *et al*., 2000). The infectious dose of this specific strain is not well known. However, compiled outbreak data has shown that it can be as low as ten bacterial cells. Only a few bacterial cells can cause illness, especially in young children and immune compromised individuals (Food and Drug Administration, 1993). Regular monitoring is therefore crucial because detection in water indicates recent faecal contamination (National Nonpoint Source Monitoring Program, 2013).

The most effective way to remove *E.coli* from drinking water is through sand filtration followed by chlorine or ozone disinfection. A combination of the two processes reduces the possibility of any pathogens entering the drinking water distribution

network (Dunlop *et al*., 2002). Slow sand filtration as a physical removal method has been reported to have a 2.4 log removal credit for bacteria (range, 1.3 to 3.2 log) (Hijnen *et al*., 2004). Chlorine is the most widely used disinfectant in the drinking water industry because it is a strong oxidant with the capacity to inactivate both bacteria and viruses present in bulk water. The process of chlorination has been found to be quite effective for treatment of *E.coli* (LeChevallier, 2003; Health Canada, 2012). The maximum acceptable concentration (MAC) of *E.coli* is that there should be none detectable per 100 ml. Any detection of this organism in domestic water at any point is unacceptable (Health Canada, 2012).

2.3.1.3. Coliphage

Coliphage bacteria are other pathogenic enteric microorganisms which may affect human health (Lin & Singh, 2012). There are two groups which are normally assayed in water i.e. somatic coliphages and male specific coliphages (US.EPA, 2001). They are viruses which infect many subspecies of *E.coli* containing single-stranded Ribonucleic Acid (RNA) and they are the smallest within the group of enteroviruses. Their food source in the environment is human and animal faeces. Coliphages are known as male specific or F+ because of their ability to infect a bacterium via the pili. The pili are used by the bacteria during the process of sexual conjugation for exchange of genetic information across the bacterial species. These male-specific coliphages target the surface of the bacterial pili as their initial point of infection (Metcalf & Eddy, 2004; Rodríguez *et al*., 2012).

On the contrary, somatic phages infect the bacterium via the cell wall and vary in size, shape and structure and are found in greater abundance in water (US.EPA, 2001). Therefore, the presence of male specific coliphages in a water body, especially in high temperature conditions indicates faecal contamination from the gastro intestinal tract of a warm blooded animal. For this reason, they are considered to serve as more effective water quality indicators for faecal contamination compared to the coliform group of bacteria (Scientific Methods, 2005).

For treatment of coliphages from drinking water, a multi-barrier approach is viewed as the best approach to reduce enteric viruses and other waterborne pathogens in drinking water (Health Canada, 2011). Drinking water systems must achieve a 4-log removal (which is a 99.99% removal) or inactivation of enteric viruses to address risk

from enteric viruses (U.S. EPA, 2006a). However, it has been found that viruses are effectively inactivated through the use of various disinfection technologies individually or in combination, at relatively low dosages (Health Canada, 2011). For example, a chemical coagulant is added to the waste water to produce a floc which adsorbs the particle associated viruses. Gravity sedimentation is then applied to remove the precipitate. This three-step approach i.e. coagulation, flocculation and sedimentation can achieve a 1.1 to 3.4 log virus removal. Further use or application of rapid sand filtration can achieve virus removal of 0.1 to 3.8 log just for the filtration step. Thus a combination of conventional filtration methods and further optimization for treatment for turbidity and particle removal can achieve a greater log removal of enteric virus (Xagoraraki *et al*., 2004; Health Canada, 2011).

2.3.2. Selected physical determinants

2.3.2.1. Temperature

Temperature is an important Determinants because of its direct effect on chemical reactions, rates of reaction, aquatic life and the suitability of water for uses that benefit mankind and the environment (Metcalf & Eddy, 2004). For most biological activities, e.g. bacteria, the optimum temperature ranges from 25˚C to 35˚C. When the temperature increases to about 50˚C, aerobic digestion and nitrification processes ends in bacteria. In contrast, when the temperature drops to about 15˚C, some methane producing bacteria become inactive with some nitrifying bacteria losing their viability altogether.

This happens because of the effect in the rates of reaction especially in enzyme functioning. Enzymes are proteins and undergo irreversible denaturation at temperatures above those to which they are ordinarily exposed in their natural environment. High temperatures also increase the toxicity or potency of certain chemicals such as cyanide, zinc and phenols, making microorganisms more vulnerable to their potency. In waste water treatment plants, high temperatures foster the growth of undesirable water plants and waste water fungus. This then increases the cost of water treatment and affects the aesthetic value of water (Metcalf & Eddy, 2004; Dallas & Day, 2004).

For South Africa, the DWS TWQR for temperature conclude that the background value must not differ by more than 2ºC or 10% from the background average water temperature considered to be normal for the specific site and time of the day (DWAF, 1996e; Dallas & Day, 2004).

2.3.2.2. Water hardness

Water is termed “hard” when it contains high quantities of multivalent cations such as calcium and magnesium cations. The hardness is determined by the concentration of these multivalent cations in the water. Total hardness is the sum of the harness of calcium and magnesium and is expressed in mg/l of Calcium carbonate ($CaCO_3$) because calcium and carbonate are the most dominant ions in water (Roxas and Salgados, 2014). Other cations such as Manganese (Mn^{+2}), Iron (Fe^{+2} and Fe^{+3}) and Aluminium (Al^{+3}) can also contribute to water hardness (DWAF, 1996a). However, their levels are much lower than that of calcium and magnesium and usually not included in calculations of hardness (Wurts, 1993). The hardness of water can be classified from soft to very hard water as indicated in the Table 2.2 below.

Table 2.2: Classification of water hardness (DWAF, 1996a)

Range of hardness	Description of hardness
0-50	Soft
50-100	Moderately soft
100-150	Slightly hard
150-200	Moderately hard
200-300	Hard
>300	Very hard

Hardness can be calculated by using this formula: Hardness (mg $CaCO_3$/l) =2.497 x Ca (mg/l) + 4.118 x Mg (mg/l), when the concentration of both calcium and magnesium is known. Excessive water hardness presents a challenge of formation of scale on heat exchange surfaces e.g. hot water pipes, kettles and geysers. There’s formation of scum on bath surfaces through the formation of insoluble salts of long-chain fatty acids requiring increased soap use to produce a lather when bathing or cleaning. Water that is “too soft” can also cause a problem of interfering with the buffering capabilities of copper plumbing material, whereby it causes corrosion on copper plumbing material. This leads to copper being released into the water and increasing in concentration. Water hardness can be treated by the addition of lime followed by re-carbonation or an ion exchange technique for mineralisation (DWAF, 1996a). In de-mineralisation, the ion exchange columns

remove all the hardness forming ions together, with other ions in solution. In South Africa, the DWS TWQR for total hardness is between 50-100mg as $CaCO_3$ (DWAF, 1996a).

2.3.2.3. Turbidity

Turbidity is a measure of the light transmitting properties of water. It is one amongst many tests that indicates colloidal and residual suspended matter in both natural and waste discharged water. Turbidity decreases the clarity of water impeding light penetrating deep down into the bottom of the stream. The results of a turbidity measurement are reported in nephelometric turbidity units (NTU) (Metcalf & Eddy, 2004). The water flow regime of a stream has an influence on the turbidity of the water. High rainfall events influence the turbidity because suspended solids are introduced during heavy rainfall and also when suspended solids are brought back into suspension from the bottom sediments, especially in seasonally turbid rivers (Kistenmann *et al*., 2002; Dallas & Day, 2004).

Large suspended solid particles tend to settle out as water flow decreases. The settlement rate depends on the particle size and hydrological processes occurring in the water. However, there are some particles which are below 0.45µm in size which remain in suspension even in low or zero flow conditions. High water turbidity has some negative influences in a water body, such as decreasing the rate of photosynthesis because of the reduced light penetration. This has a direct effect on primary production because there is a marked decrease in primary production. Food availability to organisms that feed higher up in the food chain becomes affected e.g. a decrease in periphyton and macrophytes will have a direct effect on invertebrates and fish communities that feed on the periphyton and macrophytes (Dallas and Day, 2004).

Turbidity within a water body can have positive effects. For example, the suspended solids that brings about the turbidity adsorbs nutrients, trace metals and toxins and transports them out of the stream, thus cleansing the stream of these impurities. In South Africa, a standard value of 5mg/l has been proposed, but the actual TWQR should be 10% less of the background turbidity and a specific site and time (DWAF, 1996e; Dallas & Day, 2004).

2.3.2.4. Conductivity

Electrical conductivity (EC) is defined as a measure of the ability of water to pass an electrical current. Within the water medium, conductivity is influenced directly by dissolved ions e.g. chloride anions and calcium cations as well as the size of the ions. Organic compounds such as phenols, oils and alcohol are not good at conducting electricity when in water, and thus have low conductivity. Temperature also affects electrical conductivity. This is due to the effect of temperature on the viscosity of water. For this reason, higher conductivity can be observed at higher temperatures and hence conductivity is reported at 25˚C to account for the effect of temperature and measured in SI units at millisiemens per metre (mS/m) using a conductivity probe and meter (U.S. EPA, 2012; Clor *et al*., 2012).

Fine sediment also influences conductivity. Conductivity increases after filtering for suspended sediment. This observation is probably due to desorption of ions held on sediment surfaces. Electrical conductivity can be used as a tool to identify groundwater discharge zones and as an indicator of differing hydrologic behaviour. For example, a study done by Moore *et al*. (2008) showed that changes in conductivity along a short stretch of stream was an indication of chemically dissimilar water, thus pointing to possible sources which might influence the water quality in that area.

2.3.2.5. pH

Another important parameter for natural and waste waters is hydrogen ion concentration or pH. It is the intensity factor of acidity in a water body and is calculated as –Log [H^+] (Bezuidenhout, 2013). The suitable pH range for most biological life is 6 to 9. The concentration of the hydrogen ion is governed by the extent to which water molecules dissociate i.e. water dissociates to form hydrogen and hydroxyl ions (Metcalf & Eddy, 2004) and the amount of acids and bases available in the water. The rate of change of pH on addition of a given quantity of an acid or base depends on the buffering capacity of the water. The most important buffering system in fresh water is the carbonate-bicarbonate system, and between pH values of 6.4 and 10.3, the hydrogen carbonate ion predominates. For all aquatic ecosystems, the pH values should not be allowed to vary from the range of the background pH values for a specific site and time of day, by > 0.5 of a pH unit, or by

> 5 %, and should be assessed by whichever estimate is the more conservative (DWAF, 1996e).

2.3.2.6. Dissolved oxygen and Chemical Oxygen Demand

The amount of dissolved oxygen is linked to the temperature, atmospheric pressure and the saturation capacity regime within the water body. High water temperatures are known to reduce the solubility of dissolved oxygen in water, thus, decreasing its concentration and the overall availability to aquatic organisms. This is because the high water temperature increases metabolic rates, including respiration and thus oxygen demand, of aquatic organisms. The demand for oxygen therefore increases, leading to a decrease in dissolved oxygen supply according to the DWS Aquatic Ecosystems guideline (DWAF 1996e).

Dissolved oxygen also fluctuates with altitude. At higher altitudes, water tends to have a low holding capacity for oxygen because of the decreasing atmospheric pressure. In streams and rivers, dissolved oxygen fluctuates more horizontally along the course of the stream or waterway, whereas in lakes, there is vertical variation of dissolved oxygen in the water column (U.S. EPA, 2012).

The presence of oxidisable organic matter, regardless of the source, can also lead to reduction in the concentration of dissolved oxygen in surface waters. The potential for organic wastes to deplete oxygen is measured as chemical oxygen demand (COD) and biochemical oxygen demand (BOD). Unpolluted water has a COD of less than 20 mg/l. Aerobic organisms require dissolved oxygen in water for survival. Therefore, low oxygen levels may be lethal within short time scales e.g. minutes to hours. Fish and invertebrates are sensitive to changes in dissolved oxygen concentrations depending on the species and the life stages (eggs, larvae or adult) as well as behavioural changes i.e. feeding and reproduction. Conditions whereby the oxygen concentrations are above saturation may cause gas bubble disease in fish. Under these supersaturated conditions, photosynthesis can be inhibited in green algae, favouring the growth of blue green algae, which are more tolerant of super-saturation. The impact is that blue green algae will overgrow and become a nuisance affecting water users. The percentage saturation of dissolved oxygen is given in terms of the Minimum Allowable Values (MAV), to provide limits which will

ensure protection of aquatic biota from the adverse effects of oxygen depletion (DWAF, 1996e).

2.3.2.7. Total dissolved solids

Total dissolved solids (TDS) comprises inorganic salts, mainly calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulphates as well as small amounts of organic matter that are dissolved in water. It is important to measure TDS especially in areas where discharges from sewage treatment plants, industrial plants, or extensive crop irrigation are most prominent. Streams and rivers in dry areas where evaporation rates and input from land use activities are high, tend to have high concentrations of solids. Total dissolved solids in surface water bodies increases sharply during rainfall events and during dry weather when there is increased soil erosion. Total dissolved solids are closely related to stream flow and velocity and should be correlated with these factors when assessing water quality. This implies that any change in total dissolved solids over time should be measured at the same site and at the same flow rate. The concentration of TDS in surface water is also influenced by the dominant geological composition of the area, because different minerals have varying solubility. The WHO does not have a guideline value for TDS as it is not of health concern at levels found in drinking water (WHO, 2011).

2.3.3. Selected chemical determinants

2.3.3.1. Aluminium

Aluminium (Al) is a non-essential trace metal whose solubility in water depends on the pH of the water and its toxicity depends on the presence of other chemicals in the surrounding water. At high pH, it occurs as a hydroxide complex which is biologically unavailable and at low pH, it's soluble and available as hexahydrate ($Al^{6+}{\cdot}H_20$) which is toxic (Dallas & Day, 2004). It is neurotoxic at elevated concentrations and it has been suggested that it might cause Alzheimer's disease. However, it has beneficial uses as a coagulant in water treatment processes to reduce levels of organic matter, colour, turbidity and microorganism levels in water (WHO, 2011). It also affects the aesthetic value of water as it causes discolouration of water, especially in the presence of manganese or iron. In the natural environment, it mobilises from soil and sediment via weathering and acidification processes making it detectable in surface water. The DWS Aquatic Ecosystems

guidelines include other sources such as liquid effluents from metal construction, leather and textile industries and paper industries (DWAF, 1996e).

2.3.3.2. Ammonia

Ammonia occurs in ionized (NH_4^+) and non-ionized (NH_3) forms. In natural waters, its concentrations are quite low at about 0.2 mg/l, but groundwater can have concentrations up to 3mg/l. Sources of ammonia in the environment range from agricultural, industrial and metabolic processes. The disinfection of water using chloramines can also cause formation of ammonia. Industries which manufacture cement mortar pipe linings can be sources of contamination of ammonia. Animal farming is a major source of ammonia in surface water. It is a good indicator of possible contamination by sewage and animal pollution. Ammonia has low toxicity on its own, but in the presence of transition metals, it can be toxic as well as when the pH is raised in a solution (WHO, 2011).

The presence of high levels of ammonia in the water presents some challenges. Ammonia interferes with disinfection efficiency and causes taste and odour problems in purification processes. High ammonia concentration results in nitrite formation through the nitrification process in which *Nitrosomonas spp* and *Nitrobacter spp* bacteria oxidise to form nitrite and nitrite being further oxidised to form nitrate. High nitrite and nitrate levels of greater than 1.0 mg/l in water, leads to low dissolved oxygen content, causing methemoglobinemia or blue baby syndrome (Metcalf & Eddy, 2004). The DWS domestic guideline TWQR for ammonia is 1.0 mg/l and 7g/l in the DWS Aquatic Ecosystems guideline (DWAF, 1996a; 1996e).

2.3.3.3. Arsenic

Arsenic (As) is a trace metal which is mostly toxic in gaseous form as arsine and trimethyl arsine. It occurs as arsenates, metal arsenides or sulphides. Arsenates are less toxic with arsenates being more toxic (Dallas & Day, 2004). Arsenic is present in natural waters in concentrations between 1 and 2 µg/l but in high concentrations in groundwater, where the dominant underground rocks are sulphide mineral rock or deposits from volcanic rocks (WHO, 2011). It is used as an alloy additive for metals, cable sheaths, battery grids, detergents manufacturing as well as production of pesticides and fertilisers (Metcalf & Eddy, 2004). Arsenic is highly carcinogenic and mutagenic, causes dermatitis, loss of energy and fatigue. Reduced reproductive potential and changes in behaviour of fish and invertebrate populations have been

recorded e.g. reduced migration in fish. It easily accumulates in the body tissue as it is slowly excreted from the body. The DWS Aquatic Ecosystems TWQR in SA is 10 µg/l (DWAF, 1996e) and 10g/l for domestic waters (DWAF, 1996a).

2.3.3.4. Cadmium

Cadmium (Cd) is one of the priority pollutants due to its carcinogenic, teratogenic and mutagenic effects (Bhattacharya *et al*., 2014). It is used in the steel, batteries and plastics manufacturing industries and introduced into surface waters through waste water discharges and local air pollution. Contamination in drinking water is from dissociation from metal fittings and impurities in the zinc of galvanised pipes. It is known to interfere with bone repair mechanisms and causing renal failure as it concentrates in the liver, kidneys, pancreas and thyroid organs of the body (WHO, 2011). The WHO has a guideline value of 3µg/l in drinking water (WHO, 2011) and the DWS Domestic water guideline has a TWQR of 5 µg/l for drinking water (DWAF, 1996a).

2.3.3.5. Calcium

Calcium (Ca) is an essential mineral needed by living organisms to carry out many important functions. It forms part of the structural material in bones, teeth, mollusc shells supporting their structure and hardness. It also plays a role in muscle contractions, nervous system activity and energy metabolism and it is a dominant cation in inland water (Dallas & Day, 2004). It is also used in the determination of water hardness by using its concentration to calculate total water hardness (Roxas and Salgados, 2014). In fresh water systems, its concentration is about 15 mg/l and in sea water is approximately 400 mg/l (DWAF, 1996e).

2.3.3.6 Copper

The WHO (2011) classifies copper (Cu) as an essential nutrient because humans and other organisms need it in very small quantities for enzyme functioning and carbohydrate metabolism. In vertebrates, its function is to transport haemoglobin and haemocyanin oxygen molecules in the blood. It is slightly soluble in water and has a strong affinity for organic matter and sediments. Copper is most toxic in its cupric (Cu^{2+}) form (Solomon, 2009). Therefore, it is found in lower concentrations in the water column compared to the sediments as it will bind with the organic matter. Its sources in the environment are quite diverse including mining activities, electric wiring, plumbing material, jewellery, coins and alloys (Solomon, 2009).

Its toxicity is also influenced by the hardness of water because the copper concentration increases with decreasing water hardness. Because of its strong binding capacity to organic matter and sediments, it impacts and decreases the degradation of organic matter by microorganisms, thus reducing bacterial growth even at very low concentrations (Tom-Petersen *et al*., 2011).

The reproductive potential of aquatic organisms is reduced, e.g. the sperm and egg production of sea scallops was reduced after exposing them to copper concentrations of 10 to 20 µg/l. Algal growth is affected by copper and therefore, the food availability of zooplankton, insects and other aquatic animals becomes compromised as algae forms the base of food chains in an aquatic ecosystem (Solomon, 2009). The WHO (2011) guideline value is 2 mg/l and the DWS Aquatic Ecosystems guideline has a TWQR of 0.3 µg/l to 1.4 µg/l, depending on the hardness of the water (DWAF, 1996e).

2.3.3.7. Fluoride

Fluorine is widely distributed in the earth's crust and exists in the form of fluorides in a number of minerals such as fluorspar, cryolite and fluorapatite. In the natural environment, traces of fluorides are present in many waters, with higher concentrations often associated with groundwater containing concentrations of up to 10 mg/l. The highest concentration of fluoride recorded in the natural environment is 2800 mg/l (WHO, 2011).

The occurrence of fluoride in water has been linked to the geology of that area. High grade metamorphic rocks have high fluoride content with streams in the area having high fluoride content. High fluoride content causes dental problems and skeletal fluorosis, and change in bone structure in communities extracting drinking water directly from wells and streams, in which concentrations of 3 to 6 mg/l have been detected. This has been well documented in some communities in Sri Lanka, India, China, Central Africa and South America (Dissanayake, 1991; Edmunds & Smedley, 2012). The WHO has a limit of 1.5 mg/l for fluoride in drinking water (WHO, 2011).

2.3.3.8. Iron

Iron (Fe) is an essential micronutrient in all organisms, forming part of the haem containing pigments, catalases, and peroxidase enzymes. It plays a role in chlorophyll and protein synthesis. It is found in three oxidation states zero (0), Iron II and Iron III, with Iron III being the most common form. In water, it occurs as dissolved ferric iron, ferrous iron and as suspended iron hydroxides. It is easily oxidised, therefore reduced forms can quickly deplete oxygen levels in the environment (Dallas & Day, 2004).

When it complexes with humic acids in natural waters, it forms a brown discolouration when in high concentrations, affecting the aesthetic value of water. The concentration of iron in unpolluted waters ranges from 0.001 to 0.5mg/l and 0.002mg/l in seawater. Iron is released into the environment by leaching from sandstones with iron oxides and hydroxides. Industrial sources include discharges from the petro-chemical, fungicide and chlor-alkali industries and iron is used as iron ore in metallurgical processes. When low pH conditions of less than 3.5 prevail, iron concentration can be high as in the case of acid mine drainage (DWAF, 1996a).

Iron is toxic at high concentrations interfering with the function of several enzymes. Prolonged ingestion of water with high iron concentration causes tissue damage or haemochromatosis, as a result of iron accumulation in the tissue cells. The WHO has no guideline value as the iron levels in drinking water are not of health concern (WHO, 2011; DWAF, 1996a). However, the DWS has a TWQR of 0.1 mg/l for domestic water (DWAF, 1996a) but for aquatic ecosystems, the level of iron must not be more than 10% of the background dissolved iron concentration at a particular site at a given time (DWAF, 1996e).

2.3.3.9. Lead

Lead (Pb) is a priority pollutant because of its high toxicity and carcinogenicity. It is found in batteries, cable covering, foil, bearing alloys and as a gasoline additive as it is good in resisting corrosion. Lead is found in tap water as it dissolves from lead household plumbing systems. The WHO guideline value for Pb is 0.01 mg/L for drinking water. It is toxic when ingested and causes birth defects, brain and kidney damage on a long-term basis (Metcalf & Eddy, 2004; WHO, 2011). It also interferes with the synthesis of haem, which is an important component of haemoglobin

molecule and affects membrane permeability hindering calcium channels from opening (Dallas & Day, 2004).

In aquatic ecosystems, it is present as lead carbonate ($PbCO_3$) and as lead-organic complexes and as free ions, although in small proportions. Its presence in aquatic systems is mainly associated with suspended sediment. The DWS Domestic water guideline TWQR for lead in soft waters is 0.2 µg/l (DWAF, 1996a).

2.3.3.10. Magnesium

Magnesium (Mg^{2+}) is an essential mineral which is a co-factor in many enzyme reactions such as nucleic acid, protein and mitochondria in both plants and animals. It facilitates the transmission of nerve impulses, muscle contractions and glucose metabolism in humans. In the environment, it conjugates with mineral deposits and occurs as magnesium carbonate ($MgCO_3$) and dolomite ($CaMg(CO_3)_2$), making it easily soluble in water and thus easily accessible or available for use by organisms in the water (Jahnen-Dechet & Kettleler, 2012).

Magnesium sources in the environment include soil and industrial wastes. Its concentration together with that of calcium can be used to calculate total water hardness, and thus contributes to water hardness. In high concentrations, magnesium tends to exert a laxative effect on mammals (Krenkel, 2012; Roxas and Salgados, 2014).

2.3.3.11. Nickel

Nickel (Ni) is a trace metal known to be toxic even in small concentrations, altering the functioning of cytochrome oxidase and other enzymes responsible for the citric acid cycle. It is classified as a priority pollutant as it can interfere with beneficial uses of water because of its toxicity. It has been shown to be carcinogenic in mammals. It is soluble under acidic conditions of less than 6.5 pH; where it is in its most toxic form e.g. Nickel carbonyl ($Ni(CO)_4$). In this form, it is both water and fat soluble. Under alkaline conditions, it is insoluble, forming nickel hydroxides. In freshwater systems, nickel occurs in ionic form mostly but also in a form of humic complexes which then adsorb to clay particles (Dallas & Day, 2004).

2.3.3.12. Nitrates-nitrites

Nitrogen (N) is an essential element required for the growth of plants, animals, and microorganisms; hence it's often referred as a bio-stimulant. It is an essential building block required for protein synthesis in all living organisms. The main sources of nitrogen are nitrogenous compounds of plants and animals, sodium nitrate and atmospheric nitrogen. It occurs in many oxidation states and has a complex chemistry depending on the prevailing environmental conditions, e.g. aerobic or anaerobic. In natural and polluted waters, inorganic nitrogen is available in many forms (Metcalf & Eddy, 2004). However, ammonia, ammonium, nitrates and nitrites forms are the ones measured by common water quality tests.

Nitrates enter the water system through agricultural runoff and fertilisers but are detected in low concentrations of less than 0.1 mg/l in natural waters. This is because they are constantly being converted to organic nitrogen in plant cells through photosynthetic actions. Nitrite formation occurs through the nitrification process whereby, *Nitrosomonas spp* and *Nitrobacter spp* bacteria oxidize ammonia to form nitrite and nitrite being further oxidised to form nitrate. High nitrite and nitrate levels of greater than 1.0 mg/l in water lead to low dissolved oxygen content. Nitrite is toxic, causing methemoglobinemia or blue baby syndrome, which is a non-functional molecule and cannot bind with oxygen, thus leading to low oxygen levels in infants. Nitrates, together with phosphorus have been implicated in causing eutrophication (Metcalf & Eddy, 2004; Dallas and Day, 2004).

2.3.3.13. Phosphorus

Phosphorus (P) is a naturally occurring element, essential for all life. It is found in water, living organisms and in the crust of the earth, weathering of rocks and leaching of the phosphate salts into surface from anthropogenic sources. Different forms of phosphorus e.g. orthophosphates, metaphosphates and pyrophosphates are commonly found in natural water since elemental phosphorus does not occur in the natural environment (DWAF, 1996e; Frost & Sullivan, 2010).

Phosphates are used extensively in agriculture where they are applied in soil as a supplement in order to increase growth and yield of crops, where levels in soil are limited. Phosphates play a role in cell division, energy formation, photosynthesis,

root formation of plants and soft tissue in organisms. Therefore, they improve crop quality and overall yield (Mullins, 2009).

Phosphates are the main drivers of anthropogenic eutrophication or nutrient enrichment in surface waters. Non-point or diffuse sources of phosphates include in particular leaching and drainage from agricultural land, especially where fertilisers were directly applied on the soil as well as run-off and atmospheric precipitation (Mustapha and Gesto, 2014). Input into fresh water systems is due to soil erosion (Shaw & Chadwick, 1998).

In South African surface waters, phosphate concentrations of 10-50 g/l are commonly found, 1 g/l in very pristine water and as high as 200 mg/l in saline waters (DWAF, 1996e). Phosphates are highly reactive and easily oxidize with cations such as aluminium, iron and calcium, to form insoluble compounds which will precipitate out of water due to influences from pH of water. Within a water body, the availability of phosphates is also influenced by adsorption to particulate and humic substances. In addition, the flow of water will affect the mobility, availability and overall distribution of phosphates within a water body. High particulate matter reduces available phosphate from the water and settles it in sediment in periods of low river discharge. However, the phosphate levels will increase during rainfall events due to run-off from land and re-suspension from the river bed to the surface. The concentration of phosphorus is always linked with that of nitrogen. Nitrogen occurs in the form of nitrates (NO_3^-) in aquatic environments. In South Africa, pristine streams have been recorded to have a phosphorus: nitrogen ratio (N: P) of 25 to 40: 1 whereas impacted streams have an N: P ratio of 10: 1. This implies that when dissolved phosphates in surface water have been used up, so is the nitrogen (DWAF, 1996e).

2.4.3.14. Sodium

Sodium (Na^+) cations end up in water from rock and soils. It's mainly a dietary mineral and plays a role in nerve functioning and muscle contraction. It regulates extracellular fluids, membrane potential and acid-base balancing in organisms (Dallas & Day, 2004) The DWS Domestic water guideline TWQR for sodium is 100 mg/l (DWAF, 1996a).

2.3.3.15. Sulphur

In water, sulphur occurs mostly as sulphate ions (SO_4^{2-}). Sulphur is an essential element needed for protein synthesis. In living organisms, it is released when protein degrades. In natural waters, sulphates occur in low concentrations. However, if in abundance, sulphates form sulphuric acid which is detrimental to aquatic ecosystems. Sulphuric acid is a strong acid and reduces the pH of water bodies drastically and results in a salty or bitter taste in water. In the absence of oxygen, sulphate ions are reduced to hydrogen sulphide (H_2S) which is also toxic. Hydrogen sulphide interferes with cellular and enzyme functioning. In waste water treatment plants, it is corrosive to gas and sewer pipes and if inhaled, it can cause loss of smell in people (Metcalf & Eddy, 2004; Dallas & Day, 2004).

In drinking water, the DWS TWQR is 100 mg/l in South Africa (DWAF, 1996a). In the coal mining Witbank region of South Africa, sulphate concentration in the Witbank Dam regularly exceeds 200 mg/l level, which is more than the recommended maximum in water for domestic use (McCarthy, 2011).

2.3.3.16. Selenium

Selenium (Se) is a non-metallic element occurring in the environment in elemental form as Selenide, Selenade (SeO_4^{2-}) or Selenite (SeO_3^{2-}). It is found in trace amounts in most plant and animal tissue. It also occurs in natural waters where it incorporates into sediment but in extremely small quantities e.g. 10g/l in surface water (Health Canada, 1992; DWAF, 1996e). It is most prevalent in environments located close to industrial areas which manufacture electronics, ceramics, metallic computer cores, and animal feeds. The health risks associated with the ingestion of high levels of selenium include depression, liver damage, red staining of fingers, hair and teeth and general weakness in the body (Metcalf & Eddy, 2004). The DWS TWQR for Aquatic Ecosystems in South Africa is 2 µg/l (DWAF, 1996e) and 20 g/l for drinking water (DWAF, 1996a).

2.3.3.17. Zinc

Zinc (Zn) is also a trace element needed for biological growth. In aquatic ecosystems, it occurs in two oxidation states i.e. as a metal and as zinc (II), with zinc (II) occurring in small concentrations. Within the environment, its sources are through the weathering of rocks, erosion and through industrial activities or industrial wastes.

It is resistant to corrosion hence it is widely used in the dye manufacturing and processing industries, pharmaceuticals and in pigment formation processes (DWAF, 1996). Its main function in living organisms is to form active sites of metalloenzymes for both ribonucleic acid (RNA) and deoxyribonucleic acid (DNA) polymerases (Dallas & Day, 2004).

High zinc levels in water results in a bitter taste and exhibits a milky appearance in water, thus affecting the aesthetic value of the water. It can cause gastrointestinal disturbances if ingested water has high concentrations of zinc. For aquatic ecosystems in SA, the DWS TWQR is 2 µg/l (DWAF, 1996e) and 3 mg/l for domestic water (DWAF, 1996a).

2.4. Water quality of the Katse Dam

The quality of water is defined by the amount of pathogens, chemicals salts, sediments and nutrients in the water (Brauman *et al*., 2007). The Katse Dam is constantly being monitored by the LHDA due to the occurrence of industries, human settlements, schools and clinics in the catchment area. The Katse Dam water quality is considered to be of high quality (LHDA, 2010, 2011, 2012). The water is exported to South Africa without being treated (Lewis *et al*., 2015).

In a separate study conducted by Iliso Consulting (Hooghiemstra & Van Veelen, 2012), the findings supported the fact that the water quality of the Katse Dam is of a high quality. Using the fitness for use assessment categories, the study concluded that determinants such as alkalinity, electrical conductivity, chlorides and sulphates were within the ideal category. Chemical oxygen demand, iron, pH and ammonia were within the acceptable category and phosphates at a tolerable level (Hooghiemstra & Van Veelen, 2012). The exception was suspended solids which was higher than expected. It was therefore, suspected that other factors such as rainstorm events, strong winds and wave action during the sampling, and might have contributed to the high concentration. This could have caused sediment to become suspended (Hooghiemstra & Van Veelen, 2012). Therefore, an assessment of the five rivers would give an indication on the likely impacts on the Katse Dam should the assessment indicate deteriorating water quality. It is important to assess the suitability of the water for its' intended use e.g. agriculture, drinking, aquatic ecosystem and aquaculture.

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CHAPTER 3

3. DESCRIPTION OF THE STUDY AREA AND METHODOLOGY

3.1. Description of the study area

3.1.1. Location

The altitude of Lesotho varies between 1500m to 3482m above sea level. It's divided into four geographical regions, firstly, the Maluti deep river valleys in the mountain region, constituting 59% of the entire country; secondly, the Maluti river valleys and the lowlands areas, constituting 15% of the entire country; thirdly, a narrow band of low-lying areas constituting 17% in the lowland regions, and fourthly, the Senqu-Orange valley which constitutes 9% of the country which is a narrow band of land occurring on both sides of the Orange River, penetrating deep into the Maluti mountains (Taele *et al*., 2012).

The Katse Dam catchment area (approximate area: 1867 square kilometers) is located in the mountains ecological region and falls within all four main districts, namely; 51.5 % of the catchment consists of the Both-Bothe, 36.2 % is the Leribe, 12.2 % is the Thaba-Tseka and 0.1 % is the Mokhotlong (Figure 3.1) (Lewis *et al*., 2015).

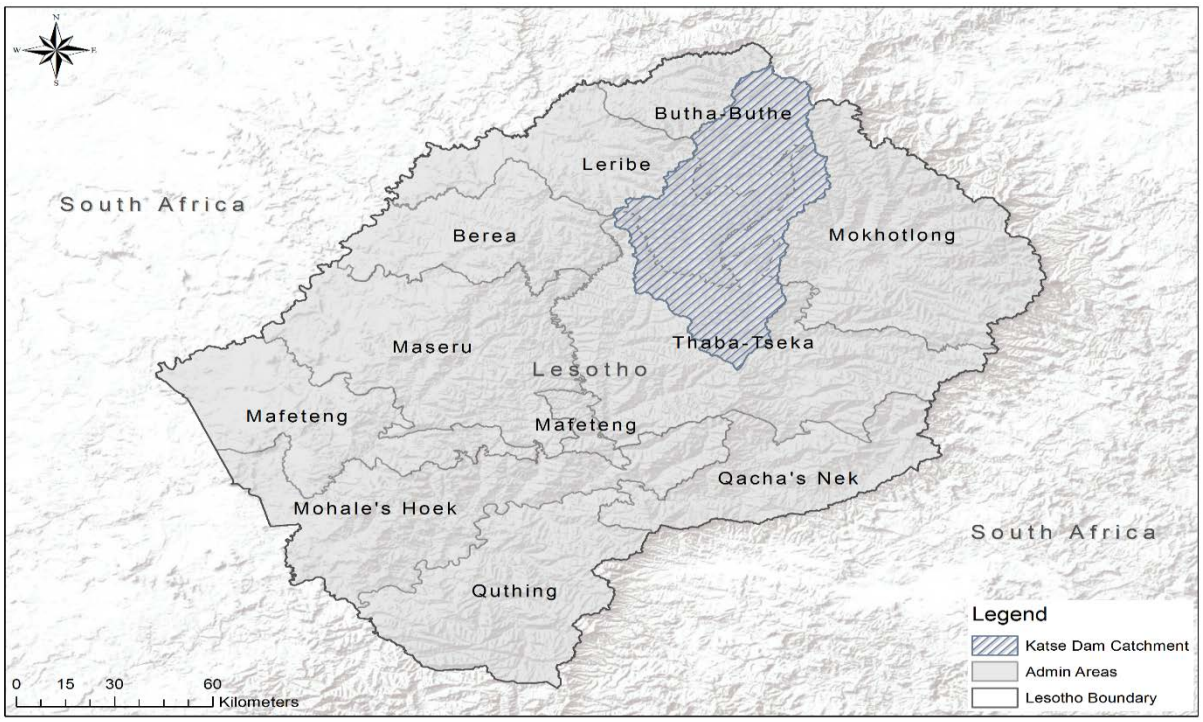

Figure 3.1: The location of the Katse Dam catchment area in Lesotho (adapted from Lewis *et al*., 2015)

3.1.2. Climate

Generally, the Lesotho climate is temperate, with summer months dominated by high temperatures (as high as 35 ˚C) and high rainfall events. The rivers in this catchment have erratic seasonal flows which results in heavy siltation. The winter months are dominated by snowfall, low temperatures (as low as -12 ˚C) in the mountains and low rainfall events (Taele *et al*., 2012; Mafisa, 1993). Flood damage from heavy rainfall and storms has been reported several times. Because of these extreme events, Lesotho is vulnerable to climate change (LMS, 2013).

3.1.3. Topography and geology

The catchment area is dominated by bare, steep slopes with sparsely located vegetation, exacerbating the challenge of soil erosion (Figure 3.2). The steep valleys which are the immediate surroundings of the Katse Dam are most vulnerable to soil erosion with potential to increase sedimentation in the dam and surrounding rivers (Lewis *et al*., 2015).

The geological composition of Lesotho is dominated by basalt rock. During chemical weathering, basalt forms calcium, sodium and magnesium cations which are water soluble. The Malibamatso River is dominated by calcium carbonate, with low conductivity and nutrient content, as well as a pH ranging from 7.2-7.6 and has less sediment (Chutter, 1993). The Bokong River catchment area is dominated by wetlands with two soil types, namely Umbrisols and Stagnasols (Mapeshoane, 2013). Stagnasols are soils which periodically experience water stagnation on the upper, permeable soil profile leading to waterlogging, saturation and mobilization of iron or manganese (Jones *et al*., 2010). Umbrisols are sandy to clay soils, dark in colour due to high humus content (Blume *et al*., 2015). Umbrisols are associated with gullies and steep slopes (García-Calderon *et al*., 2006).

Soil formation is shallow, low in organic carbon and very fragile (Taele *et al*., 2012; Olaleye *et al*., 2014). Due to the poor soil quality, the farmers have to apply cow manure, urea and other fertilisers in about 26 to 46 % of the agricultural fields to improve the soil quality (Mokuku *et al*., 2002; Lewis *et al*., 2015).

Figure 3.2: The Malibamatso River valley on the downstream of the Katse Dam (adapted from Letsebe, 2012).

3.1.4. Population

The mountains' agro-ecological zone, where the catchment area is located, has the second highest population of 383 729 people. This is much lower compared to the most populated lowlands agro-ecological zone with a population of 1 064 404 people. The Leribe district has the highest population and highest population growth of about 12.9 % between 2006 and 2011 and the Bothe-Bothe has the smallest population with a decreasing population within the catchment area (Lewis *et al*., 2015).

The communities around the catchment area can be considered to be poor in terms of household possessions, with the Thaba-Tseka being the poorest in when compared to the national average. Economically active communities are located closer to the Maseru district which has a vibrant economy (Bos, 2014a). Most of the communities are without household running water and electricity (Letsebe, 2012). The human settlements on the mountain slopes and valleys are mostly rural, isolated and scattered and the population density is increasing, especially in the Thaba-Tseka district. Human settlement in the catchment area is about 0.9% (Lewis *et al*., 2015).

3.1.5. Land and water use

The current land cover and land use in the catchment area include agriculture, especially livestock farming, forestry, grassland, settlement, wetlands and the Katse Dam. Grassland is the dominant land cover per hectare, followed by agriculture as illustrated in Figure 3.3 and Figure 3.4. There is a high livestock density in the catchment area which provides income earning opportunities for the local communities (Figure 3.8). Crop cultivation and production is also dominant next to the rivers and valley sides of the Katse Dam. For example, the riparian areas around the Malibamatso River are used by community members for grazing animals, fishing, and other agricultural activities. It is necessary to emphasize that those communities on the mountain slopes and valleys are mostly rural. Lesotho is a major producer and exporter of wool and mohair products. The high livestock density in the catchment area supplies the wool and mohair industry, thus it provides income opportunities for the local communities (Lewis *et al*., 2015; Moore *et al*., 2012).

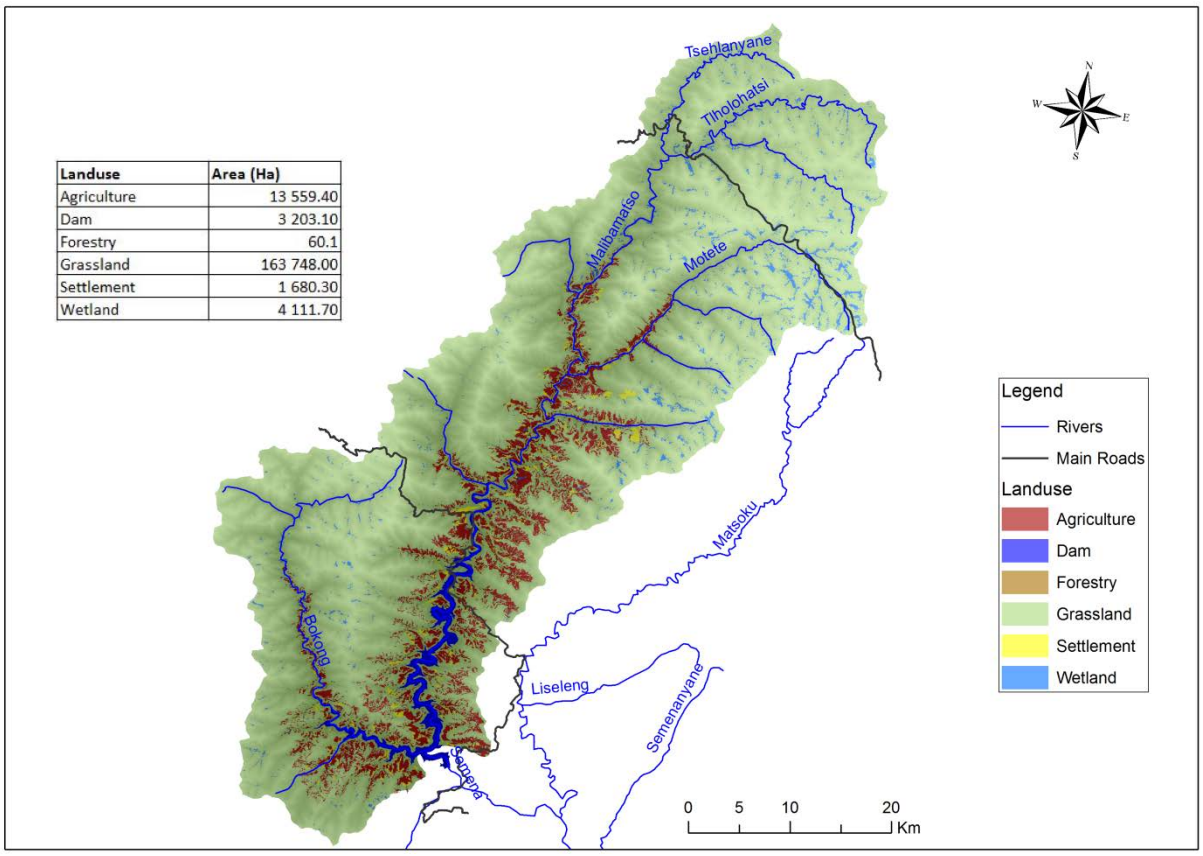

Figure 3.3: Land use activities within the Katse Dam catchment area (Data sourced from the Institute of Natural Resources NPC, Lewis *et al*., 2015).

From 2008/2009 to 2012/2013, the wool and mohair yields have increased, indicating the increased number of livestock sheared over the period (Lewis *et al*., 2015). In order to sustain this industry, the catchment area tends to experience a lot of overstocking of sheep and goats, leading to overgrazing and reduction in vegetation cover which could cause a siltation of surface water resources due to increased soil erosion (Lewis *et al*., 2015).

Figure 3.4: Sparse, isolated households and agricultural activities in the Thaba-Tseka District (adapted from Letsebe, 2012)

Within the catchment area, there are three main competing uses for water, namely; direct human consumption, supporting the availability of ecosystem services and maintaining economic production such as electricity generation (Matete, 2004; Lewis *et al*., 2015).

There are two nature reserves in the catchment area, namely; the Bokong (located around the Bokong River) and Liphofung (located around the Liphofung River) Nature Reserves. The Bokong Nature reserve covers about 1970 hectares of land and is a tourist attraction area. The reserve provides a visitor's centre, a waterfall and bird watching activities. It is located in a wetland area, being a habitat to endemic plants and animals. The Liphofung Reserve is a historical site which covers about four hectares of land, exhibiting rock art and archaeological deposits (OIWRMP, 2007).

The hydropower plant (Muela plant) is located about 123 metres below the spillway of the Katse Dam and generates about 72 megawatts of electricity, which is also supported by two other smaller hydropower plants (Taele *et a*l., 2012; Liu *et al*., 2013). There is an aquaculture project in the Katse Dam which farm trout fish for commercial purposes. Another fish farming activity occurs in the Malibamatso River, close to the Ha-Lejone village (Figure 3. 5) (Eilertsen, 2013).

Figure 3.5: Rainbow trout farming cages in the Katse Dam (taken from Eilertsen, 2013)

There is a diamond mining activity, known as the Kao Diamond Mine, about ten kilometers from the Malibamatso River (Figure 3.6). The mine draws water from the Malibamatso River, through a pipeline to sustain the running and functioning of the mine, especially during drought seasons (Pottinger, 1997; Namakwa Diamonds Limited, 2012).

Figure 3.6: The Kao open-pit diamond mine (taken from http://www.namakwadiamonds.co.za/images/image_kaogal08lrg.jpg)

Sanitation is a major challenge within the catchment area because less than 5% of the villagers around use toilets or pit-latrines (Figure 3.7). The majority utilise the natural environment to relieve themselves (Kravitz *et al*., 1999). There is very little industrial and chemical pollution in the catchment area due to limited human settlement. However, possible sources of chemical pollution include acaricides which are used to control mice and ticks at cattle dipping sites, fertilizers and other pesticides applied or used in most irrigation schemes (Lewis *et al*., 2015; Motsamai *et al*., 2003).

Figure 3.7: A pit-latrine used in the Thaba-Tseka District (adapted from Letsebe, 2012)

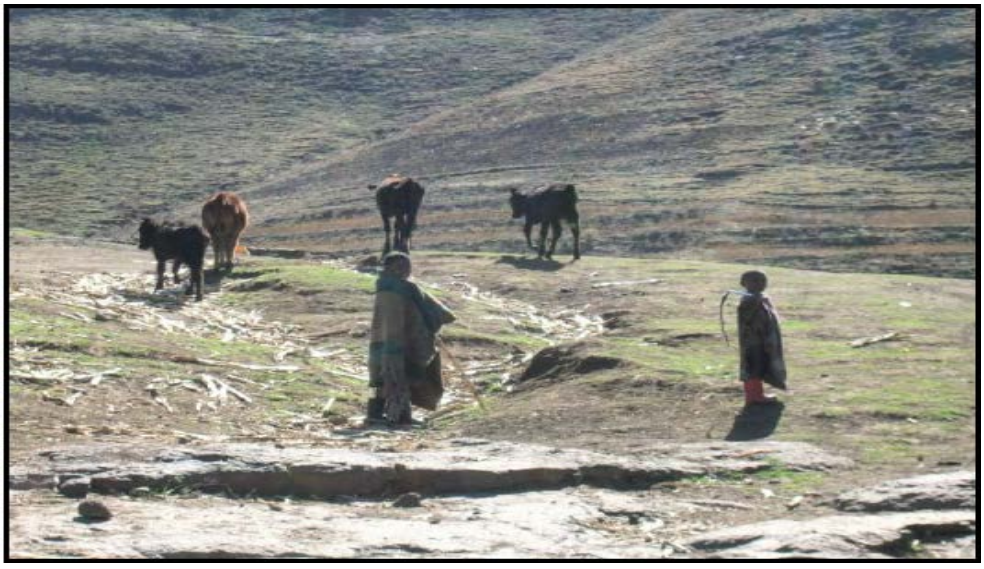

Figure 3.8: Livestock farming on the hillsides in the Thaba-Tseka District (adapted from Letsebe, 2012)

3.2. Methodology

3.2.1. Sampling periods and sites

In order to determine the water quality status of the five main rivers (Malibamatso, Bokong, Pelaneng, Mokhoulane and Liphofung) feeding into the Katse Dam, samples were collected from January 2000 until July 2014. Samples were taken before the confluence of the rivers with the Katse Dam (Table 3.1). Only one site per river was selected due to accessibility to the rivers and financial constraints (Figure 3.9).

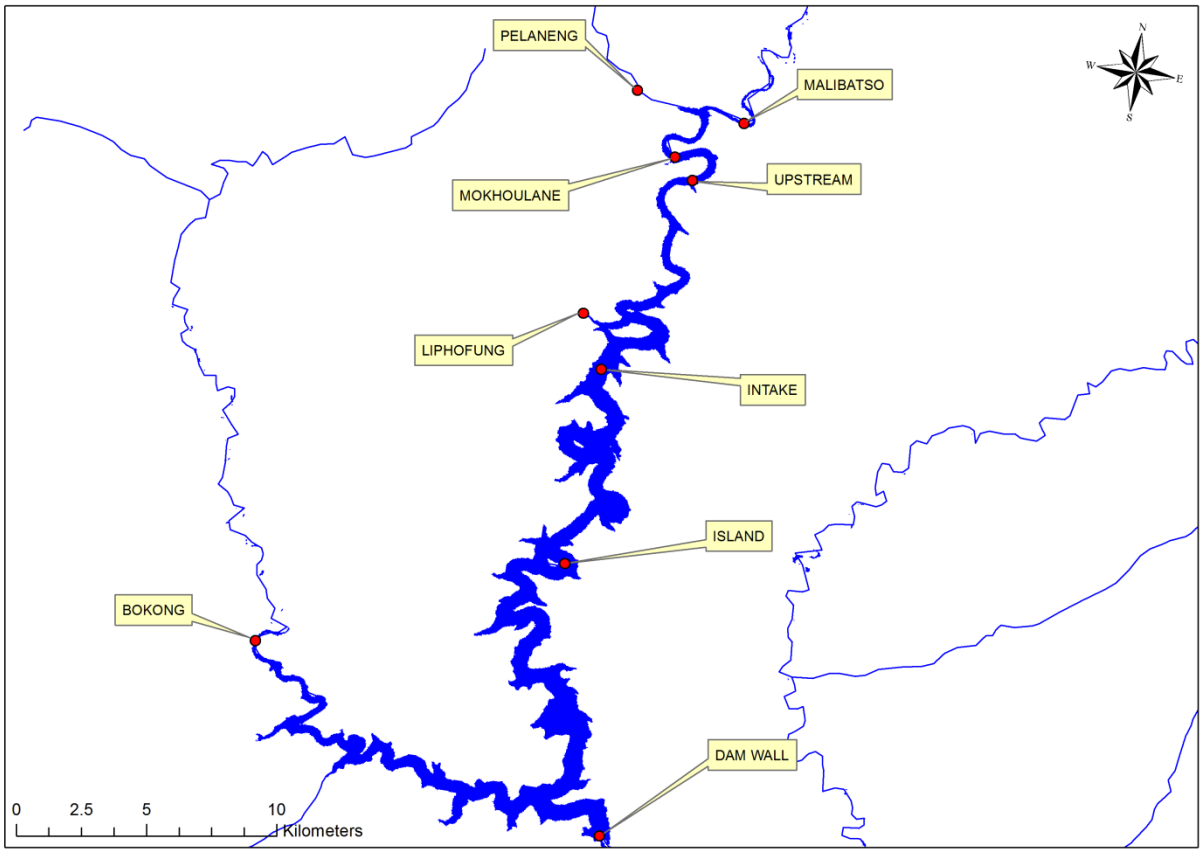

Figure 3.9: sampling sites on the Katse Dam and on each river (Rand Water, 2014)

Samples were taken once every month for Study Period: A (2000-2005), every second month for the Study Period: B (2006-2011) and four times a year for Study Period: C (January 2012-July 2014). The data from the period January 2000 to December 2011 are viewed as historic data and were obtained from the Laboratory Information Management System (Labware LIMS) at the Analytical Services of the Rand Water while the samples collected from January 2012 to July 2014 were collected as the current status data.

Table 3.1: Sampling sites of the rivers feeding into the Katse Dam

No. of sites	Sampling points	GPS Coordinates	
		Latitude	Longitude
1	Bokong River (C-BOKO)	29˚ 9' 30.46" S	28˚ 22' 2.30" E
2	Liphofung River (C-LIPHO)	29˚ 9' 30.46" S	28˚ 28' 26.77" E
3	Malibamatso River (C-MALI)	29˚ 5' 8.09" S	28˚ 3' 9.82" E
4	Mokhoulane River (C-MOK)	29˚ 6' 1.87" S	28˚ 29' 51.28" E
5	Pelaneng River (C-PELA)	29˚ 4' 46.54" S	28˚ 28' 52.83" E

3.2.2. Sampling procedure

The sampling procedures followed, were according to the methodology described by the Rand Water Analytical Services laboratory. This laboratory has been accredited under the International Standard ISO/IEC/17025 (ISO/IEC, 1999). At the sampling site, seven sampling bottles were used to collect the water samples and transported to the laboratory for further analysis. The physical determinants such as temperature, pH, conductivity and dissolved oxygen were measured in situ, with the use of a portable handheld meter at each site.

3.2.3 Sampling for physical and chemical analysis

Clean, labelled, one litre polypropylene bottles were used to collect samples for physical and chemical analysis. The sampling bottles were first rinsed with sample water and where possible, then submerged 10 to 15 cm below the water surface. The sampling bottles were filled to the brim, sealed to prevent contamination and transported to the laboratory in a cooler box filled with ice packs.

3.2.4. Sampling for microbiological analysis

Samples for microbiological analysis (*Escherichia coli*, coliforms, faecal coliform and coliphage bacteria), were collected in clean, sterile, labelled 500 ml polypropylene bottles. The sampling bottles were first rinsed by exposing them to 1.8 % mass per volume of sodium thiosulphate pentahydrate solution and sterilised before sampling could commence (Ramcharan, 2009). At each sampling site, the sampling bottle was submerged 10 to 15 cm below the water surface, and filled to approximately 10 cm from the top of the bottle. The bottles were sealed and placed in a cooler box filled with ice packs and transported to the laboratory. At each site, a 10 litre volume of river water was collected in a carboy for *Cryptosporidium* and *Giardia* analysis.

3.2.5. Transportation of samples and reception at the laboratory

The samples were kept in a cool environment and shielded from ultra-violet radiation to ensure that the growth of microbes is controlled and kept at a minimum and also to minimise bacterial cell death. The samples were analysed at the Rand Water Chemistry and Biology Sections of Analytical Services. When the samples arrived at the laboratory, they were logged at the Rand Water's Analytical Services' Laboratory Customer Services. A collection data sheet and chain of custody sheet were completed and verified and the samples were inspected for possible damage which might have occurred during transportation.

3.2.6. Analysed determinants

The determinants that were selected for analysis are summarised in Table 3.2. Concentrations below the detection limits were not recorded (Rand Water, 2014).

Table 3.2: List of determinants analysed after sampling was conducted

Chemical determinants	**Units**	**Detection limit**
Aluminium	mg/l	4.09 mg/l
Ammonium	mg/l	0.243 mg/l
Calcium	mg/l	0.036 mg/l
Cadmium	mg/l	0.719 µg/l
Chloride	mg/l	0.114 mg/l
Copper	mg/l	5.54 µg/l
Fluoride	mg/l	0.0476 mg/l
Iron	mg/l	3.87 µg/l
Lead	mg/l	10.30 µg/l
Magnesium	mg/l	0.011 mg/l
Manganese	mg/l	3.43 µg/l
Nitrate	mg/l	0.022 mg/l
Nitrite	mg/l	0.006 mg/l
Nickel	mg/l	2.16 mg/l
Phosphorus	mg/l	0.050 mg/l
Phosphates	mg/l	0.004 mg/l
Potassium	mg/l	0.102 mg/l
Sodium	mg/l	0.372 mg/l
Sulphate	mg/l	0.209 mg/l
Sulphur	mg/l	0.257 mg/l
Total Silica	mg/l	Calculated
Total Organic Carbon	mg/l	0.48 mg/l
Zinc	mg/l	2.91 µg/l
Physical determinants	**Units**	
Alkalinity	mg/l	2.43 mg/l
Chemical oxygen demand	mg/l	4.5 mg/l
Conductivity at 25 ˚C	mS/m	0.075 mS/m
Dissolved oxygen	mg/l	-
Dissolved organic carbon	mg/l	0.7 mg/l
Hardness	mg/$CaCO_3$/l	-
pH at 25 ˚C	-	N/A

Table 3.2: (Continued) List of determinants analysed after sampling was conducted

Physical determinants	Units	Detection limit
Suspended solids	mg/l	4.94 mg/l
Temperature	ºC	-
Total dissolved solids	mg/l	4.7 mg/l
Turbidity	NTU	0.127 NTU
Microbiological determinants	**Units**	
Cryptosporidium sp	Oocysts/10L	N/A
Coliphage bacteria	CFU/10ml	N/A
E.coli	MPN.100ml^{-1}	N/A
Faecal coliform	FC/100ml	N/A
Giardia sp	Cysts/10L	N/A

3.2.7 Physical and chemical analysis

A range of different analytical methods were used to gather data on physical and chemical determinants of the five rivers.

3.2.7.1. In situ measurements

The following physical determinants were measured in situ: temperature, pH, conductivity and dissolved oxygen. The measurements were taken according to the Rand Water Method Numbers 1.1.2.16.1.; 1.1.2.15.1 and 2.1.3.01.2. (Rand Water, 2012b, 2006b & 2006c). These determinants were measured using a YSI 6600 Multi Parameter System (MPS) fitted with the appropriate probes.

3.2.7.2 Determination of electrical conductivity

Electrical conductivity (EC) is defined as a measure of the ability of water or a solution to pass an electrical current. Within the water medium, conductivity is influenced directly by dissolved ions, temperature as well as the size of the ions (U.S. EPA, 2012). Electrical conductivity will increase with increasing temperature. Electrical conductivity is also an indication of the total dissolved solids concentration in the water and indicates the ionic strength of a solution. Electrical conductivity is therefore the preferred method for detecting the salinity of a solution as it is more accurate than measurement of salinity using total dissolved solids (Rand Water, 2006c).

The hand held YSI 6600 MPS instrument was used to measure electrical conductivity. The measurement was taken at 25 ˚C for accuracy at a range of 0 to 200 MilliSiemens per metre after calibration at various concentrations of potassium

chloride. The method of measurement was in accordance with the Rand Water Method Number 1.1.2.15.1. (Rand Water, 2006c). The probe was placed directly in the stream and the reading taken off the instrument (Rand Water, 2006c).

3.2.7.3. Determination of dissolved oxygen

Dissolved oxygen was measured on site in accordance with the Rand Water Analytical Service Method Number 1.1.2.16.1. (Rand Water, 2006b). Dissolved oxygen is the amount of gaseous oxygen that has dissolved in water. To measure dissolved oxygen in situ, the hand-held YSI 6600 MPS instrument was used and the reading taken from the instrument (Rand Water, 2006b).

3.2.7.4. Determination of pH

pH is defined as the intensity factor of acidity in a given water body, calculated as – log $[H^+]$ (Bezuidenhout, 2013).The sampling of pH was conducted on site in accordance with the Rand Water Analytical Service Method Number 2.1.3.01.2. (Rand Water, 2012b). To measure pH *in-situ*, the hand held YSI 6600 MPS instrument was used and the reading taken from the instrument.

3.2.8. Laboratory measurement of selected chemical water quality determinants

3.2.8.1. Determination of ammonium concentration

The determination of ammonium concentration in the samples was conducted using the Rand Water Method Number 2.1.8.04.2 (Rand Water, 2011b). The colorimetric method was used to quantify ammonium, with the use of indophenol blue. In addition, a liquid waveguard capillary cell was added to allow sub-micromolar detection of ammonium (Li *et al*., 2005). A hypochlorite solution made up of sodium phenolate, sodium nitroprusside and sodium hydroxide caused a reaction with the ammonium in the water sample to produce indophenol blue. With the use of the automated colorimetric system, the optical absorption of the solution was quantified at 660 nanometres (Rand Water, 2011b).

3.2.8.2. Determination of anions concentration

The determination of anions such as chloride, nitrate, nitrite, fluoride and sulphate was conducted in accordance with the Rand Water Method Number 2.1.7.02.1. (Rand Water, 201a). Ion chromatography is a method based on the detection of anions in the anionic mobile phase (carbonate-bicarbonate eluent) and ionic stationary phase (ion exchanger column) (Rand Water, 201a). The sampled water

was injected into the mobile phase and allowed to pass through the stationary phase which is an ion exchange column. The base anion exchanger separated the anions which have an affinity for a low capacity. The anions were then passed through a suppressor module for conversion to a highly conductive acid form, whereas the eluent is converted to a weak conductive carbonic acid. The acid forms to which the anions were converted, were determined by conductivity, compared to standards and identified based on their retention time (Rand Water, 2010a).

3.2.8.3. Determining of heavy metals concentration

The analysis of heavy metals in the sample was determined in accordance with the Rand Water Method Number 2.1.4.02.1., using the Induced Coupled Plasma-Optical Emission Spectrometry (Rand Water, 2009a). Heavy metals are highly toxic and carcinogenic; therefore it is important that their presence is detected in water (Rand Water, 2009a). During this process, a water sample is exposed to an argon-based, high temperature and radio frequency plasma. The energy in the plasma is transferred to the sample. Ions are generated in the transfer process and these ions are then extracted and counted by a mass spectrometer. In this study, the sampled water was filtered, acidified and exposed at about 9726 ˚C, followed by the excitement of the atoms and readings taken using a mass spectrometer (Ramcharan, 2009; Rand Water, 2009a).

3.2.9 Laboratory measurement of selected physical water quality determinants

3.2.9.1. Determination of water turbidity

The analysis of turbidity in the samples was conducted in accordance with the Rand Water Method Number 2.2.2.02.1 (Rand Water, 2011a). Turbidity is defined as a measure of the light transmitting properties of water. It indicates colloidal and residual suspended matter in both natural and waste discharged water. The turbidity of a water sample is measured by making a comparison of the amount of light scattered in the sample to the amount of light scattered in the reference sample. High light scattering is indicative of high turbidity. The reference sample and test sample were subjected to the same conditions for accuracy (Bezuidenhout, 2013).

3.2.9.2. Determination of alkalinity

The analysis of alkalinity was conducted in accordance with the Rand Water Method Number 2.1.3.01.2 (Rand Water, 2012b). Alkalinity is the buffering capacity of water, measuring the hydroxide, carbonate and bicarbonate concentration in a water

sample. The acidity of the water is lowered by the removal of the alkaline compounds by hydrogen ions, causing an increase in the pH of the water (US EPA, 2012). To measure alkalinity, the sample was titrated with a standard acid solution to pH end-point values of 8.3 and 4.3. The carbonate and all the hydroxides were titrated at pH 8.3 end-point, where the hydroxide forms water and carbonic acid. The total alkalinity of the sample was titrated at pH 4.3 end-point value where all the carbonate and bicarbonate is transformed into carbonic acid (Rand Water, 2012b).

3.2.9.3. Determination of total dissolved solids

To determine the concentration of total dissolved solids, the Rand Water Method Number 2.1.1.04.1 was used (Rand Water, 2012a). Total dissolved solids constitute inorganic salts and organic matter dissolved in water and it negatively impacts water quality by making it unsuitable to ingest (WHO, 2011). A standard glass fibre filter was used to filter the water samples and the filtrate was evaporated in a weighed dish, and then dried to constant weight at 180 ˚C ± 2˚C. The increased weight of the dish was representative of the total dissolved solids (Rand Water, 2011d).

3.2.9.4. Determination of chemical oxygen demand

Rand Water Method Number 2.1.3.0.3.1 was used to determine the chemical oxygen demand (Rand Water, 2014b). The water sample was refluxed in an acidic solution with excess potassium dichromate at a temperature of 148˚C ± 5˚C for a period of two hours. Silver sulphate was used as a catalyst and mercuric sulphate was used as a masking agent. The oxidisable material partially reduced dichromate and the remaining dichromate was analysed photometrically between 345-436 nanometers (Rand Water, 2014b).

3.2.10. Microbiological analysis

3.2.10.1. *Escherichia coli* and coliform bacteria

The Rand Water Method Number 1.2.2.09.1 was used to enumerate the amount of *E. coli* and coliform in the water samples (Rand Water, 2010f). A reference culture control was first prepared by pouring 100 ml of sterile reagent into a vessel, followed by inoculating the vessel with the *E.coli* reference cultures. The Colilert-18 medium was then added for processing of the samples. Colilert-18 is a medium containing *o*-nitrophenyl-D-galactopyranoside (ONPG) and 4-methyl-umbelliferyl-D-glucuronide (MUG) substrates. These substrates are only broken down by coliform bacteria and *E.coli*. The hydrolysis of ONPG by coliform bacteria indicates galactosidase activity,

creating a yellowish colour reaction. Glucuronidase activity is illustrated by *E.coli* hydrolysing MUG which gives out a fluorescent reaction (Rand Water, 2012c).

Sterile vessels (100 ml) were filled with the corresponding water samples taken. The vessels containing the test samples, the procedural blank sample and the reference cultures used as a control were filled with dehydrated Colilert-18 medium. The water samples and procedural blank were further transferred into Quanti-Trays which were then sealed and incubated at 37˚C ± 1˚C for 18 to 24 hours. The results for the blank were examined by exposure of the trays in visible light and the reference culture control was examined by exposure to ultra-violet light at 365 nanometres. Those incubation trays which did not exhibit any yellow colour after 18 hours of incubation were recorded and discarded. The trays showing a yellow colour were incubated for fully 24 hours and the results were recorded. The number of coliform present was determined using the Most Probable Number (MPN) table. The number of yellow well counts determined MPN values for coliforms per 100 ml. The yellow and fluorescent well counts determined the MPN values for *E.coli* per 100 ml (Rand Water, 2010f).

3.2.10.2. *Cryptosporidium* and *Giardia*

To determine the number of *Cryptosporidium* oocysts and *Giardia* cysts in the sampled water, the Rand Water Method Number 1.2.2.06.1 was used (Rand Water, 2014b).

Water samples were filtered using a filter capsule. The filter capsule was then eluted using a buffer solution and centrifuged such that the oocysts and cysts form a pellet. The cysts and oocysts were then attached to magnetic beads in order to magnetise them. Any extraneous particles are isolated using the magnet and discarded. The magnetic beads are conjugated to anti-*Cryptosporidium* and anti-*Giardia* antibodies. The beads are later detached from the oocysts and cysts, followed by staining of cysts and oocysts in wells with fluorescently labelled monoclonal antibodies and 4, 6-diamidino-2-phenylindole (DAPI). The stained sample was examined with the use of fluorescent and Differential Interference Contrast (DIC) microscopy and the number of cysts and oocysts fluorescing counted and expressed as counts per volume (Rand Water, 2014c; Sigudu *et al*., 2008, 2014).

3.3. Statistical analysis

The results were analysed using Microsoft Office EXCEL Statistics. Tables and graphs were used to illustrate and interpret the data received from the sampled water.

3.4. Statistical evaluation of the water quality data against guidelines and standards

The water quality data were assessd against international and national guidelines and standards i.e. the WHO guideline, South African water quality guidelines (domestic, irrigation, livestock and watering, aquaculture, and aquatic ecosystems), and the SANS: 241 (2015) standard for drinking water. This was done to give indication of the the fitness for use and possible impacts on the aquatic environment. Although the WHO guideline and SANS standard are for treated water, these were used because the people living in the catchment at times, do not directly consume water from the rivers. It also forms the basis for risk assessment when developing treatment interventions.

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CHAPTER 4

4. RESULTS

4.1. Bokong River

4.1.1. Historic data: 2000 to 2011

The concentration of the chemical, physical and microbiological determinants of the Bokong River was measured from January 2000 to December 2005 (Study Period: A) and from January 2006 to December 2011 (Study Period: B). The concentration with standard deviation and the ranges of the selected water quality determinants concentrations for Study Period: A and Study Period: B are presented in Table 4.1. and Table 4.2. respectively.

During the periods under investigation the chemical determinants were mostly compliant to one or more guidelines. However, during Study Period: A, the exception was aluminium, ammonium, copper, lead, nitrite, nickel, magnesium and zinc, which were not compliant to one or more of the water quality guidelines. The chemical determinants listed above were all non-compliant to the DWS Aquatic Ecosystems guideline (DWAF, 1996e) with the exception of nickel and nitrite (Table 4.1). During Study Period: B, the chemical determinants which were non-compliant with one or more guidelines was aluminium, ammonium, copper, magnesium, zinc and nitrite (Table 4.2).

The concentration of aluminium during Study Period: A was 0.05 ± 0.05 mg/l (range of 0.01 to 0.19 mg/l) and 0.04 ± 0.05 mg/l (range of 0.01 to 0.18 mg/l) for Study Period: B. These concentrations are both higher than the DWS Aquaculture (DWAF, 1996d) and Aquatic Ecosystems (DWAF, 1996e) guideline values. The ammonium concentration for Study Period: A was 0.06 ± 0.01 mg/l (range of 0.05 to 0.1 mg/l) whereas for Study Period: B, the concentration was 0.16 ± 0.20 mg/l (range of 0.05 to 0.59 mg/l) respectively. These concentrations were not compliant with the DWS Aquaculture (DWAF, 1996d) guideline. Nitrite concentration was not compliant with the DWS Aquaculture (DWAF, 1996d) guideline in both Study Periods. Study Period: A had a concentration of 0.60 ± 0.03 mg/l (range of 0.03 to 0.14 mg/l) and 0.46 ± 0.76 mg/l (range of 0.11 to 3.1 mg/l) for Study Period: B.

The concentration of nickel during Study Period: A was not compliant with the WHO (2011) and SANS: 241 (2015) drinking water guidelines. During this Study Period, the concentration was 0.08 ± 0.06 mg/l with a range of 0.02 to 0.30 mg/l. During Study Period: B, there were no nickel concentrations that could be detected in the water samples.

Copper, magnesium and zinc concentrations were not in compliance with the DWS Aquatic Ecosystems (DWAF, 1996e) guideline values. During Study Period: A, copper concentration was 0.01 ± 0.04 mg/l (range of 0.01 to 0.02 mg/l) and 0.08 ± 0.04 mg/l with a range of 0.01 to 0.06 mg/l in Study Period: B. Magnesium concentrations showed a greater degree of variation (0.47 to 8.6 mg/l), with a concentration of 2.26 ± 1.18 mg/l during Study Period: A. For Study Period: B, the concentration was 3.41 ± 2.63 mg/l (range of 1.3 to 19 mg/l).

Lead was not compliant with four of the guidelines, namely; the WHO (2011), SANS: 241 (2015), DWS Aquaculture (DWAF, 1996d) and Aquatic Ecosystems (DWAF, 1996e) guidelines during Study Period: A. The concentration was 0.05 ± 0.05 mg/l, with a range of 0.01 to 0.11 mg/l. However, lead concentrations were not determined during Study Period: B. Therefore a comparison was not possible.

Zinc concentration was 0.02 ± 0.01 mg/l during Study Period: A with a range of 0.01 to 0.04 mg/l. Study Period: B showed a concentration of 0.06 ± 0.11 mg/l with a range of 0.01 to 0.30 mg/l. The mean concentration was significant enough to cause non-compliance with the DWS Aquatic Ecosystems (DWAF, 1996e) guideline in both Study Periods.

Table 4.1: Historic surface water quality concentrations of the Bokong River during the Study Period: A-January 2000 to December 2005

Orange shading indicates a non-compliance with one or more of the guidelines or the standard, green shading indicates compliance.

Determinants	Units	Concentration		Standard or guideline						
						DWAF				
		Mean +/- SD	Range	WHO (2011)	SANS:241 (2015)	Domestic (1996a)	Irrigation (1996b)	Livestock and Watering (1996c)	Aquaculture (1996d)	Aquatic Ecosystems (1996e)
Chemical Determinants										
Aluminium	mg/l	0.05 ± 0.05	0.01-0.19	0-0.9	0-0.3	*	0-5	0-5	0-0.03	0-0.005
Ammonium	mg/l	0.06± 0.01	0.05-0.1	*	0-1.5	*	*	*	0-0.025	*
Calcium	mg/l	6.85± 2.73	2.6-19	*		*	*	0-1000	*	*
Copper	mg/l	0.01±0.04	0.01-0.02	0-2	0-2	*	0-0.2	0-0.5	*	0-0.0012
Iron	mg/l	0.07±0.10	0.01-0.56	0-2	0-2	*	0-5	0-10	*	< 10 % background value
Lead	mg/l	0.05± 0.05	0.01-0.11	0-0.01	0-0.01	*	0-0.2	0-0.1	0-0.01	0-0.001
Potassium	mg/l	0.44±0.39	0.11-1.9	*	*	0-50	*	*	*	*
Magnesium	mg/l	2.26±1.18	0.47- 8.6	*	*	*	*	0-500	*	*
Manganese	mg/l	0.04± 0.07	0.01-0.27	0-0.4	0-0.5	*	0-0.02	0-10	0-0.1	0-0.18
Nickel	mg/l	0.08±0.06	0.02-0.3	0-0.007	0-0.07	*	0-0.2	0-1	*	*
Nitrite as N	mg/l	0.60±0.03	0.03-0.14	0-3	0-0.9	*	*	*	0-0.05	*
Nitrate as N	mg/l	0.21±0.25	1.5-0.1	0-50	0-11	*	*	0-100	0-300	*
Phosphorus	mg/l	0.48±0.77	0.04-2.7	*	*				*	0-5
Sodium	mg/l	2.33±1.94	0.66-11	0-200	0-200	*	0-70	0-2000	*	*
**Sulphur	mg/l	1.13±0.57	0.51-4.6	*	*	*	*	*	*	*
**Total Organic Carbon	mg/l	1.88 ± 0.75	0.85-5.2	*	*	*	*	*	*	*
**Total Phosphates	mg/l	0.4 ± 0.40	0-0.85	*	*	*	*	*	*	*
**Total Silica	mg/l	10.71 ± 3.87	1-16	*	*	*	*	*	*	*
Zinc	mg/l	0.02±0.01	0.01-0.04	0-3	0-5	*	0-1	0-20	*	0-0.002
Physical Determinants										
Alkalinity	mg/l $CaCO_3$	27.34 ± 7.49	14-52	*	*	*	*	*	20-100	*
**Chemical Oxygen Demand	mg/l	13.7 ± 4.22	10-23	*	*	*	*	*	*	*

Table 4.1: (Continued) Historic surface water quality concentrations of the Bokong River during the Study Period: A-January 2000 to December 2005

Orange shading indicates a non-compliance to one or more of the guidelines or the standard, green shading indicates compliance.

Determinants	Units	Concentration		Standard or guideline						
						DWAF				
		Mean +/- SD	Range	WHO (2011)	SANS:241 (2015)	Domestic (1996a)	Irrigation (1996b)	Livestock & Watering (1996c)	Aquaculture (1996d)	Aquatic Ecosystems (1996e)
Conductivity at 25 ˚C	mS/m	5.14 ± 1.27	3.4-8.5	*	0-170	*	0-40	0-154	*	*
Dissolved oxygen	mg/l	7.18 ± 2.18	2.5-11.97	*		*	*	*	6.0- 9.0	80-120 % saturation
Hardness	mg/l $CaCO_3$	26.45 ± 11.50	8.4-82	*	*	50-100	*	*	20-100	*
pH at 25 ˚C	pH units	8.18 ± 0.61	7-9.2	*	5.0-9.7	*	6.5-8.4	*	6.5-9.0	< 5% background value
Suspended solids	mg/l	27.28 ± 21.54	4-88	*	*	*	0-50	*	*	*
Temperature	˚C	22.34 ± 1.60	16.7-26	*	*	*	*	*	*	*
Total dissolved solids	mg/l	59.53 ± 35.17	10-270	*	0-1200	*	0-260	0-1000	0-0.02	<15% background value
Turbidity	NTU	2.30 ± 3.80	0.17- 25	*	0-1.0	*	*	*	*	<10% background value
Microbiological Determinants										
Coliphage	CFU/ 10ml	4 ± 14.6	0- 75	0	*	0-1	*	*	*	*
Faecal coliform	Count/ 100ml	108 ± 245.03	0- 1210	0	0	0	0-10 000	*	*	*

*Determinant value not stipulated **No comparison value

Table 4.2: Historic surface water quality concentrations of the Bokong River during Study Period: B-January 2006 to December 2011

Orange shading indicates a non-compliance to one or more of the guidelines or the standard, green shading indicates compliance.

Determinants	Units	Concentration		Standard or guideline						
						DWAF				
		Mean +/- SD	Range	WHO (2011)	SANS:241 (2015)	Domestic (1996a)	Irrigation (1996b)	Livestock & Watering (1996c)	Aquaculture (1996d)	Aquatic Ecosystems (1996e)
Chemical Determinants										
Aluminium	mg/l	0.04 ± 0.05	0.01-0.18	0-0.9	0-0.3	*	0-5	0-5	0-0.03	0-0.005
Ammonium	mg/l	0.16 ± 0.2	0.05-0.59	*	0-1.5	*	*	*	0-0.025	*
Boron	mg/l	0.02 ± 0.02	0.02-0.06	0-2.4	*	*	0-0.5	0-5	*	*
Calcium	mg/l	8.44 ± 2.0	4.6-13	*		*	*	0-1000	*	*
Copper	mg/l	0.08 ±0.04	0.01-0.06	0-2	0-2	*	0-0.2	0-0.5	*	0-0.0012
Fluoride	mg/l	0.08 ± 0.04	0.05-0.26	0-1.5	0-1.5	*	0-2.0	0-2.0	*	0-0.75
Iron	mg/l	0.03 ±-0.5	0.01-0.24	0-2	0-2	*	0-5	0-10	*	< 10 % background value
Magnesium	mg/l	3.41 ±2.63	1.3-19	*	*	*	*	0-500	*	0-0.18
Manganese	mg/l	0.02± 0.01	0.01-0.04	0-0.4	0-0.5	*	0-0.2	0-10	0-0.1	0-0.18
Nitrite as N	mg/l	0.46 ±0.76	0.11-3.1	0-3	0-0.9	*	*	*	0-0.05	*
Nitrate as N	mg/l	0.49 ± 0.84	0.12-2.2	0-50	0-11	*	*	0-100	0-300	*
Potassium	mg/l	2.22 ± 4.32	0.33-12	*	*	0-50	*	*	*	*
Phosphorus	mg/l	0.13±0.6	0.06-0.27	*	*	*	*	*	*	0-5
**Phosphates	mg/l	0.08 ± 0.2	0.04-0.11	*	*	*	*	*	*	*
Sodium	mg/l	4.95±11.64	1.5-64	0-200	0-200	*	0-70	0-2000	*	*
Sulphate	mg/l	7.38 ± 3.31	5.2-14	*	0-600	0-200	*	0-1000	*	*
**Sulphur	mg/l	2.41 ± 6.76	0.54-44	*	*	*	*	*	*	*
**Total Organic Carbon	mg/l	2.02 ± 0.77	0.46-4.4	*	*	*	*	*	*	*
**Total Silica	mg/l	12.68±2.45	0.99-16	*	*	*	*	*	*	*
Zinc	mg/l	0.06 ± 0.11	0.01-0.3	0-3	0-5	*	0-1	0-20	*	0-0.002

Table 4.2: (Continued) Historic surface water quality concentrations of the Bokong River during Study Period: B – January 2006 to December 2011

Orange shading indicates a non-compliance to one or more of the guidelines or the standard, green shading indicates compliance.

Determinants	Units	Concentration		Standard or guideline						
						DWAF				
		Mean +/- SD	Range	WHO (2011)	SANS:241 (2015)	Domestic (1996a)	Irrigation (1996b)	Livestock & Watering (1996c)	Aquaculture (1996d)	Aquatic Ecosystems (1996e)
Physical Determinants										
Alkalinity	mg/l $CaCO_3$	35.27±5.67	19-44	*	*	*	*	*	20-100	*
**Chemical oxygen demand	mg/l	14 ± 5.32	10.0-23	*	*	*	*	*	*	*
Conductivity at 25 ˚C	mS/m	6.72 ± 1.73	3.4-11	*	0-170	*	0-40	0-154	*	*
Dissolved oxygen	mg/l	9.18 ± 1.17	7.26-12.21	*		*	*	*	6.0-9.0	80-120% saturation
Hardness	mg/l $CaCO_3$	37.70±26.38	17-195	*	*	50-100	*	*	20-100	*
pH at 25˚C	N/A	8.37 ± 0.57	7.1-9.9	*	5.0-9.7	*	6.5-8.4	*	6.5-9.0	< 5% background value
Suspended Solids	mg/l	14.5 ± 4.65	10.0-19	*	*	*	0-50	*	*	*
Total Dissolved Solids	mg/l	60.24 ± 17.28	30-120	*	0-1200	*	0-260	0-1000	0-0.02	<15% background value
Temperature at 25 ˚C	˚C	14.30±5.19	2.2-22.8	*	*	*	*	*	*	*
Turbidity	NTU	1.28 ± 1.91	0.22-11	*	0-1.0	*	*	*	*	<10% background value
Microbiological Determinants										
Cryptosporidium	Oocysts/ 10L	3 ± 3.5	1-7.0	0	0	*	*	*	*	*
Coliphage	CFU/ 10ml	9 ± 34.32	0-166	0	*	0-1		*	*	*
E. coli	MPN/ 100ml	17 ± 27.70	0-78	0	0	0	0-10	0-200	0-10	*
Faecal coliform	FC/ 100ml	217 ± 1072.53	0-6080	0	0	0	0-10 000	*	*	*

*Determinant value not stipulated **No comparison value

Most of the physical determinants were compliant with the guidelines during Study Period: A (Table 4.1), with the exception of turbidity which was non-compliant with the SANS: 241 (2015) and total dissolved solids which was non-compliant to DWS Aquaculture (DWAF, 1996d) water guideline. In this study period, the concentration of turbidity was 2.30 ± NTU (range of 0.17 to 25 NTU) and 59.53 ± 35.17 mg/l (range of 10 to 270 mg/l) for total dissolved solids. During Study Period: B, only four physical determinants (TDS, turbidity, hardness and dissolved oxygen) were not compliant to one or more of the guidelines (Table 4.2). Total dissolved solids had a concentration of 59.53 ± 35.17 mg/l (range: 30 to 120 mg/l) and dissolved oxygen concentrations were 9.18 ± 1.17 mg/l (range: 7.26 to 12.21 mg/l) were non-compliant with the DWS Aquaculture (DWAF, 1996d) guideline while turbidity had a concentration of 1.28 ± 1.91 NTU (range: 0.22 to 11 NTU) which was non-compliant with the SANS: 241 (2015) guideline.

The microbiological determinants were mostly non-compliant with one or more of the guidelines (Table 4.1. and Table 4.2). During Study Period: A, coliphage bacteria concentration was not compliant with both the WHO (2011) and DWS Domestic water (DWAF, 1996a) guidelines. The faecal coliform bacteria concentration was 108 ± 245.0 counts per 100ml (range: 0 to 1210 counts per 100 ml) which was not compliant with three of the guidelines i.e. WHO (2011), SANS: 241 (2015) and DWS Domestic water (DWAF, 1996a) guidelines (Table 4.1). Coliphage bacteria concentration was 4 ± 14.6 CFU/10ml with a range of zero to 75 CFU/10ml.

The mean concentration of faecal coliform bacteria of 217 ± 1072.5 (range: 0 to 6080 FC/100ml) far exceed the WHO (2011), SANS: 241 (2015) and DWS Domestic water (DWAF, 1996a) guidelines during Study Period: B (Table 4.2). The concentration of coliphage bacteria of 9 ± 34.3 CFU/10ml (range of 0 to 166 CFU/10ml) was non-compliant with the WHO (2011) and the DWS Domestic water (DWAF, 1996a) guidelines. The concentration of *Cryptosporidium* was 3 ± 3.5 Oocysts/10L (range of 1 to 7 Oocysts/10L) and was non-compliant with the WHO (2011) and SANS: 241 (2015) guidelines. *Escherichia coli* was non-compliant with four of the guidelines, namely; WHO (2011), SANS: 241 (2015), DWS Domestic (DWAF, 1996a) and Irrigation (DWAF, 1996b) guidelines, with a concentration of 17 ± 27.7 MPN/100ml

and a range of 0 to 78 MPN/100ml. In comparison with the previous study period (Study Period: A), *Cryptosporidum* and *E.coli* were not detected but an increase in both faecal coliform and coliphage bacteria can be noted in this study period.

It must be noted that for some of the chemical determinants, there were no comparison guideline values to allow for comparison to determine compliance or non-compliance e.g. total silica and total organic carbon (Table 4.1 and Table 4.2).

4.1.1.1 Annual concentrations of non-compliant chemical, physical and microbiological determinants for Study Period: A and Study Period: B

The determinants that showed non-compliance during both study periods, that is for Study Period: A as well as for Study Period: B, were further analyzed using box-plots to observe trends and show variation over the individual years.

(a) Aluminium

Aluminium concentrations during Study Period: A, from 2000 to 2002, were less than 0.10 mg/l. However, the concentration can be seen increasing from 2003 to 2005 with the highest concentration in the years 2003 and 2005. The concentration of aluminium fluctuated with low concentrations during Study Period: B in 2006 and 2007 and with below detection levels in the year 2009 and 2010 (Figure 4.1). The maximum concentration was in the year 2011 which was 0.18 mg/l and hence, the non-compliance with the DWS Aquaculture (DWAF, 1996d) and Aquatic Ecosystems (DWAF, 1996e) guidelines.

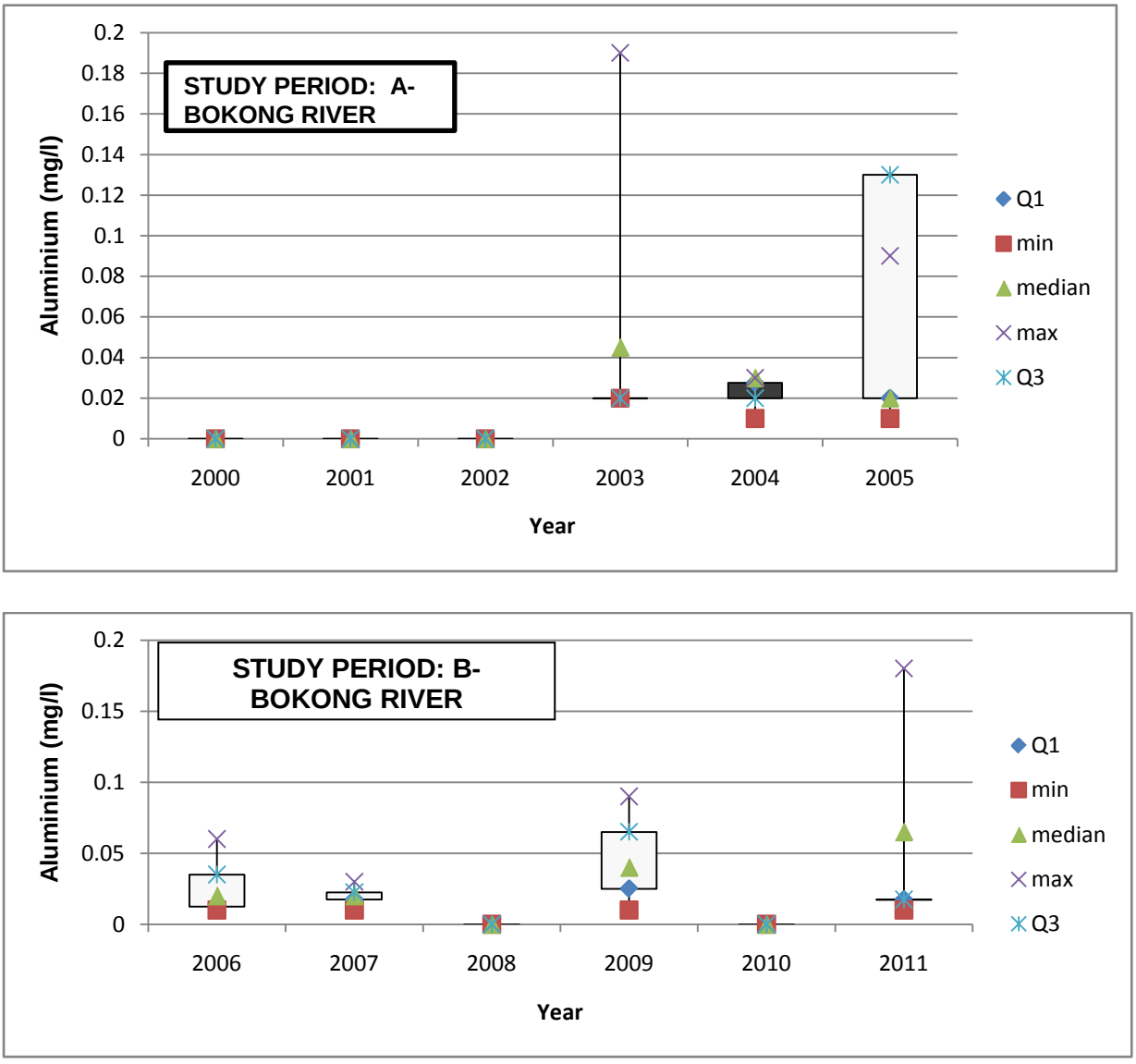


Figure 4.1 Concentrations of aluminium recorded during Study Period: A (January 2000 to December 2005) and Study Period: B (January 2006 to December 2011) for the Bokong River

(b) Ammonium

During Study Period: A, the concentration of ammonium fluctuated considerably. In the year 2000, the concentration is just above 2 mg/l and decreases in 2001 (Figure 4.2.). However, in 2002, the maximum concentration of above 10 mg/l could be observed with a substantial decrease again from 2003 to 2005. Study Period: B (Figure 4.2.) showed a peak concentration of ammonium in 2006. Ammonium levels were below the detection limit in 2007, 2009 to 2011. In 2008, a slight concentration

of just below 0.1 mg/l could be observed. These maximum concentrations caused a non-compliance with the DWS Aquaculture (DWAF, 1996d) water guideline.

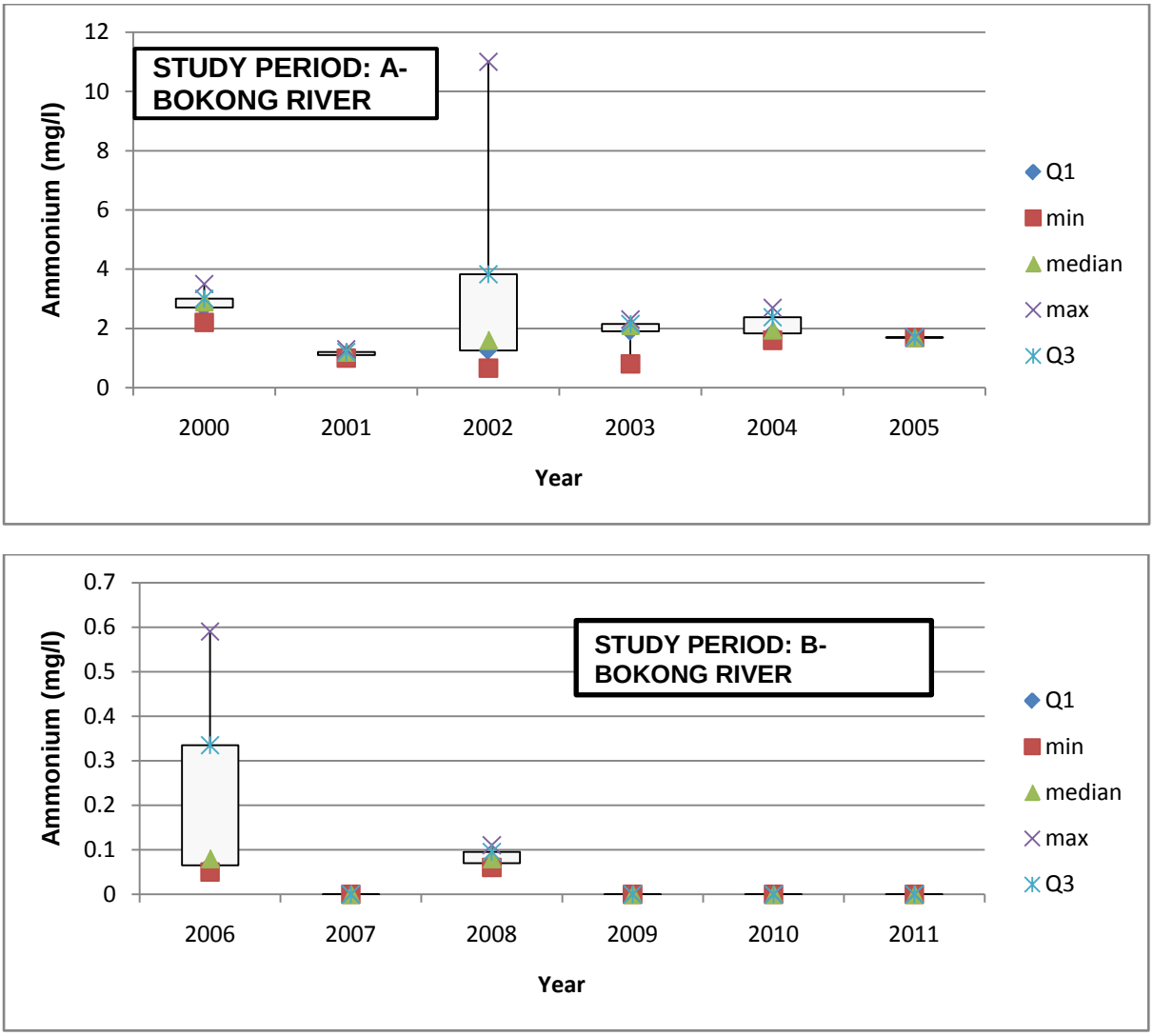


Figure 4.2 Concentrations of ammonium recorded during Study Period: A (January 2000 to December 2005) and Study Period: B (January 2006 to December 2011) for the Bokong River.

(c) Copper

Copper concentrations were below the detection limit of 5.54 µg/l during Study Period: A, from 2000 to 2002 (Figure 4.3). An increase however, can be noted in 2003 which then remains constant until 2005. The maximum concentration of 0.02 mg/l can be observed in 2005. During Study Period: B (Figure 4.3.), copper concentrations were also below the detection limit in 2006, 2010 and 2011. In 2009,

a maximum concentration of 0.06 mg/l can be observed on the graph, contributing to non-compliance with the DWS Aquatic Ecosystems water (DWAF, 1996e) guideline.

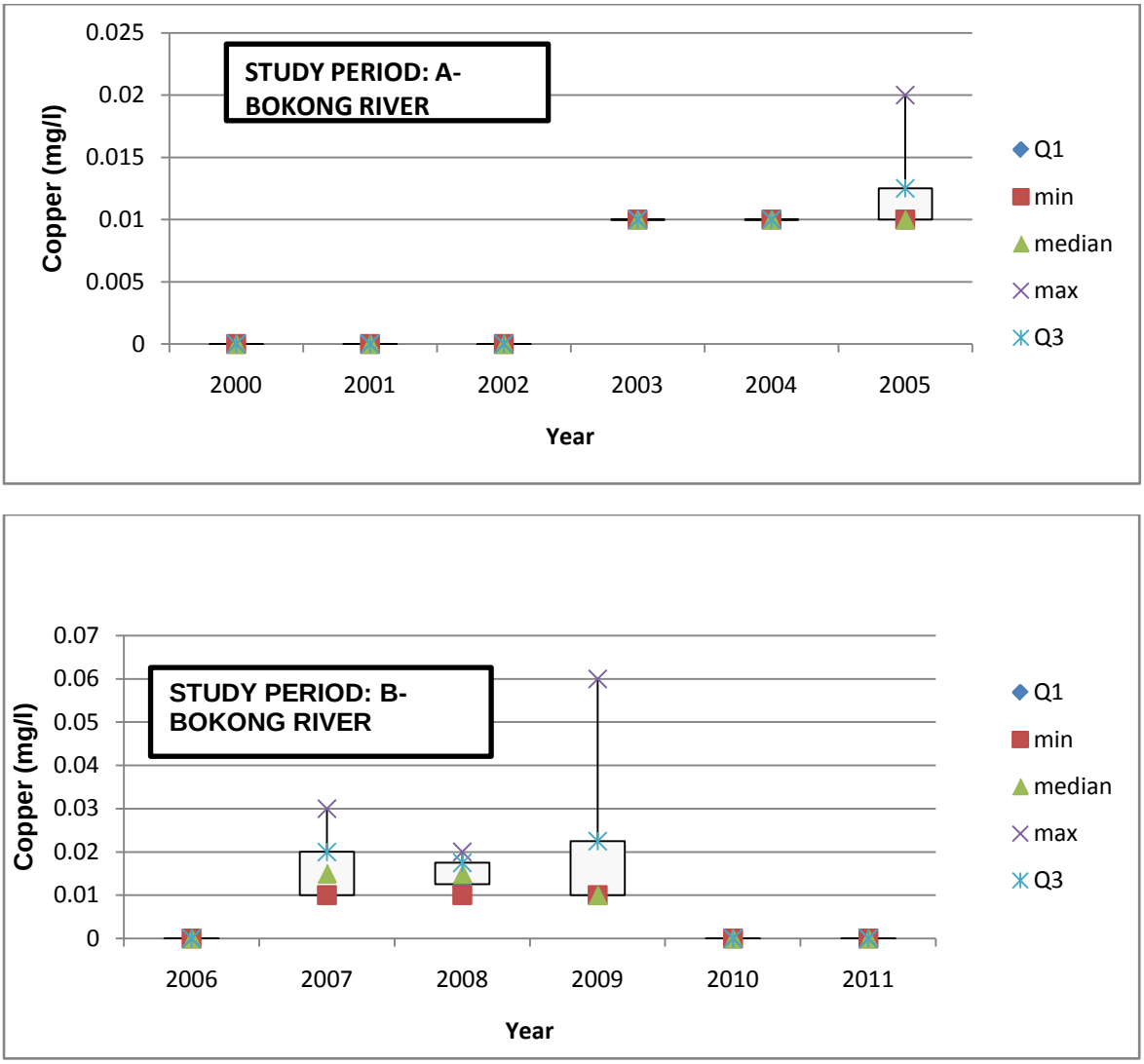


Figure 4.3 Concentrations of copper recorded during Study Period: A (January 2000 to December 2005) and Study Period: B (January 2006 to December 2011) for the Bokong River

(d) Lead

The concentration of lead during Study Period: A was non-compliant with the WHO (2011), SANS: 241 (2015), DWS Aquaculture (DWAF, 1996d) and Aquatic Ecosystems (DWAF, 1996e) water guidelines. In the year 2000, lead concentrations were below the detection limit of 10.30 µg/l. However, an increase in the concentration could be observed in the year 2001 (Figure 4.4.), thus contributing to lead being non-compliant to the said guidelines. From the year 2003 to 2005, very

minimum concentrations could be detected in the water samples. During Study Period: B, lead concentrations were below the detection limit and comparison with Study Period: B was not possible.

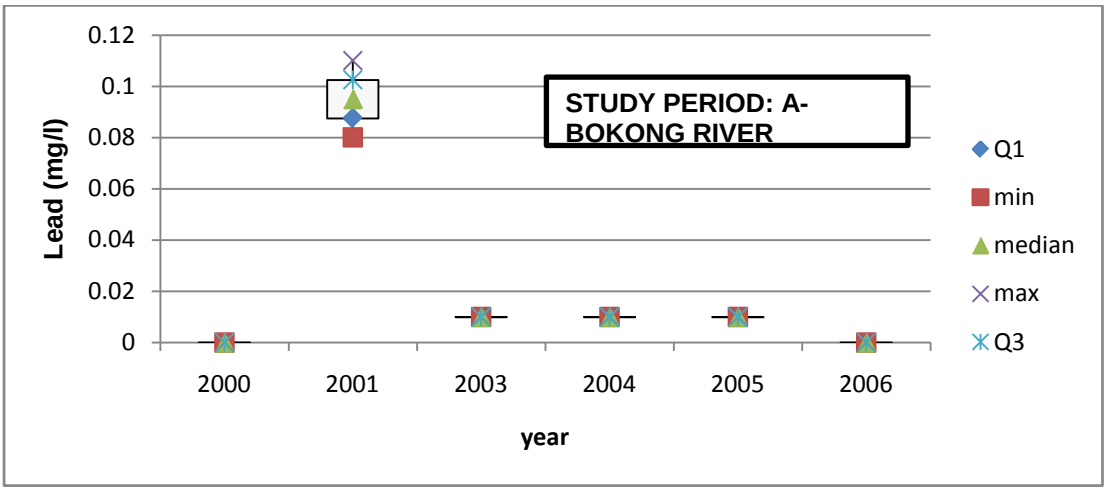


Figure 4.4 Concentrations of lead recorded during Study Period: A (January 2000 to December 2005)

(e) Magnesium

The concentration of magnesium could be detected throughout the Study Period: A (Figure 4.5.) with maximum concentrations in 2000 and 2002. During Study Period: B, the concentration of magnesium was lower in comparison with Study Period: A except for the year 2009 which had a maximum of above 18 mg/l, contributing to non-compliance with the DWS Aquatic Ecosystems water (DWAF, 1996e) guideline.

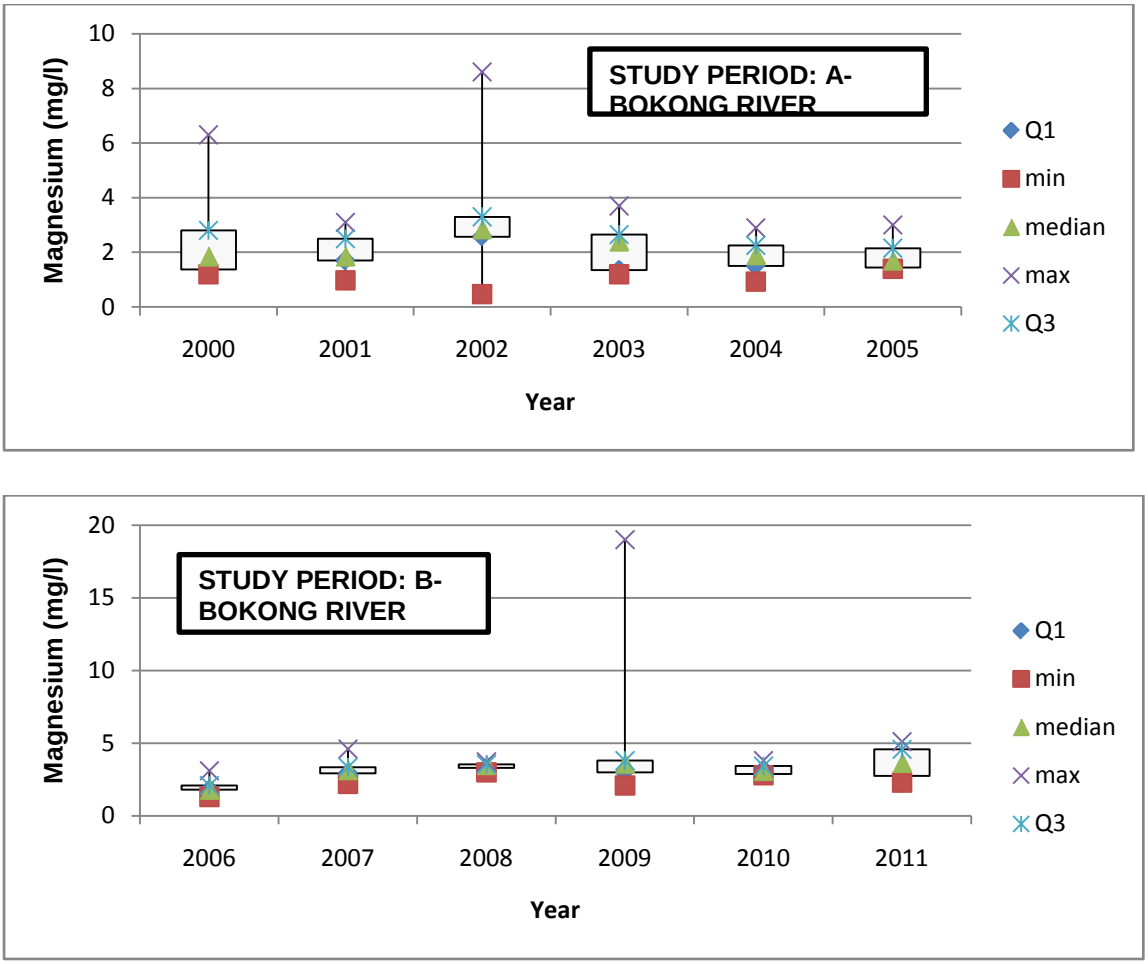


Figure 4.5 Concentrations of magnesium recorded during Study Period: A (January 2000 to December 2005) and Study Period: B (January 2006 to December 2011) for the Bokong River

(f) Nickel

Nickel concentrations were below the detection limit from 2000 to 2002 of Study Period: A. However, an increase could be noted in 2003, followed by a decrease in 2004 and an increase again in 2005 (Figure 4.6.). These increased concentrations contributed to nickel being non-compliant with the WHO (2011) and SANS: 241 (2015) guidelines (Table 4.1.) During Study Period: B, the concentrations of nickel were below the detection limit.

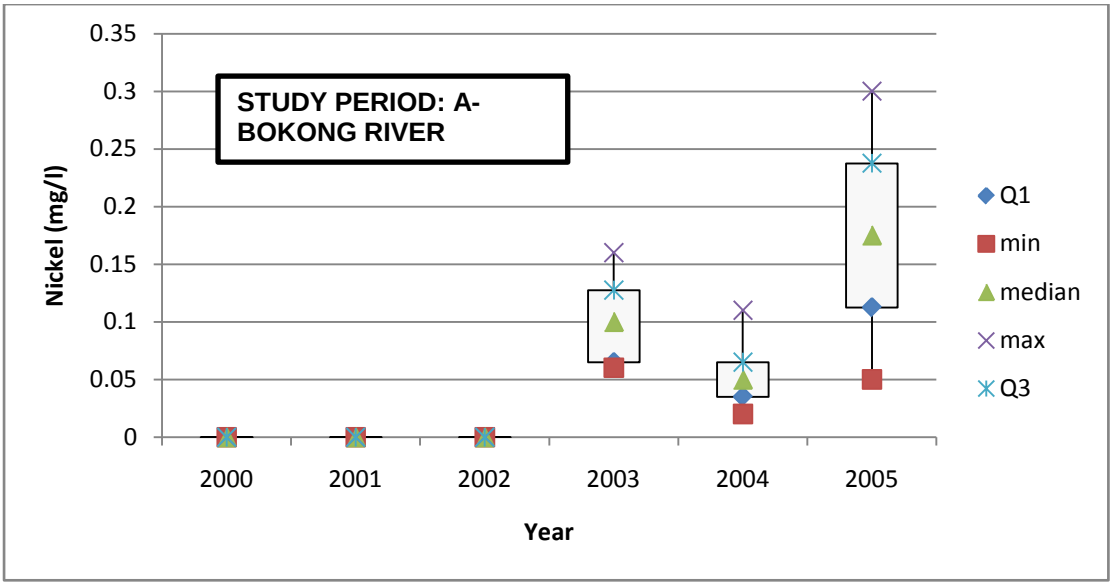
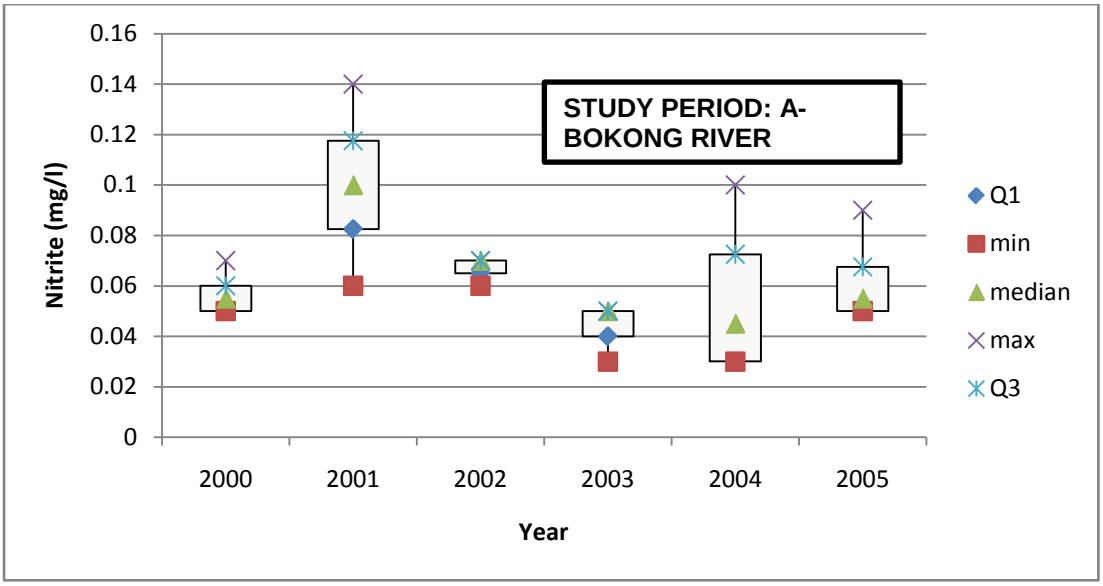


Figure 4.6 Concentrations of nickel recorded during Study Period: A (January 2000 to December 2005)

(g) Nitrite

Nitrite concentrations fluctuated throughout Study Period: A, with maximum concentrations in the year 2001 and 2004 (Figure 4.7.) The concentration was 0.14 mg/l. During Study Period: B, there was a gradual increase in concentration from 2006 to 2008. An increase in the concentration of nitrite could be noted in 2009 which was above 8 mg/l, a maximum concentration for this period. A significant decrease in concentration can be noted from 2009 to 2010 as can a further gradual decrease to below 0.5 mg/l in 2011. For both Study Periods: A and B, nitrite was non-compliant with the DWA& S Aquaculture water guideline (DWAF, 1996d).



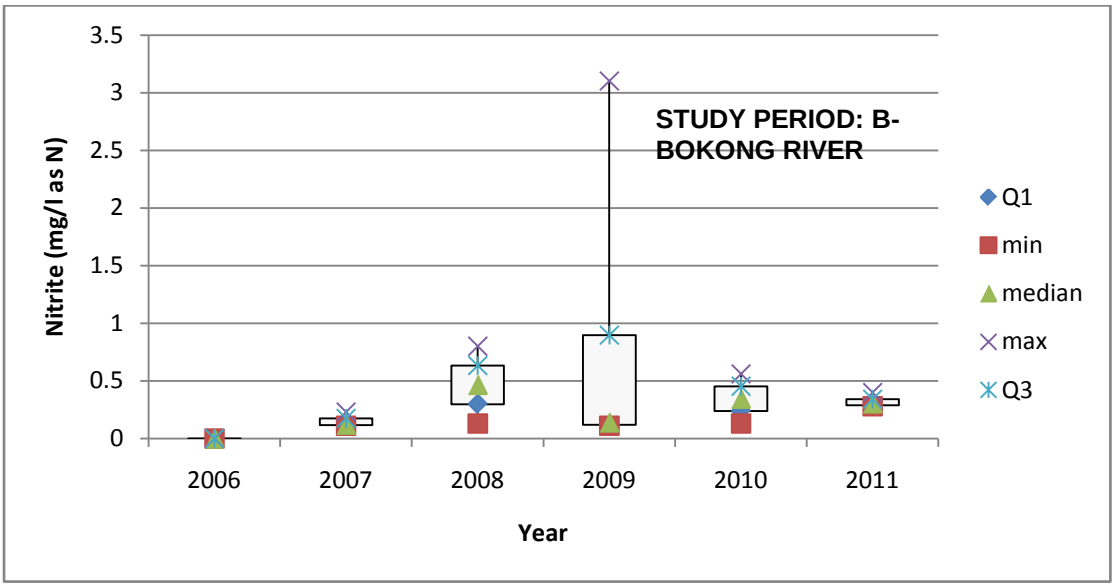


Figure 4.7 Concentrations of nitrite recorded during Study Period: A (January 2000 to December 2005) and Study Period: B (January 2006 to December 2011) for the Bokong River

(h) Zinc

During Study Period: A, the concentration of zinc was below the detection limit of 2.91 µg/l, from the year 2000 to 2003. However, in the year 2004, a concentration of 0.04 mg/l was detected which was the maximum concentration for the period. In 2005 and 2006, the concentration was constant at 0.03 mg/l (Figure 4.8.). During Study Period: B, the concentration was very low (less than 0.05mg/l) in the year 2006 and 2007. In the year 2008, a maximum concentration of 0.3 mg/l was detected with a decrease in 2009 and 2010. This sudden peak concentration contributed to

zinc not complying with the DWA& S Aquatic Ecosystems (DWAF, 1996e) water guideline. The concentration of zinc was below the detection limit in the year 2011 (Figure 4.8).

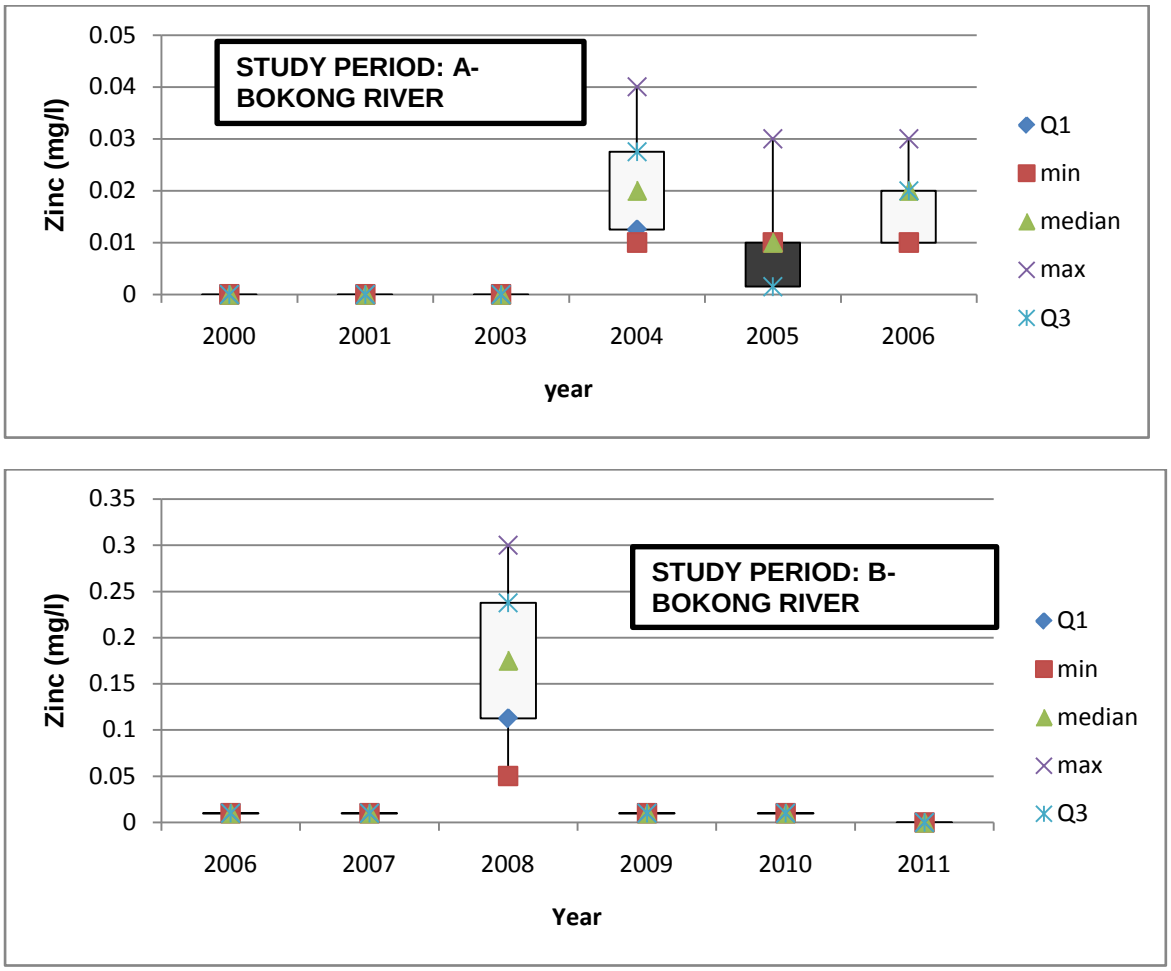


Figure 4.8 Concentrations of zinc recorded during Study Period: A (January 2000 to December 2005) and Study Period: B (January 2006 to December 2011) for the Bokong River

(i) Dissolved oxygen

The dissolved oxygen concentration of the river water was not measured during Study period A. During Study Period: B (Figure 4.9.), the concentration of dissolved oxygen fluctuated slightly throughout the years, in a range of 7.26 to 12.21 mg/l. However, maximum values can be observed in 2006 and 2009, contributing to the non-compliance with the DWS Aquaculture guideline (DWAF, 1996d).

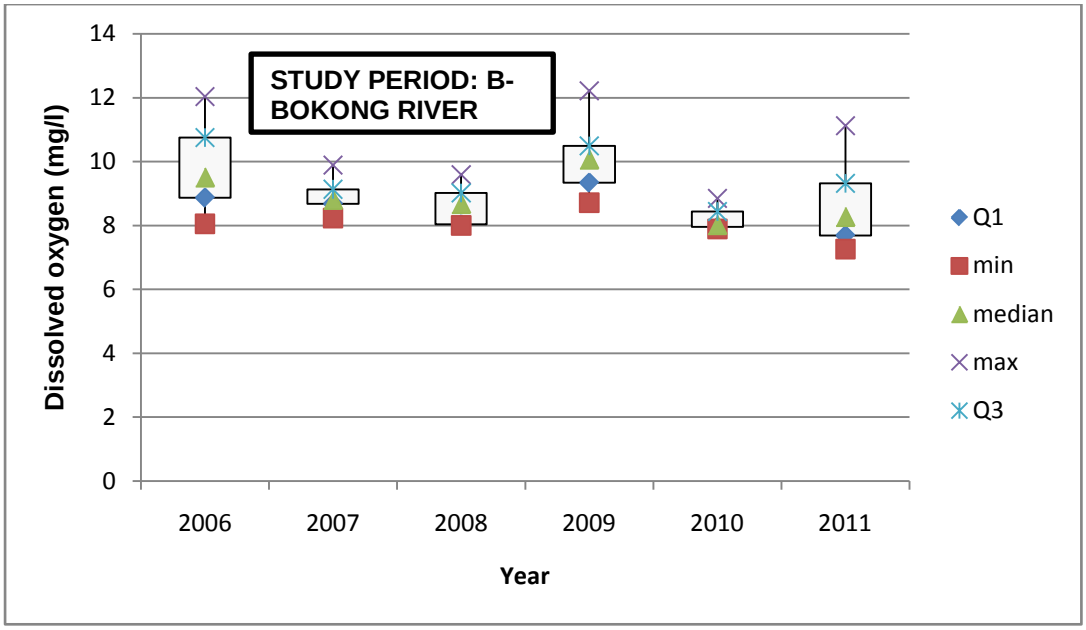


Figure 4.9 Concentrations of dissolved oxygen recorded during Study Period: B (January 2006 to December 2011) for the Bokong River

(j) Hardness

The concentration of hardness during Study Period: A fluctuated considerably (Figure 4.10). Maximum concentrations could be observed in the year 2000 and 2002 which was 70 mg/l and 80 mg/l (as $CaCO_3$) respectively. During Study Period: B, the concentration was below 50 mg/l for all the years except for the year 2009, where the concentration was about 200 mg/l (as $CaCO_3$) (Figure 4.10). For both Study Periods, the non-compliance with the DWS Domestic water (DWAF, 1996a) guideline was because the concentration of hardness was below the stipulated value in the guideline and not above the guideline value.

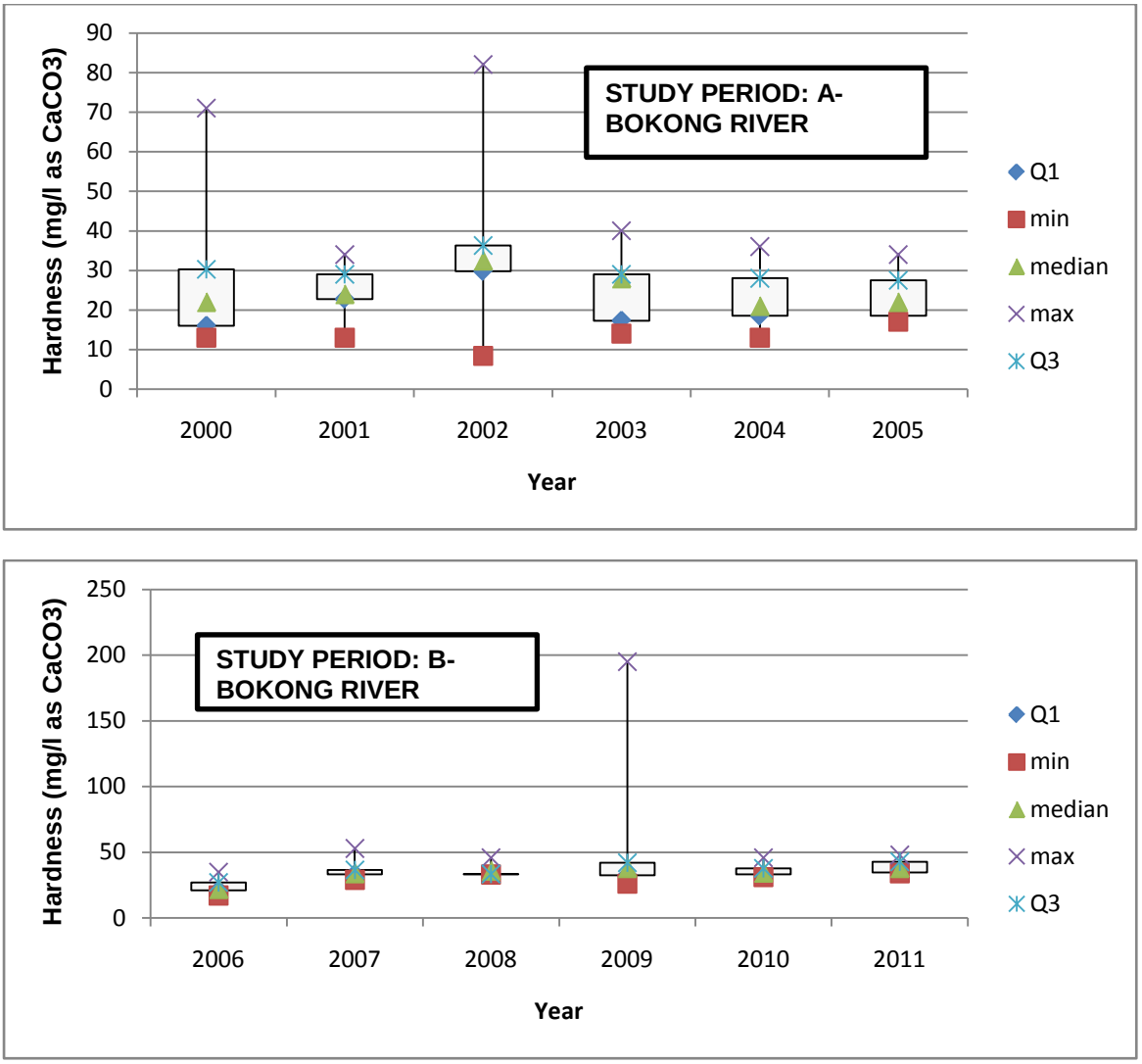


Figure 4.10 Concentrations of hardness recorded during Study Period: A (January 2000 to December 2005) and Study Period: B (January 2006 to December 2011) for the Bokong River

(k) Total Dissolved Solids

During Study Period: A, total dissolved solids showed fluctuations throughout the years. Maximum concentrations could be observed in the year 2001 (150 mg/l) and 2003 (270 mg/l) (Figure 4.11.). In comparison with Study Period: B (Figure 4.11.), the concentration of total dissolved solids increased from 2006 to 2008. The year 2008 had the maximum concentration of above 100 mg/l. The concentration decreased in 2009 but increased again from 2010 to 2011, resulting in non-compliance with the DWS Aquatic Ecosystems (DWAF, 1996e) guideline.

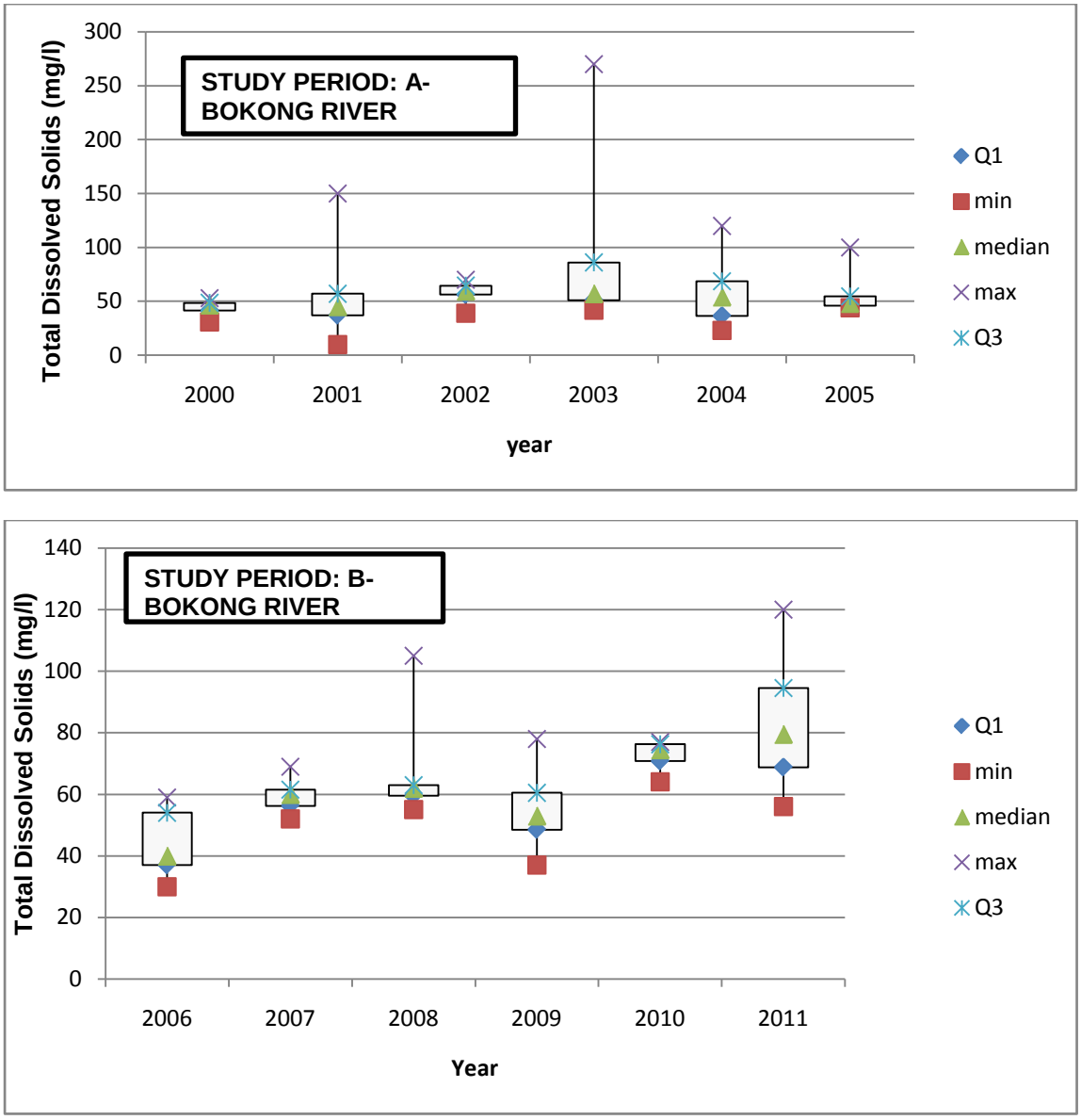


Figure 4.11 Concentrations of total dissolved solids recorded during Study Period: A (January 2000 to December 2005) and Study Period: B (January 2006 to December 2011) for the Bokong River

(l) Turbidity

The turbidity of the water was not compliant with the SANS: 241 (2015) during both Study Period: A and Study Period: B. The turbidity concentrations fluctuated quite considerably during Study Period: A. The highest turbidity concentration of 25 NTU was observed in 2002 for Study Period: A. During Study Period: B, turbidity levels were highest in 2007 at 11 NTU. The concentration is observed to decrease from 2008 to 2009, where it was zero in 2009 (Figure 4.12.).

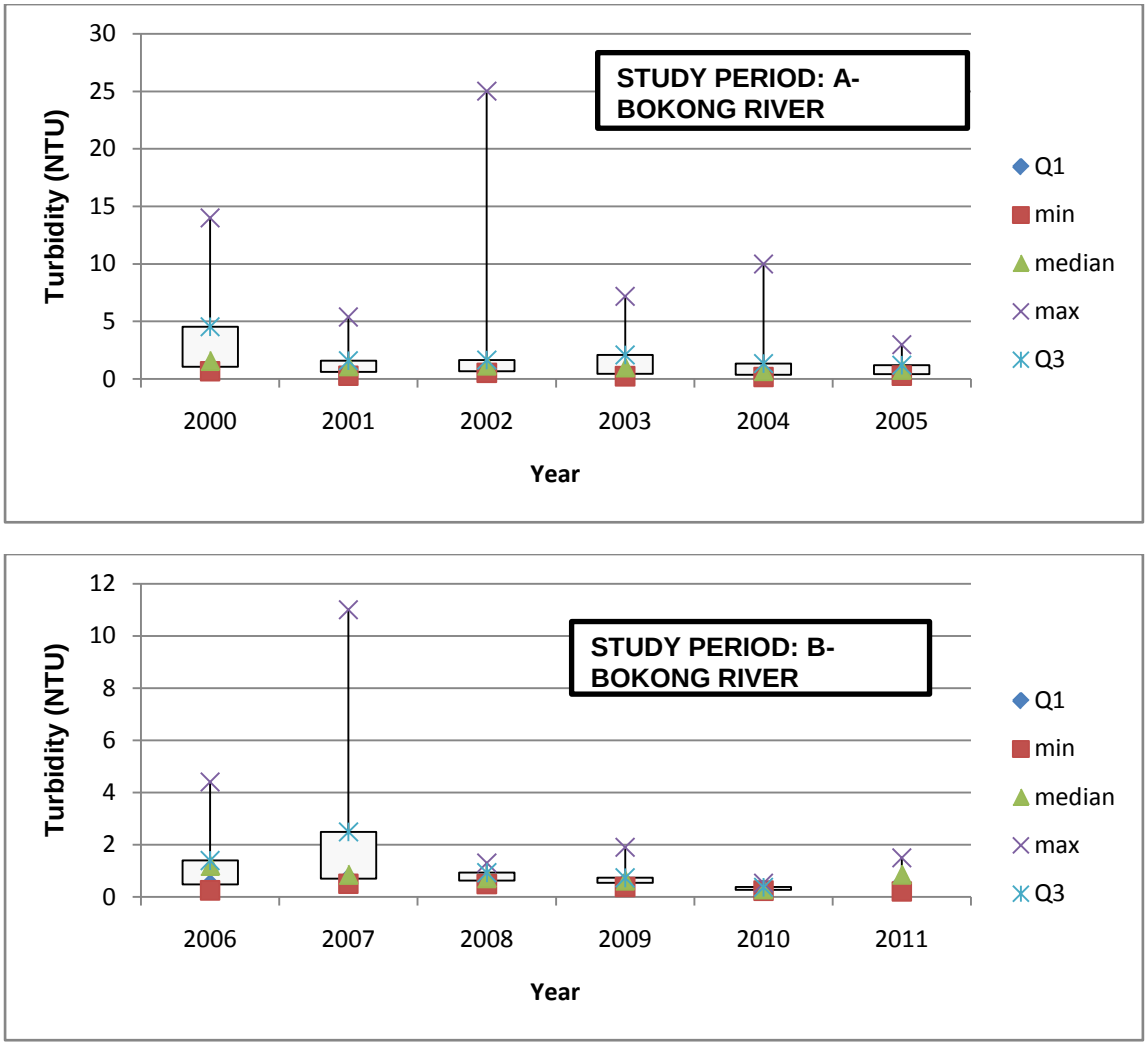


Figure 4.12 Concentrations of turbidity recorded during Study Period: A (January 2000 to December 2005) and Study Period: B (January 2006 to December 2011) for the Bokong River

(m) Faecal coliform bacteria

Faecal coliform bacteria could be detected in substantial concentrations throughout the Study Period: A, with the maximum concentration of 1200 FC/100ml recorded in the year 2005 (Figure 4.13.) The concentration for each individual year was not in compliance with the WHO (2011), SANS: 241 (2015) and DWS Domestic (DWAF, 1996a) guidelines. During Study Period: B, the maximum concentration of 6000 FC/100ml faecal coliform bacteria can be observed in 2007. It is this peak concentration that contributed to non-compliance with the WHO (2011), SANS: 241 (2015) and DWS Domestic (DWAF, 1996a) guidelines (Figure 4.13.). There was no data available from 2008 to 2011 as the Analytical Services Laboratory adopted the

Colilert-18/Quanti-Tray method for the direct detection of *E. coli* and the monitoring of faecal coliform bacteria was discontinued (Du Preez, pers. comm., 2014).

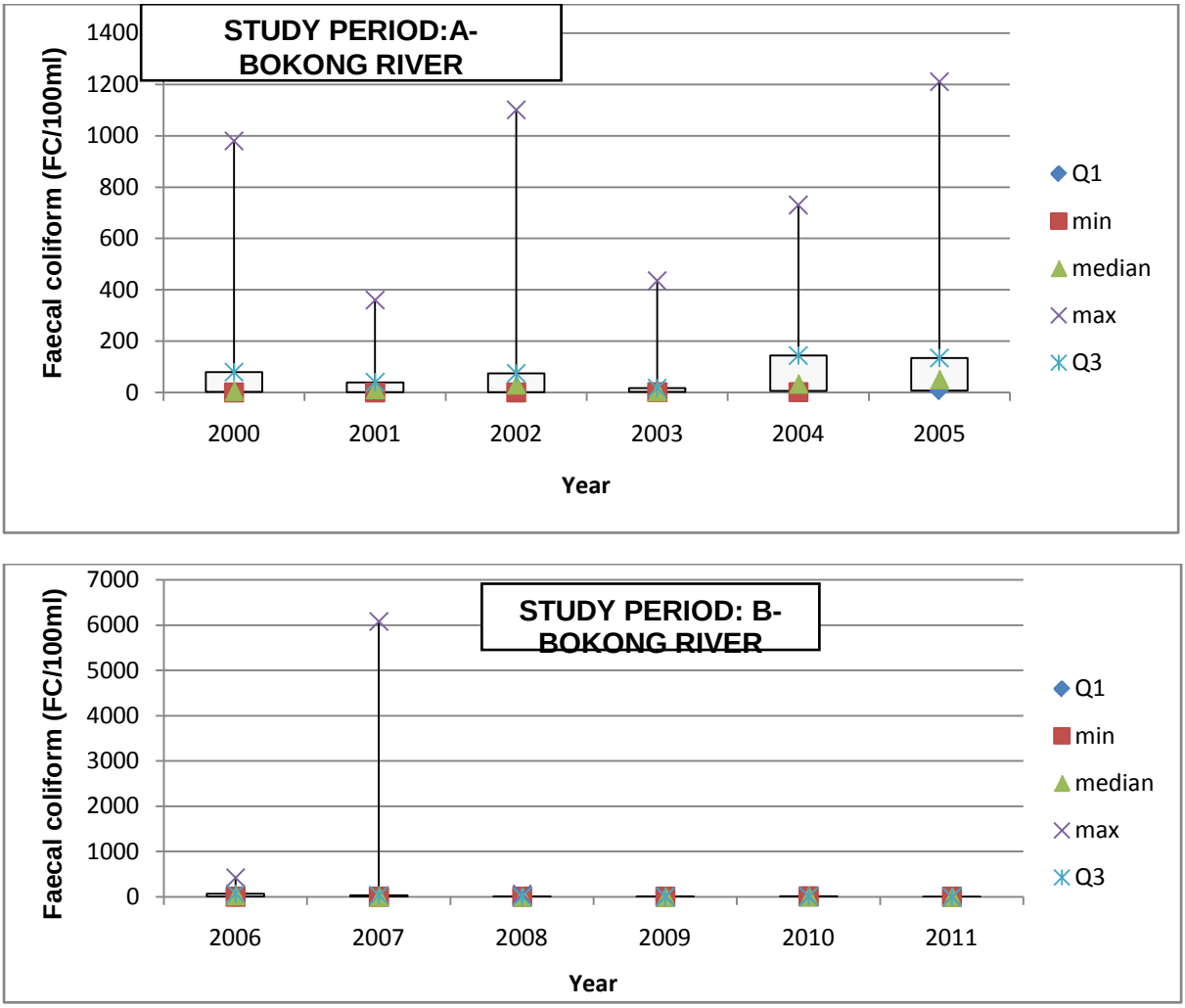


Figure 4.13 Faecal coliform bacteria concentrations recorded during Study Period: A (January 2000 to December 2005) and Study Period: B (January 2006 to December 2011) for the Bokong River

(n) Coliphage bacteria

High concentrations of coliphage bacteria were observed from 2000 to 2002 during Study Period: A. The maximum concentration was 75 CFU/10 ml in 2002. During the Study Period: B, the maximum concentration was 166 CFU/10 ml (in the year 2006). Coliphage bacteria were below the detection limit from 2009 to 2011 (Figure 4.14.). Because of these very high concentrations, there was non-compliance with the WHO (2011) and DWS Domestic (DWAF, 1996a) guidelines.

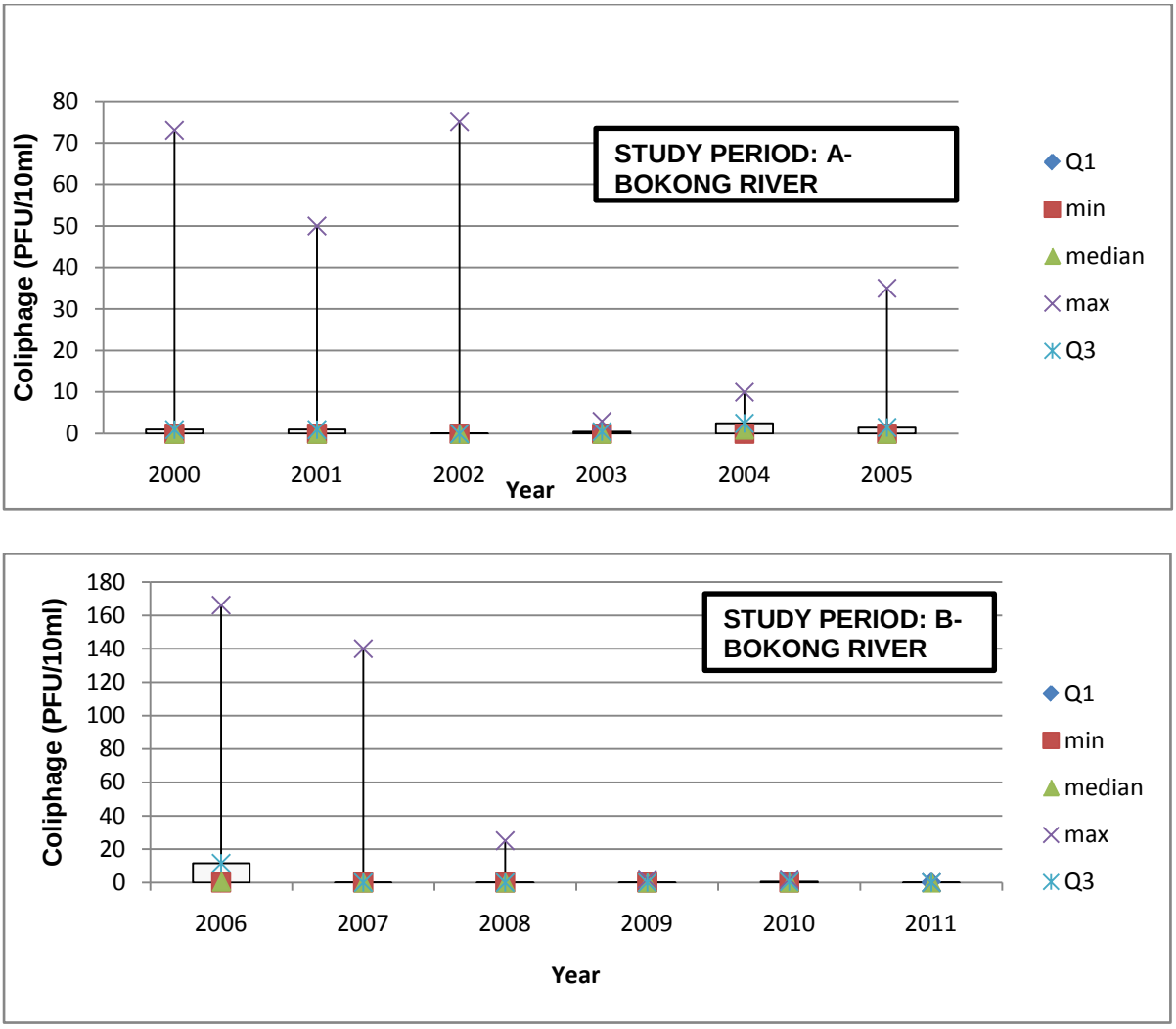


Figure 4.14 Concentrations of coliphage bacteria recorded during Study Period: A (January 2000 to December 2005) and Study Period: B (January 2006 to December 2011) for the Bokong River

(o) *Escherichia coli*

Escherichia coli bacteria concentrations were below detection limit during Study Period: A (Table 4.1.). During Study Period: B from 2006 to 2009 (Figure 4.15), bacterial concentrations were below the detection limit. However, there were detections in 2010 and 2011. The year 2011 had a maximum concentration of 78 CFU/100ml. The concentrations during 2010 and 2011 alone caused a non-compliance with the WHO (2011), SANS: 241 (2015), DWS Domestic (DWAF, 1996a) and Irrigation (DWAF, 1996b) guidelines.

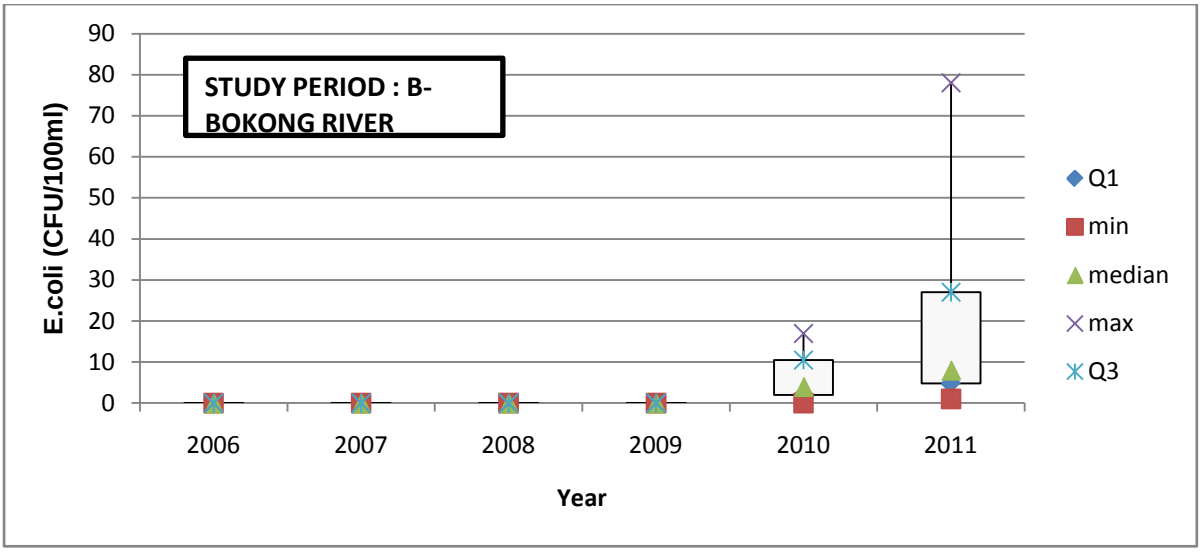


Figure 4.15 Concentrations of *E. coli* recorded during Study Period: B (January 2006 to December 2011) for the Bokong River

(p) *Cryptosporidium*

During Study Period: A, *Cryptosporidium* was below the detection limit in the water samples. However, during Study Period: B, a mean concentration of 3 ± 3.5 Oocysts/10L could be detected, with a range of 1 to 7 Oocysts/10L. This implied non-compliance with the WHO (2011) and SANS: 241 (2015) guidelines. A box-plot to observe trends over the years could not be produced because the individual concentration in each year was not sufficient to create a graph e.g. only one detection in each year.

4.1.2. Study Period C: 2012 (January) to 2014 (July)

This study period covers the current data from January 2012 to July 2014. The chemical determinants are mostly compliant with one or more of the guidelines as seen in Table 4.3. Aluminium was not compliant with the WHO (2011), SANS: 241 (2015), and DWS Aquaculture (DWAF, 1996d) and Aquatic Ecosystems (DWAF, 1996e) guidelines. The concentration ranged from zero to 5.53 mg/l with a mean value of 1.39 mg/l.

The ammonium concentration was not compliant with the DWS Aquaculture (DWAF, 1996d) guideline. Even though the range was 0.04 to 0.05 mg/l which is narrow, the mean concentration of 0.05 mg/l was more than double the DWS Aquaculture (DWAF, 1996d) guideline value. Other chemical determinants which were non-compliant included copper, iron and magnesium which did not comply with only one of the guideline. Copper had a mean concentration of 2.72 ± 5.45 mg/l (range of 0.01 to 14.50mg/l) and was non-compliant with the WHO (2011), SANS: 241 (2015), DWS Irrigation (DWAF, 1996b), Livestock & Watering (DWAF, 1996c) and Aquatic Ecosystems (DWAF, 1996e) guidelines. Iron was non-compliant with the WHO (2011) and SANS: 241 (2015) guidelines, with a mean concentration of 2.75 ± 6.06 mg/l (range of 0.01 to 13.60 mg/l). Magnesium had a mean concentration of 2.40 ± 2.37 mg/l (range of 0.57 to 8.19 mg/l), thus non-compliant with the DWS Aquatic Ecosystems (DWAF, 1996e) guideline. Zinc was non-compliant with the WHO (2011), DWS Irrigation (DWAF, 1996b) and Aquatic Ecosystems (DWAF, 1996e) guidelines. The mean concentration of zinc was 3.02 ± 7.37 mg/l with a range of zero to 18.06 mg/l.

The physical determinants which were not compliant were dissolved oxygen and total dissolved solids. Both were non-compliant with the DWS Aquaculture (DWAF, 1996d) guideline. The mean concentration of dissolved oxygen was 9.50 ± 1.08 mg/l (range: 7.94 to 11.2 mg/l. The mean concentration of total dissolved solids was 62.30 ± 38.08 mg/l, which was way above the guideline value for the DWS Aquaculture (DWAF, 1996d) guideline. The concentration ranged from 28 to 132 mg/l. Under the microbiological determinants, only *E.coli* could be detected in the sampled water with a mean concentration of 11 ± 14.6 MPN/100ml (range of 0 to 35

MPN/100ml). The high concentration implied non-compliance with the following water guidelines and standard, namely the WHO (2011), SANS: 241 (2015), DWS Domestic (DWAF, 1996a), Irrigation (DWAF, 1996b) and Aquaculture (DWAF, 1996d)guidelines.

Table 4.3: Current surface water quality concentrations of the Bokong River during Study Period: C – January 2012 to July 2014

Orange shading indicates non-compliance with one or more of the guidelines while the standard, green shading indicates compliance

Determinants	Units	Concentration		Standard or guideline						
						DWAF				
		Mean +/- SD	Range	WHO (2011)	SANS:241 (2015)	Domestic (1996a)	Irrigation (1996b)	Livestock & Watering (1996c)	Aquaculture (1996d)	Aquatic Ecosystems (1996e)
Chemical Determinants										
Aluminium	mg/l	1.39 ± 2.76	0-5.53	0-0.9	0-0.3	*	0-5	0-5	0-0.03	0-0.005
Ammonium	mg/l	0.05 ± 0.01	0.04-0.05	*	0-1.5	*	*	*	0-0.025	*
Boron	mg/l	0.08 ± 0.16	0.0-0.40	0-2.4	*	*	0-0.5	0-5	*	*
Calcium	mg/l	2.72 ± 5.45	0.01-14.50	*	*	*	*	0-1000	*	*
Chloride	mg/l	1.33 ± 0.23	1.2-1.6	0-250	0-300	*	0-100	0-1500	*	*
Copper	mg/l	2.72 ±5.45	0.01-14.50	0-2	0-2	*	0-0.2	0-0.5	*	0-0.0012
Iron	mg/l	2.75 ±-6.06	0.01-13.60	0-2	0-2	*	0-5	0-10	*	< 10 % background value
Potassium	mg/l	0.52 ± 0.52	0-1.2	*	*	0-50	*	*	*	*
Magnesium	mg/l	2.40 ± 2.37	0.57-8.19	*	*	*	*	0-500	*	0-0.18
Manganese	mg/l	0.11± 0.08	0.01-0.18	0-0.4	0-0.5	*	0-0.2	0-10	0-0.1	0-0.18
Nitrite as N	mg/l	0.02 ±0.02	0-0.04	0-3	0-0.9	*	*	*	0-0.05	*
Nitrate as N	mg/l	0.23 ± 0.20	0.1-0.46	0-50	0-11	*	*	0-100	0-300	*
Phosphorus	mg/l	0.17 ±0.13	0.08-0.27	*	*	*	*	*	*	0-5
**Phosphates	mg/l	0.09 ± 0.03	0.04-0.13	*	*	*	*	*	*	*
Sodium	mg/l	3.22 ±1.54	1.7-6	0-200	0-200	*	0-70	0-2000	*	*
Sulphate	mg/l	3.36 ± 2.92	0-5.27	*	0-600	0-200	*	0-1000	*	*
**Sulphur	mg/l	2.46 ± 2.78	0.37-8.2	*	*	*	*	*	*	*
**Total Organic Carbon	mg/l	1.85 ± 1.53	0.64-5.1	*	*	*	*	*	*	*
**Total Silica	mg/l	10.05 ± 1.46	7.6-12.02	*	*	*	*	*	*	*

Table 4.3: (Continued) Current surface water quality concentrations of the Bokong River during Study Period: C – January 2012 to July 2014

Orange shading indicates non-compliance with one or more of the guidelines while the standard, green shading indicates compliance

Determinants	Units	Concentration		Standard or guideline						
						DWAF				
		Mean +/- SD	Range	WHO (2011)	SANS:241 (2015)	Domestic (1996a)	Irrigation (1996b)	Livestock & Watering (1996c)	Aquaculture (1996d)	Aquatic Ecosystems (1996e)
Zinc	mg/l	3.02 ± 7.37	0-18.06	0-3	0-5	*	0-1	0-20	*	0-0.002
Physical Determinants										
Alkalinity	mg/l $CaCO_3$	23.66 ± 16.00	12-64.42	*	*	*	*	*	20-100	*
**Chemical Oxygen Demand	mg/l	5.67 ± 1.15	5.0- 7	*	*	*	*	*	*	*
Conductivity 25 ˚C	mS/m	4.51 ± 1.83	2.0-8 .0	*	0-170	*	0-40	0-154	*	*
Dissolved Oxygen	mg/l	9.50 ± 1.08	7.94-11.2	*		*	*	*	5.0-8.0	60-120 % saturation
Hardness	mg/l $CaCO_3$	27.70 ± 23.53	10-86.60	*	*	50-100	*	*	20-100	*
pH at 25˚C	N/A	8.31 ± 0.81	7.29-9.7	*	5.0-9.7	*	6.5-8.4	*	6.5-9.0	< 5% background value
Total Dissolved Solids	mg/l	62.30 ± 38.08	28-132	*	0-1200	*	0-260	0-1000	0-2	<15% background value
Temperature 25˚C	˚C	11.13 ± 7.70	2.3-25.50	*	*	*	*	*	*	*
Turbidity	NTU	0.65 ± 0.48	0.33-1.82	*	0-1.0	*	*	*	*	<10% background value
Microbiological Determinants										
E. Coli	MPN/ 100ml	11 ± 14.57	0-35	0	0	0	0-10	0-200	10	*

*Determinant value not stipulated **No comparison value

4.1.2.1 Annual concentrations of non-compliant chemical, physical and microbiological determinants for Study Period: C

The determinants that showed non-compliance during Study Period: C (Table 4.3.) were further analyzed using box-plots to observe trends and show variation over the individual years.

a) Aluminium

As observed in the Table 4.3, aluminium was non-compliant with four of the guidelines. During this investigation period, concentrations of aluminium were below the detection limit in 2012 and 2013 as shown in Figure 4.16 below. However, in 2014, there was a significant increase in the concentration, with the mean of 1.39 ± 2.76 mg/l. The maximum value of 5.53 mg/l (range of 0 to 5.53 mg/l) can be observed for the year 2014 only.

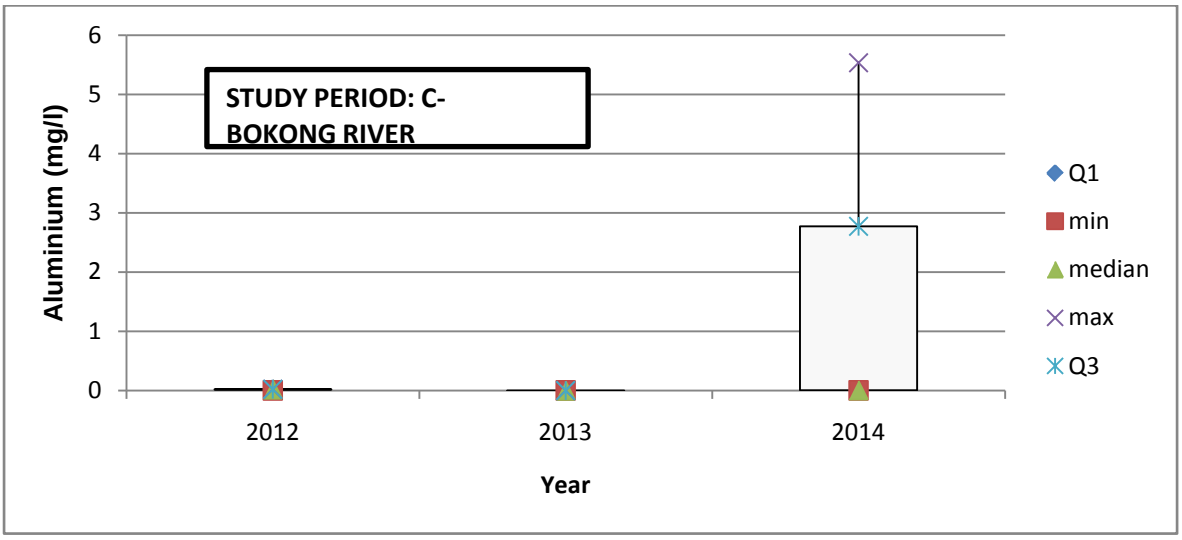


Figure 4.16: Aluminium concentrations recorded during Study Period: C (January 2012 to July 2014) for the Bokong River

b) Ammonium

The Ammonium concentrations during 2012 and 2013 were below the detection limit. A significant increase can be noted in 2014, where the mean concentration was 0.05 ± 0.01 mg/l (range of 0.04 to 0.05 mg/l) (Figure 4.17). The 2014 concentration was high enough to cause non-compliance with the DWS Aquaculture (DWAF, 1996d) guideline.

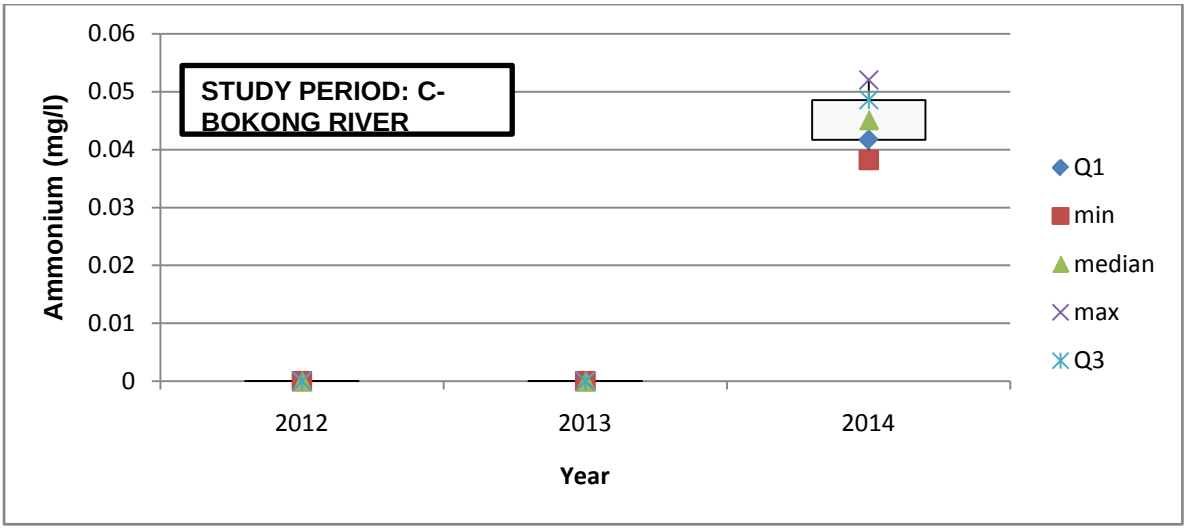


Figure 4.17: Ammonium concentrations recorded during Study Period: C (January 2012 to July 2014) for the Bokong River

(c) Copper

During Study Period: C, copper concentrations were below the detection limit in the water samples during 2012 and 2013. In the year 2014, a significant increase to a maximum concentration of 14.5 mg/l can be noted (Figure 4.18). This high concentration in one year only resulted in non-compliance with the WHO (2011), SANS: 241 (2015) and DWA& S Irrigation (DWAF, 1996b), Livestock & Watering (DWAF, 1996c) and Aquatic Ecosystems (DWAF, 1996e) guidelines.

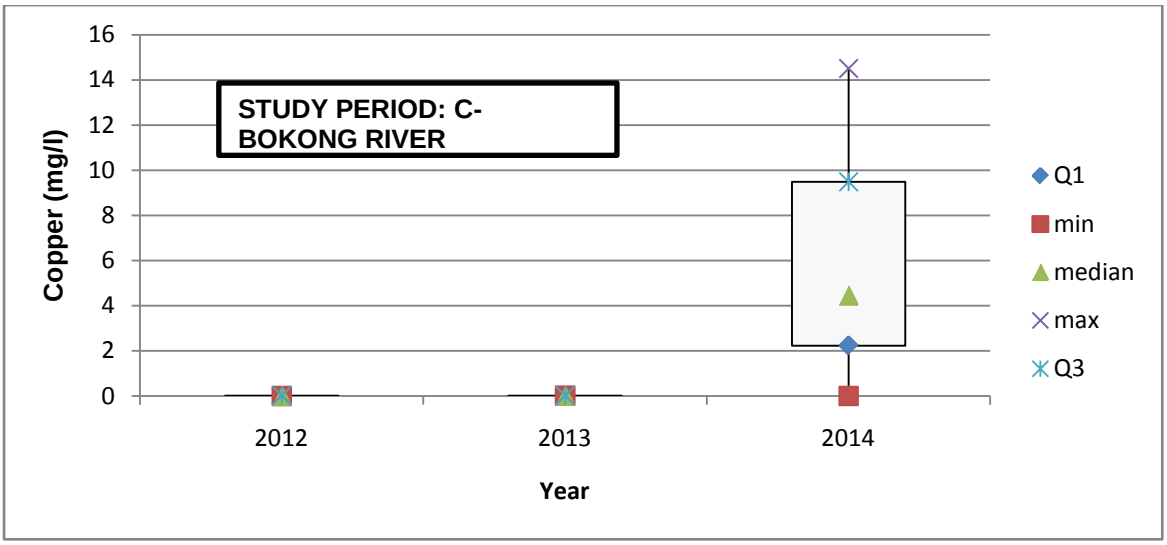


Figure 4.18: Copper concentrations recorded during Study Period: C (January 2012 to July 2014) for the Bokong River

(d) Iron

As shown in Figure 4.19, the concentration of iron was below the detection limit of 3.87 µg/l or 0.00387 mg/l in the year 2012 and 2013. However, a significant increase with a maximum concentration of 13.60 mg/l can be noted in the year 2014. The concentration in 2014 was sufficient to cause non-compliance with the WHO (2011) and SANS: 241 (2015) guidelines.

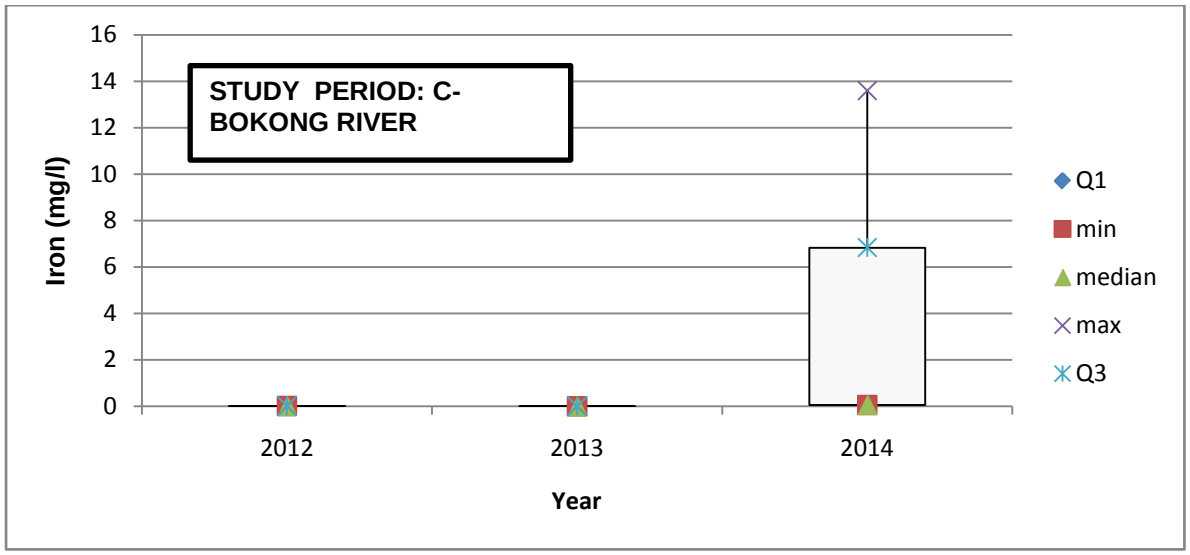


Figure 4.19: Iron concentrations recorded during Study Period: C (January 2012 to July 2014) for the Bokong River

(e) Magnesium

During this Study Period, the concentration of magnesium showed fluctuations, with high concentration noted for 2012 and 2014 (Figure 4.20). The maximum concentration of 8.19 mg/l can be observed for the year 2014; hence magnesium was non-compliant with the DWS Aquatic Ecosystems (DWAF, 1996e) guideline.

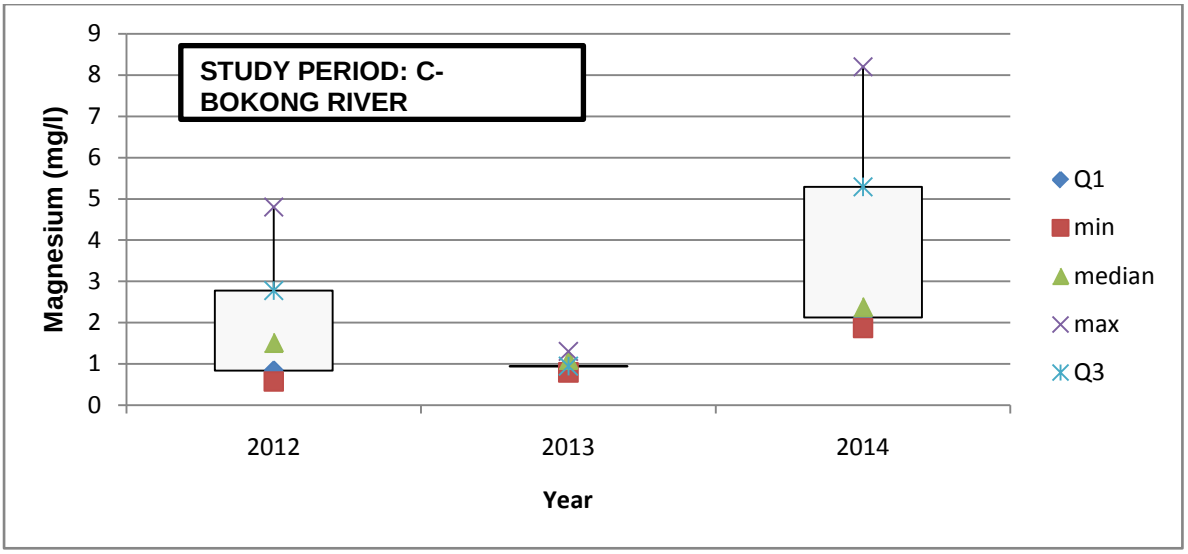


Figure 4.20 Magnesium concentrations recorded during Study Period: C (January 2012 to July 2014) for the Bokong River

(f) Zinc

Zinc concentrations were below the detection limit of 2.91 µg/l or 0.00291 mg/l during 2012 and 2013. However, in the year 2014, a maximum concentration of 18 mg/l was detected in the water samples (Figure 4.21).This concentration was substantial such that there was non-compliance with the WHO (2011), DWS Irrigation (DWAF, 1996b) and Aquatic Ecosystems (DWAF, 1996e) guidelines.

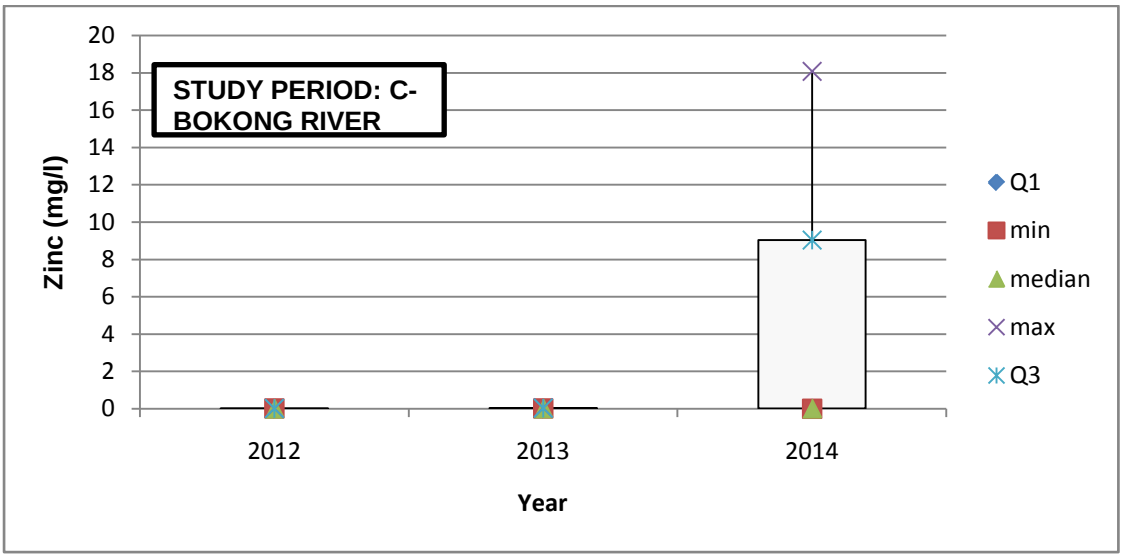


Figure 4.21 Zinc concentrations recorded during Study Period: C (January 2012 to July 2014) for the Bokong River

(g) Dissolved Oxygen

The concentration of dissolved oxygen was of substantial levels throughout this Study Period: C (Figure 4.22). The concentration seems to have increased slightly from 2012 to 2014. The maximum concentration was 11.2 mg/l in 2014. For this Study Period, dissolved oxygen was non-compliant with the DWS Aquaculture (DWAF, 1996d) guideline.

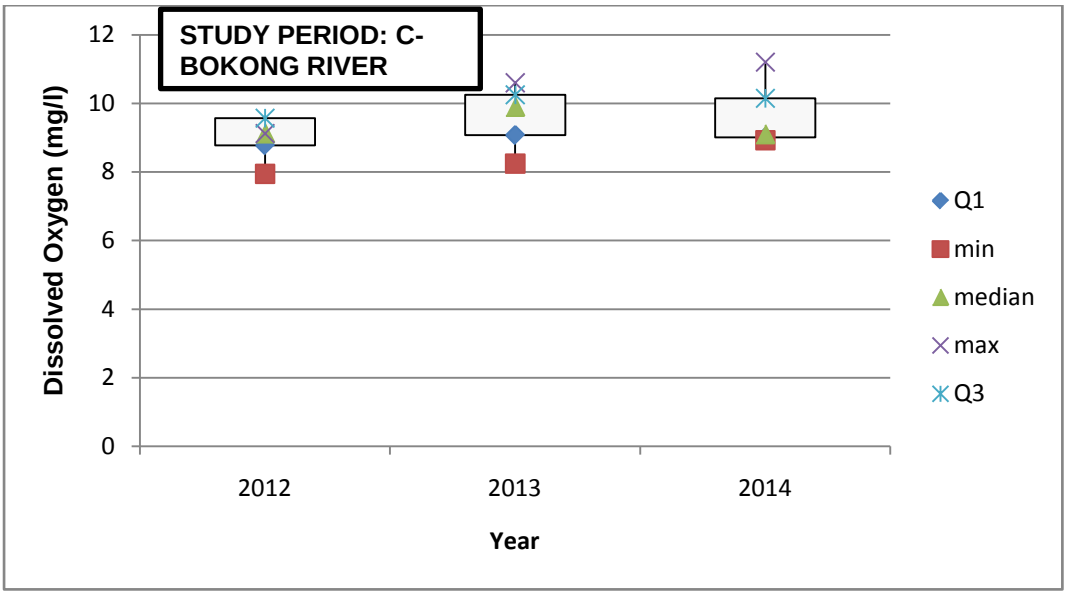


Figure 4.22 Dissolved oxygen concentrations recorded during Study Period: C (January 2012 to July 2014) for the Bokong River

(h) Total Dissolved Solids

The concentration of total dissolved solids was detected throughout 2012 to 2014, with the maximum concentration of 132 mg/l during 2014 (Figure 4.23). This maximum concentration was way above the DWS Aquaculture (DWAF, 1996d) guideline value.

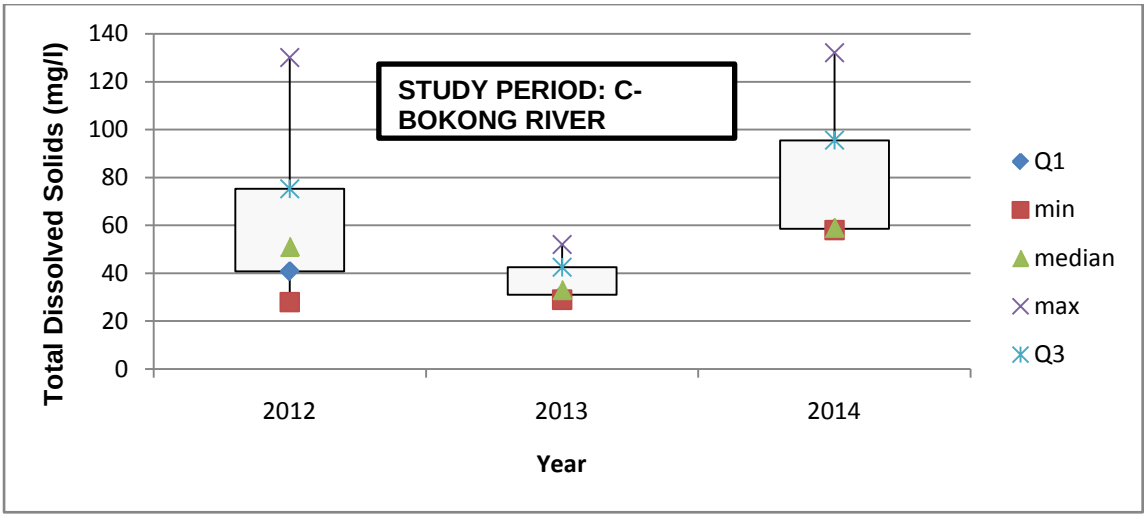


Figure 4.23: Total dissolved solids concentrations recorded during Study Period: C (January 2012 to July 2014) for the Bokong River

(i) *E. coli*

E. coli was non-compliant with four of the water quality guidelines for this study period i.e. WHO (2011), SANS: 241 (2015), DWS Domestic (DWAF, 1996a), Irrigation (DWAF, 1996b) and Aquaculture (DWAF, 1996d) guidelines (Table 4.3). The maximum concentration of 35 MPN/100ml can be observed in 2012, then a decrease in 2013 and another significant increase in 2014 (Figure 4.24). As is evident from Figure 4.24 below, the concentration showed great variation between the individual years.

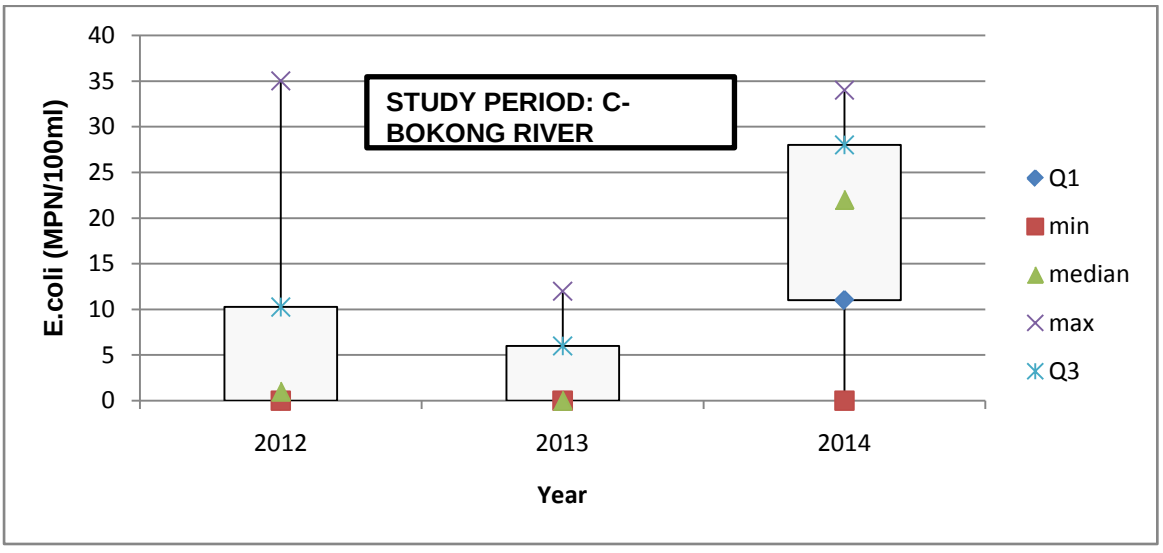


Figure 4.24 *E. coli* concentrations recorded during Study Period: C (January 2012 to July 2014) for the Bokong River

4.2. Pelaneng River

4.2.1. Historic data: 2000 to 2011

The concentration of the chemical, physical and microbiological determinants of the Pelaneng River was measured from January 2000 to December 2005 (Study Period: A) and from January 2006 to December 2011 (Study Period: B). The concentration with standard deviation and the ranges of the selected water quality determinants concentrations for Study Period: A and Study Period: B are presented in Table 4.4. and Table 4.5. respectively.

Most of the chemical and physical determinants during Study Period: A and Study Period: B were compliant with one or more of the water quality guidelines. During Study Period: A, the chemical determinants that were not compliant with one or more of the guidelines included aluminium, ammonium, iron, magnesium, nickel and zinc, whereas in Study Period: B, aluminium, ammonium, copper, magnesium and zinc were not compliant with one or more of the water quality guideline values. During Study Period: A, the mean concentration of aluminium was 0.07 ± 0.11 mg/l (range of 0.01 to 0.45 mg/l), hence the non-compliance with the DWS Aquaculture (DWAF, 1996d) and DWS Aquatic Ecosystems (DWAF, 1996e) guidelines. During Study Period: B, aluminium was non-compliant only with the DWS Aquatic Ecosystems (DWAF, 1996e) guideline, with a mean concentration of 0.03 ± 0.04 mg/l (range of 0.01 to 0.16 mg/l).

The mean concentration of ammonium during Study Period: A was 0.06 ± 0.0 mg/l (range of 0.05 to 0.07 mg/l) and 0.25 ± 0.36 mg/l (range of 0.05 to 1.1mg/l) during Study Period: B. In both Study Periods, ammonium was not compliant with the DWS Aquaculture (DWAF, 1996d) guideline. The concentration of magnesium was not compliant with the DWS Aquatic Ecosystems (DWAF, 1996e) guideline during Study Period: A and Study period: B. The mean concentration during Study Period: A was 2.12 ± 0.82 mg/l (range of 1.1 to 5.9 mg/l) and 2.34 ± 0.74 mg/l during Study Period: B (range of 0.68 to 4.7 mg/l).

The mean concentration of nickel was not compliant with the WHO (2011) and SANS: 241 (2015) guidelines during Study Period: A. The mean concentration was 0.08 ± 0.04 mg/l (range of 0.02 to 0.16 mg/l). However, during Study Period: B, the concentration of nickel was below the detection limit (Rand Water, 2014). The mean

concentration of nitrite was not compliant with the DWS Aquaculture (DWAF, 1996d) guideline during Study Period: A. The mean concentration was 0.06 ± 0.03 mg/l with a range of 0.03 to 0.19mg/l. In contrast, nitrite was compliant with all the water quality guidelines during Study Period: B. For both Study Period: A and Study Period: B, zinc was not compliant with the DWS Aquatic Ecosystems (DWAF, 1996e) guideline. During Study Period: A, the mean concentration of zinc was 0.02 ± 0.02 mg/l (range of 0.01 to 0.11 mg/l) whereas during Study Period: B, the mean concentration was 0.04 ± 0.05 mg/l (range of 0.01 to 0.18 mg/l).

The physical determinants that were not compliant with one or more of the guidelines Study Period: A were hardness, total dissolved solids and turbidity. During Study Period: B, suspended solids, hardness, turbidity and total dissolved solids were the determinants which were not compliant with one or more of the guidelines. The mean concentration of hardness during Study Period: A was 26.73 ± 9.33 mg/l as $CaCO_3$ (range of 15 to 69 mg/l as $CaCO_3$). This concentration is way below the DWS Domestic water guideline (DWAF, 1996a) of 50-100 mg/l as $CaCO_3$. During Study Period: B, the mean concentration of hardness was 27.49 ± 6.93 mg/l as $CaCO_3$ (range of 12.0 to 49 mg/l as $CaCO_3$), also non-compliant with the DWS Domestic guideline (DWAF, 1996a).

The concentration of total dissolved solids was so significant that there was non-compliance with the DWS Aquaculture guideline (DWAF, 1996d) during both Study Period: A and Study Period: B. The mean concentration in Study Period: A was 76.88 ± 87.18 mg/l (range of 12 to 620) and 50.00 ± 11.75 mg/l (range of 26 to 87) in Study Period: B respectively. The turbidity of the sampled water during Study Period: A was 2.30 ± 11.90 NTU (range of 0.13 to 97 NTU) and 4.02 ± 14.72 NTU (range of 0.21 to 94 NTU) during Study Period: B. The mean concentration was significantly high enough to cause non-compliance with the SANS: 241 (2015) guideline value of 0-2 NTU. The mean concentration of suspended solids during Study Period: B was 86.17 ± 116.47 mg/l and ranged from 10 to 315 mg/l. This concentration was significant and caused non-compliance with the DWS Irrigation (DWAF, 1996b) guideline. However, during Study Period: A, the concentration of suspended solids was in compliance with the guidelines.

The microbiological determinants were mostly non-compliant with one or more of the water quality guidelines in Study Period: A and Study Period: B (Table 4.4. and 4.5.). Coliphage bacteria and faecal coliforms were the two microbial determinants which were not compliant with one or more of the water quality guidelines during both study periods. Cryptosporidium and *E. coli* were non-compliant with one or more of the water quality guidelines during Study Period: B.

During Study Period: A, coliphage bacteria had a mean concentration of 4 ± 9.3 CFU/10ml (range of 0 to 51 CFU/10ml) which caused non-compliance with the WHO (2011) and DWS Domestic (DWAF, 1996a) guidelines. For Study Period: B, the mean concentration of coliphage bacteria was 34 ± 111.1 CFU/10ml (range of 0 to 552 CFU/10ml), quiet significantly higher than the specified WHO (2011) and DWS Domestic (DWAF, 1996a) guidelines. The mean concentration of faecal coliform bacteria exceeded the WHO (2011), SANS: 241 (2015) and DWS Domestic (DWAF, 1996a) water guidelines during both study periods. During Study Period: A, the mean concentration was 94 ± 265.0 FC/100ml (range of 0 to 2000 FC/100ml) and 188 ± 458 FC/100ml (range of 2.0 to 2280 FC/100ml) in Study Period: B.

The mean concentration of Cryptosporidium during Study Period: B was 3 ± 2.9 Oocysts/10L with a range of 1.0 to 6.0 Oocysts/10L and causing non-compliance with the WHO (2011) and SANS: 241 (2015) guidelines. The concentration of Cryptosporidium during Study Period: A was below the detection limit.

During Study Period: B, the mean concentration of *E.coli* was 38 ± 55.77 MPN/100ml (range of 1 to 157 MPN/100ml). This concentration was so significant that there was non-compliance with the WHO (2011), SANS: 241 (2015), DWS Irrigation (DWAF, 1996b) and DWS Aquaculture (DWAF, 1996d) water guidelines. For Study Period: A, *E.coli* concentrations were below detection levels.

Table 4.4: Historic surface water quality concentrations of the Pelaneng River during the Study Period: A – January 2000 to December 2005

Orange shading indicates non-compliance with one or more of the guidelines or the standard, green shading indicates compliance

		Concentration		Standard or guideline						
						DWAF				
Determinants	**Units**	**Mean +/- SD**	**Range**	**WHO (2011)**	**SANS:241 (2015)**	**Domestic (1996a)**	**Irrigation (1996b)**	**Livestock & Watering (1996c)**	**Aquaculture (1996d)**	**Aquatic Ecosystems (1996e)**
Chemical Determinants										
Aluminium	mg/l	0.07 ± 0.11	0.01-0.45	0-0.9	0-0.3	*	0-5	0-5	0-0.03	0-0.005
Ammonium	mg/l	0.06 ± 0.0	0.05-0.07	*	0-1.5	*	*	*	0-0.025	*
Calcium	mg/l	7.21 ± 2.50	3.6-18	*	*	*	*	0-1000	*	*
Fluoride	mg/l	0.17 ± 0.53	0.05-2.7	0-1.5	0-1.5	*	0-2.0	0-2.0	*	0-0.75
Iron	mg/l	0.03 ± 0.04	0.01-0.16	0-2	0-2	*	0-5	0-10	*	< 10 % background value
Magnesium	mg/l	2.12 ± 0.82	1.1-5.9	*	*	*	*	0-500	*	0-0.18
Nickel	mg/l	0.08 ± 0.04	0.02-0.16	0-0.007	0-0.07	*	0-0.2	0-1	*	*
Nitrite as N	mg/l	0.06 ± 0.03	0.03-0.19	0-3	0-0.9	*	*	*	0-0.05	*
Nitrate as N	mg/l	0.24 ± 0.21	0.1-1.5	0-50	0-11	*	*	0-100	0-300	*
Phosphorus	mg/l	0.26 ±0.44	0.05-1.7	*	*	*	*	*	*	0-5
Potassium	mg/l	0.37 ± 0.14	0.15-0.61	*	*	0-50	*	*	*	*
Sodium	mg/l	2.15 ± 1.07	0.71-5	0-200	0-200	*	0-70	0-2000	*	*
**Sulphur	mg/l	0.94 ± 0.30	0.53-1.7	*	*	*	*	*	*	*
**Total Organic Carbon	mg/l	1.65 ± 1.78	0.72-10	*	*	*	*	*	*	*
**Total Silica	mg/l	13.00 ±3.90	1.5-18	*	*	*	*	*	*	*
Zinc	mg/l	0.02 ± 0.02	0.01-0.11	0-3	0-5	*	0-1	0-20	*	0-0.002
Physical Determinant										
Alkalinity	mg/l $CaCO_3$	29.15 ± 5.80	18-52	*	*	*	*	*	20-100	*

Table 4.4: (Continued) Historic surface water quality concentrations of the Pelaneng River during the Study Period: A – January 2000 to December 2005

Orange shading indicates non-compliance with one or more of the guidelines or the standard, green shading indicates compliance

		Concentration		Standard or guideline						
						DWAF				
Determinants	**Units**	**Mean +/- SD**	**Range**	**WHO (2011)**	**SANS:241 (2015)**	**Domestic (1996a)**	**Irrigation (1996b)**	**Livestock & Watering (1996c)**	**Aquaculture (1996d)**	**Aquatic Ecosystems (1996e)**
Conductivity at 25 ˚C	mS/m	6.36 ± 1.63	3.5-16	*	0-170	*	0-40	0-154	*	*
Dissolved Oxygen	mg/l	7.40 ± 1.31	4.4-10.69	*	*	*	*	*	6.0-9.0	80-120 % saturation
Dissolved Organic Carbon	mg/l	2.52 ± 1.10	2-5.4	*	10.0-20	0-5	*	*	*	*
Hardness	mg/l $CaCO_3$	26.73 ± 9.33	15-69	*	*	50-100	*	*	20-100	*
Suspended Solids	mg/l	10.41 ± 4.20	4.0-18	*	*	*	0-50	*	*	*
Total Dissolved Solids	mg/l	76.88 ± 87.18	12-620	*	0-1200	*	0-260	0-1000	0-0.02	<15% background value
pH at 25 ˚C	N/A	7.40 ± 0.46	6.53-8.73	*	5.0-9.7	*	6.5-8.4	*	6.5-9.0	< 5% background value
**Temperature	˚C	22.35 ± 1.76	17.6-26	*	*	*	*	*	*	*
Turbidity	NTU	2.30 ± 11.90	0.13-97	*	0-1.0	*	*	*	*	<10% background value
Microbiological Determinants										
Coliphage	CFU/10 ml	4 ± 9.3	0-51	0	*	0-1	*	*	*	*
Faecal coliform	FC/100 ml	94 ± 265.0	0-2000	0	0	0	0-10 000	*	*	*

*Determinant value not stipulated **No comparison value

Table 4.5: Historic surface water quality concentrations of the Pelaneng River during the Study Period: B – January 2006 to December 2011

Orange shading indicates non-compliance with one or more of the guidelines or the standard, green shading indicates compliance

				Standard or guideline						
		Concentration				DWAF				
Determinants	**Units**	**Mean +/- SD**	**Range**	**WHO (2011)**	**SANS:241 (2015)**	**Domestic (1996a)**	**Irrigation (1996b)**	**Livestock & Watering (1996c)**	**Aquaculture (1996d)**	**Aquatic Ecosystems (1996e)**
Chemical Determinants										
Aluminium	mg/l	0.03 ± 0.04	0.01-0.16	0-0.9	0-0.3	*	0-5	0-5	0-0.03	0-0.005
Ammonium	mg/l	0.25 ± 0.36	0.05-1.1	*	0-1.5	*	*	*	0-0.025	*
Calcium	mg/l	7.20 ± 1.90	3.7-14	*	*	*	*	0-1000	*	*
Copper	mg/l	0.03 ± 0.03	0.01-0.1	0-2	0-2	*	0-0.2	0-0.5	*	0-0.0012
Fluoride	mg/l	0.07 ± 0.02	0.05-0.14	0-1.5	0-1.5	*	0-2.0	0-2.0	*	0-0.75
Iron	mg/l	0.04 ± 0.09	0.01-0.48	0-2	0-2	*	0-5	0-10	*	< 10 % background value
Magnesium	mg/l	2.34 ± 0.74	0.68-4.7	*	*	*	*	0-500	*	0-0.18
Manganese	mg/l	0.01 ± 0.01	0.0-0.05	0-0.4	0-0.5	*	0-0.2	0-10.0	0-0.1	0-0.18
Nitrite as N	mg/l	0.05 ± 0.13	0.01-0.58	0-3	0-0.9	*	*	*	0-0.05	*
Nitrate as N	mg/l	0.26 ± 0.10	0.15-0.55	0-50	0-11	*	*	0-100	0-300	*
Phosphorus	mg/l	0.14 ±0.07	0.06-0.3	*	*	*	*	*	*	0-5
**Phosphates	mg/l	0.09 ± 0.04	0.05-0.14	*	*	*	*	*	*	*
Potassium	mg/l	0.67 ± 0.37	0.36-1.4	*	*	0-50	*	*	*	*
Sodium	mg/l	2.51 ± 0.96	1.5-5.4	0-200	0-200	*	0-70	0-2000	*	*
**Sulphur	mg/l	0.97 ± 0.37	0.38-2.2	*	*	*	*	*	*	*
**Total Organic Carbon	mg/l	1.32 ± 0.89	0.53-6.1	*	*	*	*	*	*	*
**Total Silica	mg/l	14.63 ± 2.57	9.7-26	*	*	*	*	*	*	*
Zinc	mg/l	0.04 ± 0.05	0.01-0.18	0-3	0-5	*	0-1	0-20	*	0-0.002

Table 4.5: (Continued) Historic surface water quality concentrations of the Pelaneng River during the Study Period: B – January 2006 to December 2011

Orange shading indicates non-compliance with one or more of the guidelines or the standard, green shading indicates compliance

				Standard or guideline						
		Concentration				DWAF				
Determinants	**Units**	**Mean +/- SD**	**Range**	**WHO (2011)**	**SANS:241 (2015)**	**Domestic (1996a)**	**Irrigation (1996b)**	**Livestock & Watering (1996c)**	**Aquaculture (1996d)**	**Aquatic Ecosystems (1996e)**
Physical Determinants										
Alkalinity	mg/l $CaCO_3$	28.75 ± 5.21	19.0-38	*	*	*	*	*	20-100	*
**Chemical Oxygen Demand	mg/l	17.57 ± 9.36	10.0-16	*	*	*	*	*	*	*
Conductivity at 25 ˚C	mS/m	5.76 ± 1.88	1.9-11	*	0-170	*	0-40	0-154	*	*
Dissolved Oxygen	mg/l	8.75 ± 1.44	6.08-12.63	*	*	*	*	*	6.0-9.0	80-120 % saturation
Hardness	mg/l $CaCO_3$	27.49 ± 6.93	12.0-49	*	*	50-100	*	*	20-100	*
Suspended Solids	mg/l	86.17 ± 116.47	10-315	*	*	*	0-50	*	*	*
Total Dissolved Solids	mg/l	50.00 ± 11.75	26-87	*	0-1200	*	0-260	0-1000	0-0.02	<15% background value
pH at 25 ˚C	N/A	8.28 ± 0.54	7.1-9.4	*	5.0-9.7	*	6.5-8.4	*	6.5-9.0	< 5% background value
**Tempera-ture	˚C	15.12 ± 5.42	2.1-23.8	*	*	*	*	*	*	*
Turbidity	NTU	4.02 ± 14.72	0.21-94	*	0-1.0	*	*	*	*	<10% background value
Microbiological Determinants										
Coliphage	CFU/10 ml	34 ± 111.1	0-552	0	*	0-1	*	*	*	*
Cryptosporidium	Oocysts /10L	3 ± 2.90	1.0-6.0	0	0	*	*	*	*	*

Table 4.5: (Continued) Historic surface water quality concentrations of the Pelaneng River during the Study Period: B- January 2006 to December 2011

Orange shading indicates non-compliance with one or more of the guidelines or the standard, green shading indicates compliance

				Standard or guideline						
		Concentration				DWAF				
Determinants	**Units**	**Mean +/- SD**	**Range**	**WHO (2011)**	**SANS:241 (2015)**	**Domestic (1996a)**	**Irrigation (1996b)**	**Livestock & Watering (1996c)**	**Aquaculture (1996d)**	**Aquatic Ecosystems (1996e)**
E. Coli	MPN/100ml	38 ± 55.77	1-157	0	0	*	0-10	0-200	0-10	*
Faecal coliform	FC/100 ml	188 ± 458	2.0-2280	0	0	0	0-10 000	*	*	*

*Determinant value not stipulated **No comparison value

4.2.2. Study period C: 2012 (January) to 2014 (July)

In this Study Period, five of the chemical determinants were not compliant with one or more of the water quality guidelines, namely; aluminium, copper, iron, magnesium and manganese (Table 4.6). The mean concentration of aluminium was 0.61 ± 1.03 mg/l (range of 0.0 to 1.8 mg/l) hence the non-compliance with the SANS: 241 (2015), DWS Aquaculture (DWAF, 1996d) and Aquatic Ecosystems (DWAF, 1996e) guidelines. The mean concentration of copper was not compliant with the DWS Aquatic Ecosystems (DWAF, 1996e) guideline at 0.02 ± 0.01 mg/l (range of 0 to 0.04 mg/l). The mean concentration of iron was 7.71 ± 15.37 mg/l (range of 0.01 to 30.76 mg/l), which is a significant concentration to cause non-compliance with the WHO (2011), SANS: 241 (2015) and DWS Irrigation (DWAF, 1996b) guidelines.

Magnesium had a mean concentration of 2.00 ± 0.45 mg/l (range of 1.4 to 2.7 mg/l) which was not compliant with the DWS Aquatic Ecosystems (DWAF, 1996e) guideline. The concentration of manganese was significantly high to result in non-compliance with five of the water quality guidelines, namely; WHO (2011), SANS: 241 (2015), DWS Irrigation (DWAF, 1996b), Aquaculture (DWAF, 1996d) and Aquatic Ecosystems (DWAF, 1996e) guidelines. The mean concentration of manganese was 6.00 ± 11.70 mg/l with a range of 0.01 to 23.52 mg/l for this period.

The physical determinants which were not compliant with one or more of the water quality guidelines were hardness, total dissolved solids, pH and turbidity. Water hardness was 23.55 ± 7.36 mg/l as $CaCO_3$ (range of 6.43 to 32 mg/l as $CaCO_3$) which is below the required hardness of 50-100 mg/l as $CaCO_3$ of the DWS Domestic (DWAF, 1996a) water guideline. During this period, the mean concentration of total dissolved solids was 50.1 ± 16.00 mg/l with a range of 24 to 77 mg/l. This concentration was non-compliant with the DWS Aquaculture (DWAF, 1996d) guideline.

The pH mean concentration of 8.57 ± 0.57 (range of 7.62 to 9.3) was above the specified DWS Irrigation (DWAF, 1996b) guideline value. The water turbidity was not compliant with the SANS: 241 (2015) guideline at 1.30 ± 1.24 NTU (range of 0.27 to 3.7 NTU). Under the microbiological determinants, *E.coli* was not compliant with four of the water quality guidelines, namely; WHO (2011), SANS: 241 (2015), DWS

Irrigation (DWAF, 1996b) and Aquaculture (DWAF, 1996d). There were 24 ± 21.6 MPN/100ml enumerated with a range of 1 to 58.0 MPN/100ml in this period.

Table 4.6: Current surface water quality concentrations of the Pelaneng River during Study Period: C – January 2012 to July 2014

Orange shading indicates non-compliance with one or more of the guidelines or the standard, green shading indicates compliance

				Standard or guideline						
		Concentration				DWAF				
Determinants	Units	Mean +/- SD	Range	WHO (2011)	SANS: 241 (2015)	Domestic (1996a)	Irrigation (1996b)	Livestock & Watering (1996c)	Aquaculture (1996d)	Aquatic Ecosystems (1996e)
Chemical Determinants										
Aluminium	mg/l	0.61 ± 1.03	0.0-1.8	0-0.9	0-0.3	*	0-5	0-5	0-0.03	0-0.005
Calcium	mg/l	7.00 ± 1.31	5.4-9.2	*	*	*	*	0-1000	*	*
Chloride	mg/l	0.76 ± 0.21	0.54-1.0	0-250	0-300	*	0-100	0-1500	*	*
Copper	mg/l	0.02 ± 0.01	0.0-0.04	0-2	0-2	*	0-0.2	0-0.5	*	0-0.0012
Iron	mg/l	7.71 ± 15.37	0.01-30.76	0-2	0-2	*	0-5	0-10	*	< 10 % background value
Magnesium	mg/l	2.00± 0.45	1.4-2.7	*	*	*	*	0-500	*	0-0.18
Manganese	mg/l	0.12 ± 0.19	0.01-0.40	0-0.4	0-0.5	*	0-0.2	0-10.0	0-0.1	0-0.18
Nitrite as N	mg/l	0.03 ± 0.02	0.0-0.06	0-3	0-0.9	*	*	*	0-0.05	*
Nitrate as N	mg/l	0.22 ± 0.16	0-0.51	0-50	0-11	*	*	0-100	0-300	*
**Phosphates	mg/l	0.19 ± 0.19	0.08-0.47	*	*	*	*	*	*	*
Potassium	mg/l	0.60 ± 0.53	0.22-1.2	*	*	0-50	*	*	*	*
Sodium	mg/l	2.45 ± 1.05	1.5-4.24	0-200	0-200	*	0-70	0-2000	*	*
**Sulphur	mg/l	1.20 ± 0.45	0.62-1.70	*	*	*	*	*	*	*
Sulphate	mg/l	3.72 ± 1.30	2.2-5.8	*	0-600	0-200	*	0-1000	*	*
**Total Organic Carbon	mg/l	1.31 ± 0.70	0.61-2.33	*	*	*	*	*	*	*
**Total Silica	mg/l	14.00 ± 1.50	11.80-16	*	*	*	*	*	*	*

Table 4.6: (Continued) Current surface water quality concentrations of the Pelaneng River during Study Period: C – January 2012 to July 2014

Orange shading indicates non-compliance with one or more of the guidelines or the standard, green shading indicates compliance

				Standard or guideline						
		Concentration				DWAF				
Determinants	**Units**	**Mean +/- SD**	**Range**	**WHO (2011)**	**SANS: 241 (2015)**	**Domestic (1996a)**	**Irrigation (1996b)**	**Livestock & Watering (1996c)**	**Aquaculture (1996d)**	**Aquatic Ecosystems (1996e)**
Physical Determinants										
Alkalinity	mg/l $CaCO_3$	28.03 ± 7.11	21-45.53	*	*	*	*	*	20-100	*
**Chemical Oxygen Demand	mg/l	15 ± 17.32	5-35.0	*	*	*	*	*	*	*
Conductivity at 25 ˚C	mS/m	5.72 ± 1.87	3.4-9.2	*	0-170	*	0-40	0-154	*	*
Dissolved Oxygen	mg/l	8.35 ± 1.07	7.16-10.5	*	*	*	*	*	6.0-9.0	80-120 % saturation
Hardness	mg/l $CaCO_3$	23.55 ± 7.36	6.43-32	*	*	50-100	*	*	20-100	*
Total Dissolved Solids	mg/l	50.1 ± 16.00	24-77	*	0-1200	*	0-260	0-1000	0-0.02	<15% background value
pH at 25 ˚C	N/A	8.57 ± 0.57	7.62-9.3	*	5.0-9.7	*	6.5-8.4	*	6.5-9.0	< 5% background value
**Tempera-ture	˚C	14.90 ± 5.82	7.6-25.3	*	*	*	*	*	*	*
Turbidity	NTU	1.30 ± 1.24	0.27-3.7	*	0-1.0	*	*	*	*	<10% background value
Microbiological Determinants										
E. coli	MPN/100 ml	24 ± 21.6	1-58.0	0	0	*	0-10	0-200	0-10	*

*Determinant value not stipulated **No comparison value

4.3. Mokhoulane River

4.3.1. Historic data: 2000 to 2011

The concentration of the chemical, physical and microbiological determinants of the Mokhoulane River was measured from January 2000 to December 2005 (Study Period: A) and from January 2006 to December 2011 (Study Period: B). The concentration with standard deviation and the ranges of the selected water quality determinants concentrations for Study Period: A and Study Period: B are presented in Tables 4.7. and Table 4.8. respectively.

The chemical determinants which were not compliant during Study Period: A were aluminium, ammonium, lead, nickel and zinc whereas in Study Period: B, aluminium, ammonium, copper, magnesium, nitrite and zinc were not compliant with one or more of the water quality guidelines. During Study Period: A, the mean concentration of ammonium was 0.08 ± 0.10 mg/l (range of 0.01 to 0.5 mg/l) and 0.04 ± 0.04 mg/l (range of 0.01 to 0.14 mg/l) in Study Period: B. In both Study Periods, the mean concentration was significant enough to cause non-compliance with the DWS Aquaculture (DWAF, 1996d) and Aquatic Ecosystems (DWAF, 1996e) guidelines.

During Study Period: A, ammonium had a mean concentration of 0.15 ± 0.28 mg/l (range of 0.05 to 1 mg/l) and 0.07 ± 0.02 mg/l (0.05 to 0.11 mg/l) during Study Period: B. In both study periods, ammonium was non-compliant with the DWS Aquaculture (DWAF, 1996d) guideline.

The mean concentration of lead during Study Period: A was 0.03 ± 0.03 mg/l with a range of 0.01 to 0.08 mg/l. This concentration was substantial to the extent that there was non-compliance with the WHO (2011), SANS: 241 (2015), DWS Aquaculture (DWAF, 1996d) and Aquatic Ecosystems (DWAF, 1996e) guidelines. However, during Study Period: B, lead concentrations were below the detection limit of 10.30 µg/l or 0.0103 mg/l. Copper concentrations during Study Period: A were below the detection limit of 5.54 µg/l or 0.00554 mg/l. During Study Period: B however, the mean concentration of copper was 0.03 ±0.02 mg/l (range of 0.01 to 0.08 mg/l) causing non-compliance with the DWS Aquatic Ecosystems (DWAF, 1996e).

The mean concentration of magnesium during Study Period: A was 4.47 ± 1.60 mg/l (range of 1.9 to 8.7 mg/l) and 3.46 ±1.57 mg/l (range of 1.1 to 7.8 mg/l) during Study Period: B. On both study periods, magnesium was non-compliant with the DWS Aquatic Ecosystems (DWAF, 1996e) guideline.

The mean concentration of nickel during Study Period: A was not in compliance with the WHO (2011) and SANS: 241 (2015) guidelines. The concentration was 0.10 ± 0.05 mg/l with a range of 0.02 to 0.21 mg/l in this study period. During Study Period: B, the concentration of nickel was below the detection limit of 2.16 mg/l. Nitrite concentrations during Study Period: A were also below the detection limit of 0.006 mg/l. However, in Study Period: B, nitrite had a mean concentration of 0.3 ± 0.25 mg/l ranging from 0.1 to 1.2 mg/l such that there was non-compliance with the DWS Aquaculture (DWAF, 1996d) guideline.

Zinc was non-compliant with the DWS Aquatic Ecosystems (DWAF, 1996e) guideline during Study Period: A and Study Period: B respectively. In Study Period: A, the mean concentration of zinc was 0.02 ± 0.02 mg/l (range of 0.01 to 0.11 mg/l) and 0.04 ± 0.06 mg/l (range of 0.01 to 0.16 mg/l) during Study Period: B.

The physical determinants which were not compliant with one or more of the guideline during Study Period: A were total dissolved solids and turbidity (Table 4.7). In Study Period: B, the non-compliant physical determinants were hardness, total dissolved solids and turbidity (Table 4.8). The mean concentration of total dissolved solids was way above the DWS Aquaculture (DWAF, 1996d) guideline value during Study Period: A and Study Period: B. The mean concentration was 90.24 ± 45.35 mg/l (range of 29 to 310 mg/l) during Study Period: A. In Study Period: B, the mean concentration of total dissolved solids was 64.49 ± 20.74 mg/l (range of 13 to 105 mg/l). The concentration of water hardness during Study Period: A was below the detection limit. Water hardness was 38.43 ± 14.77 mg/l as $CaCO_3$ with a range of 19 to 82 mg/l as $CaCO_3$ during Study Period: B and was non-compliant with the DWS Domestic (DWAF, 1996a) guideline.

Water turbidity was 7.49 ± 41.02 NTU (0.19-335 NTU) during Study Period: A and 3.44 ± 6.73 NTU (range of 0.26 to 38 NTU) during Study Period: B. In both study periods, the water turbidity was non-compliant with the SANS: 241 (2015) guideline.

The microbiological determinants which were non-compliant with one or more of the water quality guidelines during Study Period: A, were coliphage bacteria and faecal coliforms (Table 4.7). During Study Period: B, *Cryptosporidium,* coliphage bacteria, faecal coliform, *E. coli* and *Giardia* were non-compliant with one or more of the water quality guidelines (Table 4.8). The mean concentration of coliphage bacteria enumerated during Study Period: A was 13 ± 39.0 CFU/10ml (range of 0 to 233 CFU/10ml) and 17.21 ± 43.96 CFU/10ml (range of 0 to 193 CFU/10ml) in Study Period: B. The concentration was significant enough to result in non-compliance with the WHO (2011) and DWS Domestic (DWAF, 1996a) water guidelines in both study periods. Faecal coliform bacteria had a mean concentration of 199 ± 411.3 FC/100ml (range of 0 to 2220.0) in Study Period: A and 646 ± 1607.3 FC/100ml (range of 0 to 5920 FC/100ml) in Study Period: B. In both study periods, there was non-compliance with the WHO (2011), SANS: 241 (2015) and DWS Domestic (DWAF, 1996a) guidelines.

Cryptosporidium had a mean concentration of 4 ± 3.5 Oocysts/10L (range of 1 to 6.0 Oocysts/10L) during Study Period: B and was not compliant with the WHO (2011) and SANS: 241 (2015) guidelines. During Study Period: A, *Cryptosporidium* oocysts were below the detection limit. The mean concentration of *E.coli* was significantly high, resulting in non-compliance with the WHO (2011), SANS: 241 (2015), DWS Domestic (DWAF, 1996a), Irrigation (DWAF, 1996b) and Aquaculture (DWAF, 1996d) guidelines during Study Period: B. The mean concentration of *E.coli* was 172 ± 368.6 MPN/100ml with a range of 0 to 921 MPN/100ml in this study period. In Study Period: A, *E.coli* cells were below the detection limit.

Giardia had a mean concentration of 2 ± 0.7 Cysts/10L with a range of 1.0 to 2.0 Cysts/10L in Study Period: B, which resulted in non-compliance with the WHO (2011) and SANS: 241 (2015) guidelines. For Study Period: A, *Giardia* cysts were below the detection limit.

Table 4.7: Historic surface water quality concentrations of the Mokhoulane River during the Study Period: A – January 2000 to December 2005

Orange shading indicates non-compliance with one or more of the guidelines or the standard, green shading indicates compliance

		Concentration		Standard or guideline						
						DWAF				
Determinants	**Units**	**Mean +/- SD**	**Range**	**WHO (2011)**	**SANS: 241 (2015)**	**Domestic (1996a)**	**Irrigation (1996b)**	**Livestock & Watering (1996c)**	**Aquaculture (1996d)**	**Aquatic Ecosystems (1996e)**
Chemical Determinants										
Aluminium	mg/l	0.08 ± 0.10	0.01-0.5	0-0.9	0-0.3	*	0-5	0-5	0-0.03	0-0.005
Ammonium	mg/l	0.15 ± 0.28	0.05-1	*	0-1.5	*	*	*	0-0.025	*
Calcium	mg/l	12.52 ± 4.16	5.0-24	*		*	*	0-1000	*	*
Fluoride	mg/l	0.25 ± 0.94	0.05-5.9	0-1.5	0-1.5	*	0-2.0	0-2.0	*	0-0.75
Iron	mg/l	0.07 ±-0.11	0.01-0.53	0-2	0-2	*	0-5	0-10	*	< 10 % background value
Lead	mg/l	0.03 ± 0.03	0.01-0.08	0-0.01	0-0.01	*	0-0.2	0-0.1	0-0.01	0-0.001
Potassium	mg/l	0.09 ± 0.13	0.01-0.5	*	*	0-50	*	*	*	*
Magnesium	mg/l	4.47 ± 1.60	1.9-8.7	*	*	*	*	0-500	*	0-0.18
Nickel	mg/l	0.10 ± 0.05	0.02-0.21	0-0.007	0-0.07	*	0-0.2	0-1	*	*
Nitrite as N	mg/l	0.05 ±0.02	0.03-0.1	0-3	0-0.9	*	*	*	0-0.05	*
Nitrate as N	mg/l	0.94 ± 0.51	0.21-2.1	0-50	0-11	*	*	0-100	0-300	*
Phosphorus	mg/l	0.29 ±0.37	0.05-1.3	*	*	*	*	*	*	0-5
**Phosphates	mg/l	0.08 ± 0.04	0.05-0.18	*	*	*	*	*	*	*
Sodium	mg/l	2.32 ± 1.09	0.57-5.5	0-200	0-200	*	0-70	0-2000	*	*
Sulphate	mg/l	6.37 ± 1.41	5.1-10	*	0-600	0-200	*	0-1000	*	*
**Sulphur	mg/l	1.49 ± 0.42	0.59-2.4	*	*	*	*	*	*	*
**Total Organic Carbon	mg/l	1.88 ± 0.87	1-6.6	*	*	*	*	*	*	*
**Total Silica	mg/l	15.44 ± 4.90	2.0-21.0	*	*	*	*	*	*	*
Zinc	mg/l	0.02 ± 0.02	0.01-0.11	0-3	0-5	*	0-1	0-20	*	0-0.002

Table 4.7: (Continued) Historic surface water quality concentrations of the Mokhoulane River during the Study Period: A – January 2000 to December 2005

Orange shading indicates non-compliance with one or more of the guidelines or the standard, green shading indicates compliance

		Concentration		Standard or guideline						
						DWAF				
Determinants	**Units**	**Mean +/- SD**	**Range**	**WHO (2011)**	**SANS: 241 (2015)**	**Domestic (1996a)**	**Irrigation (1996b)**	**Livestock & Watering (1996c)**	**Aquaculture (1996d)**	**Aquatic Ecosystems (1996e)**
Physical Determinants										
Alkalinity	mg/l $CaCO_3$	50.11 ± 12.68	25-78	*	*	*	*	*	20-100	*
Conductivity	mS/m	11.73 ± 3.52	6.0-22	*	0-170	*	0-40	0-154	*	*
Dissolved Oxygen	mg/l	7.71 ± 2.08	4.5-13.68	*		*	*	*	6.0- 9.0	80-120 % saturation
Dissolved Organic Carbon	mg/l	2.90 ± 1.68	2-8.8	*	10.0-20	0-5	*	*	*	*
Hardness	mg/l $CaCO_3$	50.00 ± 16.80	21-96	*	*	50-100	*	*	20-100	*
Suspended Solids	mg/l	18.57 ± 15.16	1.0-59.0	*	*	*	0-50	*	*	*
pH at 25˚C	pH Units	7.93 ± 0.51	6.71-9.23	*	5.0-9.7	*	6.5-8.4	*	6.5-9.0	< 5% background value
Temperature at 25 ˚C	˚C	22 ± 3.06	2.8-25.9	*	*	*	*	*	*	*
Total Dissolved Solids	mg/l	90.24 ± 45.35	29-310	*	0-1200	*	0-260	0-1000	0-0.02	<15% background value
Turbidity	NTU	7.49 ± 41.02	0.19-335	*	0-1.0	*	*	*	*	<10% background value
Microbiological Determinants										
Coliphage	CFU/10 ml	13 ± 39.00	0-233	0	*	0-1		*	*	*
Faecal coliform	FC/100 ml	199 ± 411.3	0-2220.0	0	0	0	0-10 000	*	*	*

*Determinant value not stipulated **No comparison value

Table 4.8: Historic surface water quality concentrations of the Mokhoulane River during the Study Period: B – January 2006 to December 2011

Orange shading indicates non-compliance with one or more of the guidelines or the standard, green shading indicates compliance

				Standard or guideline						
		Concentration				DWAF				
Determinants	**Units**	**Mean +/- SD**	**Range**	**WHO (2011)**	**SANS:241 (2015)**	**Domestic (1996a)**	**Irrigation (1996b)**	**Livestock & Watering (1996c)**	**Aquaculture (1996d)**	**Aquatic Ecosystems (1996e)**
Chemical Determinants										
Aluminium	mg/l	0.04 ± 0.04	0.01-0.14	0-0.9	0-0.3	*	0-5	0-5	0-0.03	0-0.005
Ammonium	mg/l	0.07 ± 0.02	0.05-0.11	*	0-1.5	*	*	*	0-0.025	*
Calcium	mg/l	9.70 ± 3.50	5.1-20	*	*	*	*	0-1000	*	*
Copper	mg/l	0.03 ±0.02	0.01-0.08	0-2	0-2	*	0-0.2	0-0.5	*	0-0.0012
Fluoride	mg/l	0.08 ± 0.03	0.05-0.19	0-1.5	0-1.5	*	0-2.0	0-2.0	*	0-0.75
Iron	mg/l	0.07 ± 0.09	0.01-0.41	0-2	0-2	*	0-5	0-10	*	< 10 % background value
Magnesium	mg/l	3.46 ±1.57	1.1-7.8	*	*	*	*	0-500	*	0-0.18
Manganese	mg/l	0.07 ± 0.10	0.01-0.26	0-0.4	0-0.5	*	0-0.2	0-10	0-0.1	0-0.18
Nitrite	mg/l	0.3 ± 0.25	0.1-1.2	0-3	0-0.9	*	*	*	0-0.05	*
Nitrate	mg/l	0.45 ± 0.32	0.14-0.98	0-50	0-11	*	*	0-100	0-300	*
Potassium	mg/l	0.67 ± 0.38	0.35-1.4	*	*	0-50	*	*	*	*
Phosphorus	mg/l	0.11 ± 0.07	0.04-0.27	*	*	*	*	*	*	0-5
**Phosphates	mg/l	0.07 ± 0.03	0.05-0.12	*	*	*	*	*	*	*
Sodium	mg/l	2.80 ± 0.97	1.5-6	0-200	0-200	*	0-70	0-2000	*	*
**Sulphur	mg/l	1.33 ± 0.52	0.53-2.5	*	*	*	*	*	*	*
Sulphate	mg/l	6.90 ± 1.25	5.5-8.5	*	0-600	0-200	*	0-1000	*	*
**Total Organic Carbon	mg/l	1.67 ± 0.62	0.6-3.2	*	*	*	*	*	*	*
**Total Silica	mg/l	16.57 ±2.71	12.0-25	*	*	*	*	*	*	*

Table 4.8: (Continued) Historic surface water quality concentrations of the Mokhoulane River during the Study Period: B – January 2006 to December 2011

Orange shading indicates non-compliance with one or more of the guidelines or the standard, green shading indicates compliance

				Standard or guideline						
		Concentration				DWAF				
Determinants	**Units**	**Mean +/- SD**	**Range**	**WHO (2011)**	**SANS:241 (2015)**	**Domestic (1996a)**	**Irrigation (1996b)**	**Livestock & Watering (1996c)**	**Aquaculture (1996d)**	**Aquatic Ecosystems (1996e)**
Zinc	mg/l	0.04 ± 0.06	0.01-0.16	0-3	0-5	*	0-1	0-20	*	0-0.002
Physical Determinants										
Alkalinity	mg/l $CaCO_3$	38.51 ± 11.49	23-68	*	*	*	*	*	20-100	*
Conductivity at 25 ˚C	mS/m	8.37 ± 2.48	3.9-15	*	0-170	*	0-40	0-154	*	*
Dissolved Oxygen	mg/l	8.92 ± 1.55	6.6-12.53	*	*	*	*	*	6.0-9.0	80-120 % saturation
Hardness	mg/l $CaCO_3$	38.43 ± 14.77	19-82	*	*	50-100	*	*	20-100	*
Suspended Solids	mg/l	39.33 ± 47.41	10-130	*	*	*	0-50	*	*	*
Total Dissolved Solids	mg/l	64.49 ± 20.74	13-105	*	0-1200	*	0-260	0-1000	0-0.02	< 15% background value
pH at 25 ˚C	N/A	8.39 ± 0.52	7.2-9.9	*	5.0-9.7	*	6.5-8.4	*	6.5-9.0	<5% background value
**Temperature	˚C	14.57 ± 5.87	2.75-25.8	*	*	*	*	*	*	*
Turbidity	NTU	3.44 ± 6.73	0.26-38	*	0-1.0	*	*	*	*	*
Microbiological Determinants								*	*	*
Coliphage	CFU/10 ml	17.21 ± 43.96	0-193	0	*	0-1	*	*	*	*
Cryptosporidium	Oocysts /10L	4 ± 3.5	1-6.0	0	0	*	*	*	*	*
E. coli	MPN/100ml	172 ± 368.6	0-921	0	0	0	0-10	0-200	0-10	*

Table 4.8: (Continued) Historic surface water quality concentrations of the Mokhoulane River during the Study Period: B – January 2006 to December 2011

Orange shading indicates non-compliance with one or more of the guidelines or the standard, green shading indicates compliance

Determinants	Units	Concentration		Standard or guideline						
						DWAF				
		Mean +/- SD	Range	WHO (2011)	SANS:241 (2015)	Domestic (1996a)	Irrigation (1996b)	Livestock & Watering (1996c)	Aquaculture (1996d)	Aquatic Ecosystems (1996e)
Faecal coliform	FC/100 ml	646 ± 1607.3	0-5920	0	0	0	0-10 000	*	*	*
Giardia	Cysts/10L	2 ± 0.7	1.0-2.0	0	0	*	*	*	*	*

*Determinant value not stipulated **No comparison value

4.3.2. Study period C: 2012 to 2014 (July)

This study period covers the current data of the Mokhoulane River from January 2012 to July 2014. Most of the chemical determinants in this Study Period were compliant with one or more of the water quality guidelines, with the exception of aluminium, copper, magnesium and zinc (Table 4.9).

During this Study Period: C, the mean concentration of aluminium was 1.25 ± 2.12 mg/l, with a range of 0.01 to 3.70 mg/l which was significantly high enough to cause non-compliance with the WHO (2011), SANS: 241 (2015), DWS Aquaculture (DWAF, 1996d) and Aquatic Ecosystems (DWAF, 1996e) guidelines. The mean concentration of copper was 0.01 ± 0.01 mg/l (range of 0 to 0.03 mg/l) and high enough to cause non-compliance with the DWS Aquatic Ecosystems (DWAF, 1996e) guideline. Magnesium had a mean concentration of 3.33 ± 1.77 mg/l (range of 1.7 to 6.86 mg/l) and was also non-compliant with the DWS Aquatic Ecosystems (DWAF, 1996e) guideline. Zinc was also non-compliant with the DWS Aquatic Ecosystems (DWAF, 1996e) guideline at a mean concentration of 0.02 ± 0.01 mg/l (range of 0.01 to 0.03 mg/l).

The physical determinants that were non-compliant with one or more of the water quality guidelines were water hardness, total dissolved solids, pH and turbidity. Water hardness was not compliant with the DWS Domestic (DWAF, 1996a). The mean concentration of 38.08 ± 16.26 mg/l as $CaCO_3$ (range of 22-68.88 mg/l as $CaCO_3$) was below the 50 to 100 mg/l as $CaCO_3$ value of the DWS Domestic (DWAF, 1996a) guideline. The mean concentration of total dissolved solids was 70 ± 30.22 mg/l and ranged from 29 to 121 mg/l. The concentration was high enough to result in non-compliance with the DWS Aquaculture (DWAF, 1996d) guideline. The pH was 8.71 ± 0.54 (range of 7.8 to 9.6) and resulted in non-compliance with the DWS Irrigation (DWAF, 1996b) guideline. Water turbidity was at a mean concentration of 1.05 ± 0.90 NTU (range of 0.31 to 3.2 NTU) and caused non-compliance with the SANS: 241 (2015) guideline. Under the microbiological determinants, *E.coli* was non-compliant with the WHO (2011), SANS: 241 (2015), DWS Domestic (DWAF, 1996a), Irrigation (DWAF, 1996b), and Aquaculture (DWAF, 1996d) guidelines. The mean concentration was 14 ± 13.9 MPN/100ml with a range of 1.0 to 34 MPN/100ml.

Table 4.9: Current surface water quality concentrations of the Mokhoulane River during Study Period: C – January 2012 to July 2014

Orange shading indicates non-compliance with one or more of the guidelines or the standard, green shading indicates compliance

				Standard or guideline						
Determinants	**Units**	**Concentration**				**DWAF**				
		Mean +/- SD	**Range**	**WHO (2011)**	**SANS:241 (2015)**	**Domestic (1996a)**	**Irrigation (1996b)**	**Livestock & Watering (1996c)**	**Aquaculture (1996d)**	**Aquatic Ecosystems (1996e)**
Chemical Determinants										
Aluminium	mg/l	1.25 ± 2.12	0.01-3.70	0-0.9	0-0.3	*	0-5	0-5	0-0.03	0-0.005
Boron	mg/l	0.02 ± 0.02	0.01-0.03	0-2.4	*	*	0-0.5	0-5	*	*
Calcium	mg/l	10.02 ± 4.10	6.1-18.28	*	*	*	*	0-1000	*	*
Chloride	mg/l	1.72 ± 0.10	0.83-3.0	0-250	0-300	*	0-100	0-1500	*	*
Copper	mg/l	0.01 ±0.01	0-0.03	0-2	0-2	*	0-0.2	0-0.5	*	0-0.0012
Iron	mg/l	0.04 ± 0.04	0.01-0.10	0-2	0-2	*	0-5	0-10	*	< 10 % background value
Magnesium	mg/l	3.33 ±1.77	1.7-6.86	*	*	*	*	0-500	*	0-0.18
Manganese	mg/l	0.02 ± 0.01	0.01-0.04	0-0.4	0-0.5	*	0-0.2	0-10	0-0.1	0-0.18
Nitrite	mg/l	0.02 ± 0.01	0-0.04	0-3	0-0.9	*	*	*	0-0.05	*
Nitrate	mg/l	0.42 ± 0.36	0.15-1.09	0-50	0-11	*	*	0-100	0-300	*
Potassium	mg/l	0.64 ± 0.51	0.19-1.2	*	*	0-50	*	*	*	*
**Phosphates	mg/l	0.13 ± 0.07	0.06-0.22	*	*	*	*	*	*	*
Sodium	mg/l	2.68 ± 1.16	1.6-4.50	0-200	0-200	*	0-70	0-2000	*	*
**Sulphur	mg/l	1.83 ± 0.92	0.56-3.4	*	*	*	*	*	*	*
Sulphate	mg/l	6.84 ± 3.11	2.9-11	*	0-600	0-200	*	0-1000	*	*
**Total Organic Carbon	mg/l	1.47 ± 0.49	0.98-2.3	*	*	*	*	*	*	*
**Total Silica	mg/l	16.10 ± 1.27	14-18.63	*	*	*	*	*	*	*
Zinc	mg/l	0.02 ± 0.01	0.01-0.03	0-3	0-5	*	0-1	0-20	*	0-0.002

Table 4.9: (Continued) Current surface water quality concentrations of the Mokhoulane River during Study Period: C – January 2012 to July 2014

Orange shading indicates non-compliance to one or more of the guidelines or the standard, green shading indicates compliance

				Standard or guideline						
Determinants	**Units**	**Concentration**				**DWAF**				
		Mean +/- SD	**Range**	**WHO (2011)**	**SANS:241 (2015)**	**Domestic (1996a)**	**Irrigation (1996b)**	**Livestock & Watering (1996c)**	**Aquaculture (1996d)**	**Aquatic Ecosystems (1996e)**
Physical Determinants										
Alkalinity	mg/l $CaCO_3$	64.73 ± 82.00	25-280	*	*	*	*	*	20-100	*
**Chemical Oxygen Demand	mg/l	5.5 ± 0.71	5.0-6.0	*	*	*	*	*	*	*
Conductivity at 25 ˚C	mS/m	6.34 ± 2.63	4-11.75	*	0-170	*	0-40	0-154	*	*
Dissolved Oxygen	mg/l	8.61 ± 1.20	7.04-10.6	*	*	*	*	*	6.0-9.0	80-120 % saturation
Hardness	mg/l $CaCO_3$	38.08 ± 16.26	22-68.88	*	*	50-100	*	*	20-100	*
Total Dissolved Solids	mg/l	70 ± 30.22	29-121	*	0-1200	*	0-260	0-1000	0-0.02	< 15% background value
pH at 25 ˚C	N/A	8.71 ± 0.54	7.8-9.6	*	5.0-9.7	*	6.5-8.4	*	6.5-9.0	<5% background value
**Temperature	˚C	13.90 ± 7.27	5.1-26.2	*	*	*	*	*	*	*
Turbidity	NTU	1.05 ± 0.90	0.31-3.2	*	0-1.0	*	*	*	*	*
Microbiological Determinants										
E. coli	MPN/100 ml	14 ± 13.9	1.0-34	0	0	0	0-10	0-200	0-10	*

*Determinant value not stipulated **No comparison value

4.4. Malibamatso River

4.4.1. Historic data: 2000 to 2011

The concentrations of the chemical, physical and microbiological determinants of the Malibamatso River were measured from January 2000 to December 2005 (Study Period: A) and from January 2006 to December 2011 (Study Period: B). The concentration with standard deviation and the ranges of the selected water quality determinants concentrations for Study Period: A and Study Period: B are presented in Table 4.10 and Table 4.11 respectively.

Most of the chemical determinants during Study Period: A and Study Period: B were compliant with one or more of the water quality guidelines. The chemical determinants which were not compliant with one or more of the guidelines in Study Period: A included aluminium, ammonium, magnesium, nickel, nitrite and zinc, whereas in Study Period: B, aluminium, ammonium, copper, magnesium, and zinc were not compliant.

During Study Period: A, the mean concentration of aluminium was 0.07 ± 0.07 mg/l (range of 0.01 to 0.31 mg/l) and 0.03 ± 0.03 mg/l (range of 0.01 to 0.1 mg/l) during Study Period: B. The concentration in Study Period: A was high enough to result in non-compliance with the DWS Aquaculture (DWAF, 1996d) and Aquatic Ecosystems (DWAF, 1996e) guidelines. Non-compliance was with the DWS Aquatic Ecosystems (DWAF, 1996e) guideline during Study Period: B.

The mean concentration of ammonium during Study Period: A was 0.10 ± 0.07 mg/l (range of 0.05 to 0.29 mg/l) and 0.11 ± 0.10 mg/l (range of 0.05 to 0.37 mg/l) during Study Period: B. In both study periods, the ammonium mean concentration did not comply with the DWS Aquaculture (DWAF, 1996d) guideline. Copper had a mean concentration of 0.02 ±0.02 mg/l (range of 0.01 to 0.08 mg/l) during Study Period: A, which was not compliant with the DWS Aquatic Ecosystems (DWAF, 1996e) guideline. However, the concentrations of copper were below the detection limit of 5.54 µg/l or 0.00554 mg/l during Study Period: B.

During Study Period: A and Study Period: B, the mean concentration of magnesium did not comply with the DWS Aquatic Ecosystems (DWAF, 1996e). The mean concentration was 2.89 ±1.02 mg/l (range of 0.71 to 5.5 mg/l) in Study Period: A and 2.94 ± 0.91 mg/l (1.1-5.0 mg/l) in Study Period: B. The mean concentration of nickel

did not comply with the WHO (2011) guideline in Study Period: A. The concentration was 0.07 ± 0.04 mg/l with a range of 0.02 to 0.16 mg/l during this Study Period. In Study Period: B, the concentrations of nickel were below the detection limit.

Nitrite had a mean concentration of 2.94 ± 0.91 mg/l (range of 1.1 to 5.0 mg/l) during Study Period: A, which was non-compliant with the DWS Aquaculture (DWAF, 1996d) guideline. During Study Period: B, nitrite was compliant with all the guidelines. The mean concentration of zinc was not compliant with the DWS Aquatic Ecosystems (DWAF, 1996e) guideline in Study Period: A and Study Period: B. During Study Period: A, the mean concentration of zinc was 0.02 ± 0.01 mg/l (range of 0.01 to 0.04 mg/l) and 0.05 ± 0.07 mg/l (range of 0.01 to 0.18 mg/l) during Study Period: B.

The physical determinants which were not compliant with one or more of the guidelines during Study Period: A includes dissolved oxygen, hardness, total dissolved solids and turbidity (Table 4.9). In Study Period: B (Table 4.10), most of the physical determinants were not compliant with one or more of the guidelines, namely dissolved oxygen, hardness, suspended solids, total dissolved solids and turbidity.

During Study Period: A, the mean concentration of dissolved oxygen was 5.04 ± 1.28 mg/l (range of 2.4 to 6.6 mg/l) and 9.10 ± 1.05 mg/l (range of 6.96 to 12.35 mg/l) during Study Period: B. The mean concentration during Study Period: A was below the guideline value of the DWS Aquaculture (DWAF, 1996d) and Aquatic Ecosystems (DWAF, 1996e) guidelines, whereas in Study Period: B, the mean concentration was above the guideline value of the DWS Aquatic Ecosystems (DWAF, 1996e) guideline.

During Study Period: A, the mean concentration of water hardness was 33.87 ± 11.24 mg/l $CaCO_3$ (range of 13 to 65 mg/l $CaCO_3$) and 33.61 ± 9.00 mg/l $CaCO_3$ (range of 14 to 56 mg/l $CaCO_3$) during Study Period: B. In both study periods, water hardness was non-compliant with the DWS Domestic (DWAF, 1996a) guidelines, with the mean concentration being below the specified DWS guideline value.

During Study Period: A, total dissolved solids had a mean concentration of 71.20 ± 32.75 mg/l (range of 27 to 205 mg/l), and 59 ± 11.65 mg/l (range of 30 to 91 mg/l)

during Study Period: B. The concentrations were significantly high that there was non-compliance with the DWS Aquaculture (DWAF, 1996d) guideline in both Study Period: A and Study Period: B. The mean concentration of suspended solids during Study Period: A were below the detection limit. However, during Study Period: B, the mean concentration was 57.43 ± 57.01 mg/l with a range of 13 to 155 mg/l. This concentration was significantly high enough to result in non-compliance with the DWS Irrigation (DWAF, 1996b) guideline.

Water turbidity was significantly high, resulting in non-compliance with the SANS: 241 (2015) guideline in both study periods. The mean concentration was 7.30 ± 8.63 NTU (0.26 to 43 NTU) during Study Period: A and 4.21 ± 3.21 NTU (range of 0.21 to 12 NTU) in Study Period: B.

The microbiological determinants which were non-compliant with one or more of the guidelines in Study Period: A (Table 4.10) were coliphage bacteria and faecal coliform bacteria. In Study Period: B (Table 4.11), non-compliant determinants were coliphage bacteria, faecal coliform bacteria and *E. coli*. During Study Period: A, coliphage bacteria had a mean concentration of 4 ± 13.1 CFU/10ml (range of 0 to 90 CFU/10ml) and 10 ± 31.2 CFU/10ml (range of 0 to 176 CFU/10ml) during Study Period: B. In both study periods, the mean concentrations were non-compliant with the WHO (2011) and DWS Domestic (DWAF, 1996a) guidelines. *E. coli* bacteria had a mean concentration of 109 ± 272.7 MPN/100ml with a range of 0 to 727 MPN/100ml during Study Period: B. The number of bacteria enumerated was sufficiently high to result in non-compliance with the WHO (2011), SANS: 241 (2015), DWS Irrigation (DWAF, 1996b) and Aquaculture (DWAF, 1996d) guidelines. However, during Study Period: A, the concentrations of *E.coli* bacteria was below the detection limit.

Faecal coliform bacteria was non-compliant with WHO (2011), SANS: 241 (2015) and DWS Domestic (DWAF, 1996a) guidelines during Study Period: A and Study Period: B. During study Period: A, the mean concentration was 217 ± 960.3 FC/100ml (range of 0 to 7680 FC/100ml) and 309 ± 1038 FC/100ml (range of 0 to 5680 FC/100ml) during Study Period: B.

Table 4.10: Historic surface water quality concentrations of the Malibamatso River during the Study Period: A – January 2000 to December 2005

Orange shading indicates non-compliance with one or more of the guidelines or the standard, green shading indicates compliance

				Standard or guideline						
		Concentration				DWAF				
Determinants	Units	Mean +/- SD	Range	WHO (2011)	SANS: 241 (2015)	Domestic (1996a)	Irrigation (1996b)	Livestock & Watering (1996c)	Aquaculture (1996d)	Aquatic Ecosystems (1996e)
Chemical Determinants										
Aluminium	mg/l	0.07 ± 0.07	0.01-0.31	0-0.9	0-0.3	*	0-5	0-5	0-0.03	0-0.005
Ammonium	mg/l	0.10 ± 0.07	0.05-0.29	*	0-1.5	*	*	*	0-0.025	*
Calcium	mg/l	8.81 ± 2.84	3.9-17	*	*	*	*	0-1000	*	*
Fluoride	mg/l	0.24 ± 0.87	0.05-5	0-1.5	0-1.5	*	0-2.0	0-2.0	*	0-0.75
Iron	mg/l	0.08 ± 0.10	0.01-0.56	0-2	0-2	*	0-5	0-10	*	< 10 % background value
Magnesium	mg/l	2.89 ±1.02	0.71-5.5	*	*	*	*	0-500	*	0-0.18
Manganese	mg/l	0.06 ± 0.07	0.01-0.19	0-0.4	0-0.5	*	0-0.2	0-10.0	0-0.1	0-0.18
Nickel	mg/l	0.07 ± 0.04	0.02-0.16	0-0.007	0-0.07	*	0-0.2	0-1	*	*
Nitrite as N	mg/l	0.07 ± 0.04	0.03-0.2	0-3	0-0.9	*	*	*	0-0.05	*
Nitrate as N	mg/l	0.31 ± 0.33	0.1-2.4	0-50	0-11	*	*	0-100	0-300	*
Phosphorus	mg/l	0.29 ± 0.34	0.05-1.3	*	*	*	*	*	*	0-5
Potassium	mg/l	0.4 ± 0.15	0.26-0.73	*	*	0-50	*	*	*	*
Sodium	mg/l	1.89 ± 0.90	0.63-5	0-200	0-200	*	0-70	0-2000	*	*
**Sulphur	mg/l	1.32 ± 0.39	0.54-2.7	*	*	*	*	*	*	*
Sulphate	mg/l	7.38 ± 4.12	5.0-22	*	0-600	0-200	*	0-1000	*	*
**Total Organic Carbon	mg/l	2.00 ± 0.62	1-4.6	*	*	*	*	*	*	*
**Total Silica	mg/l	12.52 ± 3.82	1.1-18	*	*	*	*	*	*	*
Zinc	mg/l	0.02 ± 0.01	0.01-0.04	0-3	0-5	*	0-1	0-20	*	0-0.002

Table 4.10: (Continued) Historic surface water quality concentrations of the Malibamatso River during the Study Period: A – January 2000 to December 2005

Orange shading indicates non-compliance with one or more of the guidelines or the standard, green shading indicates compliance

				Standard or guideline						
		Concentration				DWAF				
Determinants	Units	Mean +/- SD	Range	WHO (2011)	SANS:241 (2015)	Domestic (1996a)	Irrigation (1996b)	Livestock & Watering (1996c)	Aquaculture (1996d)	Aquatic Ecosystems (1996e)
Physical Determinants										
Alkalinity	mg/l $CaCO_3$	36.31 ± 10.65	16-64	*	*	*	*	*	20-100	*
**Chemical Oxygen Demand	mg/l	11.71 ± 2.50	10.0-17	*	*	*	*	*	*	*
Conductivity at 25 ˚C	mS/m	8.19 ± 2.25	4.6-15	*	0-170	*	0-40	0-154	*	*
Dissolved Oxygen	mg/l	5.04 ± 1.28	2.4-6.6	*	*	*	*	*	6.0-9.0	80-120 % saturation
Hardness	mg/l $CaCO_3$	33.87 ± 11.24	13-65	*	*	50-100	*	*	20-100	*
Suspended Solids	mg/l	25 ± 21.21	3.0-88	*	*	*	0-50	*	*	*
Total Dissolved Solids	mg/l	71.20 ± 32.75	27-205	*	0-1200	*	0-260	0-1000	0-0.02	<15% background value
pH at 25 ˚C	N/A	7.46 ± 0.42	6.62-8.23	*	5.0-9.7	*	6.5-8.4	*	6.5-9.0	< 5% background value
**Temperature	˚C	22.36 ± 1.90	17.1-26	*	*	*	*	*	*	*
Turbidity	NTU	7.30 ± 8.63	0.26-43	*	0-1.0	*	*	*	*	<10% background value
Microbiological Determinants										
Coliphage	CFU/10 ml	4 ± 13.1	0-90	0	*	0-1	*	*	*	*
Faecal coliform	FC/100 ml	217 ± 960.3	0-7680	0	0	0	0-10 000	*	*	*

*Determinant value not stipulated **No comparison value

Table 4.11: Historic surface water quality concentrations of the Malibamatso River during the Study Period: B – January 2006 to December 2011

Orange shading indicates non-compliance with one or more of the guidelines or the standard, green shading indicates compliance

		Concentration		Standard or guideline						
						DWAF				
Determinants	**Units**	**Mean +/- SD**	**Range**	**WHO (2011)**	**SANS: 241 (2015)**	**Domestic (1996a)**	**Irrigation (1996b)**	**Livestock & Watering (1996c)**	**Aquaculture (1996d)**	**Aquatic Ecosystems (1996e)**
Chemical Determinants										
Aluminium	mg/l	0.03 ± 0.03	0.01-0.1	0-0.9	0-0.3	*	0-5	0-5	0-0.03	0-0.005
Ammonium	mg/l	0.11 ± 0.10	0.05-0.37	*	0-1.5	*	*	*	0-0.025	*
Calcium	mg/l	8.68 ± 2.34	3.9-14	*	*	*	*	0-1000	*	*
Copper	mg/l	0.02 ±0.02	0.01-0.08	0-2	0-2	*	0-0.2	0-0.5	*	0-0.0012
Fluoride	mg/l	0.08 ± 0.03	0.05-0.16	0-1.5	0-1.5	*	0-2.0	0-2.0	*	0-0.75
Iron	mg/l	0.05 ± 0.07	0.01-0.4	0-2	0-2	*	0-5	0-10	*	< 10 % background value
Magnesium	mg/l	2.94 ± 0.91	1.1-5	*	*	*	*	0-500	*	0-0.18
Manganese	mg/l	0.05 ± 0.08	0-0.27	0-0.4	0-0.5	*	0-0.2	0-10.0	0-0.1	0-0.18
Nitrite as N	mg/l	0.05 ± 0.09	0.01-0.46	0-3	0-0.9	*	*	*	0-0.05	*
Nitrate as N	mg/l	0.21 ± 0.11	0.11-0.53	0-50	0-11	*	*	0-100	0-300	*
Phosphorus	mg/l	0.11 ± 0.1	0.05-0.26	*	*	*	*	*	*	0-5
**Phosphates	mg/l	0.12 ± 0.08	0.05-0.26	*	*	*	*	*	*	*
Potassium	mg/l	0.73 ± 0.39	0.35-1.5	*	*	0-50	*	*	*	*
Sodium	mg/l	2.58 ± 1.04	1.5-6.1	0-200	0-200	*	0-70	0-2000	*	*
**Sulphur	mg/l	1.28 ± 0.48	0.4-2.7	*	*	*	*	*	*	*
**Total Organic Carbon	mg/l	1.77 ± 0.57	0.63-2.9	*	*	*	*	*	*	*
**Total Silica	mg/l	13.68 ± 1.75	11.0-19	*	*	*	*	*	*	*
Zinc	mg/l	0.05 ± 0.07	0.01-0.18	0-3	0-5	*	0-1	0-20	*	0-0.002

Table 4.11: (Continued) Historic surface water quality concentrations of the Malibamatso River during the Study Period: B – January 2006 to December 2011

Orange shading indicates non-compliance with one or more of the guidelines or the standard, green shading indicates compliance

		Concentration		Standard or guideline						
						DWAF				
Determinants	**Units**	**Mean +/- SD**	**Range**	**WHO (2011)**	**SANS: 241 (2015)**	**Domestic (1996a)**	**Irrigation (1996b)**	**Livestock & Watering (1996c)**	**Aquaculture (1996d)**	**Aquatic Ecosystems (1996e)**
Physical Determinants										
Alkalinity	mg/l $CaCO_3$	34.55 ± 6.63	19-47	*	*	*	*	*	20-100	*
**Chemical Oxygen Demand	mg/l	14 ± 4.16	11.0-23.0	*	*	*	*	*	*	*
Conductivity at 25 ˚C	mS/m	6.95 ± 1.49	3.7-9.7	*	0-170	*	0-40	0-154	*	*
Dissolved Oxygen	mg/l	9.10 ± 1.05	6.96-12.35	*	*	*	*	*	6.0-9.0	80-120 % saturation
Hardness	mg/l $CaCO_3$	33.61 ± 9.00	14-56	*	*	50-100	*	*	20-100	*
Suspended Solids	mg/l	57.43 ± 57.01	13-155	*	*	*	0-50	*	*	*
Total Dissolved Solids	mg/l	59 ± 11.65	30-91	*	0-1200	*	0-260	0-1000	0-0.02	<15% background value
pH at 25 ˚C	N/A	8.4 ± 0.53	7.3-9.8	*	5.0-9.7	*	6.5-8.4	*	6.5-9.0	< 5% background value
**Temperature	˚C	14.30 ± 5.11	4.2-22.7	*	*	*	*	*	*	*
Turbidity	NTU	4.21 ± 3.21	0.21-12	*	0-1.0	*	*	*	*	<10% background value
Microbiological Determinants										
Coliphage	CFU/10ml	10 ± 31.21	0-176	0	*	0-1	*	*	*	*
E. Coli	MPN/100ml	109 ± 272.7	0-727	0	0	*	0-10	0-200	0-10	*
Faecal coliform	FC/100ml	309 ± 1038	0-5680	0	0	0	0-10 000	*	*	*

*Determinant value not stipulated **No comparison value

4.4.2. Study period C: 2012 (January) to 2014 (July)

This study period covers the current data of the Malibamatso River from January 2012 to July 2014. In this study period, most of the chemical determinants were compliant with one or more of the water quality guidelines. The chemical determinants which were not compliant with one or more of the guidelines were aluminium, copper, magnesium, manganese and zinc (Table 4.12).

During this study period, the mean concentration of aluminium was 0.04 ± 0.02 mg/l with a range of 0.02 to 0.05 mg/l. The concentration was high enough to result in non-compliance with the DWS Aquaculture (DWAF, 1996d) and Aquatic Ecosystems (DWAF, 1996e) guidelines. Copper had a mean concentration of 1.54 ± 3.72 mg/l with a range of 0 to 9.14 mg/l which implies non-compliance with the DWS Irrigation (DWAF, 1996b), Livestock and Watering (DWAF, 1996c) and Aquatic Ecosystems (DWAF, 1996e) guidelines. The mean concentration of magnesium was not compliant with the DWS Aquatic Ecosystems (DWAF, 1996e), at 2.68 ± 0.76 mg/l with a range of 1.5 to 3.5 mg/l. Manganese was not compliant with DWS Aquaculture (DWAF, 1996d) and Aquatic Ecosystems (DWAF, 1996e) guidelines. The mean concentration of manganese was 0.19 ± 0.21 mg/l, with a range of 0.01 to 0.5 mg/l, hence non-compliance with the two guidelines. During this study period, zinc had a mean concentration of 0.06 ± 0.04 mg/l with a range of 0.03 to 0.08 mg/l. The mean concentration was significant to the extent that there was non-compliance with the DWS Aquatic Ecosystems (DWAF, 1996e) guideline.

The physical determinants which were not compliant with one or more of the guidelines in this study period were hardness, total dissolved solids, pH and turbidity. Water hardness was below the required guideline value of the DWS Domestic (DWAF, 1996a). Water hardness had a mean concentration of 30.84 ± 7.16 mg/l $CaCO_3$, ranging from 20 to 38 mg/l $CaCO_3$. The mean concentration of total dissolved solids was way above the DWS Aquaculture (DWAF, 1996d) guideline value. It was 65 ± 21.80 mg/l, ranging from 36 to 110 mg/l concentration. The pH was 8.91 ± 0.80 and ranged from 7.95 to 10.2 during this period. This mean pH was non-compliant with the DWS Irrigation (DWAF, 1996b) guideline. The mean turbidity was 6.37 ± 6.00 NTU, ranging from 0.91 to 20 NTU during this period, hence the non-compliance with the SANS: 241 (2015) guideline.

The microbiological determinants which were non-compliant with one or more of the water quality guidelines were coliphage bacteria, *Cryptosporidium* and *E.coli*. The mean concentration of coliphage bacteria was 15 ± 44.2 CFU/10ml, ranging from 0 to 141 CFU/10ml and resulting in non-compliance with the WHO (2011) and DWS Domestic (DWAF, 1996a) guidelines. There were 2 ± 3.5 Oocysts/10L (range of 0 to 7 Oocysts/10L) of *Cryptosporidium* during this study period. Consequently, the concentration did not comply with the WHO (2011) and SANS: 241 (2015) guidelines. *E. coli* had a mean concentration of 88 ± 119.9 MPN/100ml (range of 0 to 345 MPN/100ml) which was high enough to result in non-compliance with the WHO (2011), SANS: 241 (2015), DWS Irrigation (DWAF, 1996b), Livestock & watering (DWAF, 1996c) and Aquaculture (DWAF, 1996d) guidelines.

Table 4.12: Current surface water quality concentrations of the Malibamatso River during Study Period: C – January 2012 to July 2014

Orange shading indicates non-compliance with one or more of the guidelines or the standard, green shading indicates compliance

				Standard or guideline						
		Concentration				DWAF				
Determinants	**Units**	**Mean +/- SD**	**Range**	**WHO (2011)**	**SANS: 241 (2015)**	**Domestic (1996a)**	**Irrigation (1996b)**	**Livestock & Watering (1996c)**	**Aquaculture (1996d)**	**Aquatic Ecosystems (1996e)**
Chemical Determinants										
Aluminium	mg/l	0.04 ± 0.02	0.02-0.05	0-0.9	0-0.3	*	0-5	0-5	0-0.03	0-0.005
Ammonium	mg/l	0.02 ± 0.02	0.01-0.04	*	0-1.5	*	*	*	0-0.025	*
Calcium	mg/l	8.04 ± 1.74	5.4-10	*	*	*	*	0-1000	*	*
Chloride	mg/l	1.07 ± 0.46	0.61-1.70	0-250	0-300	*	0-100	0-1500	*	*
Copper	mg/l	1.54 ±3.72	0-9.14	0-2	0-2	*	0-0.2	0-0.5	*	0-0.0012
Iron	mg/l	0.05± 0.04	0.01-0.08	0-2	0-2	*	0-5	0-10	*	< 10 % background value
Magnesium	mg/l	2.68 ± 0.76	1.5-3.5	*	*	*	*	0-500	*	0-0.18
Manganese	mg/l	0.19 ± 0.21	0.01-0.5	0-0.4	0-0.5	*	0-0.2	0-10.0	0-0.1	0-0.18
Nitrite as N	mg/l	0.05 ± 0.04	0.02-0.08	0-3	0-0.9	*	*	*	0-0.05	*
Nitrate as N	mg/l	0.32 ± 0.29	0-0.85	0-50	0-11	*	*	0-100	0-300	*
**Phosphates	mg/l	0.13 ± 0.08	0.08-0.16	*	*	*	*	*	*	*
Potassium	mg/l	0.5 ± 0.16	0.37-0.60	*	*	0-50	*	*	*	*
Sodium	mg/l	2.81 ± 0.92	1.5-3.6	0-200	0-200	*	0-70	0-2000	*	*
**Sulphur	mg/l	1.45 ± 0.63	0.95-2.40	*	*	*	*	*	*	*
Sulphate	mg/l	5.00 ± 1.42	3.3-7.3	*	0-600	0-200	*	0-1000	*	*
**Total Organic Carbon	mg/l	2.00 ± 0.75	1.1-3.53	*	*	*	*	*	*	*
**Total Silica	mg/l	11.42 ±3.19	7.9-16	*	*	*	*	*	*	*
Zinc	mg/l	0.06 ± 0.04	0.03-0.08	0-3	0-5	*	0-1	0-20	*	0-0.002

Table 4.12 (Continued): Current surface water quality concentrations of the Malibamatso River during Study Period: C – January 2012 to July 2014

Orange shading indicates non-compliance with one or more of the guidelines or the standard, green shading indicates compliance

				Standard or guideline						
		Concentration				DWAF				
Determinants	Units	Mean +/- SD	Range	WHO (2011)	SANS: 241 (2015)	Domestic (1996a)	Irrigation (1996b)	Livestock & Watering (1996c)	Aquaculture (1996d)	Aquatic Ecosystems (1996e)
Physical Determinants										
Alkalinity	mg/l $CaCO_3$	34.60 ±11.90	26-64.31	*	*	*	*	*	20-100	*
**Chemical Oxygen Demand	mg/l	10.2 ± 4.15	5.0-16	*	*	*	*	*	*	*
Conductivity at 25 ˚C	mS/m	7.00 ± 2.23	4.1-11.34	*	0-170	*	0-40	0-154	*	*
Dissolved Oxygen	mg/l	8.84 ± 1.20	6.65-10.68	*	*	*	*	*	6.0-9.0	80-120 % saturation
Hardness	mg/l $CaCO_3$	30.84 ±7.16	20-38	*	*	50-100	*	*	20-100	*
Suspended Solids	mg/l	6.5 ± 8.40	1-19.0	*	*	*	0-50	*	*	*
Total Dissolved Solids	mg/l	65 ± 21.80	36-110	*	0-1200	*	0-260	0-1000	0-0.02	<15% background value
pH at 25 ˚C	N/A	8.91 ± 0.80	7.95-10.2	*	5.0-9.7	*	6.5-8.4	*	6.5-9.0	< 5% background value
**Temperature	˚C	15.50 ±6.84	5.9-25.4	*	*	*	*	*	*	*
Turbidity	NTU	6.37 ± 6.00	0.91-20	*	0-1.0	*	*	*	*	<10% background value
Microbiological Determinants										
Coliphage	CFU/10 ml	15 ± 44.2	0-141	0	*	0-1	*	*	*	*
Cryptosporidium	Oocysts /10L	2 ± 3.5	0-7	0	0	*	*	*	*	*

Table 4.12 (Continued): Current surface water quality concentrations of the Malibamatso River during Study Period: C – January 2012 to July 2014

Orange shading indicates non-compliance with one or more of the guidelines or the standard, green shading indicates compliance

				Standard or guideline						
		Concentration				DWAF				
Determinants	**Units**	**Mean +/- SD**	**Range**	**WHO (2011)**	**SANS: 241 (2015)**	**Domestic (1996a)**	**Irrigation (1996b)**	**Livestock & Watering (1996c)**	**Aquaculture (1996d)**	**Aquatic Ecosystems (1996e)**
E. coli	MPN /100ml	88 ± 119.9	0-345	0	0	*	0-10	0-200	0-10	*

4.5. Liphofung River

4.5.1. Historic data: 2000 to 2011

The concentration of the chemical, physical and microbiological determinants of the Liphofung River was measured from January 2000 to December 2005 (Study Period: A) and from January 2006 to December 2011 (Study Period: B). The concentration with standard deviation and the ranges of the selected water quality determinants and concentrations for Study Period: A and Study Period: B are presented in Table 4.13. and Table 4.14. respectively.

Most of the chemical determinants were compliant with one or more of the water quality guidelines during Study Period: A and Study Period: B. During Study Period: A, aluminium, ammonium, nickel, magnesium and zinc were not compliant with one or more of the guidelines. During Study Period: B, aluminium, ammonium, copper, potassium, nitrite and zinc were non-compliant with one or more of the water quality guidelines.

The mean aluminium concentration was 0.07 ± 0.10 mg/l (range of 0.01 to 0.48 mg/l) during Study Period: A and 0.03 ± 0.02 mg/l (range of 0.01 to 0.08 mg/l) during Study Period: B. Aluminium was non-compliant with the DWS Aquaculture (DWAF, 1996d) and Aquatic Ecosystems (DWAF, 1996e) guidelines in Study Period: A but non-compliant with only the DWS Aquatic Ecosystems (DWAF, 1996e) guideline in Study Period: B. Ammonium was non-compliant with the DWS Aquaculture (DWAF, 1996d) guideline in both Study Periods. The mean concentration was 0.06 ± 0.02 mg/l (range of 0.05 to 0.11 mg/l) during Study Period: A and 0.07 ± 0.02 mg/l (range of 0.05 to 0.1 mg/l) during Study Period: B. The mean concentration of magnesium was 3.42 ± 1.00 mg/l (range of 1.3 to 5.9 mg/l) during Study Period: A and 3.60 ±1.03 mg/l (range of 2.1 to 6.9 mg/l during Study Period: B. The concentration was significantly high. This resulted in non-compliance with the DWS Aquatic Ecosystems (DWAF, 1996e) guideline during both study periods.

During Study Period: A, the mean concentration of nickel was 0.08± 0.04 mg/l (range of 0.02 to 0.18 mg/l). There was non-compliance with the WHO (2011) and SANS: 241 (2015) guidelines. However, during Study Period: B, nickel concentrations were below the detection limit. Nitrite had a mean concentration of 0.06 ± 0.03 mg/l (range

of 0.03 to 0.21mg/l) during Study Period: A and 0.06 ±0.14 mg/l (range of 0.01 to 0.67 mg/l) during Study Period: B. This was not compliant with the DWS Aquaculture (DWAF, 1996d) guideline in both study periods. During Study Period: A, the mean concentration of zinc was 0.02 ± 0.01 mg/l (range of 0.01 to 0.03 mg/l) and 0.04 ±0.04 mg/l (range of 0.01 to 0.13 mg/l) during Study Period: B. The mean concentrations was significantly high, therefore non-compliant with the DWS Aquatic Ecosystems (DWAF, 1996e) guideline in both study periods.

The physical determinants which were non-compliant with one or more of the guidelines during Study Period: A were water hardness, suspended solids, total dissolved solids and turbidity. During Study Period: B, the physical determinants which were not compliant with one or more of the guidelines were dissolved oxygen, water hardness, total dissolved solids and turbidity.

During Study Period: A, the mean concentration of water hardness was 40.57 ± 11.70 mg/l as $CaCO_3$ (range of 16 to 71 mg/l as $CaCO_3$) and 40.92 ± 12.11 mg/l as $CaCO_3$ (range of 26 to 85 mg/l as $CaCO_3$) during Study Period: B. The concentrations were non-compliant with the DWS Domestic (DWAF, 1996a) guideline, being below the stipulated guideline value. The mean concentration of total dissolved solids was 88.16 ± 45.21 mg/l (range of 10 to 270 mg/l) during Study Period: A and 68.10 ± 17.52 mg/l (range of 43 to 135 mg/l) during Study Period: B. The concentrations were substantial enough to result in non-compliance with the DWS Aquaculture (DWAF, 1996d) guideline in both study periods. During Study Period: A, the mean concentration of suspended solids was 73.5 ± 224.19 mg/l, with a range of 7 to 970 mg/l, producing non-compliance with the DWS Irrigation (DWAF, 1996b) guideline. During Study Period: B, the concentration of suspended solids was compliant with the guideline values. The mean concentration of turbidity was 5.03 ± 16.21 NTU (range of 0.29 to 130 NTU) during Study Period: A and 3.63 ± 7.09 NTU (range of 0.3 to 42 NTU) during Study Period: B. In both study periods, the mean concentration was non-compliant with the SANS: 241 (2015) guideline.

The microbiological determinants which were non-compliant with one or more of the water quality guidelines included coliphage bacteria, faecal coliform and *Giardia* in Study Period: A and *E.coli*, coliphage bacteria, faecal coliform, and *Giardia* in Study Period: B. During Study Period: A, coliphage bacteria had a mean concentration of

33 ± 76.40 CFU/10ml (range of 0 to 484 CFU/10ml) and 48 ± 150.1 CFU/10ml (range of 0 to 843 CFU/10ml) during Study Period: B. The mean concentration was significant enough for non-compliance with the WHO (2011) and DWS Domestic (DWAF, 1996a) guidelines in both study periods. The mean concentration of *E.coli* during Study Period: A was below the detection limit, but during Study Period: B, it was 226 ± 270.6 MPN/100ml, with a range of 0 to 649 MPN/100ml. The mean concentration was high enough to result in non-compliance with five of the guidelines, namely; WHO (2011), SANS: 241 (2011), DWS Irrigation (DWAF, 1996b), Livestock & Watering (DWAF, 1996c) and Aquaculture (DWAF, 1996d) guidelines.

The mean concentration of faecal coliform was 1220 ± 2070 FC/100ml (range of 10 to 14100 FC/100ml) during Study Period: A and 1356 ± 4231.6 FC/100ml (range of 2 to 23300 FC/100ml) during Study Period: B. In both study periods, the concentration of faecal coliform bacteria was non-compliant with the WHO (2011), SANS: 241 (2015) and DWS Domestic (DWAF, 1996a) guidelines. During Study Period: A, the mean concentration of *Giardia* was 3 ± 6.0 Cysts/10L, with a range of 0 to 24 Cysts/10L, causing non-compliance with the WHO (2011) and SANS: 241 (2015) guidelines. For Study Period: B, *Giardia* cysts were at a mean concentration of 4 ± 4.2 Cysts/10L, with a range of 1.0 to 9.0 Cysts/10L, with resultant non-compliance with the WHO (2011) and SANS: 241 (2015) guidelines.

Table 4.13: Historic surface water quality concentrations of the Liphofung River during the Study Period: A – January 2000 to December 2006

Orange shading indicates non-compliance with one or more of the guidelines or the standard, green shading indicates compliance

		Concentration		Standard or guideline						
						DWAF				
Determinants	**Units**	**Mean +/- SD**	**Range**	**WHO (2011)**	**SANS:241 (2015)**	**Domestic (1996a)**	**Irrigation (1996b)**	**Livestock & Watering (1996c)**	**Aquaculture (1996d)**	**Aquatic Ecosystems (1996e)**
Chemical Determinants										
Aluminium	mg/l	0.07 ± 0.10	0.01-0.48	0-0.9	0-0.3	*	0-5	0-5	0-0.03	0-0.005
Ammonium	mg/l	0.06± 0.02	0.05-0.11	*	0-1.5	*	*	*	0-0.025	*
Calcium	mg/l	10.58± 3.12	4.2-19	*	*	*	*	0-1000	*	*
Fluoride	mg/l	0.30± 1.13	0.05-6.7							
Iron	mg/l	0.04± 0.04	0.01-0.19	0-2	0-2	*	0-5	0-10	*	< 10 % background value
Potassium	mg/l	0.40 ± 0.14	0.27-0.82	*	*	0-50	*	*	*	*
Magnesium	mg/l	3.42 ± 1.00	1.3-5.9	*	*	*	*	0-500	*	0-0.18
Nickel	mg/l	0.08± 0.04	0.02-0.18	0-0.007	0-0.07	*	0-0.2	0-1	*	*
Nitrite	mg/l	0.06± 0.03	0.03-0.21	0-3	0-0.9	*	*	*	0-0.05	*
Nitrate	mg/l	0.36± 0.29	0.11-1.6	0-50	0-11	*	*	0-100	0-300	*
Phosphorus	mg/l	0.32± 0.50	0.04-1.9	*	*	*	*	*	*	0-5
**Phosphates	mg/l	0.14± 0.15	0.05-0.6	*	*				*	*
Sodium	mg/l	2.00 ± 1.00	0.5-5.8	0-200	0-200	*	0-70	0-2000	*	*
**Sulphur	mg/l	1.66 ± 0.47	0.9-3.1	*	*	*	*	*	*	*
Sulphate	mg/l	7.05 ± 2.44	5.1-17	*	0-600	0-200	*	0-1000	*	*
**Total Silica	mg/l	14.26 ± 4.85	1.2-20	*	*	*	*	*	*	*
Zinc	mg/l	0.02± 0.01	0.01-0.03	0-3	0-5	*	0-1	0-20	*	0-0.002

Table 4.13: (Continued) Historic surface water quality concentrations of the Liphofung River during the Study Period: A – January 2000 to December 2006

Orange shading indicates a non-compliance to one or more of the guidelines or the standard, green shading indicates compliance.

		Concentration		Standard or guideline						
						DWAF				
Determinants	**Units**	**Mean +/- SD**	**Range**	**WHO (2011)**	**SANS:241 (2015)**	**Domestic (1996a)**	**Irrigation (1996b)**	**Livestock & Watering (1996c)**	**Aquaculture (1996d)**	**Aquatic Ecosystems (1996e)**
Physical Determinants										
Alkalinity	mg/l $CaCO_3$	41.12 ± 9.74	25-65	*	*	*	*	*	20-100	*
**Chemical Oxygen Demand	mg/l	14.1 ± 5.34	10.0-25.0	*	*	*	*	*	*	*
Conductivity	mS/m	9.56 ± 2.51	4.0-16	*	0-170	*	0-40	0-154	*	*
Dissolved Oxygen	mg/l	7.76± 2.01	2.8-11.26	*		*	*	*	5.0-8.0	80-120 % saturation
Dissolved Organic Carbon	mg/l	2.81± 0.10	2-4.9	*	10.0-20	0-5	*	*	*	*
Hardness	mg/l $CaCO_3$	40.57 ± 11.70	16-71	*	*	50-100	*	*	20-100	*
Suspended Solids	mg/l	73.5 ± 224.19	7-970	*	*	*	0-50	*	*	*
Total Dissolved Solids	mg/l	88.16 ± 45.21	10-270	*	0-1200	*	0-260	0-1000	0-0.02	<15% background value
pH	N/A	7.56 ± 0.43	6.7-8.55	*	5.0-9.7	*	6.5-8.4	*	6.5-9.0	< 5% background value
**Temperature	˚C	22.34 ± 1.92	17-26.1	*	*	*	*	*	*	*
Turbidity	NTU	5.03 ± 16.21	0.29-130	*	0-1.0	*	*	*	*	<10% background value
Microbiological Determinants										
Coliphage	CFU/10ml	33 ± 76.40	0-484	0	*	0-1	*	*	*	*
Faecal coliform	FC/100ml	1220 ± 2070	10-14100	0	0	0	0-10 000	*	*	*
Giardia	Cysts/10L	3± 6.04	0-24	0	0	*	*	*	*	*

Determinant value not stipulated **No comparison value

Table 4.14: Historic surface water quality concentrations of the Liphofung River during the Study Period: B – January 2006 to December 2011

Orange shading indicates non-compliance with one or more of the guidelines or the standard, green shading indicates compliance

		Concentration		Standard or guideline						
						DWAF				
Determinants	**Units**	**Mean +/- SD**	**Range**	**WHO (2011)**	**SANS: 241 (2015)**	**Domestic (1996a)**	**Irrigation (1996b)**	**Livestock & Watering (1996c)**	**Aquaculture (1996d)**	**Aquatic Ecosystems (1996e)**
Chemical Determinants										
Aluminium	mg/l	0.03 ± 0.02	0.01-0.08	0-0.9	0-0.3	*	0-5	0-5	0-0.03	0-0.005
Ammonium	mg/l	0.07± 0.02	0.05-0.1	*	0-1.5	*	*	*	0-0.025	*
Calcium	mg/l	10.48± 3.42	6.4-23	*	*	*	*	0-1000	*	*
Copper	mg/l	0.02 ±0.01	0.01-0.04	0-2	0-2	*	0-0.2	0-0.5	*	0-0.0012
Fluoride	mg/l	0.08 ± 0.03	0.05-0.17	0-1.5	0-1.5	*	0-2.0	0-2.0	*	0-0.75
Iron	mg/l	0.04 ±0.06	0.01-0.28	0-2	0-2	*	0-5	0-10	*	< 10 % background value
Potassium	mg/l	0.59 ± 0.31	0.34-1.4	*	*	0-50	*	*	*	*
Magnesium	mg/l	3.60 ±1.03	2.1-6.9	*	*	*	*	0-500	*	0-0.18
Nitrite as N	mg/l	0.06 ±0.14	0.01-0.67	0-3	0-0.9	*	*	*	0-0.05	*
Nitrate as N	mg/l	0.28 ±0.15	0.1-0.46	0-50	0-11	*	*	0-100	0-300	*
Phosphorus	mg/l	0.13 ±0.11	0.05-0.51	*	*	*	*	*	*	0-5
**Phosphates	mg/l	0.11±0.08	0.04-0.31	*	*	*	*	*	*	*
Sodium	mg/l	2.66 ±0.89	1.5-6	0-200	0-200	*	0-70	0-2000	*	*
**Sulphur	mg/l	1.75 ±0.73	0.71-3.5	*	*	*	*	*	*	*
Sulphate	mg/l	6.61 ± 1.62	5.0-12.0	*	0-600	0-200	*	0-1000	*	*
**Total Organic Carbon	mg/l	2.01 ± 0.56	0.9-3.2	*	*	*	*	*	*	*
**Total Silica	mg/l	15.26 ± 3.00	8.8-22	*	*	*	*	*	*	*
Zinc	mg/l	0.04 ±0.04	0.01-0.13	0-3	0-5	*	0-1	0-20	*	0-0.002

Table 4.14: (Continued) Historic surface water quality concentrations of the Liphofung River during the Study Period: B – January 2006 to December 2011

Orange shading indicates non-compliance with one or more of the guidelines or the standard, green shading indicates compliance

Determinants	Units	Concentration		Standard or guideline						
						DWAF				
		Mean +/- SD	Range	WHO (2011)	SANS: 241 (2015)	Domestic (1996a)	Irrigation (1996b)	Livestock & Watering (1996c)	Aquaculture (1996d)	Aquatic Ecosystems (1996e)
Physical Determinants										
Alkalinity	mg/l $CaCO_3$	41.69 ± 10.45	26-77	*	*	*	*	*	20-100	*
**Chemical Oxygen Demand	mg/l	12.27 ± 2.00	10.0-17	*	*	*	*	*	*	*
Conductivity at 25 ˚C	mS/m	10.14 ± 12.00	4.4-80	*	0-170	*	0-40	0-154	*	*
Dissolved Oxygen	mg/l	8.65± 1.37	6.04-13.7	*		*	*	*	5.0-8.0	80-120 % saturation
Hardness	mg/l $CaCO_3$	40.92 ± 12.11	26-85	*	*	50-100	*	*	20-100	*
Suspended Solids	mg/l	33.13 ± 25.41	12.0-87	*	*	*	0-50	*	*	*
Total Dissolved Solids	mg/l	68.10 ± 17.52	43-135	*	0-1200	*	0-260	0-1000	0-0.02	<15% background value
pH at 25 ˚C	N/A	8.32 ± 0.0.62	7-9.8	*	5.0-9.7	*	6.5-8.4	*	6.5-9.0	< 5% background value
**Temperature	˚C	14.25 ± 5.35	3-24.9	*	*	*	*	*	*	*
Turbidity	NTU	3.63 ± 7.09	0.3-42	*	0-1.0	*	*	*	*	<10% background value
Microbiological Determinants										
Coliphage	CFU/10ml	48 ± 150.1	0-843	0	*	0-1	*	*	*	*
E. Coli	MPN/100 ml	226 ± 270.6	0-649	0	0	*	0-10	0-200	0-10	*
Faecal coliform	FC/100ml	1356 ± 4231.6	2-23300	0	0	0	0-10 000	*	*	*
Giardia	Cysts/10L	4 ± 4.2	1.0-9.0	0	0	*	*	*	*	*

Determinant value not stipulated **No comparison value

4.5.2. Study Period C: 2012 (January) to 2014 (July)

This study period covers the current data of the Liphofung River from January 2012 to July 2014. In this study period, most of the chemical determinants were compliant with one or more of the water quality guidelines. The chemical determinants which were not compliant with one or more of the guidelines were, copper, magnesium, and zinc (Table 4.15).

In this study period, copper had a mean concentration of 0.02 ± 0.01 mg/l, ranging from 0.01 to 0.05 mg/l and caused non-compliance with the DWS Aquatic Ecosystems (DWAF, 1996e) guideline. Magnesium was also non-compliant with the DWS Aquatic Ecosystems (DWAF, 1996e) guideline, having a mean concentration of 3.33±1.07 mg/l with a range of 1.73 to 4.64 mg/l. During this Study Period, zinc had a mean concentration of 2.70± 6.57 mg/l, with a range of 0 to 6.10 mg/l, with resultant non-compliance with the DWS Irrigation (DWAF, 1996b) and Aquatic Ecosystems (DWAF, 1996e) guidelines.

The physical determinants which were not compliant with one or more of the water guidelines during this study period included dissolved oxygen, hardness, and total dissolved solids. The mean concentration of dissolved oxygen was 8.80 ± 1.35 mg/l with a range of 7.5 to 11.1 mg/l, which resulted in non-compliance with the DWS Aquaculture (DWAF, 1996d) guideline. Water hardness had a mean concentration of 41.70 ± 13.07 mg/l $CaCO_3$, at a range 23.09 to 60.92 mg/l $CaCO_3$ and consequent non-compliance with the DWS Domestic (DWAF, 1996a) guideline. During this period, total dissolved solids had a mean concentration of 72.80 ± 19.79 mg/l ranging from 48-100 mg/l. The concentration was high enough to lead to non-compliance with the DWS Aquaculture (DWAF, 1996d) guideline.

The microbiological determinants which were non-compliant with one or more of the water quality guidelines were coliphage bacteria and *E.coli.* Coliphage bacteria had a mean concentration of 2 ± 5.0 CFU/10ml, ranging from 0 to 16 CFU/10ml and therefore non-compliance with the WHO (2011) and DWS Domestic (DWAF, 1996a) guidelines. *E.coli* had a mean concentration of 476 ± 413.1 MPN/100ml, with a range of 41 to 1314 MPN/100ml. The mean concentration was high enough to result in non-compliance with five of the water quality guidelines, namely WHO (2011),

SANS: 241 (2015), DWS Irrigation (DWAF, 1996b), Livestock & Watering (DWAF, 1996c) and Aquaculture (DWAF, 1996d) guidelines.

Table 4.15: Current surface water quality concentrations of the Liphofung River during Study Period: C – January 2012 to July 2014

Orange shading indicates non-compliance with one or more of the guidelines or the standard, green shading indicates compliance

				Standard or guideline						
Determinants	**Units**	**Concentration**				**DWAF**				
		Mean +/- SD	**Range**	**WHO (2011)**	**SANS: 241 (2015)**	**Domestic (1996a)**	**Irrigation (1996b)**	**Livestock & Watering (1996c)**	**Aquaculture (1996d)**	**Aquatic Ecosystems (1996e)**
Chemical Determinants										
Calcium	mg/l	10.26 ± 5.02	0.27-17.06	*	*	*	*	0-1000	*	*
Copper	mg/l	0.02 ± 0.01	0.01-0.05	0-2	0-2	*	0-0.2	0-0.5	*	0-0.0012
Chloride	mg/l	1.23 ± 0.80	0.39-2.45	0-250	0-300	*	0-100	0-1500	*	*
Iron	mg/l	1.41±3.56	0.00-10.78	0-2	0-2	*	0-5	0-10	*	< 10 % background value
Manganese	mg/l	0.02 ± 0,02	0-0.09	0-0.4	0-0.5	*	0-0.2	0-10.0	0-0.1	0-0.18
Magnesium	mg/l	3.33±1.07	1.73-4.64	*	*	*	*	0-500	*	0-0.18
Nitrite as N	mg/l	0.01± 0.01	0.00-0.02	0-3	0-0.9	*	*	*	0-0.05	*
Nitrate as N	mg/l	0.24 ± 0.21	0-0.57	0-50	0-11	*	*	0-100	0-300	*
Potassium	mg/l	0.55 ± 0.46	0.09-1.18	*	*	0-50	*	*	*	*
**Phosphates	mg/l	0.08± 0.04	0.03-0.13	*	*	*	*	*	*	*
Sodium	mg/l	2.35 ±1.51	0.79-5.22	0-200	0-200	*	0-70	0-2000	*	*
**Sulphur	mg/l	2.10 ± 2.00	0.53-7.11	*	*	*	*	*	*	*
Sulphate	mg/l	7.83 ±5.01	3.22-19.16	*	0-600	0-200	*	0-1000	*	*
**Total Organic Carbon	mg/l	1.69 ± 0.24	1.36-2.24	*	*	*	*	*	*	*
**Total Silica	mg/l	16.21 ± 2.24	13.35-20.60	*	*	*	*	*	*	*
Zinc	mg/l	2.70± 6.57	0.0-16.10	0-3	0-5	*	0-1	0-20	*	0-0.002

Table 4.15: (Continued) Current surface water quality concentrations of the Liphofung River during Study Period: C – January 2012 to July 2014

Orange shading indicates non-compliance with one or more of the guidelines or the standard, green shading indicates compliance

Determinants	Units	Concentration		Standard or guideline						
						DWAF				
		Mean +/- SD	Range	WHO (2011)	SANS: 241 (2015)	Domestic (1996a)	Irrigation (1996b)	Livestock & Watering (1996c)	Aquaculture (1996d)	Aquatic Ecosystems (1996e)
Physical Determinants										
Alkalinity	mg/l $CaCO_3$	42.51 ± 10.73	29.4-63.25	*	*	*	*	*	20-100	*
**Chemical Oxygen Demand	mg/l	5.3 ± 0.48	5.0-6.0	*	*	*	*	*	*	*
Conductivity at 25 ˚C	mS/m	6.65 ± 3.64	0.062-12.65	*	0-170	*	0-40	0-154	*	*
Dissolved Oxygen	mg/l	8.80 ± 1.35	7.5-11.1	*		*	*	*	5.0-8.0	80-120 % saturation
Hardness	mg/l $CaCO_3$	41.70 ± 13.07	23.09-60.92	*	*	50-100	*	*	20-100	*
Suspended Solids	mg/l	3 ± 2.65	1.0-6.0	*	*	*	0-50	*	*	*
Total Dissolved Solids	mg/l	72.80 ± 19.79	48-100	*	0-1200	*	0-260	0-1000	0-0.02	<15% background value
pH at 25 ˚C	N/A	8.4 ± 0.60	7.6-9.35	*	5.0-9.7	*	6.5-8.4	*	6.5-9.0	< 5% background value
**Temperature	˚C	13.17 ± 6.62	3.8-23.5	*	*	*	*	*	*	*
Turbidity	NTU	0.95 ± 0.86	0.27-3.07	*	0-1.0	*	*	*	*	<10% background value
Microbiological Determinants										
Coliphage	CFU/10 ml	2 ± 5.0	0-16	0	*	0-1	*	*	*	*
E. coli	MPN/100ml	476 ± 413.1	41-1314	0	0	*	0-10	0-200	0-10	*

Determinant value not stipulated **No comparison value

4.6. Trend comparison of non-compliant chemical, physical and microbiological determinants between the five different rivers from 2000 to 2014

4.6.1. Chemical determinants

a) Aluminium

Compared to the other rivers the Pelaneng River showed the highest concentration of aluminium from 2000 to 2014, (Figure 4.25). The exception was for the year 2001, where no aluminium measurements were taken for all the rivers. The Bokong River showed the lowest aluminium concentration for the entire study period. Notable peak concentrations of aluminium can be observed in 2002, 2003, 2007 and 2009 but with a general decrease towards 2014. Generally, the aluminium concentrations show similar trends during the same years or time periods for all the rivers. The Pelaneng River would then have the highest input of aluminium to the Katse Dam, compared to the other rivers.

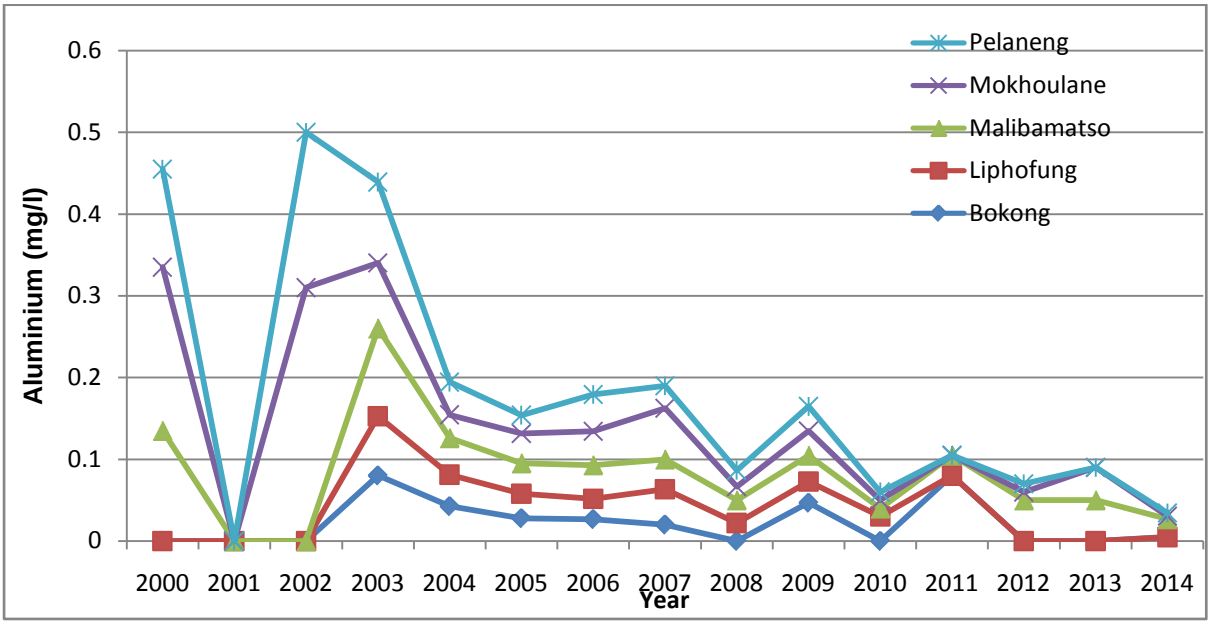


Figure 4.25: a comparison of aluminium concentration between the five rivers from 2000 to 2014

b) Ammonium

The Bokong River showed the highest ammonium concentration from 2000 to 2005 (Figure 4.26), and then fluctuated slightly from 2006 to 2008. The ammonium concentration was below the detection limit from 2009 to 2014. In the year 2006, the Pelaneng River had the highest concentration of ammonium which further decreased

significantly towards 2014. In the year 2010, the Malibamatso River had the highest concentration and was actually the only river where ammonium concentrations could be detected for that year.

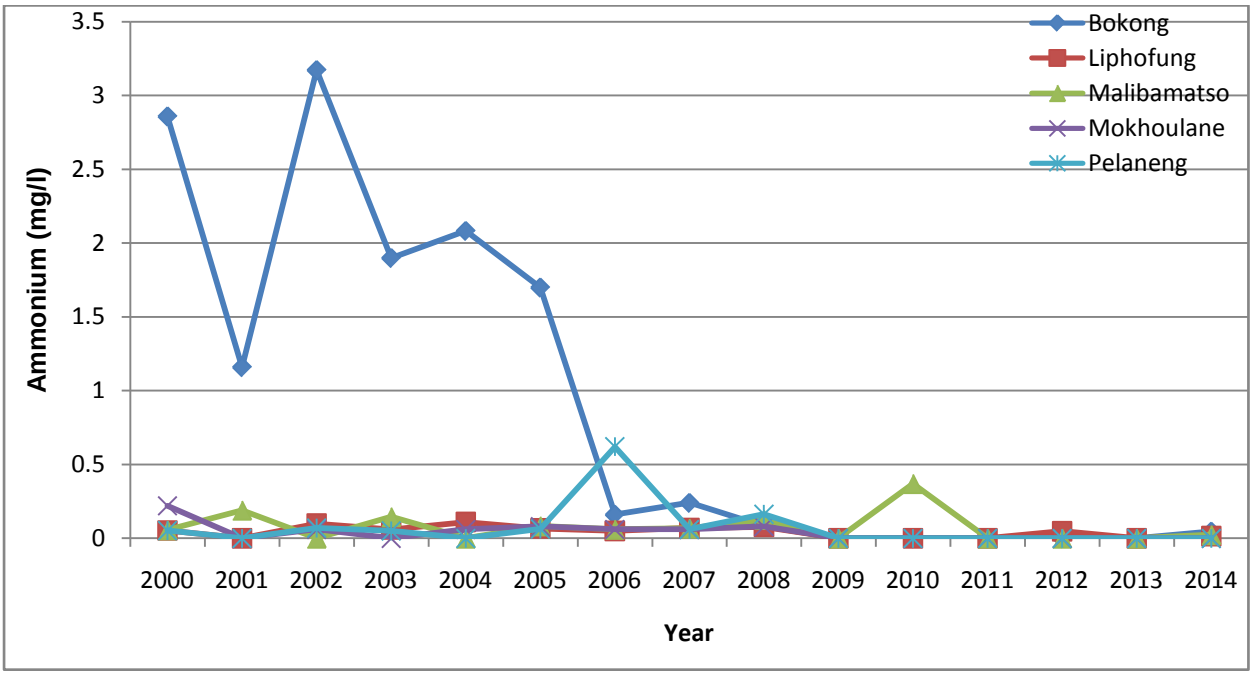


Figure 4.26: A comparison of ammonium concentration between the five rivers from 2000 to 2014

(c) Copper

The Pelaneng River showed the highest concentration of copper in 2006 and 2010 (Figure 4.27). The copper concentrations were below the detection limit for the Liphofung, Malibamatso, Mokhoulane and Pelaneng Rivers from 2000 to 2005. However, for the Bokong River, copper concentrations could be detected from the year 2003 onwards.

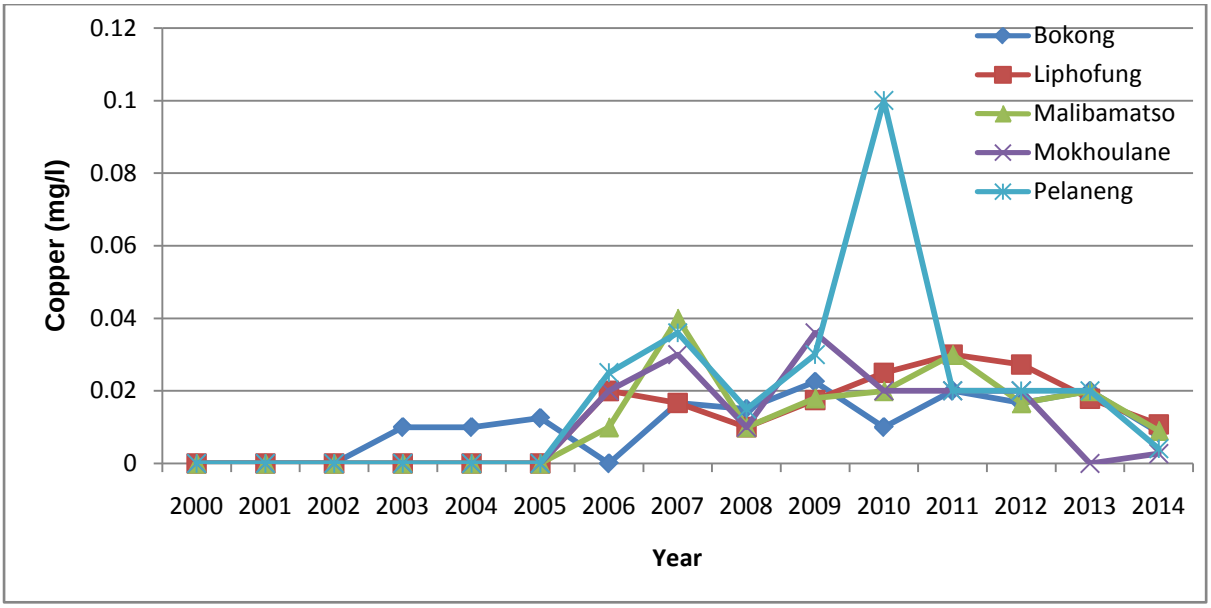


Figure 4.27: A comparison of copper concentration between the five rivers from 2000 to 2014

(d) Magnesium

The Mokhoulane River showed the highest concentration of magnesium from 2000 to 2006 (Figure 4.28). However, in 2007 the Liphofung River had the highest concentration, while the Bokong River had the highest concentration in 2010. For the other years, the magnesium concentration of the Bokong River varied quite considerably.

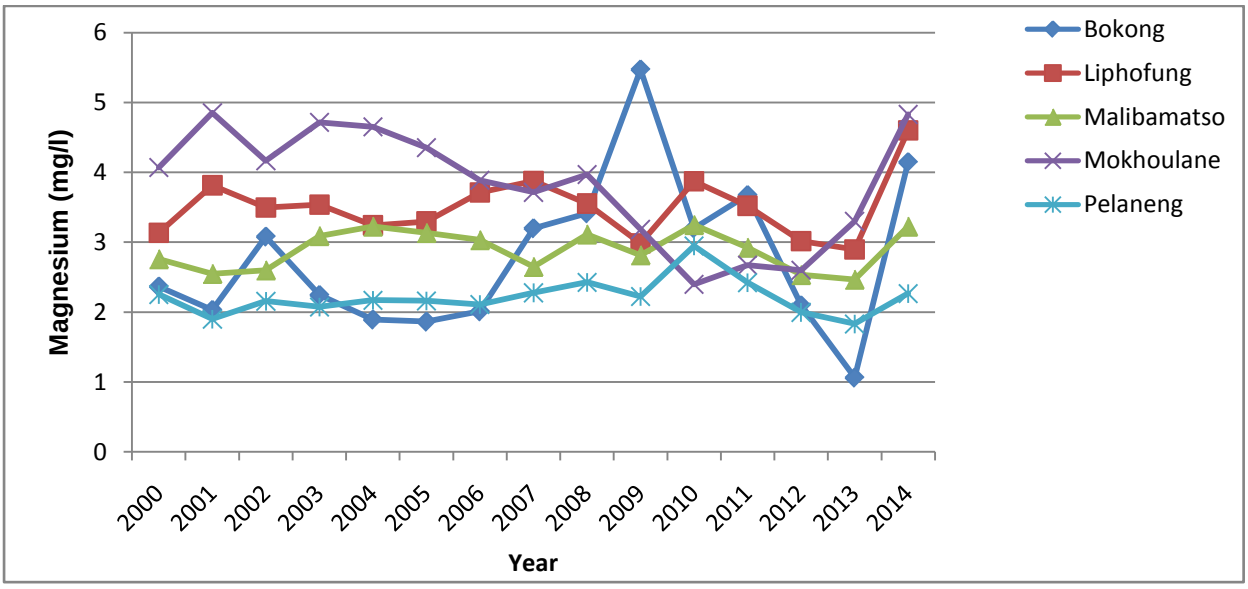


Figure 4.28: A comparison of magnesium concentrations between the five rivers from 2000 to 2014

(e) Nickel

During the year 2000, 2001 and 2006 to 2014, nickel concentrations were below the detection limit for all the rivers (Figure 4.29). However, from 2002 to 2005, the concentration of nickel was detectable in all the rivers, with the highest concentration in the Bokong River during the year 2005. With the exception of the Bokong River, the other rivers show a decrease from 2002 to 2005 and 2006 for the Liphofung River.

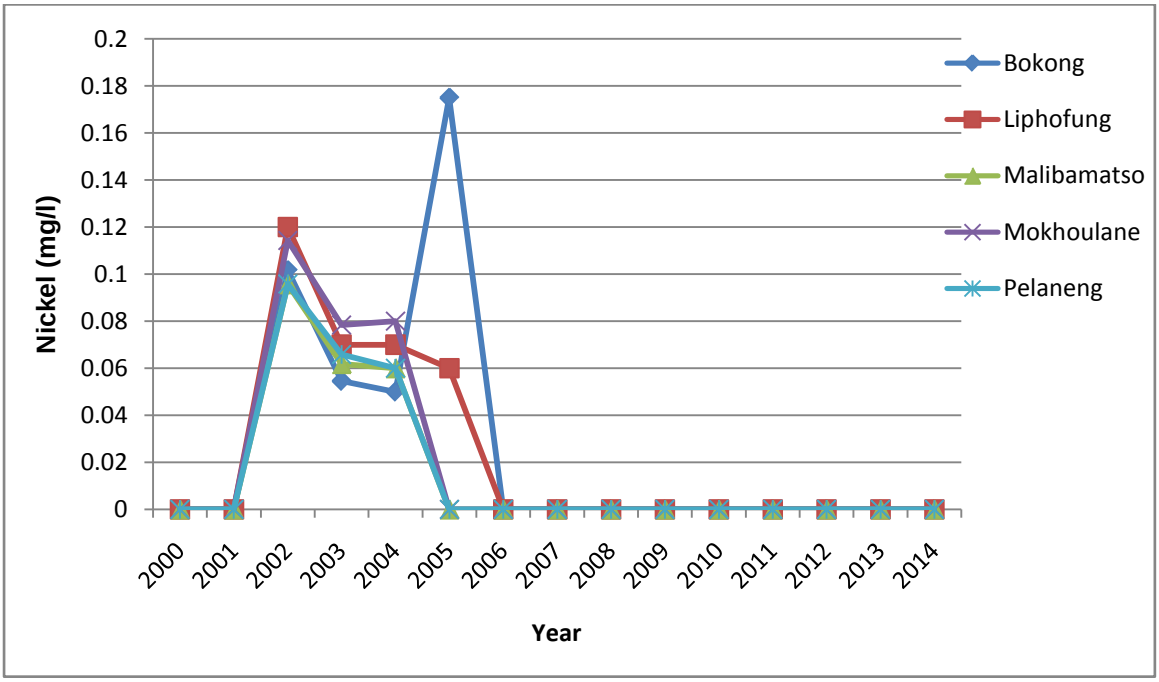


Figure 4.29: A comparison of nickel concentrations between the five rivers from 2000 to 2014

(f) Manganese

The Bokong River showed the highest concentration of manganese in the year 2000, which then decreased and fluctuated slightly until 2014 (Figure 4.30). However, from 2001 to 2006, the Malibamatso River had the highest manganese concentrations. In 2007, the Mokhoulane River showed higher concentrations than the Malibamatso River. The manganese concentration of the Malibamatso River increased again from 2010 to 2014, and was the highest during these years. The Liphofung River showed the minimal concentrations throughout the 2000 to 2014 study years.

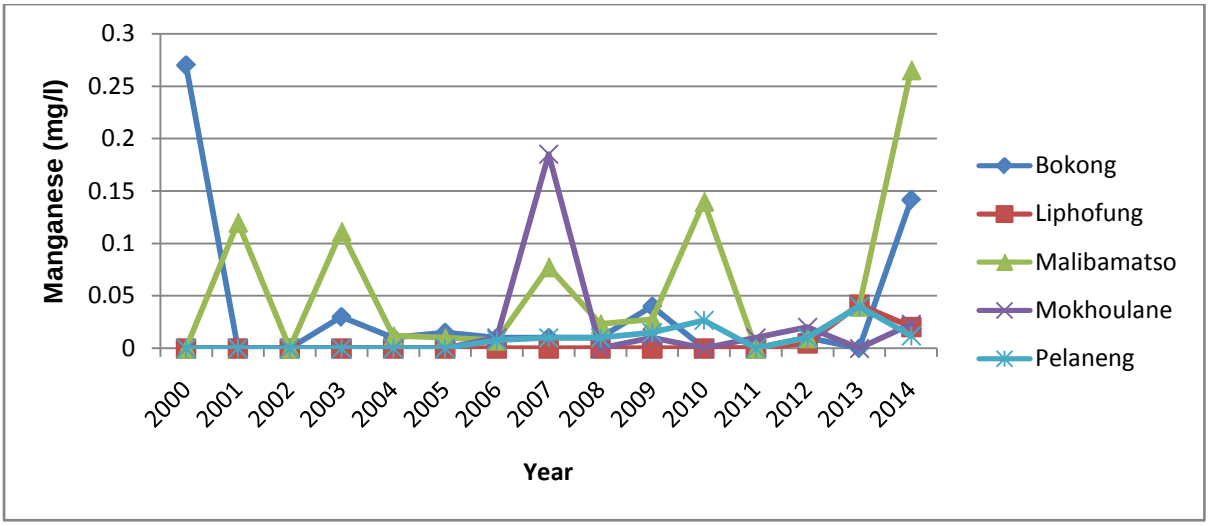


Figure 4.30: A comparison of manganese concentration between the five rivers from 2000 to 2014

(g) Lead

The Bokong River showed the highest concentration of lead during the year 2001 in comparison with the Mokhoulane River (Figure 4.31). During the year 2003 to 2004, the Mokhoulane River had a slightly higher concentration of lead than the Bokong River. However, lead concentrations were below the detection limit for the Malibamatso, Pelaneng and Liphofung Rivers from 2005 to 2014.

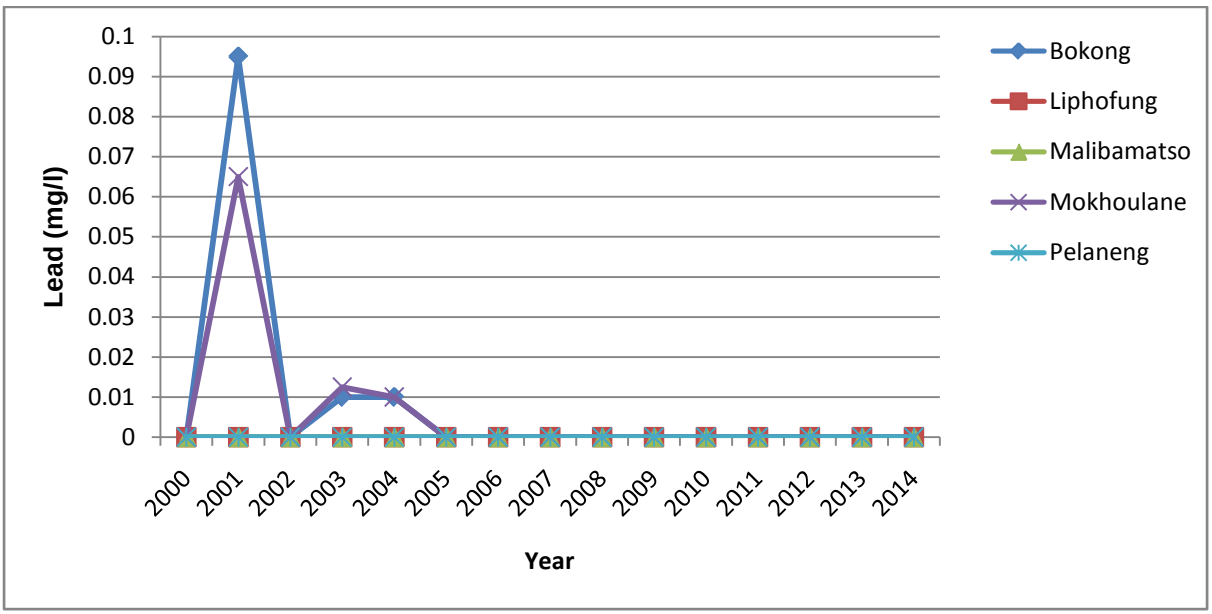


Figure 4.31: A comparison of lead concentration between the five rivers from 2000 to 2014

(h) Nitrite

The nitrite concentration of all the rivers from 2000 to 2006 was consistent and showed similar values (Figure 4.32). However, from 2006 to 2007, the Mokhoulane River had the highest nitrite concentration. In the years 2008 and 2009, the Bokong River showed the highest concentration of nitrite which then decreased sharply from 2010 until 2014.

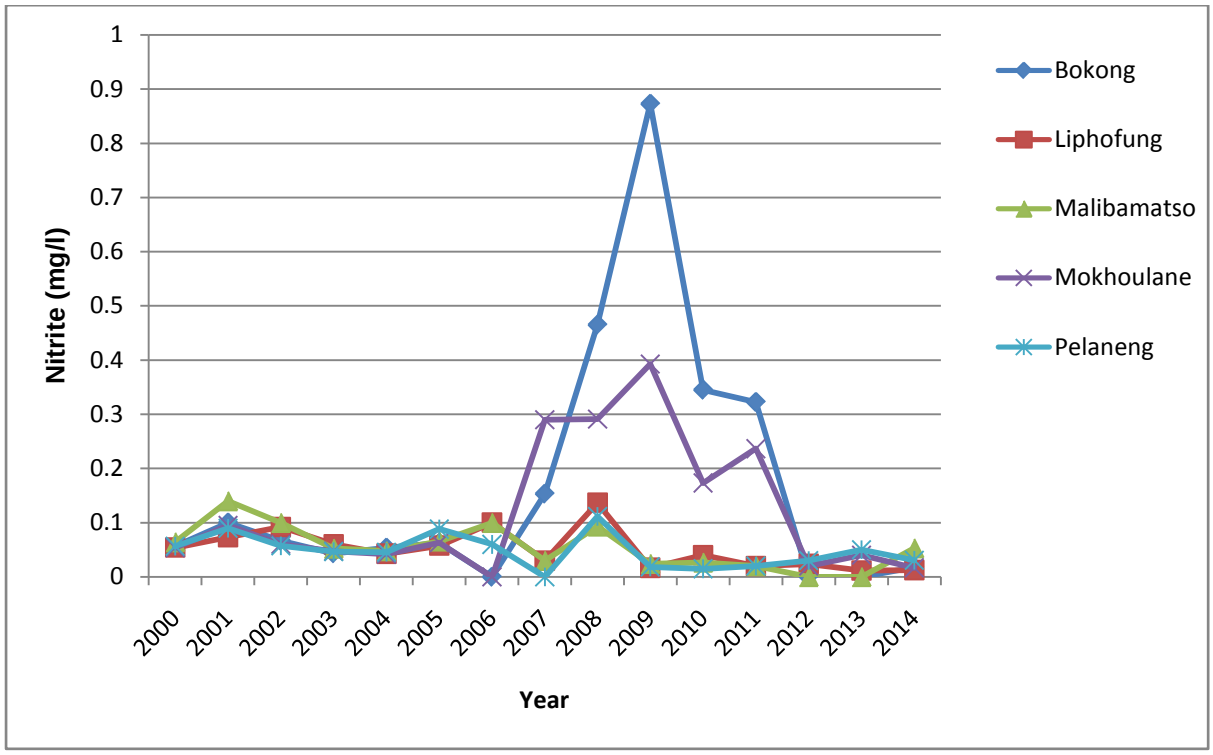


Figure 4.32: A comparison of nitrite concentration between the five rivers from 2000 to 2014

(I) Zinc

The Bokong and Pelaneng Rivers showed the highest concentration of zinc in 2009 (Figure 4.33). The second highest peak of zinc concentration can be noted in 2010 at the Liphofung River. The Mokhoulane River also showed a peak concentration of zinc in 2001.

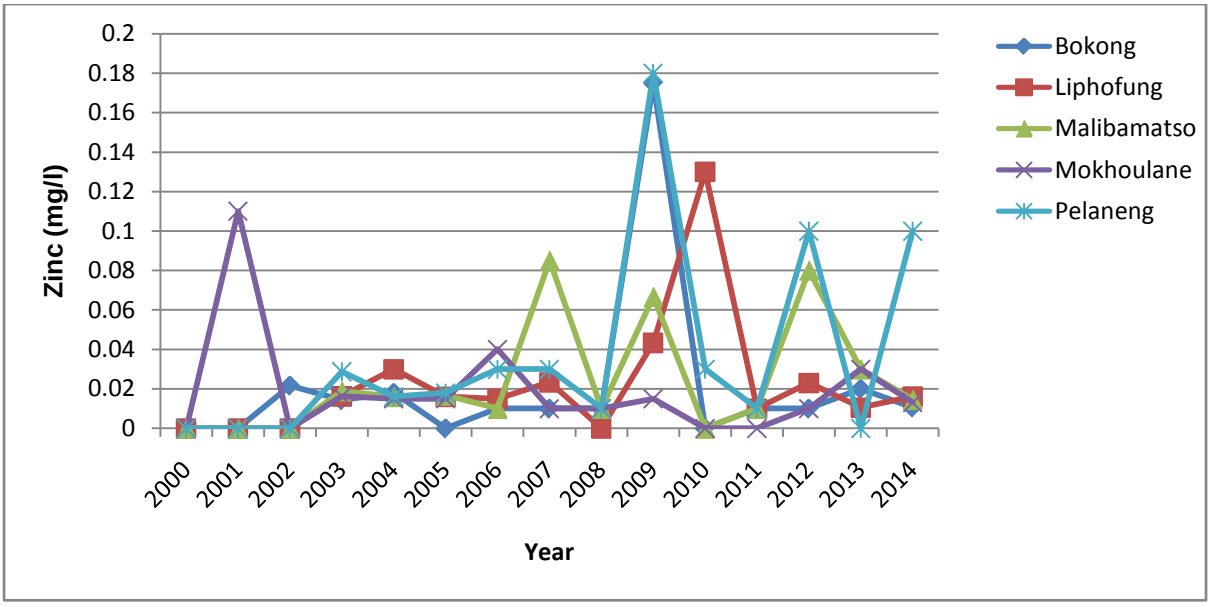


Figure 4.33: A comparison of zinc concentration between the five rivers from 2000 to 2014

4.6.2. Physical determinants

(a) Hardness

Water hardness concentration fluctuated quite considerably throughout 2000 to 2014 in all the rivers but the Mokhoulane River showed the highest concentration from 2000 to 2005 and decreased beyond 2006 (Figure 4.34). The Bokong River showed a peak concentration in 2009 but the concentrations in the other rivers fluctuated and showed variation from 2000 to 2014.

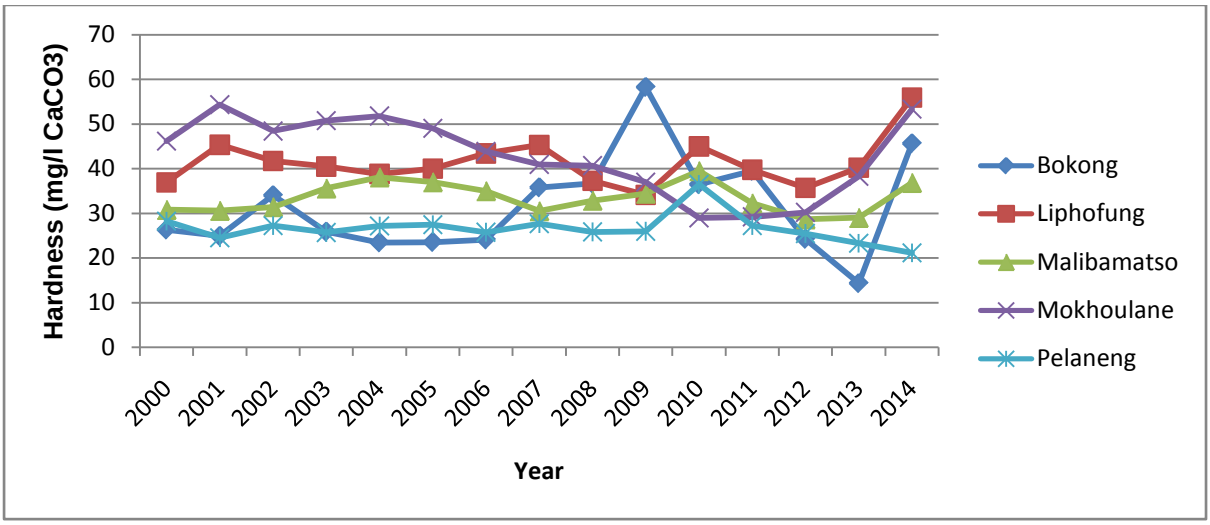


Figure 4.34: A comparison of water hardness between the five rivers from 2000 to 2014

(b) Total dissolved solids

The concentration of total dissolved solids was quite consistent and showed slight fluctuations throughout 2000 to 2014 (Figure 4.35). However, the Mokhoulane River showed the highest concentration of total dissolved solids in 2003 and in 2014.

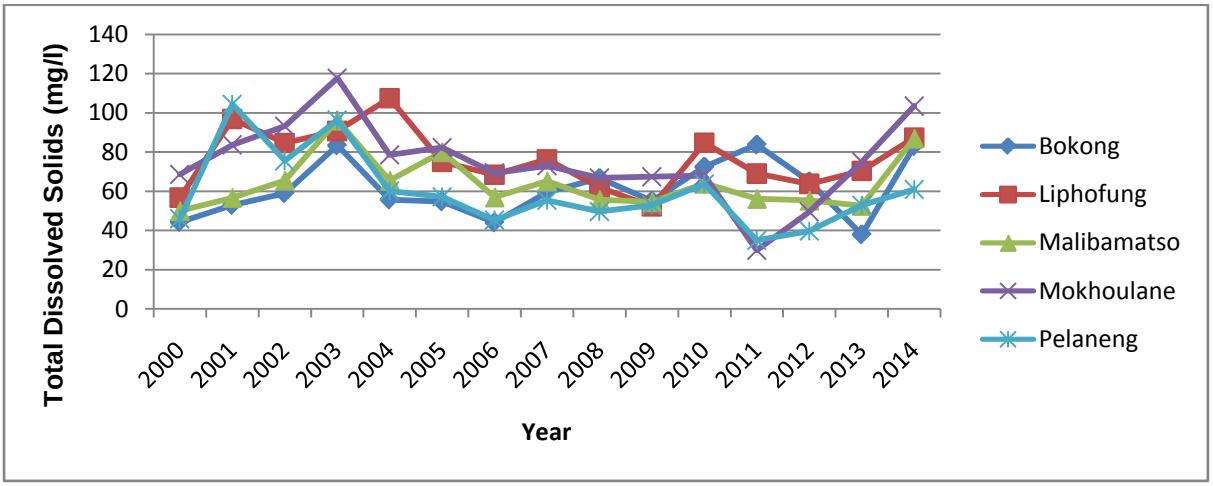


Figure 4.35: A comparison of total dissolved solids concentration between the five rivers from 2000 to 2014

(c) Turbidity

Water turbidity showed the highest concentration at the Mokhoulane River during 2002 (Figure 4.36), followed by the Liphofung River in the same year. Throughout the 2000 to 2014 period, water turbidity showed slight fluctuations between the years for the different rivers.

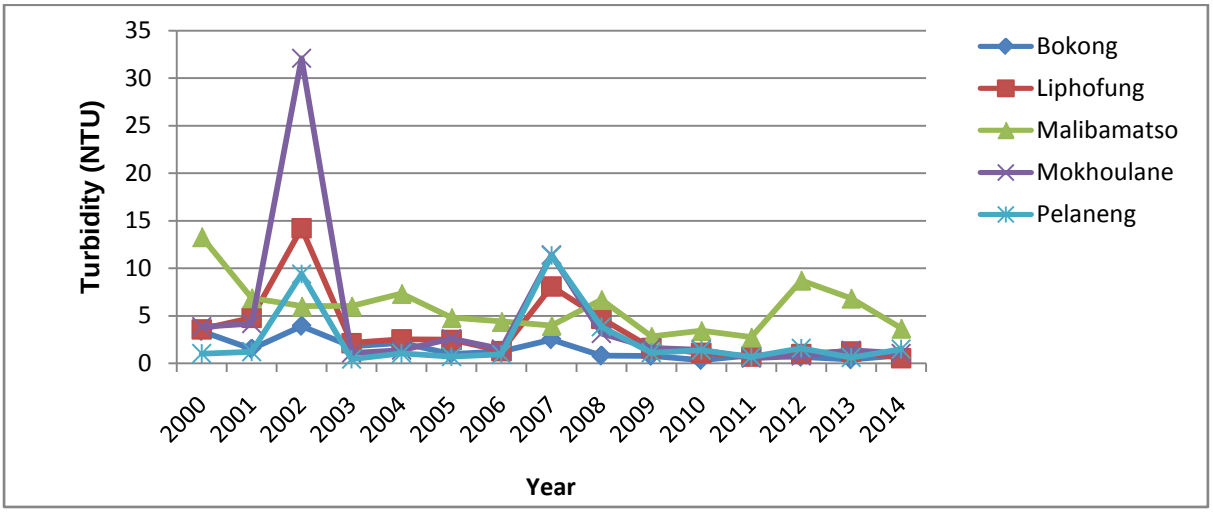


Figure 4.36: A comparison of water turbidity concentration between the five rivers from 2000 to 2014

(d) Dissolved oxygen

The concentration of dissolved oxygen was between 4 and 6 mg/l from 2000 to 2001 for all the rivers (Figure 4.37). However, during 2002, dissolved oxygen measurements were not taken in all the rivers. The concentration values were close in range from 2003 to 2014 in all the rivers, with the exception of the Malibamatso River where no measurements were taken until the year 2006.

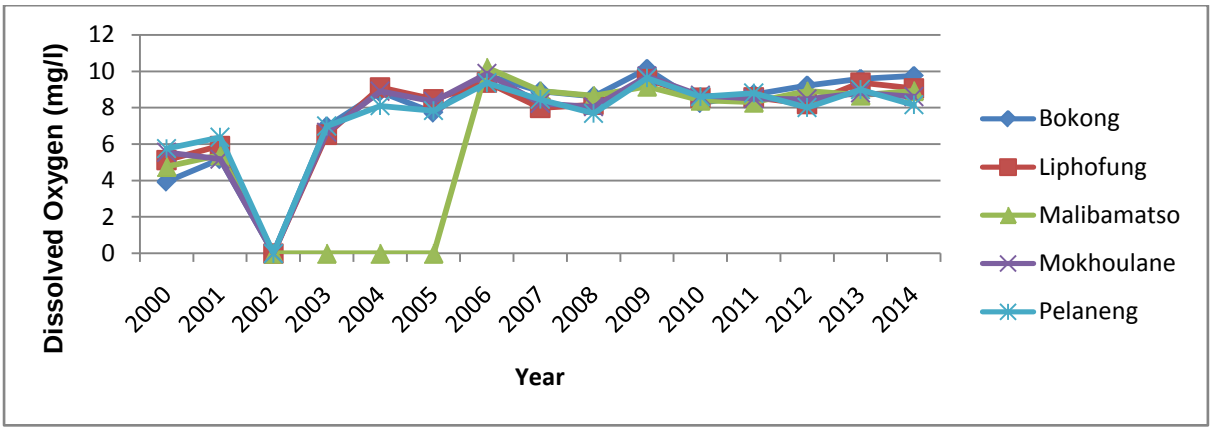


Figure 4.37: A comparison of dissolved oxygen concentration between the five rivers from 2000 to 2014

(e) Suspended solids

The concentration of suspended solids fluctuated quite considerably from 2000 to 2014 (Figure 4.38). The Liphofung River showed the highest concentration in 2002 but the concentration decreased to zero in 2003. The Malibamatso River then showed high concentrations from 2003 to 2006 and the Pelaneng River also showed high concentrations from 2007 to 2008.

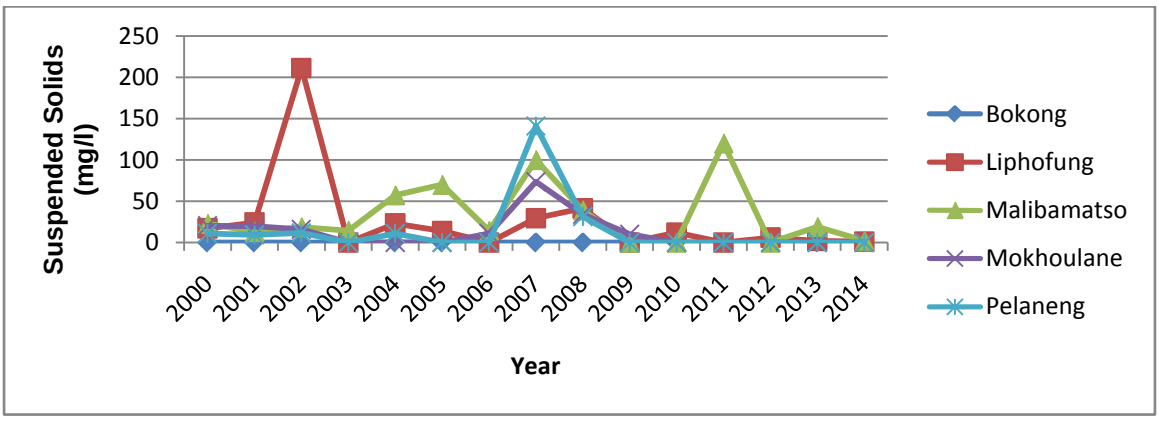


Figure 4.38: A comparison of suspended solids concentrations between the five rivers from 2000 to 2014

(f) pH

The water pH for the Bokong River was not measured in 2000 and 2001 (Figure 4.39). However, for the other rivers, the concentrations ranged from 7 to 9, with the Malibamatso River showing the highest pH value during 2012.

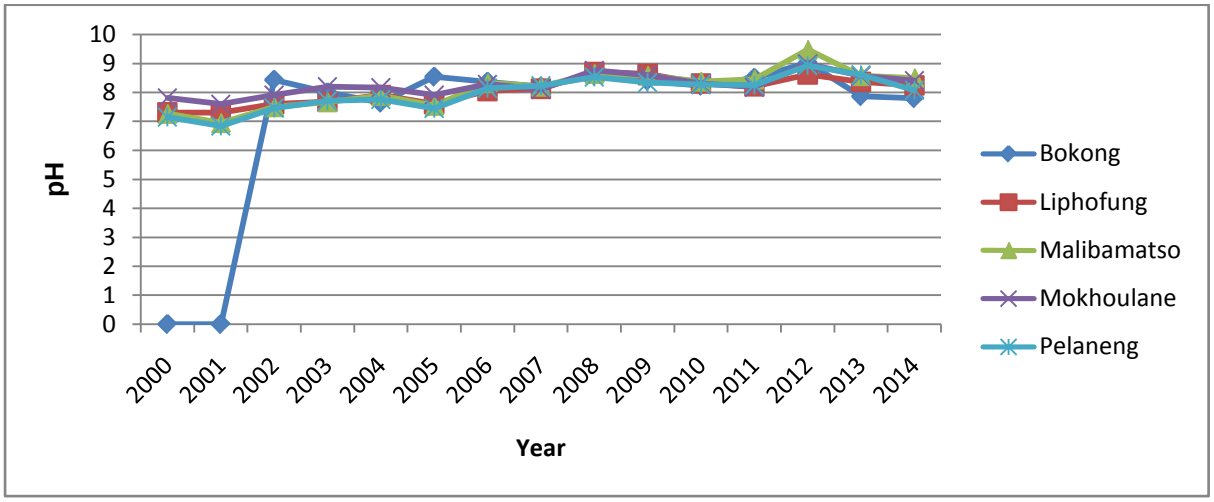


Figure 4.39: A comparison of water pH concentration between the five rivers from 2000 to 2014

4.6.3. Microbiological determinants

(a) Coliphage bacteria

The Liphofung River showed the highest concentration of coliphage bacteria from 2000 to 2003, 2005, 2006 and 2007, but then decrease sharply in 2008, fluctuating slightly until 2014 (Figure 4.40). The Malibamatso River also showed a peak concentration of coliphage bacteria in 2012.

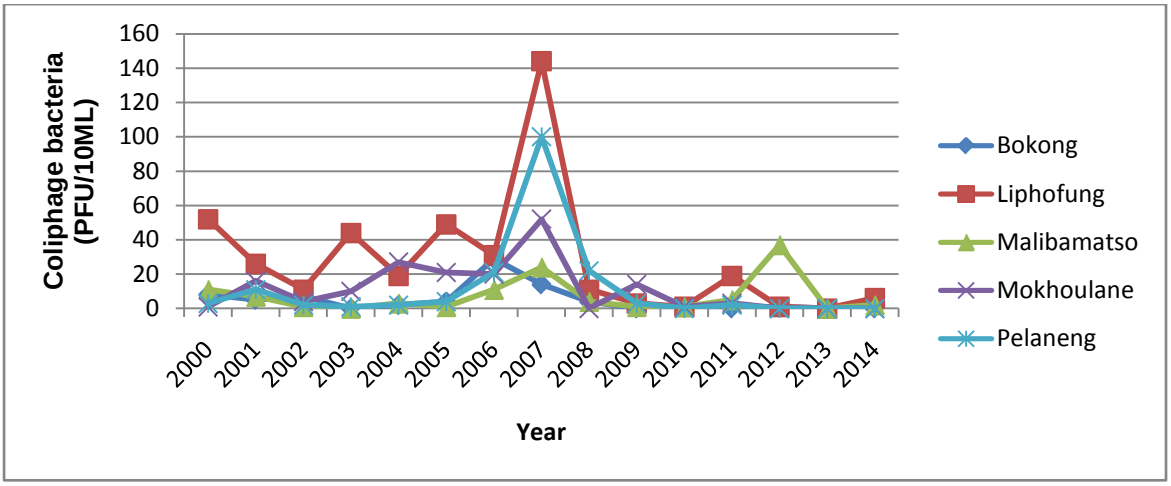


Figure 4.40: A comparison of coliphage bacteria concentration between the five rivers from 2000 to 2014

(b) Faecal coliform

The Liphofung River showed the highest concentration of faecal coliform from the year 2000 to 2008 (Figure 4.40), but then decreased to zero from 2008 to 2014. The Mokhoulane River also showed a peak concentration in the year 2009 but also decreased to zero from 2011 to 2014.

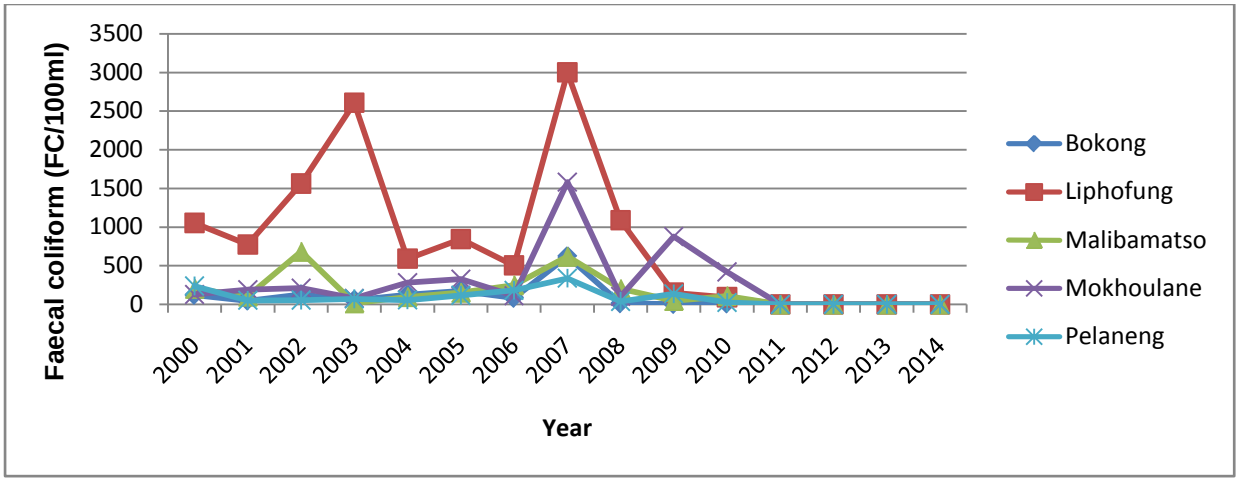


Figure 4.41: A comparison of faecal coliform bacteria concentration between the five rivers from 2000 to 2014

(c) *Escherichia coli*

The Liphofung River showed the highest concentration of *E.coli* bacteria from 2010 to 2014 (Figure 4.42). The bacterial concentrations were below the detection limit from 2000 to 2009.

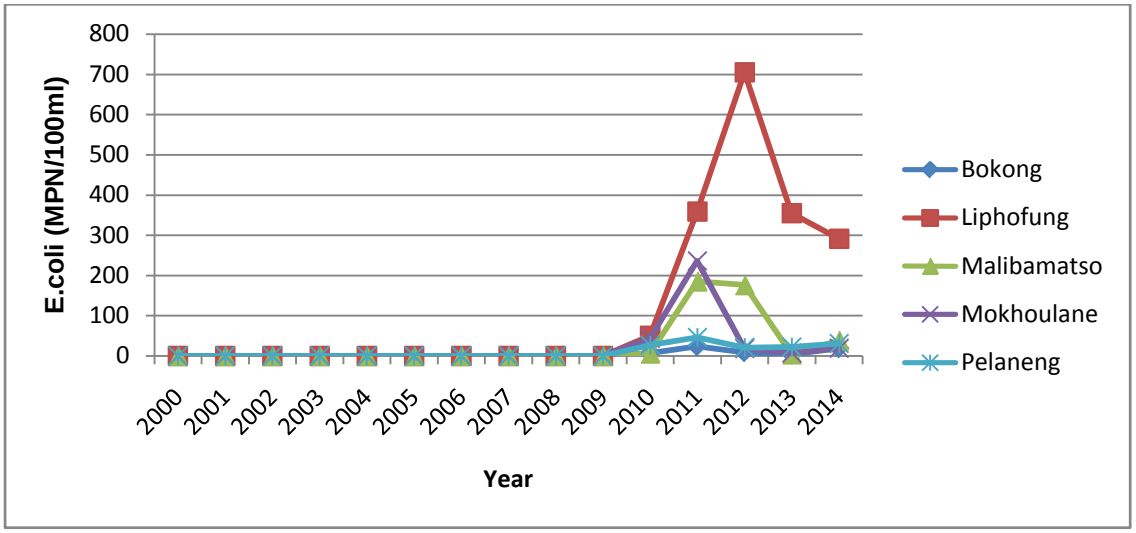


Figure 4.42: A comparison of *E. coli* bacteria concentration between the five rivers from 2000 to 2014

(d) *Giardia*

The Liphofung River showed the highest concentration of *Giardia* cysts (Figure 4.43) for most of the years in comparison with the Mokhoulane River which only had two *Giardia* cysts detections in 2006 and 2009. The cysts were below the detection limit for the other rivers throughout the 2000 to 2014 period.

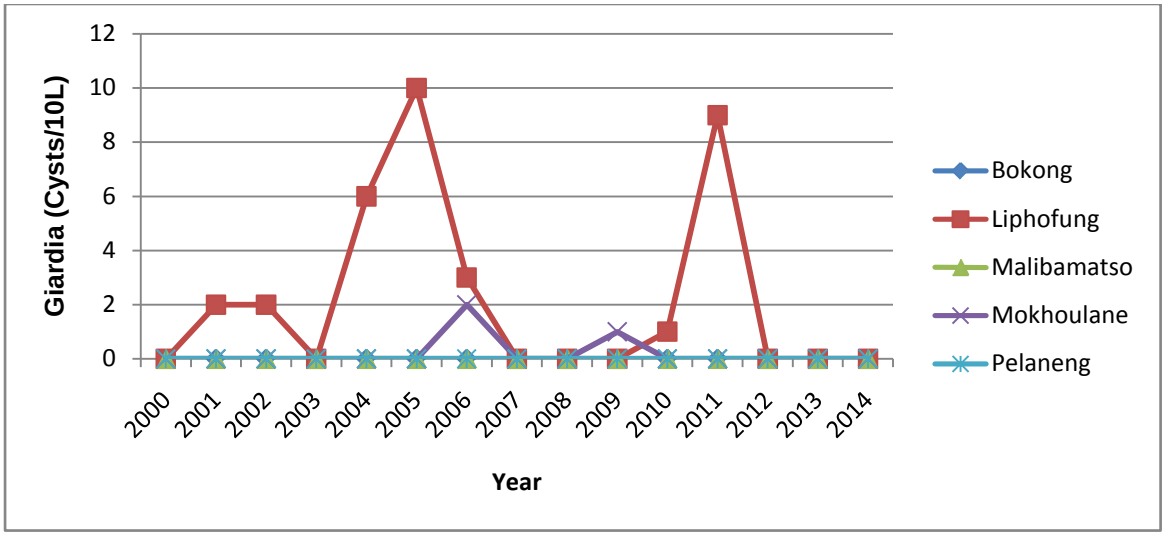


Figure 4.43: A comparison of *Giardia* concentration between the five rivers from 2000 to 2014

(e) *Cryptosporidium*

The concentrations of *Cyptosporidium* oocysts were highest in the Malibamatso and Bokong Rivers during 2010 and 2012 (Figure 4.44). However, there were no detections of this protozoon from 2000 to 2004 in all the rivers and no detections for the Bokong River for the entire study period.

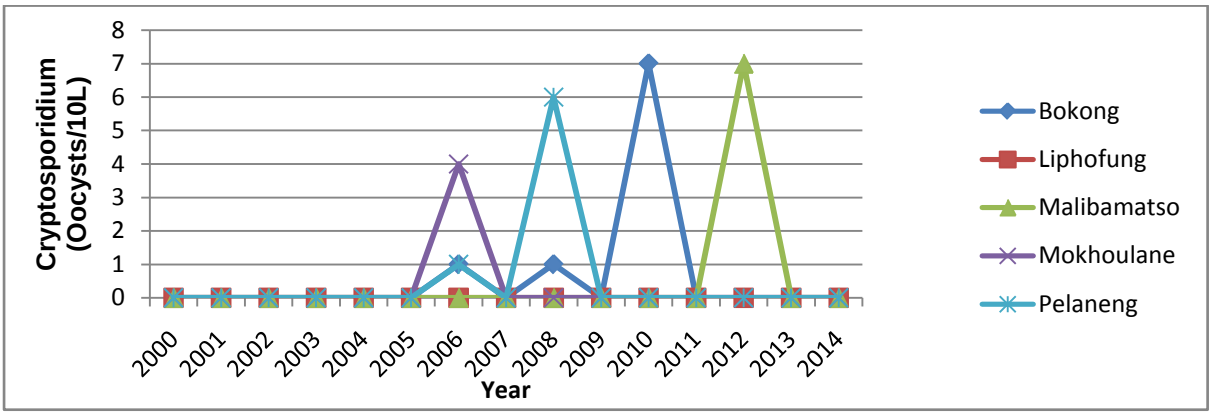


Figure 4.44: A comparison of *Cryptosporidium* concentration between the five rivers from 2000 to 2014

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CHAPTER 5

5. DISCUSSION AND CONCLUSION

5.1. General discussion

The conditions and activities that influence water quality are diverse and include natural and human influences. Natural influences include geological, hydrological and climatic factors while human activities that negatively impact the water quality are industrial, urban and agricultural activities (Palaniappan *et al*., 2010; WHO, 2011). The extent and severity of impact on the environment depends on the intensity, frequency and duration of a specific anthropogenic activity (Fulton and West, 2002; IPCC, 2012). For example, activities in a densely populated area would have a larger impact on the environment (Chigor *et al*., 2012), compared to a low density populated area (Pirrie *et al*., 2013).

The water quality of the selected rivers in the Katse Dam catchment area will therefore be a consequence of the combined effects of the natural processes and that of human activities. A large portion of the catchment area is characterized by rural and sparse human settlements, subsistence livestock farming and cultivation with a few small surrounding towns. Industrial activities are limited, but there are some diamond mining development activities. It is important to note that the population density in the catchment area has increased substantially over the past few years (BoS, 2014a; Kravitz *et al*., 1999; Mwangi, 2008), especially in the Leribe district which is part of the catchment area (Lewis *et al*., 2015).

Lesotho and thus the catchment area frequently experienced torrential rainfall and flooding, e.g. beginning of 2006, beginning of 2007, December 2010, February 2011; (World Agro Meteorological Information Centre, 2007; Reuters, 2006; World Food Programme, 2012), thus resulting in determinants like turbidity and total dissolved solids exceeding the SANS: 241, 2015 and the DWS Aquaculture (DWAF, 1996d) guidelines (Table 5.1). During heavy rainfall, there is also increased load of microbial fluxes e.g. *E.coli* (Table 5.1), exceeding the DWS Livestock & Watering and Aquaculture guidelines (DWAF, 1996c, 1996d) as well as contaminating metal fluxes e.g. lead (Table 5.1) due to the transport of fine sediment from surface soils to rivers and streams (Hostache *et al*., 2014) exceeding the WHO, 2011, SANS (2015), and

the DWS Aquaculture and Aquatic Ecosystems guidelines (DWAF, 1996d; 1996e). The impacts would thus generally be driven by the natural processes and some human activities.

Based on the comparisons of the water quality data for the various rivers against the guidelines proposed for drinking water (WHO, 2011 and SANS, 2015)), the indication is that the water quality of the rivers was of relatively good quality, complying with most of the water quality guidelines (Chapter 4: Tables 4.1 to 4.12). However, some of the determinants were non-compliant with one or more of the guidelines, but varied to some extent spatially (between rivers) as well as temporarily i.e. over the study periods (Chapter 4: Table 4.1 to 4.12; Tables 5.1 to 5. 6).

Table 5.1: Summary of non-compliant determinants to one or more of the guidelines and/or standards (Domestic, Irrigation, Livestock & Watering, Aquaculture & Aquatic ecosystems; WHO, 2011; SANS, 2015) for the Bokong River from 2000 to 2014

Determinants	Study Periods		
	A	B	C
Chemical determinants			
Aluminium	●	●	●
Ammonium	●	●	●
Copper	●	●	●
Nickel	●		
Iron	●		●
Lead	●		
Magnesium	●	●	●
Nitrite		●	
Zinc	●	●	●
Physical determinants			
Dissolved oxygen		●	●
Hardness	●	●	
Total dissolved solids	●		●
Turbidity	●	●	
Microbiological determinants			
Cryptosporidium		●	
Coliphage		●	
E.coli	●	●	●
Faecal coliform	●	●	

Table 5.2: Summary of non-compliant determinants to one or more of the guidelines and/or standards (Domestic, Irrigation, Livestock & Watering, Aquaculture & Aquatic ecosystems; WHO, 2011; SANS, 2015) for the Pelaneng River from 2000 to 2014

Determinants	Study Periods		
	A	B	C
Chemical determinants			
Aluminium	●	●	●
Ammonium	●	●	
Copper		●	●
Nickel	●		
Iron			●
Lead			
Magnesium	●	●	●
Nitrite	●		
Manganese			●
Zinc	●	●	
Physical determinants			
Dissolved oxygen			
Hardness	●	●	●
Total dissolved solids	●		●
pH at 25˚C			●
Suspended solids		●	
Turbidity		●	●
Microbiological determinants			
Cryptosporidium		●	
Coliphage	●	●	
E.coli		●	●
Faecal coliform	●	●	

Table 5.3: Summary of non-compliant determinants to one or more of the guidelines and/or standards (Domestic, Irrigation, Livestock & Watering, Aquaculture & Aquatic ecosystems; WHO, 2011; SANS, 2015) for the Mokhoulane River from 2000 to 2014

Determinants	Study Periods		
	A	B	C
Chemical determinants			
Aluminium	●	●	●
Ammonium	●	●	
Copper		●	●
Nickel	●		
Iron			
Lead	●		
Magnesium	●	●	●
Nitrite		●	
Manganese			●
Zinc	●	●	
Physical determinants			
Dissolved oxygen			
Hardness		●	●
Total dissolved solids	●	●	●
pH at 25˚C			●
Suspended solids			
Turbidity	●	●	●
Microbiological determinants			
Cryptosporidium		●	
Coliphage	●	●	
E.coli		●	●
Faecal coliform	●	●	

Table 5.3: (Continued) Summary of non-compliant determinants to one or more of the guidelines and/or standards (Domestic, Irrigation, Livestock & Watering, Aquaculture & Aquatic ecosystems; WHO, 2011; SANS, 2015) for the Mokhoulane River from 2000 to 2014

Determinants	Study Periods		
	A	B	C
Microbiological determinants			
Giardia		●	

Table 5.4: Summary of non-compliant determinants to one or more of the guidelines and/or standards (Domestic, Irrigation, Livestock & Watering, Aquaculture & Aquatic ecosystems; WHO, 2011; SANS, 2015) for the Malibamatso River from 2000 to 2014

Determinants	Study Periods		
	A	B	C
Chemical determinants			
Aluminium	●	●	●
Ammonium	●	●	
Copper		●	●
Nickel	●		
Iron			
Lead			
Magnesium	●	●	●
Nitrite	●		
Manganese			●
Zinc	●	●	●
Physical determinants			
Dissolved oxygen	●	●	
Hardness	●	●	●
Total dissolved solids	●	●	●
pH at 25˚C			●
Suspended solids		●	
Turbidity	●	●	●
Microbiological determinants			
Cryptosporidium			●
Coliphage	●	●	●
E.coli		●	●
Faecal coliform	●	●	
Giardia			

Table 5.5: Summary of non-compliant determinants to one or more of the guidelines and/or standards (Domestic, Irrigation, Livestock & Watering, Aquaculture & Aquatic ecosystems; WHO, 2011; SANS, 2015) for the Liphofung River from 2000 to 2014

Determinants	Study Periods		
	A	B	C
Chemical determinants			
Aluminium	●	●	
Ammonium	●	●	
Copper		●	●
Nickel	●		
Iron			
Lead			
Magnesium	●	●	●
Nitrite	●	●	
Manganese			
Zinc	●	●	●
Physical determinants			
Dissolved oxygen		●	●
Hardness	●	●	●
Total dissolved solids	●	●	●
pH at 25˚C			
Suspended solids	●		
Turbidity		●	
Microbiological determinants			
Cryptosporidium			
Coliphage	●	●	●
E.coli		●	●
Faecal coliform	●	●	
Giardia	●	●	

Table 5.6: Summary of non-compliant determinants to one or more of the guidelines and/or standards (Domestic, Irrigation, Livestock & Watering, Aquaculture & Aquatic ecosystems; WHO, 2011; SANS, 2015) for the Bokong River, Pelaneng, Mokhoulane, Malibamatso and Liphofung Rivers from 2000 to 2014

Determinants	Selected Rivers				
	Bokong	Pelaneng	Mokhoulane	Malibamatso	Liphofung
Chemical determinants					
Aluminium	●	●	●	●	●
Ammonium	●	●	●	●	●
Copper	●	●	●	●	●
Nickel	●	●	●	●	●
Iron	●	●			
Lead	●		●		
Magnesium	●	●	●	●	●
Nitrite	●	●	●		
Zinc	●	●	●	●	●
Physical determinants					
Dissolved oxygen	●	●		●	●
Hardness	●	●	●	●	●
Total dissolved solids	●	●	●	●	●
pH		●	●	●	●
Turbidity	●	●	●	●	●
Suspended solids		●			●
Microbiological determinants					
Cryptosporidium	●	●	●	●	

Table 5.6: (Continued) Summary of non-compliant determinants to one or more of the guidelines and/or standards (Domestic, Irrigation, Livestock & Watering, Aquaculture & Aquatic ecosystems; WHO, 2011; SANS, 2015) for the Bokong River, Pelaneng, Mokhoulane, Malibamatso and Liphofung Rivers from 2000 to 2014

Determinants	Selected Rivers				
	Bokong	Pelaneng	Mokhoulane	Malibamatso	Liphofung
Microbiological determinants					
Coliphage	●	●	●	●	●
Faecal coliform *or E.coli*	●	●	●	●	●
Giardia		●	●		●

5.2. Non-compliant water quality determinants and possible impacts

There was not a large variation on the number of total non-compliant water quality determinants between the five rivers (Table 5.7). However, between guidelines, there was a large variation. In most of the rivers, Study Period: B had a higher number of non-compliant determinants and Study Period: C had the least non-compliant determinants (Tables 5.1-5.5). Based on this assessment, the water was of a better quality during this study period because of the fewer non-compliances recorded, compared to Study Periods: A and B, which had more non-compliances.

Compliance was low for the DWS Aquaculture and Aquatic Ecosystems guidelines. Therefore the water seems to be less unfit for aquaculture and aquatic ecosystems uses. From an aquaculture perspective, this seems contradictory as trout farming is successfully being practised in the Katse Dam (Eilertsen, 2013). Furthermore, for specific aquaculture activities, small changes in concentration of a particular determinant may have an impact on the organisms e.g. during floods, hence the stringent guideline values (DWAF, 1996d). The compliance was high for the Domestic, Livestock & Watering and Irrigation guidelines (Table 5.7), thus the water is fit for domestic, livestock, watering and irrigation purposes, which are the main anthropogenic activities taking place in the catchment area. The main concern may be the microbial contamination if the water is used without basic treatment.

Table 5.7: Comparison of the total number of non-compliant determinants per river and per guideline over the study period

River	Standard or guideline							Total number of non-compliances per river
		DWAF						
	WHO (2011)	SANS :241 (2015)	Domestic (1996a)	Irrigation (1996b)	Livestock & Watering (1996c)	Aquaculture (1996d)	Aquatic Ecosystems (1996e)	
Bokong	13	12	8	3	0	13	10	59
Malibamatso	9	8	8	5	1	13	13	57
Mokhoulane	11	11	8	3	0	12	12	57
Pelaneng	9	11	7	5	0	11	11	54
Liphofung	10	9	8	4	2	12	10	55
Total / guideline	52	51	39	20	3	61	56	

5.2.1. Chemical determinants

(a) Aluminium

The river with the highest concentration of aluminium was the Pelaneng. The concentration of aluminium was highest in 2002 at 0.5 mg/l (Chapter 4: Figure 4.25) and gradually decreased towards 2014. The concentration of aluminium in the Pelaneng River was non-compliant with the DWS Aquaculture (DWAF, 1996d) and Aquatic Ecosystems (DWAF, 1996e) guidelines. However, the water in the Pelaneng River is fit for drinking according to SANS: 241(2015), DWS Irrigation, Livestock and Watering (DWAF, 1996b; 1996c) and also meets the WHO (2011) guidelines.

Non-compliance with the aquaculture and aquatic ecosystems guidelines might have negative implications for both flora and fauna in the water bodies. This is because aluminium is a trace metal whose solubility is linked to the prevailing pH of the water. Its toxicity increases in acidic conditions, as it reacts with ligands to form more toxic, chemical forms (Inostroza-Blancheteau *et al*., 2011). However, the pH of the Pelaneng River was compliant with all of the guidelines in Study Periods: A and B, but non-compliant (pH 8.57) with the DWS Irrigation guideline of pH 8.4, in Study

Period: C only. Thus the prevailing pH would not have contributed to the toxicity of aluminium. Therefore, impacts in the aquatic environment and human health would not be expected and only on human health when they ingest fish that have accumulated aluminium in their body tissue. It is necessary to note that at concentrations above 0.03 mg/l, the effects on fish health begin to manifest in aquaculture (DWAF, 1996d) water systems. This is because aluminium interferes with basic cellular functions e.g. it interferes with intracellular calcium signal pathways, which are involved in a wide range of metabolic cellular functions (Oberholzer *et al*., 2012). Since the detected concentration was 0.5 mg/l, toxic effects on fish can be expected. However with the high pH range, the aluminium would not be bioavailable and would thus not impact on the fish.

Lesotho is dominated by two types of soils i.e. Mollisols and Alfisoils (Mills *et al*., 2009). Alfisolis have a coarse top layer with fine clay underneath and dominated by aluminium and iron particles (Williams, 2014). The aluminium levels in the Pelaneng River could therefore be attributed to the high levels of aluminium in the soil which would mobilise from the soil and sediment via weathering processes making it detectable in surface water (DWAF, 1996e). This process should however be investigated in future studies.

(b) Ammonium

The Bokong River showed the highest ammonium concentration of greater than 3 mg/l during the first study period i.e. 2000 to 2005 (Chapter 4: Figure 4.26). This concentration was non-compliant with the SANS: 241 (2015) and DWS Aquaculture (DWAF, 1996d) guidelines, making it less fit for drinking and use in aquaculture. However, from 2006 to 2014, the concentration decreased substantially. In 2006, the Pelaneng River showed the highest concentration and in 2010, the Malibamatso River showed the highest ammonium concentration. The noted peaks of ammonium in 2006 (Pelaneng River) and 2010 (Malibamatso) could be attributed to run-off during the high flows when there were torrential rains in Lesotho (WFP, 2012).

The Bokong River also showed the highest concentration of about 0.09 mg/l of nitrite during Study Period: B, from 2007 to 2011 (Chapter 4, Figure 4.32), which ties in with the highest ammonium concentration in the first Study Period (Chapter 4: Figure

4.26). At this concentration, nitrite was non-compliant with the DWS Aquaculture guideline of 0.05 mg/l (DWAF, 1996d). The aquatic ecosystems guideline recommends an ammonium concentration of less than 0.007 mg/l, to minimize impacts on the aquatic environment (DWAF, 1996e). The sources of ammonium in the environment are quite diverse, ranging from agricultural, industrial and metabolic processes and their detection in water indicates possible sewage and animal faecal pollution (WHO, 2011).

Within the Katse Dam catchment area, there is livestock grazing, thus high amounts of livestock waste material are deposited on the soil surface. The rural communities around the catchment area do not have proper sanitation facilities. Therefore, they use the natural environment to relieve themselves and the human waste is thus not controlled. Due to the steep slopes in the area, the livestock and human waste is washed down during rainfall events and when the soil erodes, reaching the rivers and streams lower down (United States Agency for International Development, 2007; Mwangi, 2008). In Bothe-Bothe, farmers directly apply urea and cow manure as fertilizer. Between 28% and 46% of the fields receive this type of fertiliser. In Leribe, farmers use inorganic fertilizers to improve yields (Mokuku *et al*., 2002; Lewis *et al*., 2015). Thus the high ammonium and nitrite levels could be attributed to these livestock and human waste materials being washed into the river, as well as the direct application of urea and cow manure as fertilizer to the soil which leaches into the rivers.

Since the water was non-compliant with the SANS: 241 (2015) drinking water, there is a risk of methemoglobinemia in babies who ingest water polluted with nitrite concentration of greater than 1.0 mg/l. Methemoglobinemia is a condition whereby the red blood cells cannot transport oxygen in the blood (Kumar & Puri, 2012). Since the rural communities around the valley side of the catchment area draw water from the rivers and use it for domestic purposes without necessarily treating the water, there is a health risk associated with the detected ammonium concentration of 3 mg/l in the surface water (Kravitz *et al*., 1999) compared with the SANS: 241 (2015) recommended value of 1.0 mg/l and 1-2 mg/l for limited periods. However, in recent years the ammonium leves were well within specification levels.

(c) Copper

The Pelaneng River showed the highest concentration of copper in 2010 namely 0.1 mg/l, which decreased sharply in 2011 to 2014 (Chapter 4: Figure 4.27). The concentration complied with all water quality guidelines with the exception of the DWS Aquatic Ecosystems (DWAF, 1996e) guideline, which recommends a concentration of 0.0012 mg/l, 0.0024 mg/l as the chronic effect value and 0.0075 mg/l as the acute effect value.

The concentration of copper (0.1 mg/l) in the Katse Dam catchment area could be attributed to the drainage seeping from the Kao open-pit diamond mine into waterways and tributaries, ending up in the river systems. The mine is located about ten kilometers from the Malibamatso River. Waste rock from mining activities can pollute surface water bodies when they produce acidic runoff, mobilizing heavy metals such as copper, lead and nickel. Another mechanism is the transportation of small particles of waste rock by sediments during storm events and by wind in arid climates such as the climate in Lesotho (Namakwa Diamonds Limited, 2012; Sims *et al*. 2013). Because of the nature and size of the sediment particles (less than 2 mm) and the bare and steep slopes of Lesotho, the particles are redistributed by wind and stormwater, thus spreading the contamination over greater distances and impacting a wider area (Sanghoon, 2006). Hence presence of these metals could be detected in the catchment area.

A study on the extent of surface water pollution by industrial effluents was conducted in the waterways of the major towns of Lesotho, including Ha-Nyenye, in Leribe District (Pullanikkatil and Urama, 2011). The study area does not cover the catcment of interest. However, the study concluded that sources of copper were found to be diffuse and from textile industries, slurry from mining activities, brewing industries and canneries. All these industries mentioned make use of water for different purposes and releases it into the surface water as wastes. However, the specific contribution of each of these activities and copper loads must still be investigated. The average upstream water concentration for copper was 0.73 mg/l which, when compared to the South African water guidelines there was non-compliance with the DWS Irrigation and Livestock & Watering guidelines and Aquatic Ecosystems

(DWAF, 1996b; 1996c; 1996e). The average downstream copper concentration was 0.25 mg/l (Pullanikkatil & Urama, 2011).

The non-compliance (0.1 mg/l) is way above the recommended guideline for aquatic ecosystems (0.0012 mg/l) and could be detrimental to the aquatic environment because copper is a toxic compound and its toxicity is linked to the hardness of the water i.e. its toxicity increases with decreasing water hardness. High copper concentrations disrupt enzyme functioning, carbohydrate metabolism and reproductive potential in aquatic organisms (Solomon, 2009). There is a fish rearing facility around the Katse dam catchment area and the high copper concentrations could affect the production of fish in the facility (Eilertsen, 2013). However, the bioavailability of the copper for uptake may be less due to the alkaline water conditions.

The study by Pullanikkatil and Urama, (2011) that was undertaken in areas located outside the Katse Dam catchment area, concluded that livestock are feeding on land flooded by the industrial effluent with high copper concentration. The livestock's health is at risk as copper contamination causes liver damage and gastrointestinal discomfort. Copper toxicity in crops and plants can have an impact on crop yield. Therefore, effluents and drainage from the mine need to be monitored to asses the copper levels as well as the general water quality in order to implement mitigation measures if required and to reduce the impact on human and animal life and the environment at large. Nevertheless, the data in this study indicates that the water from the rivers entering the Katse Dam contain relatively low levels of copper compared to the studies on the water- ways of the major towns of Lesotho (Pullanikkatil and Urama, 2011).

(e) Nickel

The Bokong River had the highest nickel concentration of 0.18 mg/l in 2006 (Figure 4.29). This concentration was not in compliance with the WHO (2011), concentration of 0.07 mg/l and SANS (2015) concentration of 0.15 mg/l drinking water guidelines. Nickel concentration was below the detection limit from 2007 to 2014. However, there's a similar pattern on the concentration detected for all the rivers from 2001 to 2005. Although the nickel levels in recent years are very low, the recorded high

values from 2002 to around 2006 support the idea that the nickel levels should be monitored and especially in the catchment areas were mining operations are taking place.

(f) Manganese

As illustrated in Figure 4.30, Chapter 4, the Bokong River showed the highest manganese concentration of 0.27 mg/l in the year 2000, during Study Period: A. this concentration was non-compliant with the DWS Irrigation (0.02 mg/l), Aquaculture (0.1 mg/l) and Aquatic Ecosystems guidelines (0.18 mg/l) (DWAF, 1996b; 1996d; 1996e). From 2001, the concentration decreased substantially, fluctuating slightly until 2014. On the contrary, the Malibamatso River showed distinct peak concentrations in the 2001, 2003, 2007, 2010 and 2014.

The Bokong River catchment area is dominated by wetlands with two soil types, namely; Umbrisols and Stagnasols (Mapeshoane, 2013). Stagnasols are soils which periodically experience water stagnation on the upper, permeable soil profile leading to waterlogging, saturation and mobilization of iron or manganese (Jones *et al*., 2010). In wetlands environments, the water table fluctuation tends to promote the formation of secondary iron and manganese or manganese oxides resulting in increased concentrations depending on the depths of the soil profile. The solubility of manganese is increased under these periodic saturated conditions (Mapeshoane, 2013). Therefore, the manganese concentration of the Bokong River could be attributed to the hydraulic and redox gradients of the soil profile which promote the formation of manganese and iron.

Manganese is an essential micronutrient required by living organisms and is essential in glucose utilization (Förstner & Wittmann, 2012). Concentrations of greater than 0.1 mg/l in drinking water can cause undesirable taste but the WHO has a 0.4 mg/l health based guideline value. At concentrations above 0.4 mg/l, manganese can be toxic and exposure to high concentrations may lead to neurological impairment in humans and aquatic organisms, as the water in this catchment area is also used for drinking (Dallas & Day, 2004; US EPA, 2004; WHO, 2011). High concentrations of dissolved manganese may also bio-accumulate in the tissue of aquatic organisms, increasing the mortality rate of some aquatic organisms

(Stubblefield *et al.*, 1997; WHO, 2011). Since the surface water is also used for irrigation purposes in this catchment area, manganese toxicity and decreased crop yield can be observed at concentrations from 0.02 to 10 mg/l (DWAF, 1996b). Therefore, the detected concentration of 0.27 mg/l may affect the productivity of some crops.

(g) Zinc

The concentration of zinc was persistently high in all the rivers, especially during Study Period: A and Study Period: B. However, the Pelaneng and Bokong Rivers showed the highest concentration of 0.18 mg/l or 180 µg/l in 2009 (Chapter 4, Figure 4.33), exceeding the DWS Aquatic Ecosystems guideline of 2µg/l (DWAF, 1996e). However, the general trend of all the rivers showed a gradual increase in zinc concentration in Study Period: B and Study Period: C.

The zinc concentration at the Bokong River could be attributed to the prevailing high temperatures in the catchment area. High temperature conditions can cause zinc levels to increase sharply. During the hot, summer temperatures, stream flow decreases leaving the soil drier and causing the metal concentration to increase (Scott, 2010). Since Lesotho has high temperatures of around 29˚C during the summer months (Lesotho Meteorological Services, 2000), it is possible that the persistently high zinc concentrations in all the rivers could be attributed to the above scenario of desorption from sediments because of the high temperatures.

Since the population around the catchment area uses stream and river water for drinking and agricultural purposes, the health of both humans and animals may be impacted. The detected zinc concentration of 180 µg/l is much higher compared with the acceptable chronic effect value of 3.6 µg/l (DWAF, 1996e). Therefore, at this very high concentration, humans and animals may experience gastro-intestinal disturbances. Aquatic ecosystems can't be protected when the chronic effect value is above 3.6 µg/l. At this high concentration of zinc, there will be a decrease in the rate of algal photosynthesis and low white-blood cell counts in fish in aquatic ecosystems, upsetting the effective functioning of the entire ecosystem (DWAF, 1996a; 1996e).

(h) Lead

Lead concentrations were only detected during Study Period: A in the year 2001, 2003 and 2004. The highest peak concentration of above 0.09 mg/l was in 2001 in the Bokong River (Figure 4.31, Section 4.2.) which was non-compliant with the SANS: 241 (2015), WHO (2011), DWS Aquaculture (DWAF, 1996d) and Aquatic Ecosystems (DWAF, 1996e) guideline values of 0.01 mg/l.

The occurrence of lead in the catchment area could possibly be due to the mining activities in the catchment area. In late 2001, Lesotho experienced unexpected heavy rains such that the months of October to December were extremely wet (Obioha, 2010). Therefore, it is possible that because of the high temperatures and wet conditions, lead could have mobilised from sediments and leached from the waste rock in 2001 (Mokuku *et al*., 2002; DWAF, 1996a), leading to the detected concentrations in the surface waters. In 2003 and 2004, there was maximum distribution of rain of about 1500 mm (Obioha, 2010), which also coincides with a detection of lead of 0.01 mg/l in the Bokong and Mokhoulane rivers (Figure 4.31). However, this possibility requires futher investigation.

Since most of the rural communities obtain their drinking water from unprotected streams (Mokuku *et al*., 2002), therefore their health will be impacted negatively by the lead concentration (0.09 mg/l) in the water they collect to drink. It is interesting to note that at concentrations of above 10 g/l (DWAF, 1996a), lead causes birth defects, brain and kidney damage on a long-term basis and also bio-accumulate in the tissues of aquatic organism, becoming fatal in the long-term (WHO, 2011; DWAF, 1996a). However, the lead concentration in the surface water of the rivers is generally low and thus, does not pose a risk to the various users.

5.2.2. Physical determinants

(a)Total dissolved solids, turbidity and suspended solids

There is diamond or kimberlite mining activity around the Katse Dam catchment area, about nine kilometers from the Malibamatso River (Namakwa Diamond Limited, 2012). The waste rock, sand and soil that comes out of the kimberlite mining is dominated by kimberlite tailings which contain particulate matter such as silica,

alumina, iron oxides and magnesia, contributing to the total dissolved solids, suspended solids content and turbidity of the river water (Swami *et al*., 2007; Kumar & Shama, 2015). This makes the Malibamatso River water to be more turbid as the mine is close to the Malibamatso River. It was noted however, that the concentration of silica, alumina, iron oxides and magnesium were all within the water quality guidelines for the Malibamatso River and it appears that the upstream mining activities are not contributing significantly to the concentrations of these water quality determinants in the water of Malibamatso River just before it enters the Katse Dam.

Mining activities tend to increase total dissolved solids concentration of rivers in close proximity e.g. a ten-fold increase in total dissolved solids in the Olifants River, South Africa over a period of 30 years was observed. The increase was linked to the waste rock from coal mining activities around the area (McCarthy & Pretorius, 2009). The concentration of suspended material or silt in a river is of utmost importance, because at high concentration, the water becomes turbid. High water turbidity has some negative influences in a water body, such as decreasing the rate of photosynthesis because of the reduced light penetration. This impacts the primary productivity of the stream (Dallas & Day, 2004). High turbidity has caused fish kills in the Olifants River with the suspended material clogging the fish gills, reducing the ability of the fish to absorb oxygen. Over the long-term, the fish become susceptible to diseases, the reproductive potential and growth rate of the offspring become reduced and oxygen consumption patterns altered (Buermann *et al*., 1995).

The variation in turbidity is illustrated in Figure 4.36, Chapter 4, section 4.5.2, with the Malibamatso River having the highest turbidity levels in 2000, 2003 to 2006 and from 2008 to 2014. Even though the Mokhoulane River exhibited a peak turbidity concentration of 32 NTU in 2002 and the Bokong River in 2007, it was the Malibamatso River exhibiting consistently high turbidity levels during the study periods. At this concentration, there is non-compliance with the SANS: 241 (2015) water guideline of 1.0 NTU.

The high turbidity was due to the high concentration of suspended solids (Figure 4.38, section 4.5.2, Chapter 4), where the Malibamatso River had substantially high concentrations for most of the Study Period. The peak concentration of suspended

solids of 210 mg/l during the year 2002 in the Liphofung River and in 2007 of 140 mg/l at the Pelaneng River could be attributed to heavy rainfall events that occurred during those two years. This concentration of 210 mg/l far exceeds the 50 mg/l value given by the DWS Irrigation guideline (DWAF, 1996b).

In addition, during the 2011/2012 droughts in Lesotho, the mine was extracting water from the Malibamatso River through an installed pipeline to sustain the mining activities (Namakwa Diamond Limited, 2012). Direct water extraction from a river reduces stream flow or velocity, reduces the amount of stream area wetted, reduces stream depth of the river and eventually, downstream water discharge. The extraction leaves the river water with high levels of suspended solids and sulphates which could also lead to low dissolved oxygen concentration (McKay and King, 2006).

Total dissolved solids and suspended solids are closely related to stream flow and velocity (WHO, 2011), hence the total dissolved solids of the Malibamatso River showed an increase when stream velocity was reduced because of the water extraction to support the mine. The Mokhoulane River had the highest concentration of 120 mg/l for total dissolved solids in 2003, being non-compliant with the DWS Aquaculture guideline value of 0.02 mg/l for stenohaline and 0.12 mg/l for euryhaline species. Therefore, at this high concentration of 120 mg/l, the eggs and larvae of stenohaline fish species would have a high mortality rate because of loss of homeostatic balance and metabolic dysfunction caused by the high total dissolved solids (DWAF, 1996d).

(b) Dissolved oxygen

Dissolved oxygen is essential for the survival of all aquatic organisms and is a well established indicator of the quality of water (Akkoyunlu and Akiner, 2012). With the exception of the periods where no measurements were taken, most of the rivers were compliant with the 6-9 mg/l DWS Aquaculture and 80-120% saturation of the DWA &S Aquatic Ecosystems water guidelines (DWAF, 1996d, 1996e).

A concentration of 10 mg/l which is above the saturation level was noted in 2010 at the Bokong River (Figure 4.37, Section 4.5.2, Chapter 4) during Study Period: B.

According to the DWS Aquatic Ecosystems guideline, saturated and super saturated conditions inhibits photosynthesis in green algae, favouring the excessive growth of blue-green algae which becomes a nuisance in aquatic ecosystems. Concentrations above saturation can also cause gas bubbles disease in fish causing them to die (DWAF, 1996e). However, impacts would not be so severe given the concentration of 10 mg/l, which is a little over the target water quality range of 6 to 9 mg/l. Similarly, during Study Period: A, the Malibamatso River had a slightly low oxygen concentration of 5.04 mg/l (Table 4.10) than guideline value and thus, impact is not expected. It is also important to note that at high altitude river systems the dissolved oxygen concentration will be naturally low, while the impact on the quality of the system will also be a function of the duration of the low dissolved oxygen situation.

(c) Water hardness

Water hardness was non-compliant with the DWS Domestic guideline for all the rivers, with the exception of the Mokhoulane River which was compliant for only Study Period: A. The concentration was below the DWS Domestic guideline value of 50 to 100 mg/l $CaCO_3$ for all the non-compliances, and thus not fit for drinking. However, the rivers were compliant with the DWS Aquaculture guideline value of 20 to 100 mg/l $CaCO_3$ (Figure 4.34, Section 4.5.2, Chapter 4), except for the Bokong which was non-compliant in Study Period: C.

The non-compliance (concentration of 15 mg/l) means that the water is relatively “soft”, as the concentration was below the guideline value of 50 to 100 mg/l. This is confirmed by the pH (7-9) observed during the whole study period. Soft water is alkaline and low in calcium carbonate, meaning that the acid buffering capability of the system is low. Lesotho surface waters are known to be soft, with low levels of calcium carbonate and alkalinity (De Souza *et al*., 2002). Therefore, the dominant soft water in the catchment area is linked to the dominant rock type (Wirmver *et al*., 2013). Soft water is associated with species-poor communities of wetland plants and contributes to macrophyte deterioration in aquatic ecosystems (Arts, 2002). Other implications of soft water in the aquatic environment are that because soft water has low calcium and magnesium levels, sodium levels tend to increase causing long-term effects in the ecosystem (Charles *et al*., 2002; Li *et al*., 2013). Soft water also impacts and corrodes domestic water pipes (Lytle & White, 2014). Therefore, given

that the concentration for some of the rivers was as low as 15 mg/l, e.g. Bokong River in 2013, such impacts can be expected within the aquatic environment.

(d) pH

The pH of all the rivers was consistent between 7 and 9 throughout the Study Periods (Figure 4.39, Section 4.5.2, Chapter 4). No acidic conditions were recorded. The Bokong River showed two peak concentrations in 2002 (pH of 8.4) and 2005 (pH of 8.3) which were compliant with all the water quality guidelines, whilst the Malibamatso River showed a peak of above 9 only in 2012, showing non-compliance with the DWS Domestic water guideline (DWAF, 1996a).

The highest pH was in 2012, coinciding with the extraction of water from the Malibamatso River. When water is extracted from a river, the salinity tends to increase because of the increased suspended solids and turbidity. Consequently, the pH increase when salinity increases until calcium carbonate saturation occurs (Saraswat *et al*., 2011). According to Chutter (1993), the Malibamatso River is dominated by calcium carbonate, with low conductivity and nutrient content and a pH ranging from 7.2 to 7.6, therefore a pH above 9 was above the expected pH range. Low pH concentrations tend to increase the concentration of heavy metals by leaching. Aluminium salts are leached out at high pH conditions, and precipitated out as a carbonate compound. This also explains the high aluminium levels in the water. The precipitates can negatively impact on fish and other aquatic organisms (Alabaster & Lloyd, 2013).

5.2.3. Microbiological determinants

***(a) E. coli*, coliphage bacteria and faecal coliform**

The Liphofung River showed the highest concentrations of *E.coli*, coliphage bacteria and faecal coliforms throughout the Study Periods (Figures 4.40, 4.41 and 4.42) and was non-compliant with most of the water quality guidelines. For example, the Liphofung River had a concentration of 140 CFU/10ml in 2007 for Coliphage bacteria and 700 MPN/100 ml for *E. coli* in 2012 (Figures 4.40 and 4.42), whereas the domestic water guideline has a guideline value of 1 CFU/10 ml and 200 MPN/100ml for the Livestock and Watering guideline. The concentration of faecal coliform for the

Liphofung River was 3000 FC/100ml in 2007 (Figure 4.41), complying only with the DWS Irrigation guideline of 10 000 FC/100ml (DWAF, 1996b).

The high concentrations of these bacteria in water indicates that there has been recent faecal contamination, most probably linked to the faecal matter deposited by grazing of animals and people living close to the river (National Nonpoint Source Monitoring Program, 2013). When it rains, the faecal matter flows into the tributaries and eventually into the main river, contaminating the river. This also poses a health risk because the community members draw water from the river and use it for drinking without necessarily treating the water (Chigor *et al*., 2013).

The valleys of the Liphofung River are more densely populated and a tourist attraction area frequented by tourists has been developed in the area. There are agricultural activities such as animal grazing, fishing and subsistence farming in the valley areas. The tourist centre has functioning ablution facilities. However, less than 5% of the villagers do not have access to toilets and pit-latrines. The majority use the bush or riverside to relieve themselves, therefore increasing faecal contamination on surface water (Armstrong, 2006; Kravitz *et al*., 1999). These activities could explain the high concentrations of faecal coliform, *E. coli* and coliphage bacteria during the entire study period.

(b) *Giardia and Cryptosporidium*

The occurrence of *Giardia* cysts and *Cryptosporidium* oocysts in this catchment area supports the data indicating faecal pollution from both humans and livestock e.g. the Liphofung River had a concentration of 10 cysts/10L in 2005 (Figure 4.43), whereas the guideline values for both the WHO (2011) and SANS:241 (2015) are zero oocyts per 10 litres. The Bokong River had a concentration of 7 Oocysts/10L in 2010 (Figure 4.44) whereas the SANS: 241 (2015) and WHO (2011) gives a guideline value of zero cysts per 10 litres. These concentrations by far exceed what is specified in the water quality guidelines.

Giardia cysts and *Cryptosporidium* oocysts have the ability to withstand a variety of environmental stresses, including freezing. Therefore, they are very persistent in the water (Health Canada, 2012). The cysts are also resistant to chlorine. Water for drinking purposes is not treated with chlorine and therefore, there is a challenge of

exposing people to this organism. *Giardia* is one of the leading causes of gastrointestinal diseases linked with drinking water worldwide, and thus its impact on human health cannot be underestimated (Putignani & Menichella, 2010), especially because the water in the catchment area is used directly by the community without any treatment. Even if the water was treated, the protozoa would still be persistent and survive. Since the catchment area experiences very low winter temperatures and high summer temperatures (Lesotho Meteorological Services, 2000; Moeletsi & Walker, 2013), the protozoa can withstand and survive under these conditions. Therefore, they are more likely to be detected in the surface waters on a continuous basis. Due to the high concentrations of the protozoa detected in the catchment area, the health of humans and animals will be impacted severely.

5.3. Conclusion

The study focused on the five rivers, namely the Bokong, Malibamatso, Liphofung, Mokhoulane and the Pelaneng, that feed into the Katse Dam. Based on the comparison with the guidelines and/or standards for the aquatic environment and for the various intended uses (drinking water or direct consumption, agriculture, aquatic ecosystem), the water quality is deemed to be of relatively good quality, even though there were non-compliances with some of the guidelines and/or standards. These findings support previous assessments that the water quality of the Lesotho highlands is of good quality. The water quality within the Katse Dam catchment area seems to be influenced mainly by natural influences (e.g. rainfall, weathering and geological composition) and most significantly by anthropogenic activities e.g. agriculture and informal human settlements. The geological composition of the area seems to contribute to the increase in concentration of some of the chemical determinants in the surface water (Wirmver *et al*., 2013). The Bokong River had the highest number of non-compliances, especially to the WHO and DWS Aquaculture guidelines (Table 5.7). Therefore, this river's water quality could be easily compromised. There are also wetlands located around the Bokong River. Consequently, the existence and functioning of these wetlands as well as the ecosystem services offered by these wetlands could be compromised.

The Pelaneng River had the least number of non-compliances and thus would be the river with a better quality of water compared to the other rivers. However, the difference in the number of non-compliances between the rivers was not much and

therefore, the water quality can be considered to be the same or equal. Study Period: B, which is from 2006 to 2011 had the highest number of non-compliances, therefore the water quality was compromised in this period compared to Study Period: A (2000 to 2005) and Study Period: C (2012 to 2014).

The human settlement conditions and agricultural inputs seem to be the factors contributing most to contaminationof the surface water of the catchment area. The lack of sanitation systems and facilities means that community members have to use the bush and river valleys to relieve themselves, thus contributing to microbial contamination of the environment. The direct application of manure and fertilizers on the fields by farmers further exacerbates microbial contamination and high nutrient inputs into the environment. There are unsustainable livestock farming activities (e.g. overgrazing) in the catchment area which put pressure on the land. The livestock waste contributes to microbial and nutrient contamination.

The agricultural activities on the steep slopes increase the possibility of soil erosion leading to an increase in turbidity, especially during flood periods. However, the cumulative effects of the determinants impact could be also exacerbated by the extreme climatic conditions e.g. extreme rainfall events around the catchment area, which causes flooding and flushing of contaminants into surface waters. Such events could have contributed to physical determinants like turbidity, suspended solids, and total dissolved solids not complying with certain water quality guidelines.

Studies have shown that catchment areas outside of the Katse Dam area are subjected to industrialization (i.e. industrial activities in the Leribe district) and are affecting the surface water quality in these areas as effluents are at times released without being treated. It is thus important to monitor and strictly manage anthropogenic activities in the Katse Dam catchment area to prevent similar impacts. Therefore, continuous monitoring of the catchment area would be necessary and significant in order to initiate mitigation options should the contaminants exceed national and international water quality guideline values and to avoid cumulative effects of the determinants on the Katse Dam.

5.4. Chapter 5 References

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CHAPTER 6

6. RECOMMENDATIONS

The assessment has provided a better understanding of the chemical, physical and microbiological water composition of the five main rivers namely; Bokong, Malibamatso, Liphofung, Mokhoulane and Pelaneng, feeding into the Katse Dam. Based on the assessment of the data and information obtained, the following recommendations for consideration and implementation are deemed important.

- Since the water is of good quality, an integrated catchment area management approach towards conservation, development and use of the catchment areas of the Bokong, Malibamatso, Liphofung, Mokhoulane and Pelaneng must be followed.
- A detailed integrated assessment of activities, e.g. mining, industrial, agriculture, and human settlement in the catchment area should be conducted as this is not readily available.
- A detailed long-term surface water quality monitoring programme must be developed. This should include more monitoring sites, especially in areas where increased anthropogenic activities are observed.
- Monitoring of both the Bokong River and Liphofung River must be strengthened since these rivers had the highest water quality non-compliances and microbial contamination with one or more of the guidelines and/or standards respectively.
- All anthropogenic activities in the catchmnets of these rivers and thus the Katse Dam catchment area at least, must be monitored and strictly managed to prevent and and mitigate their possible impacts.
- Agricultural development must be controlled. Educational and financial support programmes must be established and implemented to ensure sustainable livestock farming, conservation agriculture and cropping practises as preventative measures to minimise environmental degradation and impacts on surface water and water quality (e.g. contour farming, manure management).
- Faecal pollution from human settlements need to be controlled, thus sanitation facilities and systems should be put in place. This should be

supported by community education programmes linked to hygiene and sanitation.

- Networks with organisations and agreement with government should be established to make it easy to access certain information to better understand the catchment areas of the Lesotho Highlands Water Scheme. A central database for all information must be established by the LHDA that will be accessible to both South African and Lesotho citizens.