



# **EVALUATION OF THE WATER QUALITY OF LAKE NSEZI IN RICHARDS BAY**

By

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# DECLARATION

Student number: 43578764

I declare that “**EVALUATION OF THE WATER QUALITY OF LAKE NSEZI IN RICHARDS BAY, KWAZULU NATAL SOUTH AFRICA**” is my own original work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references. Further I declare that I have not previously submitted this work, or part of it, for examination at UNISA for another qualification or at any other tertiary institution in South Africa.

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**SIGNATURE**  
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**DATE**

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## **DEDICATIONS**

I dedicate this research work to my Father, Anaclet Tshimanga Mukadi and Mother Kapinga Tshimanga. You have inspired and supported me from childhood to make of me the person I am today. This would not have been possible without your positive inputs.

# ABSTRACT

Freshwater of acceptable quality is crucial for certain needs and uses such as recreational, domestic and industrial activities (Bartram and Balance, 1996). Water contamination and excessive use and abuse of the fresh water environment, threaten development as well as a variety of other life aspects and make water assessment necessary for safe drinking water delivery. It has been proven that water of good quality is important to sustain development (Karolina *et al.*, 2011).

South African freshwater resources such as lakes, rivers and groundwater, undergo intense stress owing to a rapidly expanding population, a growing economy, severe pollution from various industries, a possible effect of global warming and an increase in droughts (Oberholster *et al.*, 2008). A study done by Boyd (2010), further confirmed the decline in water quality of these resources due to excessive contamination caused by urban development, human activities, industrialisation, forest establishment, agriculture and mining operations.

For this project, the analysis of physical, chemical and biological parameters of the water from Lake Nsezi was used to assess the water quality of the lake. Results from the analysis were compared to Target Water Quality Range (TWQR) of the Water Quality Guidelines for the Aquatic Environment (WQG/AE) and for Domestic Use (WQG/DU). A further comparison was done between data from the current study and available historical water quality data of Lake Nsezi.

From the results for this project and historical data, it was evident that parameters such as total dissolved solids (TDS) and chloride, metals such as aluminium, cadmium, copper, lead and manganese, and total coliform counts were above the TWQR for the WQG/AE and WQG/DU at most of the sampling sites.

Key words: Water quality, Freshwater resources, Lake Nsezi.

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## ABBREVIATIONS

AE	Aquatic Ecosystem
Cn	Cyanide
CSIR	Council for Scientific and Industrial Research
DO	Dissolved Oxygen
DU	Domestic Use
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EEA	European Environmental Agency
HAB	Harmful Algal Bloom
HPC	Heterotrophic Plate Count
ICP-OES	Inductively Coupled Plasma Optical Emission Spectrometry
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
KZN	KwaZulu-Natal province in South Africa
NCHF	North Central Hardwood Forests
NEMA	South African National Environmental Act
NLF	Northern Lakes and Forests
PCA	Principal Component Analysis
RBCT	Richards Bay Coal Terminal
RBM	Richards Bay Minerals
SA	South Africa
WQG	Water Quality Guidelines
SAWS	South African Weather Services
SOP	Standard Operating Procedures
TLI	Trophic Level Index
TDS	Total Dissolved Solids
TWQR	Target Water Quality Range
USA	United States of America
USEPA	United States Environmental Protection Agency
WCBP	Western Corn Belt Plains
WHO	World Health Organisation
WQG	Water Quality Guidelines

# CHAPTER ONE: INTRODUCTION

## 1.1 Water is needed by all

Freshwater of acceptable quality is a limited commodity and is essential for agricultural and industrial activities as well as domestic use. To sustain future developments, water of good quantity and quality becomes essential (Bartram and Balance, 1996).

It is known throughout the ages that the decline and prominence of societies has proven that a great supply of water is indispensable for the progress of a stable independent state (Solomon, 2010). It is thus a concern that water scarcity can lead to social and political instability, as well as migration of a nation (Fishman, 2011).

By the end of the 20<sup>th</sup> century, a considerable number of large dams had been constructed worldwide which increased water storage for human needs in a record time (Bigas, 2012).

Solomon (2010) however, commented that nobody was able to predict the growing, worldwide consequences that unorganised dam building, water diversions to land and crops, and the associated effects of deforestation would have on regulation and range of water availability and quality. Over years it became evident that these activities impacted on the global water system (Bigas, 2012).

Water quality and quantity are interdependent and should be managed in an integrated manner. Access to safe water is a fundamental human right (Kiefer *et al.*, 2008). Water is said to be a vital component of the human body and crucial for human survival. At the same time, it also plays a vital role in many industries such as cosmetics, food and pharmaceutical, as well as in agriculture and mining activities (Karolina *et al.*, 2011).

Water quality is a term that refers to a set of criteria against which compliance can be measured (Bartram and Balance, 1996; Puri *et al.*, 2011). The most useful standards used to measure water quality relate to the health of ecosystems, human exposure to possible pollutants and safety of drinking water (Johnson *et al.*, 1997; Smol, 2008)

Water contamination and excessive use and abuse of the fresh water environment threaten development as well as a variety of other life aspects and make water assessment necessary for safe drinking water delivery. It has been proven that water



of good quality is important to sustain developments (Karolina *et al.*, 2011).

Contamination of the aquatic ecosystems takes place when humans introduce, either through direct discharge into the water body or indirectly through atmospheric contamination, substances that result in harmful effects such as:

- Dangers to human health,
- Harm to living assets,
- Hindrances to water related activities such as fishing, and
- Deterioration of water quality due to its use in agriculture, industry and other human activities (Bartram and Balance, 1996; Hites, 2006).

Water pollution is defined as the contamination of water resources such as rivers, oceans, lakes and ground water (Bartram and Balance, 1996). Contaminants from example the burning of fossil fuels; runoff from the use of pesticides and fertiliser application and various industries, mines and informal human settlements contribute to the continuous decline in water quality (Goel, 2006).

Eutrophication is defined by Nixon (1995) as the increase in nutrient content of a specific water resource. It emanates from a range of nutrient sources such as sewage, atmospheric deposition, groundwater inflow and fertiliser runoff (Nixon, 1995; Doods *et al.*, 2008). Eutrophication is thus the build-up of nutrients such as sulphates and phosphates in the water resulting in excessive algal on the surface of water. The algae deplete the water from oxygen which then cause the death of other organisms living within the water environment (Hawkes, 1972; Withers *et al.*, 2014).

The use of fertilisers on farms remains a steady source of nutrient contamination of ground water and run-off into rivers. Vitousek *et al.* (1997) confirms that this trend is increasing at an exponential rate in many parts of the world (Padmanava *et al.*, 2014).

Human population growth and unregulated human settlements together with agricultural practices in both industrial and developing nations have contributed to high nutrient levels in ground water (Donald *et al.*, 2002).

Based on the study done by Donald *et al.*, (2002), many sources of nutrients can stimulate harmful algal blooms commonly referred to as HABs. These HABs cause

harm in different ways by producing toxins which affect cells physical structure and thus also its function. Many organisms in fresh water, marine fish species and seabirds form part of an integrated food web. Exposure of these organisms to HABs results in organism mortality but also damage to such a food web (Donald *et al.*, 2002; Guo *et al.*, 2017).

Acidification of freshwater resources and in particular lakes, is caused by the deposition of wet or dry particulates rich in mineral acids. During this process, atmospheric moisture combines with fossil fuel gases, which returns with precipitation causing acidification of surface waters such as lakes (Bartram and Balance, 1996).

Industrial activities and mining affect water resources. Although mining plays a vital role in the economy of any nation, be it underground or open pits and subsequent excavation of ores, it impacts on natural water resources (Booth, 2002). The state of pollution discharged through mine effluents can warrant the quality and usefulness of receiving waters as mining water contain a heavy load of reactive metals that will deplete dissolved oxygen in water (Younger, 2002).

South African freshwater resources such as lakes, rivers and groundwater, undergo intense stress owing to a rapidly expanding population, a growing economy and possible effects of global warming and increase in droughts (Oberholster *et al.*, 2008). Based on the study done by Boyd (2010), the decline in water quality of these resources is due to excessive contamination caused by urban development, human activities, industrialisation, forest establishment, agriculture and mining operations.

Due to actual and projected human population growth and socio-economic development, it is uncertain if South African water resources will support current water use patterns (Oberholster *et al.*, 2008). In the event of a slow increase in South African population, contaminant levels in water resources will still continue to grow and increase the cost of using these water resources (Oberholster *et al.*, 2008).

Water resource managers have the massive task to distribute water of good quality and maintain the recreational, ecological and useful features of water resources such as lakes (Bartram and Balance, 1996).

To succeed in the delivery of these goals, it is important that water resource managers be involved in the monitoring and maintenance of the quality of freshwater resources.

With this in mind, a pressing need emerges for assessment of pollution trends of water resources.

According to Bartram and Balance (1996), complete assessments of the water quality of these water resources can be accomplished by evaluating the physical, chemical and biological characteristics of the water body in the following way:

- \* Analysis of chemical content of water,
- \* Bio-monitoring of the aquatic system which include processes such as habitat evaluation and toxicity tests, and
- \* Monitoring physico-chemical parameters such as temperature, pH, conductivity and oxygen content of the water.

## **1.2 Lake Nsezi**

Lake Nsezi (Figure 1) is situated between Empangeni and Richards Bay, the two industrial hubs of Umhlathuze Municipality, KwaZulu-Natal in South Africa. Lake Nsezi is also surrounded by growing human settlements, amongst others the Nseleni and Mbonambi townships and for this reason the City of Umhlathuze Municipality has erected a water treatment plant next to the lake.

The quality of water in Lake Nsezi is highly variable (Heyneke, 2008). Raw water enters the lake via the Nseleni River in the north and water transferred from the Mhlathuze River enters in the south east through an abstraction weir (Mhlathuze Weir) erected across Mhlathuze River at about 11 km from the estuary mouth (Weerts,2002).

Lake Nsezi is subjected to pollution from approximately 1000 m<sup>3</sup>/d of secondary sewage effluent that is discharged from the Nseleni Township to the Mposa River upstream of the confluence with the Nseleni River. Secondary sewage effluent is also discharged via smaller tributaries into the Mhlathuze River from the following sewage treatment plants: Empangeni, Ngwelezana, Vulindlela and Felixton (Heyneke, 2008).

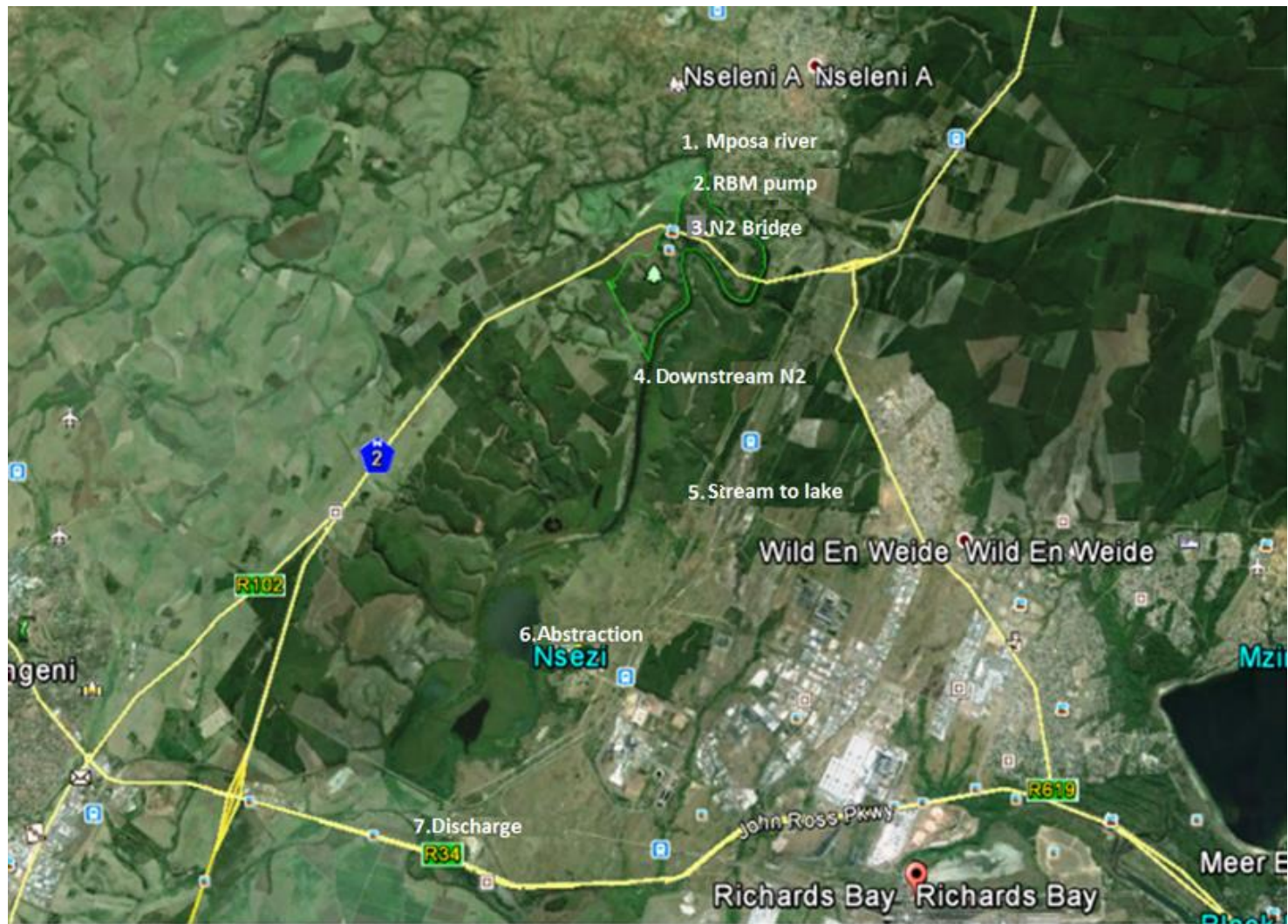


Figure 1: Lake Nsezi in Richards Bay (Adapted from Google Earth, 2016).

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### **1.3 Study Hypotheses, Aims and Objectives**

#### **1.3.1 Study Hypotheses**

This study comprises two hypotheses:

##### **First Hypothesis**

The first Hypothesis (H<sub>a</sub>) states that various water quality parameters can be used to describe the quality of the water of Lake Nsezi.

##### **Second Hypothesis**

The second Hypothesis (H<sub>b</sub>) states that the results from the water quality analysis will indicate possible pollution threats for the water environment of Lake Nsezi.

#### **1.3.2 Aim of this study**

The aim of this research project was to assess the water quality of Lake Nsezi.

#### **1.3.3 Objectives**

The aim of this study will be delivered through the following objectives:

- Conduct an extensive literature survey to find all currently available and historical water quality data for Lake Nsezi.
- Confer with uMhlathuze Water Laboratory to identify assessable sampling sites for the project.

- Conduct field trips during five seasons from May 2014 to May 2015 with the purpose to collect water samples for physico-chemical, metal and bacteriological analysis.
- Compare the results from the various analyses to the Target Water Quality Range of the Water Quality Guidelines for the Aquatic Environment and the Water Quality Guidelines for Domestic Use.
- To identify possible sources influencing the water quality of Lake Nsezi.
- Compare the results of the current project with historical data to identify possible improvement / deterioration of the water quality of Lake Nsezi

#### **1.4 Study Overview**

**Chapter 1:** A general summary of the project in international, national and regional contexts, provides a framework for the study. The study hypothesis, aims and objectives are set out.

**Chapter 2:** A literature review of international lakes and water quality of these lakes. Further focus is on some lakes in South Africa and their importance with final focus is on Lake Nsezi in Richards Bay area.

**Chapter 3:** An overview of the study area and sampling sites are given. This is followed by the specific sampling procedure and methodology used for the analysis of the water samples.

**Chapter 4:** Results of the physicochemical, metal and bacteriological analyses of water samples are presented. Historical water quality data is also included for comparison.

**Chapter 5:** Results of the water samples are discussed and compared to historical data.

**Chapter 6:** The conclusion to this study is presented in this chapter. The study hypotheses, aims and objectives are reviewed. Recommendations for future studies on Lake Nsezi water quality are also included.

## CHAPTER TWO: LITERATURE REVIEW

### 2.1 Lakes in other world regions

In the Wellington area of New Zealand, there is a number of lakes offering a variety of plant and animal life, water needs supply, entertainment and fishing opportunities (Oliver and Milne, 2012). Lake Wairarapa is the largest in the Wellington area and the water quality of the lake has been monitored by the Wellington regional council. Lake Waitawa and Lake Onoke in the south of Wairarapa, have lately been included in the routine monitoring (Perrie and Milne, 2012).

The quality of water in lakes Onoke, Waitawa and Wairarapa is greatly affected by agricultural development through extensive farming activities, urban land use and municipal waste water discharges (Oliver and Milne, 2012).

Based on regular water quality monitoring as reported by Perrie and Milne (2012), Lakes Wairarapa, Onoke and Waitawa are regarded to be in a poor quality state with increased contents of nutrients and phytoplankton. Burns *et al.* (2009) applied the Trophic Level Index (TLI) to the waters of these lakes and in the end classified the water as saturated in phosphorus and nitrogen. These components when accumulated in excess can cause overgrowth of aquatic plants and algae, also known as eutrophication. This results in the blocking of light to deeper waters and; depletion of oxygen, causing death to aquatic animals (Mueller and Helsel, 2016).

In the state of Minnesota four (4) ecoregions have been identified: Northern Lakes and Forests (NLF) where Lake Wilson is found; North Central Hardwood Forests (NCHF) where Lake Diamond is found; Western Corn Belt Plains (WCBP) where Lake George is found and Metro region where Lake Johanna is found (Ramstack *et al.*, 2004). Contamination of freshwater from these lakes is a major problem (Ramstack *et al.*, 2004). This is due to urban development creating road surfaces from where storm water pollution carrying pollutant loads to the receiving water resources (Egodawatta and Goonetilleke, 2006). This increase influences the total phosphorus content of the freshwater in the region. On the other hand, agricultural activities cause a relative increase in nutrient runoff and eutrophication of water bodies (Mueller and Helsel,

2016). From this research it is evident that human activities and subsequent pollution runoff have a great influence on the water quality of various lakes (Ramstack *et al.*, 2004). Ramstack *et al.* (2004), further indicated that increased chloride ions concentration, pH variability and increased total phosphorus are parameters influencing deteriorating water colour and water chemistry.

The eastern Kolkata wetlands in India are famous for numerous fishing activities and wetland developments. As reported by Talapatra and Banerjee (2007), high concentration in toxic elements such as chromium (Cr), zinc (Zn), copper (Cu), lead (Pb), manganese (Mn) and iron (Fe) have been observed in fish sampled from Kolkata. This is due to urbanisation and development in the area, resulting in both domestic and industrial discharge of effluents in the wetland ecosystem (Talapatra and Banerjee, 2007).

In Europe, most capital cities are a home to a river or a lake running across its landscape (Eleftheria *et al.*, 2016). These water resources have however been used as waste carrier, drinking water supply or transport media (Eleftheria *et al.*, 2016). Some of major lakes in Europe include Lake Trekanten in Stockholm (Sweden); Lake Ulemiste in Tallinn (Estonia); Lakes Wannsee, Muggelsee and Tegelersee in Berlin; Lake Zurich in Zurich (Switzerland) and the Serpentine Lake in London (Eleftheria *et al.*, 2016).

Rapid urbanisation and industrial development in Europe has come at a cost to water resources (Arle and Claussen, 2012). This includes lakes with highly reduced water quality due to wastewater discharges, increased runoff from surfaces such as roads, roofs and gardens, household contamination and industrial storm water overflow (Arle and Claussen, 2012). Of great concern is the pollution of Europe's water resources by organic and inorganic substances such as pesticides and heavy metals (Cd, Hg, Pb and Zn) reaching concentrations above European Union Target Range (Arle and Claussen, 2012).

Eutrophication of European lakes due to phosphorous content is gradually decreasing due to massive water quality assessment and remediation programmes across Europe (EEA, 2001). However, many lakes are still reported with high phosphorous



concentration emanating from agricultural land use (EEA, 2001).

Water pollution has also been reported in different African regions.

In Ghana, according to Frimpong, (2007), Kumasi (the city where Lake Volta is situated) is known as the paradise city of Africa. This metropolis is growing at an alarming rate resulting in suburbs mushrooming in recently less populous areas (Frimpong, 2007). Monitoring water pollution under these conditions are difficult. Monitors have observed that contamination of water resources stemmed from human waste and building materials (Ogututu *et al.*, 1997). Awareness campaigns in the concerned communities proved unsuccessful, since illegal waste disposal and littering continued (Frimpong, 2007).

The shortage of water carrying sewage resulted in the direct dumping of raw sewage into rivers. This is a health hazard since river water is used for domestic purposes (Frimpong, 2007). Frimpong (2007), further states that if this alarming rate of pollution is not properly addressed, Ghana faces the risk of becoming yet another, water stressed African state.

In Lake Chivero, Zimbabwe, excessive growth of water hyacinth threatens the main water supply to Harare (Magadza, 2003). In some areas of the lake, these weeds grow up to a metre in depth (Mathenjwa, 2009). The soaring weed absorbs oxygen and blocks the sun's ray to reach the surface of the water resulting in loss of fish and aquatic biodiversity (Magadza, 2003). This in turn affects surrounding communities due to a loss of food and subsequent income. This whole environmental turmoil can partly be attributed to the dumping of industrial effluent that carry phosphates and nitrates, into water of Lake Chivero promoting overgrowth of water hyacinth.

In Lake Nakuru, Rift Valley province in Kenya, urbanisation poses a threat to the lake due to uncontrolled practices of dumping urban waste, storm water discharge as well as discharge of poorly treated sewage into the lake environment (Raini, 2006).

Agricultural land use and industrial development in the lake catchment area cause pollution of Lake Nakuru (Raini, 2006). Contamination aspects include heavy metals (such as Pb, Zn, Fe and Cr), and nutrient enrichment from agriculture and urban sources. The nutrient enrichment produces toxic algae blooms which decreases the

lake's oxygen level and is a threat to aquatic animals and fish (Ballot *et al.*, 2004).

Lake Victoria is Africa's largest tropical freshwater lake crossing Uganda, Kenya and Tanzania (Bootsma and Heckey, 2003). The region has known a rapid increase in urban population as well as a steady growth of agricultural and industrial activities. These developments however threatened the water quality of Lake Victoria due to the discharge of domestic and municipal waste and the discharge of agricultural runoff. A shortage of industrial wastewater treatment plants in Uganda resulted in wastewater discharge into wetlands (Hannington *et al.*, 2007). These threats are giving rise to the presence of heavy content (such as Cr, Cu, Ni, Pb, Mn and Al); high content of phosphorus and nitrogen from fertilisers, pesticides, herbicides and land degradation practices which increase eutrophication of Lake Victoria (Hannington *et al.*, 2007).

Lake Tanganyika shore line is divided between the Democratic Republic of Congo, Tanzania, Burundi and Zambia. Lake Tanganyika water makes up 17% of the world's free freshwater and serves as an important transport media for the afore mentioned nations (Patterson and Markin, 1997).

Rapid population growth coupled with poverty give rise to environmental damage in the Lake basin where untreated industrial and municipal wastewater is discharged into the lake. Industrial effluent discharge increases metal content while agricultural land use without proper legislation in the region causes runoff that increases nutrient content and consequent eutrophication of the lake (Patterson and Markin, 1997).

Pollution incidents have also been noted in South Africa (SA). The Wilderness Lake System comprises of three lakes, including Rondevlei, Langvlei and Eilandvlei. These lakes are all affected by pollution (Russel, 1999). The Swartvlei System comprising of three waterbodies including Karatara Lake, Swartvlei Lake and Swartvlei Estuary. This vlei system situated on the south coast of the Western Cape, is unique due to its location partially within populous urban areas and, adjacent to several agro-village developments (Russel, 1999).

Research undertaken by Russel (1999), focused on physical water quality parameters such as water temperature, salinity, total dissolved solids, pH, dissolved oxygen,

secchi disc depth, turbidity and total suspended solids of this lake system. The range of these water quality variables was found to be wider than recorded in earlier studies by Hughes and Filmlater (1993). Russel (1999), further established that the extensive human impact on the environment of the lake catchments and residential developments adjacent to these waterbodies, have the potential to substantially influence water quality in the lakes.

Lake Sibaya, in the north-east of Kwazulu Natal, is South Africa's largest freshwater lake (DWAF, 2002). Due to agricultural land use, industrial effluent disposal, decommissioned old mine contamination, as well as urban and rural settlements in the lake-catchment, cause erosion, eutrophication and pollution of the lake (DWAF, 2002). Water quality parameters of Lake Sibaya indicates water chemistry highly affected including high levels of Total Dissolved Solids (TDS), high metal content (Na, Mg, K and Ca), high sulphates and chloride concentrations (DWAF, 2002).

## **2.2 Quality of water resources**

Water quality can be defined with respect to the content of the wanted or unwanted component in the water. It is inclusive of the physical parameters (temperature, pH, electrical conductivity and oxygen content); chemical parameters (heavy metals, sulphates, nitrates) and biological parameters (bacteria such as coliforms) in water of which variable concentrations will determine its suitability for an intended use (DWAF, 1996a; Matowanyika, 2010; Mathetsa, 2015).

In South Africa, the main sectors making use of water resources are domestic, industrial, agricultural, recreational and aquatic ecosystems (DWAF 1996a, b). Pollution of the water resources will affect the cost of treatment and the quality of water that will reach specific users.

### **2.2.1 Physical parameters**

#### **2.2.1.1 Temperature**

Human activities in a water resource catchment area, climate and soil hydrology affect its thermal characteristics (Palmer *et al.*, 2004). Elevated temperature of a water body causes a drop in oxygen solubility resulting in increased toxicity of some chemicals in the water which adversely affect the aquatic ecosystems (Palmer *et al.*, 2004;

Matowanyika, 2010; Mathetsa, 2015).

#### **2.2.1.2 pH**

pH is the measure of the hydrogen ion ( $H^+$ ) activity in a solution. It is a characteristic that determines the acidity or alkalinity of a solution (Mathenjwa, 2009). A pH below 7 creates acidic conditions in water, while pH of more than 7 creates an alkaline environment, low pH value in a water resource maybe as a result of industrial effluent discharges, precipitation or acidification from acid mine drainage (Palmer *et al.*, 2004; Mathenjwa, 2009; Mathetsa, 2015).

#### **2.2.1.3 Electrical Conductivity (EC) and Total Dissolved Solids (TDS)**

Electrical conductivity (EC) of water represents its ability to conduct electricity due to the presence of dissolved ions while total dissolved solids (TDS) is an indication of the amount of inorganic salts and organic materials dissolved in water (Palmer *et al.*, 2004; Phyllis *et al.*, 2007; Mathetsa, 2015).

#### **2.1.1.4 Dissolved Oxygen (DO)**

Aquatic ecosystem is widely dependent on sufficient dissolved oxygen (DO) content for respiration (WHO, 2008; Matowanyika, 2010; Mathetsa, 2015). Dissolved oxygen is introduced into surface water through atmospheric diffusion and photosynthesis, it is depleted by factors such as breakdown of organic matter, increased temperature and salt content as well as chemical decomposition of contaminants in the water, this leads to an increased toxicity of the water (DWAF, 1996a; Selman, 2007; Mathetsa, 2015).

### **2.2.2 Chemical parameters**

#### **2.2.2.1 Metals**

Heavy metals such as zinc, copper, magnesium, iron, chromium, nickel, arsenic, selenium, lead and cobalt at trace concentrations are found in water and are required for metabolism in living organisms. At elevated concentrations due to atmospheric deposition, domestic and agricultural runoff, industrial and municipal effluents, weathering of the rocks as well as acid mine drainage, these metals become toxic (DWAF, 1996a; Palmer *et al.*, 2004; Mathetsa, 2015).

### **2.2.2.2 Nitrate and Sulphate**

Nitrate is found in the air as part of nitrogen cycle; in the environment, soil and water from the decomposition of dead matter from plant and animal wastes. Agricultural runoff contributes to excess nitrate concentration in water resources and this leads to algal growth and eutrophication in surface water (Dubrovsky *et al.*, 2010; Mueller and Helsel, 2016). Sulphates as a combination of sulphur and oxygen occur in the soil and rock formation in ground water. Agricultural runoff of ammonium sulphate adds to sulphate concentration in water resources. High sulphates content causes scale build up in water pipes, bitter taste to drinking water which is harmful to humans and livestock (DWAF, 1996a; Muhammad *et al.*, 2014).

### **2.2.3 Biological parameters**

The presence of pathogens and disease causing bacteria in surface water resources are as a result of human and animal wastes from sewage effluents (Mathetsa, 2015). Total coliform bacteria which include the faecal coliform type such as *Escherichia coli* (*E. coli*) are used as indicators of biological characteristics of water (Matowanyika, 2010).

## **2.3 Lake Nsezi**

The direct area of the City of uMhlathuze Municipality has access to various sources of fresh water which includes Lake Nsezi, Lake Cubu and Lake Mzingazi.

Lake Nsezi (Figure 1) is situated between Empangeni and Richards Bay, the two industrial hubs of the municipality. The estimated storage capacity of Lake Nsezi was found to be in the order of 834 000 m<sup>3</sup> for a lake maintained at 6.2 metres above mean sea level (Nowele, 2010). The lake is fed by the Nseleni and Mposa rivers, whose catchment areas contain a large informal settlement at Nseleni (Germishuyse, 1999). The lake water capacity is also maintained with water transfer from Mhlathuze River (Weerts, 2002).

Lake Cubu is situated between Dube Township and Felixton area and Lake Mzingazi is situated between Meerensee and Mbonambi area.

Both Lake Cubu and Lake Mzingazi are referred to as coastal lakes, while Lake Nsezi

is an inland lake, located on the southern end of the Nseleni River. The outflow of Lake Nsezi flows towards the Mhlathuze River as part of the Nsezi River that has been canalised to accommodate and promote sugar cane farming in the area.

According to Heyneke (2008), the basic statistics of Lake Nsezi are:

- Volume:  $25 \times 10^6$  kilolitre
- Average depth: 2.5 m
- Length: +/- 5 km
- Width: +/- 2 km

Lake Nsezi is heavily surrounded by cane and commercial forests as well as a number of industries such as the pulp and paper factory, Mondi Kraft, the largest exporter of fertiliser Foskor, Bayside and Hillside Aluminium Smelters and Richards Bay Minerals, Bell Equipment, Tronox Minerals, The Richards Bay Coal Terminal and; Tata Steel Ferrochrome Smelter. The Lake is the main storage reservoir in the area. The development of Richards Bay and Empangeni has seen a significant increase in the abstraction rates of water from this lake over the past 20 years. To meet the demands from industry and municipal users, the required yield capacity is maintained by supplementary transfer of water from the Mhlathuze River (Nowele, 2010).

Lake Nsezi presents a beautiful appearance with a rich botanical appeal. Parts of the lake are dominated by African papyrus (*Cyperus papyrus*). Lake Nsezi is a shelter to an abundant bird life, fish, hippopotami and crocodile. The lake is an important fresh water resource for Empangeni (Moss, 2005).

The City of uMhlathuze was created in 2002 with the amalgamation of the Empangeni and Richards Bay local authorities. The municipal land which includes tribal areas, covers an area of approximately 800 square kilometres and supports approximately 300 000 people (Nowele, 2010).

Commissioning of the Richards Bay Port resulted in rapid development of the town into a thriving industrial city. A number of large importing and exporting industries have established themselves in the area over time. On the other hand, owing to Richards Bay's warm climate and scenic landscape, service sector growth was

inevitable (Jury and Sylvain, 2009). As a result, socio-economic characteristics and trends of the area, specifically related to the importance of the port city development on job creation, poverty alleviation and the area's contribution to the economic development in the provincial and national contexts, excelled.

Boyd (2010), was of the opinion that the accelerated industrial development of the City of uMhlathuze Municipality and subsequent population inflow (some of whom settled around these lakes) compromised the quality of these valuable water sources.

It is also understood that if Lake Nsezi, Lake Cubu or Lake Mzingazi are used as drinking water sources, pollution of these sources will lead to the escalation of water purification costs and therefore forcing an increase in water tariffs. It is therefore imperative to constantly protect water resources by controlling the quality of water, and particularly in a water-scarce country like South Africa.

Apart from agriculture and industries that rely on water from Lake Nsezi, deteriorating water quality of water resources in SA exacerbates an already problematic situation (Nowele, 2010). If the water from the above-mentioned lakes was polluted, the water could not be used by consumers in the surrounding areas. The Richards Bay community will seriously be affected since water will then have to be imported from distant regions.

This in turn could be a major threat to communities that depend on the lakes for household, recreation and other purposes. Farming can also be affected if contaminated water is used for crops that are consumed raw.

In view of the above, the uMhlathuze Laboratory started monitoring the water quality of Lake Nsezi since the year 2000 to assess the pollution trends, if any, for possible remediation measures to be implemented. Between 2000 and 2007 uMhlathuze Laboratory monitored Lake Nsezi focusing on the following parameters: general water quality parameters such as phosphates ( $\text{PO}_4$ ), cyanide (CN); hardness; nitrogen (N); dissolved oxygen (DO); total dissolved solids (TDS); physical parameters such as pH, electrical conductivity, temperature, turbidity, colour and bacteriological analysis. In 2012, uMhlathuze Laboratory added metal analysis to their monitoring regime. This

included metals such as- copper, potassium, zinc, sodium, aluminium, cadmium, calcium, lead, iron, magnesium and manganese and more general water parameters such as; chloride, fluoride, nitrate and sulphate (personal communication S Bhengu, 2015).

There has been no or very little independent research undertaken to address the water quality of Lake Nsezi. With the current study, more data will be added to the existing database on the water quality of Lake Nsezi. This data can be used to identify and address possible problems but also can be used in the end to guide in decision making for future water use of lake water.



## CHAPTER THREE: METHODOLOGY

### 3.1 Lake Nsezi

#### 3.1.1 Study area

Lake Nsezi is situated between Empangeni and Richards Bay, the two industrial hubs of the uMhlathuze Municipality in northern KwaZulu-Natal, South Africa. Lake Nsezi is bordered by growing human settlements, amongst others the Nseleni and Mbonambi townships and for this reason the City of uMhlathuze Municipality has erected a water treatment plant next to the lake.

The quality of water in Lake Nsezi is highly variable (Heyneke, 2008). Untreated water enters the lake via the Nseleni River in the north and water transferred from the Mhlathuze River enters in the south east through an abstraction weir (Mhlathuze Weir) erected across Mhlathuze River at about 11 km from the estuary mouth (Weerts, 2002).

Lake Nsezi is subjected to pollution of approximately 1 000 m<sup>3</sup>/d of secondary effluent that is discharged from the Nseleni Township to the Mposa River upstream of the confluence with the Nseleni River. Secondary sewage effluent is also discharged via smaller tributaries into the Mhlathuze River from the following sewage treatment plants: Empangeni, Ngwelezana, Vulindlela and Felixton (Heyneke, 2008).

Lake Nsezi is fed by the Nseleni and Mposa rivers in the north as well as water transferred from the Mhlathuze River in the south east (Figure 1) (Heyneke, 2008). The lake water discharges into sugar cane plantations in the south.

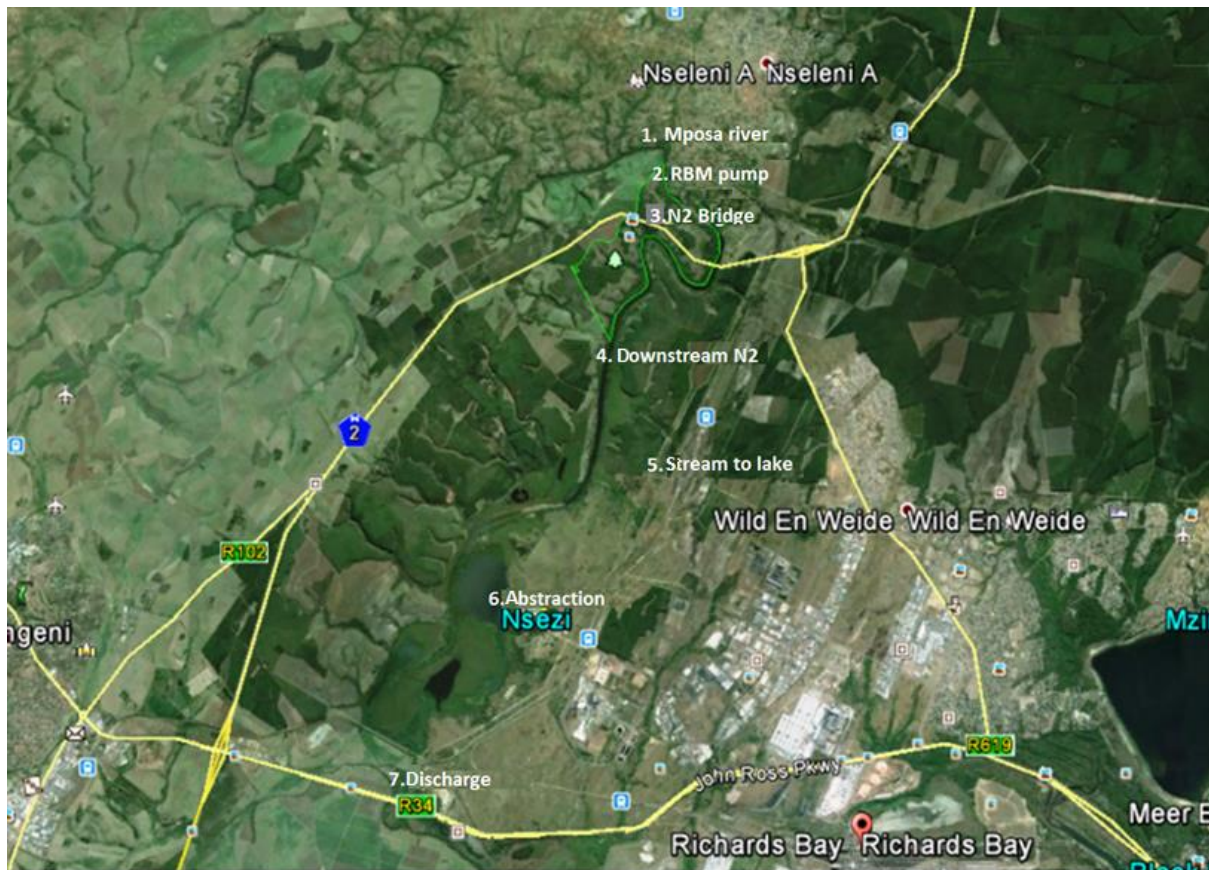


Figure 1: Lake Nsezi in Richards Bay (Adapted from Google Earth, 2016).

### 3.1.2 Climate

The climate in the Richards Bay area is subtropical to almost tropical, humid and warm with the majority of rainfall taking place in summer while winter is moderately humid (Burger, 2009).

The average monthly maximum temperature in the Richards Bay area varies between 20.6 (July 2011) to 31.2°C (January 2002) (Figure 2 and Appendix C: Table 11) while the average minimum temperature varies between 11.2 (January 2004) and 23°C (January 2008) (Figure 3 and Appendix C: Table 12) (SAWS, 2016). Monthly rainfall in the Richards Bay area varies between 0 (May 2007) and 266.6 mm (March 2000) for the period 2000 to 2016 (Figure 4 and Appendix C: Table 13) (SAWS, 2016).

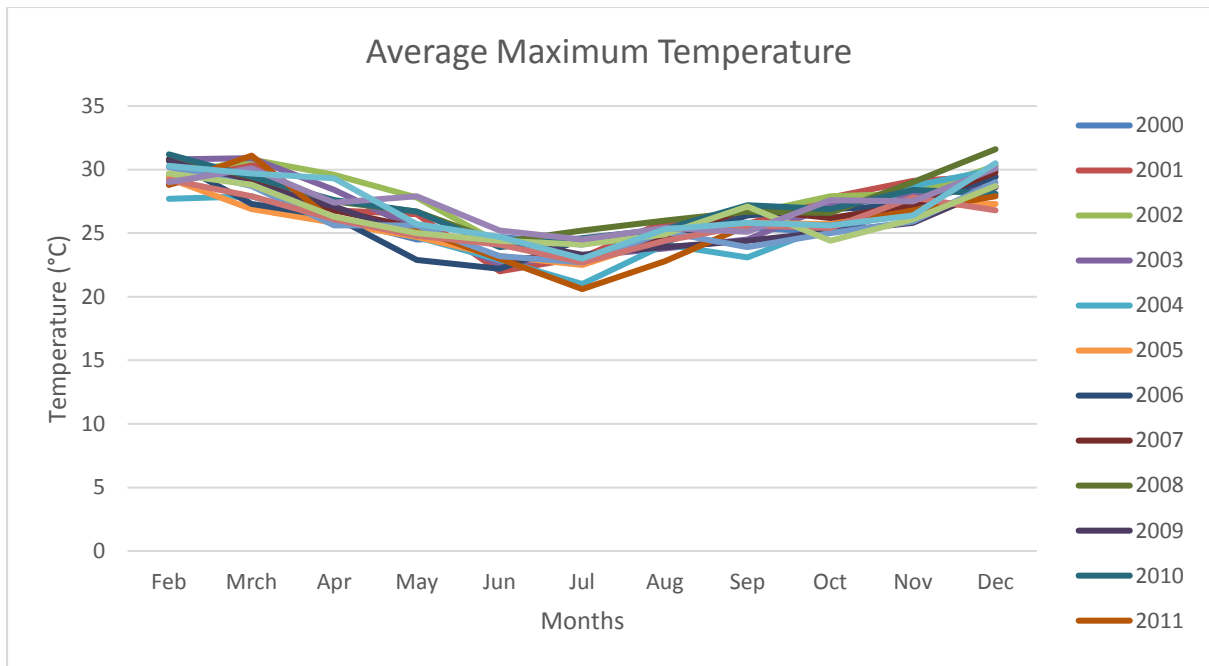


Figure 2: Average Maximum Temperature in the Richards Bay area for the period 2000 to 2016 (SAWS, 2016).

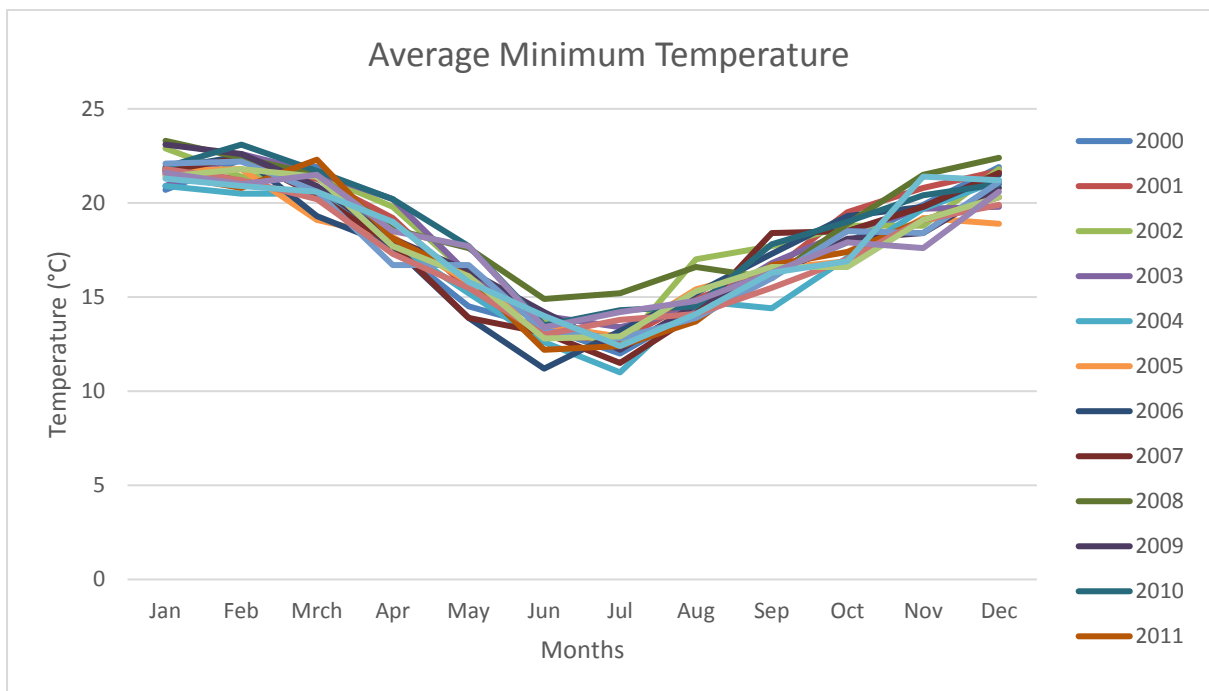


Figure 3: Average Minimum Temperature in the Richards Bay area for the period 2000 to 2016 (SAWS, 2016).

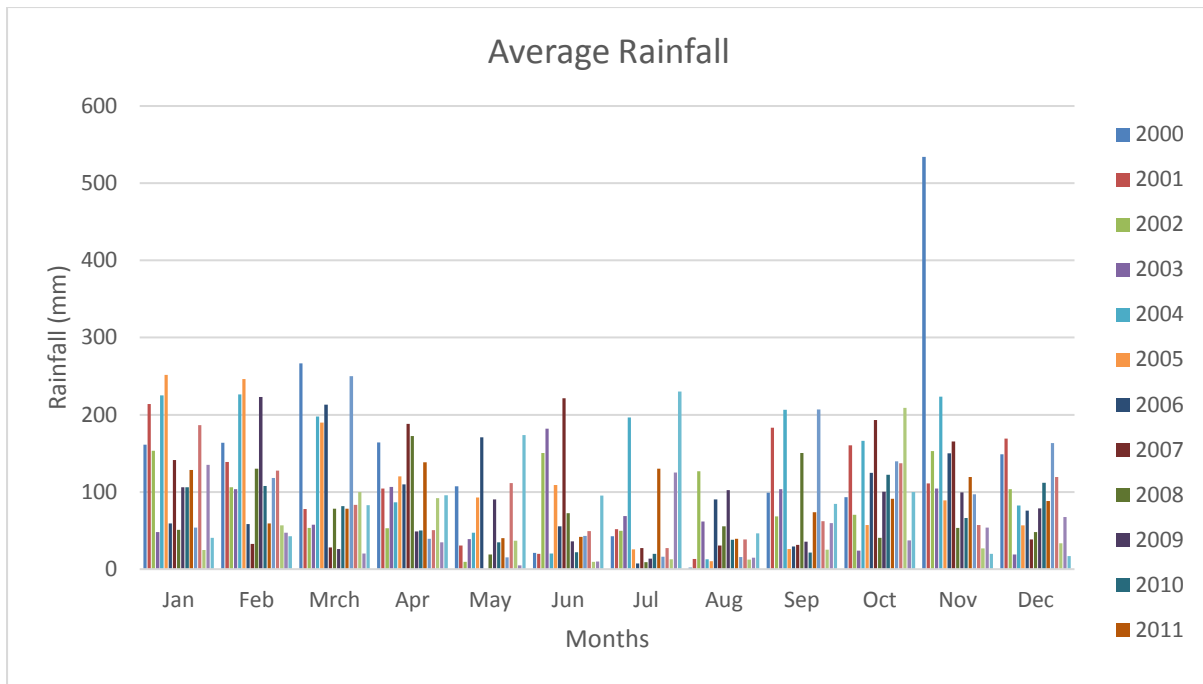


Figure 4: Average Rainfall in the Richards Bay area for the period 2000 to 2016 (SAWS, 2016).

### 3.1.3 Topography

Richards Bay lies on the Mozambican coastal plain with an elevation below 100 m (Chetty *et al.*, 2014) (Figure 5). The coastal plain consists of dune ridges which resulted from a retreating *Pleistocene* sea (Burger, 2009). The dune ridges are covered by forest and lake systems (Burger, 2009).

### 3.1.4 Geology

The Richards Bay coastal area consists mainly of unconsolidated sediment that was formed less than 65 million years ago by marine deposits forming the Cretaceous System which makes up the entire coastal plain (Burger, 2009). The Cretaceous System is made up mainly of silt stones with some thin bands of clay and limestone (Chetty *et al.*, 2014) (Figure 6).

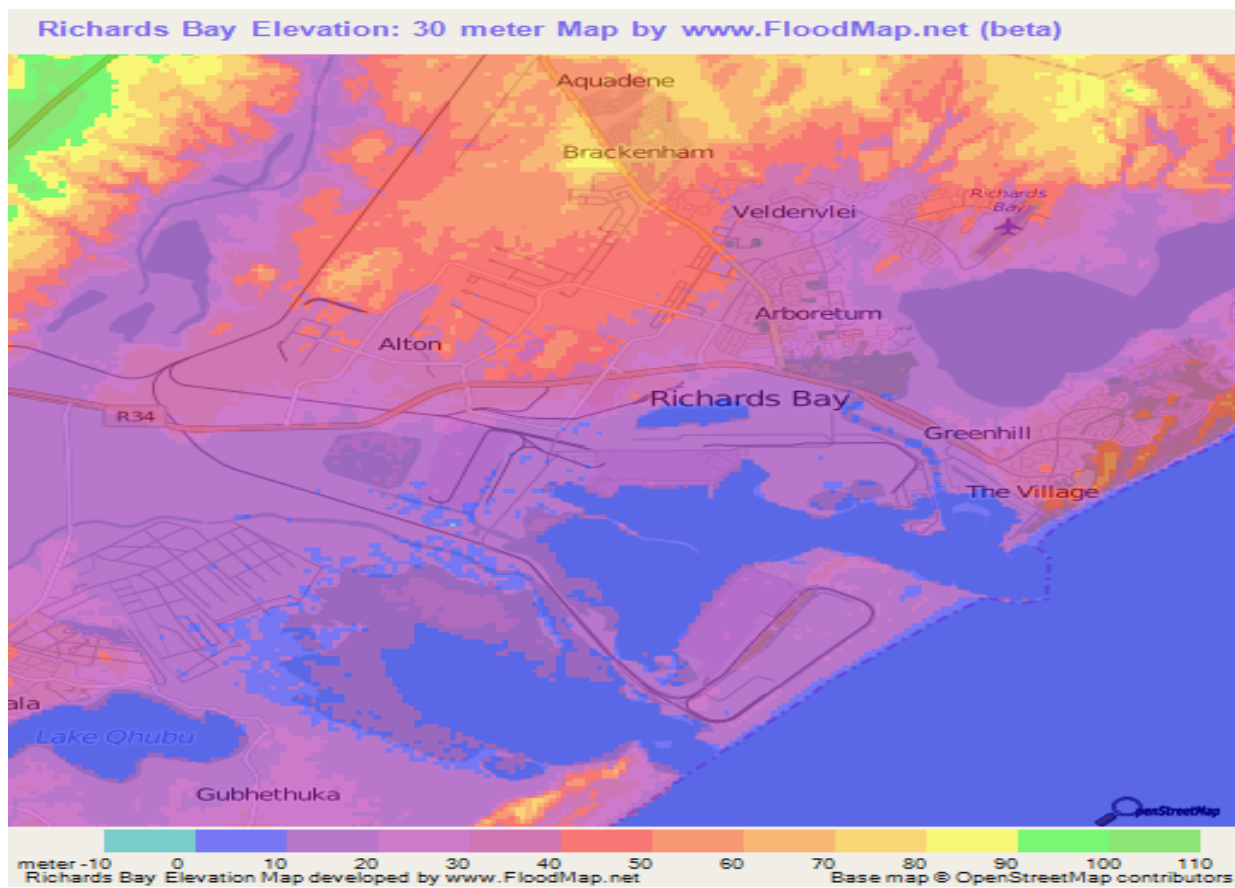


Figure 5: Topography of the Richards Bay area ([www.FloodMap.Net](http://www.FloodMap.Net) 2017).



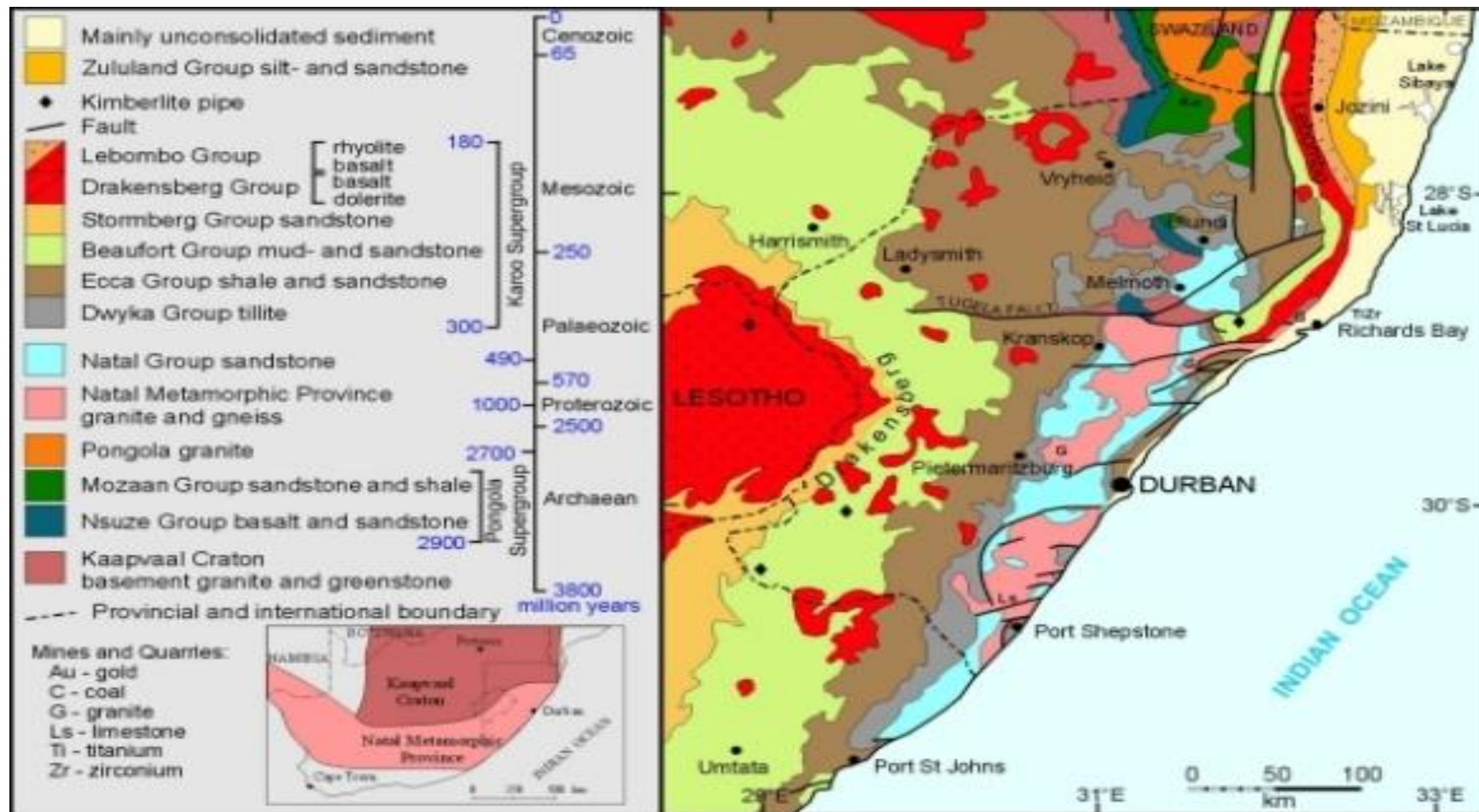


Figure 6: Geology of the Richards Bay area (KZNGeologyMap.aspx, 2017).

### 3.1.5 Vegetation

The general vegetation in the study area includes flooded grasslands, ephemeral herb lands and riverine thickets (Mucina and Rutherford, 2006; Scott-Shaw and Escott, 2011). The different plant communities in this area include: dune communities amongst others *Carprobatulus dimidiatus* and *Gazania rigens*, dune scrubs such as *Chrysanthemoides monilifera*, forest communities such as *Isoglossa woodii* (tall closed forest), *Chromolaena ordonatta* (short woodland forest), *Barringtonia racemosa* (tall swamp forest) and *Avicennia marina* (short mangrove forest). There are also grassland communities such as *Phragmites australis* (tall closed hygrophilous grassland), *Pycnus polystachyas* (open hygrophilous sedgeland), *Imperat acylindrica* (temporary agrophilous grassland) and *Paspalum distichum* (temporary agrophilous grassland) (Mucina and Rutherford, 2006; Scott-Shaw and Escott, 2011). Sugar cane fields and *Eucalyptus* timber plantations by Sappi cover large areas around the lake area.

### 3.1.6 Sampling sites

For the purpose of this study, a total of seven (7) sampling sites were selected. These sampling points started at sampling site number 1 at the inflow of the Mposa River that flowed into Lake Nsezi and ended with sampling site number 7 at the outflow from Lake Nsezi (Figure 8). Table 1 presents the Global Positioning System (GPS) coordinates for each of the sampled sites.

Table 1: GPS coordinates for the samples sites

Site number	Sampling sites	GPS coordinates
1	Mposa River	S 28° 41' 09" E 32° 01' 10"
2	RBM abstraction point	S 28° 41' 36" E 32° 01' 55"
3	N2 Bridge	S 28° 41' 45" E 32° 00' 51"
4	N2 Bridge downstream	S 28° 41' 45" E 32° 00' 51"
5	Small stream entering Lake Nsezi	S 28° 43' 22" E 32° 00' 20"
6	Abstraction point into Lake Nsezi	S 28° 44' 49" E 31° 58' 45"
7	Discharge point of Lake Nsezi	S 28° 46' 09" E 31° 57' 48"

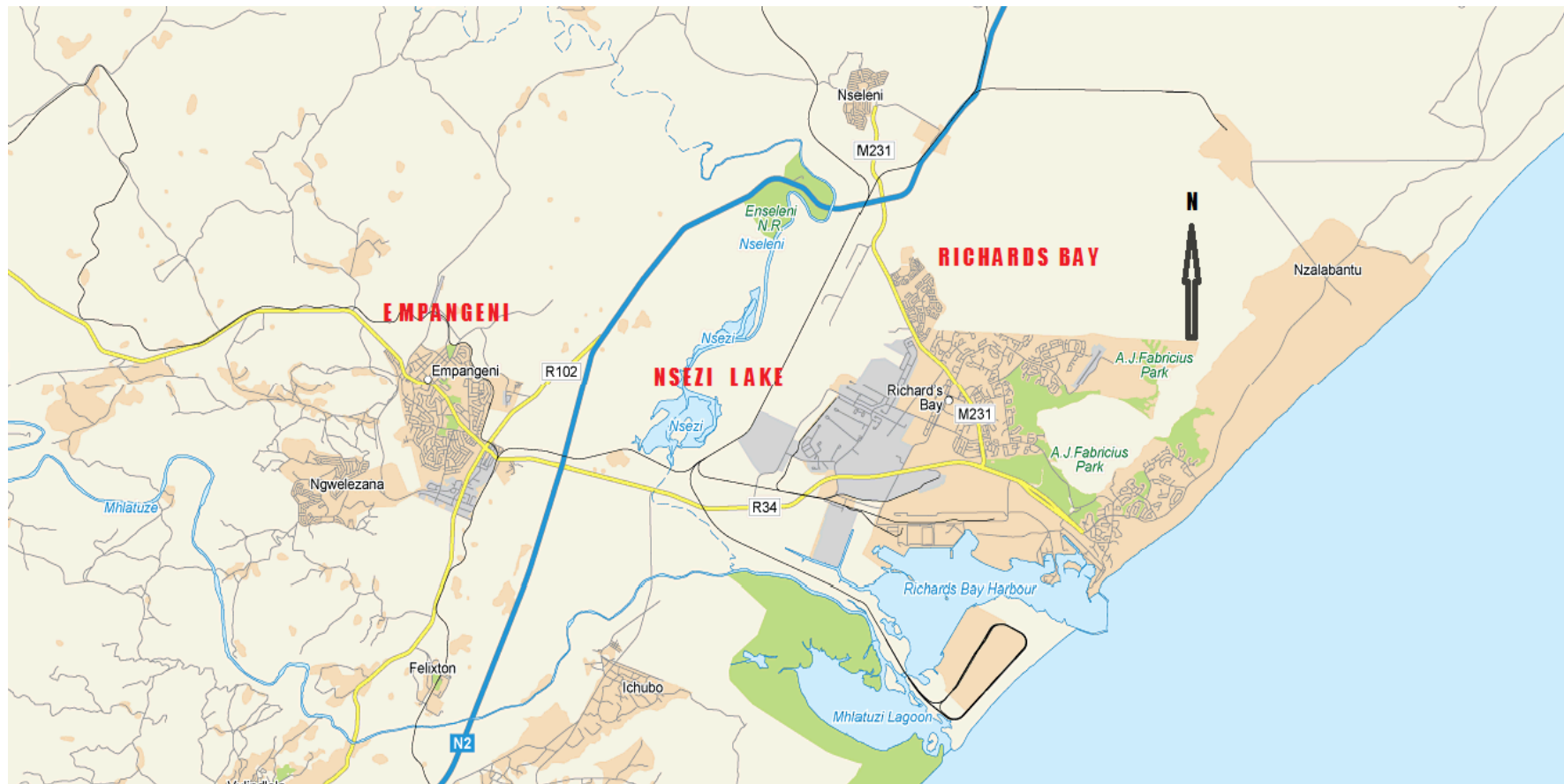


Figure 7: The Empangeni Richards Bay area with Lake Nsezi between the two (2) industrial towns (Google Earth, 2016).





Figure 8: Lake Nsezi and the different sampling points (Google Earth, 2016).

**Site 1: Mposa River discharge point** (Figure 9)

The Mposa River comes from as far as the Kwambonambi and Amangwe areas. The Mposa River discharges into Nsezi Lake at site 1. At this site cars, pedestrians and a rail way line cross in and out of Nseleni Township. The lake water is overgrown with vegetation (Fig. 9).

A sewage treatment plant (Nseleni Sewage Treatment Plant) that serves the rural town of Nseleni is located on the bank of the Mposa River as well as a concrete manufacturing plant (Collateral Trading Nseleni Asphalt Plant). It was observed that effluent from the sewage plant and concrete plant flows into the Mposa River.



Figure 9: Mposa River discharges at E'nseleni Township into Lake Nsezi. (Photograph by L. Cimanga).

**Site 2: Richards Bay Minerals (RBM) abstraction point** (Figure 10)

The Nseleni River water comes as far as the Ntambanana area. Along this stretch of the river the Zidedele Dam was built by Hullet Sugar and is used by farmers in the district. Tronox Minerals, a Kwazulu Natal sand mining company operates in Empangeni producing titanium dioxide feedstock. This company is also located along this stretch of river. Richards Bay Minerals, a mining company in Richards Bay extracts water from the Nseleni River at this point near the Nseleni Township (Figure 10).



Figure: 10. RBM abstraction point in the Nseleni River (Photograph by L. Cimanga).

**Site 3: N2 Bridge point** (Figure 11)

At this point the N2 national road crosses the Nseleni River that discharges into Lake Nsezi. Tracks in the mud indicated that cattle often graze in the area.



Figure: 11. N2 Bridge crossing the Nseleni River (Photograph by L. Cimanga).



**Site 4: Downstream of the N2 Bridge** (Figure 12)

This site is downstream from the N2 Bridge. It is surrounded by a dense forest.



Figure: 12. Sampling point in the Nseleni River downstream from the N2 Bridge (Photograph by L. Cimanga).



Figure: 13. A small stream flows into Lake Nsezi (Photograph by L. Cimanga).

**Site 5: Small stream entering into Lake Nsezi** (Figure 13)

At this sampling point, a small stream flows into the lake. Runoff from industries such as Richards Bay Coal Terminal (RBCT) shipment operations enters the stream, while a railway line also crosses over it. Pedestrians, cars and grazing cattle were often observed crossing the stream.

**Site 6: Abstraction point in Lake Nsezi** (Figure 14)

At site 6, uMhlathuze Water Laboratory erected a water treatment plant adjacent to the lake. The treatment plant extracts raw water directly from the lake and after an intensive filtration process, water is made available for use to the local municipality and various industries.



Figure: 14. Abstraction point in Lake Nsezi (Photograph by L. Cimanga).

**Site 7: Discharge point of Lake Nsezi** (Figure 15)

Site 7 is located in the southern side of Lake Nsezi. Water from Lake Nsezi discharges from this point into the Nsezi River which eventually flows into the Mhlathuze River which flows into the ocean.

Throughout the sampling period this site presented foul smelling water with a yellowish colour. The site was characterised by grasses, reeds and overgrown vegetation.





Figure15. Discharge point on the southern side of Lake Nsezi (Photograph by L. Cimanga).

### **3.2 Water Quality**

Water samples were collected at the above mentioned sampling sites and analysed accordingly.

#### **3.2.1 Sampling regime**

Sampling of the water from Nsezi Lake took place over a one (1) year period and included:

- Autumn sampling in May 2014,
- Winter sampling in July 2014,
- Spring sampling in October 2014,
- Summer sampling in January 2015 and
- Autumn sampling in May 2015.

#### **3.2.2 Sampling methodology**

At each sampling run, water samples were collected at each sampling site in specially prepared bottles supplied by the uMhlathuze Water Laboratory. One bottle was used for metal analysis and the other bottle was used for bacteriological analysis. Samples were stored in cooler bag with ice packs and either directly delivered to the laboratory on the same day or stored in a refrigerator for 24 hours before being taken to the

laboratory for analysis.

### 3.2.3 Analysis performed

The following analysis were performed either at each of the sites or at uMhlathuze Water Laboratory:

- i) *In-situ* physico-chemical parameters: *In-situ* parameters were measured at each sampling site prior to water sample collection. These parameters included pH, temperature, conductivity and dissolved oxygen (mg/L and %) using an Extech water quality kit. This kit included a RE300 ExStik ORP meter, a DO600 ExStik II Dissolved Oxygen meter and EC510 ExStik II pH/Conductivity meter.
- ii) Metal analysis: a metal scan was performed on each water sample at uMhlathuze Water Laboratory using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Standard operating procedures (SOP's) were followed to prepare and analyse these samples. The metal analysis included metals such as aluminium, barium, cadmium, chromium, cobalt, iron, lead, magnesium, manganese, molybdenum, nickel, mercury, potassium, sodium, strontium, titanium, vanadium and calcium.
- iii) General water quality analysis: This analysis was performed on each water sample at uMhlathuze Water Laboratory using Liquid chromatography. This analysis included for fluoride, chloride, nitrate and sulphate.
- iv) Bacteriological analysis: Bacteriological analysis was performed on each water sample at uMhlathuze Water Laboratory using the Colilert method for total coliform bacteria, faecal coliform bacteria and heterotrophic plate counts. Total coliform analysis was done for the general health of the water, Faecal coliform counts were done to establish pathogenic indicators in the water. Heterotrophic plate counts were done to establish the possible formation of a microbial colonies as well as the overall bacteriological quality of the water. Again SOP's were followed.

### **3.3 Historical data**

Historical data was obtained from uMhlathuze Water Laboratory data storage. Monitoring of the water from Lake Nsezi was done by uMhlathuze Water Laboratory since 2000 in order to identify and assess possible pollution trends (if any) for possible remediation measures to be implemented. Between 2000 and 2007 uMhlathuze Water Laboratory monitored the following parameters: general water quality parameters such as phosphates ( $\text{PO}_4$ ), cyanides (CN), hardness, nitrogen (N), dissolved oxygen (DO), total dissolved solids (TDS) as well as physical parameters such as pH, electrical conductivity, temperature, turbidity, colour and bacteriological analysis. In 2012, uMhlathuze Water Laboratory added metal analysis to their monitoring process with metals such as: copper, potassium, zinc, sodium, aluminium, cadmium, calcium, lead, iron, magnesium and manganese and more general water parameters such as; chloride, fluoride, nitrate and sulphate (personal communication S Bhengu, 2015).

### **3.4 Statistical analysis**

Statistical analysis was performed using the data from the current study (2014 – 2015) and the historical data that was available (Section 3.3). Capturing of the data in an Excel spreadsheet presented some data that was absent due to different sampling regimes from 2000 to 2015 as mentioned in Section 3.3. This presented data considered to be skew and a log 10 transformation was performed on all the data (except pH) to ensure homogeneity of the data set.

Multivariate statistical analysis was conducted using CANOCO v5. A principal component analysis (PCA) was chosen to represent the correlation between different variables (parameters) and the sampling sites in the data set.



## CHAPTER FOUR: RESULTS

### 4.1 Study data

#### 4.1.1 Physical water quality parameters

Physical, *in situ* water quality parameters such as pH, total dissolved solids (TDS), temperature and dissolved oxygen, were measured at each of the sampling sites (Appendix A: Table 1). The results for these measurements were compared to the Water Quality Guidelines for the Aquatic Ecosystem (WQG/AE) (DWAF, 1996a) and Water Quality Guidelines for the Domestic Use (WQG/DU) (DWAF, 1996b). For temperature and dissolved oxygen no WQG/AE were available.

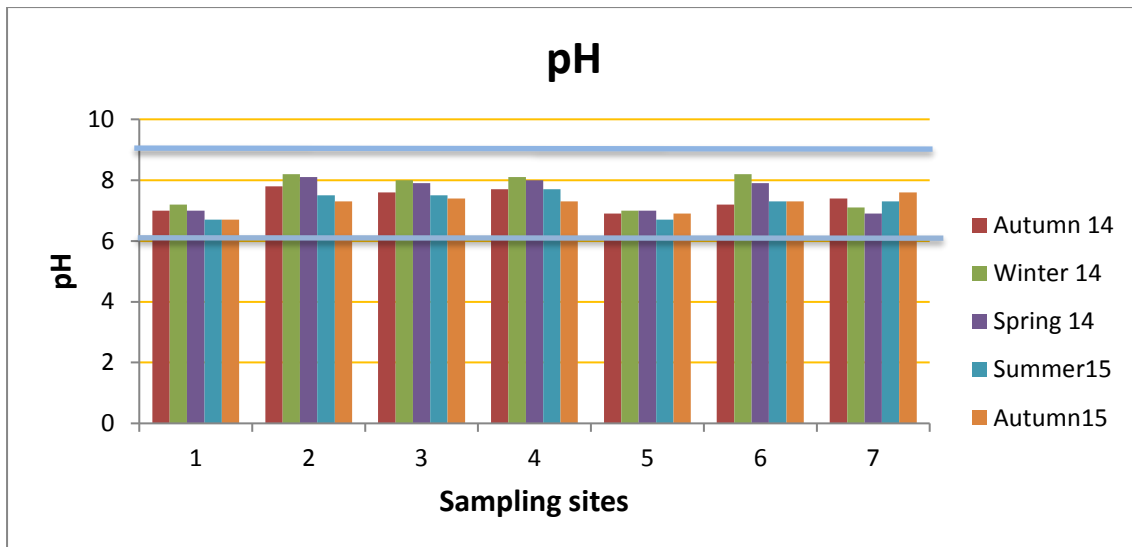
Only parameters with results above the TWQR for the different guidelines were presented in graphs such as pH and TDS. Temperature and dissolved oxygen presented results below the TWQR for the different guidelines and are discussed below while the original data is presented in Appendix A: Table 1.

Temperature at the sampling points varied for autumn 2014 between 21 and 26°C, winter 2014 between 17 and 21°C, spring 2014 between 23 and 27°C, summer 2015 between 24 and 27°C and autumn 2015 between 21 and 28°C (Appendix A: Table 1).

Dissolved oxygen levels at the sampling points varied for autumn 2014 between 25.7 and 95.6%, winter 2014 between 22.2 and 75.4%, spring 2014 between 11 and 68%, summer 2015 between 14.6 and 48.9%, and autumn 2015 between 24.1 and 114 % (Appendix A: Table 1).

##### 4.1.1.1 pH

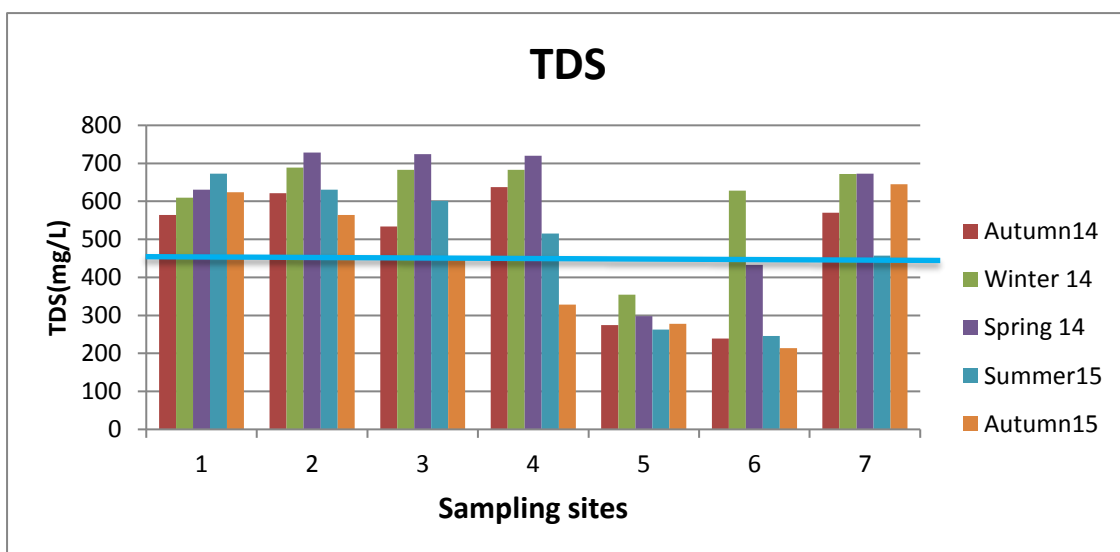
Figure 16 indicates the pH of the water samples for the sampling period 2014 to 2015. pH recorded for sampling sites 1-7 varied between 6.7 and 8.2 for the sampling period 2014 to 2015 and were within the TWQR limits for both the WQG/AE and WQG/DU (DWAF, 1996b) (Figure 16 and Appendix A: Table 1).



**Figure 16:** pH recorded at sampling sites 1-7 for the period 2014-2015. (----- pH WQG/AE and WQG/DU: TWQR between 6 and 9).

#### 4.1.1.2 Total dissolved solids (TDS)

For the monitoring period 2014 to 2015, TDS presented incidences below the TWQR for the WQG/DU (DWAf, 1996b) at Site 5 for all the sampling seasons and Site 6 for autumn 2014 and summer to autumn 2015 (Figure 17 and Appendix A: Table 1). The rest of the sampling sites presented TDS results above the TWQR (Figure 17 and Appendix A: Table 1).



**Figure 17:** TDS recorded at sampling sites 1-7 for the period 2014-2015. (----- WQG/DU: TWQR of 450 mg/L).

#### **4.1.2 General water quality parameters**

After each sampling period, the general water quality parameters were analysed and included: Fluoride, Chloride, Nitrate and Sulphate (Appendix A: Table 2).

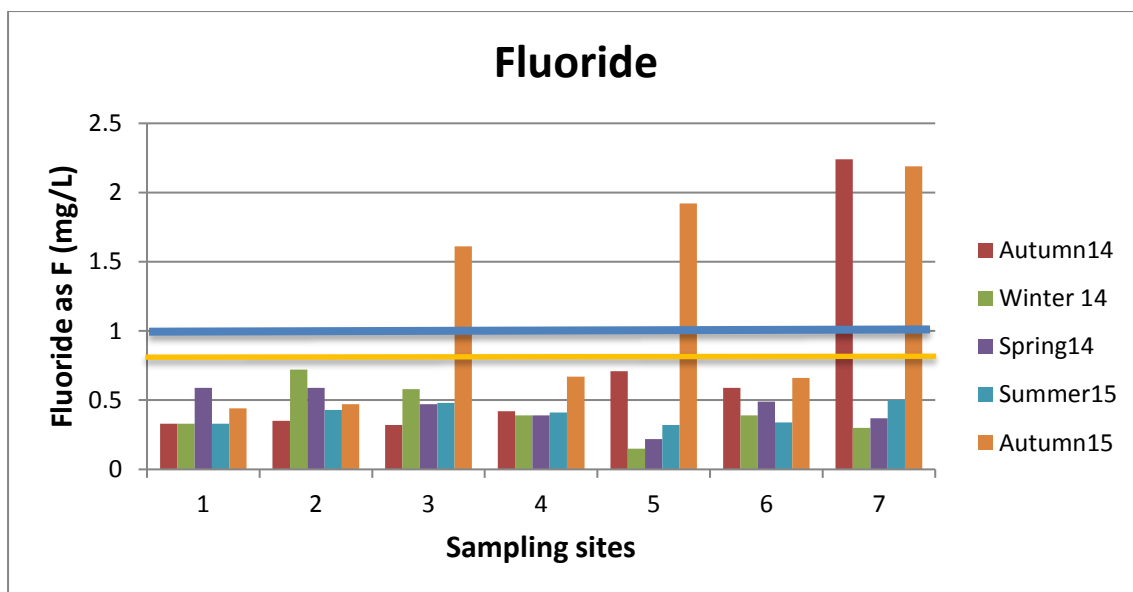
Only parameters with results above the TWQR for the different guidelines were presented in graphs such as F and Cl. Nitrates and sulphates presented results below the TWQR for the different guidelines and are discussed below while the original data is presented in Appendix A: Table 2.

For the monitoring period 2014 to 2015, nitrates varied from autumn 2014 to autumn 2015 at the different sampling points between 0.08 and 5.27 mg/L (Appendix A: Table 2). These results were below the TWQR of 6.0 mg/L for the WQG/DU (DWAF, 1996b) while the TWQR for the WQG/AE were not available (DWAF, 1996a).

Sulphates varied between 0.89 and 35.23 mg/L at the different sampling sites (Appendix A: Table 2). These results were also below the TWQR of 200.0 mg/L for the WQG/DU (DWAF, 1996b) while the TWQR for the WQG/AE were not available (DWAF, 1996a).

##### **4.1.2.1 Fluoride**

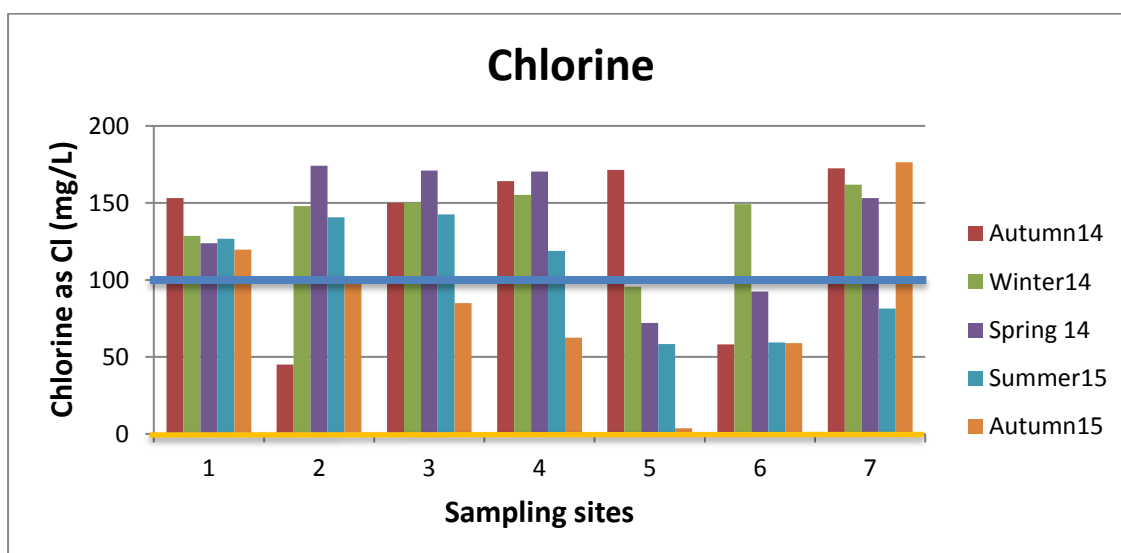
During the sampling period of 2014 and 2015, fluoride concentrations determined for the different sampling points presented four incidences of fluoride being above the TWQR for the WQG/AE (DWAF, 1996a) and WQG/DU (DWAF, 1996b). These incidences occurred at Site 7 during autumn 2014 (2.2 mg/L) and sampling sites 3, 5 and 7 during autumn 2015 (1.6, 1.9 and 2.1 mg/L respectively) (Figure 18 and Appendix A: Table 2).



**Figure 18:** Fluoride concentrations recorded at sampling sites 1-7 for the period 2014-2015 (----- Fluoride WQG/AE: TWQR of 0.75 mg/L and ----- WQG/DU: TWQR of 1.0 mg/L).

#### 4.1.2.2 Chlorine (Cl)

Chlorine concentration from autumn 2014 to autumn 2015 presented results above the TWQR of 0.002 mg/L for the WQG/DU at all the sites (Figure 19 and Appendix A: Table 2). Chlorine concentration at most of the sites presented results above the TWQR of 100 mg/L for the WQG/AE, except for Site 5 and 6 with most sampling seasons below this TWQR (Figure 19 and Appendix A: Table 2).



**Figure 19:** Chlorine concentrations recorded at sampling sites 1-7 for the period 2014-2015 (----- Chlorine WQG/AE: TWQR of 0.002 mg/L and ----- WQG/DU: TWQR of 100 mg/L).

### 4.1.3 Metal analysis

After each sampling period, the samples were analysed for: Al, Ba, B, Cd, Cr, Co, Cu, Fe, Pb, Mg, Mn, Mo, Ni, Hg, K, Sr, Ti, V and Ca (Appendix A: Table 3).

The TWQR for the WQG/AE (DWAF, 1996a) and WQG/DU (DWAF, 1996b) are not available for some of the metals analysed. These metals included Ba, Bo, Co, Fe, Mo, Mg, Ni and K. During the 2014-2015 monitoring period, these metal concentrations varied at all the sampling sites as follow: Ba between 0.03 and 0.17 mg/L, B between 0.025 and 0.128 mg/L, Co between 0.013 and 0.013 mg/L, Fe between 0.026 and 2.265 mg/L, Mo between 0.007 and 0.04 mg/L, Mg between 9.8 and 29 mg/L (this was also below the TWQR of 30 mg/L Mg for the WQG/DU (DWAF, 1996b)), Ni between 0.021 and 0.021 mg/L and K between 2.27 and 10.2 mg/L (this was below the TWQR of 50 mg/L for the WQG/DU (DWAF, 1996b)).

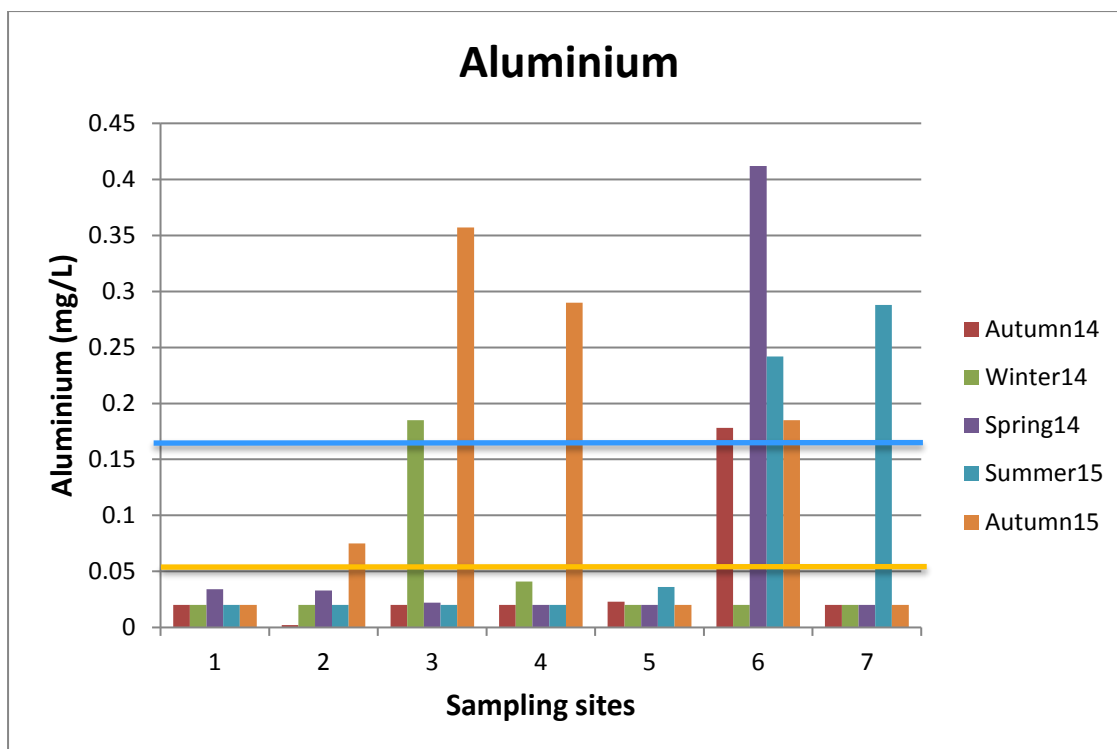
Strontium concentrations varied between 0.08 and 0.241 mg/L, Titanium between 0.004 and 5 mg/L, Vanadium between 0.003 and 0.01 mg/L and Calcium between 4.41 and 32.7 mg/L (Appendix A: Table 3).

Water quality guidelines for both the aquatic environment and domestic use were available for aluminium, cadmium, copper, lead and manganese and results are presented in the figures 20 to 24 (Appendix A: Table 3).

#### 4.1.3.1 Aluminium

During the sampling period of 2014 and 2015, aluminium concentrations determined for the different sampling sites, presented the following results:

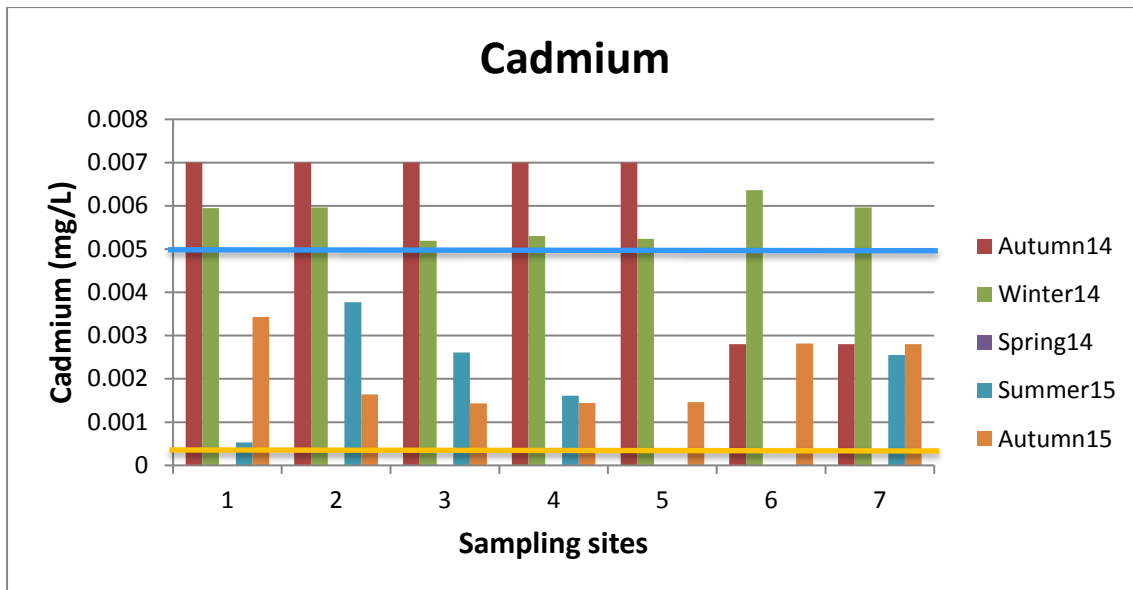
Aluminium concentrations were below the TWQR of 0.005 for the WQG/AE (DWAF, 1996a) at all the sites (Figure 20 and Appendix A: Table 3). Sites 3, 4, 6 and 7 presented Al concentrations above the TWQR of 0.15 mg/L for the WQG/DU (DWAF, 1996b) for some of the sampling months (Figure 20 and Appendix A: Table 3). These include Site 3 during winter 2014 and autumn of 2015 (0.185 mg/L and 0.02 mg/L respectively) and Site 4 during autumn 2015 (0.29 mg/L), Site 6 during autumn and spring of 2014 and also during summer and autumn of 2015 (0.178 mg/L, 0.412 mg/L, 0.242 mg/L and 0.185mg/L respectively) and Site 7 during the summer of 2015 (0.02 mg/L) (Figure 20 and Appendix A: Table 3).



**Figure 20:** Aluminium concentrations recorded at sampling sites 1-7 for the period 2014-2015 (----- Aluminium WQG /AE: TWQR of 0.005 mg/L and ----- WQG/DU: TWQR of 0.15 mg/L).

#### 4.1.3.2. Cadmium

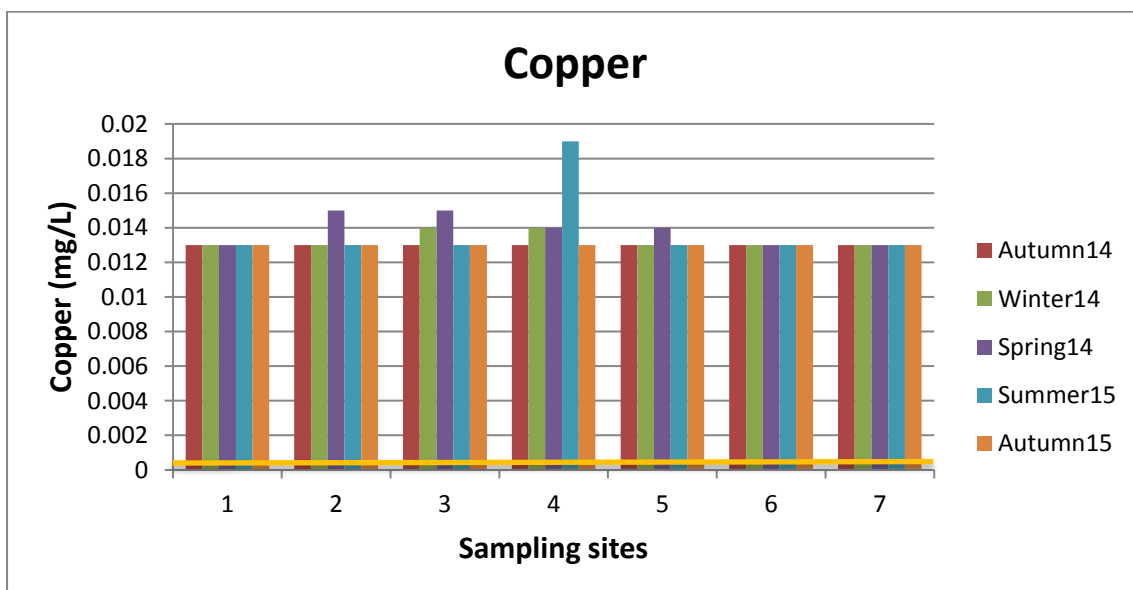
During the sampling period of 2014 and 2015, cadmium concentration recorded at the different sampling points, presented incidences of cadmium being above the TWQR for the WQG/AE (DWAF, 1996a) and the WQG/DU (DWAF, 1996b). These incidences occurred at Site 1 during autumn and winter of 2014 and summer and autumn of 2015 (0.007 mg/L, 0.00595 mg/L, 0.00053 mg/L and 0.00343 mg/L respectively), Site 2 during autumn and winter of 2014 and summer and autumn of 2015 (0.007 mg/L, 0.00596 mg/L, 0.00377 mg/L and 0.00164 mg/L respectively), Site 3 during autumn and winter of 2014 and summer and autumn of 2015 (0.007 mg/L, 0.00519 mg/L, 0.00261 mg/L and 0.000143mg/L respectively). From these results it is noted that there is no major increase in cadmium concentration from autumn 2014 to autumn 2015 downstream. Cadmium concentrations determined for spring 2014 at the different sites were below the detection limit (Figure 21 and Appendix A: Table 3).



**Figure 21:** Cadmium concentrations recorded at sampling sites 1-7 for the period 2014-2015 (----- Cadmium WQG /AE: TWQR of 0.00025 mg/L and ---- WQG/DE: TWQR of 0.0005 mg/L).

#### 4.1.3.3 Copper

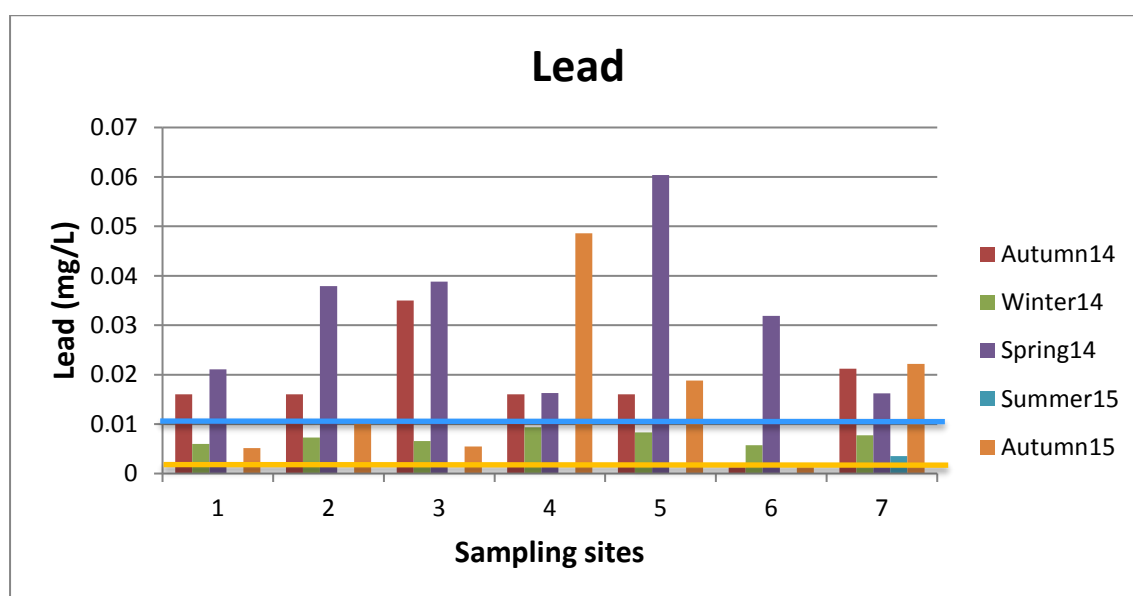
During the sampling period of 2014 and 2015, copper concentrations determined for the different sampling sites for the five (5) seasons (autumn, winter and spring 2014, summer and autumn 2015), presented incidences of copper being above the TWQR for the WQG/AE (DWAF, 1996a) but below TWQR for the WQG/DE of 1 mg/L (DWAF, 1996b) (Figure 22 and Appendix A: Table 3)



**Figure 22:** Copper concentrations recorded at sampling sites 1-7 for the period 2014-2015 (----- Copper WQG /AE: TWQR of 0.0008 mg/L and ---- WQG/DE: TWQR of 1 mg/L (not indicated)).

#### 4.1.3.4 Lead

During the sampling period of 2014 and 2015, lead concentrations at all the different sampling sites presented incidences of lead above the TWQR of 0.0005 mg/L for WQG/AE (DWAF, 1996a) (Figure 23 and Appendix A: Table 3). It is also noted that during autumn 2014 lead concentration increased from 0.00126 mg/L to 0.00212 mg/L downstream; in winter 2014, the concentration of lead increased from 0.006 mg/L to 0.00935 mg/L; during spring 2014, lead concentration increased from 0.00163 mg/L to 0.00604 mg/L downstream and during autumn 2015, lead concentration increased from 0.00129 mg/L to 0.0468 mg/L, the missing values were below detection (Figure 23 and Appendix A: Table 3).



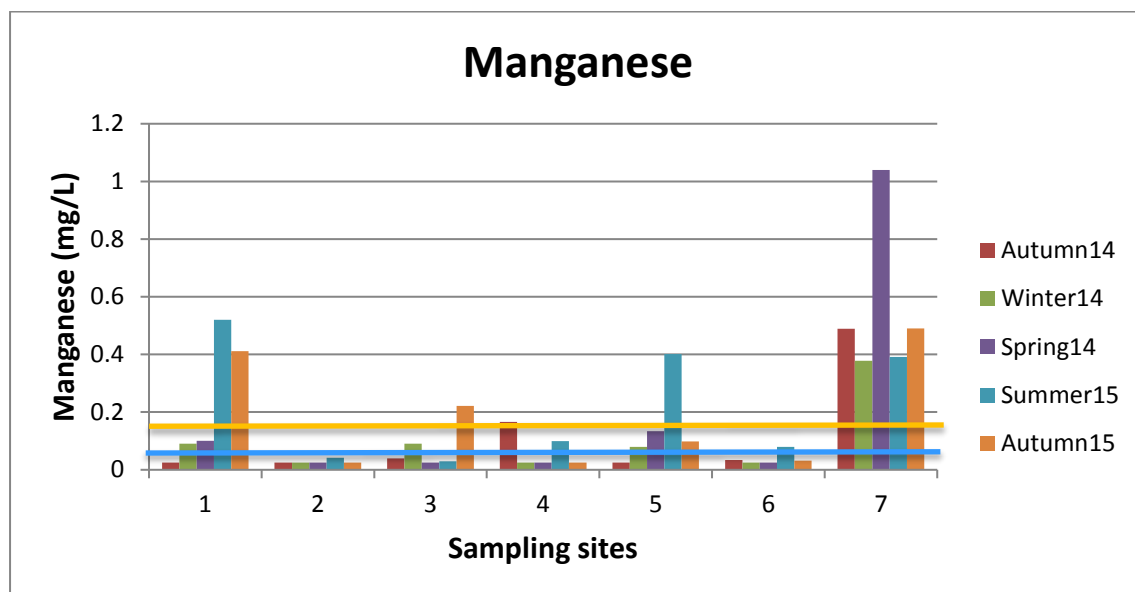
**Figure 23:** Lead concentrations recorded at sampling sites1-7 for the period 2014-2015 (----- Lead WQG /AE: TWQR of 0.0005 mg/L medium water limit and ----- WQG/DU: TWQR of 0.010 mg/L).

#### 4.1.3.5 Manganese

During the sampling period of 2014 and 2015, the following are incidences where manganese concentrations were recorded above both the TWQR of 0.18 mg/L for the WQG/AE (DWAF, 1996a) and the TWQR of 0.05 mg/L for the WQG/DU (DWAF, 1996b): Site 1 during summer (0.52 mg/L) and autumn of 2015 (0.41 mg/L); Site 3 during winter 2014 (0.091 mg/L) and autumn 2015 (0.22 mg/L); Site 4 during autumn 2014 (0.166 mg/L) and summer 2015 (0.10 mg/L); Site 5 during spring 2014 (0.134 mg/L), summer (0.401 mg/L) and autumn of 2015 (0.98 mg/L) and Site 7 during



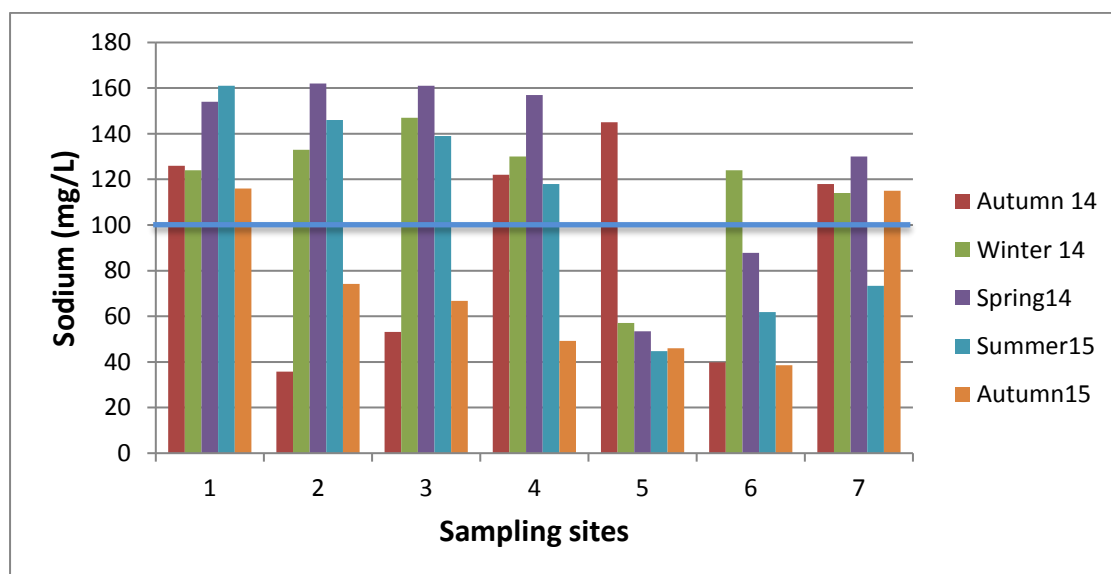
autumn (0.489 mg/L), winter (0.378 mg/L) and spring 2014 (1.04 mg/L), summer (0.391 mg/L) and autumn of 2015 (0.49 mg/L) (Figure 24 and Appendix A: Table 3).



**Figure 24:** Manganese concentrations recorded at sampling sites 1-7 for the period 2014-2015 (----- Manganese WQG /AE: TWQR of 0.18 mg/L and ----- WQG/DU: TWQR of 0.05 mg/L).

#### 4.3.1.6 Sodium

Sodium were present in concentrations above the TWQR of 100 mg/L for WQG/DU (DWAf, 1996b) at Site 1 to Site 7 for most of the seasons. Site 5 presented Na above the TWQR for the WQG/DU during autumn 2014 (145 mg/L) and Site 6 during winter 2014 (124 mg/L) (Figure 25 and Appendix A: Table 3).



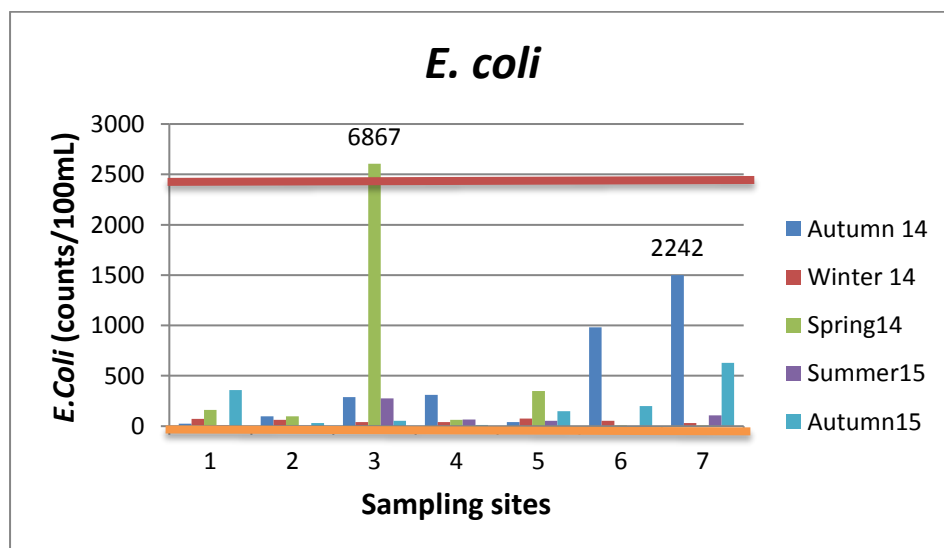
**Figure 25:** Sodium concentrations recorded at sampling sites 1-7 for the period 2014-2015 (----- Sodium WQG/DU: TWQR of 100 mg/L).

#### 4.1.4 Bacteriological analysis

After each sampling period, the following bacteriological analysis were performed: Faecal coliforms (*Escherichia coli*), heterotrophic plate counts and Total coliform counts (Appendix A: Table 4). The TWQR for the WQG/DU (DWAF, 1996b) for *E.coli* is 0 counts/100 mL, 10 000 counts/100 mL for heterotrophic plate counts and 5 counts/100 mL for total coliform counts. No TWQR was available for the WQG/AE for these parameters. It is important to notice that uMhlathuze Water Laboratory in Richards Bay is using a separate maximum allowable limit for *E. coli* of 2 400 counts/100 mL (personal communication, Bhengu S, 2015).

##### 4.1.4.1 Faecal coliforms (*E. coli*)

During the sampling period of 2014 and 2015, *E.coli* counts determined at all the different sampling points, indicated incidences of *E.coli* being above the TWQR of 0.0 counts/100 mL for WQG/DU (DWAF, 1996b) in general during the rainy season (spring, summer and autumn). One incidence of an *E.coli* recording above the uMhlathuze Water Laboratory count of 2 400 counts/100 mL, was observed at Site 3 during spring 2014 (6 867 counts/100 mL) (Figure 26 and Appendix A: Table 4).

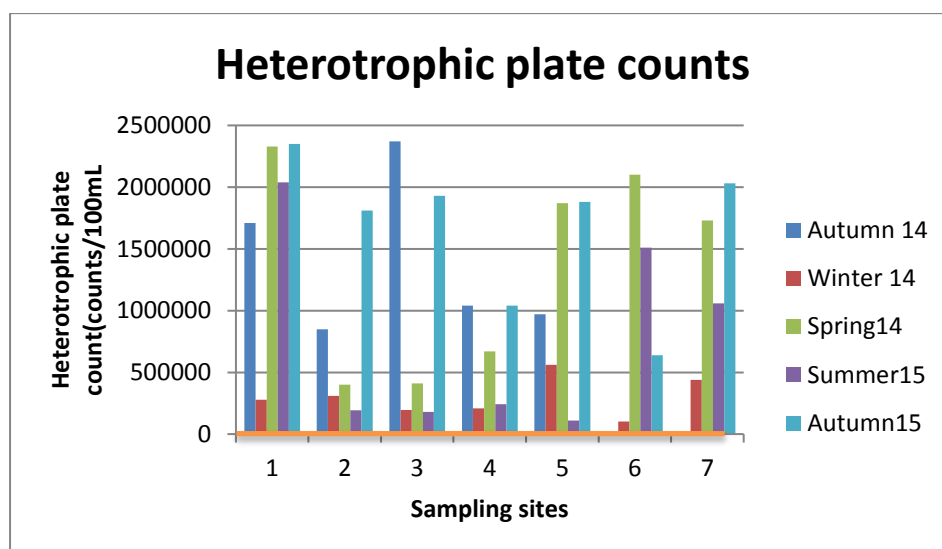


**Figure 26:** *E.coli* counts recorded at sampling sites 1-7 for the period 2014-2015 (----- *E.coli* TWQR: WQG/DU of 0.0 counts/100 mL and ----- *E.coli* uMhlathuze Water Laboratory counts of 2 400 counts/100 mL)

##### 4.1.4.2 Heterotrophic plate count

During the sampling period of 2014 and 2015, heterotrophic plate counts determined at most of sampling sites, indicated incidences of heterotrophic counts above the

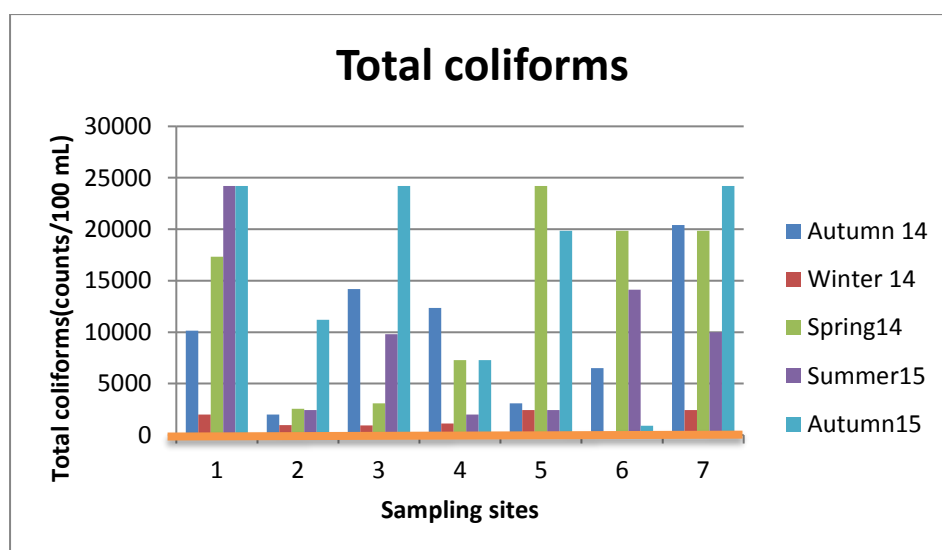
TWQR of 10 000 counts/100 mL for the WQG/DU (DWAF, 1996b) such as Site 1 during spring 2014 (2 330 000 counts/100 mL) and autumn 2015 (2 350 000 counts/100 mL); Site 3 during autumn 2014 (2 370 000 counts/100mL); Site 5 during winter 2014 (560 000 counts/100 mL) and Site 7 during summer 2015 (10 600 000 counts/100mL) (Figure 27 and Appendix A: Table 4).



**Figure 27:** Heterotrophic plate counts recorded at sampling sites 1-7 for the period 2014 to 2015 (----- heterotrophic plate counts WQG/DU: TWQR of 10 000 counts/100 mL).

#### 4.1.4.3 Total coliform counts

During the sampling period of 2014 and 2015, total coliform counts determined at all the different sampling sites, presented counts above the TWQR of 5 counts/100 mL for the WQG/DU (DWAF, 1996b) at all the sites (Figure 28, Appendix A: Table 4).



**Figure 28:** Total coliform counts recorded at sampling sites 1-7 for the period 2014 to 2015 (----- Total coliform counts WQG/DU: TWQR of 5.0 counts/100 mL).

## **4.2 Historic data**

Due to unknown circumstances at uMhlathuze Water Laboratory, data for the sampling period of 2009 and 2013 were not available.

The data for most of parameters will be compared for the period 2000 to 2015 over four (4) representative sampling sites: site 1: Mposa River, Site 2: Nseleni River at the RBM Pump Station, Site 3: Nseleni River at the N2 Bridge and Site 7: Lake Nsezi outflow. These four (4) sites are same between the historical data site of collections and sites for the current study.

### **4.2.1 Physical water quality parameters**

#### **4.2.1.1 pH**

pH data was available for the sampling period 2000 to 2015 (summer, autumn, winter and spring) and is indicated in Figure 29 and Appendix B: Table 1.

For Site 1, pH varied between 6.2 and 8.5; Site 2 between 7.1 and 8.5; Site3 between 7.1 and 8.5; and Site 7 between 6.4 and 8.2 and pH was found to be within the TWQR of the WQG/AE and WQG/DU of between 6 to 9 (DWAF, 1996b) (Figure 29, Appendix A: Table 1 and Appendix B: Table 1).

#### **4.2.1.2 Total dissolved solids (TDS)**

Total dissolved solids data for the period 2000 to 2015 is presented in Figure 30 and Appendix B: Table 2.

For Site 1, the TDS varied between 395 and 728 mg/L, Site 2, between 338 and 743 mg/L, Site 3, between 278 mg/L and 737 mg/L and Site 7, between 270 and 673 mg/L (Figure 30, Appendix A: Table 1 and Appendix B: Table 2).

All four sites presented incidences of TDS above both TWQR of the WQG/DU (DWAF, 1996b). These incidences were observed at Site 1 during autumn (718 mg/L) and spring of 2000 (728 mg/L); Site 2 during spring of 2002 (743 mg/L) and autumn 2003 (735 mg/L); Site 3 during spring of 2002 (737 mg/L) and spring 2014 (724 mg/L) and Site 7 during spring 2001 (617 mg/L) and spring 2014 (673 mg/L) (Figure 30, Appendix A: Table 1 and Appendix B: Table2).

## **4.2.2 General water quality parameters**

### **4.2.2.1 Fluoride (F)**

Figure 31, Appendix A: Table 2 and Appendix B: Table 3, illustrate Fluoride concentrations for the period 2010 to 2015 sampled during summer, autumn winter and spring for each year. No data was available for the years 2000 to 2009.

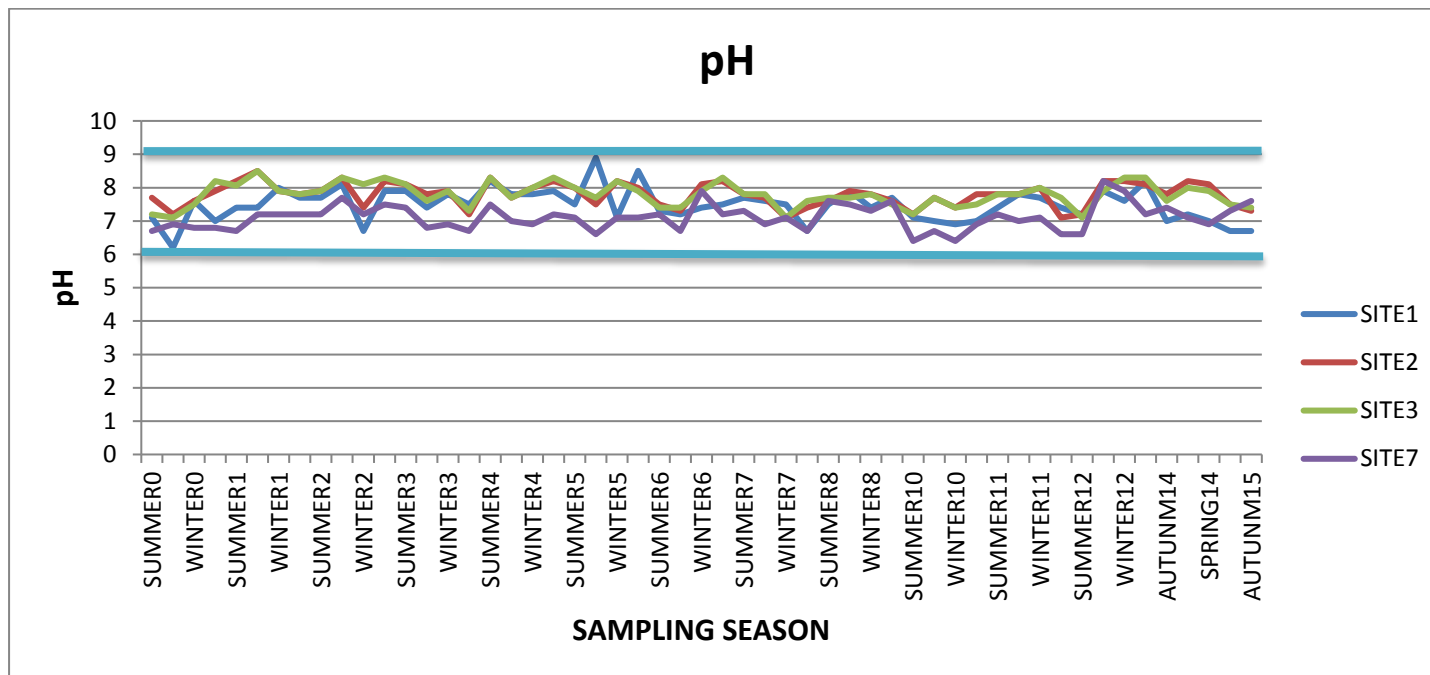
For Site 1, Fluoride concentration varied between 0.26 and 0.59 mg/L, Site 2 between 0.03 and 0.72 mg/L, Site 3 between 0.03 and 1.61 mg/L and Site 7 between 0.3 and 2.24 mg/L (Figure 31, Appendix A: Table 2 and Appendix B: Table 3).

Fluoride concentrations were above both TWQR of the WQG/AE (DWAF, 1996a) and WQG/DU (DWAF, 1996b) at the following sampling sites: Site 3, autumn 2015 (1.61 mg/L) and Site 7, autumn 2014 (2.24 mg/L) and autumn 2015 (2.29 mg/L) (Figure 31, Appendix A: Table 2 and Appendix B: Table 3).

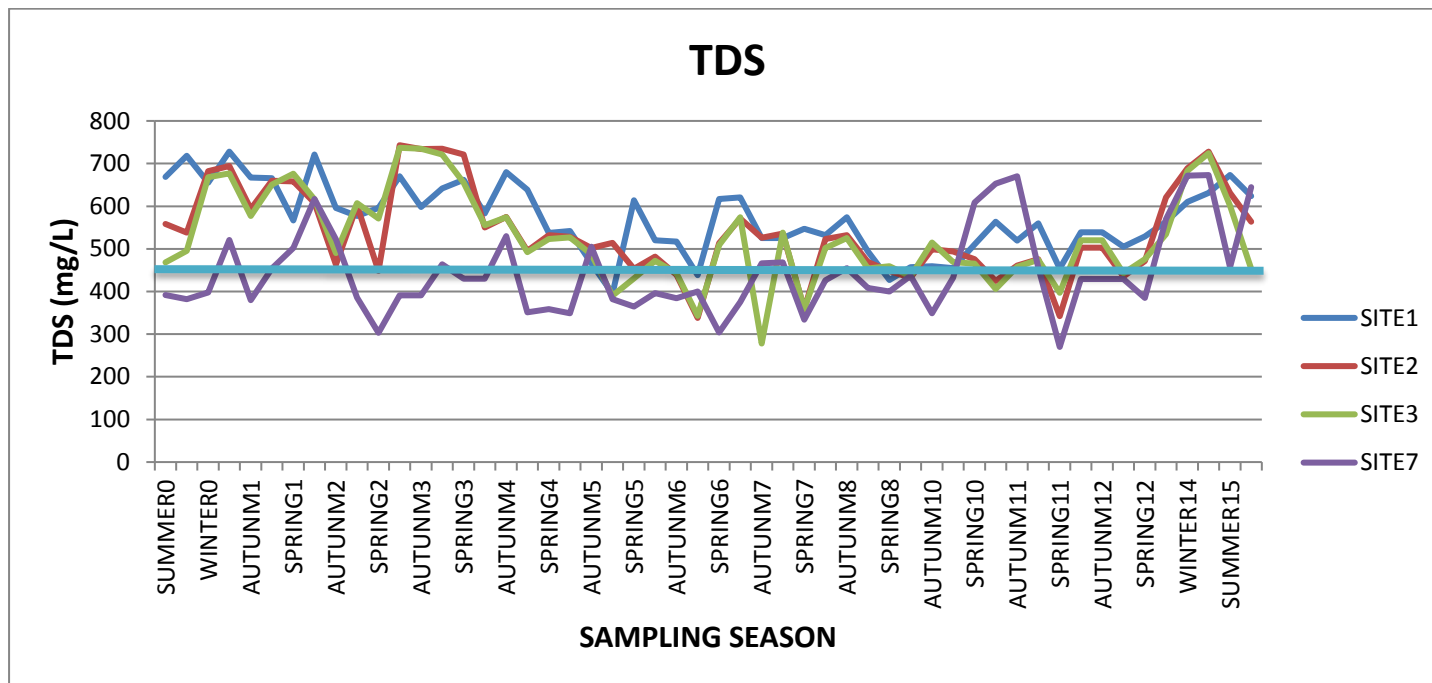
### **4.2.2.2 Chlorine**

Figure 32, Appendix A: Table 2 and Appendix B: Table 4, illustrate chloride concentrations for the period 2010 to 2015 sampled during summer, autumn, winter and spring of each year and there were no data available for the years 2000 to 2009.

Chlorine concentrations at Site 1 varied between 70.9 and 153.2 mg/L; at Site 2 it varied between 45.14 and 174.21 mg/L; at Site 3 it varied between 80.5 and 171.09 mg/L and at Site 7 it varied between 81.39 and 201 mg/L (Figure 32, Appendix A: Table 2 and Appendix B: Table 4). Most chlorine concentrations recorded at the different sampling sites were above both the TWQR of the WQG/AE of 0.0002 mg/L (DWAF,1996a) and WQG/DU of 100 mg/L (DWAF, 1996b) (Figure 32, Appendix A: Table 2 and Appendix B: Table 4).



**Figure 29:** pH recorded at sampling sites 1, 2, 3 and 7 for the period 2000 to 2015 (----- WQG/AE and WQG/DU: TWQR between 6 and 9) (X-axis: summer0 = summer 2000).



**Figure 30:** TDS recorded at sampling sites 1, 2, 3 and 7 for the period 2000 to 2015 (----- WQG/DU: TWQR of 450 mg/L).

### **4.2.3 Metals**

#### **4.2.3.1 Aluminium**

Aluminium concentrations for the sampling period 2005 to 2015 are indicated in Figure 33, Appendix A: Table 3 and Appendix B: Table 5.

For Site 1, aluminium concentrations varied between 0.008 and 4.773 mg/L; at Site 2 it varied between 0.008 and 10.783 mg/L; at Site 3, it varied between 0.008 and 10.425 mg/L and for Site 7 it varied between 0.008 and 0.69 mg/L (Figure 33, Appendix A: Table 3 and Appendix B: Table 5).

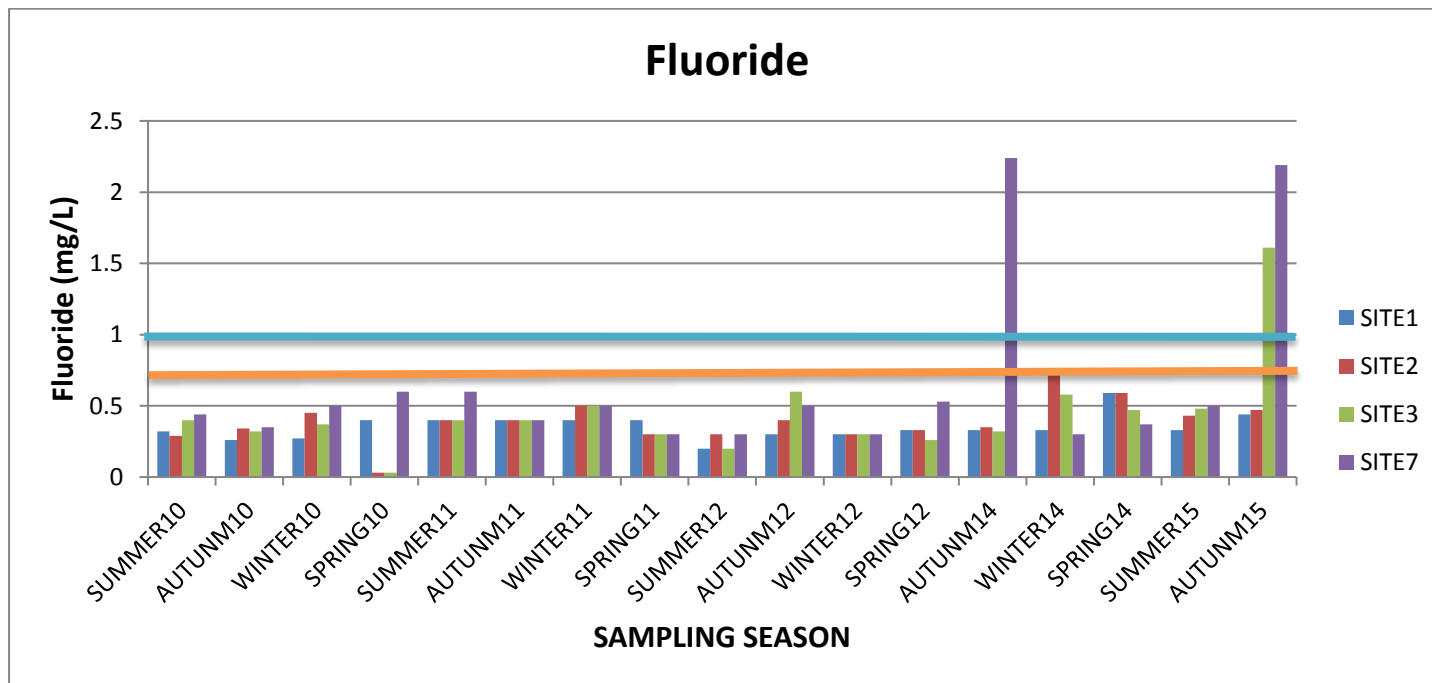
Aluminium concentrations recorded presented some incidences of concentrations above both TWQR for the WQG/AE (DWAF, 1996a) and the WQG/DU (DWAF, 1996b)

At Site 1 for during autumn (1.19 mg/L) and winter 2006 (12 mg/L), summer 2011 (2.8 mg/L) and summer (0.54 mg/L) and autumn of 2012 (4.773 mg/L).

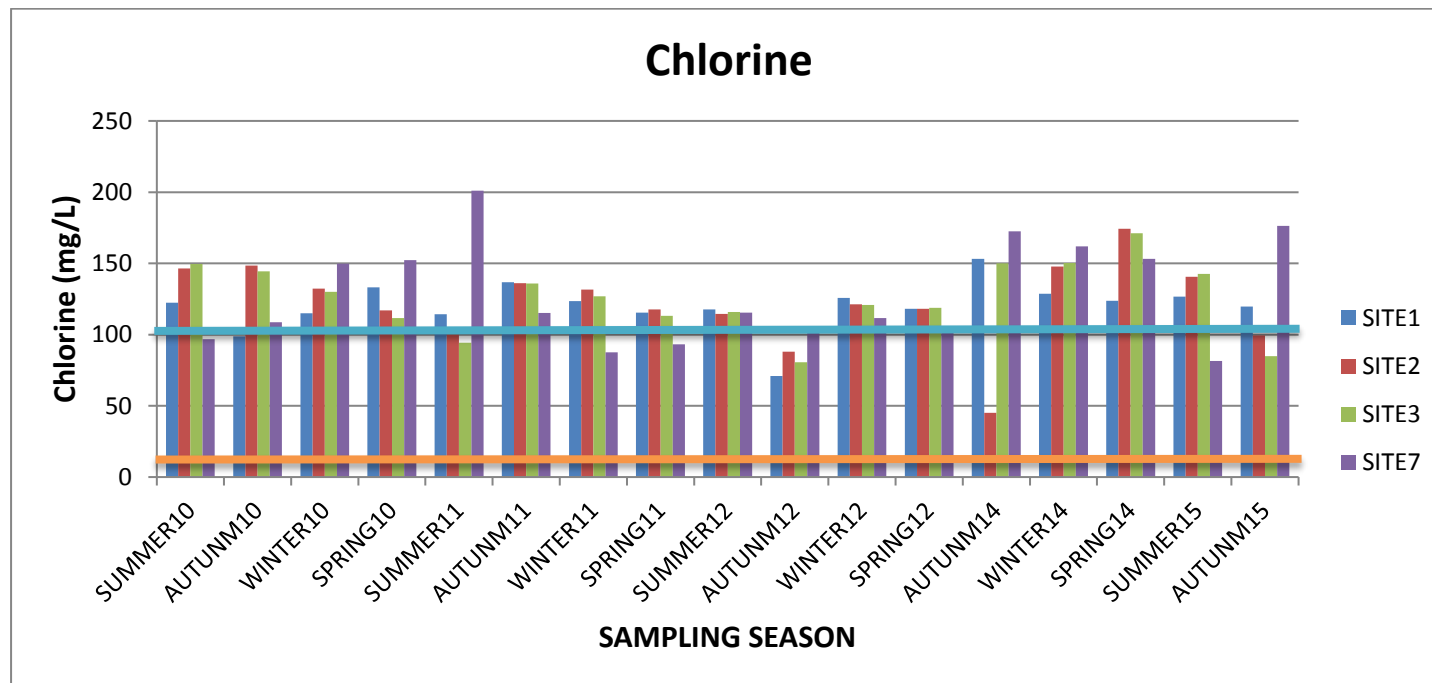
At Site 2 during autumn 2006 (1.7 mg/L), winter 2007 (2.52 mg/L), summer 2011 (2.4 mg/L) and summer (1.463 mg/L) and autumn of 2012 (10.783 mg/L).

At Site 3 during autumn 2006 (0.77 mg/L), winter 2007 (0.11 mg/L) and summer (1.254 mg/L) and autumn of 2012 (10.425 mg/L) and at Site 7 during winter 2007 (0.89 mg/L) (Figure 33, Appendix A: Table 3 and Appendix B: Table 5).





**Figure 31:** Fluoride concentrations recorded at sampling sites 1, 2, 3 and 7 for the period 2010 to 2015  
 (----- Fluoride WQG/AE: TWQR of 0.75 mg/L and ----- WQG/DU: TWQR of 1.0 mg/L).



**Figure 32:** Chlorine concentrations recorded at sampling sites 1, 2, 3 and 7 for the period 2010 to 2015 (----- Chlorine WQG/AE: TWQR of 0.0002 mg/L and ----- WQG/DU: TWQR of 100 mg/L).

#### **4.2.3.2 Copper**

Figure 34, Appendix A: Table 3 and Appendix B: Table 6 illustrate Copper concentrations for the period 2007 to 2015 sampled during summer, autumn winter and spring of each year.

For Site 1, copper concentrations varied between 0.0009 and 0.169 mg/L; Site 2 between 0.0009 and 0.016 mg/L; Site 3 between 0.0009 and 0.61 mg/L and Site 7 between 0.0009 and 0.01 mg/L (Figure 34, Appendix A: Table 3 and Appendix B: Table 6).

Copper concentrations at all the sites were below the TWQR for WQG/DU (DWAF, 1996b) for the entire sampling period (Figure 34, Appendix A: Table 3 and Appendix B: Table 6).

Copper concentrations recorded at Sites 1-7 were above the TWQR: WQG/AE of 0.0003 mg/L (DWAF, 1996a) from summer 2007 to summer 2015 such as at Site 1 during autumn 2010 (0.169 mg/L), summer 2011 (0.01 mg/L) and autumn 2014 (0.0065 mg/L); Site 2 during winter 2007 (0.016 mg/L) and spring 2014 (0.015 mg/L); Site 3 during winter 2007 (0.012 mg/L), spring 2012 (0.007 mg/L), spring 2014 (0.015 mg/L) and autumn 2015 (0.0065 mg/L) and Site 7 during winter 2007 (0.01 mg/L), autumn 2010 (0.007 mg/L), winter 2011 (0.032 mg/L) and autumn 2014 (0.0065 mg/L) (Figure 34, Appendix A: Table 3 and Appendix B: Table 6).

#### **4.2.3.3 Lead**

Lead concentrations for sampling period 2007 to 2015 are indicated in Figure 35, Appendix A: Table 3 and Appendix B: Table 7. There were no data available for the sampling period 2000 to 2006.

Lead concentrations at Site 1 varied between 0.0046 and 0.0211 mg/L; Site 2 between 0.0046 and 0.0379 mg/L; Site 3 between 0.00003 and 0.0388 mg/L and Site 7 between 0.0046 and 0.024 mg/L (Figure 35, Appendix A: Table 3 and Appendix B: Table 7).

Lead concentrations recorded at the different sampling sites were above the TWQR of the WQG/AE of 0.0005 mg/L medium water limit (DWAF, 1996a) (Figure 35, Appendix A: Table 3 and Appendix B: Table 7). There were incidences however, where lead concentrations were above the TWQR: WQG/DU of 0.01 mg/L (DWAF, 1996b). This was noted at Site 1 during summer, autumn and spring of 2010 and spring of 2011 (0.02 mg/L), summer, autumn, and winter 2011 as well as spring and

summer 2012 (0.012 mg/L), spring 2014 (0.0211 mg/L) and summer 2015 (0.08 mg/L) (Figure 35, Appendix A: Table 3 and Appendix B: Table 7).

At Site 2, Pb concentrations were above the TWQR's WQG/DU (DWAF, 1996b) during winter 2007 (0.015 mg/L), autumn 2008 (0.011 mg/L), summer, autumn and winter of 2010, spring 2011 (0.02 mg/L), summer, autumn and winter of 2011 as well as spring and summer of 2012 (0.012 mg/L), autumn (0.08 mg/L) and spring 2014 (0.0379 mg/L), summer (0.08 mg/L) and autumn 2015 (0.011 mg/L) (Figure 35, Appendix A: Table 3 and Appendix B: Table 7).

At Site 3, Pb concentrations were above the TWQR of the WQG/DU (DWAF, 1996b) during winter 2007 (0.013 mg/L), summer, autumn and winter 2010 as well as spring 2011 (0.02 mg/L), summer, autumn, winter 2010 as well as spring and summer 2011 (0.012 mg/L), autumn 2014 (0.035 mg/L) and spring 2015 (0.0388 mg/L) (Figure 35, Appendix A: Table 3 and Appendix B: Table 7).

At Site 7, Pb concentrations were above the TWQR's WQG/DU (DWAF, 1996b) during winter 2007 (0.017 mg/L), spring 2008 (0.024 mg/L), summer (0.02 mg/L), autumn (0.02 mg/L) and winter of 2010 (0.02 mg/L), spring 2011 (0.02 mg/L), summer (0.012 mg/L), autumn (0.012 mg/L) and winter of 2011 (90.012 mg/L) as well as spring and summer of 2012 (0.012 mg/L), autumn (0.02119 mg/L) and spring of 2014 (0.0162 mg/L) and autumn 2015 (0.0222 mg/L) (Figure 35, Appendix A: Table 3 and Appendix B: Table 7).

#### **4.2.3.4 Cadmium**

Figure 36, Appendix A: Table 3 and Appendix B: Table 8, illustrate cadmium concentrations obtained for the period 2007 to 2015 sampled during summer, autumn, winter and spring of each year.

For Site 1, cadmium concentrations varied between 0.00053 and 0.008 mg/L; sites 2, 3 and 7 between 0.0015 and 0.008 mg/L (Figure 36, Appendix A: Table 3 and Appendix B: Table 8).

Cadmium concentrations recorded at the different sampling points for the period 2007 to 2015 were above the TWQR: WQG/AE of 0.00015 mg/L (DWAF, 1996a) (Figure 36, Appendix A: Table 3 and Appendix B: Table 8). Some incidences of cadmium

concentrations above the TWQR of the WQG/DU (DWAF, 1996b), were observed at Site 1 during winter of 2007 (0.007 mg/L); summer, autumn, winter and spring of 2010 (0.008 mg/L respectively); and autumn (0.007 mg/L) and winter 2014 (0.0059 mg/L) (Figure 36, Appendix A: Table 3 and Appendix B: Table 8).

Site 2, presented Cd concentrations above the TWQR's WQG/DU (DWAF, 1996b) during autumn 2007 (0.007 mg/L); summer, autumn, winter and spring of 2010 (0.008 mg/L) and autumn (0.007 mg/L) and winter 2014 (0.0059 mg/L) (Figure 36, Appendix A: Table 3 and Appendix B: Table 8).

At Site 3, Cd concentrations were above the TWQR's WQG/DU (DWAF, 1996b) during winter 2007 (0.007 mg/L); summer, autumn, winter and spring of 2010 (0.008 mg/L respectively) and autumn (0.007 mg/L) and winter 2014 (0.0052 mg/L) (Figure 36, Appendix A: Table 3 and Appendix B: Table 8).

At Site 7, Cd concentrations above the TWQR: WQG/DU were observed during winter 2007 (0.007 mg/L); summer, autumn, winter and spring of 2010 (0.008 mg/L respectively) and winter 2014 (0.0059 mg/L) (Figure 36, Appendix A: Table 3 and Appendix B: Table 8).

#### **4.2.3.5 Manganese**

Figure 37, Appendix A: Table 3 and Appendix B: Table 9, illustrate Manganese concentrations for the period 2010 to 2015 sampled during summer, autumn, winter and spring of each year.

Manganese concentration at Site 1 varied between 0.0125 and 0.59 mg/L; Site 2 between 0.008 and 0.046 mg/L; Site 3 between 0.004 and 0.424 mg/L and Site 7 varied between 0.007 and 1.04 mg/L (Figure 37, Appendix A: Table 3 and Appendix B: Table 9).

Manganese concentrations presented incidences above the TWQR of the WQG/AE (DWAF, 1996a) and WQG/DU (DWAF, 1996b) at the following sites: Site 1 during spring 2010 (0.317 mg/L) and summer (0.52 mg/L) and autumn 2015 (0.411 mg/L) (Figure 37, Appendix A: Table 3 and Appendix B: Table 9).

At Site 3, Mn concentrations peaked during the summer of 2011 (0.424 mg/L) and of autumn 2015 (0.222 mg/L) (Figure 37, Appendix A: Table 3 and Appendix B: Table 9). At Site 7, high Mn concentrations were observed during the winter of 2010 (1.033 mg/L), summer of 2011 (0.928 mg/L), winter of 2012 (0.336 mg/L), winter of 2014 (1.04 mg/L) and autumn of 2015 (0.49 mg/L) (Figure 37, Appendix A: Table 3 and Appendix B: Table 9).

#### **4.2.4 Bacteriological analysis**

##### **4.2.4.1 Faecal Coliforms (*E. coli*)**

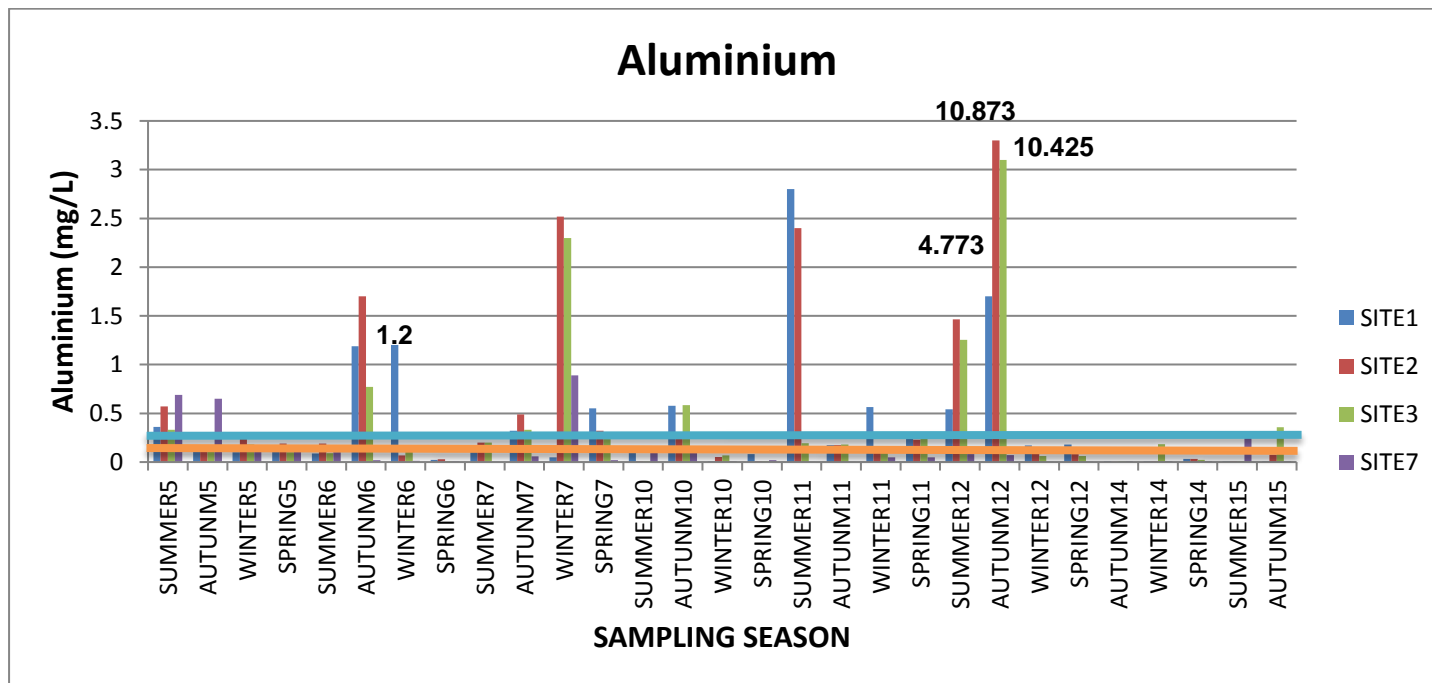
Figure 38, Appendix A: Table 4 and Appendix B: Table 10 present *E.coli* results for the period 2000 to 2015 with samples taken during summer, autumn, winter and spring each year.

For Site 1, *E. coli* counts varied between 8 and 203 590 counts/100 mL; Site 2 between 5 and 870 counts/100 mL; Site 3 between 2 and 6 870 counts/100 mL and Site 7 between 2 and 24 200 counts/100 mL (Figure 38, Appendix A: Table 4 and Appendix B: Table 10).

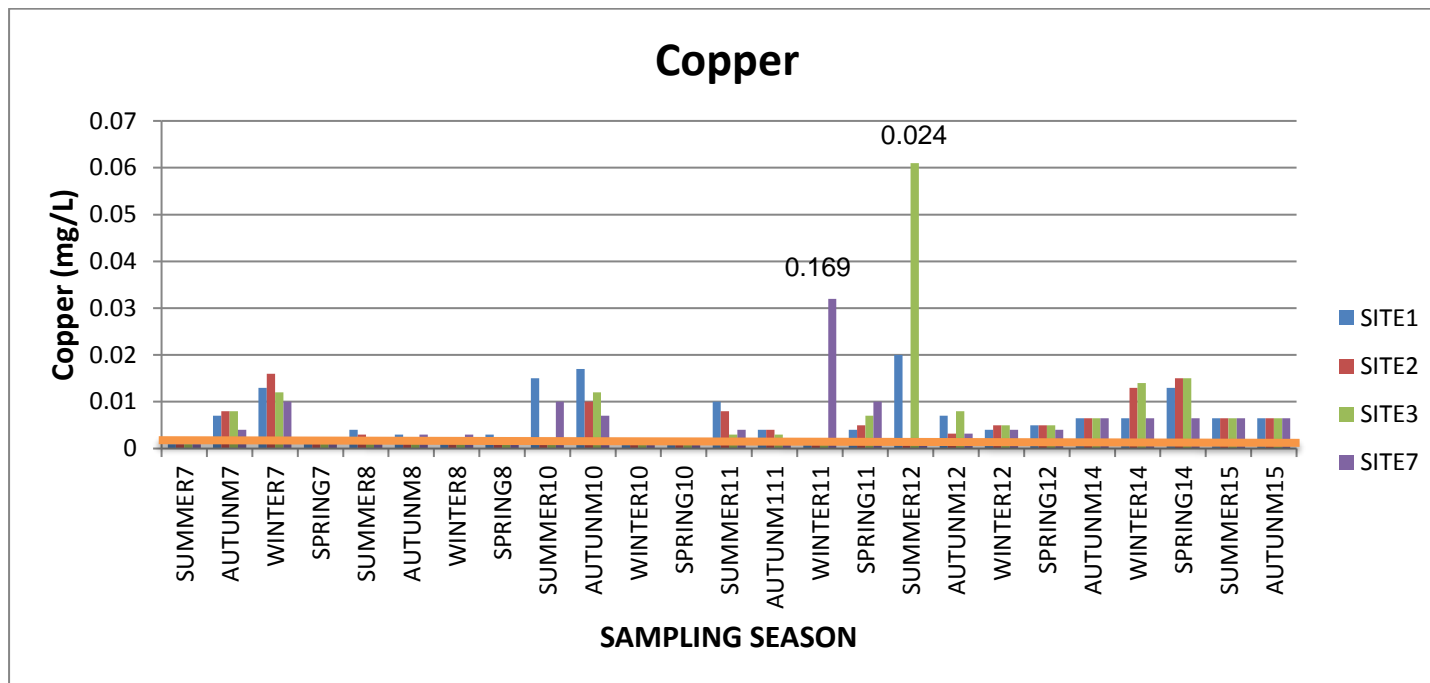
All *E.coli* counts recorded at sampling points 1, 2, 3 and 7 were above the TWQR: WQG/DU of 0.0 counts/100 mL (DWAf, 1996b).

Incidences of *E.coli* counts above the uMhlathuze Water Laboratory limit were observed at Site 1 during the winter of 2000 (5 550 counts/100 mL), spring (7 350 counts/100 mL), autumn (2 775 counts/100 mL) and winter of 2001 (9 525 counts/100 mL), spring (51 725 counts/100 mL), summer (27 850 counts/100 mL), autumn (6 350 counts/100 mL) and winter of 2002 (3 013 counts/100 mL), spring (4 816 counts/100 mL), summer (7 225 counts/100 mL), autumn (34 183 counts/100 mL) and winter of 2003 (3 888 counts/100 mL), autumn (203 590 counts/100 mL) and winter 2004 (21 584 counts/100 mL), summer of 2005 (3 055 counts/100 mL) and winter 2006 (10 478 counts/100mL) (Figure 38, Appendix A: Table 4 and Appendix B: Table 10).

At Site 3, *E. coli* counts were above the uMhlathuze Water Laboratory limit during spring 2014 (6 870 counts/100 mL), while at Site 7, results were above this limit during autumn 2014 (24 200 counts/100 mL) (Figure 38, Appendix A: Table 4 and Appendix B: Table 10).

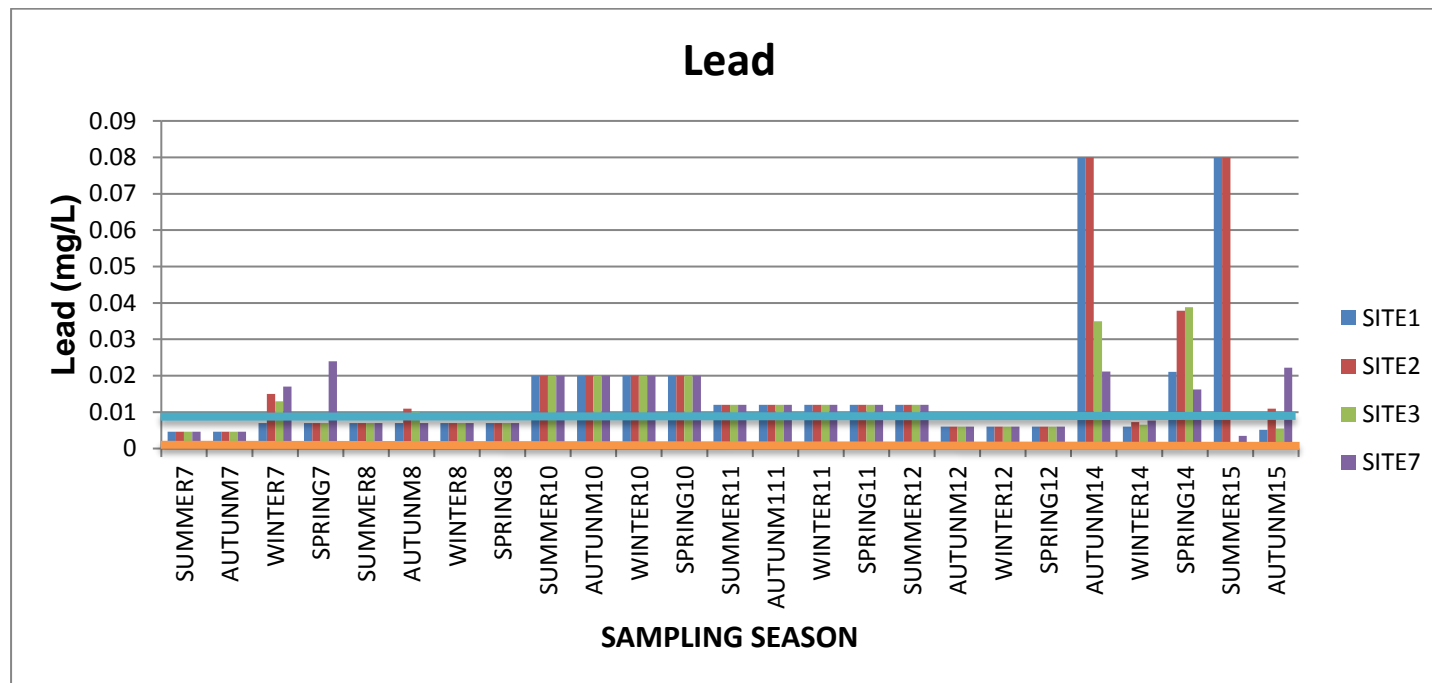


**Figure 33:** Aluminium concentrations recorded at sampling sites 1, 2, 3 and 7 for the period 2005 to 2015 (----- Aluminium WQG /AE: TWQR of 0.010 mg/L and ----- WQG/DU: TWQR of 0.15 mg/L).

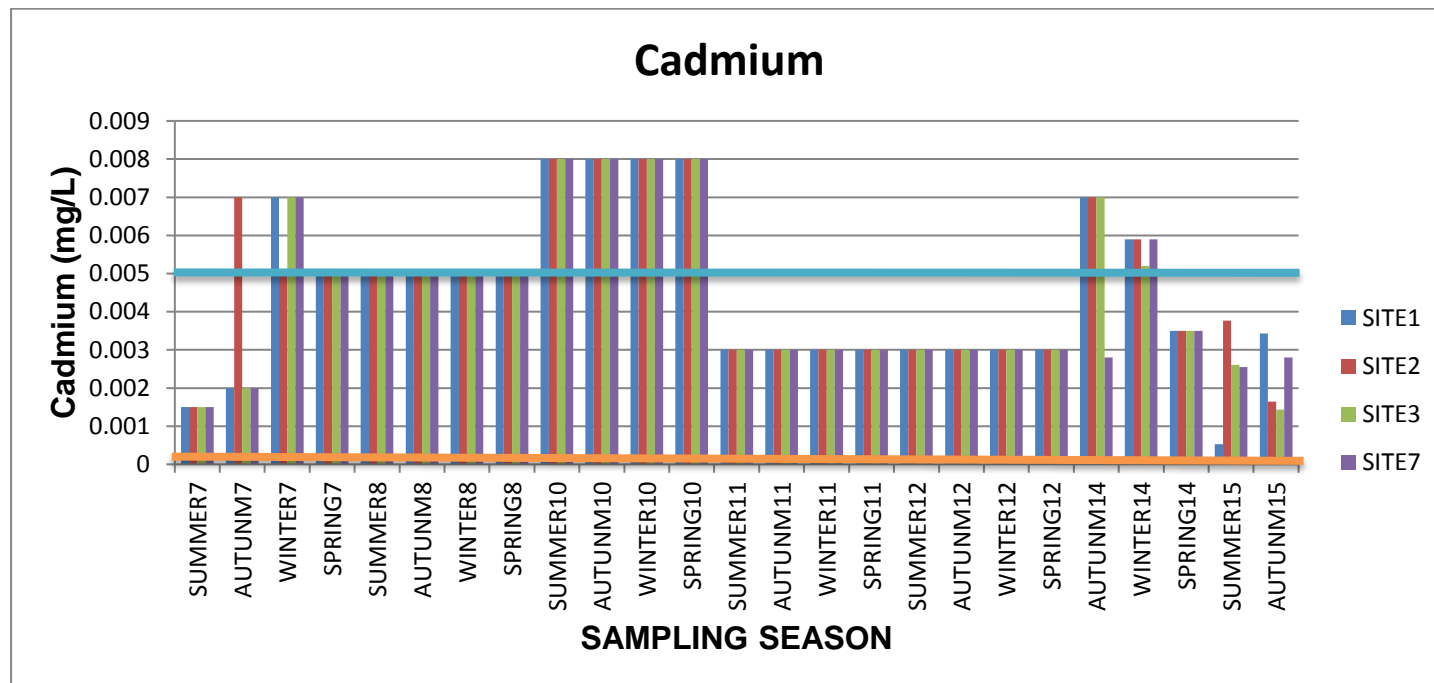


**Figure 34:** Copper concentrations recorded at sampling sites 1, 2, 3 and 7 for the period 2007 to 2015  
 (--- Copper WQG /AE: TWQR of 0.0008 mg/L and --- WQG/DU: TWQR of 0-1 mg/L).

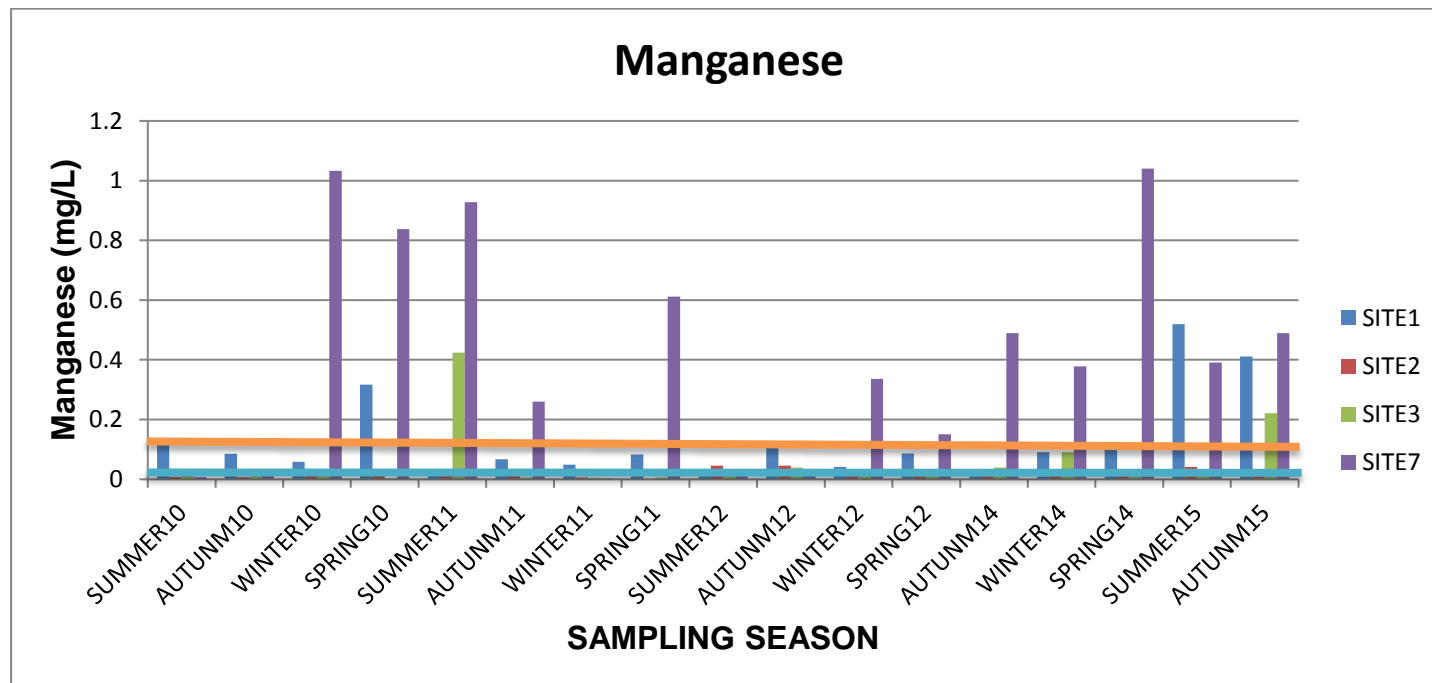




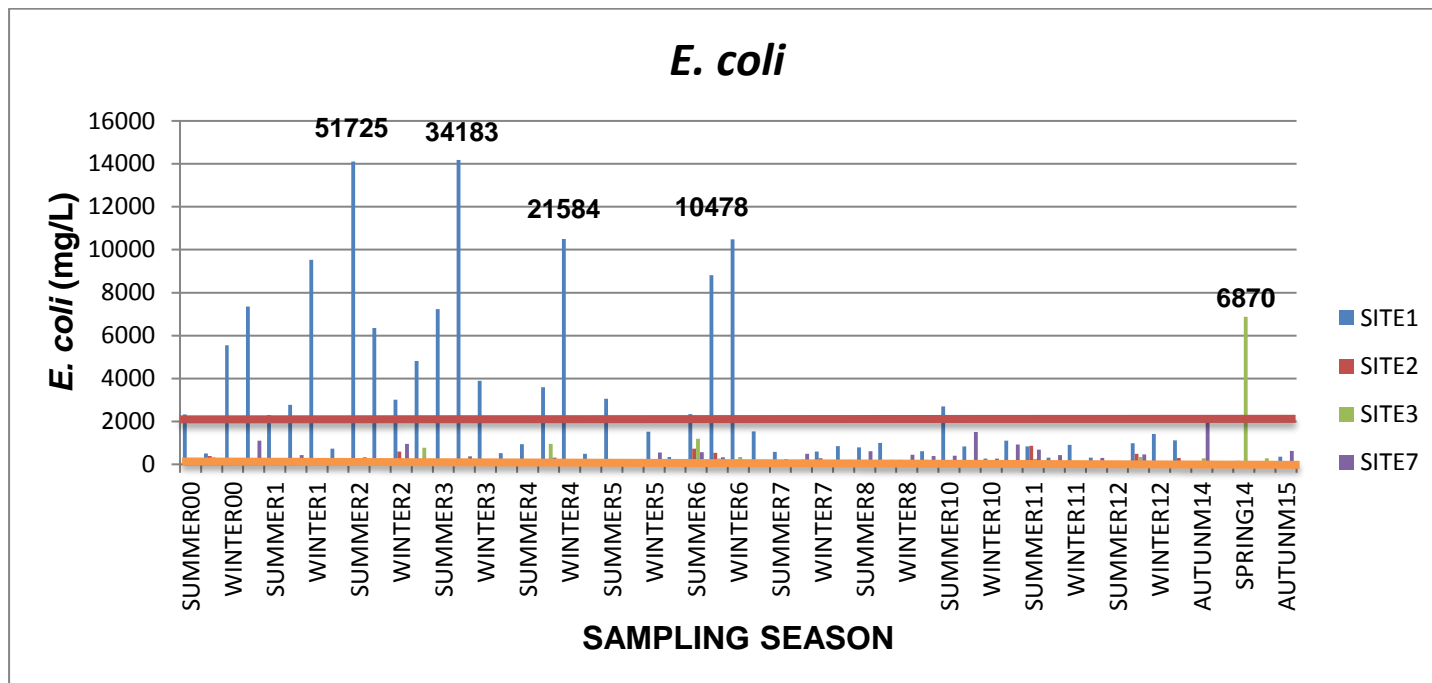
**Figure 35:** Lead concentrations recorded at sampling sites 1, 2, 3 and 7 for the period 2007 to 2015  
 (----- Lead WQG /AE: TWQR of 0.0005 mg/L and ----- WQG/DU: TWQR of 0.010 mg/L).



**Figure 36:** Cadmium concentrations recorded at sampling sites 1, 2, 3 and 7 for the period 2007 to 2015 (--- Cadmium WQG /AE: TWQR of 0.00015 mg/L and ---- WQG/DU: TWQR of 0.005 mg/L).



**Figure 37:** Manganese concentrations recorded at sampling sites 1, 2, 3 and 7 for the period 2010 to 2015 (--- Manganese WQG /AE: TWQR of 0.18 mg/L and ---- WQG/DU: TWQR of 0.05 mg/L).

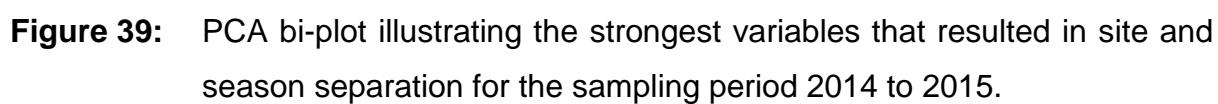


**Figure 38:** *E.coli* counts recorded at sampling sites 1, 2, 3 and 7 for the period 2000 to 2015. (----- *E.coli* TWQR: WQG/DU of 0.0 counts/100mL and ----- *E.coli* uMhlathuze Water Laboratory counts of 2 400 counts/100mL)

### **4.3 Statistical analysis**

For the sampling period autumn 2014 to autumn 2015, a PCA bi-plot was performed, ordering the sites based on different variables (Figure 39). For ease-of-interpretation, only the strongest driving variables have been graphically represented, however, all variables are still included in the analysis. Over both visible axes 38.99 % of the total variation is explained with 20.26 % explained on axis 1 and 18.73 % explained on axis 2. These strong variables included the general water quality parameters, physical parameters, metals and bacteriological populations, per site for the sampling period. Ordination of all sites and seasons is similar except for S6 and S7 from Autumn 2014, which are separating out on the positive side of axis 2 (y axis).

Strong correlations are observed between variables themselves such as potassium and Heterotrophic plate counts (HPC). Most of the metals are separating out together in the bottom left quadrant of the ordination with TDS, HPCs and total coliform counts (TCC) correlating in this direction. Inverse trends were noted between DO% and HPCs, TDS and temperature as well as TCCs and SO<sub>4</sub> and Fe.



## **CHAPTER FIVE: DISCUSSION**

### **5.1 Introduction**

Lake Nsezi is the main storage reservoir in the uMhlathuze municipality. The development of Richards Bay and Empangeni has seen a significant increase in the abstraction rates of water from this lake over the past 20 years (Nowele, 2010).

Water resource managers have the massive task to distribute water of good quality and maintain the recreational, ecological and useful features of water resources such as lakes (Bartram and Balance, 1996).

To succeed in the delivery of these goals, it is important that water resource managers be involved in the monitoring and maintenance of the quality of freshwater resources. With this in mind, a need emerged for assessment of the water quality and possible pollution trends of Lake Nsezi.

Assessments of the water quality of Lake Nsezi were accomplished by evaluating the physical, chemical and biological characteristics. Results of this study will be brought to the attention of the water resource managers at uMhlathuze Water Laboratory focussing on the general aquatic health of Lake Nsezi and if possible pollution trends emerging from this study.

### **5.2 Physical water quality parameters**

#### **5.2.1 Temperature**

The water temperature of Lake Nsezi during the sampling period of 2014 to 2015, varied between 17.2°C in winter and 29°C in summer (Appendix A: Table 2). According to Nowele (2010), water temperatures of between 20 and 24°C is suitable for the survival of aquatic life in the area such as fish, crocodile and hippopotami.

#### **5.2.2 Dissolved oxygen**

During the sampling period of 2014 to 2015, dissolved oxygen concentrations varied between 11 and 114% (Appendix A: Table 1). According to DWAF (1996a), continuous

exposure to dissolved oxygen concentrations in the range of 80 to 120% saturation, will protect most of the aquatic organisms. This is cause for concern as at these concentrations aquatic life will suffer adverse effects of oxygen depletion (DWAF, 1996a).

### **5.2.3 pH**

pH is the measure of hydrogen ion activity in a solution. It is a characteristic that determines the acidity or alkalinity in any solution. pH is often used to assess water quality.

A pH below 7 creates acidic conditions in water, while a pH above 7 creates an alkaline environment (Mathenjwa, 2009). The pH of water resources presents a direct effect on human and animal health. This becomes more obvious when water tastes either soapy due to the water being alkaline or bitter due to the water being acidic (Mathenjwa, 2009). For organisms in the aquatic environment to survive safely, pH should ideally be between 6.0 and 9.0 (DWAF, 1996a). In some cases, an acidic pH (pH below 6) of water may allow some metals such as copper, zinc or lead to dissolve in the water, resulting in the water to become toxic to humans and animals, while it also becomes corrosive to piping systems and household utensils (DWAF, 1996a).

The pH of Lake Nsezi's water for the sampling period 2014 to 2015, as well as the historical data (2000 to 2012), varied between 6.2 and 8.9 (Figure 16 and 29, Appendix A: Table 1 and Appendix B: Table 1). These values were within limits of the Water Quality Guidelines for the Aquatic Environment (WQG/AE) (DWAF, 1996a), as well as the Water Quality Guidelines for the Domestic Use (WQG/DU) (DWAF, 1996b).

According to Neary and Clark (1992), pH of lake water affects the chemical and biochemical reactions of salts in water, while at the same time it determines availability of substances and controls the distribution of many aquatic organisms. Considering this statement and the pH values for the whole sampling period, water pH of Lake Nsezi has remained within the set requirements for the Department of Water and Sanitation (DWS) (DWAF, 1996a, 1996b) and should pose little or no effects to living organisms.



#### 5.2.4 Total dissolved solids (TDS)

According to the WQG/DU (DWAF, 1996b), TDS above 3000 mg/L makes water taste extremely salty and bitter. This causes corrosion and scaling on water piping and kitchen utensils. Long term exposure of humans and animals to high TDS over time contribute to destabilising the body salt content of these organisms (DWAF, 1996b). Changes in TDS values of a surface water resource can have the following effects on aquatic organisms: it affects the adaptation of individual species, it affects the community structure of different aquatic organisms, and it affect the rate of metabolism as well as the nutrient cycle (DWAF, 1996a; Phyllis *et al.*, 2007).

The Target Water Quality Range (TWQR) for TDS is 450 mg/L for the WQG/DU (DWAF, 1996b). Total Dissolved Solids recorded for the sampling period 2014 to 2015 presented results above the TWQR for Sites 1, 2, 3, 4 and 7 (Figure 17 and 30, Appendix A: Table 2 and Appendix B: Table 2), while the TDS for the sampling period 2000 to 2015 varied between 270 mg/L at Site 7 during winter 2011 to 737 mg/L during spring 2002 at Site 3 (Figure 17 and 30, Appendix A: Table 2 and Appendix B: Table 2).

According to the World Health Organization (WHO, 2004), TDS is described as inorganic salts and organic matter dissolved in water while the main components of TDS include calcium, magnesium, sodium and potassium cations and carbonate, hydrogen carbonate, chloride, sulphate and nitrate ions. Increase in TDS values causes toxicity through increased salinity content of the water body, increased ionic composition and toxicity of individual ions (Phyllis *et al.*, 2007). This can affect aquatic ecosystems and also humans who uses water for domestic purposes.

Total Dissolved Solids is a concern since water from Lake Nsezi serves as a major source of fresh water for Richards Bay, Empangeni and surrounding areas. The consistent high levels of TDS in Lake Nsezi can be as a result of domestic effluent discharge via municipal secondary sewage effluent discharge and surface runoff from urban and industrial areas (Nowele, 2010). Lake Nsezi is positioned between the Industrial hubs of Empangeni and Richards Bay. Surface runoff from cultivated areas can also contribute to this increase since Lake Nsezi is primarily surrounded by farming activities (Nowele, 2010). Municipal and industrial effluents as well as surface

runoff carry an elevated content of cations and anions to the water resources (Phyllis *et al.*, 2007).

### **5.3 General water parameters**

#### **5.3.1 Nitrate**

Nitrate is found in the air as part of nitrogen cycle (Dubrovsky *et al.*, 2010). Nitrate in the environment, soil and water is as a result of the decomposition of dead matter from plant and animal waste (Dubrovsky *et al.*, 2010). Runoff of nitrate based fertilizers directly add to the concentration of nitrate in water resources (Mueller and Helsel, 2016). Excess nitrate concentration causes overstimulation of algal growth resulting in eutrophication of aquatic systems (Mueller and Helsel, 2016).

For the sampling period 2014 to 2015, as well as the historical data from 2010 to 2012, nitrate concentrations varied between 0.08 and 5.27 mg/L (Appendix A: Table 2 and Appendix B: Table 11). These values were below the TWQR of 6.0 mg/L N for the WQG/DU (DWAF, 1996b) but above the TWQR of 5 mg/L for the WQG/AE (DWAF, 1996a). This increase in nitrate to 5.27 mg/L in the autumn of 2015 may be indicative of possible systematic eutrophication of the water body. This is a cause of concern for Lake Nsezi and this parameter should be monitored continuously.

Sources of nitrate in Lake Nsezi can be as a result of: urban and agricultural runoff, secondary sewage effluents discharges from Nseleni, Empangeni, Ngwelezane, Vulindlela and Felixton sewage treatment plants (Yu *et al.*, 2016).

#### **5.3.2 Sulphate**

Sulphate consist of a combination of sulphur and oxygen, minerals that occur naturally in the soil and some rock formation in the ground water (DWAF, 1996a). Runoff of ammonium-sulphate based fertilizers directly adds to sulphate concentration in water resources. Elevated sulphates content in water can cause scale build up in water pipes, a bitter taste to drinking water that leads to laxative effects for humans and livestock (Muhammad *et al.*, 2014).

For the sampling period 2014 to 2015, as well as the historical data from 2010 to 2012, sulphate content varied between 0.89 and 35.74 mg/L (Appendix A: Table 2 and

Appendix B: Table 12). These values were below the TWQR of 200 mg/L SO<sub>4</sub> for the WQG/DU (DWAF, 1996b).

### **5.3.3 Fluoride**

The WQG/AE sets a TWQR for Fluoride at 0.75 mg/L while the WQG/DU presents a TWQR of 1.0 mg/L (DWAF, 1996b). Low concentrations of fluoride (below 1 mg/L) strengthen teeth in mammals, while high concentrations can cause damage to the skeletal system of aquatic animals (Mathenjwa, 2009).

Fluoride concentrations recorded for the study period of 2014 to 2015, ranged from a lower concentration during winter (0.15 mg/L) 2014 at sampling Site 5 to a higher concentration during autumn (2.24 mg/L) 2014 at Site 7 (Figures 18 and 31, Appendix A: Table 2 and Appendix B: Table 3). For the monitoring period 2010 to 2015 fluoride concentration were below the TWQR for both the WQG/AE (DWAF, 1996a) and WQG/DU (DWAF, 1996b) thus for the moment fluoride concentrations are of no immediate concern to humans and animals (Mathenjwa, 2009).

### **5.3.4 Chlorine (Cl)**

In water resources, chloride originate from dissolved salts of elements such as sodium, potassium, calcium or magnesium (Mathenjwa, 2009). Chlorine makes water acquire a salty taste when in high concentrations and at the same time accelerates the corrosion of metals (Mathenjwa, 2009). Elevated concentrations are also detrimental to garden plants (DWAF, 1996a). Lake Nsezi is an inland freshwater impoundment and appears to have no direct inflow contact with the ocean from where sodium chlorine infiltrations could occur (Heyneke, 2012), but other sources such as sewage effluent discharge into the lake stream can contribute to the chlorine content (Yu *et al.*, 2016).

For the monitoring period 2010 to 2015, the lowest concentration of chlorine was recorded at Site 2 during autumn (45.14 mg/L) 2014 and the highest at Site 7 during summer (201.0 mg/L) 2011 (Figure 9 and 32, Appendix A: Table 2 and Appendix B: Table 4). Chlorine concentrations for the whole monitoring period were above the TWQR of 0.0002 mg/L for the WQG/AE (DWAF, 1996a) and TWQR of 100 mg/L for the WQG/DU (DWAF, 1996b) at most of sampling sites (Figure 9 and 32, Appendix A:

Table 2 and Appendix B: Table 4). These high incidences of chlorine in Lake Nsezi can also partly be explained as a result of secondary sewage effluent discharges from Nseleni, Empangeni, Ngwelezane, Vulindlela and Felixton sewage treatment plants (Yu *et al.*, 2016).

## **5.4 Metals**

The TWQR for the WQG/AE (DWAF, 1996a) is not available for barium, boron, cobalt, iron, molybdenum, magnesium, nickel, sodium, potassium, strontium, titanium, vanadium and calcium, while the TWQR for the WQG/DU (DWAF, 1996b) is not available for barium, boron, cobalt, molybdenum, nickel, strontium, vanadium and titanium.

### **5.4.1 Aluminium**

Water used for domestic purposes with aluminium concentrations present, will present adverse effects such as discolouration of water at elevated concentrations but without any possible human health effects (Galal, 1998). High concentrations of aluminium affect aquatic organisms resulting in possible chronic toxic effects such as a loss of plasma and haemolymph in gill breathing animals such as fish (Rosseland *et al.*, 1990).

The TWQR for WQG/DU (DWAF, 1996b) is 0.15 mg/L Al and for WQG/AE (DWAF, 1996 a) is 0.0005 mg/L Al at pH< 6.5 and 0.01mg/L Al at pH> 6.5. It has been noted that aluminium concentrations were above the TWQR for both domestic use and aquatic ecosystems at sampling sites 3, 4, 6 and 7 for the monitoring period 2014 and 2015 (Figure 20 and Appendix A: Table 3). Further monitoring done by uMhlathuze Water Laboratory, presented above TWQR concentrations for aluminium at sampling Site 1 during autumn (12 mg/L) 2006, summer (2.8 mg/L) 2010 and autumn (4.77 mg/L) of 2012; at Site 2 during winter (2.52 mg/L) of 2007 and autumn (10.78 mg/L) of 2012; and Site 3 during autumn (10.42 mg/L) 2012 (Figure 33 and Appendix B: Table 5). This is a cause for concern since aluminium acts as a toxic agent for gill breathing animals such as fish and some invertebrates. As mentioned before, over exposure to aluminium can cause the loss of plasma and at the same time reduce activities of gill enzymes (Rosseland *et al.*, 1990). The concentrations above the

TWQR for both the WQG's may be as a result of effluent from some industries in the vicinity of the Lake Nsezi, for example:

- Aluminium smelter emissions (Hillside and Bay side Aluminium);
- Aluminium sulphate used as an additive in some processes in the pulp and paper industry (Pengxian *et al.*, 2011) – (Mondi Kraft); and
- Aluminium sulphate as used in most water treatment processes (Genter and Amyot, 1994).

#### **5.4.2 Barium**

Barium concentrations varied from 0.03 to 0.13 mg/L (Appendix A: Table 3). Barium as a metal is found in high concentrations in soil, food such as nuts, sea weeds, fish and certain plants (Wright, 2003). Barium forms insoluble salts with other components in the environment such as carbonates and sulphates. When fish and other aquatic organisms get in contact with these compounds, barium accumulates in their systems and causes a risk (Wright, 2003).

For the sampling period 2014 to 2015, barium concentrations are not of concern as it is below the WHO target concentration of 0.7 mg/L (WHO, 2004).

#### **5.4.3 Boron**

Boron concentrations varied from 0.045 to 0.121 mg/L (Appendix A: Table 3). Boron being a metalloid is usually found in a combined state such as Borax (sodium salt of boron) which occurs naturally in the environment (Emiroglu *et al.*, 2010). Over exposure to boron affects male reproductive organs in aquatic animals (Wright, 2003).

Boron concentrations at the sampled sites are not of concern since the result concentrations were all below 1.0 mg/L B according to Turkish regulations (2004) (Cisek *et al.*, 2014).

#### **5.4.4 Cadmium**

Cadmium is defined by the United States Environmental Protection Agency (USEPA) as potentially hazardous to most forms of life, and is considered to be toxic and relatively accessible to aquatic organisms (USEPA, 1986; Okocha and Adededeji, 2011). The presence of cadmium in drinking water is of concern because it accumulates in

the liver and kidneys tissues of mammals and has potentially acute irreversible human health effects (Buchet *et al.*, 1995). Cadmium is a cumulative toxin and in mammals it affects organs such as kidneys, bone and lungs (Yost, 1984). It damages lungs and kidneys by acute inhalation, high dosage exposure and occupational exposures (Yost, 1984).

The WQG/AE presents a TWQR of 0.005 mg/L and the WQG/DU a TWQR of 0.00025 mg/L for cadmium (WQG/AE is based on water hardness, DWAF, 1996). For the study period 2014 to 2015, cadmium concentrations were above the TWQR of the WQG/DU (DWAF, 1996a) at all the sampling sites and above the WQG/AE (DWAF, 1996b) during autumn and winter at all the sampling sites (Figure 21, Appendix A: Table 3). Historic data indicate cadmium concentrations at Site 1, 2, 3 and 7 above the TWQR for the WQG/DU from 2007 to 2015 and above the TWQR for the WQG/AE during 2010 and 2014 (Figure 36 and Appendix B: Table 8). These high concentration are of concern.

In the study area, possible cadmium source(s) into Lake Nsezi include runoff from agricultural soils where famers are using phosphate fertilizers in which cadmium is a common impurity (Fatoki and Awofulu, 2003).

Sampling points 1, 2 and 3 are situated close to the Nseleni Township where small scale farmers, commercial forests and sugar cane farms are located, making use of fertilizers and pesticides (containing cadmium) that are washed into the lake by precipitation and runoff afterwards. Between sampling points 6 and 7, the same farming scenario can be observed, possibly explaining the cadmium concentration at sampling point 7. Available historic data from 2007 to 2012 confirms the same (Figure 36 and Appendix B: Table 8).

#### **5.4.5 Calcium (Ca)**

Calcium concentrations varied between 4.41 and 33.0 mg/L (Appendix A: Table 3) at the different sampling sites. Calcium being the third most abundant metal in the earth's crust, is found as limestone, gypsum and fluorite (Bowen, 1979). Calcium is responsible for water hardness and this causes the decrease in the lifespan of equipment and piping system for domestic purposes (Bowen, 1979). According to

Pallav (2013), hard water is said to cause a high incidence of kidney stones in humans depending the volume of water consumed per individual per day.

Calcium concentrations at the sampled sites is currently not a concern since the results were below the TWQR of 32 mg/L Ca of the WQG/DU (Appendix A: Table 3) (DWAF, 1996b).

#### **5.4.6 Cobalt**

Cobalt concentrations remained constant at <13 mg/L (Appendix A: Table 3) during the entire sampling period. Cobalt is found in the earth's crust only in combined form such as cobaltite (CoAsS) and mainly extracted as a by-product of copper and nickel mining (DWAF, 1996a).

Mammals, including humans, are exposed to natural sources of cobalt in their food, water and air where overexposure of cobalt is associated with decreased reproductive effects (Anderson *et al.*, 1992).

During a study by James *et al.* (2006), cobalt concentration ranged between 5 and 20 mg/L in surface water, and is favourable for the growth of *Cyanobacterium anabaena* (algal bloom) during summer. However, no positive evidence exist of a possible algal bloom in Lake Nsezi despite cobalt concentrations of <13 mg/L (Appendix A: Table 3).

#### **5.4.7 Copper**

In small quantities, copper is toxic and known to cause brain damage in mammals (DWAF, 1996a). It can also cause water to have a dry taste, stains laundry and plumbing fittings (Brewer, 2010). At high concentration, copper causes gastrointestinal disruptions leading to liver, kidney and red blood cell damage (DWAF, 1996a).

The TWQR for the WQG/DU is 1 mg/L Cu (DWAF, 1996 b) and for the WQG/AE is 0.0008 mg/L Cu for medium water (DWAF, 1996a). From Figure 22 and Appendix A: Table 3, it is evident that the highest recorded concentration of copper was at Site 4 during summer (0.019 mg/L) of 2015 and the lowest concentration was observed for most of the sampling sites at 0.013 mg/L during the study period. Both the low and high concentration of Cu are below the TWQR of the WQG/AE (DWAF, 1996a), but above the WQG/DU (DWAF, 1996b).

For the monitoring period 2007 to 2015, all Cu concentrations were above the TWQR for the WQG/DU (DWAF, 1996b) and below the TWQR for the WQG/AE (DWAF, 1996a). The concentration of copper being above the TWQR for the WQG/DU but also below the TWQR for the WQG/AE is evident in the long term from 2007 to 2015 (Figure 34 and Appendix B: Table 6).

The suspected source(s) of copper into the aquatic environment at the study area may be amongst others:

- Sewage treatment plant effluents (Donna *et al.*, 2011),
- Runoff and ground water contamination from the use of copper as fungicides (Kosta *et al.*, 2008), and
- Pesticides in the treatment of soils (DWAF, 1996b).

Lake Nsezi is surrounded by Sappi and Mondi commercial forests, sugar cane farms as well as small scale farming activities along the Nseleni River. These activities may require the use of algacides and fungicides in their operations. This may possibly explain the incidences of copper concentrations at sampling point 1, 2, 3 and 7 (Figures 22 and 33, Appendix A: Table 3 and Appendix B: Table 6).

#### **5.4.8 Iron**

Iron concentrations varied from 0.026 to 2.625 mg/L (Appendix A: Table 3). Iron makes up 34.6% of the earth's crust (DWAF, 1996a). It is a dietary requirement for most organisms and plays an important role in natural processes such as iron being part of respiratory enzymes of all organisms. It forms a basic component of haemoglobin in humans as well as animals (Aucamp and Viviers, 1990).

Although iron concentrations at the sampled sites varied between being below the TWQR for the WQG/DU of 0.1 mg/L (DWAF, 1996b) to a high of 2.652 mg/L (Appendix A: Table 3). These concentrations may affect the taste of water and in humans may pose a slight health effect to small children and adults who present sensitivity to iron concentrations in water (DWAF, 1996b). The presence of iron at the sampled sites is therefore currently of no concern (Appendix A: Table 3).



#### **5.4.9 Lead**

At relatively low concentrations, particularly with continuous exposure, lead can cause neurological impairment in fetuses and young children (Cotruvo *et al.*, 2011). On the other hand, low concentrations of lead affect fish by causing the formation of a film of coagulated mucous covering the gills and subsequently the entire body causing death of fish by suffocation (DWAF, 1996a).

According to DWAF (1996b), the TWQR for lead for the WQG/DU is 0.010 mg/L and the TWQR for the WQG/AE is 0.0005mg/L (DWAF, 1996a). From Figure 23 and Appendix A: Table 3, it is evident that lead concentrations recorded at different sites during 2014 to 2015 sampling period, were all above the TWQR for both the water quality guidelines. This was more evident during autumn 2014, spring 2014 and autumn 2015 (Figure 23 and Appendix A: Table 3). The highest concentration was recorded at Site 5 during spring 2014 (0.604 mg/L) (Figures 23 and Appendix A: Table 3).

For the monitoring period 2007 to 2015, all the recorded results were above the TWQR for the WQG/DU (DWAF, 1996b), while incidences above the TWQR for the WQG/AE (DWAF, 1996a) were observed during 2007, 2010, 2011, 2014 and 2015 (Figure 34 and Appendix B: Table 7). Most of the sampling sites are positioned next to roads where either farm tractors and/or cars, all gasoline-powered, are in constant motion emitting lead dust into the atmosphere.

The possible source of lead into the aquatic environment of the study area is anthropogenic and includes:

- Precipitation and fallout of lead dust and street runoff associated with lead emissions from gasoline- powered motor vehicles (Thomas, 1995).

#### **5.4.10 Magnesium**

Magnesium concentrations varied between 9.49 and 26.50 mg/L for the sampling period 2014 to 2015 (Appendix A: Table 3). In the earth's crust, magnesium occurs as a mineral of magnesium such as magnesium carbonate or silicate (DWAF, 1996a). Magnesium in water makes up an important contribution to total dietary needs of mammals including humans (Kempster and Smith, 1985). When water with excess

magnesium is exposed to high temperatures, magnesium precipitates with calcium posing scaling in hot water systems (Kempster and Smith, 1985). Magnesium concentrations at the various sampling sites presented no threat as it is below the TWQR for WQG/DU of 30 mg/L (DWAF, 1996b).

#### **5.4.11 Manganese**

At concentrations not exceeding 20 mg/L, aesthetic effects limit the acceptance of water containing manganese (DWAF, 1996b). As the presence of manganese makes beverages have an unpleasant taste, it also stains plumbing fixtures and laundry (DWAF, 1996b). Manganese in mammals is an essential component of enzymes used for various metabolic processes (Bellas *et al.*, 2008). Exposure to low concentrations of manganese (0.01-0.02 mg/L) interfere in growth, bone formation and reproduction of many organisms, while over exposure to manganese can cause lung, liver and vascular disturbances (Crowley *et al.*, 2000).

The TWQR for manganese for WQG/AE is 0.018mg/L (DWAF, 1996a) and that of the WQG/DU is 0.05 mg/L (DWAF, 1996b). From Figure 24 and Appendix A: Table 3, it is evident that the highest concentration of manganese recorded was at sampling Site 7 during spring 2014 (1.04 mg/L) (Figure 24 Appendix A: Table 3). Manganese concentrations above the TWQR for the WQG/DU and /or WQG/AE (DWAF, 1996a and b) were observed at Sites 1, 3, 5 and 7 (Figures 24 and 37, Appendix A: Table 3 and Appendix B: Table 9).

For the monitoring period 2010 to 2015, manganese concentrations were above the TWQR for the WQG/AE (DWAF, 1996a) and above the TWQR of the WQG/DU at Site 1 and 7 results presented incidences of increased manganese concentration at sampling sites 1, 3 and 7 (Figures 24 and 37, Appendix A: Table 3 and Appendix B: Table 9).

A possible source of manganese in the aquatic environment of the study may be the use of fertilizers containing manganese as micro-nutrient (Bellas *et al.*, 2008). Lake Nsezi is surrounded by commercial forests, sugar cane farms and all along Nseleni River there are small scale subsistence farmers cultivating crops. These farms make use of fertilizer in which manganese is a known micro-nutrient (Huang and Lin, 2004).

#### **5.4.12 Molybdenum**

Molybdenum concentrations varied from 0.007 to 0.040 mg/L during the study period (Appendix A: Table 3). Molybdenum is obtained as a by-product of tungsten and copper production (Knothe *et al.*, 1988). Molybdenum is essential to all species but experiments with various animals have shown that over exposure to molybdenum causes fatal deformities (Knothe *et al.*, 1988).

Molybdenum concentration for the different sampling sites is not of concern since it is below the TWQR of 0.07 mg/L as prescribed by the WHO (WHO, 2011).

#### **5.4.13 Nickel**

From 2014 to 2015, nickel concentration remained constant at 0.021 mg/L (Appendix A: Table 3). Nickel makes up almost 3% of the earth's crust (Cempel and Nikel, 2005). It is mostly extracted from iron nickel sulphates and ends up in surface water as part of wastewater streams (Cempel and Nikel, 2005). Nickel is found to be an essential trace metal for many animal species, organisms and plants however, over exposure may induce nickel toxicity that has effects on the respiratory tract and immune system of living organisms (Cempel and Nikel 2005).

Anti *et al.* (2007), confirmed that no fish activities were observed during a study in a small watercourse affected by Nickel Smelters' emissions when nickel concentrations in the water reached a level of 0.064 mg/L. With this in mind, nickel concentration at the sampling sites for this study was constant at 0.021 mg/L Ni, and at the moment is of little concern.

#### **5.4.14 Potassium**

For the study period, potassium concentrations varied between 2.37 and 10.2 mg/L (Appendix A: Table 3). Potassium is found in a mineral form in the earth's crust and may form clay soil where potassium is leached by weathering (Bowen, 1979). Potassium compounds such as potassium dichromate are water soluble (DWAf, 1996a). Potassium is a dietary requirement for many organisms, in humans it has been reported that a potassium rich diet helps reduce blood pressure and prevents kidney stones (Raman, 2017).

The TWQR for WQG/DU (DWAF, 1996b) for potassium is 50 mg/L. Considering the potassium concentrations at the sampling sites for the study period (2.37-10.2 mg/L K), potassium concentrations are presently of little concern.

#### **5.4.15 Strontium**

Strontium concentrations varied from 0.074 to 0.241 mg/L during the study period (Appendix A: Table 3). Strontium is a highly reactive metal that occurs naturally combined with other elements and compounds (Joseph, 2016). It forms 0.034% of all igneous rock on earth (Joseph, 2016). At high concentrations, strontium is found to accumulate in bone and affect bone formation in mammals (Joseph, 2016).

According to Xu *et al.* (1997), studying strontium concentrations in drinking water, strontium results ranged from 5 to 500 mg/L. These concentrations were harmful to the growth and development of rats used during the study (Xu *et al.*, 1997).

Strontium concentrations at the various sampling sites were low in comparison to the above mentioned study, and concentrations are for now of little concern.

#### **5.4.16 Titanium**

Titanium concentrations varied for the sampling period from 0.004 to 0.050 mg/L (Appendix A: Table 3). Titanium makes up 0.63% of the earth's crust by mass. The main mined ore Ilmenite occurs in vast deposits of sand and titanium dioxide (TiO<sub>2</sub>) is commonly found as a dark brownish form known as rutile (Greenwood and Earnshaw, 2002).

Titanium as an element is not toxic in water but when combined with halogens, it becomes toxic and harmful to small aquatic organisms by altering their blood pH values (Greenwood and Earnshaw, 2002). In another study, Xiong *et al.* (2011) confirmed that zebrafish exposed to titanium dioxide in water with a concentration of 124.5 mg/L Ti, caused cell membrane damage. When comparing the titanium concentration of the above study to the titanium concentrations in the water at the various sampling sites of this study, the concentrations at the sampling sites are of little concern.

#### **5.4.17 Vanadium**

During the study period, vanadium concentrations varied from 0.003 to 0.041 mg/L (Appendix A: Table 3). Vanadium occurs in a mineral form that includes vanadium sulphate and calcium salt of vanadium (Underwood, 1997). Exposure to high concentrations of vanadium can cause severe chronic bronchitis in humans (Underwood, 1977).

Vanadium concentrations at the sampling sites are below the TWQR for the WQG/DU of 0.1 mg/L (DWAF, 1996b) and is at the moment of no concern.

### **5.5 Bacteriological analysis**

#### **5.5.1 Faecal coliforms (*E. coli*)**

Faecal coliforms are a group of microorganisms that indicate the presence of faecal contamination, such as the thermo-tolerant bacterial group *Escherichia coli* (*E. coli*) (Palmer *et al.*, 1993). These organisms usually give an indication whether pathogens may be present and are the most appropriate group of coliforms to indicate faecal pollution from warm-blooded mammals (Palmer, *et al.*, 1993).

These microorganisms are passed on through faecal or oral ways in polluted and ill-treated drinking water, causing diseases such as gastroenteritis, salmonellosis, dysentery, cholera and typhoid fever (DWAF, 1996b).

During a personal conversation with the laboratory manager of uMhlathuze Water Laboratory in Richards Bay, the allowable limit of *E. coli* in water used by uMhlathuze Water Laboratory, is 2 400 counts/100 mL (personal communication by S. Bhengu, 2015).

Figure 25 and Appendix A: Table 4 illustrate the *E. coli* results for the 2014 to 2015 sampling period. All of the results were above the TWQR for the WQG/DU (DWAF, 1996b) and a results of 6 870 counts/100 mL was noted at Site 3 during the spring of 2014 (Figure 25, Appendix A: Table 4). This reading is above the maximum allowable limit for uMhlathuze Water Laboratory. This count may possibly originate from faeces of mammals occurring in the direct area of Lake Nsezi (Figure 25, Appendix A: Table 4).

For the monitoring period 2000 to 2015, *E.coli* counts recorded at sites 1, 2, 3 and 7 were above the TWQR of the WQG/DU (DWAF, 1996b) (Figure 38, Appendix A: Table 4 and Appendix B: Table 10).

Site 1 presented results above the uMhlathuze Water Laboratory limits from 2000 – 2006, 2010 and 2011. Site 3 presented one incidence above the uMhlathuze Water Laboratory limits during spring 2014 (6 870 counts/100 mL) (Figure 38, Appendix A: Table 4 and Appendix B: Table 10).

The high counts of the bacteria observed at Site 1 and 3 may possibly originate from cattle grazing nearby and drinking water directly from the Lake. Site 7 is open to traffic and pedestrians. Human settlements in this area can also contribute to bacteria counts in the water.

### **5.5.2 Heterotrophic Plate Counts**

Heterotrophic Bacterial Counts represent the general microbial quality of water (Aucamp and Viviers, 1990). Heterotrophic Plate Counts (HPC) are not an indication of existing faecal contamination and do not indicate the total number of bacteria available in the water. This is however, a method that measures colony formation of heterotrophic bacteria in water used for domestic purposes in private and public water systems (Aucamp and Viviers, 1990).

During the sampling period of 2014 and 2015, HPC's determined at most of the sampling sites, indicated incidences of Heterotrophic Counts above the TWQR of 10 000 counts/100 mL for the WQG/DU (DWAF, 1996b) at Site 1 during spring 2014 (2 330 000 counts /100 mL) and autumn 2015 (2 350 000 counts /100 mL); Site 3 during autumn 2014 (2 370 000 counts/100mL); Site 5 during winter 2014 (560 000 counts /100 mL) and Site 7 during summer 2015 (10 600 000 counts /100mL) (Figure 26 and Appendix A: Table 4).

According to Falkinham *et al.* (2001), some factors influencing the occurrence and growth of coliforms and HPC bacteria on surface water are:

- \* Non filtered surface water favours coliform regrowth through multiplication of different colonies as they come together;

- \* Water temperatures above 15°C influences rapid growth of bacteria and residence time; and
- \* Stagnating surface water favours microbial growth as the enclosed temperatures rise.

At sampling sites 1 and 7 water stagnates for as long as there is no heavy rain fall. For the entire study period, water temperatures were above 15°C at all the sampling sites and water from the lake was exposed to direct sunlight during daytime. This may explain the high occurrence of heterotrophic bacteria at the sampled sites.

### 5.5.3 Total Coliform Counts

Total coliforms consist of a diverse group of bacteria including *Escherichia*, *Citrobacter*, *Enterobacter*, *Klebsiella*, *Serratia* and *Rahnella* (Aucamp and Viviers, 1990). Most of these bacteria originate from faecal contamination from faeces of warm-blooded animals including humans (Aucamp and Viviers, 1990).

For the sampling period 2014 to 2015, total coliform counts determined at all the sampling sites, indicated all the counts being above the TWQR of 5 counts/100 mL for the WQG/DU (DWAF, 1996b) (Figure 27, Appendix A: Table 4).

The occurrence of the total coliform counts can be attributed to the following facts:

- Small subsistence farming occurs along Lake Nsezi;
- Cattle grazing around the Lake;
- At some sampling sites people gather for fishing or other social events;
- The lack of built sanitation amenities such as toilet facilities, makes people use the bushveld as toilet allowing rain water to wash faecal matter into the lake.

### 5.6 Statistical analysis

The strong correlation between potassium and Heterotrophic plate counts (HPCs) (Figure 38) could possibly be because 1) potassium is part of the earth crust and in the water environment, may become soluble in water (DWAF, 1996a); 2) potassium is a nutrient in the diet of many organisms supporting nerve functions (Bowen, 1979) and 3) due to its availability may be supporting a large bacteriological population at various sites.

An inverse relationship exists between HPCs and dissolved oxygen (DO) (Figure 38). Some heterotrophic bacteria require oxygen for certain life processes and these bacteria are utilising the DO for survival at various sites. It may then also be possible that as the HPCs increase, there may be a decrease in DO.

A negative correlation / inverse relationship exists between total coliforms counts (TCCs) and sulphate ( $\text{SO}_4$ ). Sulphate as a possible nutrient may also support a growing total coliform community. Thus as the total coliforms increase there may be a systematic decrease in  $\text{SO}_4$ .



## CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

Lake Nsezi is a large freshwater lake used as a storage reservoir in the uMhlathuze municipality. Through many years there have been a systematic increase in industries, plantations and formal and informal settlements in the vicinity of the lake. This contributed to a drastic increase in abstraction of water from the lake (Nowele, 2010). The increase in water usage and growth in human population requires water of a good quality. Since 2000 the uMhlathuze Water Laboratory in Richards Bay have been monitoring the water quality of Lake Nsezi. The current project contributed to the monitoring program but also revealed water quality parameters of concern.

### 6.1 Aim, Objectives and Hypothesis

The aim, objectives and hypothesis of this study are reviewed.

#### 6.1.1 AIM

The aim of this research project was to assess the water quality of Lake Nsezi.

This aim was met as the quality of the water from Lake Nsezi was addressed by focussing on *in-situ* water quality parameters and chemical and bacteriological analysis. These results were compared to the Water Quality Guidelines of the Department of Water and Sanitation for the Aquatic Environment and those guidelines for Domestic Use.

#### 6.1.2 OBJECTIVES

The aim of this study was delivered through the following objectives:

**Objective 1:** Conduct an extensive literature survey to find all currently available and historical water quality data for Lake Nsezi.

The literature survey provided essential background information for this study. Currently available, historical and data from this study were used to assess the water quality of Lake Nsezi.

**Objective 2:** Confer with uMhlathuze Water Laboratory to identify assessable sampling sites for the project.

Seven (7) assessable sampling sites (Sites 1 – 7), were identified and used for samples collected during the course of the study.

**Objective 3:** Conduct field trips during five seasons from May 2014 to May 2015 with the purpose to gather water samples for physico-chemical, chemical and bacteriological analysis.

For the sampling period of May 2014 to May 2015, water samples were collected during autumn, winter and spring of 2014, as well as summer and autumn of 2015. The water samples were collected at Sites 1 to 7. *In-situ* parameters (pH, Oxygen, Temperature and Total Dissolved Solids) were determined at each sampling site. Water samples were collected and submitted to uMhlathuze Water Laboratory in Richards Bay where chemical and bacteriological analysis were performed.

**Objective 4:** Compare the results from the various analysis to the Target Water Quality Range of the Water Quality Guidelines for the Aquatic Environment and the Water Quality Guidelines for Domestic Use.

*In-situ* parameters, chemical and bacteriological results were all compared to the Target Water Quality Range (TWQR) of the Water Quality Guidelines for the Aquatic Environment (WQG/AE) (DWAF, 1996a) and for Domestic use (WQG/DU) (DWAF, 1996b).

Monitoring Lake Nsezi's water quality has been a prerogative of the uMhlathuze Water Laboratory in Richards Bay since 2000. The current project focused on the same water quality parameters. Total dissolved solids (TDS), chlorine, metal such as aluminium, cadmium, copper, lead and manganese; bacteriological parameters such as faecal coliform counts, Heterotrophic plate counts (HPC's) and total coliform counts have been identified as water quality parameters of concern. The parameters were above the TWQR for either or both the water quality guidelines, many since the early 2000's.

Treatment of the Lake Nsezi water need to be adjusted to cater for these concerns. To deliver water of good quality, improvement is essential.

**Objective 5:** To identify possible sources influencing the water quality of Lake Nsezi.

For the duration of this project, the water quality of Lake Nsezi had been addressed focussing on the analysis of various water quality parameters. Possible sources that may be contributing to these water quality parameters being above the Water Quality Guidelines for the Aquatic Environment and for Domestic Use, include surface runoff from Richards Bay; surface runoff from agricultural activities along the tributaries of the lake; municipal and industrial effluents and secondary sewage effluents discharged from various water treatment plants in the vicinity of Lake Nsezi. These possible sources should however be further investigated.

**Objective 6:** To compare the results of the current project with historical data to identify possible improvement / deterioration of the water quality of Lake Nsezi.

Comparing results from current study with the available historical data, it was noted that general water quality parameters such as TDS and Chloride; metals such as Aluminium, Cadmium, Copper, Lead and Manganese; and Total Coliform Counts (*E. coli*) had been present in concentrations above the Water Quality Guidelines for the Aquatic Environment and for the Domestic Use since uMhlathuze Water Laboratory started monitoring the water of Lake Nsezi in 2000.

### 6.1.3 STUDY HYPOTHESIS

This study comprised of two hypotheses:

The first Hypothesis ( $H_a$ ) stated that various water quality parameters could be used to describe the quality of the water of Lake Nsezi.

This hypothesis is accepted. *In-situ* water parameters, chemical and bacteriological analysis could be used to assess the water quality of Lake Nsezi.

The second Hypothesis ( $H_b$ ) stated that the results from the water quality analysis will indicate any possible pollution threats for the water environment of Lake Nsezi.

This hypothesis is accepted. Water quality results for the current study identified general water quality parameters such as TDS and chloride; metals such as

Aluminium, Cadmium, Copper, Lead and Manganese as well as Heterotrophic Plate Counts and Total Coliform Counts, all as possible parameters contributing to poor water quality of Lake Nsezi.

## **6.2 RECOMMENDATIONS**

Pollution and the systematic deterioration of the water quality of Lake Nsezi poses a threat to organisms surviving in the water, but also to humans and various industries that rely on this water resource not only for survival, but for the continuation of various essential processes / industries in Richards Bay and surrounding areas.

Considering the outcome of this study, the following recommendations can be made:

- To meet with the manager from uMhlathuze Water Laboratory in Richards Bay and discuss the outcome of this study. Information from this project can contribute to the existing data base of uMhlathuze Water Laboratory.
- Some of the sampling sites selected for this study are the same than sites used by uMhlathuze Water Laboratory for monitoring the water of Lake Nsezi. Water quality parameters identified during this project as possible parameters contributing to water deterioration, can be suggested as possible parameters to be monitored on a continuous basis. These parameters can in the end contribute to possible complete deterioration of the aquatic environment of Lake Nsezi.
- From this study, sources such as industries and informal settlements have been identified as possible contributors to polluting the aquatic environment of Lake Nsezi. This information can be shared with the Department of Water and Sanitation (DWS). A follow up study is recommended to identify specific contributors to poor water quality.
- uMhlathuze Water Laboratory should focus on monitoring specific effluent into Lake Nsezi by comparing data with the Water Quality Guidelines for the Aquatic Environment and for Domestic Use, as well as guidelines from the World Health Organisation. Act 107 of NEMA (1988) may also be used to create awareness and responsible processing within industries occurring in the direct area of Lake Nsezi.
- uMhlathuze Water Laboratory should also create awareness for a safer aquatic

environment by informing industries, informal settlements and small scale farmers on the safe and effective use of chemicals, effluent generated through various activities to comply to certain standards and in general creating a sustainable and safe aquatic environment for future generations.

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# **APPENDICES**

## **APPENDIX A: 2014-2015 RESULTS**

TABLE 1: Physical parameters for the study period 2014 - 2015 at Sites 1-7. (Target Water Quality Range for the ■ WQG/AE and ■ WQG/DU are included)

Season	Site	pH	Total dissolved solids(TDS)	Temperature(°C)	Dissolved Oxygen (%)
Autumn 2014	1	7.0	5.24	21.9	25.7
	2	7.8	5.77	21.6	57.1
	3	7.6	4.99	23.6	69.1
	4	7.7	5.92	23.1	51.3
	5	6.9	2.55	23.3	76.2
	6	7.2	2.22	26.4	82.1
	7	7.4	5.29	22.1	95.6
	Average	7.4	4.57	23.1	65.3
	WQG/AE	6.0-9.0	435		80-120
	WQG/DU	6.0-9.0	450		
Winter 2014	1	7.2	5.67	17.7	22.2
	2	8.2	6.4	20.4	62.9
	3	8.0	6.34	18.4	62.4
	4	8.1	6.34	21.4	75.4
	5	7.0	3.29	21.8	41.2
	6	8.2	5.84	19.9	62.6
	7	7.1	6.24	17.2	35.3
	Average	7.7	5.73	19.4	51.7
	WQG/AE	6.0-9.0	435		80-120
	WQG/DU	6.0-9.0	450		
Spring 2014	1	7.0	5.86	23.5	11
	2	8.1	6.76	25.7	66.7
	3	7.9	6.72	26.5	68.1
	4	8.0	6.82	26.4	57.4
	5	7.0	2.76	24.0	42.1
	6	7.9	4.02	24.2	59.3
	7	6.9	6.25	24.3	22.6
	Average	7.5	5.58	24.9	46.7
	WQG/AE	6.0-9.0	435		80-120
	WQG/DU	6.0-9.0	450		

TABLE 1: continued

Season	Site	pH	TDS	Temperature(°C)	Dissolved oxygen (%)
Summer 2015	1	6.7	6.25	24.6	14.6
	2	7.5	5.86	26.1	42.0
	3	7.5	5.58	26.5	36.0
	4	7.7	4.78	26.9	46.7
	5	6.7	2.24	25.8	40.0
	6	7.3	2.28	27.4	48.9
	7	7.3	4.24	24.4	40.9
	Average	7.2	4.29	25.9	38.4
	WQG/AE	6.0-9.0	435		80-120
	WQG/DU	6.0-9.0	450		
Autumn 2015	1	6.7	5.79	22.7	24.1
	2	7.3	5.23	23.6	69.0
	3	7.4	5.04	24.5	71.2
	4	7.3	3.05	28.1	76.0
	5	6.9	2.52	24.3	78.0
	6	7.3	1.98	28.9	95.0
	7	7.6	5.99	21.0	114.0
	Average	7.2	4.23	24.7	75.3
	WQG/AE	6.0-9.0	435		80-120
	WQG/DU	6.0-9.0	450		

TABLE 2: General water quality parameters for the study period 2014 - 2015 at Sites 1-7. (Target Water Quality Range for the:   WQG/AE and   WQG/DU are included)

Season	Site	Fluoride as F(mg/L)	Chloride as Cl (mg/L)	Nitrate as N(mg/L)	Sulphate as SO <sub>4</sub> (mg/L)
Autumn 2014	1	0.33	153.2	< 0.08	6.73
	2	0.35	45.14	0.34	9.21
	3	0.32	150.08	< 0.08	1.25
	4	0.42	164.09	< 0.08	11.59
	5	0.71	171.42	< 0.08	12.61
	6	0.59	58.12	0.82	15.34
	7	2.24	172.42	<0.08	1.53
	Average	0.71	130.6		8.32
	WQG/AE	0.00075	0.0002	5.0	
	WQG/DU	1.0	100	6.0	200
Winter 2014	1	0.33	128.65	< 0.08	17.24
	2	0.72	147.88	< 0.08	12.39
	3	0.58	150.26	< 0.08	12.34
	4	0.39	155.16	< 0.08	8.00
	5	0.15	95.48	1.37	17.02
	6	0.39	149.24	< 0.08	5.58
	7	0.30	161.96	< 0.08	0.89
	Average	0.40	141.23		10.49
	WQG/AE	0.00075	0.0002	5.0	
	WQG/DU	1.0	100	6.0	200
Spring 2014	1	0.59	123.79	0.20	10.78
	2	0.59	174.21	< 0.08	7.83
	3	0.47	171.09	< 0.08	8.10
	4	0.39	170.48	< 0.08	12.72
	5	0.22	72.08	1.06	12.26
	6	0.49	92.34	< 0.08	8.75
	7	0.37	153.18	< 0.08	7.67
	Average	0.45	136.74		9.73
	WQG/AE	0.00075	0.0002	5.0	
	WQG/DU	1.0	100	6.0	200

TABLE 2: continued

Season	Site	Fluoride as F(mg/L)	Chloride as Cl(mg/L)	Nitrate as N(mg/L)	Sulphate as SO <sub>4</sub> (mg/L)
Summer 2015	1	0.33	126.71	<0.08	9.05
	2	0.43	140.56	< 0.08	9.37
	3	0.48	142.52	< 0.08	7.79
	4	0.41	118.80	< 0.08	5.87
	5	0.32	58.28	1.70	35.23
	6	0.34	59.34	< 0.08	6.98
	7	0.50	81.39	0.19	12.36
	Average	0.40	103.94		12.38
	WQG/AE	0.00075	0.0002	5.0	
	WQG/DU	1.0	100	6.0	200
Autumn 2015	1	0.44	119.65	0.09	6.46
	2	0.47	99.53	0.11	8.06
	3	1.61	84.89	5.27	17.24
	4	0.67	62.54	0.42	7.29
	5	1.92	3.76	0.09	88.32
	6	0.66	59.02	0.94	16.22
	7	2.19	176.34	< 0.08	1.67
	Average	17.08	86.53	1.00	20.75
	WQG/AE	0.00075	0.0002	5.0	
	WQG/DU	1.0	100	6.0	200

TABLE 3: Metal analysis for the study period 2014 – 2015 at Sites 1-7. (Target Water Quality Range for the: ■ WQG/AE and ■ WQG/DU are included)

Season	Site	Al mg/L	Ba mg/L	B mg/L	Cd mg/L	Cr mg/L	Co mg/L	Cu mg/L	Fe mg/L	Pb mg/L	Mg mg/L	Mn mg/L	Mo mg/L	Ni mg/L	Hg mg/L	K mg/L	Na mg/L	Sr mg/L	Ti mg/L	V mg/L	Ca (mg/L)
Autumn 2014	1	<0.02	0.045	0.094	<7	<6	< 13	< 13	<0.026	< 16	17.80	<0.025	< 0.007	<0.021	<0.7	7.85	126	0.129	<0.004	<0.003	15.90
	2	0.002	0.038	0.033	< 7	< 6	< 13	< 13	0.364	< 16	9.49	<0.025	< 0.007	<0.021	< 0.7	4.40	35.70	0.080	<0.004	<0.003	12.30
	3	<0.02	0.03	0.025	< 7	< 6	< 13	< 13	0.739	35	11.40	0.039	< 0.007	<0.021	< 0.7	4.92	53.10	0.095	<0.004	<0.003	13.40
	4	<0.02	0.089	0.071	< 7	< 6	< 13	< 13	2.625	<16	23.20	0.166	0.009	<0.021	< 0.7	6.82	122	0.181	<0.004	<0.003	26.00
	5	0.023	0.043	0.104	< 7	< 6	< 13	< 13	<0.026	< 16	21.30	0.025	< 0.007	<0.021	< 0.7	9.21	145	0.139	<0.004	<0.003	15.80
	6	0.178	0.053	0.035	2.8	<6	<13	<13	0.252	1.26	9.82	0.034	<0.007	<0.021	<0.1	2.28	39.82	0.114	0.010	0.007	10.89
	7	<0.02	0.072	0.068	2.79	<6	<13	<13	0.036	21.19	26.13	0.489	0.016	<0.021	<0.1	2.89	118	0.241	0.006	<0.003	32
	Average	0.04	0.053	0.061	<7	<6	<13	<13	0.581	16.77	17.02	0.114	<0.007	<0.021	<0.5	5.48	91.37	0.140	<0.004	<0.003	18.04
	WQG:AE	0.005			0.000 15			0.000 8		0.0002		0.18			0.04						
	WQG/DU	0.15			0.000 5			0-1		10		0.05			1.0	400				0.1	32
Winter 2014	1	<0.02	0.046	0.110	5.95	8	< 13	< 13	0.123	6.01	19.90	0.091	0.032	<0.021	< 0.7	9.43	124	0.124	0.015	0.005	18.40
	2	<0.02	0.055	0.128	5.96	8	< 13	13	0.061	7.30	25.50	<0.025	0.029	<0.021	< 0.7	9.02	133	0.156	0.015	0.007	18.50
	3	0.185	0.06	0.127	5.19	8	< 13	14	0.401	6.59	25.00	0.091	0.027	<0.021	< 0.7	9.51	147	0.157	0.020	0.010	18.20
	4	0.041	0.056	0.122	5.33	8	< 13	14	0.094	9.35	26.50	<0.025	0.040	<0.021	< 0.7	9.23	130	0.155	0.015	0.008	17.80
	5	<0.02	0.049	0.050	5.24	8	< 13	13	0.476	8.31	14.80	0.080	0.029	<0.021	<0.7	5.21	57.10	0.111	0.012	0.005	14.00
	6	<0.02	0.061	0.105	6.36	8	< 13	13	0.035	5.70	25.10	<0.025	0.027	<0.021	< 0.7	8.34	124	0.163	0.012	0.007	21.10
	7	<0.02	0.100	0.083	5.95	8	< 13	< 13	1.352	7.73	29.70	0.378	0.023	<0.021	< 0.7	5.88	114	0.193	0.012	0.004	27.30
	Average	0.047	0.061	0.104	5.71	8	<13	13	0.363	7.28	23.79	0.102	0.030	<0.021	<0.7	8.66	118	0.151	0.014	0.007	19.30
	WQG/AE	0.005			0.000 15			0.000 8		0.0002		0.18			0.04						
	WQG/DU	0.15			0.000 5			0-1		10		0.05			1.0	400				0.1	32
Spring 2014	1	0.034	0.052	0.110	-2.97	< 6	< 13	13	0.215	21.10	17.40	0.101	0.026	<0.021	< 0.7	8.79	154	0.125	0.017	0.012	19.70
	2	0.033	0.072	0.121	-2.83	< 6	< 13	15	<0.026	37.90	22.80	<0.025	0.017	<0.021	< 0.7	10.2	162	0.169	0.017	0.011	20.10
	3	0.022	0.071	0.120	-3.22	< 6	< 13	15	<0.026	38.80	23.00	<0.025	0.010	<0.021	< 0.7	10.2	161	0.164	0.017	0.008	20.20
	4	<0.02	0.068	0.114	-1.59	< 6	< 13	14	0.026	16.30	22.60	<0.025	0.011	<0.021	< 0.7	9.72	157	0.165	0.016	0.006	20.60
	5	<0.02	0.050	0.038	-2.81	< 6	< 13	14	0.597	60.40	10.90	0.134	< 0.007	<0.021	< 0.7	4.92	53.40	0.108	0.015	0.005	14.40
	6	0.412	0.067	0.071	-2.60	< 6	< 13	13	0.258	31.90	14.50	<0.025	0.009	<0.021	< 0.7	6.08	87.80	0.127	0.030	0.008	17.70
	7	<0.02	0.130	0.074	-2.86	< 6	< 13	< 13	0.514	16.20	24.40	1.040	< 0.007	<0.021	< 0.7	6.34	130	0.227	0.015	0.004	32.70
	Average	0.08	0.073	0.093	-2.69	<6	<13	14	0.237	31.80	19.37	0.196	0.012	<0.021	<0.7	8.03	129	0.155	0.018	0.008	17.81
	WQG:AE	0.005			0.000 15			0.000 8		0.0002		0.18			0.04						
	WQG/DU	0.15			0.000 5			0-1		10		0.05			1.0	400				0.1	32

TABLE 3: continued

Season	Site	Al mg/L	Ba mg/L	B mg/L	Cd mg/L	Cr mg/L	Co mg/L*	Cu mg/L	Fe mg/L	Pb mg/L	Mg mg/L	Mn mg/L	Mo mg/L	Ni mg/L	Hg mg/L*	K mg/L	Na mg/L	Sr mg/L	Ti mg/L	V mg/L	Ca mg/L
Summer 2015	1	<0.02	0.055	0.119	0.53	7	13	13	0.609	0.00	19.50	0.520	0.030	<0.021	<0.7	9.36	161	0.174	0.012	<0.003	19.80
	2	<0.02	0.030	0.115	3.77	<6	<13	<13	0.089	0.00	20.10	0.042	0.031	<0.021	<0.7	6.60	146	0.186	0.014	<0.003	15.40
	3	<0.02	0.034	0.112	2.61	7	<13	<13	0.076	0.03	19.70	0.030	0.026	<0.021	<0.7	6.09	139	0.178	0.010	0.009	15.30
	4	<0.02	0.056	0.100	1.61	7	<13	19	0.178	0.00	16.70	0.100	0.029	<0.021	<0.7	4.55	118	0.157	0.013	0.008	13.00
	5	0.036	0.0570	0.045	-2.39	7	<13	<13	0.664	0.00	8.72	0.401	0.034	<0.021	<0.7	5.71	44.7 0	0.141	0.011	0.005	14.90
	6	0.242	0.045	0.076	-2.08	<6	<13	<13	0.786	0.00	8.22	0.079	0.026	<0.021	<0.7	3.51	61.9 00	0.074	0.050	0.010	4.41
	7	0.288	0.540	0.121	2.55	7	<13	<13	0.923	3.51	14.20	0.391	0.018	<0.021	<0.7	8.47	73.4 0	0.198	0.053	0.005	29.40
	Average	0.092	0.117	0.098	0.94	7	<13	<13	0.475	0.50	15.30	0.223	0.028		<0.7	6.33	106. 3	0.158	0.023	0.006	16.03
	WQG:A E	0.005			0.000 15			0.0008		0.000 2		0.18			0.04						
	WQG/D U	0.15			0.000 5			0-1		10		0.05			1.0	400				0.1	32
Autumn 2015	1	<0.02	0.067	0.090	3.43	<6	<13	<13	0.265	5.12	17.70	0.411	0.021	<0.021	0.97	8.44	116	0.146	0.011	0.041	19.20
	2	0.075	0.049	0.074	1.64	<6	<13	<130.	0.096	11	13.70	<0.025	0.010	<0.021	0.16	4.04	74.2 0	0.120	0.009	0.011	11.80
	3	0.357	0.061	0.071	1.43	<6	<13	<13	0.426	5.48	12.90	0.222	0.008	<0.021	0.10	4.74	66.8 0	0.113	0.025	0.011	11.80
	4	0.290	0.046	0.056	1.44	<6	<13	<13	0.304	46.80	11	<0.025	<0.00 7	<0.021	<0.1	2.58	49.2 0	0.102	0.016	0.008	9.97
	5	<0.02	0.057	0.032	1.46	<6	<13	<13	0.308	18.80	11.30	0.098	<0.00 7	<0.021	<0.1	2.88	46	0.122	0.005	0.007	13.60
	6	0.185	0.050	0.037	2.82	<6	<13	<13	0.258	1.29	9.80	0.032	<0.00 7	<0.021	<0.1	2.27	38.6 0	0.104	0.011	0.007	11.80
	7	<0.02	0.068	0.071	2.80	<6	<13	<130.	0.038	22.20	25.10	0.490	0.014	<0.021	<0.1	2.87	115	0.239	0.005	<0.003	33.00
	Average	0.138	0.057	0.062	2.15	<6	<13	<13	0.242	15.8	14.5	0.186	0.011		0.23	3.97	72.2 6	0.135	0.012	13	15.8 8
	WQG:A E	0.005			0.000 15			0.0008		0.000 2		0.18			0.04						
	WQG/D U	0.15			0.000 5			0-1		10		0.05			1.0	400				0.1	32

\*: concentration= x10<sup>-3</sup>



TABLE 4: Bacteriological analysis for the study period 2014 - 2015 at Sites 1-7. (Target Water Quality Range for the: ■ WQG/AE and ■ WQG/DU are included)

Season	Site	<i>Escherichia coli</i> (counts/100 mL)	Heterotrophic plate count(counts/100 mL)	Total coliform count (counts/100 mL)
Autumn 2014	1	26	1710000	10133
	2	98	850000	1986
	3	288	2370000	24196
	4	310	1040000	12360
	5	41	970000	3076
	6	982	1000	6500
	7	2242	1000	20400
	Average	3706	853100	11236
	WQG/AE			
	WQG/DU	2400	10000	5
Winter 2014	1	8	279000	1986
	2	5	310000	980
	3	276	195000	921
	4	65	209000	1120
	5	52	560000	2420
	6	1	101000	236
	7	109	440000	2420
	Average	74	299100	1440
	WQG/AE			
	WQG/DU	2400	10000	5
Spring 2014	1	73	2330000	17329
	2	63	400000	2542
	3	6867	410000	3076
	4	41	670000	7270
	5	75	1870000	24196
	6	52	2100000	19863
	7	31	1730000	19863
	Average	54	1358600	13448
	WQG/AE			
	WQG/DU	2400	10000	5

TABLE 4: continued

Season	Site	<i>Escherichia coli</i> (counts/100 mL)	Heterotrophic plate count (counts/100 mL)	Total coliform count (counts/100 mL)
Summer 2015	1	359	2040000	24196
	2	32	193000	2420
	3	52	180000	9804
	4	11	243000	1986
	5	148	111000	2420
	6	199	1510000	14136
	7	109	10600000	220295
	Average	15257	2356714	39322
	WQG/AE			
	WQG/DU	2400	10000	5
Autumn 2015	1	160	2350000	24196
	2	97	1810000	11199
	3	41	1930000	24196
	4	63	1040000	7270
	5	350	1880000	19863
	6	10	640000	909
	7	10	2030000	24196
	Average	1080	4155714	15976
	WQG/AE			
	WQG/DU	2400	10000	5

## APPENDIX B:

### HISTORIC DATA COMBINED WITH PRIMARY DATA: PERIOD 2000-2015

Four (4) sampling sites are used: Site 1, Site 2, Site 3 and Site 7.

**Table 1:** pH data for the period 2000-2015 at Sites 1, 2, 3 and 7. (Target Water Quality Range for the: ■ WQG/AE and ■ WQG/DU are included)

Year	Season	pH site1	pH site 2	pH site3	pH site 7
2000	summer	7.1	7.7	7.2	6.7
	Autumn	6.2	7.2	7.1	6.9
	winter	7.6	7.6	7.5	6.8
	spring	7	7.9	8.2	6.8
2001	Summer	7.4	8.2	8.1	6.7
	Autumn	7.4	8.5	8.5	7.2
	Winter	8	7.9	7.9	7.2
	Spring	7.7	7.8	7.8	7.2
2002	Summer	7.7	7.9	7.9	7.2
	Autumn	8.1	8.3	8.3	7.7
	Winter	6.7	7.4	8.1	7.2
	Spring	7.9	8.2	8.3	7.5
2003	Summer	7.9	8.1	8.1	7.4
	Autumn	7.4	7.8	7.6	6.8
	Winter	7.8	7.9	7.9	6.9
	Spring	7.5	7.2	7.3	6.7
2004	Summer	8.2	8.3	8.3	7.5
	Autumn	7.8	7.7	7.7	7
	Winter	7.8	8	8	6.9
	Spring	7.9	8.2	8.3	7.2
2005	Summer	7.5	8	8	7.1
	Autumn	8.9	7.5	7.7	6.6
	Winter	7.1	8.2	8.2	7.1
	Spring	8.5	8	7.9	7.1
<b>WQG/AE</b>			<b>6.0-9.0</b>		
<b>WQG/DU</b>			<b>6.0-9.0</b>		

**Table 1 continued**

Year	Season	pH site1	pH site 2	pH site3	pH site 7
2006	Summer	7.3	7.5	7.4	7.2
	Autumn	7.2	7.3	7.4	6.7
	Winter	7.4	8.1	7.9	7.9
	Spring	7.5	8.2	8.3	7.2
2007	Summer	7.7	7.8	7.8	7.3
	Autumn	7.6	7.7	7.8	6.9
	Winter	7.5	7.1	7.1	7.1
	Spring	6.7	7.4	7.6	6.7
2008	Summer	7.5	7.6	7.7	7.6
	Autumn	7.9	7.9	7.7	7.5
	Winter	7.4	7.8	7.8	7.3
	Spring	7.7	7.6	7.5	7.6
2010	Summer	7.1	7.2	7.2	6.4
	Autumn	7	7.7	7.7	6.7
	Winter	6.9	7.4	7.4	6.4
	Spring	7	7.8	7.5	6.9
2011	Summer	7.4	7.8	7.8	7.2
	Autumn	7.8	7.8	7.8	7
	Winter	7.7	8	8	7.1
	Spring	7.4	7.1	7.7	6.6
2012	Summer	7.2	7.2	7.1	6.6
	Autumn	7.9	8.2	7.9	8.2
	Winter	7.6	8.2	8.3	7.9
	Spring	8.2	8.1	8.3	7.2
2014	Autumn	7	7.8	7.6	7.4
	Winter	7.2	8.2	8	7.1
	Spring	7	8.1	7.9	6.9
2015	Summer	6.7	7.5	7.5	7.3
	Autumn	6.7	7.3	7.4	7.6
<b>WQG/AE</b>			<b>6.0-9.0</b>		
<b>WQG/DU</b>			<b>6.0-9.0</b>		

**Table 2:** TDS data for the period 2000-2015 at Sites 1, 2, 3, and 7. (Target Water Quality Range for the: ■ WQG/AE and ■ WQG/DU are included)

YEAR	Season	TDS site 1	TDS site 2	TDS site 3	TDS site 7
2000	summer	669	558	468	392
	Autumn	718	538	495	382
	Winter	655	682	668	398
	Spring	728	694	677	521
2001	Summer	667	594	577	380
	Autumn	666	660	651	454
	Winter	567	658	676	502
	Spring	721	608	616	617
2002	Summer	596	463	490	522
	Autumn	577	602	607	386
	Winter	596	448	571	303
	Spring	670	743	737	391
2003	Summer	598	734	735	391
	Autumn	642	735	721	464
	Winter	662	721	655	430
	Spring	583	550	555	430
2004	Summer	680	575	574	530
	Autumn	639	495	492	351
	Winter	537	532	523	359
	Spring	542	528	527	349
2005	Summer	466	502	487	505
	Autumn	395	514	390	382
	Winter	614	453	431	365
	Spring	520	482	472	396
2006	Summer	517	439	443	384
	Autumn	438	338	343	400
	Winter	617	513	509	304
	Spring	621	571	574	375
<b>WQG/AE</b>			<b>435</b>		
<b>WQG/DU</b>			<b>450</b>		

**Table 2 continued**

YEAR	Season	TDS site 1	TDS site 2	TDS site 3	TDS site 7
2007	Summer	525	526	278	466
	Autumn	525	536	538	468
	Winter	547	359	359	334
	Spring	532	523	502	426
2008	Summer	574	532	525	455
	Autumn	494	469	454	408
	Winter	427	448	459	400
	Spring	457	432	435	437
2010	Summer	459	499	515	349
	Autumn	455	494	469	432
	Winter	510	476	465	609
	Spring	564	425	406	653
2011	Summer	519	461	458	670
	Autumn	560	476	474	456
	Winter	454	342	397	270
	Spring	539	503	520	429
2012	Summer	539	503	520	429
	Autumn	505	435	443	429
	Winter	529	471	476	385
	Spring	542	465	469	376
2014	Autumn	564	621	534	570
	Winter	610	689	683	672
	Spring	631	728	724	673
2015	Summer	673	631	601	457
	Autumn	624	564	453	645
<b>WQG/AE</b>			<b>435</b>		
<b>WQG/DU</b>			<b>450</b>		

**Table 3:** Fluoride data for the period 2010-2015 at Sites 1, 2, 3 and 7. (Target Water Quality Range for the:      WQG/AE and      WQG/DU are included)

YEAR	Season	Fluoride (mg/L) site 1	Fluoride (mg/L) site 2	Fluoride (mg/L) site 3	Fluoride (mg/L) site 7
2010	summer	0.32	0.29	0.4	0.44
	Autumn	0.26	0.34	0.32	0.35
	winter	0.27	0.45	0.37	0.5
	spring	0.4	0.03	0.03	0.6
2011	Summer	0.4	0.4	0.4	0.6
	Autumn	0.4	0.4	0.4	0.4
	Winter	0.4	0.5	0.5	0.5
	Spring	0.4	0.3	0.3	0.3
2012	Summer	0.2	0.3	0.2	0.3
	Autumn	0.3	0.4	0.6	0.5
	Winter	0.3	0.3	0.3	0.3
	Spring	0.33	0.33	0.26	0.53
2014	Autumn	0.33	0.35	0.32	2.24
	Winter	0.33	0.72	0.58	0.3
	Spring	0.59	0.59	0.47	0.37
2015	Summer	0.33	0.43	0.48	0.5
	Autumn	0.44	0.47	1.61	2.19
WQG/AE			0.00075		
WQG/DU			1.0		

**Table 4:** Chloride data for the period 2010-2015 at Sites 1, 2, 3 and 7. (Target Water Quality Range for the: ■ WQG/AE and ■ WQG/DU are included)

YEAR	Season	Chloride (mg/L) site 1	Chloride (mg/L) site 2	Chloride (mg/L) site 3	Chloride (mg/L) site 7
2010	Summer	122.4	146.4	149.5	96.7
	Autumn	98.7	148.4	144.5	108.6
	Winter	115	132.3	130	149.8
	Spring	133.1	117.1	111.7	152.2
2011	Summer	114.2	99.84	94.2	201
	Autumn	136.7	136.1	135.9	115.3
	Winter	123.6	131.7	126.8	87.6
	Spring	115.5	117.6	113.2	93.1
2012	Summer	117.6	114.5	115.8	115.4
	Autumn	70.9	88.1	80.5	103.7
	Winter	125.7	121.3	120.9	111.6
	Spring	118.1	118.1	118.8	104.5
2014	Autumn	153.2	45.14	150.08	172.42
	Winter	128.65	147.88	150.26	161.96
	Spring	123.79	174.21	171.09	153.18
2015	Summer	126.71	140.56	142.52	81.39
	Autumn	119.65	99.53	84.89	176.34
<b>WQG/AE</b>			<b>00002</b>		
<b>WQG/DU</b>			<b>100</b>		



**Table 5:** Aluminium data for the period 2005-2015 at Sites 1, 2, 3 and 7. (Target Water Quality Range for the: ■ WQG/AE and ■ WQG/DU are included)

YEAR	Season	Aluminium (mg/L) site 1	Aluminium (mg/L) site 2	Aluminium (mg/L) site 3	Aluminium (mg/L) site 7
2005	Summer	0.36	0.57	0.33	0.69
	Autumn	0.12	0.14	0.12	0.65
	Winter	0.1	0.28	0.18	0.12
2006	Spring	0.13	0.19	0.1	0.14
	Summer	0.089	0.19	0.09	0.1
	Autumn	1.19	1.7	0.77	0.02
	Winter	12	0.07	0.11	0.013
2007	Spring	0.024	0.03	0.01	0.009
	Summer	0.17	0.2	0.2	0.002
	Autumn	0.32	0.49	0.33	0.06
	Winter	0.05	2.52	2.3	0.89
2010	Spring	0.55	0.32	0.3	0.02
	Summer	0.159	0.008	0.008	0.129
	Autumn	0.578	0.3	0.583	0.127
	Winter	0.008	0.052	0.068	0.008
2011	Spring	0.08	0.008	0.008	0.02
	Summer	2.8	2.4	0.194	0.004
	Autumn	0.172	0.173	0.179	0.004
	Winter	0.564	0.115	0.119	0.05
2012	Spring	0.273	0.229	0.245	0.048
	Summer	0.54	1.463	1.254	0.08
	Autumn	4.773	10.783	10.425	0.073
	Winter	0.17	0.12	0.063	0.002
2014	Autumn	0.01	0.002	0.01	0.01
	Winter	0.01	0.01	0.185	0.01
	Spring	0.034	0.033	0.022	0.01
2015	Summer	0.01	0.01	0.01	0.288
	Autumn	0.01	0.075	0.357	0.01
<b>WQG/AE</b>			<b>0.005</b>		
<b>WQG/DU</b>			<b>0.15</b>		

**Table 6:** Copper data for the period 2007-2015 at Sites 1, 2, 3 and 7. (Target Water Quality Range for the: ■ WQG/AE and ■ WQG/DU are included)

YEAR	Season	Copper (mg/L) site 1	Copper (mg/L) site 2	Copper (mg/L) site 3	Copper (mg/L) site 7
2007	Summer	0.0009	0.0009	0.0009	0.0009
	Autumn	0.007	0.008	0.008	0.004
	Winter	0.013	0.016	0.012	0.01
2008	Spring	0.002	0.002	0.002	0.002
	Summer	0.004	0.003	0.002	0.002
	Autumn	0.003	0.002	0.002	0.003
	Winter	0.002	0.002	0.002	0.003
2010	Spring	0.003	0.002	0.002	0.002
	Summer	0.015	0.002	0.002	0.01
	Autumn	0.169	0.01	0.012	0.007
	Winter	0.002	0.002	0.002	0.002
2011	Spring	0.002	0.002	0.002	0.002
	Summer	0.01	0.008	0.003	0.004
	Autumn	0.004	0.004	0.003	0.002
	Winter	0.002	0.002	0.002	0.032
2012	Spring	0.004	0.005	0.007	0.01
	Summer	0.024	0.002	0.061	0.002
	Autumn	0.007	0.0032	0.008	0.0032
	Winter	0.004	0.005	0.005	0.004
2014	Spring	0.005	0.005	0.005	0.004
	Autumn	0.0065	0.0065	0.0065	0.0065
	Winter	0.0065	0.013	0.014	0.0065
	Spring	0.013	0.015	0.015	0.0065
2015	Summer	0.0065	0.0065	0.0065	0.0065
	Autumn	0.0065	0.0065	0.0065	0.0065
<b>WQG/AE</b>			<b>0.0003</b>		
<b>WQG/DU</b>			<b>0-1</b>		

**Table 7:** Lead data for the period 2007-2015 at Sites 1, 2, 3 and 7. (Target Water Quality Range for the: ■ WQG/AE and ■ WQG/DU are included)



YEAR	Season	Lead (mg/L) site 1	Lead (mg/L) site 2	Lead (mg/L) site 3	Lead (mg/L) site 7
2007	summer	0.0046	0.0046	0.0046	0.0046
	Autumn	0.0046	0.0046	0.0046	0.0046
	winter	0.007	0.015	0.013	0.017
2008	Spring	0.007	0.007	0.007	0.024
	Summer	0.007	0.007	0.007	0.007
	Autumn	0.007	0.011	0.01	0.007
	Winter	0.007	0.007	0.007	0.007
2010	Spring	0.007	0.007	0.007	0.007
	Summer	0.02	0.02	0.02	0.02
	Autumn	0.02	0.02	0.02	0.02
	Winter	0.02	0.02	0.02	0.02
2011	Spring	0.02	0.02	0.02	0.02
	Summer	0.012	0.012	0.012	0.012
	Autumn	0.012	0.012	0.012	0.012
	Winter	0.012	0.012	0.012	0.012
2012	Spring	0.012	0.012	0.012	0.012
	Summer	0.012	0.012	0.012	0.012
	Autumn	0.006	0.006	0.006	0.006
	Winter	0.006	0.006	0.006	0.006
	Spring	0.006	0.006	0.006	0.006
2014	Autumn	0.08	0.08	0.035	0.02119
	Winter	0.00601	0.0073	0.00659	0.00773
	Spring	0.0211	0.0379	0.0388	0.0162
2015	Summer	0.08	0.08	0.00003	0.00351
	Autumn	0.00512	0.011	0.00548	0.0222
<b>WQG/AE</b>			<b>0.0002</b>		
<b>WQG/DU</b>			<b>10</b>		

**Table 8:** Cadmium data for the period 2007-2015 at Sites 1, 2, 3 and 7. (Target Water Quality Range for the: ■ WQG/AE and ■ WQG/DU are included)

YEAR	Season	Cadmium (mg/L) site 1	Cadmium (mg/L) site 2	Cadmium (mg/L) site 3	Cadmium (mg/L) site 7
2007	Summer	0.0015	0.0015	0.0015	0.0015
	Autumn	0.002	0.007	0.002	0.002
	Winter	0.007	0.005	0.007	0.007
2008	Spring	0.005	0.005	0.005	0.005
	Summer	0.005	0.005	0.005	0.005
	Autumn	0.005	0.005	0.005	0.005
	Winter	0.005	0.005	0.005	0.005
2010	Spring	0.005	0.005	0.005	0.005
	Summer	0.008	0.008	0.008	0.008
	Autumn	0.008	0.008	0.008	0.008
	Winter	0.008	0.008	0.008	0.008
2011	Spring	0.008	0.008	0.008	0.008
	Summer	0.003	0.003	0.003	0.003
	Autumn	0.003	0.003	0.003	0.003
	Winter	0.003	0.003	0.003	0.003
2012	Spring	0.003	0.003	0.003	0.003
	Summer	0.003	0.003	0.003	0.003
	Autumn	0.003	0.003	0.003	0.003
	Winter	0.003	0.003	0.003	0.003
2014	Spring	0.003	0.003	0.003	0.003
	Autumn	0.007	0.007	0.007	0.0028
	Winter	0.0059	0.0059	0.0052	0.0059
	Spring	0.0035	0.0035	0.0035	0.0035
2015	Summer	0.00053	0.00377	0.00261	0.00255
	Autumn	0.00343	0.00164	0.00143	0.0028
<b>WQG/AE</b>			<b>0.00015</b>		
<b>WQG/DU</b>			<b>0.0005</b>		

**Table 9:** Manganese data for the period 2010-2015 at Sites 1, 2, 3 and 7. (Target Water Quality Range for the: ■ WQG/AE and ■ WQG/DU are included)

YEAR	Season	Manganese (mg/L) site 1	Manganese (mg/L) site 2	Manganese (mg/L) site 3	Manganese (mg/L) site 7
2010	Summer	0.13	0.008	0.014	0.007
	Autumn	0.085	0.007	0.011	0.014
	Winter	0.059	0.032	0.022	1.033
	Spring	0.317	0.012	0.004	0.838
2011	Summer	0.016	0.023	0.424	0.928
	Autumn	0.067	0.012	0.006	0.26
	Winter	0.049	0.006	0.005	0.004
	Spring	0.083	0.001	0.006	0.612
2012	Summer	0.016	0.046	0.027	0.015
	Autumn	0.107	0.046	0.039	0.011
	Winter	0.041	0.011	0.011	0.336
	Spring	0.086	0.011	0.011	0.151
2014	Autumn	0.0125	0.0125	0.039	0.489
	Winter	0.091	0.0125	0.091	0.378
	Spring	0.101	0.0125	0.0125	1.04
2015	Summer	0.52	0.042	0.03	0.391
	Autumn	0.411	0.0125	0.222	0.49
<b>WQG/AE</b>			<b>0.18</b>		
<b>WQG/DU</b>			<b>0.05</b>		

**Table 10:** *E. coli* data for the period 2000-2015 at Sites 1, 2, 3 and 7. (Target Water Quality Range for the:  WQG/AE and  WQG/DU are included)

YEAR	Season	<i>E.coli</i> (counts/100mL) site 1	<i>E.coli</i> (counts/100mL) site 2	<i>E.coli</i> (counts/100mL) site 3	<i>E.coli</i> (counts/100mL) site 7
2000	summer	2325	53	130	24
	Autumn	500	380	325	46
	winter	5550	25	25	28
2001	spring	7350	47	30	1100
	Summer	2300	140	155	110
	Autumn	2775	38	19	430
	Winter	9525	29	22	220
2002	Spring	51725	23	21	144
	Summer	27850	56	29	328
	Autumn	6350	25	20	233
	Winter	3013	590	12	948
2003	Spring	4816	13	780	45
	Summer	7225	14	97	2
	Autumn	34183	42	37	365
	Winter	3888	36	157	14
2004	Spring	520	161	20	4
	Summer	935	28	161	39
	Autumn	203590	32	960	318
	Winter	21584	34	242	14
2005	Spring	496	224	31	36
	Summer	3055	50	80	16
	Autumn	159	100	128	20
	Winter	1514	17	19	555
<b>WQG/AE</b>			<b>0-1</b>		
<b>WQG/DU*</b>			<b>2400</b>		

\*uMhlathuze water guideline

**Table 10 continued**

YEAR	Season	<i>E.coli</i> (counts/100mL) site 1	<i>E.coli</i> (counts/100mL) site 2	<i>E.coli</i> (counts/100mL) site 3	<i>E.coli</i> (counts/100mL) site 7
2006	Spring	336	12	37	209
	Summer	2343	733	1185	572
	Autumn	8814	528	273	320
	Winter	10478	129	346	115
2007	Spring	1528	60	38	180
	Summer	583	93	158	240
	Autumn	161	79	220	485
	Winter	600	275	135	70
2008	Spring	853	113	110	214
	Summer	785	160	155	605
	Autumn	1000	65	50	201
	Winter	200	30	20	450
2010	Spring	603	204	120	392
	Summer	2700	30	21	400
	Autumn	830	10	120	1500
	Winter	260	10	2	270
2011	Spring	1100	10	30	920
	Summer	840	870	250	680
	Autumn	313	31	98	432
	Winter	906	31	30	134
2012	Spring	305	10	20	295
	Summer	130	46	88	88
	Autumn	980	488	345	458
	Winter	1414	26	43	86
2014	Autumn	26	98	288	2242
	Winter	73	63	41	31
	Spring	160	97	6870	10
2015	Summer	8	5	276	109
	Autumn	359	32	52	630
<b>WQG/AE</b>			<b>0-1</b>		
<b>WQG/DU</b>			<b>2400</b>		

**Table 11: Nitrate as N data for the period 2010-2015 at Sites 1, 2, 3 and 7.**

YEAR	Season	Nitrate (mg/L) site 1	Nitrate (mg/L) site 2	Nitrate (mg/L) site 3	Nitrate (mg/L) site 7
2010	Summer	<0.08	<0.08	<0.08	<0.08
	Autumn	0.09	<0.08	<0.08	<0.08
	Winter	0.43	<0.08	<0.08	<0.08
	Spring	<0.08	<0.08	<0.08	<0.08
2011	Summer	0.18	0.38	<0.08	<0.08
	Autumn	0.71	<0.08	<0.08	<0.08
	Winter	2.08	0.5	0.09	<0.08
	Spring	1.46	<0.08	<0.08	<0.08
2012	Summer	1.2	0.45	0.45	<0.08
	Autumn	1.09	0.49	0.43	<0.08
	Winter	2.68	0.48	0.33	<0.04
	Spring	0.26	0.31	0.32	0.06
2014	Autumn	<0.08	0.34	<0.08	<0.08
	Winter	<0.08	<0.08	<0.08	<0.08
	Spring	0.20	<0.08	<0.08	<0.08
2015	Summer	<0.08	<0.08	<0.08	0.19
	Autumn	0.09	0.11	5.27	<0.08
WQG/AE					
WQG/DU					



**Table 12: Sulphate as SO<sub>4</sub> data for the period 2010-2015 at Sites 1, 2, 3 and 7**

YEAR	Season	Sulphate (mg/L) site 1	Sulphate (mg/L) site 2	Sulphate (mg/L) site 3	Sulphate (mg/L) site 7
2010	summer	16.63	17.58	16.76	1.75
	Autumn	19.85	13.68	13.74	1.55
	winter	17.44	11.59	10.71	0.91
	spring	5.60	11.76	12.30	0.98
2011	Summer	13.21	13.29	1.89	1.87
	Autumn	23.81	18.89	18.33	3.63
	Winter	20.82	14.46	13.3	2.68
	Spring	23.49	16.08	15.74	2.05
2012	Summer	35.74	16.60	16.59	5.39
	Autunm	18.78	14.74	12.85	5.52
	Winter	20.09	19.96	20.06	2.19
	Spring	18.2	17.68	16.61	2.18
2014	Autumn	6.73	9.21	1.25	1.53
	Winter	17.24	12.39	12.34	5.58
	Spring	10.78	7.83	8.10	7.67
2015	Summer	9.05	9.37	7.79	12.36
	Autumn	6.46	8.06	17.24	1.67
<b>WQG/AE</b>					
<b>WQG/DU</b>					

# APPENDIX C

## RICHARDS BAY CLIMATE DATA PERIOD: 2000-2016

**Table 1: Average maximum temperatures (°C) in Richards Bay**

Year/Month	Jan	Feb	March	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	28.6	29.6	29.7	26.2	24.5	24.7	24.1	25.5	25.4	25.1	27	30.3
2001	29.1	28.8	30.5	26.8	26.5	22	23.1	25.9	25.7	27.8	29.1	29.5
2002	31.8	29.5	30.8	29.6	27.8	24.2	24.3	24.9	26.5	27.9	28.1	30.3
2003	29.4	30.8	30.9	28.4	25.3	22.6	23.2	23.8	24.5	27.2	28	28.7
2004	28.9	27.7	27.9	25.9	24.7	22.9	21	24.1	23.1	25.6	28.7	30
2005	28.9	29.3	26.9	25.8	24.7	23.2	22.5	24.6	25.8	25.7	27.2	27.3
2006	29.2	30.8	27.3	26.3	22.9	22.2	24.5	24.3	26.4	26.9	27.2	29.4
2007	30.1	30.8	29.1	26.8	25.4	23	23.1	24.7	26.9	26.2	27.2	29.8
2008	30.7	30.7	29.5	27.5	26.7	24.3	25.2	26	26.7	26.6	29	31.6
2009	30.5	30.7	28.8	27.1	24.8	24.5	23.3	23.9	24.4	25.1	25.8	28.6
2010	29.4	31.2	29.4	27.6	26.7	23.9	24.6	25.3	27.2	26.9	28.4	28.1
2011	29	28.8	31.1	25.9	25.3	23	20.6	22.8	25.6	25.6	26.8	27.9
2012	29.9	30.2	28.7	25.6	25.6	23.2	22.7	25.1	23.9	25	25.9	29
2013	28.9	29.2	27.9	26.1	24.8	24.1	22.7	24.4	25.6	25.4	27.8	26.8
2014	29.2	29.7	28.8	26.3	25	24.4	24.1	24.9	27.1	24.4	26.1	28.7
2015	29.9	29	30.1	27.4	27.9	25.2	24.5	25.4	25.1	27.6	27.5	30.1
2016	30.3	30.3	29.7	29.3	25.7	24.7	23	25.3	25.8	25.6	26.4	30.5

**Table 2: Average minimum temperatures (°C) in Richards Bay**

Year/Month	Jan	Feb	March	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	20.7	22.3	21.9	17.7	14.5	13.4	12	14.3	16.2	17.9	19.9	21.9
2001	21.6	21.3	21.3	19.2	15.4	13	12.7	14.9	16.4	19.5	20.8	21.7
2002	22.9	21.4	21.5	19.8	16.2	13.7	12.3	17	17.7	18.8	18.8	21.8
2003	20.9	22.6	21.6	20.2	16.2	14	13.4	14.4	16.8	18.5	19.7	19.8
2004	20.9	20.5	20.5	17.9	15.2	12.6	11	14.8	14.4	17.1	19.7	21.2
2005	21.7	21.8	19.1	18.2	15.8	13.5	12.9	15.4	16.5	16.9	19.2	18.9
2006	21.8	22.5	19.3	17.7	13.9	11.2	13.2	15.2	17.3	19.3	19.8	21.5
2007	21.7	22.4	20.4	17.8	13.9	13.1	11.5	14.1	18.4	18.5	19.8	21.6
2008	23.3	22.4	21.5	18.6	17.6	14.9	15.2	16.6	16	18.9	21.5	22.4
2009	23.1	22.6	20.9	18.1	16.4	14.2	12.2	14.6	16.1	18.1	18.4	20.8
2010	21.9	23.1	21.7	20.2	17.7	13.5	14.3	14.5	17.8	19	20.4	21
2011	21.5	20.8	22.3	18.1	16.1	12.2	12.4	13.7	16.7	17.4	19.1	20.3
2012	22.1	22.2	20.6	16.7	16.7	13.2	12.8	13.9	16	18.5	18.4	21.1
2013	21.8	21.2	20.2	17.3	15.5	13	13.8	14.1	15.5	17	19.1	19.9
2014	21.4	21.8	21.4	17.7	16.1	12.8	12.9	15.3	16.6	16.6	19.1	20.3
2015	21.6	21	21.5	18.5	17.7	13.4	14.2	14.8	16.3	17.9	17.6	20.6
2016	21.3	20.9	20.6	19	15.8	14	12.4	14.1	16.3	16.9	21.4	21.2

**Table 3: Average Rainfall (mm) in Richards Bay**

Year/Month	Jan	Feb	March	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	161.4	163.8	266.6	164.2	107.4	21	42.6	1.8	99	93.2	534	148.8
2001	214	139	77.8	104.6	30.8	20	51.8	13	183.4	160.6	111.2	169
2002	153.2	106	53.6	53	9.6	150.4	49.8	127	68.2	70.6	152.8	103.8
2003	48.2	103.4	57.4	106.6	39	182	68.8	61.6	103.6	24	104.6	18.8
2004	225	226.4	197.8	86.6	47	20.2	196.6	12.8	206.4	166.2	223.4	82.6
2005	251.6	246.2	190	120	92.8	108.8	25.8	10.4	26	57	89.2	56.8
2006	59.2	58.4	213.2	109.8	170.6	55.4	7.4	90.4	29.2	124.6	150	75.8
2007	141.2	32.8	28	188.4	0	221.4	27.4	30.8	31.6	193	165.4	38.4
2008	50.8	130	78.4	172.6	19.2	72.4	9.2	55.6	150.4	40.6	53.6	48
2009	106	223.2	26	48.8	90.4	36.2	13.4	102.2	35.4	100.2	99.4	78.8
2010	106	107.6	81.8	50	34.8	21.8	20	38	21.6	122.4	66.4	111.8
2011	128.6	59.4	78.2	138.4	40	42	130.2	39.2	73.6	91.2	119.4	88.4
2012	53.8	118	249.8	39.2	15.4	43.2	16	15.8	206.8	139.8	97	163.4
2013	186.6	127.6	83.4	50.6	111.6	49.2	27.4	38.4	62	137.4	57	119.4
2014	24.6	56.6	99.8	91.8	37	9.4	12.8	12.2	25.4	208.8	27	33.4
2015	135	47.2	20.2	34.6	5	10	125	14.8	59.6	37.2	53.8	67.6
2016	40.4	42.6	82.8	95.8	173.6	95.4	230.2	46.2	84.6	100	20	17