ASSESSMENT OF SPATIAL AND TEMPORAL VARIATION IN WATER QUALITY OF THE PIENAARS RIVER, LIMPOPO WATER MANAGEMENT AREA

By

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Student Declaration

Assessment of spatial and temporal variation in water quality of the Pienaars River, Limpopo Water Management Area

I, Lungile Wendy Mlotshwa, student number: 210527477 declare that:

i. The research reported in this dissertation, except where otherwise indicated, is the result of my own endeavours in the School of Life Sciences, University of KwaZulu-Natal Pietermaritzburg;

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We hereby declare that we acted as Supervisors of this MSc student:

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Regular consultation took place between the student and ourselves throughout the investigation. We advised the student to the best of our ability and approved the final document for submission to the College of Agriculture, Engineering and Science Higher Degrees Office for examination by the University appointed examiners.

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Declaration – Publications

DETAILS OF CONTRIBUTION TO PUBLICATIONS that form part of and/or include research presented in this thesis (include publications in preparation, submitted, *in press* and published and give details of the contributions of each author to the experimental work and writing of each publication)

Publication 1 (in preparation):

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Contributions: Laboratory analysis and manuscript preparation were performed by the first author under the supervision of the three supervisors.

Lungile Wendy Mlotshwa

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Abstract

The Pienaars River is a major tributary of the most important river system in Gauteng and South Africa in general, the Crocodile River. The Crocodile River catchment is one of the most deteriorated catchments in the country. It is a hub for various detrimental economic activities which contribute significantly to the country's economy. Some of these activities are sources of contaminants polluting the Pienaars River. The study assessed the water quality dynamics and conditions of the Pienaars River based on historical water quality data (1980-2015) and newly collected data from February 2017, both collected from eight different stations. For the new data, 16 parameters were analysed to assess the river's water quality status and suitability for predominant uses. The historical data was obtained from the Department of Water and Sanitation database to assess spatial and temporal variation of 17 water quality parameters.

The results indicated that the water quality fluctuated over the years. Some parameters, namely; pH, TAL, DMS, K, KJEL-N and Si showed a significant deterioration over the years. A significant improvement was also observed in Cl^-, DMS, EC, F, Mg, NO_3+NO_2-N, P-Tot, PO_4^{-3} and SO_4^{-2} over the years. The results also revealed spatial and temporal variation in water quality. The upstream catchment of the river is the most developed, and land use becomes more natural vegetated land with sparse dryland agricultural fields in the downstream catchment. The results revealed that Pienaars River receives a considerable amount of pollutants in the upstream reaches. The water quality further deteriorated towards the downstream reaches along the gradient as the river passes through different land uses. It was therefore concluded that the upstream reaches had significant impact on the river's water quality. A significant seasonal variation in water quality was observed between summer, spring, autumn and winter. Generally, the water quality was better during the high flow period due to rainfall dilution effect. High-flow periods played a major role in not only regulating the pollution levels but the high runoff acted as a transporting mechanism for pollutants. Overall, DMS, TAL and Si displayed a strong seasonal variation whereas F was the least influenced by seasonality.

Suitability analysis indicated that water from some parts of the river were not ideal for domestic use due to the nitrate, total coliform and *E. coli* being above recommended limits. The water quality in some sampling stations was not suitable for irrigation due to elevated nitrate, EC and pH. No potential risks were identified pertaining to the use of water for recreation or aquatic use. The Water Quality Index (WQI) for the river was 86.32, which implies that the river was in a good condition during the period of study. Although this suggests the water quality is acceptable for drinking, some form of treatment may still be required before use. The statistical tools were able to analyse the data about the water quality of river, but was also able to draw relevant and meaningful information about the river. The techniques used in this study demonstrated the importance of understanding water quality trends in modelling future water conditions which enables formulation of proactive and long term-term water quality solutions.

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List of Abbreviations

AMD	Acid-Mine Drainage
ANOVA	Analysis of Variance
ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
BCWQI	British Columbia Water Quality Index
CCMEWQI	Canadian Council of Ministers of Environment Water Quality Index
CMA	Catchment Management Agency
CMS	Catchment Management Strategy
CSIR	Council for Scientific and Industrial Research
DEA	Department of Environmental Affairs
DEAT	Department of Environmental Affairs and Tourism
DEHP	Department of Environment and Heritage Protection
DMRT	Duncan's Multiple Range Test
DO	Dissolved Oxygen
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWM	Development Water Management
DWS	Department of Water and Sanitation
E. coli	*Escherichia coli*
EC	Electrical conductivity
ENSO	El Nino Southern Oscillation
EPA	Environmental Protection Agency
FAO	Food Agriculture Organization
GCRWQ	Guideline for Canadian Recreational Water Quality
GDP	Gross Domestic Product
ICP-OES	Inductively Coupled Plasma Optical Emission Spectrometric
ISCW	Institute of Soil, Climate and Water
IWRM	Integrated Water Resources Management
MAP	Mean Annual Precipitation
NSFWQI	National Sanitation Foundation Water Quality Index

NWA	National Water Act (Act No. 36 of 1998)
NWMS	National Water Management System
OIP	Overall Index of Pollution
OWQI	Oregon Water Quality Index
S.E	Standard Error
SAWQGs	South African Water Quality Guidelines
SPSS	Statistical Package for the Social Sciences
TDS	Total Dissolved Solids
UNEP	United Nations Environment Programme
UN-WWAP	United Nations World Water Assessment Programme
UWQI	Universal Water Quality Index
WAWQI	Weighted Arithmetic Water Quality Index
WHO	World Health Organization
WMA	Water Management Area
WQI	Water Quality Index
WRC	Water Research Commission
WUAs	Water-User Associations
WWF	World Wide Fund

List of Units & Symbols

B	Boron
Ca	Calcium
Cl^-	Chloride
CFU	Colony forming unit
DMS	Dissolved Major Salts
EC	Electrical Conductivity
F	Fluoride
K	Potassium
KJEL N	Kjeldahl Nitrogen
Mg	Magnesium
mg/l	Milligram/litre
ml	Millilitre
mS/m	Millisiemens/meter
mg/l	Milligram/litre
N	Nitrogen
Na	Sodium
NH_4-N	Ammonium Nitrogen
NO_2^-	Nitrite
NO_3^-	Nitrate
P	Phosphorus
PO_4^{-3}	Phosphate
P-Tot	Total Phosphorus
Qi	Sub-index for ith water quality parameter
Si	Silicon
SI	Sub-index of ith parameter.
SO_4^{-2}	Sulphate
TAL	Total Alkalinity
TC	Total Coliform
Wi	Weight associated with ith water quality parameter

Definition of Terms

Aquatic Ecosystem “The abiotic and biotic components, habitats and ecological processes contained within the water body and/or riparian habitats” (DWAF, 1996a, p. 6).

Catchment or Watershed “The area of land drained by a particular stream or river In relation to a watercourse or watercourses or part of a watercourse, means the area from which any rainfall will drain into the watercourse or watercourses or part of a watercourse, through surface flow to a common point or common points” (DWAF, 1998, p. 8).

Pollution “Direct or indirect alteration of the physical, chemical or biological properties of a water resource so as to make it –

(a) Less fit for any beneficial purpose for which it may reasonably be expected to be used; or

(b) Harmful or potentially harmful to the welfare, health or safety of human beings; to any aquatic or non-aquatic organisms; to the resource quality; or to property” (DWAF, 1998, p. 8).

Season each of the four divisions of the year (spring, summer, autumn, and winter) marked by particular weather patterns and daylight hours, resulting from the earth's changing position with regard to the sun.

For the purpose of this study the four main seasons were categorised into wet and dry seasons as indicated below:

(i) Wet season:

- Spring – September, October and November.
- Summer – December, January and February.

(ii) Dry season:

- Autumn – March, April and May.
- Winter – June, July, August.

Watercourse	"Include the following: (a) a river or spring; (b) a natural channel in which water flows regularly or intermittently; (c) a wetland, lake or dam into which, or from which, water flows; and (d) any collection of water which the Minister may, by notice in the Gazette, declare to be a watercourse, and a reference to a watercourse includes, where relevant, its bed and banks" (DWAF, 1998, p. 9).
Water Quality	"Refers to the physical, chemical and biological properties of the water" (DEA, 2016a) (Also refer to Section 2.1).
Water Quality Constituents or Variables or Parameters	"The properties of water and/or the substances suspended or dissolved in it. In the international and local literature, several other terms are also used to define the properties of water or for the substances dissolved or suspended in it" (DWAF, 1996a, p. 3).
Water Quality Monitoring	Refers to a planned process of obtaining quantitative and qualitative information about the quality of water in specific sampling locations and at specific intervals to provide information about the trends and variables, which influence water quality (Sanders *et al*., 2000; Van Niekerk, 2004).

Chapter 1 : General Introduction

1.1. Background

Water is a prime but finite natural resource on which all aquatic and terrestrial organisms depend for survival (Cessford and Burke, 2005; Arain *et al*., 2014). Water resources are also an essential commodity that underpin and sustain a range of social and economic developments upon which societies rely. Despite the importance of water, less than 1% of the earth's total water resources are available for consumption as freshwater in the form of surface or ground water (Zia *et al.,* 2013). Although the amount available in the form of freshwater is sufficient for survival on a global scale, its spatial and temporal distribution suggests that it is often not available where it is most required; leaving billions of people living in water-scarce environments (Zia *et al.,* 2013). For example, Africa holds 15% of the global human population, but only has 9% of the world's water resources, which are also distributed unevenly across the continent (UN-WWAP, 2017). Similarly, the Asia-Pacific region is home to 60% of the world's population, however, only less than 40% of world's water resources occur in this region (UN-WWAP, 2012).

In many parts of the world, water demand is already exceeding the supply capacity. Ashton (2002) found that some countries in Africa have already reached or passed the point where water deficits are effectively limiting further developments. It is estimated that virtually 3,800 km^3 of freshwater is drawn globally from water resources for human use on a yearly basis. This amount of water is sufficient to sustain the flow of the Nile River for more than 40 years (Maas, 2012). Approximately 50% of water drawn does not return to the natural catchments, it is instead diverted away and/or lost through vaporisation (Maas, 2012). Agricultural use accounts for most of the water drawn from the earth's freshwater resources. In South Africa, the agricultural sector alone uses over 60% of the country's freshwater resources (DWA, 2013). Similarly, in Latin America, the water footprint for agricultural activities is over 70% of the total water consumptive uses followed by domestic usage (17%) and then industrial uses (13%) (UN-WWAP, 2017).

Number of studies suggest that population growth is the major driving force behind the increase in global water demands (Sandford, 2012; Grady *et al.,* 2014). This is a great challenge for the developing countries that are already battling to meet their current water demands, due to lack of access to potable water amongst other challenges. Approximately 20% of the global human population lives in areas of physical water shortage, where the quantity is not adequate for various demands (Cooley *et al.,* 2013) such as agricultural, industrial and domestic purposes. An additional 1.6 billion people live in regions of economic water shortage (Cooley *et al.,* 2013). In these areas, water is available; however, the lack of human capacity and capital limits the supply (Rivett *et al.,* 2013). Concerns about dwindling water supplies have reached a point where there is uncertainty as to whether the global supply will reach a point of inclination, which could possibly result in a greater number of wars over the control of water bodies (Sandford, 2012).

An inevitable exponential population growth coupled with global climate change are expected to exacerbate variability and compromise the reliability of the supply of already constrained water resources (Ashton, 2002). South Africa is no exception to this water depletion crisis. Approximately 60% of the country is characterised as semi-arid to arid (Nomquphu *et al.,* 2007), and is ranked the 30th driest country in the world (Kohler, 2016). Thus, South Africa is categorised as a water stressed country (Kohler, 2016). Research suggests that 84% of the country's largest river systems are threatened by urban expansion, agriculture and mining along with other water uses and contaminants associated with such human activities (Nel *et al.,* 2011) and almost entirely exploited (Rossouw *et al*., 2005). More than half of the water sources in seven provinces in South Africa are provided via inter-basin transfers, which demonstrates the level at which the country's available water resources are exploited (Van der Merwe-Botha, 2009). Figure 1-1 illustrates the distribution of major water catchments in the country. In addition to uneven distribution of freshwater, there is a growing concern of pollution of local water resources.

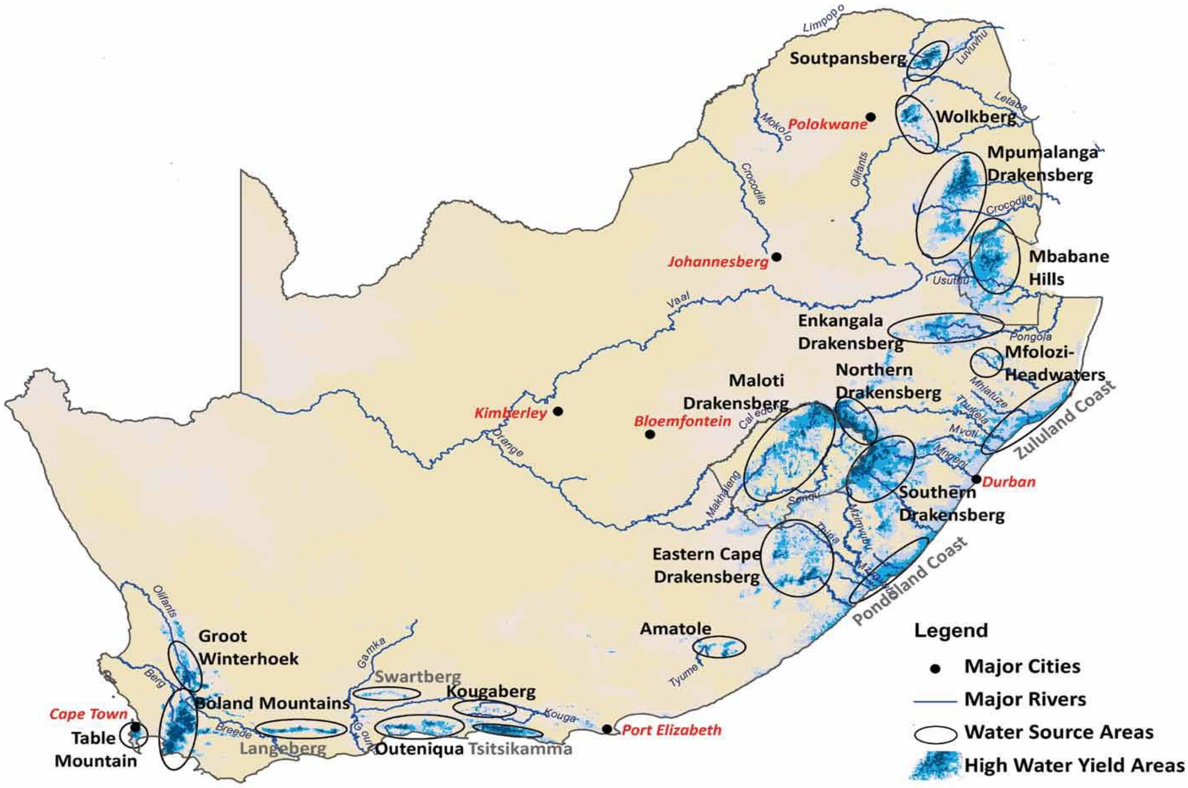

Figure 1-1: Map showing the distribution of major water catchments or high water yield areas in South Africa (WWF-SA, 2013)

The "global water crisis" is generally perceived as a water quantity or scarcity issue (Abbaspour, 2011). Over the years however, water quality has progressively become acknowledged as a fundamental dimension of water crisis (Ongley, 2000). This study focused in water quality aspect, particularly the spatial and temporal difference in a river system in South Africa. While not all countries are facing a water shortage crisis, all have to some extent serious problems associated with deteriorating water quality (Abbaspour, 2011) and such impacts can reach a catastrophic level when not addressed timeously (Ding *et al.,* 2015). In the Agenda 21 of the 1992 Earth Summit, freshwater was identified as an issue of global concern (UNEP, 2016). Since then, the deterioration of natural water resources has become a global environmental concern (Chang, 2008; Arain *et al*., 2014) and amongst the most cited environmental subjects of the 21st century (Kraemer *et al.,* 2001). However, the extent and nature of water quality challenges vary from country to country and continent to continent.

Developing countries, especially in Africa tend to be more vulnerable to freshwater quality threats due to lack of effective technology and infrastructure to manage water resources (Rivett *et al*., 2013). The conditions are further aggravated by a lack or inability to enforce regulations that have been put in place. African cities are rapidly expanding and current water management practices cannot keep up with the ever-increasing pressure on the quantity and quality on water resources (Qadir *et al.,* 2010). With the current rate of development, the deterioration of freshwater systems will inevitably hasten. This is expected in resource-poor nations and arid regions, which will further compromise the natural environment, human well-being and sustainable economic growth (UN-WWAP, 2017).

Global research indicates that the greatest water quality challenge in Africa is pathogen pollution (Edokpayi *et al.,* 2018). Approximately 30% of all river stretches in Africa are suffering from serious pathogen pollution, due to the increased faecal coliform bacteria (UN-WWAP, 2017). To date the declining water quality in Africa has claimed more than 3 million lives since 2005 and approximately 5% of the Gross Domestic Product (GDP), equivalent to US$28.4 billion is lost on a yearly basis due to poor quality of water sources (UN-WWAP, 2009).

Discharge of industrial wastewater is another big threat to African freshwater systems. In many parts of the world, rivers are often seen as a convenient disposal point for various waste streams. A case in point is the Pienaars River in South Africa, which is the focus of this study. Approximately 70% of industrial wastewater in developing countries, especially in Africa is disposed into surface waters without adequate treatment which pose health risks to the aquatic ecosystem and society in general due to content of undesirable elements in the water (Qadir *et al.,* 2010). In Nigeria, only <10% of industries process their waste effluents before discharging them into rivers (UN-WWAP, 2017). In Ghana, only 16% of the water treatment facilities are functioning and it is not likely that any of them meet the prescribed treatment standards (Qadir *et al.,* 2010). The human water quality footprint is observed in numerous river systems across South Africa. The evident deteriorating conditions of the South African river systems justified the need to undertake this study as elaborated below.

1.2. Problem Statement

South Africa is currently in the grip of a water crisis, also known as an El Niño-induced drought, with some regions already edging to ‘water shedding’ as one of the possible measures to reduce pressure on water supplies. Water shortages are mainly attributed to overconsumption of the country's limited water resources. Water quality also has direct impacts on the availability of water resources. Essentially, water quality compromises water supply and aggravates demand. Despite the need to monitor the deteriorating state of many river systems, South Africa has a poor water quality monitoring system. There are many gaps in water quality data because monitoring stations are not sampled consistently. This can be attributed to a shortage of resources (i.e. funds and expertise) within the water institutions to properly scope the issues, identify and implement appropriate remedial actions.

Due to the complexity of water systems, the responsible agencies or decision makers are challenged in their efforts of managing water resources (Huang *et al.,* 2010). Categorisation of the spatial variation and identification of water pollution sources can provide insights into the interaction of water with the environment (Huang *et al.,* 2010). Although various methods of quantifying and evaluating the impacts of adjacent land-use practices on rivers have been explored and developed (Dabrowski and de Klerk, 2013; Ding *et al*., 2015; Pullanikkatil *et al*., 2015); research on the assessment of spatial and temporal variation of water quality in river systems is particularly lacking in South Africa. Such information can improve an understanding and assessment of the variability of water quality and thus aid in decision making and in implementing a well-informed plan of action to mitigate the identified challenges.

The Pienaars River is one of the main sources of water supply in Pretoria and one of the few river systems in Gauteng that has been monitored for water quality for many decades. Such monitoring is often assumed to play a key role in managing river health. Although this might be accurate to some degree, the mere collection of water quality data has proven to be insufficient in addressing water quality problems. The available data suggests that the water quality of rivers has been declining. However, without an understanding of the hydrological dynamics and interaction of water with the environment, the water quality monitoring information has limited usefulness. Often, water quality monitoring data tend to suffer from the 'data-rich but information-poor' syndrome, which implies that the data is collected but there is no abstraction/interpretation of meaningful information and application thereafter (Wanda *et al.,* 2016). This creates the need for techniques to translate monitoring data into useful manageable information that can be put into action plans and implementation (Wanda *et al.,* 2016).

The use of mathematical techniques such as multivariable statistics to understand spatial and temporal trends in river systems have proven to provide a defendable scientific basis for water management practices or framework. In light of the above, this study therefore sought to evaluate the water quality status and suitability of the Pienaars River for various water uses. Moreover, the study assessed the spatio-temporal variation and investigate the influential factors of the river's water quality using univariate statistical techniques. Ultimately the findings of the research were expected to provide a frame of reference for future management strategies for this river and potentially other rivers in South Africa.

1.3. Research Aim and Objectives

This study aimed to assess and compare the water quality dynamics and conditions of the Pienaars River based on historical water quality data and newly collected water quality data. The status of water quality was measured in terms of the physical, chemical and microbiological characteristics.

The objectives of the study were:

- To assess the temporal and seasonal variation in water quality of the Pienaars River, using historical water quality data (between 1980 and 2015) obtained from the Department of Water and Sanitation (DWS) database;
- To determine the spatial variation in water quality of the Pienaars River with respect to land-use impacts; and
- To evaluate the overall current water quality by calculating the river's Water Quality Index (WQI) and comparing the water quality parameters against the international[1] and national[2] water quality standards and guidelines.

[1] World Health Organization (WHO) Drinking Water Quality Guidelines, Food Agriculture Organization (FAO) Irrigation Water Quality Guidelines, International Water Quality Guidelines for Ecosystems and Guidelines for Canadian Recreational Water Quality

[2] South African Water Quality Guidelines (SAWQGs) for Recreational Use, Aquatic Ecosystems, Domestic Use and Agricultural Use

1.4. Assumptions and Limitations of the Study

The following assumptions and limitations are applicable to this study:

- The historical water quality data used in this research was sourced from the DWS database and it is assumed that this information is accurate;
- The water quality samples and data analysed excluded that of the tributaries of the Pienaars River;
- The DWS monitors only certain physical and chemical parameters in the Pienaars River. In view of this, the assessment of seasonal variation in water quality will be limited to available data;
- Groundwater has the potential of contributing to surface water pollution. However, this study did not assess groundwater contribution to the Pienaars River quality (Shrestha and Kazama, 2007);
- Some stations on the Pienaars were only monitored for a short period of time, which creates a gap in the data. Monitoring stations with significant information gaps were omitted from the analysis;
- The status of the Pienaars River is interpreted based on the results obtained from the sampling stations from which the water samples were collected;
- The water samples were only collected in one season; therefore, no comparison of the different seasons was done for the newly collected data; and
- The spatial variation in water quality is only assessed in terms of land use activities impacting on the river system.

1.5. Thesis Structure

CHAPTER 1 introduces the research study particularly the water crisis in South Africa and globally, it also notes research questions, aims and objectives, assumptions, uncertainties and limitations. CHAPTER 2 gathered and conceptualized pertinent literature concerning the different water quality characteristics impacting river health and useful techniques used to convert water quality monitoring data into meaningful information that can be used to devise effective water management strategies. CHAPTER 3 and 4 give a detailed discussion of the findings in relations to the set objectives of the study (refer to Section 1.4). These chapters were written as standalone research papers, with introduction, methods, results and discussion, and conclusion sections. CHAPTER 3 is based on historical water quality data of the study river, while CHAPTER 4 assessed the current state of the river based on newly collected water quality data. In both chapters repetition was unavoidable, particularly with respect to description of the study site. CHAPTER 5 is a general conclusion that provides a summary of the main aim and findings of the study, recommendations and management implications based on the findings made in the study.

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Chapter 2 : Literature Review

2.1. Introduction

Water quality is aptly defined by the physical, chemical and biological properties of water (Figure 2-1). These properties determine its fitness for use and its ability to support healthy functioning of aquatic ecosystems and safety of human contact (Van der Merwe-Botha, 2009). Water quality variables are generally defined by the source or type of pollution the system is exposed to, the nature of the system and external forces such as climate. The water quality variables can also be influenced by the presence of other variables directly and/or indirectly.

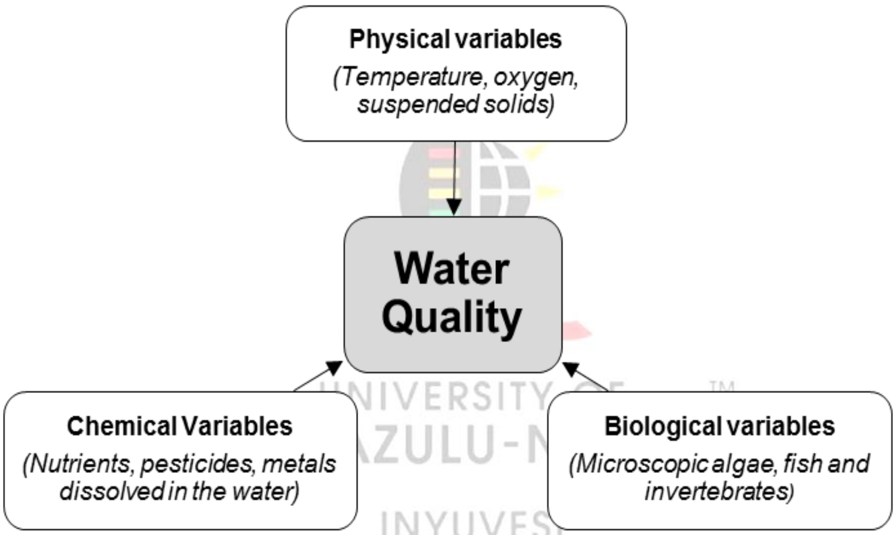

Figure 2-1: The three (3) main groups of water quality indicators

2.2. Water Quality Indicators

2.2.1. Physical water quality indicators

Physical attributes indicate the physical state of the water and the indicators include but are not limited, to the following:

2.2.1.1. Temperature

Water bodies experience changes in temperature due to variations in atmospheric conditions (Li *et al*., 2017), which could also be human-induced. Temperature is a vital aspect of aquatic ecosystems, as it determines the distribution and the aquatic organisms that can survive in the system (Dallas and Ross-Gillespie, 2015). Due to thermal adaptation of aquatic species, if temperatures are outside the ideal range for a prolonged period, it may affect the metabolism, growth, feeding patterns and reproduction of the aquatic species (Whitehead *et al.*, 2009). The increase in water temperature is also directly proportional to the rates of chemical processes in the water (Baron *et al.,* 2003).

2.2.1.2. pH (acidity and total alkalinity)

pH is a measure of hydrogen ions activity, which indicates the acidity or alkalinity of the water (WHO, 2007). The pH is a crucial variable for sustaining aquatic life, and all aquatic organisms are adapted to a specific pH range (Farrell-Poe, 2000). Most natural waters have pH levels of between 6.0 and 8.5 (Rossouw *et al.,* 2005) and most freshwater organisms can survive in water with pH levels of 4.5-9 (Farrell-Poe, 2000). Water with a low pH (<6) is considered to be acidic and corrosive in nature. Conversely, water with a higher pH level (>8) is alkaline. Alkalinity measures the buffering capacity of a water body or the ability of water to regulate metal content and pH levels (Salminen *et al.,* 2005).

2.2.1.3. Electrical conductivity

Electrical conductivity (EC) measures the ability of the water to conduct electricity. This ability is dependent on the solids and/or compounds dissolved in the water (Gupta *et al.,* 2017). Although dissolved solids pose no human or aquatic health threat; it can however be an indicator of other water quality problems (Vaishali and Punita, 2013). When a sudden increase in the conductivity of a river is observed, it is generally an indication of a source of dissolved ions in the surrounding area.

2.2.2. Chemical water quality indicators

Chemical attributes are usually responsible for the chemistry and/or chemical processes within the water. This can also affect the toxicity levels, odour and taste of the water.

2.2.2.1. Phosphorus

Phosphorus (P) occurs in organic and inorganic forms and is a crucial macronutrient that influences productivity within a water system and a limiting factor for algal growth

(Nikanorov and Brazhnikova, 2009). It is usually found in low concentrations in natural freshwater systems due to its low solubility, while just a slight increase may result in excessive growth of plants and algae (EPA, 2001). Excessive concentrations of P in water indicates pollution generally emanates from anthropogenic sources such as industrial discharge and runoff from fertilised agricultural land (Nikanorov and Brazhnikova, 2009); and are responsible for eutrophic conditions (Rossouw *et al.,* 2005).

2.2.2.2. Chloride

Most chlorine occurs in the form of chloride ions (Cl^-) in water (Nikanorov and Brazhnikova, 2009), and it is a common element that exists in all natural water systems (EPA, 2001). The sources of this element in most freshwater systems include rock weathering, agricultural runoff, atmospheric deposition, and waste effluent discharges (Khatri and Tyagi, 2015). Sewage waste has been found to be a rich source of chloride, and thus, can be used as an indicator of probable faecal contamination (Nikanorov and Brazhnikova, 2009). In natural freshwater systems, chloride occurs in low concentrations, usually less than 10 mg/l (Chapman, 1996).

2.2.2.3. Nitrate

Nitrate (NO_3^-) is a source of nitrogen (N) that is found in very low concentrations in surface water (Bartram and Ballance, 1996). This nutrient is important for plants and algal growth. High levels of NO_3^- in water bodies are more likely to indicate increased nutrient run-off from agricultural lands due to fertiliser application; and this may lead to eutrophic conditions (Grady *et al.,* 2014). High concentrations are also found in sewage effluents and industrial wastes (Bartram and Ballance, 1996). Nitrate on its own is not toxic but can have health implications once converted to NO_2^- (EPA, 2001). This is known as a reduction process, where the oxygen atom becomes dissociated from the NO_3^- molecule (Fewtrell, 2004), due to absence of oxygen (Cabello, *et al*., 2004).

2.2.2.4. Calcium

Calcium (Ca) is an essential dietary element that is generally found in abundance in both surface and groundwater resources (Potasznik and Szymczyk, 2015). Calcium salts together with those of magnesium, are responsible for the hardness of water (DWAF, 1996a). Calcium comes from a variety of sources and these include weathered rock materials rich in Ca and industrial discharges (Bartram and Ballance, 1996). In natural waters, Ca concentrations are generally less than 15 mg/l, and may reach up to 100 mg/l depending on the type of underlying rocks (Chapman, 1996).

2.2.2.5. Fluoride

Fluoride (F) is a halogen gas and one of the major ions of seawater (Bartram and Ballance, 1996). This element is rarely found in natural water bodies, as it is sourced almost exclusively from processing of domestic water supplies and effluent discharges from certain industrial activities (EPA, 2001). Monitoring F content in water is particularly important in potable or domestic supply because at high concentrations (above 1.5-2.0 mg/l) it is toxic to humans (Chapman, 1996).

2.2.2.6. Magnesium

Magnesium (Mg) is generally present in natural water systems as Mg^{2+} (Potasznik and Szymczyk, 2015). It enters water through weathering of mg-rich rocks (Nikanorov and Brazhnikova, 2009). Magnesium is required for the growth of aquatic plants. Depletion of Mg results in the reduction of phytoplankton population because it is an essential nutrient required for the growth of aquatic plants. In freshwater systems its natural concentrations range from 1 to 100 mg/l, this is dependent on the geological formation of the system (Chapman, 1996).

2.2.2.7 Ammonia

Ammonia (NH_3) is common in natural water systems, although it is found in very small concentrations (Chapman, 1996). It is also a common pollutant and nutrient that causes eutrophication (Rossouw *et al.,* 2005). In water resources where its levels are above 0.1 mg/l, it is an indication of possible sewage or industrial contamination and excessive usage of NH_3 rich fertilisers (DWAF, 1996a). From a human health perspective, high concentrations of NH_3 in excess of the recommended limits may be harmful. According to EPA (2001), it is the un-ionised species of NH_3 that are most dangerous to aquatic life, which arise from the complex reaction between NH_3, pH and temperature.

2.2.2.8. Potassium

Rocks are the natural source of potassium (K) (Tiwari, 2015). It occurs in small quantities (less than 10 mg/l) in natural waters since rocks that contain K are generally resistant to weathering (Chapman, 1996). It is naturally low in surface water due to its poor migratory ability and this is attributed to its absorption by living aquatic organisms (Nikanorov and Brazhnikova, 2009). High levels of K are predominantly introduced into surface water through runoff from agricultural land due to application of fertilisers or industrial discharges (Tiwari, 2015).

2.2.2.9. Sodium

Sodium (Na) is another major ion like magnesium and potassium that is naturally abundant on earth and is found in natural water resources (Bartram and Ballance, 1996). Natural concentrations can range from 1 mg/l or less to 105 mg/l, and enhanced concentrations are generally associated with sewage and/or industrial discharges (Chapman, 1996). Sodium is commonly monitored for water that is used domestically (particularly drinking) and for irrigation (WHO, 2003).

2.2.2.10. Sulphate

Sulphates ions (SO_4^{-2}) exist in nearly all natural waters and its concentrations vary depending on the underlying parent rock (Khatri and Tyagi, 2015). Under natural conditions SO_4^{-2} in freshwater systems range between 2 and 80 mg/l (Chapman, 1996). Its concentration in water can vary from a few milligram (mg) to thousands of mg per litre (Bartram and Ballance, 1996). Known sources of SO_4^{2-} include atmospheric precipitation, sulphur-containing compounds from industrial wastes and mine drainage (Nikanorov and Brazhnikova, 2009). The presence of SO_4^{2-} in most river systems in South Africa is usually associated with mining activities (DWAF, 1996a).

2.2.2.11. Boron

Boron (B) is a semi-metal that is a natural constituent of freshwaters arising from various natural processes, including rock weathering, and once in water it is not easily removed (DWAF, 1996b). Agricultural run-off, industrial or municipal waste water may also contribute B to surface water systems (WHO, 2009). Boron also acts as an essential nutrient for plants and can be toxic when occurring in very small concentrations (WHO, 2009). The occurrence of this element in freshwaters is generally in relatively low concentrations; with an average of approximately 0.1 mg/l (Chapman, 1996).

2.2.3. Microbiological water quality indicators

Microbiological indicators are common microorganisms found in freshwater. The bacteria, protozoa, viruses, helminths and parasites are the most common types of microbial organisms (Hageskal *et al.,* 2009). Most microbial organisms generally occur as clumps or in association with particulate matter (Bartram and Ballance, 1996).

2.2.3.1. Escherichia coli

Escherichia coli (E. coli) is a type of faecal coliforms (FC) that is often used as an indicator of for faecal contamination (Bartram and Ballance, 1996). This bacterium comes from human and warm-blooded animal faeces. FC are not pathogenic bacteria, but because they tend to occur along with pathogenic organisms; their occurrence is an indication of disease-causing organisms in water bodies (WHO, 2008). Thus, water used for consumption must not have *E.coli* bacteria (DWAF, 1996a).

2.2.3.2. Total coliforms

Total coliforms (TC) refer to all bacteria that produce colonies (DWAF, 1996c). They are used as a practical indicator of the general hygienic quality of water (Meride and Ayenew, 2016). TC include faecal and other similar bacteria derived from the soil and non-faecal sources (EPA, 2001). TC bacteria are primarily monitored for domestic and recreational purposes. In South Africa, the faecal coliform counts may not exceed 5 counts per 100 mg/l for safe drinking (DWAF, 1996c).

2.2.3.3 Fungi

Fungi are a diverse collection of microorganisms that belong to the Kingdom *Eumycota* and consists of five phyla (Hageskal *et al.,* 2009). The phyla *Chytridiomycota* are the type of fungi that are adapted to aquatic environments, and naturally occur in freshwater (Hageskal *et al.,* 2009). Fungi are major pollutants of surface water and yet their presence is necessary for nutrient cycling (Al-Gabr *et al*., 2014). The factors such as temperature, pH, organic nutrients and water flow regime are some of the driving factors which influence the occurrence and growth of fungi (Babic *et al*., 2013). The impacts of fungi in water quality have mostly been underestimated, but over time they have become acknowledged as water pollutants although their potential health impacts are still poorly understood. While not all fungal species are pathogenic, many are the causative agents of foul smell and taste in drinking water (Hageskal *et al.,* 2009).

Depending on the various conditions the water is exposed to, it may be enriched by numerous constituents in different forms and quantities. Due to the content of toxic constituents in water, water quality assessment is often required to determine the composition and prescribe suitable treatment method. Different standards and/or guidelines for water qualities have been adopted in various countries. These serve as water quality criteria against which the suitability of the water can be measured. There are also other scientific tools used in conjunction with the guidelines to interpret and extrapolate more information about the quality of the water. Many water quality assessment techniques exist. The choice of technique used is based on the objective of the assessment or desired output. The different techniques used in this study to measure the quality of Pienaars River are described in the subsequent sections.

2.3. Water Quality Assessments

2.3.1. Water quality guidelines and standards

The guidelines describe scientifically-derived sets of thresholds or limits for the water constituents in order to protect both the water resources and the users (WHO, 2011). The guidelines and standards stipulate permitted limits (acceptable levels) of water quality parameters and effects on the fitness of water for specific uses (ANZECC and ARMCANZ, 2000). They also serve as a guide for developing and implementing national water-related policies and regulations (UNEP, 2016). The exceedance of the guideline thresholds is an indication of potential environmental impacts, and thus used as tools for assessing water quality (ANZECC and ARMCANZ, 2000).

From a legal point of view, guidelines and standards have contrasting meanings. Standards are expected to provide a superior level of protection for water supply, as they are legally binding and enforceable by law (Enderlein *et al*., 1997). Conversely, guidelines are implemented on a voluntarily basis, no remedial or legal actions are required in case of violations (Boyd, 2006). South Africa has water quality guidelines for all water use sectors which are used to inform the quality requirements for the specific water uses. For the purpose of this study, the focus was only on the water quality guidelines developed for the major water users of the Pienaars River.

2.3.1.1. Drinking water

The main purpose of developing guidelines for drinking-water quality is to protect the health of consumers (WHO, 2011). These guidelines refer to the suitability of raw drinking water supply, assuming minimal treatment will be undertaken i.e. coarse screens (DEHP, 2009). The World Health Organization (WHO) numerical benchmarks for physical and chemical parameters of drinking water in a good condition is appended in Annexure A. Although the WHO guidelines have global significance, it is vital that the local environmental, economic and social are considered when they are implemented (WHO, 2008). The main shortfall of the South African drinking water guidelines is the absence of details pertaining to organic chemical parameters and no reference to pesticides although they are extensively applied in the agricultural fields (WRC, 2008).

2.3.1.2. Aquatic ecosystems

The purpose of aquatic water quality guidelines is to protect aquatic life to ensure sustainable ecosystem goods and services. The water quality criteria for aquatic ecosystem guidelines considers the exposure-effect. For example, in Canada, water quality criteria are based on the lowest concentration of a substance or observable effects that affect test organisms. This require considerable efforts to identify key species to serve as indicators of ecosystem quality. The key indicator species must be widely distributed within the ecosystem, easy to quantify, indigenous, suitable for laboratory analysis and display a graded response to different levels of environmental stressors, and this must be quantifiable (Enderlein *et al.,* 1997).

2.3.1.3. Recreational use

Recreational water quality guidelines are developed to assess the safety of water to be used for water-related activities such as diving, fishing and swimming (Enderlein *et al.,* 1997). Biological indicators (i.e *E.coli*, TC bacteria and algae) are the key components when developing recreational water use guidelines. National guidelines are developed based on indigenous biological indicators. For instance, Queensland has guidelines to manage cyanobacteria (blue-green algae) in recreational water (DEHP, 2009). Depending on the level of cyanobacteria recorded, a water body can be classified as suitable or unsuitable for primary contact recreation (DEHP, 2009).

2.3.1.4. Agricultural use

Poor quality of irrigation water may affect soil productivity and potentially contaminate the crops and their consumers (Enderlein *et al.,* 1997). The guidelines for agriculture are therefore, used as management tools to assist in understanding the effect of water quality on agricultural production (WRC, 2014). They measure the suitability of the water supply for irrigation and livestock drinking (DEHP, 2009). The acceptable or threshold values provided in the guideline must be interpreted and applied with an understanding of the crop characteristics or requirements and site-specific conditions such as soil properties (WRC, 2014).

2.3.2. Water quality index

Another tool used to assess water quality is the Water Quality Index (WQI). WQI is a measure used to evaluate the quality of water status (Amadi *et al.,* 2010). It incorporates different water parameters using various mathematical expressions to give a single value which represents the overall water quality (Rangeti et *al*., 2015). Numerical indices are one of the most effective methods for assessing water quality (Khwakaram *et al.,* 2012; Akter *et al*., 2016). They are efficient tools used to convey the information on water quality patterns by transforming large set of data into a single value (Abdel-Satar *et al.,* 2017; Gupta *et al.,* 2017). The WQI value is therefore, an expression of overall water quality at a specific location and period, based on specific water quality parameters (Boah *et al*., 2015). The indices also enable comparisons between water samples collected from different locations (Akter *et al.,* 2016).

Depending on the influence of the parameters used to calculate the WQI, the overall water quality can be classified as excellent, good or bad (Khwakaram *et al.,* 2012; Boah *et al*., 2015; Abdel-Satar *et al.,* 2017). Indices are therefore useful in assessing water quality or suitability of the water for the different beneficial uses viz. recreational, drinking, aquatic life and wildlife protection, cultivation, and livestock uses (Edwin and Murtala, 2013). The WQI can also be compared to the water quality guidelines or regulatory standards for that particular area (Mophin-Kani and Murugesa, 2011) to identify the parameters that are above or fall within the permissible concentrations (Edwin and Murtala, 2013).

Although WQIs are widely used tools and beneficial in ascertaining conditions of water quality; a single value cannot tell a complete story of the water conditions due to exclusion of some critical parameters in the index calculation (Rangeti *et al*., 2015). Hence, they serve as a general indication of the quality of water (Yogendra and Puttaiah, 2008). Different WQIs use different numbers and types of water quality parameters (Akter *et al.,* 2016) depending on the intended use of water. None of the indices are without limitations. This includes the loss of information when transforming large sets of data (Tyagi *et al.,* 2013). Another shortcoming of using WQIs is that the water quality parameters used are weighted according to their supposed importance to overall water quality which is subjective as this is based on researcher's judgement (Fu and GanWang, 2012; Oke *et al*., 2017). The exclusion of some parameters may result in false picture of the water quality status, and in some instance, WQI might also mask and/or exaggerate water quality status depending on the parameters used (Rangeti *et al*., 2015).

The WQI technique was first developed by Horton in 1965 (Akter *et al.,* 2016) and has been broadly used in many countries across Africa, Asia and Europe (Tyagi *et al.,* 2013). Horton's WQI has since been improved (Mophin-Kani and Murugesa, 2011). Many WQIs exist today, i.e Canadian Council of Ministers of Environment Water Quality Index-(CCMEWQI), National Sanitation Foundation Water Quality Index (NSFWQI), Oregon Water Quality Index (OWQI), Weighted Arithmetic Water Quality Index Method (WAWQI) (Gupta *et al.,* 2017). None of these indices have been universally accepted; they are often adopted with slight modifications and the greatest constraint of using WQIs is that a loss of data can occur easily (Tyagi *et al.,* 2013).

The Weighted Arithmetic Water Quality Index (WAWQI) technique was selected to determine the WQI for Pienaars River because of its wide use and is one of the simplest and most effective WQI methods (Tyagi *et al.,* 2013). The WAWQI uses common measures of water quality variables, such as DO, phosphate (PO_4^{-3}), pH, TDS and temperature amongst others (Gupta *et al.,* 2017).

The limitations of this method are that it may not reflect sufficient information about actual water quality conditions. It also tends to over-emphasize the value of a single bad parameter. Similar to the other WQIs, the WAWQI uses a limited number of parameters and the single WQI value is not adequate to provide comprehensive information about the water quality of a water body. Nevertheless, if the key essential parameters (i.e. pH, oxygen etc.) are used in the calculations, the WQI can serve as a simple indicator of overall water quality. Due to the variability of water conditions, a good WQI score is also not necessarily an indication that water quality is always good. It simply suggests that the water is not permanently in a poor water quality condition. The WQI score can also be used to identify potential pollution sources of the water resource in question (Tyagi *et al.,* 2013).

2.3.3. Statistical assessment of water quality data

Statistical methods are valuable tools in water quality management, because most of the information known about water quality is in numerical form (Fu and GanWang, 2012). However, in order to draw sound conclusions and provide valuable inputs into water quality, appropriate statistical techniques must be applied when analysing the water quality data (Fu and GanWang, 2012). Statistical tools allow for effective comparison, trend analysis, enable interpretation of complex datasets and assessment of potential factors that influence water quality (Su *et al.,* 2011). Several studies have looked at the spatial and temporal water quality variation using different statistical techniques (e.g. Singh *et al.,* 2004; Sundaray *et al*., 2006; Shrestha and Kazama. 2007; Pejman *et al*., 2009; Huang *et al*., 2010; Su *et al.,* 2011; Wang *et al.,* 2012; Chounlamany *et al*., 2017).

As indicated, the assessment techniques described in this section are widely used globally. However, every country has their own regulatory frameworks which inform their standards, usage, conservation and development of water resources. The overview of the South African water resource management framework in terms of regulations and institutional arrangements is outlined below.

2.4. Water Quality Management Framework

The notion of water governance has evolved over the years and there is increasing acknowledgement that the multifaceted water-related issues are not confined to national boundaries, and thus cannot be adequately addressed by national policies alone as it goes beyond the geographical boundaries of countries (Cooley *et al.,* 2013). Many large river systems are not confined to one country, but rather shared between neighbouring countries. For example, the Limpopo River traverses through Botswana, Zimbabwe, South Africa and Mozambique. Africa has approximately 30% of the world's major water basins which are shared between two or more countries and at least 63 transboundary river and lake basins are found in Africa alone (UN-WWAP, 2012). Managing such transboundary river systems often becomes a tremendous challenge, especially because each country has its own water quality challenges, national water priorities, obligations and water management frameworks. Moreover, it is challenging to address water quality issues in downstream countries where the problem originates outside their borders, from their upstream neighbouring countries (UN-WWAP, 2012). The section below describes the South African legislation and institutions responsible for governing the country's water resources.

2.4.1. Legislative framework

The pressing need for economic growth and subsequent pressure on limited water resources has resulted in a global shift and transformation in the environmental policies and legislation of their management (Rossouw *et al.,* 2005). More stringent policies have been adopted in many countries to regulate the use of their natural water resources. In spite of the efforts and progress made by government agencies with regards to creating and improving policies and regulations, there is still a challenge in ensuring the implementation and enforcement of these policies (Maas, 2012). This is particularly true in most African countries, where some forms of regulations do exist, but due to poor governance, the quality of freshwater resources continues to dwindle (UN-WWAP 2017).

Post 1994, South Africa embarked on a reformation of the country's water policies and institutions. The country also became a signatory to numerous global environmental treaties (Nomquphu *et al*., 2007). Due to the country's own water crisis, water reform legislation was deemed necessary based on the constitutional acknowledgment of the right of access to water as a basic need (Gowlland-Gualtieri, 2007). The National Water Act (No. 36 of 1998) (NWA) was promulgated as the principal governing Act for all the country's water resources. The NWA sets out the blueprint for the management and utilisation of water resources in the country. This is one of the most far-reaching and pro-active water acts in the world (Rossouw *et al.*, 2005). As the primary statute for managing water resources in the country; its aim is to promote sustainable use and management of the country's water resources (Republic of South Africa, 1998).

2.4.2. Water resources management institutions

The key role of water resources management institutions is to develop appropriate regulations to manage water resources. The functions and structures of water institutions vary from country to country. South Africa has an intergovernmental structure that consists of three spheres of government; local, provincial and national government. While certain obligations are allocated to respective spheres, many other responsibilities are shared among all the spheres of government (DWAF, 2002). The same structure applies to the water management institutions, as water resources are co-ordinated by different authorities. South Africa has hierarchal water management institutions with specific roles and/or responsibilities for effective water management from the national to local scale (DWAF, undated) as indicated in Figure 2-2.

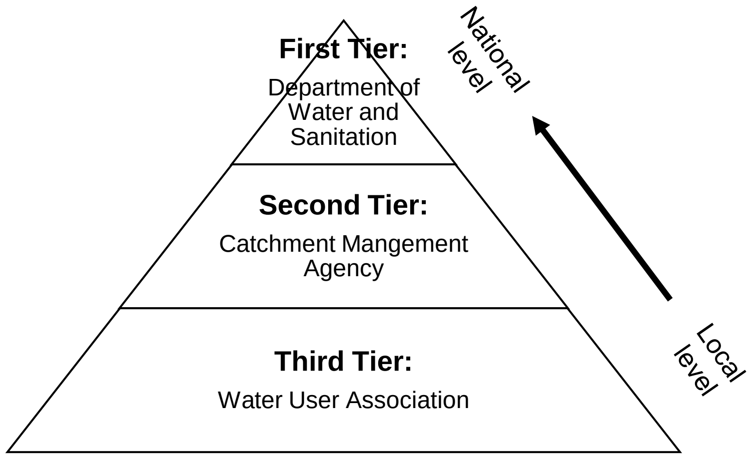

Figure 2-2: The hierarchal structure of the water management institutions of the South African government (DWAF, undated)

As the first tier of the water resource management structure and public trustee of the country's water resources, the DWS has the overall responsibility for all aspects of NWA delegated by the Minister (Republic of South Africa, 1998). The Department of Water and Sanitation (DWS) is not only required to implement the goals and objectives of NWA, but also develop national policies/ strategies and regulatory frameworks to manage the country's water resources (Republic of South Africa, 1998). Catchment Management Agencies (CMAs) are statutory bodies established as per the requirement of the NWA. The Catchment Management Agencies (CMAs) are responsible for ensuring that water resources are managed in accordance with national regulations and Catchment Management Strategy (CMS) in their respective jurisdictions or WMAs through the involvement of relevant stakeholders including the local communities (DEAT, 2006). Water-User Associations (WUAs*)* represent the third tier of the water management institutions. This institution is established in terms of the NWA to function at a local level. These associations are made up of individual water users that undertake water-related activities for the joint benefits or common intent (DWA, undated); an example of such an association is the Hartebeespoort Irrigation Board.

2.5 Importance of Managing Water Pollution

Water quality management has now reached prime importance on a global scale (Enderlein *et al.,* 1997) and yet still proves to be a challenge for many countries. Water resource management comprises of a range of aspects, which include water allocation, regulation of pollution, protection of aquatic ecosystems, water quality and maintenance of natural and man-made water storage infrastructures (UN-WWAP, 2012). Despite the importance of conserving water resources, water is considered to be one of the most poorly managed resources globally. This is owed to excessive consumption and inappropriate water management measures (Zia *et al.,* 2013) amongst other factors. Inadequate research and/or inconsistent data about water-related issues is one of the greatest challenges particularly facing Africa in attempt to manage natural water resources (UN-WWAP, 2012). Water quality monitoring programmes in most African countries range from insufficient to non-existent, due to negligence and/or lack of resources (Ongley, 2000) amongst other country-specific challenges. In view of this, the need to maintain water availability and water quality for survival cannot be over-emphasised. The sections below outline the importance of managing water quality and trade-offs when the quality is compromised.

2.5.1 Water availability effects

Water quantity and quality are inherently interlinked, where one is dependent on the other (Palaniappan *et al.,* 2011) and this can happen in various ways. This scenario implies that both water quality and quantity are equally significant. Contaminated water resources cannot be used for certain purposes thus constraining the use of such resources in the absence of costly pre-treatment (Palaniappan, *et al*., 2010). The more polluted the water is, the more treatment is required to bring it to an acceptable standard where it can be utilised (Palaniappan *et al.,* 2011). Due to the intrinsic dependency of water quantity and quality, the most effective management approach is to manage both water quality and quantity in an integrated manner (WMO, 2013); such that one variable does not ultimately deplete the other.

2.5.2 Environmental effects

Freshwater ecosystems are among the most degraded in the world as a result of deteriorating water quality and quantity thereof (Palaniappan *et al.,* 2010). The ecosystems support and provide ecological and economic goods and services (Baron *et al.,* 2003). Water with poor quality can therefore impair natural ecosystem functions, which can lead to loss of both aquatic and terrestrial biological diversity and the ability to provide valuable goods and services. The diversity and number of aquatic species present in the water are the best biological indicator of how well the ecosystem is functioning. To assess or quantify such ecological impacts, scientific methods such as biomonitoring and River Health Programmes (RHP) can be used for this purpose.

2.5.3 Human health effects

Access to clean water is a basic need necessity upon which many livelihoods depend**.** The need for good water quality to support livelihoods is often underestimated compared to the need for adequate quantity of water (Palaniappan *et al.,* 2010). Poor water quality has become the greatest threat to drinking water supplies worldwide and impends human health (Kraemer *et al.,* 2001). Palaniappan *et al.,* (2010) found that the majority of the health problems in the developing nations are as a result of poor water quality, especially those in marginalised communities. Approximately 80% of deaths in third world countries are caused by unsafe drinking water (Edwin and Murtala, 2013). Research has shown that in South Africa, 10% of deaths among children between 0 and 5 years are related to diarrhoea, which is a water-borne disease (CSIR, 2010).

2.5.4 Economic effects

As the availability of water is key to support the economic welfare, poor water quality creates an extra burden to economic development (CSIR, 2010). Degraded water quality can directly affect economic activities that rely on water supply; such activities include industrial production, tourism and agriculture (UN-WWAP, 2017). Thus, poor water quality is a major setback for economic development opportunities (Kraemer *et al.,* 2001). There is particularly a history of agriculture collapsing as a result of compromised irrigation water quality (Palaniappan *et al*., 2010). Agriculture plays a vital role in the economy of many developing countries, and South Africa is one such good example. The agricultural sector alone uses approximately 60% of water in South Africa (DWA, 2013), which makes the sector by far the largest water user.

2.6. Conclusion

Most elements occur naturally and they are found in almost all the water resources, especially those that are abundant on the earth's surface. Many water elements are essential to aquatic life and humans; but not all of them are beneficial. Some elements are harmful and will inevitably be introduced into water by natural processes or human activities, and they can be tolerable until they reach certain threshold levels before they become toxic. Hence it is important to have water polices and/or legislation as they form the foundation statute for managing water resources.

Assessing water quality status based on numerous samples and parameters can be a complex process. Techniques such as the WQIs and statistical analysis can be useful in converting complex water quality data into usable information. These are defendable, scientifically-derived techniques that can be used to inform regulatory framework or guideline values of water parameters. The following chapter demonstrates the use of statistical techniques in evaluating spatial and temporal distributions of water quality. The study made use of existing historical water quality data collected from different monitoring stations of the Pienaars River between 1980 and 2015.

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Chapter 3 : Evaluation of Spatial and Temporal Variations in Water Quality of the Pienaars River

3.1 Abstract

In many parts of the world water resources have increasingly become severely polluted, as a result posing threats to the environment and people on which they depend on for survival. The present study evaluated the spatial and temporal variations in water quality using statistical methods to assess the historical water quality data (1980-2015) from 8 different monitoring stations of the Pienaars River within the Limpopo Water Management Area in South Africa. From a spatial perspective, the upstream reaches were found to have substantial influence to on the water quality in the river. The results indicated a plausible effect of build-up of pollutants from upstream to the downstream regions of the river. The temporal differences in water quality of the river was assessed in terms of seasons and long-term on a yearly basis. The results showed a significant seasonal variation of the water quality parameters during the study period. The poor water quality conditions were prevalent in the low flow season (specifically in winter) and the reverse conditions during the high flow period due to rainfall dilution effect. No distinct pattern or trend in the water quality of the river was recorded between the study period (1980 to 2015) although most water quality parameters fluctuated between different years.

3.2 Introduction

Natural water composition is constantly changing through time and this can range from hourly to annually (Ji, 2008). The changes may be driven by a range of factors including the change in climate over time. While the impacts of climatic conditions or seasonal trends on water resources is natural, the interest in the climate-water quality nexus has undeniably grown over the past decades given the far-reaching impacts of global climate change on water resources (Dallas and Rivers-Moore, 2014). Water quality is also influenced by its immediate environment, where the quality of the water changes spatially due to different landscapes. These spatial variations are largely driven by the natural mechanisms or surroundings (i.e altitude, geology and flow rate). However, land-use activities may also contribute to facilitating and introducing pollutants into water resources. The objectives of this chapter were to assess the spatial variation in water quality of the Pienaars River with respect to land-use impacts; and the temporal variation in water quality of the Pienaars River on a yearly and seasonal basis using historical water quality data obtained from the Department of Water and Sanitation (DWS) database for the period 1980-2015.

Global climate has been changing over time and its observable adverse impacts on the environment have been widely researched; with induced changes in freshwater resources being one of such major impacts. While the impacts of climate change in water are first observed in water availability, the secondary impacts on water quality would generally follow (Gündüz, 2015). In this regard, changes in water temperature have been identified as the main factor influencing the vital components of the hydrological system and water quality constituents (Hossein *et al.,* 2017; Miller and Hutchins, 2017). The impacts of climate change are usually depicted over long term monitoring or observation of water quality trends.

Variation in water quality can also be as a result of seasonality. Dry seasons are characterised by low rainfall events or intermittent flow conditions. The Pienaars River experiences the dry season during winter and autumn, which broadly falls within the March and August months. Low flow hydrological conditions not only change the biotic composition but also the instream concentrations of water quality variables (Zeinalzadeh and Rezaei, 2017). During these seasons the flowing rivers are primarily fed by groundwater resources which are largely impacted by geological formations (Acuna and Dahm, 2007). Although the natural low flow or dry periods can exacerbate conditions for some aquatic biota and have adverse impacts on water quality as a whole, such periods are a fundamental component of many riverine ecosystems. They are also essential for numerous developments, maintenance and functionality of the systems. This is also considered a growing period for the riparian vegetation provided there is enough rainfall to support growth (Rossouw *et al*., 2005).

In contrast, wet seasons are characterised by high rainfall events and subsequently high river flow conditions. The wet season in the region where Pienaars River is located occurs during spring and summer, which broadly falls within the months of September and February. Wet seasons are also associated with high runoff events which tend to introduce high sediment loads and pollutants (organic and inorganic) from various land-based activities (Acuna and Dahm, 2007; Grady *et al.,* 2014). During the wet season, runoff transports non-point source pollutants that end up in river systems (Bae, 2013; Vaishali and Punita, 2013). The first few episodes of rainfall during the wet season usually produce 'first-flush' loads of stressors (Rossouw *et al.,* 2005). Bae (2013) reported that the rainfall experienced after lengthy dry periods accelerates water quality depletion due to pollutants that accumulates on the surface areas.

It is unambiguous that water quality and aquatic ecosystems are not only influenced by climatic factors, but also a reflection of the conditions and human activities within the catchment area. River systems also flow through various landscapes where "human nature" interactions have strong and lasting effects (Huang *et al.,* 2010). Constant human transformation of natural landscapes subject the river systems to pollution. Different land uses also exert different impacts on the quality of water either directly and/or indirectly. The Pienaars River is one of the major tributaries of the most important river system in Gauteng and South Africa in general - the Crocodile River. The river catchment is a hub for various economic activities (mining, industries and urban activities) which contribute the largest proportion to the South African economy (DWAF, 2004a). Like most rivers in the country, the water quality of Pienaars River is likely to have been deteriorating over the years due to direct and indirect impacts of human activities. The key land use activities along Pienaars River which could potentially be sources of pollution include but are not limited to agriculture, residential areas and waste water treatment plants.

Research has shown that agriculture has detrimental and enduring impacts on water quality (Huang *et al*., 2013; Holden *et al*., 2015; Zeinalzadeh and Rezaei, 2017). Such impacts include release of nutrients and/or chemicals into a water body through diffuse pathways such as surface flow and leaching (Huang *et al*., 2013; Zia *et al.,* 2013). The Edendalespruit, which is one of the tributaries of the Pienaars River drains commercial agricultural fields (Walmsley and Toerie, 1978). Agricultural runoff typically contains high salts such as nitrate amongst other nutrients due to fertilizer application and this contributes to eutrophication which ultimately leads to depletion of dissolved oxygen (Grady *et al.,* 2014; Han *et al.,* 2016). In South Africa, agriculture is among the prominent causes of water quality pollution and has increased concerns about the degradation of water resources (Shabalala *et al.,* 2013). Eutrophication and salinisation are some of the major known water quality problems affecting Pienaars River and its entire catchment (DWA, 2011). The Roodeplaat and Klipvoor Dams, situated on the Pienaars River are severely impacted by eutrophication due to high nutrient load. The dams are classified as hyper-eutrophic ecosystems (Walmsley and Toerie, 1978).

Urban areas across the globe are faced with challenges of poor water quality, attributed to accelerating population growth (Miller and Hutchins 2017). The water quality of river systems in the urban areas are degraded by discharge of waste water at point sources, pollutants from non-point pathways and altered hydrological regimes (Miller and Hutchins, 2017). Impervious surfaces in most urban environments is described as one of the main factors enhancing surface flow and transportation of pollutants (Ji, 2008; Palaniappan *et al.,* 2011). Another challenge is the rapid expansion of informal settlements which are densely populated with limited or no water or sanitation services and waste water usually ends up in the nearby river systems, ultimately posing health risks to the water users. Numerous water quality problems are associated with the river systems traversing dense informal settlements, the most common being microbial contamination by faecal pathogens (DWAF, 1999).

Pienaars River quality mirrors the typical urban impacts exerted by various activities. The river receives point and non-point source pollution from urban runoff and discharge of waste water effluents from industrial activities. The Morelettaspruit-Hartbeesspruit system which is another tributary system feeding into the Pienaars River, originates in urban parts of Pretoria and traverse Silverton which is an industrial area (Walmsley and Toerie, 1978). The Pienaars River, also passes a residential area, Mamelodi Township, which affects the quality of the river. The Roodeplaat Dam on the Pienaars River receives point source pollution as it is located downstream of two waste water treatment works (WTWs), Baviaanspoort and Zeekoegat that discharge treated effluents directly into the river (Walmsley and Toerie, 1978).

3.3. Methods

3.3.1. Study area

The Pienaars River is situated between Gauteng and the North-West provinces. This river system is also located within the Crocodile (West) and Marico Sub-WMA of the Limpopo WMA. The study area falls within four local municipal jurisdictions, namely; the City of Tshwane, and Bela-Bela, Morelete and Madibeng local municipalities from its origin to the mouth. The entire river system lies between 25°55′29.6”S; 28°30′6.8”E and 25°6′14.2”S; 27°33′57.4”E. It has a length of approximately 185 km and its width varies at different locations or sections.

The Pienaars River meanders through several land uses, predominantly residential, recreational and agricultural land. Pienaars River drains highly populated areas in the City of Tshwane (Pretoria) (DWAF, 2004b). The urban section of the river catchment is characterised by a well-developed manufacturing and commercial urban economy (DWA, 2013) and comprises of various settlements, mainly townships including Mamelodi, Ga-Rasai, Morelete and Eerste Fabriek. The rural section is predominantly characterised by agriculture and eco-tourism activities (DWA, 2013).

The river is situated in a complex landscape that varies from lowlands to mountainous areas with the relief varying from moderate to high. The altitude ranges between 900 and 1 700 m above sea level (DWA, 2012). The river originates from the Tshwane area of Gauteng Province, and flows in a north-western direction into the Roodeplaat, Dam also in Gauteng Province, passing through the Pienaarsrivier town in Limpopo Province and the Klipvoor Dam within the Borakalalo National Park, North West Province before eventually draining into the Crocodile River south of the confluence of the Elands and Crocodile rivers (Cessford and Burke, 2005).

The catchment of the study area occurs is characterised by temperate and semi-arid climatic conditions (DEAT, 2006). The area experiences a Mean Annual Precipitation (MAP) of between 400 and 800 mm from the western to the eastern parts of the catchment respectively (DWA, 2011). Most rainfall occurs in the summer months from October to April. Mean temperatures range between 18 and 20°C annually, with maximum temperatures experienced during the month of January (DWA, 2011). The climatic conditions experienced in this catchment are one of the essential determinants of the vegetation types and distribution found adjacent to the river. Numerous bushveld and grassland vegetation types occur throughout the course of the river, however the Waterberg Moist Mountain Bushveld, Mixed Bushveld; and North-Eastern Mountain Grassland are the most definitive of the region (Kleynhans *et al*., 2005).

From a geological perspective, the Pienaars River straddles rocks of various ages from the Precambrian Transvaal Supergroup to Cenozoic Quaternary Sediments (Keyser, 1997). The area to the south where the river originates is underlain by the Transvaal Supergroup. North of Roodeplaat Dam, the river is underlain by alkaline and basic rocks of the Roodeplaat and Bushveld complexes. The Bushveld Complex hosts the world's largest reserves of platinum group elements, with mines primarily established along the western and eastern limbs of the complex. The river ends on a dolomitic sequence of the lower Transvaal Supergroup approximately 15 km west of Ramokokastad in the North-West Province (Moore *et al.,* 2001).

3.3.2. Water sample collection

Historical data were obtained from the DWS's National Water Management System (NWMS) database. The DWS has water quality monitoring stations on the Pienaars River. The water quality results from the monitoring stations were screened in order to identify outliers or anomalies in the dataset. Monitoring stations where the data has been collected over a number of years, in all four seasons (between 1980 and 2015) were used for the study and the rest were discarded. The seasons were further categorised into wet and dry seasons as indicated below:

- Wet season:
  - Spring – September, October and November.
  - Summer – December, January and February.
- Dry season:
  - Autumn – March, April and May.
  - Winter – June, July, August.

The map on Figure 3-1 indicates the location of the monitoring stations (upper, middle and lower stream – based on where they are located along the river) selected for analysis in this study.

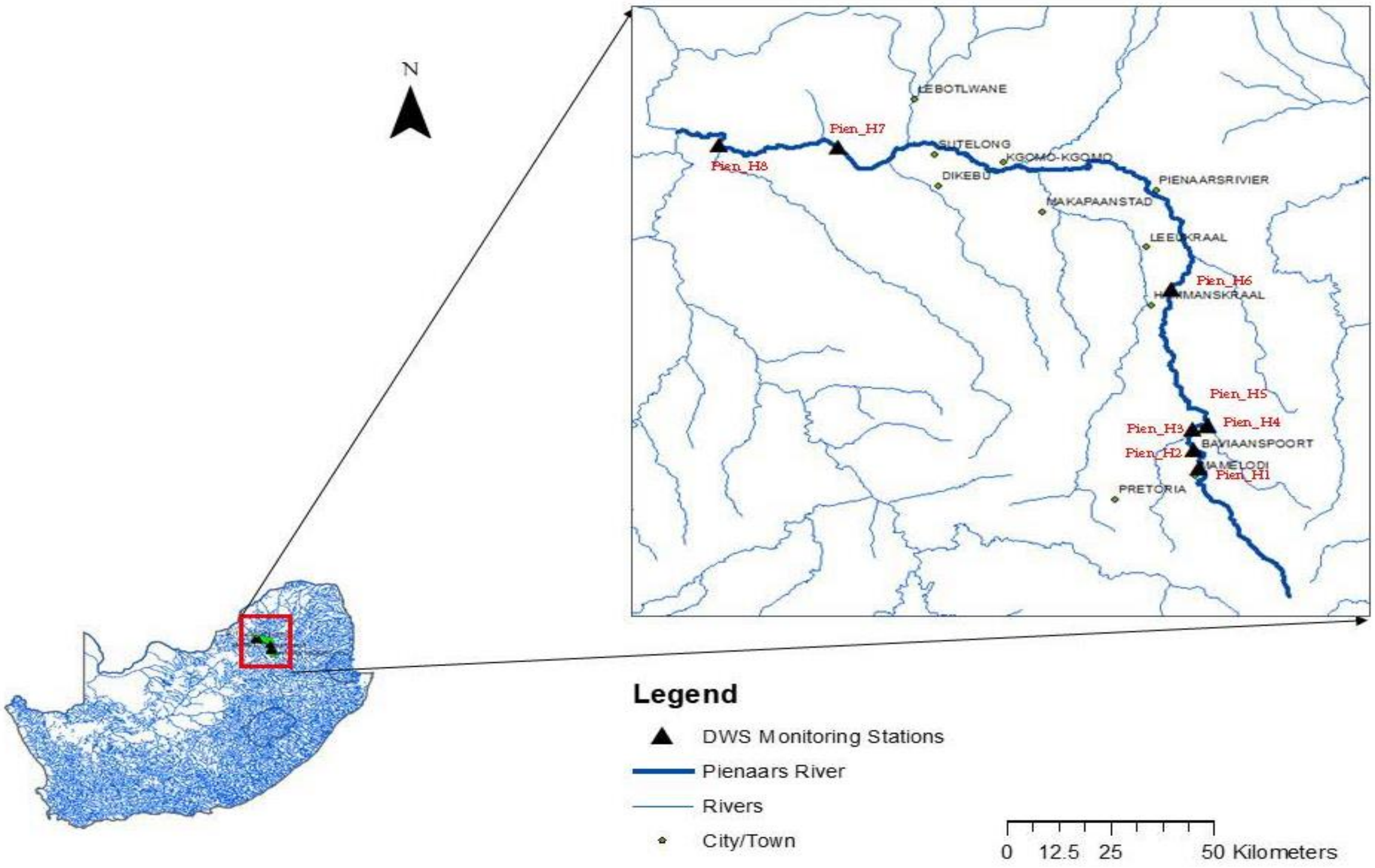

Figure 3-1: Existing water quality monitoring stations monitored by the Department of Water and Sanitation between 1980 and 2015 on Pienaars River

3.3.3. Parameters analysed

No analysis of parameters was required as the historical information was readily available. The historical data obtained from the DWS database was limited in terms of water quality variables assessed. Table 3-1 lists the water quality parameters analysed by the DWS in various monitoring stations on the river over the years.

Table 3-1: List of water quality parameters monitored by the Department of Water and Sanitation (DWS) on the Pienaars River

Water Quality Parameters	Abbreviations	Units	Method of analysis
Calcium	Ca	mg/l	The methods of analysis were not specified in the database and these methods may have changed through the years.
Chloride	Cl^-	mg/l	
Dissolved Major Salts	DMS	mg/l	
Electrical Conductivity	EC	mS/m	
Fluoride	F	mg/l	
Potassium	K	mg/l	
Kjeldahl Nitrogen	KJEL N	mg/l	
Magnesium	Mg	mg/l	
Sodium	Na	mg/l	
Ammonium Nitrogen	NH_4-N	mg/l	
Nitrate + Nitrite Nitrogen	NO_3+NO_2-N	mg/l	
Total Phosphorus	P-Tot	mg/l	
pH	pH	Units of pH	
Phosphate as phosphorus	PO_4^{-3}-P	mg/l	
Silicon	Si	mg/l	
Sulphate	SO_4^{-2}	mg/l	
Total Alkalinity (as Calcium Carbonate)	TAL	mg/l	

Source: DWS 2016. National Water Management System data extracted on 2016-03-24. Department of Water and Sanitation, Pretoria.

3.3.4. Data analysis

Statistical analysis was conducted using the Statistical Package for the Social Sciences (SPSS) software Version 25. The univariate statistical analysis technique (Analysis of Variance - ANOVA) was performed on the water quality data across stations to assess the spatial and temporal variations in water quality. The analysis was also performed on the data grouped in seasons and years to assess the seasonal and temporal variation in water quality. Significantly different means were separated using Duncan's multiple range test at $p<0.05$ level of significance (95% confidence interval). The relationship between the parameters was also analysed, using Pearson correlation at $p<0.05$ level of significance (Landua and Everitt, 2004).

3.4. Results and Discussion

3.4.1. Spatial analysis

The historical water quality data of the river was obtained from eight water quality monitoring stations monitored by the DWS. This section provides the results of mean values of water quality parameters of the different stations (Table 3-2). The study revealed significant ($p<0.05$) spatial variation in all the water quality parameters and each parameter displayed a different spatial characteristic pattern, which implies that the factors causing the water quality impairment changed over space.

Table 3-2: The mean values and standard errors (±S.E) of water quality parameters per monitoring station on the Pienaars River measured by the Department of Water and Sanitation (DWS) between 1980 and 2015, the values with different letters in each column indicate significantly different means for each parameter as separated by Duncan's Multiple Range Test (DMRT) at p= 0.05.

Stations	Location	Ca (mg/l)	Cl^- (mg/l)	DMS (mg/l)	EC (mS/m)	F (mg/l)	K (mg/l)	KJEL N (mg/l)	Mg (mg/l)	Na (mg/l)	NH_4-N (mg/l)	NO_3+NO_2-N (mg/l)	P-Tot (mg/l)	pH	PO_4^{-3}-P (mg/l)	Si (mg/l)	SO_4^{-2} (mg/l)	TAL (mg/l)
Pien_H1	Upstream	34.50±0.25^{f}	20.71±0.35^{a}	354.16±3.10^{d}	46.34±0.35^{b}	0.27±0.00^{a}	3.25±0.07^{a}	2.88±1.28^{b}	26.65±0.30^{g}	17.44±0.33^{a}	0.36±0.05^{c,d}	2.34±0.09^{f}	0.35±0.03^{b}	8.17±0.01^{c,d}	0.17±0.01^{b}	7.48±0.07^{e}	26.26±0.30^{a}	176.13±1.61^{g}
Pien_H2	Upstream	32.89±0.09^{e}	53.23±0.25^{e}	410.57±1.29^{e}	59.10±0.17^{c}	0.31±0.00^{b}	9.33±0.04^{f}	3.44±0.07^{b}	18.78±0.06^{f}	52.25±0.25^{e}	1.64±0.04^{f}	4.67±0.04^{g}	2.39±0.02^{e}	7.80±0.00^{a}	1.93±0.02^{e}	8.21±0.03^{f}	52.94±0.27^{d}	132.88±0.46^{c}
Pien_H3	Upstream	25.35±0.14^{a}	38.12±0.28^{c}	300.59±1.21^{a}	43.93±0.15^{a}	0.33±0.00^{c}	6.23±0.05^{d}	1.45±0.02^{a}	17.06±0.08^{b}	33.60±0.27^{c}	0.24±0.01^{b,c}	0.67±0.02^{c,d}	0.26±0.00^{a,b}	8.39±0.02^{f}	0.17±0.00^{b}	2.93±0.05^{b}	33.11±0.25^{c}	118.60±0.49^{a}
Pien_H4	Upstream	26.35±0.07^{c}	37.63±0.13^{c}	307.98±0.66^{b}	44.45±0.08^{a}	0.31±0.00^{b}	6.43±0.02^{e}	1.65±0.02^{a}	16.75±0.04^{a}	33.23±0.13^{c}	0.50±0.01^{d}	0.78±0.01^{e}	0.24±0.00^{a,b}	8.34±0.00^{e}	0.16±0.00^{b}	3.41±0.02^{c}	32.15±0.11^{b,c}	126.04±0.29^{b}
Pien_H5	Upstream	25.81±0.08^{b}	35.90±0.13^{b}	301.57±0.67^{a}	44.10±0.08^{a}	0.37±0.00^{d}	5.48±0.02^{b}	1.68±0.02^{a}	18.71±0.04^{e,f}	30.24±0.11^{b}	0.86±0.01^{e}	0.44±0.01^{a,b}	0.26±0.00^{a,b}	7.87±0.00^{b}	0.19±0.00^{b}	2.40±0.03^{a}	26.96±0.20^{a}	127.27±0.39^{b}
Pien_H6	Midstream	29.50±0.14^{d}	40.13±0.32^{d}	345.81±1.71^{c}	46.92±0.18^{b}	0.54±0.00^{f}	5.93±0.04^{c}	0.94±0.03^{a}	18.27±0.10^{d}	38.15±0.27^{d}	0.05±0.00^{a}	0.50±0.02^{b}	0.15±0.00^{a}	8.15±0.00^{c}	0.07±0.00^{a}	4.03±0.05^{d}	31.33±0.25^{b}	147.32±0.77^{d}
Pien_H7	Downstream	35.31±0.19^{g}	56.21±0.62^{f}	446.54±3.49^{f}	60.49±0.42^{d}	0.48±0.00^{e}	10.59±0.09^{g}	1.57±0.03^{a}	18.41±0.12^{d,e}	59.13±0.72^{f}	0.24±0.01$^{b.c}$	0.30±0.02^{a}	0.73±0.03^{d}	8.51±0.01^{g}	0.56±0.01^{d}	3.96±0.24^{d}	52.36±0.56^{d}	170.20±1.07^{f}
Pien_H8	Downstream	36.39±0.22^{h}	62.44±0.67^{g}	444.63±3.46^{f}	63.63±0.43^{e}	0.54±0.00^{f}	10.65±0.08^{g}	1.24±0.04^{a}	17.47±0.15^{c}	61.96±0.64^{g}	0.10±0.00^{a,b}	0.53±0.02^{b,c}	0.52±0.02^{c}	8.19±0.01^{d}	0.47±0.01^{c}	4.03±0.06^{d}	54.87±0.69^{e}	160.15±1.19^{e}

3.4.1.1. Upstream stations

The upstream reaches of the river consist of five monitoring stations, namely; Pien_H1, Pien_H2, Pien_H3, Pien_H4 and Pien_H5 in order of position along the river (Figure 3-1). Station Pien_H1 is situated approximately 1 km north of Mamelodi Township, 6 km north is station Pien_H2 and both Pien_H3 and Pien_H4 are in the Roodeplaat Dam and Pien_H5 is immediately after the dam wall (approximately 0.3 km). The ANOVA analysis revealed that the water quality parameters between two or more upstream stations were not significantly different ($p<0.05$) from each other except for Ca, DMS, K, pH and Si (Table 3-2). These 5 parameters were significantly different from each upstream station. It was also observed that for 70% of the total water quality parameters monitored, the station Pien_H2 recorded the highest mean concentrations in comparison to the other upstream stations. This station receives wastewater from Baviaanspoort WWTWs, which is located 5 km south of this station. Phosphate (PO_4^{-3}) and nitrogen (N) which were also very high and are usually from sewage effluent discharge. The results from this study corroborate the findings of Dabrowski and de Klerk (2013), where the sites situated immediately downstream of the Riverview sewage works in Witbank on the Olifants River had elevated ortho-phosphate and N concentrations.

The concentrations of water quality parameters in monitoring station Pien_H1 were relatively low. A significant positive trend/ correlation was observed from Pien_H1 to the second station (Pien_H2), except for Ca, Mg, pH and TAL, where there was a significant negative trend (Table 3-2). The similar responses of Ca and Mg may be associated with their similar characterises which is responsible for the hardness of water (Potasznik and Szymczyk, 2015). From station Pien_H2 to Pien_H4 (third station), the water quality showed significant improvements, except for one element; F, which remained unchanged between the two monitoring stations. The general decrease in the mean water parameter concentrations between stations over the period under study could be as a result of dilution of contaminants from the main sources of pollution at Zeekoegat and Baviaanspoort WWTWs. Both station Pien_H3 and Pien_H4 are located within the Roodeplaat Dam, which is affected by formal residential areas and dryland agricultural activities around the dam. The water quality in Pien_H4 was generally poor than the water quality observed in Pien_H3 which is situated 3 km further upstream. However, no significant differences were observed in KJEL N, P-Tot, PO_4^{-3}-P and TAL. Station Pien_H4 is situated close to the dam wall, and the higher contamination observed at this station may be due to cumulative effects of pollution that drains towards the dam wall from the different tributaries, namely Hartbeesspruit and Edendalespruit located in the western and eastern wing of the dam respectively. The water draining from Edendalespruit is likely to be nutrient enriched due to numerous plantations along the catchment. Hartbeesspruit on the other hand originates in the urban parts of Pretoria and traverses industrial areas in Silverton (Walmsley and Toerie, 1978).

In station Pien_H5 (immediately after the dam), the majority (53%) of the water quality parameters concentrations were notably higher compared to the last station preceding the dam (Pien_H4) with 24% of water parameters (DMS, EC, KJEL-N and PO_4^{-3}-P) not significantly different. Conversely, 41% of the parameters (Cl^-, K, Na, NO_3, pH, Si and SO_4^{-2}) were significantly lower downstream after the dam, a scenario of which may explain the water quality status of the dam. Be that as it may, the fact that stations Pien_H5 is approximately 0.30 km downstream of the dam assert to the contribution of the surrounding land uses and activities to these observed water parameter differences in this study. These results are however, contrary to the observations reported by Dabrowski and de Klerk (2013), where the PO_4^{-3} levels were reduced downstream of the Witbank Dam, which implied that the dam acted as a sink for phosphates. In this study, PO_4^{-3} levels increased downstream of the Roodeplaat Dam although this was not statistically significant from those of the station preceding the dam. Similar observations were also reported by Perona *et al*. (1999) where there was an overall steady increase in alkalinity, Ca, SO_4^{-2} and Cl^- downstream of the reservoir. In this study, all these elements showed the opposite response, except for alkalinity which was slightly higher but not significantly different after the Roodeplaat Dam. Dabrowski and de Klerk (2013) also found similar TDS concentrations in and after the Witbank Dam, which was different from the observations made in this study where EC and DMS were slightly elevated after the Roodeplaat Dam but not significantly different from those recorded in the dam. These reported contrasting differences could be experienced on the dynamics of the quality contributing factors between the study sites such as the underlying rock type, economic and other human activities in the upstream reaches of the river.

3.4.1.2. Midstream stations

Only one monitoring station (Pien_H6) is located midstream, near Ramotshe village, on the outskirts of Pretoria (Figure 3-1). With the exception of Mg, NH_4-N and PO_4^{-3}-P, there was a general characteristic increase in the accumulation of elements from the last upstream station (Pien_H5) (approximately 35 km apart) to station Pien_H6 with 65% of these being significant different. This implies accumulation of pollutants downstream along the river gradient. Nitrogen concentrations were similar in both Pien_H5 and Pien_H6 (Table 3-2).

The 35 km stretch between upstream and midstream stations, the adjacent land uses predominantly consists of agricultural land after Roodeplaat Dam. After the river crosses Kloppersbos Pyramid Road (about 11 km after the dam) it's mostly natural landscape with sparse vegetation cover. The river also flows pasts a quarry for construction aggregates, which is located 660 m west of the river path and 26 km downstream of the dam. The last portion of the river before station Pien_H6 is natural landscape and dense low-income residential areas. All these activities and/ land uses may have contributed directly or indirectly to the overall high-water quality parameters measured in the midstream in comparison to the upstream reaches.

3.4.1.3. Downstream stations

The downstream segment of the river is the least urbanized. There are two monitoring stations there: PIen_H7 is situated in Klipvoor Dam while Pien_H8 further downstream close to the river mouth. The concentration of water quality parameters in station Pien_H7 were significantly higher than the mid-stream station. The overall characteristic trend was a general increase in all measured parameters from the midstream station to the first downstream segment of the river except for F and NO_3+NO_2-N and Si, which are slightly lower between the two monitoring stations (midstream and downstream) (Table 3-2).

From Pien_H7 to Pien_H8 further increase in values of most parameters was observed (i.e. Ca, Cl^-, EC, F, K, Na, NO_3+NO_2-N, Si and SO_4^{2-}). Other parameters (e.g. Mg, P-Tot, pH, PO_4^{-3}-P and TAL) showed improvement in the quality of water as indicated by the decrease in their concentrations between the two stations.

Of notable interest in the results of this study is a plausible effect of accumulation of pollutants from upstream to the lower reaches. Several studies (i.e Ding *et al.,* 2015; Duan *et al.,* 2016) have also reported similar trends. Most of the pollutants are introduced upstream at station Pien_H2, due to inputs of effluents from a point source at Baviaanspoort WWTWs. This WWTWs is one of the many operational treatment plants in South Africa not complying with the set standard of the green drop system (Green Drop Annual Report of 2014). Baviaanspoort and Zeekoegat WWTWs are one of the WWTWs in critical and high risk in terms of their performance against the green drop system. Silberbauer and Esterhuyse (2014), report that Baviaanspoort and Zeekoegat WWTWs are constant sources of orthophosphate and nitrogen, both of which contribute to algal blooms.

The water quality continued to deteriorate from main pollution source towards the downstream reaches as the river traverses different land uses (i.e. natural vegetated land, residential areas and scattered agricultural fields) which are known sources of pollution. However, six parameters (KJEL-N, Mg, NH_4-N, NO_3+NO_2-N, P-Tot and PO_4^{3-}-P) were significantly lower in the furthest station (Pien_H8) in the downstream reaches, compared to station Pien_H2 (the main source of pollutant inputs). Most of these parameters are predominantly associated with agricultural activities, and are introduced into the river systems though soil erosion (Charkhabi and Sakizadeh, 2006; Huang *et al.,* 2013). The improvement of some water quality parameters recorded in this study are consistent with the results of Ling *et al*. (2017), where the NO_3^- and P-Tot decreased significantly with gradient towards the downstream reaches.

The observations in this study suggest that the impact of agricultural activities observed along the stretch of the river had the least effects on the water quality of the river compared to the point source discharge. This could also imply that the impact of cultivated land on the river was masked or suppressed by predominant vegetated land or it may be that the farmers are applying good agricultural practises. It can therefore be concluded that the upstream reaches (which is predominantly characterised by urban land use) had significant impacts on water quality of the river, which agrees with other studies (Huang *et al*., 2013; Huang *et al.,* 2010; Mei *et al.,* 2014; Ding *et al.*, 2015; Duan *et al.,* 2016). Soko and Ababio (2015) also reported poor water quality in the downstream reaches of the Crocodile River compared to the upper and middle reaches. However, Shrestha and Kazama (2007) found the least amount of pollution in the upstream sites while downstream sites were the most polluted.

3.4.2. Temporal analysis

The temporal assessment of water quality variation was conducted on a seasonal and yearly basis, based on the data collected between 1980 and 2015 on the Pienaars River for selected parameters and stations.

3.4.2.1. Seasonal variation

There was a general seasonal variation in some water quality parameters, while some parameters showed a slight or no variations between seasons (Table 3-3), which is consistent with findings of numerous other studies (Charkhabi and Sakizadeh, 2006; Pejman *et al*., 2009; Garg *et al.,* 2010; Vaishali and Punita, 2013; Poudel *et al*., 2016). All mean values of the parameters were found to be significantly different ($p<0.05$) between seasons.

Table 3-3: The mean values and standard errors (S.E) of water quality parameters on the entire stretch of Pienaars River during summer, spring, autumn and winter seasons from 1980 to 2015

Parameters	Summer	Autumn	Winter	Spring
Ca	27.78 ± 0.10^{a}	28.72 ± 0.09^{b}	30.74 ± 0.10^{c}	30.54 ± 0.11^{c}
DMS	331.61 ± 1.31^{a}	340.98 ± 1.23^{b}	373.23 ± 1.42^{d}	368.94 ± 1.50^{c}
EC	47.69 ± 0.17^{a}	48.54 ± 0.16^{b}	53.00 ± 0.17^{c}	52.99 ± 0.18^{c}
KJEL-N	1.86 ± 0.03^{a}	2.08 ± 0.03^{a}	2.63 ± 0.17^{b}	2.12 ± 0.05^{a}
Mg	17.58 ± 0.06^{a}	17.89 ± 0.06^{b}	18.77 ± 0.06^{c}	18.61 ± 0.06^{c}
PO_4-P	0.52 ± 0.01^{a}	0.69 ± 0.01^{b}	0.83 ± 0.02^{c}	0.70 ± 0.02^{b}
SO_4^{-2}	36.68 ± 0.27^{b}	35.61 ± 0.26^{a}	41.99 ± 0.27^{c}	41.96 ± 0.28^{c}
NO_3+NO_2-N	1.37 ± 0.04^{a}	1.75 ± 0.04^{b}	2.23 ± 0.04^{c}	1.77 ± 0.03^{b}
TAL	128.44 ± 0.46^{a}	131.83 ± 0.42^{b}	139.85 ± 0.44^{d}	138.37 ± 0.51^{c}
Cl^{-}	40.91 ± 0.24^{a}	40.75 ± 0.23^{a}	45.53 ± 0.24^{d}	47.25 ± 0.27^{c}
K	6.97 ± 0.04^{a}	6.93 ± 0.04^{a}	7.70 ± 0.04^{b}	7.83 ± 0.05^{b}

Na	37.14±0.25^{a}	37.85±0.26^{a}	43.66±0.27^{b}	44.33±0.29^{b}
F	0.35±0.00^{a}	0.35±0.00^{a}	0.36±0.00^{a}	0.37±0.00^{b}
NH_4-N	0.61±0.02^{a}	0.81±0.02^{b}	1.02±0.03^{c}	0.73±0.03^{b}
P-Tot	0.72±0.01^{a}	0.94±0.02^{b}	1.05±0.02^{b}	0.89±0.02^{c}
pH	8.17±0.00^{d}	8.06±0.00^{b}	7.99±0.00^{a}	8.15±0.00^{c}
Si	4.87±0.05^{c}	5.36±0.04^{d}	4.28±0.04^{a}	4.44±0.06^{b}

Values with different letters within each row indicate significantly different means as separated by Duncan's Multiple Range Test (DMRT) at p= 0.05

(a) Conventional parameters

The pH values ranged from 7.99±0.00 mg/l in winter to 8.17±0.00mg/l in summer. The pH was not similar according to the homogenous groups in Table 3-3 i.e. for summer^{d} and spring^{c}**.** Conversely, the minimum average for TAL was in the summer season (128.44±0.46 mg/l) and increased to a maximum of 139.85±0.44mg/l in winter. Ouyang *et al*. (2006) and Pullanikkatil *et al.* (2015) found that the greater dilution effect experienced during the rainy (summer) season resulted in reduced alkalinity compared to the winter season. The variations in TAL between the two seasons were found to be significant ($p<0.05$) while a similar trend was also observed by Kaur and Kaur (2014).

Dissolved Major Salts (DMS) ranged from 331.61±1.31 mg/l in summer to 373.23±1.42 mg/l in winter, and statistically there were significant differences in this parameter among seasons (Table 3-3). Similarly, EC varied from 47.69±0.17 mg/l in summer to 53.00±0.17 mg/l in winter. The lower concentrations observed during summer for both DMS and EC parameters may also be attributed to dilution by high rainfall and runoff as reported elsewhere (Saifullah *et al.*, 2012; Mei *et al.*, 2014; Pullanikkatil *et al.*, 2015). High EC during the dry seasons may be caused by high evaporation which leaves the water concentrated with major ions (Kazi *et al*., 2009; Gondwe and Masamba, 2015).

(b) Mineral parameters

The mean Mg varied between 17.58±0.06mg/l and 18.77±0.06mg/l in summer and winter respectively (Table 3-3). Similar observations were reported by Garg *et al*.

(2010) and Pullanikkatil *et al.* (2015). In these studies, Mg cation concentrations were high in the dry seasons compared to the wet seasons. Contrastingly, Kaur and Kaur (2014) found Mg to be lower in winter season, with no significant variations among the seasons. In this study, Mg was significantly different among seasons except for spring and winter. A similar seasonal trend was observed for in the Ca cation concentrations which showed lower concentration in summer (27.78±0.10 mg/l) and higher in the winter season (30.74±0.10 mg/l). Coinciding with this study, Pullanikkatil *et al.* (2015) reported lower Ca concentration during summer than winter in the Likangala River.

The seasonal pattern for Cl^- anion concentrations were slightly different from the other elements in that the maximum concentration (47.25±0.27mg/l) was recorded in spring and the minimum concentration (40.75±0.23mg/l) was in autumn (Table 3-3). Soko and Gyedu-Ababio (2015) found Cl^- to be influenced by high sedimentation resulting from high rainfall and runoff during summer seasons. Spring occurs during the wet season; therefore, the results of this study are corroborated by Soko and Gyedu-Ababio (2015).

Similar to Mg and Ca cations trends, the Na cation content was lower in summer than in spring (Table 3-3). Na content was similar between spring and winter. As indicated above the high Na content during summer may be as a result of evaporation processes. In the present study, Na concentrations were higher in spring, although this season experiences climatic conditions almost similar to those experienced during the summer months. Concentrations of Si differed significantly between winter and autumn ($p<0.05$). Sundaray *et al.* (2006) found high Si concentrations in wet seasons, due to high sediment input from elevated runoff. Fluoride (F) was similar among seasons, with values of 0.35±0.00 mg/l in summer and 0.36±0.00 mg/l in winter. The highest F concentration was in spring season (0.35±0.00 mg/l) but remained relatively constant throughout the seasons.

(c) Nutrient parameters

Seasonal variations were also noted values in water nutrient elements. The least concentration of K was in autumn but was not significantly different from the highest concentration recorded in spring (Table 3-3). Garg *et al.* (2010) found the least content of K in winter months and suggested that this was due to utilisation by aquatic biota.

NH_4-N concentrations differed significantly between summer and autumn but was not significant between spring and autumn. The NH_4-N content ranged from 0.61 mg/l in summer to 1.02 mg/ml in winter. Charkhabi and Sakizadeh (2006), found contrasting results where the average concentrations of NH_4^+ increased from 1.77 mg/l in the winter to 5.54.mg/l in the autumn. The study also suggested naturally the NH_4^+ concentration in the river was high during winter due to higher temperatures in summer which are conducive for the nitrification process, a phenomenon which Vaishali and Punita (2013) alluded to. In the present study, higher NH_4-N in winter were consistent with Charkhabi and Sakizadeh (2006) and depict the typical conditions of unpolluted natural system. Several authors have reported similar results to those of the present study (Vaishali and Punita, 2013; Duan *et al.,* 2016). Changes in local hydrologic conditions between dry and wet seasons affect the concentrations of NH_4^+, with the high flow periods significantly diluting NH_4-N. Furthermore, there are fewer aquatic species present in the water during the dry season which utilise NH_4-N (Duan *et al.,* 2016).

On the other hand, both KJEL-N and NO_3+NO_2-N showed similar seasonal trends, with significantly lower concentrations in summer than in winter (Table 3-3). KJEL-N ranged from 1.86±0.03mg/l to 2.63±0.17; whereas, NO_3+NO_2-N ranged from 1.37±0.04 mg/l to 2.23±0.04 mg/l throughout the study. Nitrogen (N) levels are generally low during high flow periods due to dilution (Mei *et al.,* 2014). Results of several other studies (Kuyeli *et al*., 2009; Poudel *et al.,* 2013) agree with the findings of this study. Nitrogen is introduced into the river systems mainly through runoff from agricultural fields that are fertilised with inorganic fertilizers (Soko and Gyedu-Ababio, 2015). However, a higher intake of nitrates by microalgae in wet season may result in lower concentrations in summer (Pullanikkatil *et al*., 2015).

Both PO_4-P and P-Tot were significantly lower in summer than in winter (Table 3-3). For both parameters, the mean values in spring and autumn were similar. Phosphate showed to be higher in wet seasons due to washing out of nutrients from fertilised agricultural fields (Mishra and Tripathi, 2007; Bu *et al.,* 2010). The lower concentrations found during summer in this study can be explained by the fact that most cultivated land along Pienaars River is dryland agriculture/ farming, which implies minimal application of fertilizers. This suggests that there could be another source of phosphate during winters as slightly higher concentrations are observed in this season. Charkhabi and Sakizadeh (2006) showed the mean concentrations of total phosphate increasing from summer to the winter season in all the sampling stations. The lower biological processes in autumn and winter seasons (Rossouw *et al.,* 2005). may be used to explain the rise in phosphate levels during the dry season.

Most parameters displayed significant differences among the seasons. Generally, the water quality was better during the high flow period due to rainfall dilution effect. Xia *et al*. (2010) noted that contaminants with higher concentrations in low-flow periods and low concentrations in high-flow periods tend to be from a constant point source discharge, while the inverse trend is associated with inputs from non-point sources transported through run-off during high-flow periods. Overall, DMS, TAL and Si showed strong seasonal variation whereas F was the least influenced by seasonality.

3.4.2.2. Temporal trend analysis

The objective of trend analysis was to determine whether the level of pollution has increased or decreased over the study period. The data was grouped into five-year intervals and analysed for variations. Overall, all the elements showed significant differences ($p<0.05$) between the different year intervals (Table 3-4).

Table 3-4: Mean (±S.E) of water quality parameters per 5 year-interval on the Pienaars River as measured on a monthly basis by the Department of Water and Sanitation (DWS) between 1980 and 2015.

Year interval	Ca (mg/l)	Cl (mg/l)	DMS (mg/l)	EC (mS/m)	F (mg/l)	K (mg/l)	KJEL N (mg/l)	Mg (mg/l)	Na (mg/l)	NH_4-N (mg/l)	NO_3+NO_2-N (mg/l)	P-tot (mg/l)	pH	PO_4^{-3}-P (mg/l)	Si (mg/l)	SO_4^{-2} (mg/l)	TAL (mg/l)
1980-1985	$28.66\pm0.00^{a,b}$	42.53±0.25c	347.58 ± 1.32^{a}	51.04 ± 0.18^{d}	0.38 ± 0.00^{d}	6.74 ± 0.05^{b}	2.53 ± 0.05^{c}	20.02 ± 0.05^{e}	39.39 ± 0.26^{c}	1.11 ± 0.03^{d}	2.11 ± 0.04^{e}	1.40 ± 0.03^{e}	7.86 ± 0.01^{b}	1.19 ± 0.02^{e}	4.86 ± 0.05^{c}	39.70 ± 0.32^{c}	127.76 ± 0.37^{b}
1986-1990	$30.25\pm0.16^{c,d}$	49.75±0.33e	361.63 ± 1.85^{b}	52.05 ± 0.25^{e}	0.35 ± 0.00^{c}	8.29 ± 0.06^{f}	1.96 ± 0.05^{b}	16.66 ± 0.06^{b}	45.84 ± 0.35^{e}	0.82 ± 0.04^{c}	2.53 ± 0.05^{f}	1.08 ± 0.03^{d}	7.77 ± 0.01^{a}	0.78 ± 0.02^{d}	5.13 ± 0.07^{d}	44.11 ± 0.41^{d}	124.41 ± 0.53^{a}
1991-1995	29.93 ± 0.21^{c}	54.73 ± 0.49^{f}	386.05 ± 2.59^{c}	53.74 ± 0.33^{f}	0.48 ± 0.01^{e}	9.31 ± 0.09^{g}	1.91 ± 0.06^{b}	16.03 ± 0.11^{a}	53.19 ± 0.53^{f}	0.41 ± 0.03^{a}	1.22 ± 0.07^{b}	0.56 ± 0.02^{b}	8.47 ± 0.02^{f}	0.31 ± 0.01^{a}	3.26 ± 0.07^{a}	43.39 ± 0.50^{d}	141.11 ± 0.97^{d}
1996-2000	$30.55\pm0.13^{d,e}$	34.98 ± 0.36^{a}	346.86 ± 1.63^{a}	47.62 ± 0.22^{a}	0.33 ± 0.00^{b}	6.19 ± 0.06^{a}	$1.53\pm0.04^{a,b}$	17.92 ± 0.11^{c}	34.91 ± 0.35^{a}	0.40 ± 0.03^{a}	1.49 ± 0.05^{c}	0.69 ± 0.03^{c}	8.40 ± 0.01^{e}	0.42 ± 0.02^{c}	4.27 ± 0.07^{b}	37.00 ± 0.26^{b}	144.74 ± 0.72^{e}
2001-2005	28.43 ± 0.13^{a}	44.53 ± 0.27^{d}	345.27 ± 1.44^{a}	50.24 ± 0.19^{c}	0.31 ± 0.00^{a}	8.07 ± 0.05^{e}	1.45 ± 0.03^{a}	16.61 ± 0.09^{b}	40.59 ± 0.31^{d}	0.38 ± 0.02^{a}	$1.08\pm0.03^{a,b}$	0.34 ± 0.01^{a}	8.37 ± 0.01^{e}	$0.25\pm0.01^{a,b}$	4.09 ± 0.05^{b}	$36.26\pm0.24^{a,b}$	134.76 ± 0.64^{c}
2006-2010	30.92 ± 0.11^{f}	42.86 ± 0.31^{c}	350.05 ± 2.17^{a}	48.98 ± 0.19^{b}	0.32 ± 0.00^{a}	6.99 ± 0.06^{c}	$1.73\pm0.06^{a,b}$	18.38 ± 0.10^{d}	36.07 ± 0.34^{b}	0.56 ± 0.03^{b}	0.93 ± 0.03^{a}	0.41 ± 0.02^{a}	8.13 ± 0.01^{c}	0.39 ± 0.01^{c}	5.13 ± 0.10^{d}	35.13 ± 0.25^{a}	141.08 ± 0.68^{d}
2011-2015	28.88 ± 0.17^{b}	38.68 ± 0.25^{b}	357.64 ± 2.18^{b}	48.98 ± 0.23^{b}	0.34 ± 0.00^{c}	7.18 ± 0.07^{d}	3.12 ± 0.37^{d}	18.25 ± 0.10^{d}	39.34 ± 0.39^{c}	1.12 ± 0.05^{d}	1.94 ± 0.06^{d}	0.38 ± 0.02^{a}	8.31 ± 0.01^{d}	$0.37\pm0.02^{b,c}$	5.51 ± 0.04^{e}	$36.24\pm0.23^{a,b}$	147.70 ± 0.76^{f}

Values with different letters within each column indicate significantly different means as separated by Duncan's Multiple Range Test (DMRT) at *p= 0.05*

Most parameters fluctuated inconsistently during the period under study with no clearly defined temporal trend. Although significant differences were shown between certain year intervals, the lack of a distinct overall trend in the concentrations of each parameter points to the fact that these parameters were non-cumulative but rather a function of the season's qualities and the extent of contamination from other human activities on a year-to-year basis. However, Cl^-, DMS, EC, F, Mg, NO_3+NO_2-N, P-Tot, PO_4^{-3} and SO_4^{-2} had significantly lower concentrations in the period 2011-2015 than 1980-1985 period (Table 3-4).

One of the most striking trend observed was that the 1990-1995 period recorded the highest concentrations in approximately 45% of the water quality parameters, their mean concentrations were also significantly different from the rest of the year groups. The parameters excluded Ca, KJEL N, Mg, NH_4 NO_3+NO_2-N, PO_4^{-3}-P, Si, SO_4^{-2}, TAL and P-tot (Table 3-4). This observed temporal trend in water quality cannot be isolated from inter-annual weather conditions, which also affected seasonality trends. The observations might be related to severe El Nino-related drought conditions experienced in South Africa between 1992 and 1995 (Baudoin *et al*., 2017). A strong El Nino Southern Oscillation (ENSO) which also triggered severe drought might have been a contributing factor to poor water quality conditions observed during this period. These drought events are, however, not a rare phenomenon in South Africa, ffour drought events have been experienced since 1980 including the most recent in 2015-2016 (Baudoin *et al*., 2017).

The lack of distinct temporal trend in water quality in almost all variables in this study may have been masked by significant spatial variations observed in the different stations. Thus, temporal variability may also have been influenced by changes in land use over the study period. The google earth imagery of study site which goes as far back as 1984 showed variation in the general landscape. The developed areas (especially around the Roodeplaat Dam, Silverton and Mamelodi Township) have continued to expand, and more structures have been built close to the river. Most of the naturally vegetated lands have remained relatively intact although the density of vegetation has shrunk and become fragmented, including the riparian vegetation now show evidence of erosion. The riparian vegetation acts as a buffer, preventing the river from flooding but also traps sediments and absorb potentially contaminated runoff which can end up in the stream. There was also a clear decline in stream volume, potentially due to high demands for water. Huang *et al*. (2010) examined spatial variation of water pollution in Qiantang River, and revealed that a river system with greater volume and velocity of flow has greater dilution capacity to mitigate contaminant inputs. This suggests that the dilution capacity of Pienaars River to mitigate pollution inputs has decreased over the years, which might be one of the reasons for deterioration observed in some parameters.

3.4.3. Correlation analysis between water quality parameters

The section provides the results of Pearson correlation analysis between various physico-chemical parameters. The data from all river sampling stations were combined to calculate the correlation matrix (Table 3-5). All the parameters showed a positive correlation ($r \geq 0.5$) with one or more other parameters, except for KJEL-N, pH and NH_4-N. There were also a few cases where the parameters displayed inverse relationship or negative correlation, however no parameters have a strong inverse relationship ($r \geq -0.5$).

Table 3-5: Correlation coefficients between the measured parameters on the Pienaars River, with values in bold indicate strong correlation ($r \geq 0.90$).

Parameters	Ca (mg/l)	Cl^- (mg/l)	DMS (mg/l)	EC mS/m	F (mg/l)	K (mg/l)	KJEL-N (mg/l)	Mg (mg/l)	Na (mg/l)	NH_4-N	NO_3+N O_2-N	P-Tot (mg/l)	pH	PO_4-P (mg/l)	Si (mg/l)	SO_4^{-2} (mg/l)	TAL (mg/l)
Ca	1																
Cl^-	0.52*	1															
DMS	0.81*	0.80*	1														
EC	0.75*	0.85*	**0.95***	1													
F	0.15*	0.18*	0.18*	0.17*	1												
K	0.47*	0.88*	0.77*	0.81*	0.08*	1											
KJEL N	0.12*	0.14*	0.21*	0.21*	-0.01	0.15*	1										
Mg	0.44*	0.00	0.37*	0.30*	0.11*	-0.14*	0.05*	1									
Na	0.57*	**0.93***	0.87*	**0.90***	0.21*	**0.92***	0.15*	0.01	1								
NH_4-N	0.15*	0.20*	0.34*	0.32*	-0.07*	0.24*	0.42*	0.06*	0.21*	1							
NO_3+NO_2-N	0.34*	0.33*	0.44*	0.44*	-0.20*	0.39*	0.13*	0.11*	0.39*	0.18*	1						
P-Tot	0.42*	0.47*	0.59*	0.62*	-0.00	0.54*	0.19*	0.21*	0.56*	0.32*	0.55*	1					
pH	-0.07*	0.01	-0.02**	-0.07*	-0.01**	0.02*	-0.04*	-0.10*	0.01	-0.12*	-0.26*	-0.25*	1				
PO_4^{-3}-P	0.36*	0.39*	0.52*	0.55*	-0.06*	0.48*	0.18*	0.22*	0.48*	0.30*	0.51*	**0.95***	-0.24*	1			
Si	0.36*	0.22*	0.38*	0.36*	-0.13*	0.28*	0.12*	0.13*	0.29*	0.21*	0.54*	0.50*	-0.18*	0.46*	1		
SO_4^{-2}	0.58*	0.74*	0.77*	0.79*	0.08*	0.75*	0.12*	0.15*	0.80*	0.15*	0.42*	0.57*	-0.04*	0.51*	0.34*	1	
TAL	0.65*	0.26*	0.68*	0.53*	0.23*	0.22*	0.17*	0.53*	0.34*	0.30*	-0.02*	0.13*	0.10*	0.11*	0.11*	0.18*	1

[*] Correlation is significant at the *$p<0.05$* (2-tailed).

[**] Correlation is significant at *$p<0.01$* (2-tailed).

3.5. Conclusion

This chapter revealed some of the plausible drivers of water quality variability in the Pienaars River, and the following conclusions can be deduced:

The results indicated a plausible effect of build-up of pollutants from upstream to the downstream reaches of the river. The upstream is the most developed part of the river and results revealed that Pienaars River receives a considerable amount of pollutants, particularly from the Baviaanspoort WWTWs. The water quality further deteriorated towards the lower reaches along the gradient as the river passes through different land uses including natural vegetated land, residential areas and sparse agricultural lands which are known sources of pollution. It was therefore concluded that the upstream reaches have significant influence in water quality of the Pienaars River.

The temporal differences in water quality of the river was assessed in terms of seasons and long-term on a yearly basis. The null hypothesis (H_0) which assumed that water quality does not change between seasons was rejected as the results confirmed or showed a significant seasonal variation of the water quality parameters during the study period. The water quality at Pienaars River was clearly influenced by seasonality. The poor water quality conditions were particularly observed in the dry winter season, and this was observed for most parameters. Generally, the water quality was better during the high flow period due to rainfall dilution effect. Overall, DMS, TAL and Si displayed strong seasonal variation while F was the least influenced by seasonality.

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Chapter 4 : Evaluation of Water Quality Status of the Pienaars River

4.1. Abstract

Freshwater is the most indispensable natural resource for human life, with many purposes that range from supporting daily human livelihoods to sustaining functional natural ecosystems and various economic developments. The quality of freshwater can constrain the use of such resources. Many countries including South Africa have developed water quality guidelines which are used to inform the quality requirements for the specific water uses. This study was carried out on the Pienaars River, in the Limpopo Water Management Area (WMA), South Africa. The objective of this study was to assess the water quality status of the Pienaars River and the suitability of the river for drinking, aquatic life, irrigation and recreational uses based on the compliance of the results against South African and international water quality guidelines. The water samples were collected from eight different stations along the river in February 2017 and were analysed for selected physio-chemical and microbiological water quality parameters. The study revealed that some parts of the river are not suitable for domestic and irrigation purposes according to the water quality guidelines. The computed Water Quality Index (WQI) for the river was 86.32, which implies that the river was in a good condition during the period of study. Although this suggests the water quality is acceptable for drinking, some form of treatment may still be required before use. However, in terms of the other water uses such as recreation and aquatic use, no potential risks were identified.

4.2. Introduction

Freshwater is the most indispensable natural resource for human life (Baron *et al.,* 2003; Abdel-Satar *et al*., 2017), with many purposes that range from supporting daily human livelihoods to sustaining functional natural ecosystems and various economic developments. It is however, the quality of the water that determines its suitability for intended use. Different water uses have different quality requirements, for instance river water may be suitable for irrigation and yet considered unfit for domestic consumption without prior treatment. Thus, the chemical composition of water is essential in understanding its suitability for various usages. Since not all accessible water resources are appropriate for all beneficial uses, one needs to be aware of the set standards of water quality for each specific use.

The suitability of water is assessed by determining its physical, chemical, and biological constituents as well as the general aesthetic condition (Raman *et al*., 2009). Based on the quantity and nature of the constituents in the water, fitness of water for its various use can be classified into four distinct categories, namely: ideal, acceptable, tolerable and unacceptable (DWA, 2011). Water quality is ideal if the water is not affected in any way and is fit for use at all times. When the water resource's quality is moderately transformed from its natural condition it is considered acceptable, while significant transformation falls under the tolerable category. Lastly, unacceptable water quality is extremely contaminated water that cannot be used for its intended use (DWA, 2011). In this study, both national and international water quality guidelines were used to assess the suitability of Pienaars River water for various purposes, which include irrigation, domestic, ecosystem and recreational.

Water that does not meet the desired quality may have ripple adverse effects on the users and ecosystem health in general. In drinking water, microbiological pollution is a prime water quality concern, especially in developing countries (Sorlini *et al.,* 2013). On a global scale, the presence of chemical constituents such as fluoride and arsenic pose a great health concern (Sorlini *et al.,* 2013). The public health threat of these elements in drinking water far exceeds that of other chemical pollutants (Sorlini *et al.,* 2013). For irrigation water, quality has a significant impact on crop productivity and determines the kind of crops that can be grown successfully. The main chemical constituents of concern in irrigation water include sodium (Na), amount and kind of dissolved salts, abundance of nutrients, pH levels, and trace elements (DWAF, 1996a). The water quality suitable for aquatic ecosystems is determined by toxic constituents (i.e. Manganese (Mn), Fluoride (F), Copper (Cu)), non-toxic inorganic constituents (i.e. total dissolved solids (TDS)), system variables (i.e. pH, dissolved oxygen (DO)) and concentration of nutrients (i.e. nitrate (NO_3^-), ammonia (NH_3)) (DWAF, 1996b). Some of the mentioned constituents are associated with a certain level of threat, as they may disrupt essential ecosystem or ecological processes and overall aquatic ecosystem structure depending on their concentration. Monitoring for microbial contamination of water that is used for recreational purpose, especially with human contact is crucial (ANZECC and ARMCANZ, 2000). The suitability for recreation water quality should be assessed based on human safety, potential health and aesthetic impacts of the water (DWAF, 1996c). It is therefore imperative to assess the suitability of using any water resource for any activities such as those mentioned herein.

It is evident that the impacts that population growth, urban expansion, agricultural practices, industrialisation and climate change pose on the natural water systems raise serious concerns about the ability of these resources to continue providing ecosystem goods and services. The key to effective management of water resources is, therefore, to ensure that the water quality is suitable for the intended uses, while allowing the resources to be utilised and developed (Abbaspour, 2011). This implies that socio-economic development should be balanced with resource protection (Abbaspour, 2011) which may not always be feasible. Many countries have instigated river water quality monitoring and assessment systems in an effort to obtain adequate and reliable data on water quality and/or characteristics for effective water pollution abatement and management (Raman *et al*., 2009). The objective of this chapter was to assess the water quality status of the Pienaars River and the suitability of the water for drinking, aquatic life, irrigation and recreational uses based on the compliance of the results against South African and international water quality guidelines.

The department is the main entity collecting water quality data and/or monitoring the status of the Pienaars River. While the water quality information about the river is readily available, this information is inconsistent and there is no scientific literature that exists on the analysis of the quality of the river and implications on its various water uses. However, there is a few literatures specifically on the Roodeplaat Dam which studied the water quality of the dam, but not necessarily assessing the water suitability aspects (i.e Silberbauer and Esterhuyse, 2014). Thus, there is information gap about the water quality of Pienaars River as a whole and its suitability for the various water uses. Amongst many other uses of this river are to supply domestic water to Pretoria area, while the two main dams on the river (Klipvoor and Roodeplaat Dam) are known for various water-based recreational activities and agricultural purposes. There are also other informal activities such as swimming, cultural or ritual activities which take place in areas where the river traverses townships and/or villages which were observed during the field work.

4.3. Methods

4.3.1. Study area

Pienaars River originates in the City of Tshwane (Gauteng Province) at 25°55′29.6”S; 28°30′6.8”E and 25°6′14.2”S; 27°33′57.4”E, flows past the Limpopo Province and the river mouth from Gauteng and eventually flows into the Crocodile River in the North-West Province (Cessford and Burke, 2005). The total length of the river is approximately 185 km and its width vary at different locations or sections. The river meanders through different land uses, these include residential, recreational and agricultural land uses. The climatic conditions in the study area are characterised by temperate and semi-arid conditions (DEAT, 2006). Average temperature varies from 18 to 20°C annually, with maximum temperatures experienced during summer months (DWA, 2011) and the Mean Annual Precipitation (MAP) falls between 400 and 800 mm from the western to the eastern parts of the river catchment respectively (DWA, 2011). The vegetation types found in the study area range from bushveld to grassland vegetation types along the gradient of the river. However, the Waterberg Moist Mountain Bushveld, Mixed Bushveld; and North-Eastern Mountain Grassland are the most definitive of the region (Kleynhans *et al*., 2005). In terms of the geology, the river is predominantly situated on the Precambrian Transvaal Supergroup and Cenozoic Quaternary Sediments (Keyser, 1997).

4.3.2. Water sample collection

Water samples were collected on the identified sampling points along the main stem of the Pienaars River (Figure 4-1). The sampling stations were sited at accessible points and strategically selected to encompass the different land use types or identified sources of pollution along the river. The samples were collected during summer (February 2017) at eight sampling locations. Four replicates were collected at each sampling site. Due to difficulties in accessing the same sampling points, no sample were collected during the dry season.

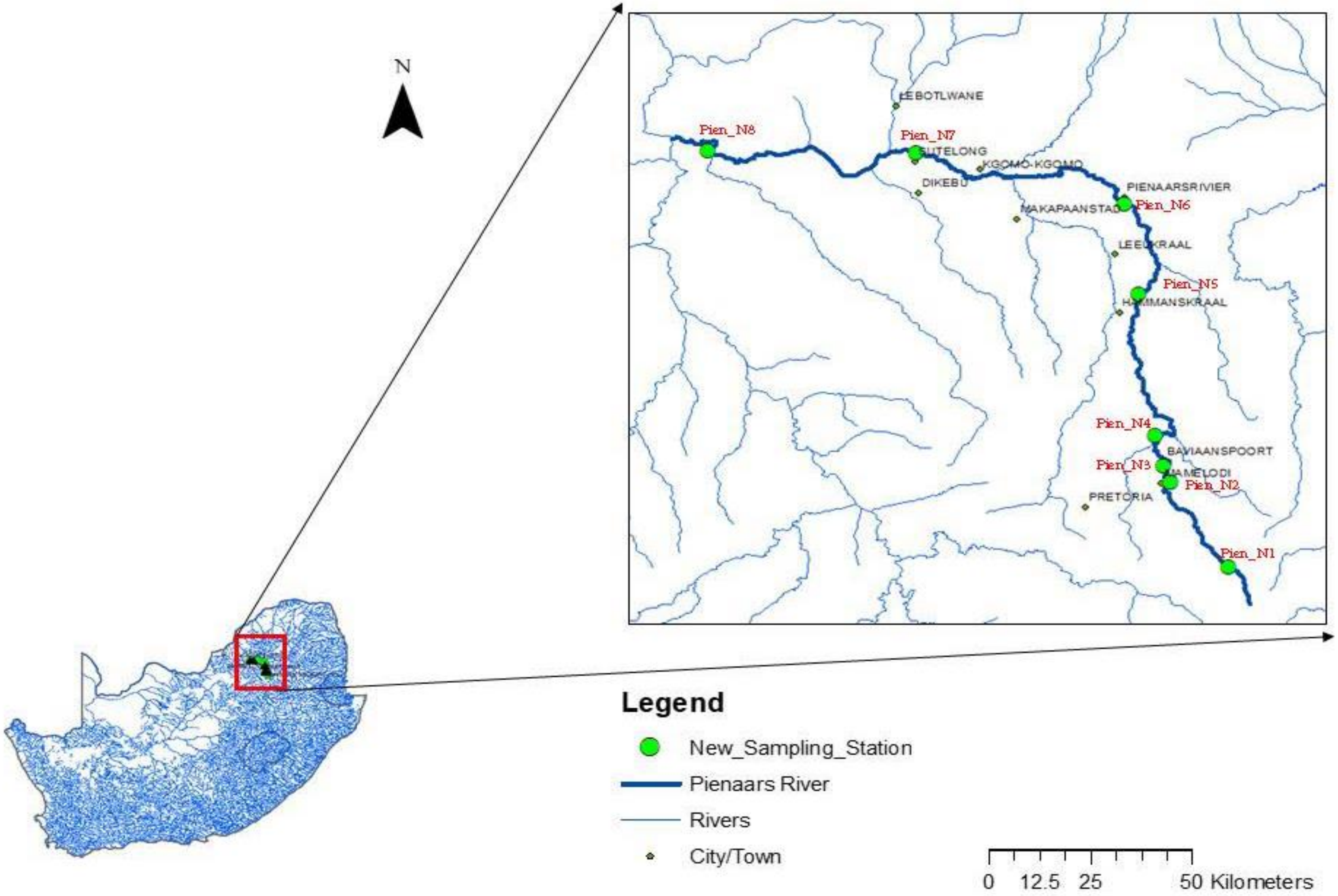

Figure 4-1: Location of the study area (Pienaars River) and the water sampling stations

The aesthetic condition of the river was visually assessed during the collection of water samples in each station. The visual assessment is key to obtaining qualitative evidence about the river's physical conditions or characteristics (DWA, 2009). Visually assessed information includes the colour of the water, activities in close proximity of the river, odour and floating matter.

The samples were collected as per the standard sampling procedures (DWAF, 2009) as summarised in Figure 4-2.

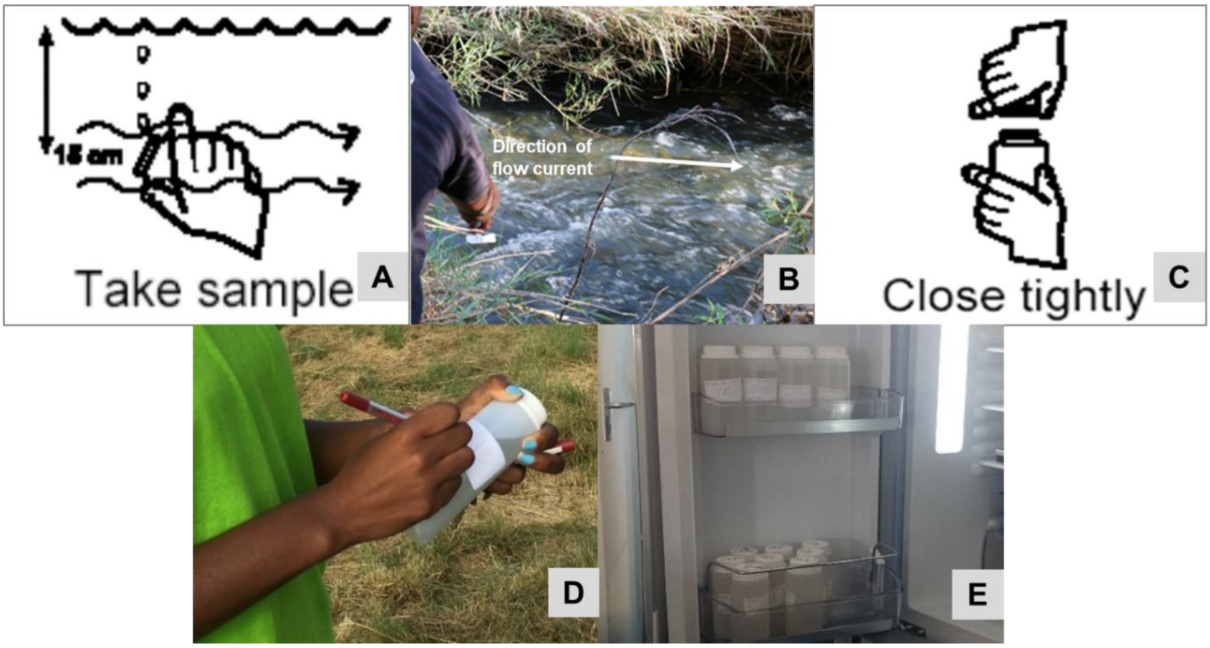

Figure 4-2: Field sampling procedure. Water samples were collected approximately 15cm beneath the surface and mid-way between the surface and the bottom in shallow reaches of the stream (A). Samples were collected in slow-moving water and against the direction of flow of the stream (B). Containers were sealed immediately once filled to prevent potential contamination of the samples (C). Sample containers were labelled and placed in an insulated cooler containing ice and transported to the laboratory (D), and refrigerated at 4°C until analysis (E)

4.3.3. Methods of analysis

4.3.3.1. Parameters analysed

The water samples were analysed at the Agricultural Research Council (ARC) laboratory based in Pretoria. To meet the objectives of this study, a total of 16 parameters were analysed (Table 4-1). All parameters were analysed at the laboratory except for temperature, which was measured with a portable electronic thermometer in the field during sampling.

Table 4-1: Selected water quality parameters and their methods of analysis

Parameters	Abbreviations	Units	Method of Analysis
pH	pH	pH unit	pH probe
Electric Conductivity	EC	mS/m	EC meter
Calcium	Ca	mg/l	ICP-OES[3]
Magnesium	Mg	mg/l	ICP-OES
Sodium	Na	mg/l	ICP-OES
Potassium	K	mg/l	ICP-OES
Boron	B	mg/l	ICP-OES
Fluoride	F	mg/l	ICP-OES
Chloride	Cl^-	mg/l	ICP-OES
Nitrite	NO_2^-	mg/l	ICP-OES
Nitrate	NO_3^-	mg/l	ICP-OES
Sulphate	SO_4^{-2}	mg/l	ICP-OES
Phosphate	PO_4^{-3}	mg/l	ICP-OES
Total Coliform	TC	CFUs/100 mL	Standard plate count method[4]
Escherichia coli	*E.coli*	CFUs/100 mL	Standard plate count method
Fungi	Fungi	CFUs/100 mL	Standard plate count method

4.3.3.2. Laboratory analysis

Physical parameters - Both pH and EC were measured using portable probes. The probes were rinsed with distilled water and submerged into the sample to take the readings, rinsed again before taking another reading on the next sample.

Chemical Parameters - An aliquot of the water sample was used for the ICP-OES (Inductively Coupled Plasma Optical Emission Spectrometric) determination of chemical parameters (Table 4-1). The ICP-OES is a multi-element instrument. The instrument used is an Agilent 725 (700 Series) simultaneous instrument, where all the elements (and all wavelengths) are determined simultaneously. Several elements were determined at more than one wavelength, allowing confirmation of the values, with no increase in analysis time or consumption of digest solution. Each element was measured at one or two appropriate emission wavelengths, chosen for high sensitivity and lack of spectral interferences.

[3] Agilent Technologies, 2010

[4] World Health Organization, 2011a

The instrument was set up and operated according to the recommended procedures in the instrument manual and when conditions had been optimised. The instrument was calibrated against a series of standard solutions, containing all the elements of interest in the proportions found in typical water samples. The method was developed and optimised at the ARC's Institute of Soil, Climate and Water, based on recommended procedures in the instrument manual (Agilent Technologies, 2010).

Biological parameters - The micro biological parameters were measured using the plate count method. The initial dilution was made by transferring 1 ml of the sample to a 99 ml sterile saline blank, this is a 1/100 (or 10^{-2}) dilution. The dilution was shaken to distribute the bacteria and break up any clumps. The 10^{-2} dilution was aseptically transfer 1 ml to a second 99 ml saline blank which is a 10^{-4} dilution of the original sample. The same process was repeated up to 10^{-8} dilution.

From each dilution, 1 ml was transferred onto one petri dish and 0.1 ml to another petri plate. In the plates, dilution samples were carefully mixed with agar that was removed from a 48-50°C water bath. After the mixtures had cooled, they were overturned and incubated at 25°C for 48 hours. After incubation, the petri plates containing between 30 and 300 colonies were selected as plates with more than 300 colonies are considered too many to count, while fewer than 30 colonies are too few to count. The colonies on each plate were counted using a Semi-automatic Digital J-3 colony counter (Chincan, Shanghai) (Reynolds and Farinha, 2005).

The microbial colonies were counted using a Semi-Automatic Digital Displayer J-3 Colony counter (manufactured by Chincan in Shanghai) and results were expressed as number of bacteria per mL, using the equation shown below:

$$\frac{Number\ of\ colonies\ (CFUs)}{Dilution\ X\ Number\ of\ plates} = Number\ of\ Bacteria\ (per\ mL)$$

4.3.4. Data analysis

4.3.4.1. Statistical analysis

One-Way ANOVA was carried out at 5% level of significance to compare the water quality at different sampling stations in SPSS version 25. Statistically significant different means were separated using Duncan's Multiple Range Test (DMRT). A Pearson correlation analysis was also performed to identify water quality parameters that are related to each other.

4.3.4.2. Fitness-for-use

The water quality from the Pienaars River was compared against South African and international water quality guidelines to determine its suitability for various water uses. The fitness of the water for a specific use was classified into four categories as prescribed in the national water quality guidelines (Section 4.1).

4.3.4.3. Water quality index for the river

To examine the overall water quality of the river, the Weighted Arithmetic Water Quality Index (WAWQI) was applied. The effectiveness of using WQI is that it determines the complex influence of each parameter on the overall water quality (Raman *et al.,* 2009). This was achieved through the following steps, based on Sener *et al.* (2017):

i. Selection of parameters for measurement of water quality

Selection of important water quality variables is vital to have a good representation of the water quality status (Edwin and Murtala, 2013). A total of ten physio-chemical parameters were selected to determine the WQI using the standards of drinking water quality recommended by the World Health Organization (WHO) and SAWQGs (Annexure A). The measured parameters are Ca, Mg, F, Na, pH, NO_3^-, EC, NO_2^-, SO_4^{2-} and Cl^-.

ii. Development of a rating scale

The water samples were segregated into five distinct classes with different ratings. The rating scale ranged from excellent to unsuitable based on the water quality guidelines for domestic use (Table 4-2).

Table 4-2: List and description of the fitness for use criteria used to assess the suitability of water for its intended use (Sener *et al.,* 2017)

WQI Range	Classification
<50	Excellent
50-100	Good
100-200	Moderately polluted
200-300	Severely polluted
>300	Unsuitable for drinking

iii. Determination of the rating scale

The quality rating scale (Qi) for each parameter was calculated as follows:

$$Qi = \left(\frac{Ci}{Si}\right) \times 100$$

Where,

- Ci is concentration for each water quality parameter; and
- Si is the respective standard, based on the South African Water Quality Guideline for Domestic Use and the World Health Organization (WHO)'s guidelines for drinking water.

iv. Estimation of the unit weight of each indicator parameter

The relative weight (Wi) of each parameter was computed using the following equations:

$$Wi = \frac{1}{Si}$$

Where,

- Wi is the unit weight for each water quality parameter; and
- Si is the respective standard.

v. Calculation of the overall WQI

This index method is calculated using the following mathematical expression:

$$WQI = \sum QiWi / \sum Wi$$

Where,

- Wi is the unit weight for each water quality parameter; and
- Qi is the quality rating scale for each parameter.

Detailed calculations of the WQI for each sampling station, based on the selected parameters is shown in Annexure H.

4.4. Results and Discussion

Water quality varied from one sampling site to another. In some cases, the impacts of the adjacent environment or surrounding human activities was clearly evident in the water quality observed at each site. The visual or aesthetic conditions of the sampling stations ranged from muddy coloured water (Pien_N5 to 8), eutrophication (Pien_N4), clear water (Pien_N1), bad odour (Pien_N3) and floating matter (Pien_N2) (Figure 4-3).

Figure 4-3: Water sampling stations – Pien_N1: Tiepoort, Pretoria east; Pien_N2: Mamelodi township, Pretoria; Pien_N3: Baviaanspoort, Pretoria north; Pien_N4: Roodepoort Dam, Pretoria north; Pien_N5: Dinokeng Nature Reserve north of Pretoria; Pien_N6: Piennarsrivier town; Bela-Bela, Pien_N7: Morelete town, Brits and Pien_N8: Assen, Brits

4.4.1. Spatial variation in water quality

This section provides the results of spatial variation in water quality between the different stations (Table 4-3).

Table 4-3: Mean (±SE) values of the water quality parameters for each sampling station on the Pienaars River, based on sampling carried out in February 2017, the values with different letters in each column indicate significantly different means for each parameter as separated by Duncan's Multiple Range Test at p= 0.05 and ND indicates parameters that are not detected

Station	Ca (mg/l)	Temp (°C)	Mg (mg/l)	Na (mg/l)	K (mg/l)	B (mg/l)	pH	EC (mS/m)	F (mg/l)	Cl^- (mg/l)	NO_2^- (mg/l)	NO_3^- (mg/l)	SO_4^{-2} (mg/l)	PO_4^{-3} (mg/l)	TC (CFUs/100 mL)	*E. coli* (CFUs/100 mL)	Fungi (CFUs/100 mL)
Pien_N1	16.61±0.01^{a}	19.35±0.75^{a}	12.03±0.02^{b}	7.22±0.01^{a}	0.84±0.01^{a}	0.01±0.00^{a}	8.31±0.01^{a,b}	23.00±0.00^{a}	0.23±0.04^{a}	6.82±0.06^{a}	0.01±0.00	0.70±0.15^{a}	6.93±0.30^{a}	0.01±0.00^{a}	4.50±0.50^{a}	0.00±0.00^{a}	ND
Pien_N2	34.97±5.09^{c}	21.40±0.10^{b}	30.29±0.07^{h}	19.37±0.00^{b}	1.92±0.06^{b}	0.01±0.00^{a}	8.75±0.00^{f}	47.00±0.00^{c}	0.34±0.05^{a,b}	26.76±0.17^{b}	0.01±0.00	12.62±0.14^{c}	32.46±0.44^{b}	0.03±0.02^{a}	22.50±12.50^{c}	0.50±0.50^{a}	ND
Pien_N3	30.45±0.09^{b,c}	22.55±0.55^{b,c}	20.00±0.05^{g}	46.95±0.05^{f}	8.32±0.02^{e}	0.05±0.00^{d}	8.37±0.00^{b}	53.00±0.00^{d}	0.37±0.03^{a,b}	39.21±1.87^{c,d}	0.01±0.00	68.33±1.70^{f}	54.41±0.67^{d}	5.47±1.13^{b}	3.00±1.00^{a}	0.00±0.00^{a}	ND
Pien_N4	31.26±0.06^{b,c}	23.75±0.05^{c,d}	11.33±0.01^{a}	59.68±0.00^{g}	13.85±0.04^{h}	0.07±0.00^{e}	8.34±0.01^{a,b}	54.00±0.00^{d}	0.35±0.03^{a,b}	68.05±0.57^{f}	0.01±0.00	40.73±0.29^{e}	52.57±0.18^{d}	7.10±0.01^{b}	29.50±14.50^{d}	1.00±1.00^{a}	ND
Pien_N5	29.12±0.18^{b,c}	21.45±0.95^{b}	16.24±0.03^{e}	35.07±0.19^{c}	6.58±0.04^{c}	0.03±0.00^{c}	8.47±0.05^{c}	43.00±0.00^{b}	0.48±0.15^{b,c}	38.07±1.60^{c}	0.01±0.00	8.07±0.49^{b}	33.47±0.11^{b}	1.70±0.40^{a}	4.00±0.0^{a}	0.00±0.00^{a}	ND
Pien_N6	28.42±0.01^{b}	23.45±0.05^{c}	16.07±0.01^{d}	36.07±0.00^{d}	6.81±0.02^{d}	0.02±0.00^{b}	8.30±0.00^{a}	43.00±0.00^{b}	0.66±0.03^{c}	41.58±0.45^{d}	0.01±0.00	7.23±0.05^{b}	32.71±0.11^{b}	1.61±0.10^{a}	2.50±0.50^{a}	0.00±0.00^{a}	ND
Pien_N7	41.26±0.01^{d}	25.40±0.70^{d,e}	19.50±0.02^{f}	75.24±0.28^{h}	12.15±0.01^{c}	0.05±0.00^{d}	8.66±0.00^{e}	66.00±0.00^{e}	0.51±0.03^{b,c}	73.80±0.30^{g}	0.01±0.00	24.39±1.60^{d}	58.32±1.21^{e}	6.25±1.32^{b}	2.00±2.00^{a}	0.00±0.00^{a}	ND
Pien_N8	32.68±0.13^{b,c}	26.10±0.10^{e}	14.00±0.04^{c}	45.26±0.65^{e}	9.15±0.07^{f}	0.03±0.00^{c}	8.56±0.00^{d}	47.00±0.00^{b}	0.48±0.01^{b,c}	52.20±0.06^{e}	0.01±0.00	5.93±0.02^{b}	41.68±0.06^{c}	1.20±0.62^{a}	16.50±7.50^{b}	0.00±0.00^{a}	ND

4.4.1.1. Pien_N1

This station had the least concentrations of all water quality parameters except for Mg and TC (Table 4-3). The low levels of water parameters recorded in Pien_N1 suggests that the water quality is relatively good. This is likely to be as a result of the least human influence in this part of the river in terms of the surrounding activities, as it is predominantly natural vegetated land. These results also validate the visual aesthetic qualities of the river in this station observed during the sampling. The water was flowing and clear with no evidence of pollution.

4.4.1.2. Pien_N2

Pien_N2 recorded the second highest TC (22.50 mg/l) after Pien_N4 and *E. coli* (0.50 mg/l) was detected (Table 4-3). Although the occurrence of these bacteria is not exceedingly high, their presence indicates some form of faecal contamination at this station. This was expected as the station is located in Mamelodi Township, the river is used as a refuse dump and a few metres upstream of this station there is a sewer pipeline crossing over the river, although no evidence of leakage from the pipe was observed during the sampling. Similar observations were made in the study by Pullanikkatil *et al.,* (2015), where *E. coli* was detected in the river where it passes through the urban areas, close to the settlements and sewage discharge point.

4.4.1.3. Pien_N3

The nitrate concentration was exceedingly high in Pien_N3 (68.33 mg/l). This station is located approximately 1.8 km downstream of Baviaanspoort WWTWs that discharges directly into the river. The recorded mean concentration was above that of natural conditions in surface water which would normally be between 0 and 18 mg/l (WHO, 2011c). External sources of pollution such as runoff from agricultural fields, refuse dump runoff or contamination from human or animal wastes (WHO, 2011c) are among the major contributors of elevated NO_3- levels in a water system. Meride and Atenew (2016) found industrial effluents to be one of the major sources of nitrate in surface water resources. In this case Baviaanspoort WWTWs is likely to be the point source of NO_3^-.

4.4.1.4. Pien_N4

The highest mean concentrations of K, B, PO_4^{3-}, TC and *E. coli* were recorded at station Pien_N4 (Table 4-3). The Pien_N4 is located on the west of Roodeplaat Dam which receives direct discharges of waste water effluents from Zeekoegat WWTWs, this is the main potential source of TC and *E. coli*. Nutrients such as K and PO_4^{-3} are known to be one of the micronutrients that contributes to algal blooms (Rossouw *et al.,* 2005), which is evident at the dam, hence it is considered to be hyper-eutrophic. Although previous studies suggest that sewage and industrial effluents are rich sources of Cl^- (Nikanorov and Brazhnikova, 2009; Sener *et al.,* 2017), this station did not have the highest Cl^- in this study, same applies for Pien_N3 which is located close to Baviaanspoort WWTW.

4.4.1.5. Pien_N5

Most water quality parameters were generally of acceptable concentrations. Pien_N5 is stationed within the boundary of Dinokeng Nature Reserve and approximately 500 m east of Ramotse village. Given the distance between this station and the residential areas, it is unlikely that there is any pollution from the village that ends up in the river, especially in this station. Local residents do not have unauthorised access to this portion of the river, which could be another explanation for reasonable water quality.

4.4.1.6. Pien_N6

No concerning levels of water quality parameters at this station were recorded the period of study. It should however be noted that the amount of F (0.66 mg/l) in WQ 11 was relatively higher than the rest of the stations, but was still within permissible guideline limits. The water quality in the portion of the river is likely to be defined by non-point pollution sources such as runoff. The main land uses that could be main pollution contributors are agricultural fields which are situated on the western parts river and eastern part is natural vegetated land.

4.4.1.7. Pien_N7

In this station, five water quality parameters (i.e. Ca, Na, EC, Cl^- and SO_4^{2-}) were significantly higher than the other stations (Table 4-3). The nature of the landscape and land use where Pien_N7 is located could explain the potential source of impurities measured in this station. High EC is usually associated with a higher anion such as Cl^- and NO_2^- ions, as well as cations such as Ca and Mg in the water (Babovic *et al.,* 2011). This characteristic was clearly noticed in this study, where the candidate anions and cations recorded in Pien_N7 were relatively higher in comparison to the other stations. The Pien_N7 is located on an open grassland, appeared to be degraded due to overgrazing. The colour of the river was also muddy due to sparse riparian vegetation and increased sediments washing into the river. This is a potential key factor facilitating the transfer of pollutants trapped in sediments from land into the river and increasing EC levels and other impurities indicated above. The low TC and absence of *E. coli* counts in Pien_N7 sampling station was however, unexpected, as the area adjacent to this sampling station is an open grassland park, grazed by cattle and a few piles of cow dung were observed along the riparian zone which could have contributed to faecal contamination at this station.

4.4.1.8. Pien_N8

The water quality at this station was relatively good, with pH, EC and TC exceeding some of the guideline thresholds which is discussed in Section 4.4.3 with respect their suitability for different uses. It is however, worth noting that the TC recorded ion this station was among the highest (16.50 mg/l) of the sampled areas (Table 4-3). Total Coliform (TC) is derived from both faecal and non-faecal sources (including soil) (EPA, 2001). This site is characterised by agricultural fields, therefore the TC recorded could be from both soil and faecal sources potentially from livestock. Nutrient water quality parameters (NO_2^-, NO_3^-, PO_4^{3-} and K) were expected to be high in this station due to potential runoff from the agricultural fields located upstream of this station.

4.4.2. Correlation analysis between water quality parameters

The data from all river sampling stations were combined to calculate the correlation matrix shown in Table 4-4. At least all the water quality parameters showed a significant positive correlation ($r \geq 0.5$) with one or more other parameters. There were a few cases of strong positive correlation ($r \geq 0.9$) between K – B, K – Cl^-, PO_4^{-3} – B and EC – SO_4^{2-}. There were also a few cases where the parameters displayed inverse relationship or negative correlation, however none of these showed a strong inverse relationship ($r \geq - 0.5$).

Table 4-4: Correlation coefficients between the measured parameters on the Pienaars River, with values in bold indicate strong correlation r ≥ 0.90

Parameters	Ca (mg/l)	Temp (ºC)	Mg (mg/l)	Na (mg/l)	K (mg/l)	B (mg/l)	pH	EC (mS/m)	F (mg/l)	Cl^- (mg/l)	NO_3^- (mg/l)	SO_4^{-2} (mg/l)	PO_4^{-3} (mg/l)	TC (CFUs/100 mL)	*E. coli* (CFUs/100 mL)
Ca	1														
Temp	0.67*	1													
Mg	0.47	-0.11	1												
Na	0.39	-0.14	0.58**	1											
K	0.56**	0.75*	-0.34	-0.29	1										
B	0.45	0.53**	-0.29	-0.27	**0.92***	1									
pH	0.68*	0.27	0.73*	0.47	-0.05	-0.12	1								
EC	0.89*	0.71*	0.29	0.04	0.78*	0.73*	0.44	1							
F	0.31	0.57**	-0.01	-0.24	0.31	0.03	0.06	0.32	1						
Cl^-	0.73*	0.83*	-0.14	-0.17	**0.95***	0.82*	0.20	0.87*	0.41	1					
NO_3^-	0.26	0.15	0.09	-0.07	0.49	0.71*	-0.16	0.54**	-0.16	0.35	1				
SO_4^{-2}	0.78*	0.71*	0.13	-0.06	0.86*	0.84*	0.24	**0.95***	0.27	0.87*	0.70*	1			
PO_4^{-3}	0.44	0.44	-0.19	-0.23	0.84*	**0.92***	-0.12	0.73*	0.08	0.76*	0.75*	0.82*	1		
TC	0.05	0.09	0.05	-0.01	0.16	0.16	0.18	0.11	-0.22	0.17	0.05	0.12	0.06	1	
E. coli	0.01	-0.00	0.01	-0.08	0.20	0.27	0.02	0.14	-0.21	0.18	0.17	0.14	0.23	0.87*	1

[*] Correlation is significant at $p<0.05$ (2-tailed)

[**] Correlation is significant at the $p<0.01$ (2-tailed).

Fungi was not detected in all the stations and nitrite could not be computed as the mean values (0.01) were constant in all the stations.

4.4.3. Fitness for use

The mean water quality indices for each parameter at each sampling station (see Annexure H) were compared with the relevant South African Water Quality Guidelines (SAWQGs) and international guidelines to determine the suitability of the Pienaars River water and if the parameters tested were within the permissible limits. It is important to note that not all parameters had recommended limit values for either of the following reasons (WHO, 2011b):

- the parameter occurs in water at concentration below those of concern;
- available data is inadequate to permit derivation of guideline limit;
- when the parameter or chemical is seldom found in water; and
- parameters that degrade rapidly; hence are not expected to occur in measurable amounts.

The suitability of the measured water quality parameters is detailed below according to their similar properties.

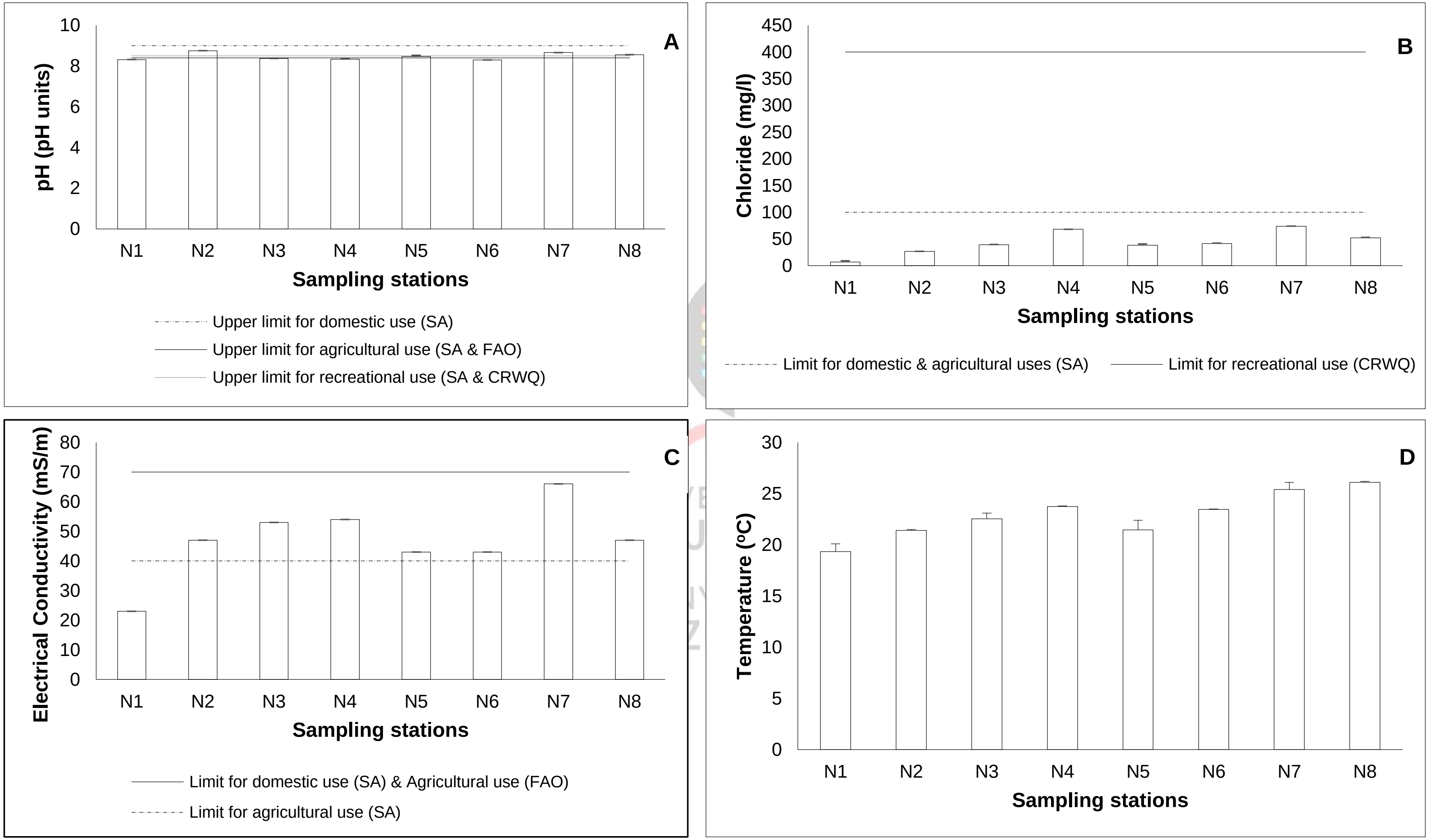

Figure 4-4: Mean (±SE) of pH (A), chloride (B), electrical conductivity (C) and temperature (D) recorded for eight sampling stations on the Pienaars River

The mean pH varied from 8.30 at sampling site Pien_N6 to 8.75 at Pien_N2 (Figure 4-4 A), which suggest that the water is alkaline. Only two stations (Pien_N5 and N2) had pH values that exceeded the recommended upper range (8.4), at pH 8.47 and 8.75 respectively for irrigation use. High pH can affect nutrient uptake by plants and decreases crop yield (DWAF, 1996a). Therefore, water in Pien_N5 and N2 could potentially pose a risk to agricultural uses. For recreational usage, only Pien_N2 exceeded the permissible limit (8.5). The SAWQGs also sets the limits of pH from 6 to 9 for domestic use (DWAF, 1996d) and all the sampling sites were within the objective range. Although no guideline specifies the acceptable limit suitable for aquatic ecosystems, a pH range of 6.5–8.0 is however suitable for the majority of the different aquatic species and biodiversity decline can be expected where pH is not within this range (Babovic *et al*., 2011).

Chloride (Cl^-) concentration ranged between 6.82 and 73.80 mg/l (Figure 4-4 B). The observed concentrations were within the ideal threshold of 100 mg/l for domestic and agricultural use (DWAF, 1996a). However, the SAWQGs state that the human health effects can only be experienced at very high concentrations (i.e. >1 200 mg/l: DWAF, 1996b). South Africa guidelines for recreation do not specify the recommended Cl^- concentration; however, the ANZECC and ARMCANZ (2000) allows for a concentration of up to 400 mg/l and none of the stations exceeded this limit. Based on the above-mentioned guidelines, the amount of Cl^- in the water would not have negative impacts on its suitability for irrigation, domestic and recreational purposes.

The EC ranged from 23 to 66 mS/m in site Pien_N1 and N7 respectively with an average of 47 mS/m (Figure 4-4 D). From an agricultural use perspective, the EC was within the prescribed limit of 70 mS/m for FAO guideline in all the stations but exceeded the limit of 40 mS/m stipulated in the SAWQG for agricultural use except for Pien_N1. Overall no adverse impacts are likely to arise from the recorded EC concentrations. However, some form of treatment may still be required prior to application, especially when used to irrigate salt-sensitive crops (DWAF, 1996a). The SAWQGs requirements for domestic use is the same as FAO guideline value (70 mS/m), therefore the EC values for all the sampling stations were also within permissible threshold for domestic usage.

The mean temperature of the water samples measured on site varied between 19.35ºC in Pien_N1 and 26.10ºC in Pien_N3. None of the water quality guidelines stipulate the temperature thresholds (Figure 4-4 C). However, there are specific temperature requirements to sustain aquatic life. The SAWQG stipulates that the temperature of the water should not be allowed to vary by 2ºC from the daily mean temperature (DWAF, 1996a).

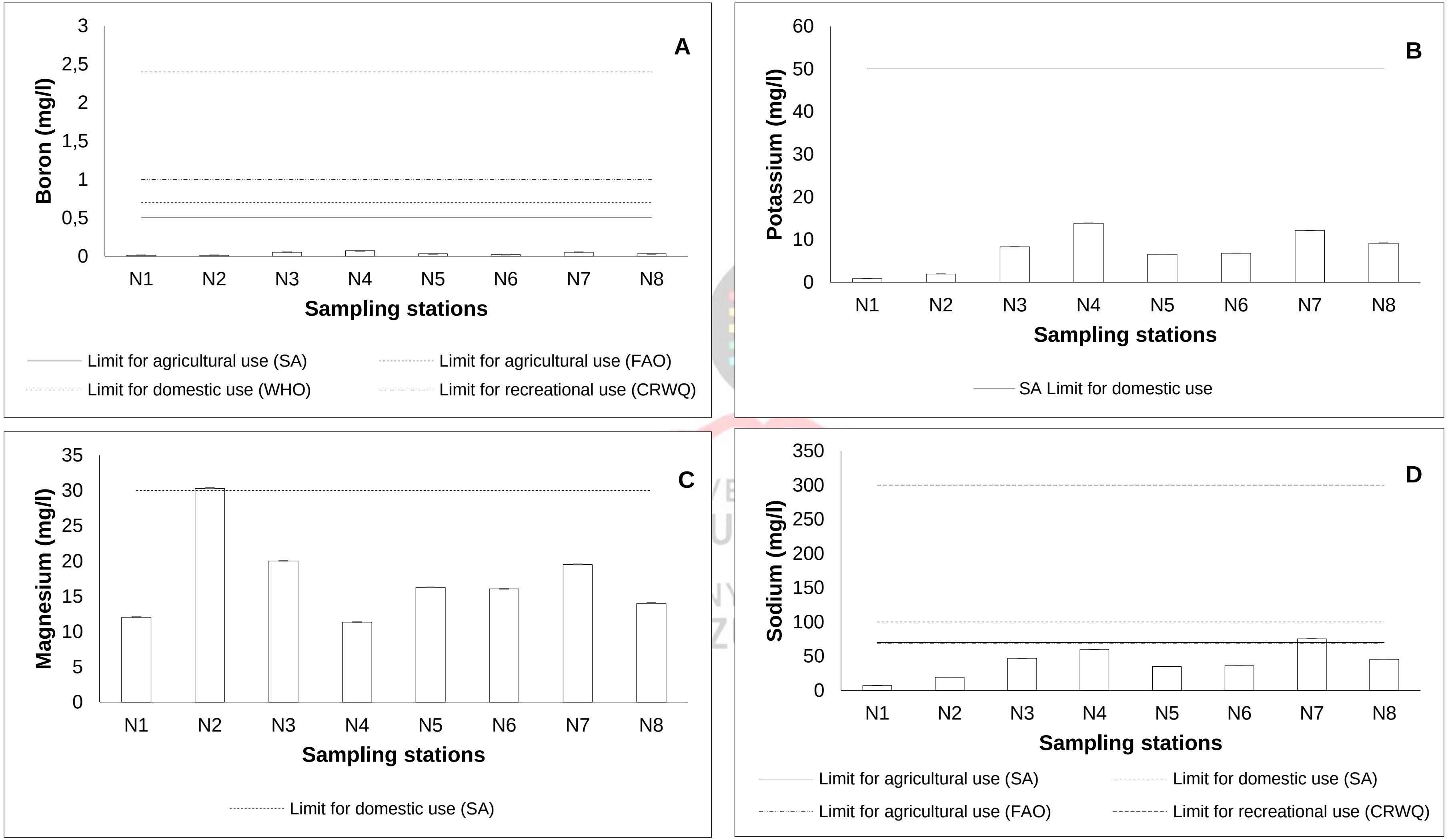

Figure 4-5: Mean (±SE) concentrations of boron (A), potassium (B), magnesium (C) and sodium (D) measured from eight sampling stations on the Pienaars River

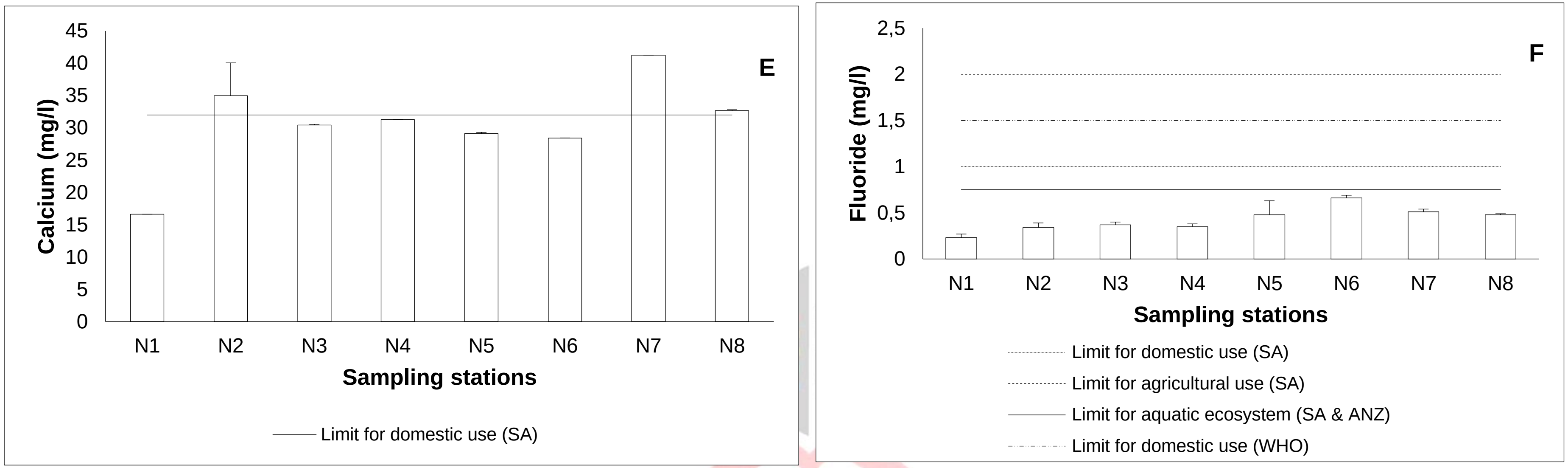

Figure 4-6: Mean (±SE) concentrations of calcium (E) and fluoride (F) measured from eight sampling stations on the Pienaars River

The lowest mean B values, i.e. less than 0.01 mg/l, were observed in two sites: Pien_N1 and N2. This is normal as this metal is generally found in small quantities in water. It is usually less than 0.1 mg/l in freshwater, elevated concentrations are generally indicative of saline conditions (DWAF, 1996a). The highest mean concentration of 0.07 mg/l was recorded at Pien_N4 (Figure 4-5 A), which is still less than the concentration expected in a freshwater system. For irrigation water use, the permissible limit is 0.5 mg/l and 0.7 mg/l for SAWQGs and FAO respectively. In this study, all the observed concentrations were within the permissible limits for both agricultural guidelines. Boron (B) are likely to become toxic to plants above 1.0 mg/l although the level of toxicity may vary from one plant species to another (DWAF, 1996a). The WHO guidelines for drinking water has the highest allowance of 2.4 mg/l followed by 1.0 mg/l limit stipulated in the Canadian guideline for recreational water use (Health Canada, 2012) which were still higher than the concentrations recorded in all the sampling stations. Thus, the concentration of B metal is ideal for recreational and drinking purposes.

The observed mean for K value in the entire river was 7.45 mg/l. The mean concentration per station ranged from a minimum of 0.84 mg/l to a maximum of 13.85 mg/l at Pien_N1 and N4, respectively. Both K values were within the prescribed limit of 50 mg/l for domestic use (Figure 4-5 B). Drinking water with this amount of K is not expected to have aesthetic or human health effects associated with this element. Although the SAWQG states that the ideal limit is 50 mg/l, any concentration between 50 and 100 mg/l is also considered to be relatively acceptable (DWAF, 1996d). However, any concentration beyond 400 mg/l is considered undesirable and dangerous for consumption (DWAF, 1996d).

The mean concentrations of Mg determined in most stations (except for Pien_N2) were within the 30 mg/l recommended limit for domestic use (Figure 4-5 C) and were also consistent with levels of about 100-200 mg/l expected in freshwaters (Chapman, 1996). Magnesium is predominantly derived from the geology of the river catchment through weathering processes and considering the concentrations recorded in all the sampling stations, they are likely to be merely associated with natural processes within the river rather than external sources or inputs.

All the stations had average concentration of Na that was within allowable maximum of 100 mg/l, which is suitable for domestic consumption according to the South African guidelines (Figure 4-5 D). The taste threshold associated Na in water is only from 135 mg/l depending on the other anions present in the water (DWAF, 1996d), although this threshold according to the WHO guidelines is 200 mg/l (WHO, 2003). For irrigation purposes, Na was within the acceptable limit except for Pien_N7 station. The ideal concentration for agricultural use is 70 mg/l in South Africa and 69 mg/l in the FAO guidelines. Sodium (Na) is not recognised as an essential plant nutrient, and when it reaches high levels, it can become toxic to plants (DWAF, 1996a). For recreational use, the SAWQGs do not specify a limit for Na content, but the Canadian guidelines allow for up to 300 mg/l (Health Canada, 2012). In this particular case, its level in all the stations was within the limit.

The mean Ca concentrations for most stations was within the South African permissible level of 32 mg/l for domestic use, except for Pien_N2, N7 and N8 (Figure 4-5 E). Although the Ca levels went as far as 41.26 mg/l at Pien_N7, which is above the typical Ca concentrations in natural waters (15 mg/l) its concentration is still acceptable for drinking purposes (DWAF, 1996b). The water is also not expected to have distinct taste from Ca ions. The concentrations determined in all the stations was within taste threshold, which is between 100 and 300 mg/l, depending on other anions present in the water (WHO, 2011).

Fluoride (F) concentration obtained in this study ranged between 0.23 mg/l and 0.66 mg/l in Pien_N1 and N6 respectively. In South African guidelines, the ideal limit for F in domestic water is 1.0 mg/l, while the WHO guideline stipulates a higher threshold of 1.5 mg/l (Figure 4-5 F). The F values recorded in all the sampling sites had mean concentrations below the limits recommended in both the guidelines. The level of F in drinking water is therefore, not likely to pose health impacts. WHO (2004) states that the intake of drinking water with the concentration above 1.5 mg/l is associated with increased risk of dental fluorosis (WHO, 2004). The concentration of F was also within the permissible limit for the survival of aquatic life (0.75 mg/l) and irrigation purposes (2 mg/l). High concentration of F in irrigation water can affect plant growth when used for irrigation, however this is dependent on the length of exposure; no effects are expected if the exposure is for a very short term and site specific (DWAF, 1996a).

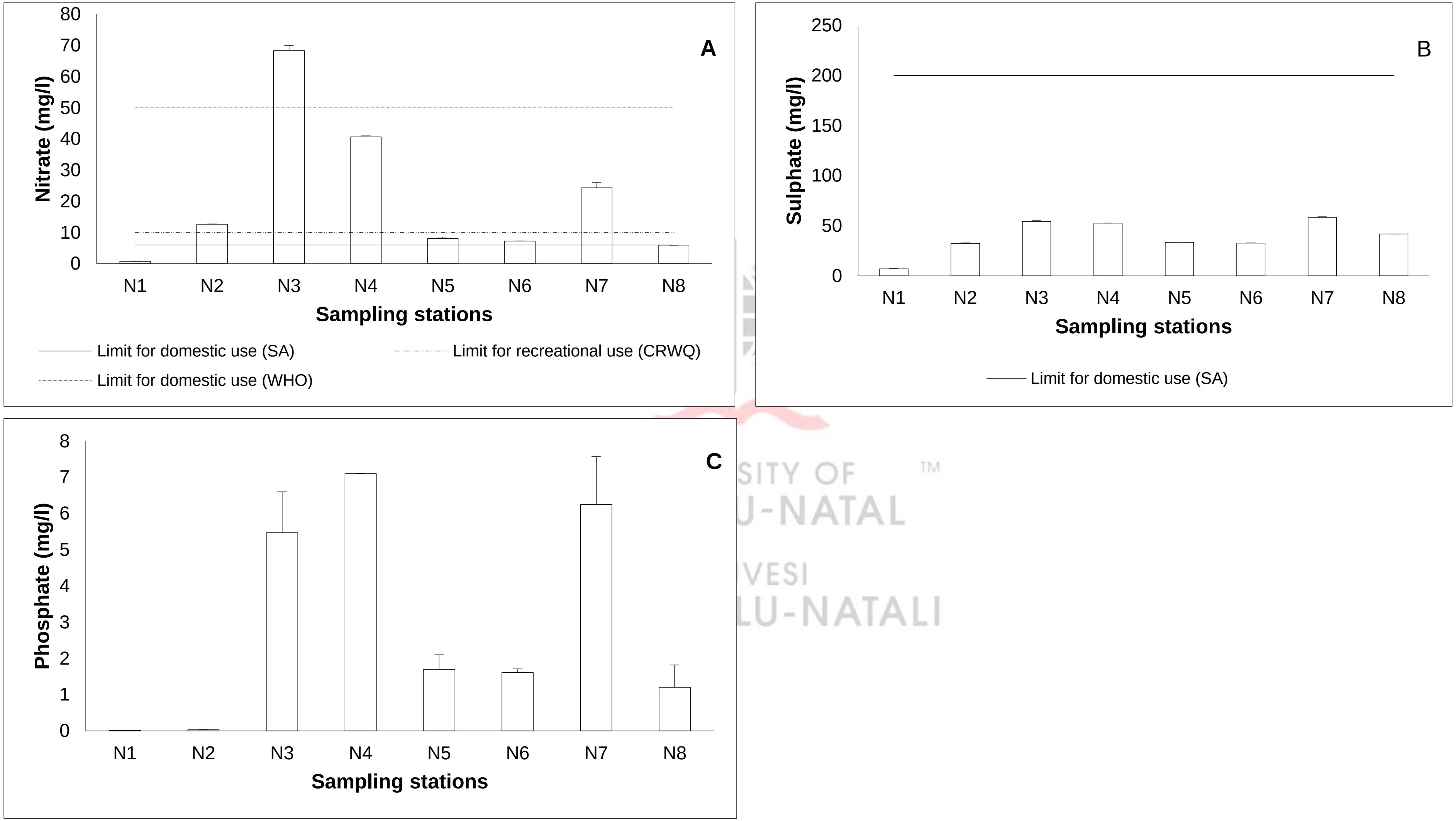

Figure 4-7: Mean (±SE) concentrations of nitrate (A), sulphate (B) and phosphate (C) measured at eight sampling stations on the Pienaars River

Two stations (Pien_N1 and N8) out of the eight stations were found to be desirable for domestic use (< 6 mg/l) in terms of the SAWQGs limits for Nitrate (NO_3^-) (Figure 4-7 A). Although NO_3^- concentration range between 6 and 10 mg/l is still tolerable, concentrations above 20 mg/l are considered unacceptable and three stations exceeded this unacceptable limit (Pien_N3, N4 and N7). Unacceptable levels (>20 mg/l) of NO_3^- are likely to pose health risks if present in drinking water supply, such as mucous membrane irritation (DWAF, 1996d). Contrastingly, in the WHO drinking guideline, the threshold is 50 mg/l, and only site Pien_N3 (68.33 mg/l) exceeded this limit. For irrigation purposes, the FAO stipulates that NO_3^- may not exceed 5 mg/l, this value was exceeded in all the sampling stations except for Pien_N1. South African guidelines do not have a limit for NO_3^- for recreation purposes, while the Canadian guideline stipulates 10 mg/l (Health Canada, 2012) which was exceeded by all stations except for Pien_N1, N5, N6 and N8.

In all eight stations, the mean SO_4^{-2} level was well within the limit for drinking purposes (Figure 4-7 B). The permissible range for SO_4^{-2} in drinking water according to the SAWQG for domestic use is between 0 and 200 mg/l (DWAF, 1996d). According to Chapman (1996), sulphate between 2 and 80 mg/l are typical natural concentrations in freshwater systems, and under anaerobic conditions, bacteria can use it as an oxygen source by converting it to hydrogen sulphide. Noticeable taste associated with SO_4^{2-} in drinking water is only triggered when the concentration exceeds 200 mg/l, depending on the other elements present in the water such as Na, K, Ca or Mg (DWAF, 1996d).

The PO_4^{3-} values ranged within 0.02 to 7.10 mg/l (Figure 4-7 C). There are no stipulated values in the guidelines used in the study to compare with the results. The recorded values were therefore compared with a typical natural PO_4^{3-} range of 0.005 - 0.020 mg/l and in some pristine waters it can be as low as 0.001 mg/l (DWAF, 1996a). According to the SAWQG for aquatic ecosystem, the phosphorus levels should not increase by more than 15 % from the water's normal or unimpacted conditions (DWAF, 1996a). Based on this, the PO_4^{3-} level in most of the samples was high. With the exception of Pien_N1 (0.02 mg/l), all the sampling stations exceeded the 15% allowance of PO_4^{3-}. Thus, in most stations of the river the levels of PO_4^{-3} are likely to compromise the aquatic ecosystems.

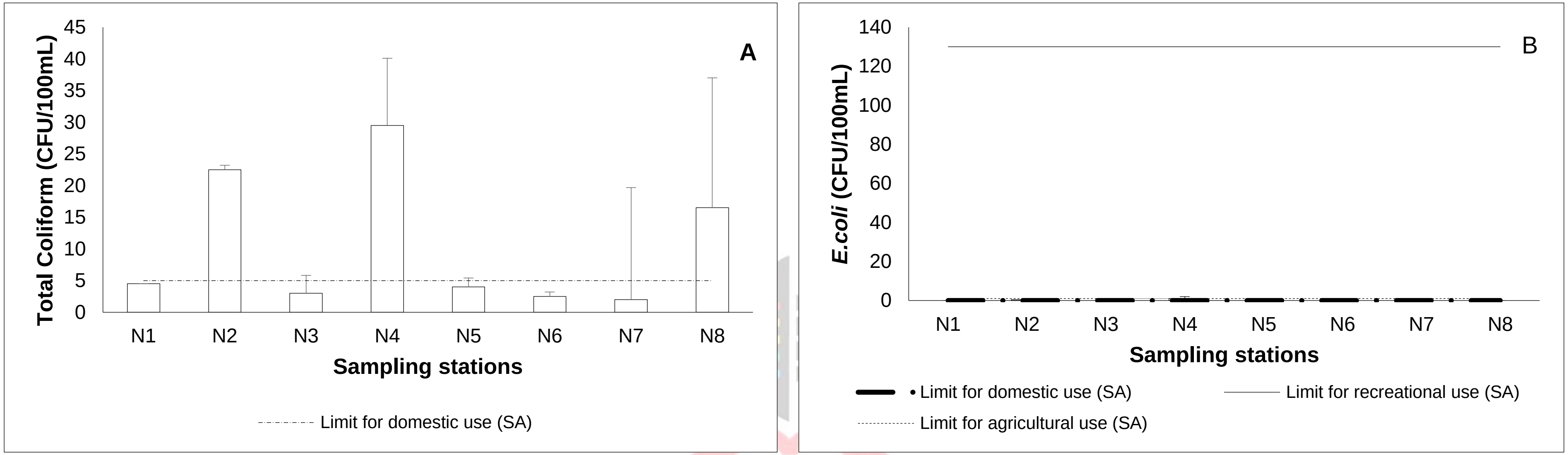

Figure 4-8: Mean (±SE) concentrations of total coliforms (A) and E. coli (B) measured from eight sampling stations on the Pienaars River

Total coliform (TC) was detected in all the sites ranged between 2 and 29.5 CFU in Pien_N8 and Pien_N4 respectively (Figure 4-8 A). The maximum allowed TC in drinking water is 5 mg/l (DWAF, 1996d). Total coliform (TC) was detected in all the sampling stations, but the threshold was only exceeded in Pien_N2, N4 and N8. Total coliform (TC) bacteria are good indicators of the presence of potentially disease-causing micro-organisms in the water (Meride and Ayenew, 2016). They are derived from both faecal and non-faecal sources (EPA, 2001). This can be an indicator of other pathogenic bacteria (DWAF, 1996d). The presence of these microorganisms in drinking water can cause possible health illnesses such as, typhoid fever, cholera and salmonellosis amongst other water-borne diseases (DWAF, 1996d). Based on the quantity of TC recorded, the hygienic status of the water is poor for informal domestic use or consumption without prior treatment.

Escherichia coli was only picked up in 2 stations, Pien_N2 (0.5 CFU 100mL) and Pien_N4 (1 CFU 100mL) (Figure 4-8 B). *E. coli* is primarily monitored in water for drinking purposes and ideally no *E. coli* should be present in water used for domestic or drinking purposes (DWAF, 1996d). According to the SAWQGs, the 1 count per 100 ml is still acceptable but there is a slight risk of microbial infection and possible waterborne diseases if the water is used for drinking (DWAF, 1996d). From a microbial point of view, the *E. coli* in the river was found to be within acceptable limits, except for Pien_N4 due to faecal contamination. Informal use of the water from this station without treatment is likely to cause water borne diseases. For agricultural use, 1 CFU 100mL is permissible limit, while the ideal guideline value for recreational use is 130 CFU 100mL

Fungi was the only water quality parameter measured that was not detected in all the stations. The presence of fungi is known to be associated with various environmental factors such as temperature, pH, organic nutrients and water flow regime (Babic *et al.,* 2017). Their absence in the studied river could suggests that the other determining environmental factors or conditions were negligible or not suitable for the fungi to grow. No health implications associated with fungi may be expected from drinking the water as no fungi was detected and no impacts on the other uses as well.

4.4.4. Assessment of the water quality using WQI

The WQI method was used to evaluate the suitability of the river for drinking. Table 4-5 is a summation of the river's WQI obtained from each sampling station on the river as described in Table 4-2. The indices were calculated based on the WAWQI method, using pH, Ca, Mg, NO_3^-, EC, NO_2^-, SO_4^{2-}, Na, F and Cl parameters. The detailed WQI calculations are shown in Annexure H.

Table 4-5: Computation of Water Quality Index (WQI) for each sampling station on the Pienaars River

Sampling point	WQI	Classification
Pien_N1	30.56	Excellent
Pien_N2	63.89	Good
Pien_N3	165.80	Moderately polluted
Pien_N4	114.44	Moderately polluted
Pien_N5	67.98	Good
Pien_N6	82.49	Good
Pien_N7	100.94	Moderately polluted
Pien_N8	64.45	Good
Overall WQI:	**86.32**	

The WQI for the stations ranged from 30.56 to 165.80 (Table 4-5). Only one out of eight sampling points (12.5%) was "excellent" (Pien_N1), 50% were "good" (Pien_N2, 5, 6 and 8), and 37.5% was "moderately polluted" (Pien_N3, 4 and 7). None of the sampling stations had a "severely polluted" or "unsuitable" WQI. The river started with an "excellent" WQI at the first station Pien_N1 close to where the river starts, gradually dropped to "good" in Pien_N2, then further deteriorated to "moderately polluted" in Pien_N3 and Pien_N4 respectively. The WQI improved again to "good" in Pien_N5 and Pien_N6, "moderately polluted" in Pien_N7 before improving again to "good" in the last station (Pien_N8) (Table 4-5).

The high WQI values (moderately polluted) observed in Pien_N3, Pien_N4 and Pien_N7 sampling sites is likely to be associated with the elevated nitrate content recorded on these stations. All the physio-chemical parameters used to calculate the WQI were within the permissible limits for drinking use, except for nitrate Pien_N3, Pien_N4 and Pien_N7 stations. Three stations had water with the highest concentrations of nitrate; 68.33 mg/l (Pien_N3), 40.73 and 24.39 mg/l at Pien_N4 and 7, respectively. The WQI ranking suggests that the suitability of the water for drinking purposes is questionable, although the general results are compliant with prescribed domestic target limits. The WQI at Pien_N1 was “excellent” which was influenced by the low levels of nitrate. The rest of the sampling points (Pien_N5, 8, 11 and 12) were classified as “good” with 50-100 WQI range.

The overall WQI value (86.32) for the river falls within “good” (50-100) of the classification of water quality as shown (Table 4-5). Although the WQI suggests that the river is suitable for informal domestic use, some form of treatment would still be required. As highlighted earlier, one of the limitations of WQI calculations is that it does not reflect the ecological status of the river, as limited number of parameters (maximum of 10) are used in calculating WQIs. The calculation excluded microbiological parameters and heavy metals yet these are some of the crucial constituent measures of water quality used for domestic purposes. Another limitation of the WQI method is that it also tends to over-emphasize the value of a single bad parameter. In this particular case it was nitrate. All the stations with the highest nitrate concentrations were classified as moderately polluted.

4.5. Conclusion

The spatial variation in water quality was assessed by analysing different water quality parameters from the different sampling stations. Fungi was the only parameter that was not detected in the water. In all the stations, the water quality parameters showed a significant variation along the gradient of the river, except for *E. coli*. Overall Pien_N1 was the least polluted station may be due to the least human influence in this part of the river course. The area is predominantly natural vegetated land. Pien_N7 and Pien_N4 on the contrary, had the highest concentrations of the most water quality parameters. What was also clearly evident in term of spatial distribution of water quality parameters is that they were not necessarily accumulating downstream but rather fluctuating from one point to another. Although in some cases the sources of pollutants were easily identifiable, it is also accepted that some of the observed increases in water quality parameters in certain stations could be related to non-point pollution sources which are difficult to identify or quantify. There are also natural sources of contaminants or impurities such as geological formations, which are also difficult to differentiate from the impacts of the land use activities. Shallow groundwater is another source of contaminant inputs, and this aspect of the catchment and its contribution to the water quality of the river could not be assessed with confidence.

The water quality of the Pienaars River and its suitability for various uses was also evaluated. Comparing the results of the study to the water quality guidelines, some stations on the river were found not to be ideal for drinking or domestic use without prior treatment. This was particularly due to high content of NO_3^-, *E. coli* and TC above the recommended limits. In some cases, the water was found to be above the limits for irrigation purposes due to elevated NO_3^-, EC and pH. No potential risks were identified pertaining to the use of the water for recreational purposes or aquatic ecosystems. It is however, acknowledged that there are other water quality constituents that were not assessed, which could conflict with the findings of this study. The conclusions made in this research study are therefore, only based on the water quality parameters that were measured.

Additional assessment of the overall water quality for drinking purposes was conducted using a WQI method. Water quality parameters: pH, Ca, Mg, NO_3^-, EC, NO_2^-, SO_4^{2-}, Na, F and Cl were used to calculate WQI values. The calculated WQI values ranged from 30.56 ("excellent") to 165.80 (moderately polluted). Three out of the eight stations were considered to be moderately polluted, these stations were Pien_N7, Pien_N3 and Pien_N4. It was concluded that the poor water quality in these stations can be attributed to excessive NO_3^- content, which was exceedingly above the recommended domestic limit. In general, most of the elements observed in these three sampling stations were relatively higher compared to the rest of the points. The overall WQI for the river was 86.32, and this value obtained is an indication that the river was in a good condition during the period of study. Although this suggests the water is acceptable for drinking purposes, some form of treatment may still be required before use. The study, however does not provide any insight on how the WQI of river changes between the different seasons as reported by other studies (Amadi et al., 2010; Edwin and Murtala, 2013; Akter et al., 2016; Sener et al., 2017). Nonetheless, the application of WQI technique in this study was useful in identifying the areas and constituents of concern or high pollution risk from a water quality point of view.

4.6. Acknowledgements

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Chapter 5 : General Discussion, Conclusion and Recommendations

South Africa's water shortage is not only attributed to overconsumption but also poor water quality management. Deterioration of freshwater is one of the key environmental issues in the country. Although there are various interventions and measures in place to manage and abate water quality, in most cases these have not been effective due to institutional paralysis with the Department of Water and Sanitation. As a result, the deterioration of water quality continues to be the main constraint to socio-economic development. The water quality of most rivers in the country are monitored, however the monitoring data tend to suffer from the 'data-rich but information-poor' syndrome, which implies that the data is collected but there is no abstraction/interpretation of meaningful information and application thereafter. Water quality data on its own is not adequate for government entities to make informed decisions regarding the protection, consumption, development and management of water resources.

The study made use of the existing data about the water quality of the Pienaars River and interpreted the information about the effects of season and land use impacts, which can assist the government entities to identify areas of concern pollution and identify whether or not the measures in place are effective in water pollution abatement.

5.1. Review of Research Aim and Objectives

The aim of the study was to assess and compare the water quality dynamics and conditions of the Pienaars River based on the physical, chemical and microbiological characteristics of the water: The aim of the study was attained by addressing the following set objectives as provided in Section 1.3:

- Assess temporal and seasonal variation in water quality of the Pienaars River, using historical water quality data

  The temporal differences in water quality of the river were assessed in the short-terms by season and long-term on a yearly basis. The null hypothesis (H_0) which stated that water quality does not change between seasons was rejected as the results showed a significant seasonal variation of the water quality parameters during the study period. Generally, the water quality was better during the high flow period due to the dilution effect of rainfall. High-flow periods played a major role in not only regulating the pollution levels but the high runoff acted as a transporting mechanism for pollutants. Overall, DMS, TAL and Si displayed a strong seasonal variation whereas F was least influenced by seasonality.

- Determine spatial variation in water quality of the Pienaars River with respect to land-use impacts

The results obtained along the river varied spatially. In some instances, poor water quality or high concentrations of certain elements could be clearly linked to the direct impact of the adjacent land use activities. What was also clear is that the water quality elements were not necessarily accumulating downstream but they rather fluctuated from one point to another. Rivers are known to have a natural ability to buffer or dilute pollutants. It is also accepted that some of the observed increases in values of water quality parameters in certain stations could be related to non-point pollution sources which are difficult to identify or quantify. There are also natural sources of contaminants or impurities such as geological formations, which are also difficult to differentiate from the impacts of the land use activities especially if the geological settings are not fully understood.

Spatial analysis was also carried out using the historical data, whose results also showed that the water quality was variable between the stations. The null hypothesis (H_0) that water quality does not change between stations was therefore rejected. The results indicated a plausible effect of build-up of pollutants from upstream to the downstream regions of the river. The upstream catchment of the river is the most developed part of the river, and land use becomes predominantly a natural vegetated land with sparse dryland agricultural fields. The results revealed that Pienaars River receives a considerable amount of pollutants in the upstream catchment, particularly in station Pien_H2 from the Baviaanspoort WWTWs. The water quality further deteriorated towards the downstream reaches as the river passes through different land uses including natural vegetated land, residential areas and scattered agricultural lands which are known sources of pollution. It was therefore concluded that land uses in the upper catchment had significant impact on the river's water quality.

- Evaluate the overall current water quality by calculating the river's Water Quality Index (WQI) and comparing the water quality parameters against the global and national water quality standards and guidelines

Despite the known point sources of pollution such as waste water effluent discharged from the WWTWs, the quality of the water was found to be within the prescribed standards. Water from the Pienaars River was found not to be ideal for drinking or domestic use without prior treatment due to high nitrate content and the presence of *E. coli* and total coliform. The water was also not ideal for irrigation purposes due to elevated nitrate, EC and alkaline pH in some points of the river. The measured parameters were found to be within the acceptable limits for recreational purposes and suitable for aquatic life. It is, however, acknowledged that there are other water quality constituents that were not assessed, which could conflict with the findings of this study. The conclusions made in this research are therefore based on the proposed scope and water quality parameters that were measured.

The water quality of the river from a domestic point of view was further evaluated using a WQI method. The WQI values ranged from 30.56 ("excellent") to 165.80 (moderately polluted) and the overall WQI was 86.32, which is an indication that the river was in a good condition during the period of this study. Although this suggests the water is acceptable for drinking purposes, some form of treatment may still be required before use.

5.2. Recommendations

The need for improvement in water quality management for the study river have been identified and the following recommendations have been made based on the research findings:

- The DWS needs to come up with a more effective management system to ensure that the WWTWs are not discharging inadequately treated waste water into natural rivers. The DWS also should tighten up and enforce regulations on WWTWs so they can adhere to the water quality treatment protocols.
- The department can also consider implementing a permitting or licensing system to enforce buffer zones on river banks. For instance, they can develop a set of standards or specifications for agricultural activities within a certain distance from the river banks that they would need to comply with to minimise pollutants in the nearby streams. Specifications could include the type of fertiliser to be used, the farming methods to be used and installation of a drainage system on the farm.
- As highlighted in this study, water quality is defined by its physical, chemical and biological constituents. It is therefore recommended and necessary to include microbiological variables in the list of variables that are frequently monitored by the department. Microbial organisms are one of the key indicators of the suitability of the water for domestic use. Many of these organisms transmit water-borne diseases.

5.3. Recommendations for Future Research

The following can be considered further insights on research on spatial and temporal water quality dynamics:

- Comparison of WQI in the wet versus dry seasons;
- Assessment of heavy or trace metal content may also be important in assessing the level of contamination and toxicity. Sources of heavy metals can be easily identified as they are primarily associated with industrial processes and mining activities;
- The need to collect micro and macro biological information about the river may also be useful ecological and water quality indicators;

- The use of tools such as Geographical Information Systems (GIS) and remote sensing would be recommended as measurements by DWS are limited to the accessible sampling points as was the case in this study; and lastly
- Assessment of the cumulative effects of tributaries on the river system as sources of water pollution input need to be explored further.

Annexure A: Drinking water quality guideline values for parameters measured on Pienaars River

WQ Parameter	Unit	International WQ Guideline*	South African Water Quality Guideline Values			
			Ideal	Acceptable	Tolerable	Unacceptable
pH	pH Units	NS**	5-9.5	4.5-10	4-10.5	<4->10.5
EC	mS/m	NS	0-70	70-150	15-300	>300
PO_4^{-3}	mg/l	NS	NS	NS	NS	NS
Cl^-	mg/l	NS	0-100	100-200	200-600	>600
NO_3^-	mg/l	50	0-6	6-10	10-20	>20
Ca	mg/l	NS	0-32	32-80		>80
F	mg/l	1.5	0-1.0	1.0-1.5	1.5-3.5	>3.5
Mg	mg/l	NS	0-70	70-100	100-200	>200
K	mg/l	NS	0-50	50-100	100-400	>400
Na	mg/l	NS	0-100	100-200	200-400	>400
SO_4^{-2}	mg/l	NS	0-200	200-400	400-600	>600
B	mg/l	2.4	NS	NS	NS	NS
E. coli	CFUs/100 mL	NS	0	1-10	10-20	>20
TC	CFUs/100 mL	NS	0-5	5-100	>100	

* World Health Organization (WHO) Drinking Water Quality Guideline (2011)

**NS: Not Specified

Annexure B: Aquatic ecosystems water quality guideline values for parameters measured on Pienaars River

WQ Parameter	Unit	International WQ Guideline*	South African Water Quality Guideline Values			
			Ideal	Acceptable	Tolerable	Unacceptable
pH	pH Units	NS**	5-9.5	4.5-10	4-10.5	<4->10.5
EC	mS/m	NS	70	150	370	>370
PO_4^{-3}	mg/l	NS	NS	NS	NS	NS
Cl^-	mg/l	NS	100	200	600	>600
Ca	mg/l	NS	80	150	300	>300
F	mg/l	0.75	0.75	1.5	2.5	>2.5
Mg	mg/l	NS	70	100	200	>200
K	mg/l	NS	25	50	100	>100
Na	mg/l	NS	100	200	400	>400
SO_4^{-2}	mg/l	NS	200	400	600	>600
E.coli	CFUs/100 mL	NS	0	1	10	>10
TC	CFUs/100 mL	NS	0	10	100	>100

* Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000)

**NS: Not Specified

Annexure C: Agricultural use water quality guideline values for parameters measured on Pienaars River

WQ Parameter	Unit	International WQ Guideline*	South African Water Quality Guideline Values			
			Ideal	**Acceptable**	**Tolerable**	**Unacceptable**
Temp	°C	NS	NS	NS	NS	NS
pH	pH Units	6.5-8.4	6.5-8.4	-	-	<6.5->8.4
EC	mS/m	<70.0	0-40	40-90	90-270	>270
PO_4^{-3}	mg/l	NS	NS	NS	NS	NS
Cl^-	mg/l	NS	0-100.0	100-140	140-175	>175.0
NO_3^-	mg/l	<5	NS	NS	NS	NS
F	mg/l	NS	0-2.0	2.0-15.0	>15.0	
Na	mg/l	<69.0	70.0	115.0	460	>460.0
SO_4^{-2}	mg/l	NS	NS	NS	NS	NS
B	mg/l	<0.7	0-0.5	-	-	>1.0
E. coli	CFUs/100 mL	NS	<1	1-1000	>1000	

* Food Agriculture Organization (FAO) Irrigation Water Quality Guideline (1985)

**NS: Not Specified

Annexure D: Recreational use water quality guideline values for parameters measured on Pienaars River

WQ Parameter	Unit	International WQ Guideline*	South African Water Quality Guideline Values			
			Ideal	Acceptable	Tolerable	Unacceptable
pH	pH Units	6.5-8.5	6.5-8.5	5.75-8.75	5.0-9.0	<5.0->9.0
P	mg/l	NS	NS	NS	NS	NS
Cl^-	mg/l	400	NS	NS	NS	NS
NO_3^-	mg/l	10	NS	NS	NS	NS
NO_2^-	mg/l	1	NS	NS	NS	NS
Ca	mg/l	NS	NS	1	NS	NS
Na	mg/l	300	NS	NS	NS	NS
B	mg/l	1	NS	NS	NS	NS
E. coli	CFUs/100 mL	NS	0-130	130-600	600-2000	>2000

* Guidelines for Canadian Recreational Water Quality (2012)

**NS: Not Specified

Annexure E: Existing and new water sampling stations on Pienaars River

Annexure E.1: New sampling stations on the Pienaars River collected in February 2017

Site Reference Name	Geographical Co-ordinates	Location along the river	Remark
Pien_N1	25° 52' 15.98"S 28° 26' 29.49"E	Downstream reaches	• Water was crystal clear and flowing • Riparian vegetation intact.
Pien_N2	25° 42' 24.83"S 28° 22' 05.35"E	Downstream reaches	• Water was crystal clear and flowing • Weeds were observed along the banks • Solid waste floating on the water
Pien_N3	25° 40' 42.35"S 28° 21' 26.32"E	Downstream reaches	• Water was flowing rapidly • The water had a bad odour
Pien_N4	25° 37' 32.78"S 28° 20' 39.73"E	Downstream reaches	• Water was flowing slowly; • Water was in eutrophic conditions
Pien_N5	25° 22' 42.26"S 28° 19' 03.48"E	Middle reaches	• Water was flowing and clear • Few riparian plants were observed
Pien_N6	25° 13' 08.39"S 28° 17' 39.67"E	Middle reaches	• Water was flowing very slow • Milky brown in colour
Pien_N7	25° 07' 50.54"S 27° 57' 34.29"E	Upstream reaches	• The river was flowing • Water was brown and dirty • Animal droppings along the banks of the river
Pien_N8	25° 07' 33.32"S 27° 37' 28.67"E	Upstream reaches	• Water was clear and flowing

Annexure E.2: Existing monitoring stations on the Pienaars River monitored by the Department of Water and Sanitation (DWS)

Monitoring Point ID				
IDs used in this study	**Original IDs assigned by DWS**	**Database Site Description**	**Monitoring Period**	**Geographical Co-ordinates**
Pien_H1	90239	Pienaars River at Baviaanspoort (Magaliesberg)	1995 - 2016	25° 41' 42.00"S; 28° 21' 30.90"E
Pien_H2	90174	Pienaars River at Baviaanspoort	1967 -2016	25° 39' 47.52"S; 28° 21' 4.14"E
Pien_H3	90283	Roodeplaat Dam on Pienaars River: Point in Dam	1980 - 2015	25° 37' 37.20"S; 28° 20' 56.40"E
Pien_H4	90275	Roodeplaat Dam on Pienaars River: near Dam Wall	1968 - 2016	25° 37' 19.2"S; 28° 22' 22.80"E
Pien_H5	90223	Roodeplaat Dam on Pienaars River: Left Canal	1980 - 2016	25° 37' 6.96"S; 28° 22' 18.84E"
Pien_H6	90160	Pienaarsrivier 90 JR at Klipdrift on Pienaars River	1976 - 2016	25° 22' 50.16"S; 28° 19' 0.01"E
Pien_H7	90227	Klipvoor Dam on Pienaars River: Down Stream Weir	1985 - 2016	25° 07' 51.96"S; 27° 48' 39.90"E
Pien_H8	90168	Pienaars River at Buffelspoort	1971 - 2016	25° 07' 40.08"S; 27° 37' 44.00"E

Annexure F: Comparison of water quality results obtained from Pienaars River with the national and international water quality guidelines for domestic, agricultural, recreational and aquatic uses

Parameters	Units	Mean values for the sampling points (N = 4)								Overall Mean	Domestic use		Agricultural use		Recreational use		Aquatic use	
		Pien_N1	Pien_N2	Pien_N3	Pien_N4	Pien_N5	Pien_N6	Pien_N7	Pien_N8		WHO[5]	SA[6]	FAO[7]	SA[8]	CRWQ[9]	SA[10]	ANZ[11]	SA[12]
Calcium	mg/l	16.61	**34.97**	30.45	31.26	29.12	28.42	**41.26**	**32.68**	30.59	NS	0-32	NS	NS	NS	NS	NS	NS
Magnesium	mg/l	12.03	**30.29**	20.00	11.33	16.24	16.07	19.50	14.00	17.43	NS	0-30	NS	NS	NS	NS	NS	NS
Sodium	mg/l	7.22	19.37	46.95	59.68	35.07	36.07	**75.24**	45.26	40.60	NS	0-100	0-69	0-70	0-300	NS	NS	NS
Potassium	mg/l	0.84	1.92	8.32	13.85	6.58	6.81	12.15	9.15	7.45	NS	0-50	NS	NS	NS	NS	NS	NS
Boron	mg/l	<0.01	<0.01	0.05	0.07	0.03	0.02	0.05	0.03	0.04	2.4	NS	0-0.7	0-0.5	0-1	NS	NS	NS
pH	mg/l	8.31	**8.75**	8.37	8.34	**8.47**	8.30	**8.66**	**8.56**	**8.47**	NS	6-9	6.5-8.4	6.5-8.4	6.5-8.5	6.5-8.5	NS	NS
Temperature	ºC	19.35	21.40	26.1	23.75	21.45	23.45	22.55	25.4	22.90	NS	NS	NS	NS	NS	NS	NS	NS
EC	mS/m	23.00	**47.00**	**53.00**	**54.00**	**43.00**	**43.00**	**66.00**	**47.00**	**47.00**	NS	0-70	0-70	0-40	NS	NS	NS	NS
Fluoride	mg/l	0.23	0.34	0.37	0.35	0.48	0.66	0.51	0.48	0.43	0-1.5	0-1.0	NS	0-2	NS	NS	0-0.75	0-0.75
Chloride	mg/l	6.82	26.76	39.215	68.05	38.07	41.58	73.80	52.2	43.31	NS	0-100	NS	0-100	0-400	NS	NS	NS
Nitrite	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NS	0-6	NS	NS	0-1	NS	NS	NS
Nitrate	mg/l	0.70	**12.62**	**68.33**	**40.73**	**8.07**	**7.23**	**24.39**	5.93	**21.00**	0-50	0-6	0-5	NS	0-10	NS	NS	NS
Sulphate	mg/l	6.93	32.46	54.41	52.57	33.47	32.71	58.32	41.68	39.07	NS	0-200	NS	NS	NS	NS	NS	NS
Phosphate	mg/l	0.02	0.06	5.475	7.10	1.70	1.61	6.25	1.20	2.92	NS	NS	NS	NS	NS	NS	NS	NS
Total Coliform	CFUs/100 mL	**4.50**	**22.50**	**3.00**	**29.50**	**4.00**	**2.50**	**2.00**	**16.50**	**10.56**	NS	0-5	NS	NS	NS	NS	NS	NS
E.coli	CFUs/100 mL	0.00	**0.50**	0.00	**1.00**	0.00	0.00	0.00	0.00	**0.17**	0	0	NS	0-1	NS	0-130	NS	NS
Fungi	CFUs/100 mL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NS	NS	NS	NS	NS	NS	NS	NS

NS: Not Specified

Values in bold mark parameters that exceeded one or more water quality guideline limits

5 World Health Organization (WHO) Drinking Water Quality Guideline (2011)
6 South African Water Quality Guideline for Domestic Use (1996)
7 Food Agriculture Organization (FAO) Irrigation Water Quality Guideline (1985)
8 South African Water Quality Guideline for Agricultural Use (1996)
9 Guidelines for Canadian Recreational Water Quality (2012)
10 South African Water Quality Guideline for Recreational Use (1996)
11 Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000)
12 South African Water Quality Guideline for Aquatic Use (1996)

Annexure G: Water quality index calculations, based on samples collected on Pienaars Rivers in February 2017

Sampling Point: Pien_N1

Physio-chemical Parameters	Value (Q)	SA Water Quality Limit for Domestic use	Qi	Wi	WQI
Ca	16.61	0-80	20.76	0.01	0.26
Mg	12.03	0-70	17.19	0.03	0.57
Na	7.22	0-100	7.22	0.01	0.07
pH	8.31	5-9.5	87.47	0.11	9.72
EC	23	0-70	32.86	0.01	0.47
Cl^-	6.82	0-100	6.82	0.01	0.07
NO_2^-	<0.01	0-6	0.17	0.17	0.03
NO_3^-	0.705	0-6	11.75	0.17	1.96
SO_4^{-2}	6.93	0-200	3.47	0.01	0.02
F	0.235	0.7	33.57	1.00	33.57
				1.53	**46.74**
				Overall WQI	**30.56**

Sampling Point: Pien_N2

Physio-chemical Parameters	Value (Q)	SA Water Quality Limit for Domestic use	Qi	Wi	WQI
Ca	34.975	0-80	43.72	0.03	1.37
Mg	30.295	0-70	43.28	0.03	1.44
Na	19.375	0-100	19.38	0.01	0.19
pH	8.755	5-9.5	92.16	0.11	10.24
EC	47	0-70	67.14	0.01	0.96
Cl^-	26.765	0-100	26.77	0.01	0.27
NO_2^-	<0.01	0-6	0.17	0.17	0.03
NO_3^-	12.62	0-6	210.33	0.17	35.06
SO_4^{-2}	32.46	0-200	16.23	0.01	0.08
F	0.345	0.7	49.29	1.00	49.29
				1.55	**98.92**
				Overall WQI	**63.89**

Sampling Point: Pien_N3					
Physio-chemical Parameters	**Value (Q)**	**SA Water Quality Limit for Domestic use**	**Qi**	**Wi**	**WQI**
Ca	30.45	0-80	38.06	0.03	1.19
Mg	20.005	0-70	28.58	0.03	0.95
Na	46.955	0-100	46.96	0.01	0.47
pH	8.375	5-9.5	88.16	0.11	9.80
EC	53	0-70	75.71	0.01	1.08
Cl^-	39.215	0-100	39.22	0.01	0.39
NO_2^-	<0.01	0-6	0.17	0.17	0.03
NO_3^-	68.33	0-6	1138.83	0.17	189.81
SO_4^{-2}	54.41	0-200	27.21	0.01	0.14
F	0.37	0.7	52.86	1.00	52.86
				1.55	**256.71**
				Overall WQI	**165.80**

Sampling Point: Pien_N4					
Physio-chemical Parameters	**Value (Q)**	**SA Water Quality Limit for Domestic use**	**Qi**	**Wi**	**WQI**
Ca	31.265	0-80	39.08	0.03	1.22
Mg	11.33	0-70	16.19	0.03	0.54
Na	59.685	0-100	59.69	0.01	0.60
pH	8.34	5-9.5	87.79	0.11	9.75
EC	54	0-70	77.14	0.01	1.10
Cl^-	68.055	0-100	68.06	0.01	0.68
NO_2^-	<0.01	0-6	0.17	0.17	0.03
NO_3^-	40.73	0-6	678.83	0.17	113.14
SO_4^{-2}	52.575	0-200	26.29	0.01	0.13
F	0.35	0.7	50.00	1.00	50.00
				1.55	**177.19**
				Overall WQI	**114.44**

Sampling Point: Pien_N5					
Physio-chemical Parameters	**Value (Q)**	**SA Water Quality Limit for Domestic use**	**Qi**	**Wi**	**WQI**
Ca	29.12	0-80	36.40	0.03	1.14
Mg	16.24	0-70	23.20	0.03	0.77
Na	35.075	0-100	35.08	0.01	0.35
pH	8.475	5-9.5	89.21	0.11	9.91
EC	43	0-70	61.43	0.01	0.88
Cl^-	38.075	0-100	38.08	0.01	0.38
NO_2^-	<0.01	0-6	0.17	0.17	0.03
NO_3^-	8.075	0-6	134.58	0.17	22.43
SO_4^{-2}	33.47	0-200	16.74	0.01	0.08
F	0.485	0.7	69.29	1.00	69.29
				1.55	**105.26**
				Overall WQI	**67.98**

Sampling Point: Pien_N6					
Physio-chemical Parameters	**Value (Q)**	**SA Water Quality Limit for Domestic use**	**Qi**	**Wi**	**WQI**
Ca	28.425	0-80	35.53	0.03	1.11
Mg	16.07	0-70	22.96	0.03	0.77
Na	36.07	0-100	36.07	0.01	0.36
pH	8.3	5-9.5	87.37	0.11	9.71
EC	43	0-70	61.43	0.01	0.88
Cl^-	41.58	0-100	41.58	0.01	0.42
NO_2^-	<0.01	0-6	0.17	0.17	0.03
NO_3^-	7.23	0-6	120.50	0.17	20.08
SO_4^{-2}	32.71	0-200	16.36	0.01	0.08
F	0.66	0.7	94.29	1.00	94.29
				1.55	**127.72**
				Overall WQI	**82.49**

Sampling Point: Pien_N7					
Physio-chemical Parameters	**Value (Q)**	**SA Water Quality Limit for Domestic use**	**Qi**	**Wi**	**WQI**
Ca	41.265	0-80	51.58	0.03	1.61
Mg	19.505	0-70	27.86	0.03	0.93
Na	75.24	0-100	75.24	0.01	0.75
pH	8.66	5-9.5	91.16	0.11	10.13
EC	66	0-70	94.29	0.01	1.35
Cl^-	73.805	0-100	73.81	0.01	0.74
NO_2^-	<0.01	0-6	0.17	0.17	0.03
NO_3^-	24.39	0-6	406.50	0.17	67.75
SO_4^{-2}	58.32	0-200	29.16	0.01	0.15
F	0.51	0.7	72.86	1.00	72.86
				1.55	**156.29**
				Overall WQI	**100.94**

Sampling Point: Pien_N8					
Physio-chemical Parameters	**Value (Q)**	**SA Water Quality Limit for Domestic use**	**Qi**	**Wi**	**WQI**
Ca	32.68	0-80	40.85	0.03	1.28
Mg	14.005	0-70	20.01	0.03	0.67
Na	45.265	0-100	45.27	0.01	0.45
pH	8.56	5-9.5	90.11	0.11	10.01
EC	47	0-70	67.14	0.01	0.96
Cl^-	52.2	0-100	52.20	0.01	0.52
NO_2^-	<0.01	0-6	0.17	0.17	0.03
NO_3^-	5.935	0-6	98.92	0.17	16.49
SO_4^{-2}	41.685	0-200	20.84	0.01	0.10
F	0.485	0.7	69.29	1.00	69.29
				1.55	**99.79**
				Overall WQI	**64.45**