Nutrient loading in the Vaal River over the past two decades

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Declaration

I Pargeant Ntshalintshali, acknowledge that

1. I am presenting this mini-dissertation in fulfilment of the requirements for my degree

2. I know the meaning of plagiarism and declare that all the work in the dissertation is my own.

Signature Signed by candidate Date: 21 October 2019

Acknowledgement

I would like to express my gratitude to everyone who played a role directly and indirectly in making this journey a success.

To the Lord Almighty, Thank you Lord for your endless grace and mercy. You have carried me through it all.

To my supervisor Dr Kevin Winter, thank you for your guidance, wisdom, support and your belief in my abilities which has immensely contributed to the success of this study.

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Abstract

Nutrient loading is negatively affecting South Africa's freshwater resources and ecosystems. Anthropogenic activities are the leading causes of continuous nutrient loading in the country's water resources. This study examines the dynamics of nutrient loading in the Vaal River. The objectives are to explore nutrient loading in the Vaal River over the past two decades and to compare the differences between the two decades. Water quality data were obtained from the Department of Water and Sanitation (DWS) Water Resource Quality Information Services (RQIS) database. Elevated nutrients of NH^{4+}, $N0_3$, $P0_4^{3-}$ and chlorophyll-a were observed at selected sites at various times during the 20 year period under analysis. Nutrients concentration are elevated alongside agricultural and industrial activities, and urban areas. Student t-tests investigated the difference between the two decades and in most cases showed significant differences between these decades. The last decade showed elevated nutrient levels for $N0_{3,}$ NH^{4+} and chlorophyll-a in most of the DWS monitoring sites. Only $P0_4^{3-}$ at some sites showed a reduction from the previous decade. The study concludes that upper and middle sections of Vaal River are eutrophic and hypertrophic and a trend toward a permanent state of these conditions is likely without a long-term solution to address the problem of excessive nutrient loading entering the Vaal River system.

Acronyms

DWA - Department of Water Affairs

DWAF- Department of Water Affairs & Forestry

DWS - Department of Water & Sanitation

EC - Electrical Conductivity

GDP -Gross Domestic Product

IFPRI - International Food Policy Resource Institute

IWQGE - International Water Quality Guidelines for Ecosystems

IWRM - Integrated Water Resource Management

LV - Lower Vaal

MV - Middle Vaal

$N0_3$ - Nitrate

NEMP- National Eutrophication Monitoring Programme

NH_{4+} - Ammonium

$P0^{3-}{}_4$ - Phosphate

pH – Potential of Hydrogen

PMO - Phosphorus Management Objectives

SAWQGEA – South African Water Quality Guidelines for Aquatic Ecosystems

UN - United Nations

UNEP - United Nations Environmental Programme

UV - Upper Vaal

WHO - World Health Organization

WMA - Water Management Area

WQP - Water Quality Policy

WRC - Water Research Commission

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Chapter One: Introduction

1.1 Background and scope of study

Eutrophication is known to occur more readily in lentic water bodies such as dams, reservoirs, lakes or fish ponds, however over the recent years there is a growing body of evidence indicating that eutrophication occurs in many large free-flowing fresh water systems such as rivers and marine systems across the globe (UNEP 2016; Xia et al. 2016; UN-Water 2011). Eutrophication is a worldwide problem that has affected many fresh water systems from excessive and extensive use of inorganic fertilizers and pesticides (Khan, 2014; Khan et al. 2007). Anthropogenic activities, coupled with climate change, contribute to increasing the rate of eutrophication in global water systems (Xia et al. 2016; Khan, 2014; Khan et al. 2007). In general, poor land use and planning, increased population, increased domestic wastewater discharge, poorly managed sewage infrastructure, urban run-off, industries and agriculture negatively are known to impact on freshwater systems (de Villiers 2007; Griffin et al. 2014). The aforementioned factors have led to an increase in the transfer of nutrients into freshwater systems resulting in eutrophication in the receiving water bodies (Griffin et al. 2014; van Ginkel 2011; de Villiers 2007; Bath 1989).

The World Health Organization (WHO) (2002) states that since the rise of the Industrial Revolution there has been a significant increase in nutrient loading due to multiple causes including extensive use of fertilizers by farmers and poor agricultural practices such as ploughing in riparian zones; industrial wastewater that is being discharged into freshwater bodies; human induced hydrological changes in catchment areas such as building of dams; increased waste water treatment plants often operating beyond the design capacity; sewage spillages; and increasing urban run-off coupled with settlement patterns that encroach on riparian zones of river banks. Khan (2014) adds that these anthropogenic activities have transformed high quality water systems into eutrophic conditions. The trophic status of water bodies is classified into four classes based of nutrient concentration levels (International Water Quality Guidelines for Ecosystem (IWQGES) 2016; National Eutrophication Monitoring Programme (NEMP) 2002; and the South African Water Quality Guidelines for Aquatic Ecosystems (SAWQGAE) 1996). These four classes are: oligotrophic which is low in nutrient concentration; mesotrophic which has intermediate levels of nutrient concentration that mildly affect aquatic life and give the first indication of a deterioration in water quality; eutrophic conditions which are rich in nutrient concentration and severely affect aquatic plants and animals, and lastly, hypertrophic conditions which are extremely high in nutrient concentration.

The South African Department of Water and Sanitation (DWS) (2017) defines eutrophication as a transfer of nutrients in water bodies which is associated with cyanobacterial and algal blooms that affect ecological systems and negatively impact on development and human health. An increase in eutrophication continues to be observed in many water bodies throughout the country despite legislative, policy and management frameworks including the National Water Act (No.36 of 1998) and water quality management strategies such as NEMP (Griffin et al. 2014; van Ginkel 2011).

Matthews and Bernard (2014) in a study conducted between 2002 and 2012, observed 50 of the largest water bodies in South Africa using satellite remote sensing. They found that 62% of these water bodies had high concentrations of nutrients, while 26 of these water bodies displayed cyanobacterial blooms. Also, according to NEMP (2013), it is estimated that 5 out of 75 major impoundments, and 18 out of 25 major rivers catchments were classified as eutrophic. In addition, approximately 28% of surface water samples were hypertrophic, 33% were eutrophic, 37% were mesotrophic and only 3% were oligotrophic (DWAF 2013). Cyanobacteria, including *Microcystis* and *Anabaena* species were found in all major impoundments of the country (DWAF 2013). These toxic blooms are a threat to human health in drinking water supplies and pose a risk to livestock (Matthews and Bernard 2014). Studies conducted on eutrophication include work on cyanobacteria (blue-green algae) and toxin production in major impoundments by van Ginkel (2004); deteriorating nutrients status of the Berg River in the Western Cape by de Villiers (2007); cyanobacteria research post-2000 by Harding et al. (2009); and the development of an integrated water quality management plan for the Vaal River system by Moodley et al. (2009). All identify the concern of increasing eutrophication in the country's water resources.

1.2 Rationale

In summary, there is growing evidence of a continuous increase in eutrophication in freshwater systems in South Africa. This study seeks to understand the state of eutrophication of the Vaal River and how this varies along the length of the river. According to van Ginkel (2011), since the 1980s, measures to reduce eutrophication were undertaken on the Vaal River, however, it is clear from studies already cited that the problem persists and is increasing observed in freshwater storage dams and in river systems.

1.3 Hypothesis

According to WWF-SA (2016), South African water resources have significantly deteriorated in the past two decades due to increasing population, urban growth, poor maintenance of water infrastructure and acid mine drainage. Most of the pollutants affecting water resources in the country come from poorly treated sewage effluent, dysfunctional sanitation infrastructure in informal settlements, agricultural run-off and mining activities, and all of these conditions are found in most municipalities throughout the country. This study investigates the contention that eutrophication is increasing and aims to address this contention by using existing data from the Department of Water and Sanitation (DWS) Water Resource Quality Information Services (RQIS). The hypothesis is to prove or disprove that eutrophication levels have increased in the Vaal River in the past decade (2007-2017) compared to the previous (1996-2006).

1.4 Research Questions

The Vaal River is the third longest river in South Africa (DWS 2013). It supplies water to South Africa's industrial region in the Gauteng Province (Coleman and van Niekerk 2007). Industrial areas supported by the Vaal River produce more than 50% of South Africa's Gross Domestic Product (GDP) (DWS 2013; Coleman and van Niekerk 2007). The Vaal River also supplies water to gold and platinum industries as well as coal reserves in the country (DWS 2013). In the study on the development of an integrated water quality management plan for the Vaal River (2009) findings showed that development and land use practices in the Vaal River catchment had a negative impact on the quality of the river (Moodley et al. 2009).

1.4.1 Research Questions

The research will address three key questions to determine the following:

1. To what extent has nutrient loading changed in the Vaal River over the past two decades?

2. Which areas are showing elevated nutrient loading and why?

3. What is the trend of nutrient loading?

1.5 Aim

The aim is to study the changing trends in nutrient concentration in the Vaal River over the past two decades

1.5.1 The objectives

1. To analyze nutrient concentration in the Vaal River over the past two decades.

2. To investigate the trophic status of the Vaal River using guidelines and benchmarks from the IWQGES 2016, NEMP 2002 and SAWQGAE 1996.

1.6 Study Area

The Vaal River is one of the major water sources supplying water to different industries such as mines, agriculture and urban settlements. It rises at Sterkfontein Beacon near Breyten in the Mpumalanga Province and flows 1415 km southwest to where it meets with the Orange River near Douglas (Moodley et al. 2009) (See Figure 1). The catchment area is approximately 197 000 km² and lies in the geographical centre of the country. It stretches from Ermelo in the northeast to Vryburg in the northwest to Douglas in the southeast to Harrismith in the east (Moodley et al. 2009). The Vaal River is separated into three water management areas (WMAs) (the upper, middle and lower) (DWS 2013 Moodley et al. 2009; Coleman and van Niekerk 2007). Approximately 300m^3/s is discharged from storage dams during summer months to support multiple urban areas, industries and agricultural production within the catchment. During the dry season the transfer of water from the south supports the level of base flow. The Vaal River experiences is a sub-tropical dry savannah climate with mean annual evaporation of approximately 1300mm in which evaporation exceeds annual rainfall by approximately 600mm (Jury 2016).

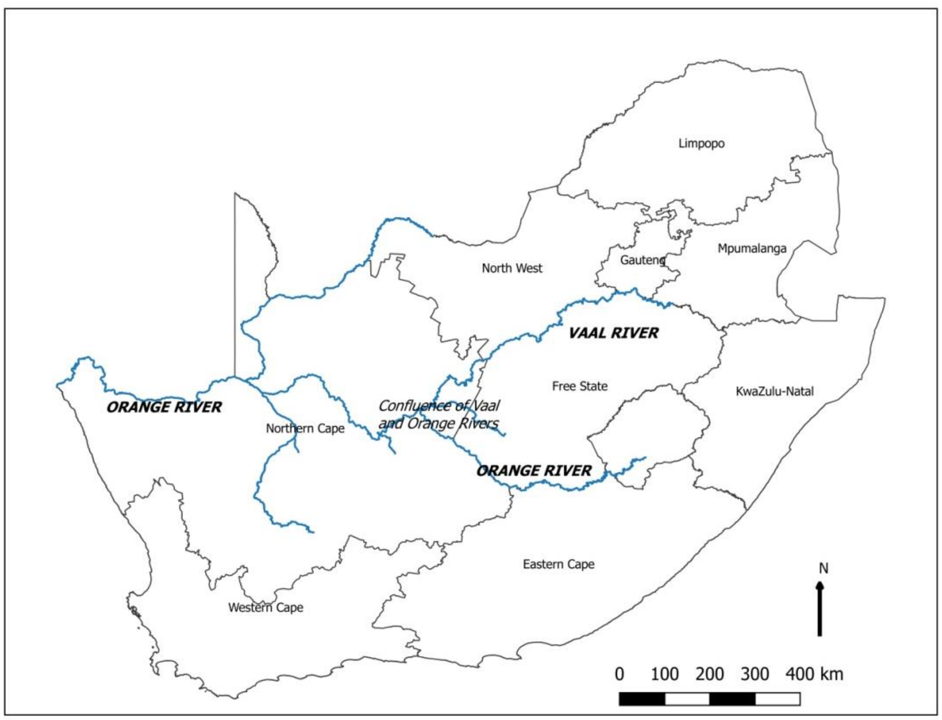

Figure 1: The Vaal River Catchment

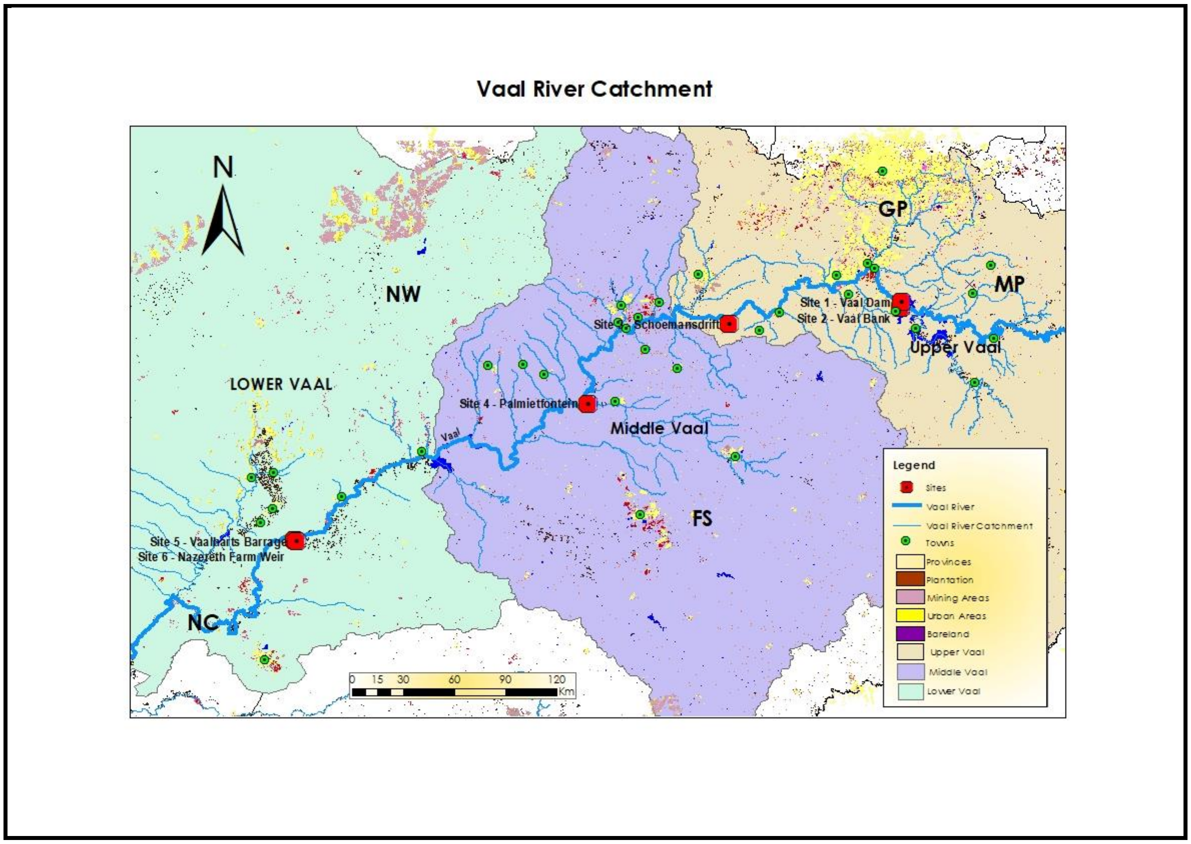

Figure 2: Monitoring sites in the Vaal River

1.6.1 Upper Vaal

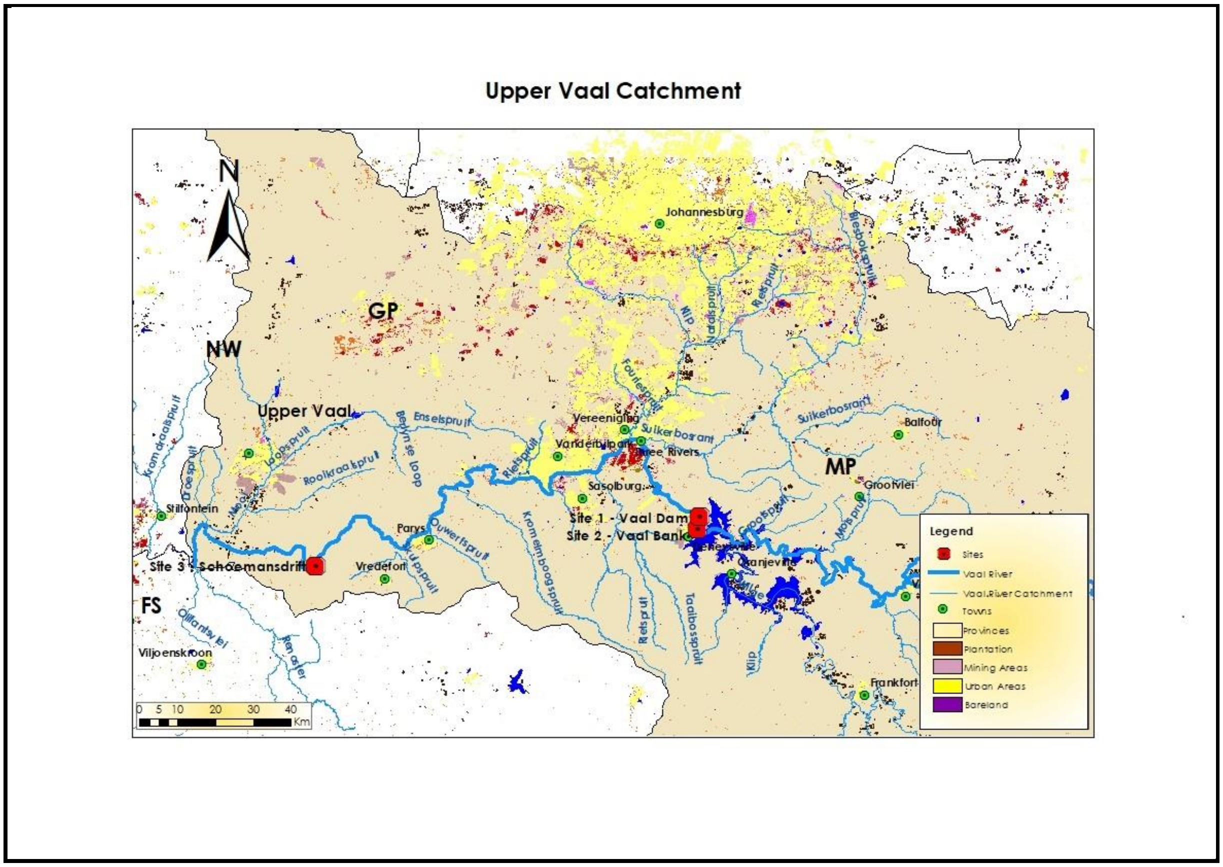

Figure 3: Monitoring sites in the Upper Vaal

The Upper Vaal includes parts of Mpumalanga, Gauteng, Free State and Northwest Provinces (Moodley et al. 2009; DWA 1986). It includes major storage dams of Grootdraai and Vaal Dams. It has relatively uniform climate with average temperature of 15ºC with mean annual temperatures ranging between 16ºC in the west to 12ºC in the east and receives rainfall during the summer months that ranges between 1300mm to 1700mm per year (Moodley et al. 2009; Coleman and van Niekerk 2007).

The Upper Vaal WMA is densely populated with most of the population residing downstream and in urban areas (Moodley et al. 2009; Coleman and van Niekerk 2007). It is the most developed and industrialized area of all the Vaal WMAs. It is economically important for the country and contributes close to 20% of GDP which makes it the second largest contributor to the national wealth amongst all the nineteen WMAs of the country (Moodley et al. 2009).

Land use practices in the Upper Vaal WMA area are characterized by growing urbanization, mining industries, and industrial areas especially in the northern and western parts between the Grootdraai Dam and Mooi River (Moodley et al. 2009). These activities occur mostly in the Gauteng Province. The urban areas in this WMA are densely populated with the largest metropolitan including Boksburg, Germiston, Benoni, Alberton, Springs, Brakpan and Nigel on the East Rand. On the West Rand, towns of Vereeniging, Vanderbijlpark, Sasolburg and Carletonville are all supplied by Rand Water Bulk Network from the Vaal Dam (Moodley et al. 2009). These areas are responsible for large sewage return flows into the Vaal River from adjacent municipalities in which wastewater is discharged into the tributaries of the catchment (Moodley et al. 2009).

According to Moodley et al. (2009) and DWAF (2009), agricultural activities dominate the WMA which includes dry-land agriculture and livestock farming. These dry-lands agricultural activities occur mainly in the central and south-western parts and produce mainly maize and wheat. Irrigation is taking place along the main reaches of the river (Moodley et al. 2009; DW&F 2009; Coleman and van Niekerk 2007). According to Moodley et al. (2009), major industries, mining and power stations are found in this WMA. Operational power generating stations in this WMA include Tutuka, Majuba and Lethabo which are owned by Eskom, a state-owned energy enterprise. These power stations impact on water resources since they require large quantities of water for their operation. These operations do not discharge effluent because most of the water that is re-used for cooling (Moodley et al. 2009). The only discharge comes from a wastewater treatment plant treating domestic sewage effluent (Moodley et al. 2009).

The production of petro-chemicals is the main activity in this area (Moodley et al., 2009). The Mittal steel located in Gauteng Province near Vanderbijlpark abstracts water from the Vaal Dam and Vaal Barrage. The production of iron and steel products in Mpumalanga Province near Secunda is supplied by pipelines from the Grootdraai Dam (Moodley et al. 2009). Downstream of the Vaal Dam there are large mining activities ranging from gold to quarrying which are dominant in places such as Klipspruit, Suikerbosrand, Vaal Dam to Vaal Barrage and Mooi River sub-catchment.

1.6.2 Middle Vaal

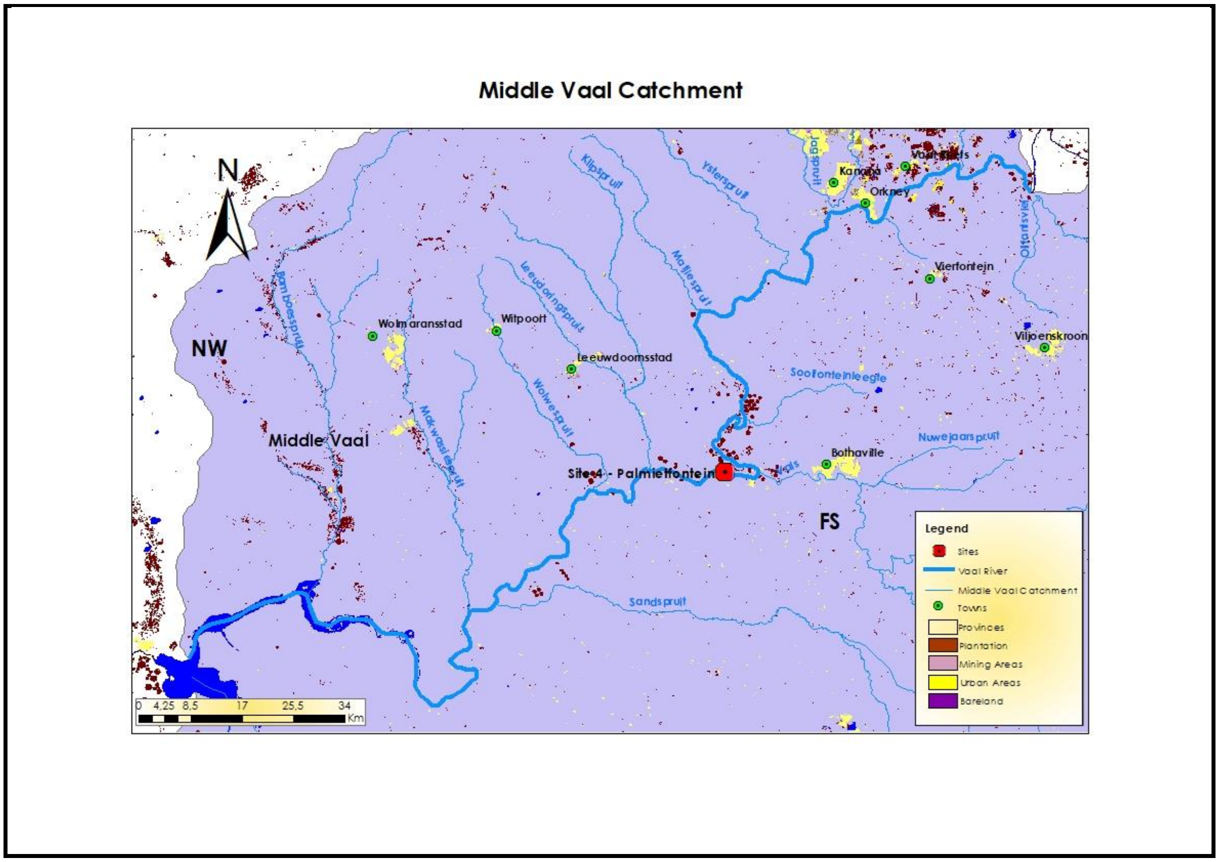

Figure 4: Monitoring sites in the Middle Vaal

The middle Vaal WMA forms part of the Orange River watercourse and covers parts of the Free State and North-West Provinces covering an area of approximately 52 563km². It flows westwards to the Lower Vaal WMA. Water is transferred via the Vaal to Bloemhof Dam, from upper Vaal WMA to the lower Vaal WMA (Moodley et al. 2009). The middle Vaal is a relatively flat area, and climate varies from west to east with an average temperature of 16ºC and mean annual temperatures ranging between 18ºC in the west to 14ºC in the east. This WMA receives between 500mm in the east and 700mm in the west annual precipitation (Moodley et al. 2009).

Most of the surface flow in the Middle Vaal originates from the upper Vaal WMA (Moodley et al. 2009). Moodley et al. (2009) argue that the middle Vaal WMA is highly dependent on the Upper Vaal to meet its bulk water demand for mining, industrial and urban areas in Klerksdrop-Orkney and Welkom- Virginia. Water is transferred into this WMA to boost local water supplies for use by smaller towns in this area and for irrigation purposes (Moodley et al. 2009). The water that is transferred from the upper Vaal to middle Vaal contains urban, industrial and mining return flows from the highly developed upper Vaal WMA. This carries elevated concentrations of salinity and fertilizers that compromise water quality of this WMA (Moodley et al. 2009). The Middle Vaal WMA is largely a rural land area that is used for livestock farming, dry-land agriculture and some irrigation farming. The middle Vaal WMA contributes about 4% of the country's GDP with the mining sector being the leading contributor followed by trade and agriculture (Moodley et al. 2009; Coleman and van Niekerk 2007).

Land use of the Middle Vaal River has been shaped by the discovery of diamonds in the north-western part of the WMA since the 1870s and by gold discoveries in the late 1800s in Klerksdrop, Welkom and Virginia (Moodley et al. 2009). Agricultural practices began around the 1930s which is characterized by extensive dry-land cultivation in the central parts of the WMA. Irrigation occurs along the main tributaries of the Vaal River (Moodley et al. 2009). Approximately 530km² of land is being used in the Middle Vaal, of which 47% of the land is urban, 39% irrigated land and 13% alien vegetation (Moodley et al. 2009). Agricultural practices include the irrigation of crops such as maize, wheat, sorghum, groundnuts, sunflower and fodder (Moodley et al. 2009).

The urban areas in this catchment are responsible for sewage return flows that most municipalities discharge into the Vaal River (Moodley et al. 2009). These flows are highly polluted and negatively impact on the water quality of the Vaal River in this WMA. The urban areas are mainly concentrated in the North West goldfields and Free State Goldfields. Other urban areas include areas such Klerksdorp, Stilfontain, Kroonstad, Winburg, Senekal, Lindley to name a few. These areas are supplied by the Midvaal Water company while Sedibeng water supplies bulk water to Free State goldfields (Moodley et al. 2009).

1.6.3 Lower Vaal

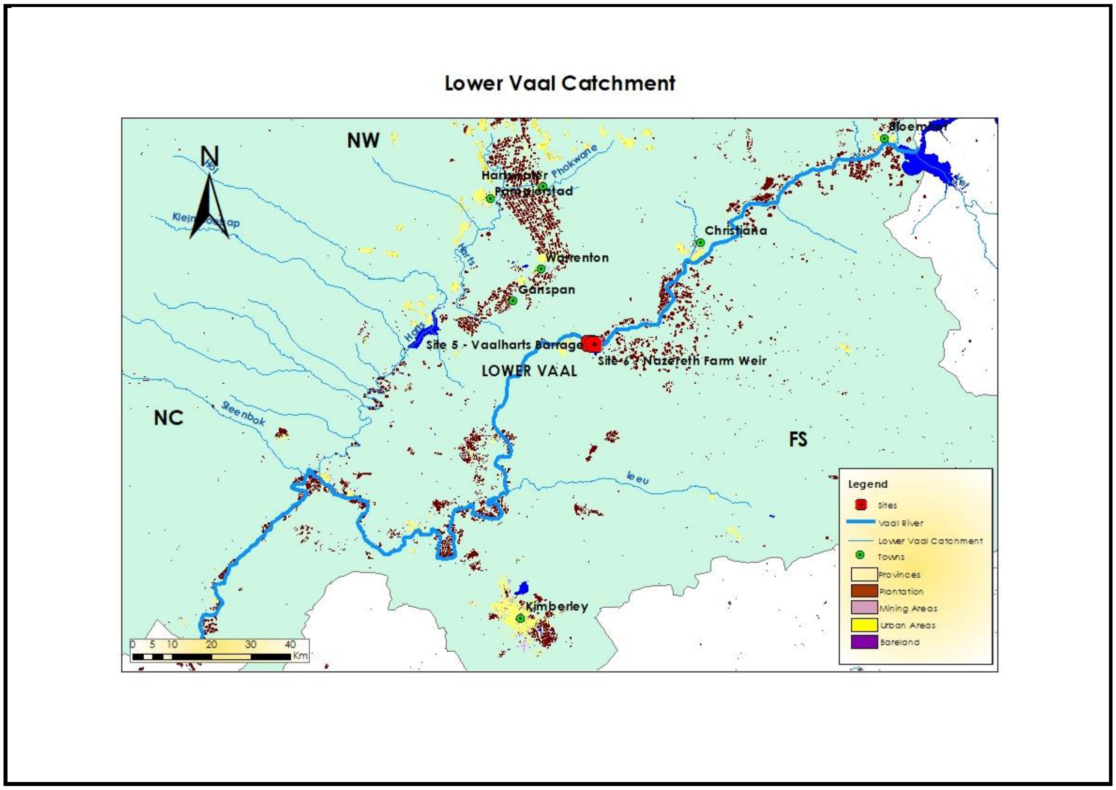

Figure 5: Monitoring sites in the Lower Vaal

The lower Vaal WMA is in the north-western of the country and forms part of the Orange River watercourse (Moodley et al. 2009). It covers approximately 133 354km² catchment area and covers parts of the Northern Cape and North-West Provinces and small parts of Free State (Moodley et al. 2009). The average temperature of the WMA is 16ºC and it has a seasonal rainfall that occurs in summer. Precipitation decreases from the western parts of the Northwest Province to the Northern Cape Province. Mean annual rainfall precipitation ranges between 100mm in the west and 500mm to the east of the catchment (Moodley et al. 2009).

The surface flow of the lower Vaal River originates from upper and middle Vaal WMAs. Very small quantities originate from this WMA due to low rainfall received. According to Moodley et al. (2009) large volumes of water are obtained from the Vaalharts weir on the Vaal River to supply the Vaalharts irrigation scheme in the Harts River Catchment. Return flows from the Vaalharts irrigation contain nutrients that enter the Harts River upstream of Spitskop Dam (Moodley et al. 2009).

The lower Vaal contributes about 2% to the country's GDP mining being the leading contributor followed by the Kimberley area characterized by most of the economic activities which include cement, cheese production and local agriculture (Moodley et al. 2009). Development in the lower Vaal is reported to have started in the early 1800s with intensive agriculture and was later influenced by the discovery of diamonds near Kimberley and Christiana. Vaalharts irrigation scheme is another reported development in the 1930s which supplies water for irrigation agriculture and livestock farming on the eastern parts of the WMA (Moodley et al. 2009).

The lower Vaal WMA has limited urban areas, Kimberley being the largest town that is situated in the south of the catchment, Lichtenburg in the north-east and Kuruman in the central parts of WMA. Major industries are manganese and iron mines which are situated on the dry north-west part of the WMA and both require large water quantities (Moodley et al. 2009).

1.7 Study design

To reiterate, this study aims to understand how eutrophication has increased over the past twenty years (1996-2017) in the Vaal River. Data of physico-chemical parameters were obtained from the DWS database (http://www.dwa.gov.za/iwqs/wms/default.aspx). A total of six sites were chosen (two from each section-upper, middle and lower Vaal). Water quality parameters that were chosen for measurements include electrical conductivity (EC), ammonium (NH_{4+}), phosphate ($P0^{3-}{}_{4}$), nitrate ($N0_3^-$) and chlorophyll to characterize the nutrient concentrations and eutrophication trends in the Vaal River. The selection of physico-chemicals was informed by land use activities and data available on the database.

1.8 Outline of research structure

The first chapter has outlined the approach of the study and introduced the main aim and rationale of the study. The second chapter discusses in detail the possible causes and challenges of eutrophication from global to national scale. The third chapter discusses in detail the design and methods of the study. Chapter four presents in details the results on eutrophication in the Vaal River in the past two decades. The last chapter concludes and gives recommendation.

1.9 Limitations of study

The researcher has had to rely on the data provided by DWS. Data is often inconsistent with missing data in some periods and different variables are measured at different times. EC was the most reliable but there were gaps in some of the other variables. Other than obvious mistakes, it was not possible to account for human errors in the database.

Chapter Two: Literature Review

2.1 Introduction

Eutrophication has become a global concern (Khan 2014; Veolia 2014; UN-Water 2011; WHO 2002). Climate change, increasing population, poor water infrastructure, poor management of contaminated water, poor agricultural and industrial practices, are some of the main factors that contribute to poor water quality across the globe (Khan 2014; UN-Water 2011). These factors play a major role in changing biological, chemical and physical characteristics of surface water which impact on the wellbeing of ecosystems, human health and development (UN-Water 2011). Surface water quality is determined by both natural processes and human activities, however, there are few exceptions where natural processes trigger challenges in water quality. Human induced factors are the main cause of water quality deterioration (UN-Water 2011; WHO 2002). Detrimental impacts caused by these factors include unhygienic and poor treatment of wastewater, poor management of water infrastructure, poor treatment of industrial discharge, poor agricultural practices and poor management of solid waste which often affect streams and lead to water eutrophication due to high concentration of nutrient loading (UN-Water 2011). These factors have been persistent since the rise of the industrial era and today the impacts are experienced in many global fresh water systems (UN-Water 2011; WHO 2002). Future projections suggest that by 2050, the world's water quality would have declined even more regardless of all the water polices and guidelines that exist on water quality (IFPRI 2014).

2.2 Eutrophication Internationally

UN-Water (2011) argues that in developing countries, over 80% of untreated sewage discharges into freshwater bodies and over 300-400 million tons of heavy metals, toxic sludge, solvents and other wastes are discharged into rivers each year. Nitrate from agricultural fields is one of the common global issue that contaminates surface and groundwater aquifers (UN-Water 2011). For example, in the United States of America, agricultural fertilizers and pesticides run-off is a significant source of water pollution with 40% nitrogen from crop-lands and 30 % of phosphorus that is added to freshwater systems per annum (UN-Water 2011).

The UNEP (2016) study on world's water quality and WHO (2002) study on guidelines for drinking water suggest that human activities play a major role in water pollution. According to UNEP (2016) the impacts of water pollution are traced back in the rise of the industrial era that was marked by massive production which has led to environmental degradation. Industrial expansion has severely impacted on water quality through discharge and poorly managed solid waste (UNEP 2016). The discharge of waste products with chemicals and metal compounds from industries does not only affect water quality, but it has also contributed to the mortality of aquatic species and negatively impact human health (UNEP 2016; WHO 2002).

Population growth, coupled with poor management of domestic and municipal wastewater, are known causes of water pollution globally (UNEP 2016; Oberholster and Ashton 2008). Human sewage contains high organic matter, pathogens and chemicals, which when poorly managed end up in fresh water bodies causing pollution (UNEP 2016). According to UNEP (2016), excrement from human and animals have bacteria and viruses that affect water quality which are present in a form of faecal matter which is detected by the presence of feacal coliform bacteria. Organic matter in sewage degrades in water, and during this process dissolved oxygen in water is used up thereby causing shortage of dissolved oxygen in the water which promotes the growth of algae and leads to the death of aquatic species (UNEP 2016; Oberholster and Ashton 2008). Also, low dissolved oxygen levels in water results in the formation of other toxins such as ammonia in water (UNEP 2016). Ansari et al. (2011) suggest that the above-mentioned factors are one of the main reasons for eutrophication in freshwater systems globally.

Countries in central and southern Europe have generally a high proportion of rivers and lakes that are polluted mainly by phosphorus (Ansari et al. 2011). By the 1990s, in Spain for example, 80% of lakes, 70% of reservoirs and 60% rivers were characterized as eutrophic (Ansari et al. 2011). World Health Organization (2002) argue that in the major European rivers, nitrate concentrations since the 1980 has generally remained the same, although there is reduced application of fertilizers in agriculture, there is no evidence of reduced nitrate concentrations in the rivers. Places such as Brittany in France, and Catalunya in Spain nutrients concentrations are still increasing in rivers (WHO 2002).

2.3 Eutrophication in South Africa

South Africa faces similar eutrophication challenges affecting global freshwater systems as discussed above as a result of cultural and natural factors (Griffin et al. 2014; Harding et al. 2009; de Villiers 2007; van Ginkel 2004; Bath 1989; DWA 1986). However, Griffin et al. (2014) argue that in South Africa, cultural eutrophication is the main contributor to water pollution which is caused by human, social and economic activities. South African climatic conditions coupled with anthropogenic activities have results in changes in aquatic ecosystems and have accelerated eutrophication in rivers and storage reservoirs (Oberholster and Ashton 2008).

According to Matthews and Bernard (2014) in a study that was conducted between 2002 and 2012 of 50 largest water bodies in South Africa using satellite remote sensing, it was found that 62% of these water bodies had high concentration levels of nutrients, while 26 of these water bodies had cyanobacterial blooms. According to NEMP (2013), 5 out of 75 major impoundments are eutrophic and 18 out of 25 major river catchments are eutrophic. Approximately 28% of surface water samples were hypertrophic, 33% were eutrophic, 37% were mesotrophic and only 3% were oligotrophic (DWAF 2013). Cyanobacteria including *Microcystis* and *Anabaena* species are found in all major impoundments of the country (Oberholster and Ashton 2008). These toxic blooms are a threat to aquatic species and compromise the safety of drinking water to the whole population of South Africa and in poisoning of livestock (Matthews and Bernard 2014). Eutrophication is also reported in studies conducted on cyanobacteria and toxin production in major impoundments by van Ginkel (2004); the deteriorating nutrients status of the Berg River in the Western Cape by de Villiers (2007); the cyanobacterial research post-2000 by Harding et al (2009) and the development of an integrated water quality management plan for the Vaal River system by Moodley et al.(2009) which all showed an increase in eutrophication levels.

According to Matthews and Bernard 2014; Griffin et al. 2014; Harding et al. 2009; de Villiers 2007; van Ginkel 2004; Bath 1989, poorly managed sewage in South Africa is one of the main problems that has resulted in freshwater pollution. They argue that sewage contain high levels of nutrients, salt, toxins and pathogens that pollute streams in the country. With the lack of or limited water infrastructure, poorly managed domestic sewage and spillages are observed in many municipalities across the country (Tissington et al. 2008). Domestic sewage from municipalities is characterized by dissolved organic matter which causes a decrease in dissolved oxygen concentration; increase turbidity; suspended solids and bacteria that contaminate water bodies (Matthews and Bernard 2014). According to Harding (2009) and van Ginkel (2004), this bacterial contamination causes *Escherichia coli* that degrade water quality and cause eutrophication. Oberholster and Ashton (2008) add that in South Africa and many other developing countries, sewage emanating from urban areas is poorly treated mainly because of lack of infrastructure and overloaded sewage treatment plant especially in highly populated areas and in areas where run off enters water system and contribute to eutrophication.

The root cause of municipal sewage discharges and overflow into fresh water systems is due to dysfunctional municipalities among others (DWA 2017). This may be due to inadequate financial support and operational planning; poor financial prioritization and lack of pro-activeness in infrastructure maintenance; poor problem reporting and response systems; lack of appropriate technical personnel; corruption and many other problems. Apart from the above-mentioned problems, poor cooperative governance and regulatory policies between the Department of Water and Sanitation and other departments and municipalities are also reasons for ongoing water pollution (DWA 2017). These problems are common in many municipalities in the country and have persisted for a long time (DWA 2017).

Increased demand for agricultural production to meet the growing population has also negatively affected the country's fresh water systems (Matthews and Bernard 2014; Griffin et al. 2014; Harding et al. 2009; de Villiers 2007; van Ginkel 2004; Bath 1989). The use of excessive fertilizers and pesticides increase the chances of water pollution by run-off (Oberholster and Ashton, 2008). Poor agricultural practices such as the use of excessive fertilizers; excessive irrigation; inappropriate tillage; encroachment as well as destruction of riparian zones and wetlands are common in the country and this has negatively impacted rivers (DWA 2017). Agriculture is one of the major economic sectors in the country that contributes more in the transfer of nutrients into water bodies and ultimately is discharged in the oceans (DWA 2017).

Walsh et al. (2005) argue that urbanization changes natural landscape. Urban growth alters hydrological and geomorphological processes thus urban streams experience elevated nutrient loading and other contaminant concentrations (Roy et al. 2016; Violin at el. 2011 & Walsh et al. 2005). The surrounding landscape such as roads, storm water drains, and leaky overflowing sanitary sewers channels contaminants into urban streams (Walsh et al. 2005). Pollutant concentrations increase not only due to increased inputs from point and non-point sources but also as a result of decreased nutrient removal efficiency in hydrological disconnected riparian zones and streambeds due to alterations (Roy, et al., 2016). An increase in paved surfaces in urban areas encourages an increase in run-off of different pollutants to nearby rivers resulting in an increase in nutrient concentrations in fresh water bodies (Violin at el. 2011, Walsh et al. 2005 & Roy et al. 2016). Urban water pollution is usually the result of impacts of contaminated water from sewage, wastewater treatment plants or site sanitation, grey water, storm water drainage and solid waste leachates and litter (ORASECOM 2011). Contamination from these sources may include a range of pollutants including nutrients (nitrate and phosphorus), microbiological components (feacal bacteria), and metals from storm water washed roads.

According to DWA (2009) the spread of algae blooms and cyanobacteria increases the cost of water treatment and excessive bloom can clog filters causing maintenance costs to be very high. Eutrophication in South African rivers is problem. It has numerous negative impacts that affect the ecological system, human health, economy, recreation and esthetic beauty (DWA&F 2009; van Ginkel 2011). The invasion of macrophyte, algae and cyanobacterial blooms out compete other aquatic species which compromise the integrity of the ecosystem such that only tolerant species survive (DWA&F 2009). Cyanabacterial decay and release toxic chemicals such as cynotoxins into water are harmful to fish, livestock, wild animals and birds. Eutrophication also affect compromise human's health. The spread of hyacinth (*Eichhrnia Crasspes*) creates breeding opportunities for mosquitoes and protect snail vector of bilharzia. It has also affected recreational services. The spread of large areas of macrophytes prevent access to waterways which cause problems for water sports such as yachting, skiing and bouts for fishing (DWA&F 2009; van Ginkel 2011).

Apart from the anthropogenic activities discussed above, large parts of South Africa are arid to semi- arid and experience high temperatures, erratic and unpredictable weather extremes such as drought and floods (Oberholster and Ashton 2008). Rivers and reservoirs that receive point source nutrient loading also have high evaporation rates. This results in rapid rate in the growth and distribution of eutrophication and spread of cyanobacterial blooms (Oberholster and Ashton 2008). Increased water temperatures, precipitation densities and prolonged droughts are projected to exacerbate many forms of pollution including nutrient loading, dissolved organic carbon, sediments pathogens, salt and thermal pollution in South African water bodies (Dallas and Rivers-Moore 2014).

2.4 Climate Change

There is also emerging literature indicating how climate change is likely to affect eutrophication. Xia et al. (2016) argue that even if anthropogenic activities contributing to eutrophication could be controlled, under climate change, eutrophication will still continue. Factors related to climate change such as increasing temperature, wind effect, precipitation effects and solar radiation effect have direct and indirect negative impacts on freshwater systems are capable of accelerating eutrophication process (Xia et al. 2016; Delpla et al. 2009).

2.4.1 Direct and indirect effects of increasing temperature

According to the Intergovernmental Panel on Climate Change (2018) an average increase of 1.5 ºC in temperature is predicted by 2050. An increase in air temperature will cause an increase in water temperature (Xia et al. 2016; Delpla et al. 2009). Increasing temperature has direct and indirect effects on water quality.

Temperature alone is one of the main factors affecting almost all physico-chemical equilibrium and biological reactions in water. Physico-chemical properties change with increasing temperature and frequently increasing endodermic reactions due to increased temperature (Xia et al. 2016; Delpla et al. 2009).

Increase in water temperature has several effects in factors such as dissolution, solubilization, degradation and evaporation (Xia et al. 2016). An increase in water temperature even by few degrees could cause thermal pollution in streams (Delpla et al. 2009). Gases such as oxygen dissolve better in colder water than in warm water. An increase in temperature reduces the ability of oxygen to dissolve in water and has a potential to affect the general health of aquatic organisms thus changing the quality of freshwater bodies (Xia et al. 2016; Delpla et al. 2009).

With increasing temperature, freshwater eukaryotic phytoplankton generally decrease allowing cyanobacteria to increase when water temperature reaches around 20 ºC but once water temperature reaches above 25 ºC, it promotes widespread growth of cyanobacteria compared to other phytoplankton groups (Xia et al. 2016). Apart from the direct effects on cyanobacterial growth rate, increasing water temperature could results in a number of indirect effects such a change in physical and chemical characteristics of aquatic environments and nutrient loading from soil and sediments. With higher water temperature, self-purification capacity is reduced which causes stratification and enhances internal nutrient loading which allows favorable conditions for cyanobacterial spread (Xia et al. 2016).

Xia et al. (2016) argue that higher temperatures also increase microbial activity in sediments and soils at the bottom of lakes and rivers, thereby increasing the rate of internal phosphorus release that could contribute a significant portion of nutrient loading in freshwater systems. Even if external sources such as control of waste-water discharges and point source pollution are controlled, an increase temperature could still increase the rate and condition of eutrophication (Xia et al. 2016).

An increase in water temperature, surface water also causes a decrease in water viscosity (ability of water to resist gradual deformation by stress) and allows nutrient loading (Xia et al. 2016). Decreasing viscosity enhances the sinking of large phytoplankton allowing cyanobacteria to spread. Thus, cyanobacteria are likely to spread and dominate phytoplankton assembles during warmer seasons (Xia et al. 2016).

2.4.1 Precipitation effect

Apart from increasing temperature effects, hydrological changes caused by precipitation changes may accelerate eutrophication process (Xia et al. 2016). Global temperature increase changes precipitation. It is expected that in the Pacific and some high latitude regions the mean annual temperature will increase, however, mean annual precipitation is likely to decrease in parts of the mid-latitude and subtropical dry regions. This suggests that there is still a possibility that extreme precipitation events will increase becoming more common and intense in some parts of the world (Xia et al. 2016).

Precipitation changes are expected to have negative impacts on hydrological regimes such as flow rate, hydraulic characteristics, water cycles, and water levels (Xia et al. 2016). Hydrological regimes are changing due to intense precipitation and extreme hydrological events such as floods and drought. An increase in rainfall intensity causes a higher concentration of sediments through erosion (Xia et al., 2016; Delpla et al. 2009). More intense precipitation events promote nutrient loading by gathering non-point pollutants and transport it to nearby water bodies. Storms cause freshwater pollution through discharge of contaminants such as pesticides, herbicides and nutrients into rivers and lakes causing degradation of water quality (Xia et al. 2016). Lower precipitation means lower flow, implying less dilution. Less dilution means higher pollution concentration with lower concentration of dissolved oxygen (DO) and increased biochemical oxygen demand (BOD) in water which potentially increases the chances of eutrophication. A general increase in nutrients coupled with increase in temperature stimulates algal growth leading to eutrophication (Xia et al. 2016; Delpla et al. 2009).

2.4.3 Wind effect

Impacts of wind on water eutrophication are both direct and indirect (Xia et al. 2016). Direct effects include wind-blown algal from lakes and rivers to lakeshores and river banks influencing residence along lakes or rivers. Indirect effects include wind-wave disturbances speeding the release of nutrients from sediments in water (Xia et al. 2016). Higher wind speeds increase circulation of water and mixing of nutrients. When temperatures are high, the upper layer of rivers gets warmer and mix with lower layers under wind action. Wind promote water movement, recirculating bottom water to the surface thus wind increases migration and transformation of contaminants (Xia et al. 2016).

2.4.4 Solar radiation effect

Solar radiation provides energy for most aquatic and terrestrial ecosystems and is a source of photosynthesis for aquatic organism (Xia et al. 2016). It is also a limiting factor for the growth of phytoplankton thus solar radiation could have negative impacts on many aquatic species and aquatic ecosystems in lakes, rivers, marshes and oceans. Solar radiation determines the efficiency of photosynthesis, which influences the rate of plants growth and therefore the survival of animals. Under normal circumstances, enough sunlight provides good conditions for the growth of algae leading to an increase in water temperature and turbidity increasing the risk of eutrophication (Xia et al. 2016).

2.5 Eutrophication projections

The study conducted by the International Food Policy Research Institute (IFPRI 2014) suggests that the world is on a path of continuous water deterioration (IFPRI 2014). Water quality is projected to decrease even more in the next decades which will pose a challenge to development pathways, ecosystem sustainability and the well-being of humanity (WHO, 2002 and IFPRI 2014). The 2050 projection on water quality predicts that there will be an increase in nitrogen and phosphorus concentrations in water bodies under three economic scenarios which include optimistic, medium and pessimistic growth projections and two climatic scenarios (high and low emissions). The optimistic projection is associated with lower population growth and high gross domestic product (GDP) whereas the pessimistic view is associated with high population growth yet lower economic growth. Under the medium projection, population is expected to reach 9.3 billion at an economic growth rate of 3.2% by the year 2050 (IFPRI 2014).

According to IFPRI (2014), nutrient loading into water resources during the base period of 2000-2005 amounted to 10 million tons per year and the highest concentrations of these pollutants were reported in the Eastern and Northern China and in the Indo-Gangetic plains in South Asia. Also, in the mid-western United States, Central Europe and South America, these regions are highly populated, and agriculture is practiced at larger scales which many studies suggest that agriculture play a major role in nutrient loading (IFPRI 2014).

IFPRI (2014) argues that there is a correlation between nutrient loading and countries income levels. Based on theory, different income classes in different countries shows a correlation, high income earning countries are the reported to have high levels of nutrients (IFPRI 2014). This is evident in the North America and African countries where income levels are higher. It is in these regions where nutrient concentration is reported to be elevated in water bodies (IFPRI 2014). Canada and the United States fall under the high income and it is projected that under the climate change and medium growth rate, United States nutrient loading will increase by 34% and Canada by 18% in the next decades. Though most African countries belong to the lower-middle income, as a contrast, it is projected that nutrient loading will double in the next few decades in most African rivers (IFPRI 2014).

2.6 Water management strategies responding to water quality challenges

According to UNEP (2016), the 2030 agenda for sustainable development represent agreement by all nations for sustainable development. The sustainable development goals (SDGs) 6, 11 and 15 highlight the need to protect and restore water resources and the importance of monitoring and reporting (UNEP 2016; IWQGES 2016). Below is the summary of SGD goals that explicitly highlight water quality related issues and encourage effective water management to ensure sustainability.

Table 1: Water quality related SDGs

SDG Goal	Description
SDG Goal 6	**Ensure availability and sustainable management of water and sanitation.** • **Target 6.1, 6.2, 6.4, 6.5 and 6.a & 6.b**: in summary, improve water-use efficiency access to sanitation, protect water ralated systems etc • **Target 6.3**: improve water quality, halting the proportion of untreated wastewater and sustaintially increase recycling and safe water re-use globally. • **Target 6.6**: by 2020, protect and restore water-related ecosystems including mountains, forests,wetlands,rivers,aquifers and lakes.
SDG Goal 11	**Make cities and human settlements inclusive, safe,resilient and sustainable.** • **Target 11.5:** by 2030 significantly reduce the number of people affected by amongst others, impacts of water realted disasters etc.
SDG Goal 15	**Protect, restore and promote sustainable use of terrestrial ecosystems, halt biodiversity loss etc.** • **Target 15.1**: by 2020, ensure conservation,restoration and sustainable use of amongst others, inland freshwater ecosystem and their services.

According to the (IWQGES 2016), ensuring water quality protection and where necessary restoration to improve degraded water resources is an urgent need that must be executed as part as an adaptive process that encourages extensive consultation and engagement of stakeholders to achieve shared understanding of the importance environmental assets such as water systems. Water quality monitoring and evaluation is an important element of adaptive management process to ensure that water quality goals and objectives are met (IWQGES 2016).

Similarly, South Africa has adopted an adaptive management approach. The South African National Water Act (No. 36 of 1998) is seen as one of the most progressive legislative and policy frameworks for water management in the world (Tissington et al. 2008) and is built on the principles of integrated water resources management (IWRM), which emphasizes on the need for participatory processes at all levels. The South African water quality policy acknowledges that water quality problems have been ongoing and it seeks to address water quality key problems which include salinization, eutrophication, micro-pollutants, micro-biological pollutants and erosion and sedimentation. It seeks to move towards an integrated water quality management (IWQM) (DWA 2017). The policy highlights that $N0_2$, $N0_3^-$, NH_4^+ and $P0^{3-}{}_4$ as key contributors to eutrophication as these chemicals manifest in a form of algae and macrophytes which are being observed in many South African reservoirs (DWA 2017).

The policy encourages a robust inclusive manner to manage the water resources which allow partnership of the private sector and civil society as well as working together with different departments to build on current strengths, identify gaps to better manage the resource (DWA 2017). It highlights the importance of aligning water management policy with current legislation to provide resolution on water quality issues (DWA 2017).

The 2013 national water strategy also emphases the need for the development water management strategy which is also considered as a part of IWRM principles. This allows good governance which includes political, administrative and economic dimensions and includes the activities of government as well as the involvement of water users and various stakeholders (DWA 2013). According to DWA (2013) good governance encourages transparency, effective participation, predictability, equity, responsiveness, accountability and informed decision making.

Good governance ensures the establishment of effective and efficient institutional framework for water management that prioritizes focus on critical water issues, clearly define mandates, roles and responsible personnel to achieve functionality, responsibility, transparency and accountability in management of water resource. It also builds on research and innovation as it promotes new knowledge which provides improved water management strategies that respond to water issues and allows sustainability. Research also contributes to the development of policies and strategies to manage water with informed better decision making at all levels of government and across the water value chain (DWA 2013). Good governance promotes skills and capacity building to provide solutions and expertise in addressing challenges with high competence to ensure sustainability in water management (DWA 2013).

Thus far, different management strategies to manage water were developed to respond to eutrophication in some water bodies in the country. Since the late 1970s and early 1980s there have been numerous studies in South Africa and options for managing eutrophication that were suggested. On the 1st of August 1980 the DWAF promulgated an effluent standard of 1mg/L orthophosphate for wastewater discharges from point source (van Ginkel 2011). The earliest of eutrophication programme focused on sensitive catchments an initiative by DWA that aimed to reduce high concentrations of phosphate entering rivers. In 1985-1988 DWA and CSIR using Reservoir Eutrophication Model (REM) to predict phosphorus standards worked on water quality sensitive catchment aiming to control eutrophication by controlling chlorophyll concentration in receiving water body (van Ginkel 2011). This translated to phosphorus management objective (PMO) to control the mean total phosphorus in water bodies (van Ginkel 2011). From 1985 onwards DWA also focused its monitoring in areas impacted by eutrophication through the trophic status project. In 2002 the department also started the national eutrophication monitoring programme and produced data and maps indicating the extent of eutrophication in water resources of the country. This data and maps indicated that most South African water bodies were affected by eutrophication especially in large metropolitan areas. All these aimed at eutrophication reduction in affected stream and to prevent water pollution (van Ginkel 2011).

The South African Water Resource Commission (WRC) also investigated positive and negative consequences associated with the introduction of zero-phosphate detergents in South Africa aiming to determine phosphate loading by phosphate detergents at waste treatment facilities, to explore the effect of introducing low to zero phosphate detergents in South Africa (van Ginkel 2011). The models used to remove detergents with phosphorus on dams showed a decrease in phosphorus ranging from 3%-35%, largely dependent on demographics of each catchment and a mean reduction of 12% across all dams (van Ginkel 2011).

Bio-manipulation techniques were initiated. This technique targeted food-chains functionality and involved the use or harvesting of non-desirable organisms to control algal growth or other components of the food chain that may cause eutrophication and related problems. By controlling certain species such as fish web that prey on zooplankton to an extent that may change the functioning of the ecosystem. DWA and DH environmental consulting developed a management plan for the Harbeespoort dam to combat severe eutrophication (van Ginkel 2011). Also, a project to predict cynobacterial blooms was initiated prompted by environmental and health problems caused by cynobacterial blooms.

2.7 Concluding remarks

Understanding boundaries in water quality categorization or classification is still a challenge which presents uncertainties and make it difficult to provide precise account of water quality. Continuous and effective monitoring is still a challenge resulting in poor water management and further pollution. Integrated governance strategy that is multi-disciplinary in linking hydrology, climate change, socio-economic and land use dynamics must be explored.

Chapter Three: Materials and Methods

3.1 Introduction

This study aims to analyze nutrient loading in the Vaal River over the past two decades. The design incorporates two activities which include exploring and analyzing eutrophication in the Vaal River and comparing any significant difference between the last two decades. Statistical analysis was used to analyze data. According to Loeb et al. (2017) statistical analysis has an ability to define concentration, trends and compare data sets. Data were collected and sampled by DWS weekly while other data were collected on monthly basis. To ensure accuracy monthly average values were used to provide comparable time series.

3.2 Monitoring sites selection

Monitoring sites were selected in relation to land use activities which include agriculture, industries and urban areas and also data availability. According to DWA (2009), these activities are some of the major causes of nutrient loading in freshwater systems. Based on the data availability, the research aims to show nutrient concentration, trends and differences between the past two decades from physico-chemical data. The Vaal River is divided into three sections-upper, middle and lower. Monitoring sites were selected along the stretch of river from all three sections.

The upper Vaal is highly populated and highly industrialized (Moodley et al., 2009; Coleman and Niekerk 2007). Both the Vaal Dam and the Vaal Bank are drained by Klip, Wilge, Molspruit and Grootspruit Rivers. The Klipriver is polluted due to mining and industrial activities taking place at the upper catchment outside Sedibeng District Municipality (Sedibeng District Municipality IDP 2017). Surrounding towns include Deneysville, Orangeville Villeirs and Franfort could also contribute to water pollution due to urban run-off. The Rand Water abstract water from the Vaal Dam to supply local municipalities and industries in the Upper Vaal (Moodley et al. 2009).

The Middle Vaal is characterized by extensive dry-land and irrigation agricultural activities such as maize, wheat, sorghum, groundnuts, sunflower and fodder. Palmietfontein is drained by Klipplaatdrift River located 60km downstream of Pilgrims estate weir. Land use in this area is mostly cultivated land as well as urban areas. Same in Schoemansdrift cultivated land is dominant as well as urban areas such as Potchefstroom in the North-West province.

The lower Vaal is characterized by livestock farming, irrigation agriculture and economic activities which include cement and cheese production (Moodley et al., 2009). Large quantity of water is abstracted from the Vaalharts barrage is supply the Vaalharts irrigation scheme in the Harts River catchment. The Nazareth farm weir is located 1km downstream the Vaalharts barrage. Agricultural activities dominate in this area and irrigation returns from the irrigation scheme enters the River. Urban areas such as Magareng and Doomfontein are responsible for urban-off that pollutes the river (DWA 2009).

Table 2: Monitoring Sites

Sites	**Longitude**	**Latitude**	**Land use activities**
Site 1 - Vaal Dam (UV)	28° 7' 15.9594"	-26° 51' 15.0114"	Mining, water abstraction, urban areas, agriculture
Site 2 - Vaal Bank (UV)	28° 7' 0.12"	-26° 53' 0.24"	Mining, urban areas, agriculture
Site 3 – Schoemansdrift (MV)	27° 12' 39.996"	-26° 58' 13.0074"	Agriculture, urban areas
Site 4 – Palmietfontein (MV)	26° 27' 50.0034"	-27° 23' 22.992"	Irrigation, urban areas
Site 5 - Vaalharts Barrage (LV)	24° 55' 32.988"	-28° 6' 55.0074"	Irrigation, urban areas
Site 6 - Nazereth Farm Weir (LV)	24° 54' 55.0074"	-28° 6' 51.012"	Irrigation, urban areas

3.3 Data Collection

The DWS database has water quality data dating back as the early 1970s until present. In general, water samples were collected weekly however there are gaps in data records, thus some variables data was on monthly basis.

The water quality parameters measured in this study include Chlorophyll, $N0_3$, $P0^{3-}_4$, NH_{4+} to understand nutrient loading in the Vaal River and EC concentration is analyzed as it gives an indication of nutrients dissolved in water.

3.4 Statistical Analysis

Time series graphs were produced to understand nutrient concentration and trends at different sites. Linear graphs were plotted to describe concentration of chemicals throughout the entire monitoring period. Pie charts were used to determine nutrient concentration percentage for each site to identify sites with elevated nutrients. Antonopolos et al. (2001) argue that statistical and trend analysis are key steps in understanding the behavior and variation of water quality in a stream flow. To compare the past two decades to see if there was any significant difference, t-tests were conducted on each parameter. Data was divided in two groups, Group 1 represented monitoring period from 1996-2006 and Group 2 represented 2007-2017.

To determine the trophic status of the river, the South African Water Quality Guidelines for Aquatic Ecosystems (SAWQGAE) 1996; National Eutrophication Monitoring Programme (NEMP) 2002 and the International Water Quality Guidelines for Ecosystems 2016 (IWQGES) were used to investigate the trophic status of the Vaal River. The water quality standards have increased greatly through the adaptation of the SDGs that promote iterative management framework to readdress concerns and achieve water quality intended goals (IWQGES 2016).

According to IWQGES (2016) water quality standards differ from international to national to local scale to suit context and ensure relevance to cover social concerns as well as ecological conditions. Standards are used as roadmaps to support and assist respective governments develop standards within their jurisdiction. All these standards use four categories to describe changing conditions in freshwater systems. The categories include category 1 (high ecosystem integrity), which reflect good condition, near natural or intact sate and is used as reference state. The system provides goods and services and is capable to recover from naturally recurring stressors. At this state water can be used for anything without being treated (UNEP 2016). Category 2 (minimally to moderately disturbed), at this state water is sustainable for many uses however, ecosystem might be compromised. Conditions allow direct human contact, indirect water use such as industries, irrigation, and artificial recharge and can provide habitat for many different fish species. Category 3 (highly disturbed), at this state, ecosystem is highly disturbed, and conditions are of concern and requires immediate management action and identifying the sources of the problem to avoid further degradation. In this condition there is a negative impact on ecosystem goods and services. Ecosystem services can no longer be provided such as drinking water supply, and recreational functions. Lastly, category 4 (extreme impairment), this category represents unacceptable condition that cause server loss of aquatic species. Ecosystem goods and services can no longer be provided. The naturalness of this state is lost and at a point of no return without man-made effective remedial action (UNEP 2016). Same with the South African standards, the guideline is divided into four categories and translated as the international standards described above

Table 2 below shows the International Water Quality Guidelines for Ecosystems (IWQGES) in rivers and streams. These guidelines are documented in a manual to guide respective governments to develop standards or guidelines for freshwater system suitable for their contexts (UNEP 2016). The IWQGES are made primarily for national governments and mainly focus on freshwater ecosystems (refer to Table 3 below). Table 4 shows the South African Water Quality Guidelines for Aquatic Ecosystems (SAWQGAE) 1996 and Table 5 shows the National Eutrophication Monitoring Programme (NEMP) 2002.

Table 3: IWQGES 2016

Variables	**Category 1 (High Integrity)**	**Category 4 (Extreme impairment)**
Total Phosphorus (TP) (µg/ℓ)	<20	>190
Total Nitrogen (µg/ℓ)	<700	>2500
Chlorophyll (µg/ℓ)	<5.0	>125
pH	6.5-9.0	<5.0
Un-ionized ammonia (µg NH_3/ℓ)	15[5]	100[5]

Table 4: SAWQGAE 1996

Variables	Oligotrophic	Mesotrophic	Eutrophic	Hypertrophic
Inorganic Nitrogen (µg/ℓ)	<500	500-2500	2500-10 000	>10 000

Inorganic Phosphate (µg/ℓ)	<5	5-25	25-250	>250

Table 5: NEMP 2002

Variable	Oligotrophic	Mesotrophic	Eutrophic	Hypertrophic
Mean Annual Chlorophyll-*a* µg/ℓ	0≤10	10≤20	20≤30	>30

3.5 Brief discussion of physical properties of variables selected

Below is a brief discussion of parameters analyzed in the study.

3.5.1 Electrical Conductivity (EC mS/m)

Solids in nature are present in solutions (DWAF 1996d). Solids that dissolve in water they either become positive or negative ions. These dissolved ions have an ability to conduct an electric current (DWAF 1996a). The main positively charged ions include calcium (Ca^{+2}), sodium (Na^{+}), Potassium (K^{+}), and Magnesium (Mg^{+2}). The main negatively charged ions include Sulphate ($S0_4^{-2}$), Chloride (Cl^{-}), Bicarbonate ($HC0_3^{-}$) and Carbonate ($C0_3^{-2}$). Nitrate ($N0_3^{-2}$) and phosphate ($P0_4^{-3}$) do not contribute much to conductivity. Conductivity vary with different water sources, ground water, rainfall, water drained from agricultural fields and municipal waste water has different conductivity levels thus EC provide the indication of nutrients dissolved in water (DWAF 1996d).

According to DWAF (1996a) total dissolved solids (TDS) is directly proportional to EC of water. Increase in TDS affects aquatic species in different ways, such as disturbing ecological processes such as nutrients cycling, affect adaptation patterns of different species, and affect community structure of species (DWAF 1996d). Changes in TDS may affect human and animal health. Excessive TDS may cause laxative effects and kidneys could be damaged by elevated levels of sodium and magnesium. If water with high TDS is used for bathing and washing, it causes skin dryness and discomfort. In animals, high TDS makes water less palatable (DWAF 1996d).

3.5.2 Nitrate ($N0_3$ µg/ℓ)

According to DWAF (1996a) nitrate is the most common nitrogen found in water. DWAF (1996a) describe nitrate as a one part of nitrogen and three parts oxygen. DWAF (1996a) argues that nitrate is caused by the oxidation of ammonia or nitrite. It is formed as a result of natural decomposition of organic nitrogenous matter by micro-organisms. Nitrate in water bodies is introduced mainly through non-point sources such as septic and sewage discharges, leaching of fertilizers from agricultural fields, and animal manure (DWAF, 1996a).

Nitrate together with phosphate result in nutrient enrichment in water bodies and promotes the growth of algae which prevent enough sunlight penetration in the water. This affects aquatic species and causes odor (DWAF 1996a). It also affects human health; excessive nitrate can cause tiredness and difficulty in breathing in infants and cyanosis. Nitrate oxidizes hemoglobin (red blood cells) which hinders the transportation of oxygen through the body which results to suffocation due to lack of oxygen in the body tissues (DWAF 1996a).

3.5.3 Phosphate ($P0^{3-}{}_4$ µg/ℓ)

Phosphate is mainly resulting from discharges of waste water treatment into water bodies; this discharge has high concentrations of domestic detergents (DWAF 1996a). Animal waste, fertilizers from agricultural fields, sewage has significant concentration of phosphate. When organic matter decomposes, phosphate increases. Excess phosphate may result in algae blooms which causes problems in oxygen levels in the water and may results in death of fish and other aquatic species (DWAF 1996g). Different studies on water quality suggest that phosphate is a major nutrient that causes eutrophication in water bodies.

3.5.4 Ammonium (NH_{4+} µg/ℓ)

Ammonia is present in water as free un-ionized form (NH_3) or as ionized form (NH_4^+). Both are formed by aerobic and anaerobic of organic material (DWAF 1996g). Ammonium ions contribute to eutrophication. Commercial agricultural fertilizers contain soluble ammonia which is carried into freshwater systems by run-off. Industrial discharge, sewage discharge, mine operation are sources of ammonia. Excessive ammonia affects the respiratory system of animals by causing problems in cellular metabolism and reduces the oxygen permeability of cell membranes. It affects fish species causing deduction in hatching, affect growth rate and affect liver and kidneys (DWAF 1996g).

3.5.5 Chlorophyll

High concentration of chlorophyll causes increase in algal biomass that affects aquatic species. Chlorophyll emanate from high level of nutrients from fertilizers, septic tanks, sewage treatment plants and urban-runoff (DWA 2002). Chlorophyll enables photosynthesis in plants and other chlorophyll containing organism and may allow the spread of algal growth (DWA 2002).

3.6 Limitations of research design and methods

According to Xie (2011), description cannot be the ultimate goal in research, however understanding the cause of theory developed by statistical models it is important rather that developing trends and correlation. Secondary data were used, it can be easily misinterpreted. If data collected used biased or faulty procedures, this might lead to misleading analysis and interpretation.

Chapter Four: Results and Discussion

4.1 Introduction

According to Dikio (2010) the Vaal River flows through a heavy industrialized region previously known as the Vaal triangle which includes the towns of Vereeniging, Vanderbijlpark and Sasolburg. Previously the Vaal River has been considered a dumping site for industries, farmers and towns (Diko 2010). This chapter shows the results and analysis of different variables of water quality from each monitoring site as described previously and will aim proof the hypothesis that nutrient loading has increased in the Vaal River over the past two decades or not. Figure 5 below is a map showing monitoring sites.

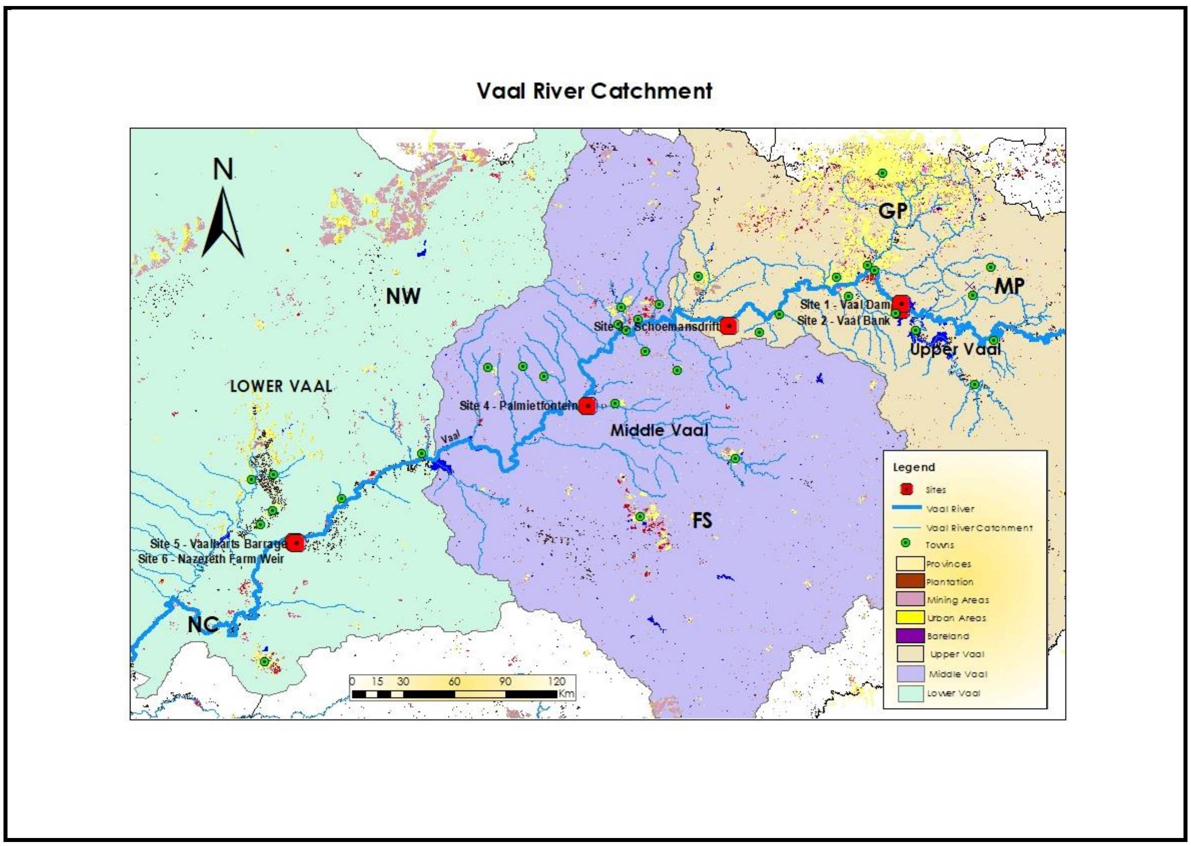

Figure 6: Monitoring Sites

4.2 Dissolved phosphorous results and analysis in all sites

Phosphate into the Vaal River is largely generated from the discharge of waste water treatment into water bodies and contains high concentrations of domestic detergents (DWAF 1996a). Animal waste, fertilizers from agricultural fields and sewage also have high concentration of phosphate which when enters stream and pollute water. The graphs below show $P0_4^{3-}$ concentration in monitoring sites over the past two decades.

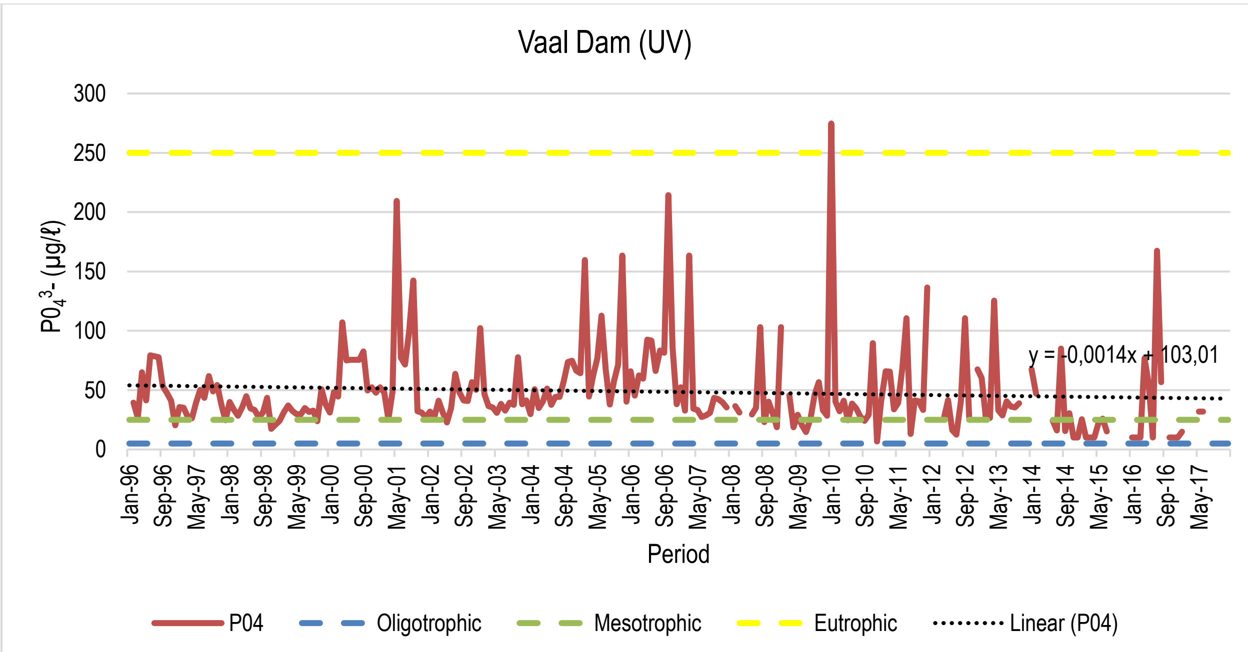

Figure 7: $P0_4^{3-}$ Concentration in the Vaal Dam

$P0_4^{3-}$ concentration in the Vaal Dam has exceeded the desired standard of <5 µg/ℓ (oligotrophic) according to SAWQGAE (1996) throughout the entire monitoring period. Concentrations have reached eutrophic level. Figure 7 above shows that the Vaal Dam has been in a eutrophic state almost throughout the monitoring period. At the start of monitoring $P0_4^{3-}$ concentration was low even though it occurred in the eutrophic category. An increase is notable from year 2000 and the graph shows an irregular pattern. Between 2005 and 2007 many peaks were observed followed by a decline in concentration such that in the last five years concentration was occurring at mesotrophic category. Loading in this site could the caused by heavy industries in the upper reaches of the Vaal River. Rivers that drains the Vaal at this point pass through mining areas, cultivated land and highly populated areas. Although the graph shows a slightly decreasing trend, $P0_4^{3-}$ concentration remain a concern in the Vaal Dam since most of the time it has occurred in the eutrophic state.

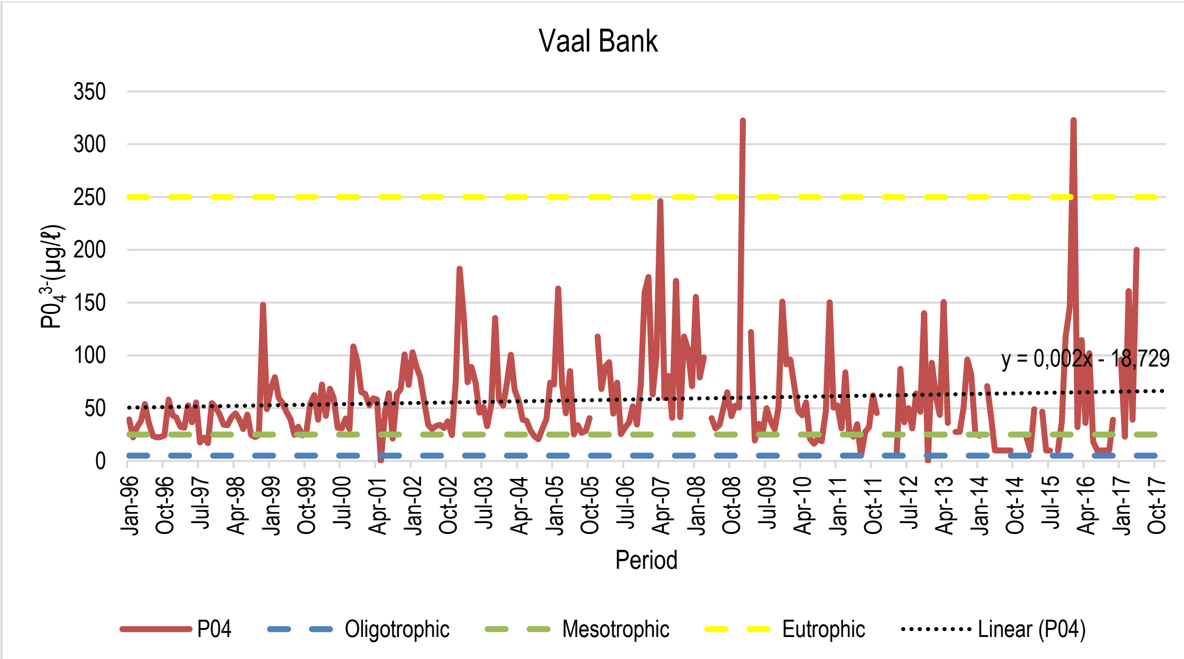

Figure 8: $P0_4^{3-}$ in the Vaal Bank

Figure 8 shows that $P0_4^{3-}$ concentration in the Vaal Bank has been mostly eutrophic. Even though during the start of monitoring periods concentration levels were low, an increase is notable from 1998 and the graphs shows an irregular pattern. In May 2007, January 2009 and in January 2016, $P0_4^{3-}$ concentration reached the hypertrophic category. This area is drained by rivers passing through industrialized and densely populated areas. Run-off from this region enters the river and cause pollution. The graph shows an increasing trend in $P0_4^{3-}$ concentration at this point.

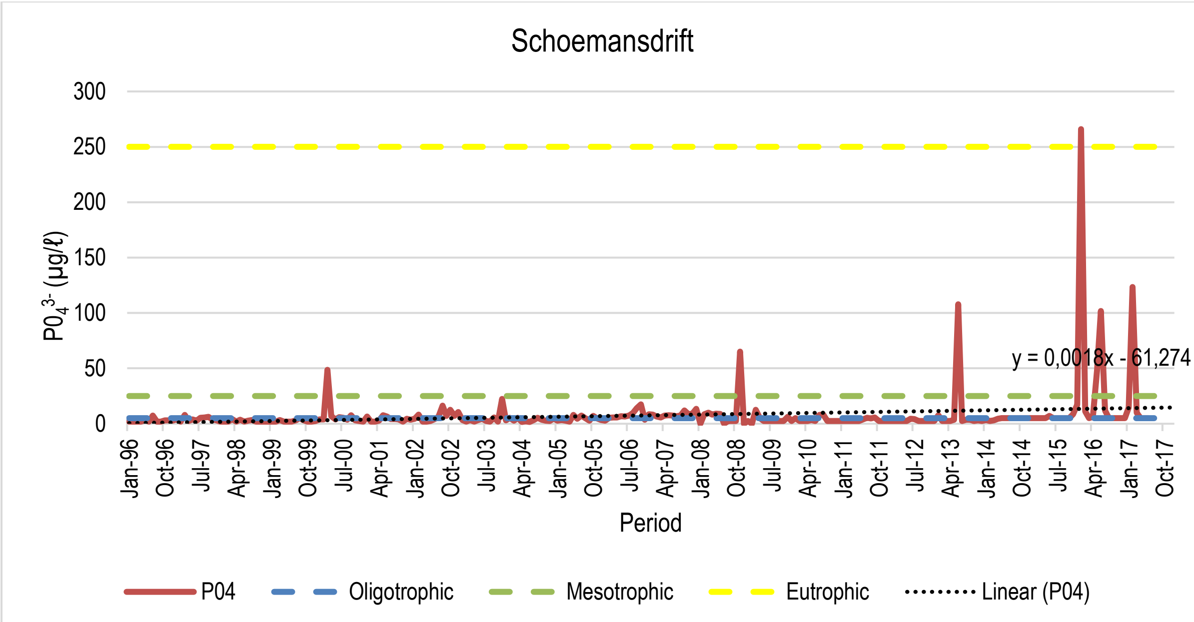

Figure 9: $P0_4^{3-}$ in Schoemansdrift

$P0_4^{3-}$ concentration in Schoemansdrift mostly occurs at desired category. Few peaks occurred in March 2000, November 2008, June 2013, January 2016, June 2016 and February 2017 that reached the eutrophic category. This point is located downstream the Upper Vaal where there are less human activities taking place. Rivers in general have the ability to naturally clean themselves. However, $P0_4^{3-}$ concentration showed an increasing trend.

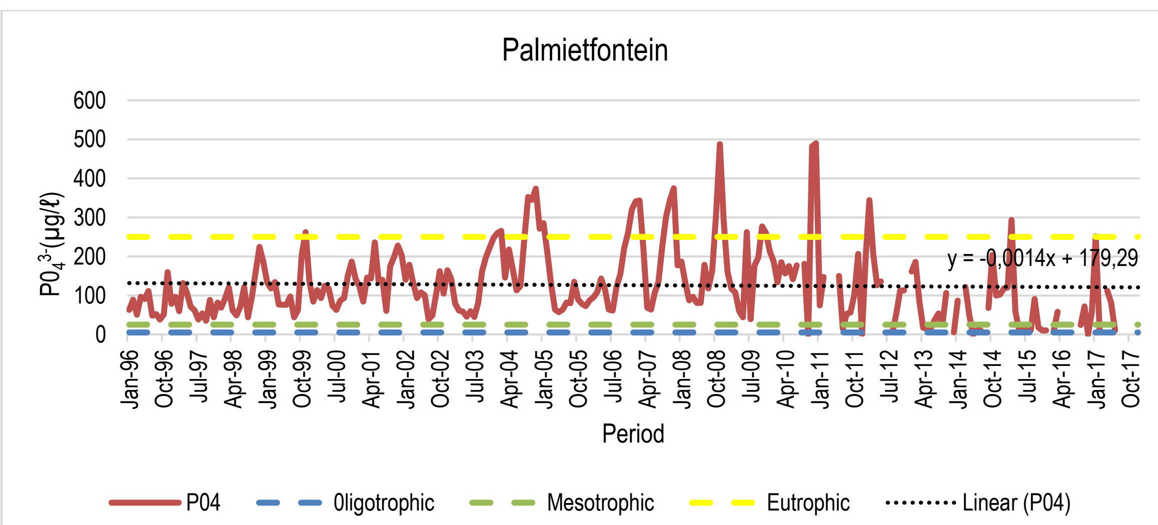

Figure 10: $P0_4^{3-}$ concentration in Palmietfontein

Figure 10 shows that the Vaal River in Palmietfontein has been eutrophic almost throughout the monitoring period. From 2002 to 2011 $P0_4^{3-}$ concentration has increased with many peaks reaching the hypertrophic category. At this site agricultural activities are taking place on the banks of the river which could be the reason of high concentration of $P0_4^{3-}$ even though it shows a decreasing trend. Also, run-off from Bothaville and sewage returns could be the reason of high concentration.

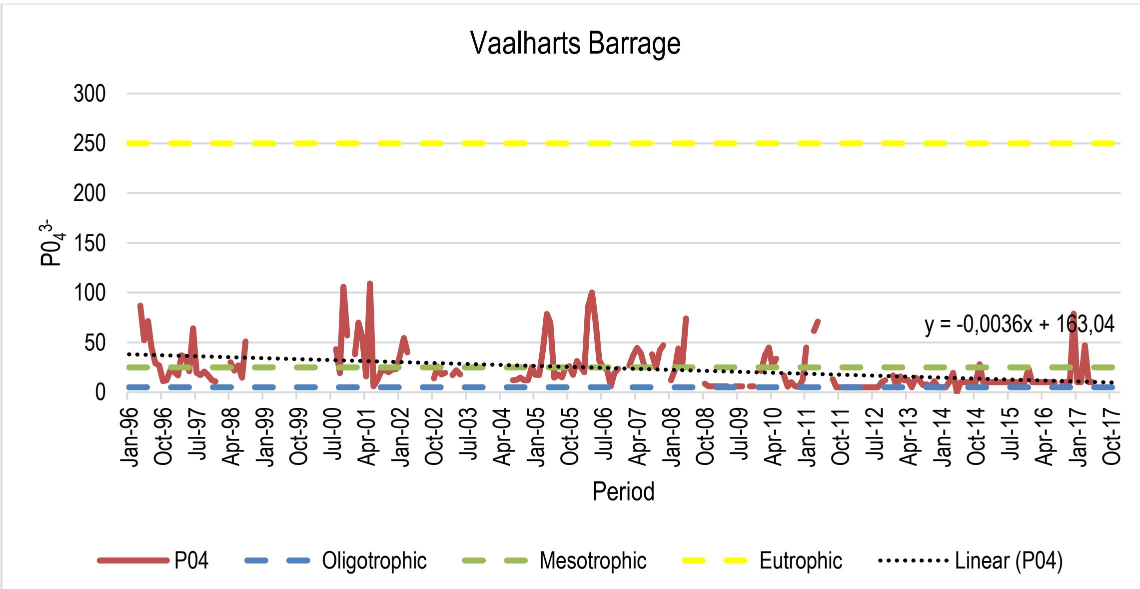

Figure 11: $P0_4^{3-}$ concentration in Vaalharts barrage

At the Vaalharts Barrage $P0_4^{3-}$ concentration occurred at eutrophic state in the first decade. In the last decade a decrease is notable, and it shows a decreasing trend.

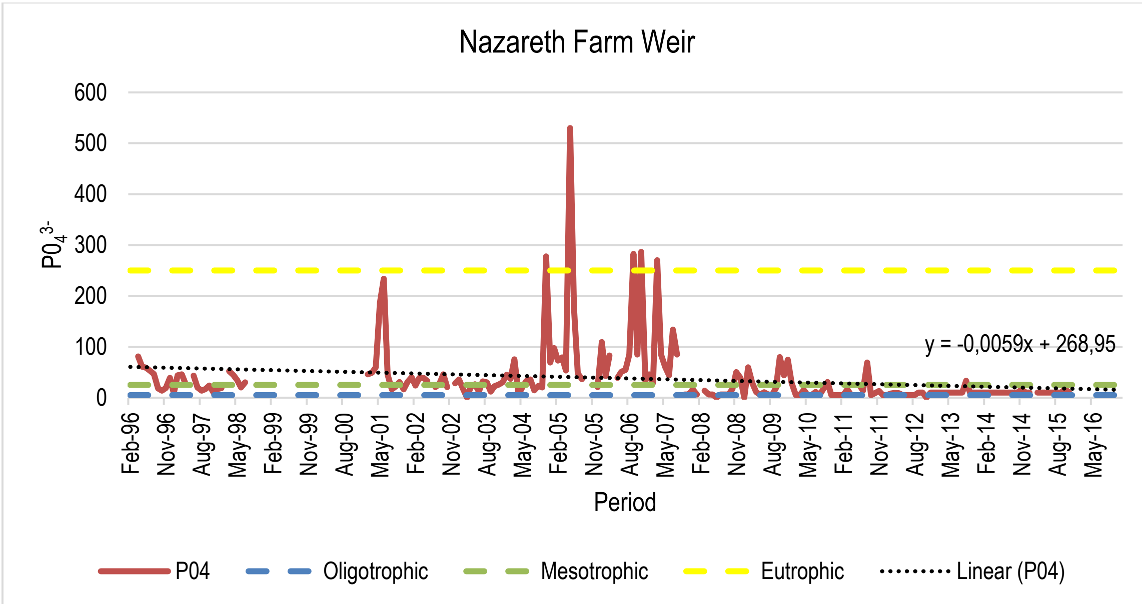

Figure 12: $P0_4^{3-}$ concentration in Nazareth Farm Weir

At Nazareth Farm Weir $P0_4^{3-}$ concentration mostly occurred at a eutrophic state. In the last five years it has occurred within the mesotrophic category. In general, it shows a decreasing trend

In the Vaalharts Barrage the graphs show $P0_4^{3-}$ concentration mostly occurred in the mesotrophic category and it shows a decreasing trend.

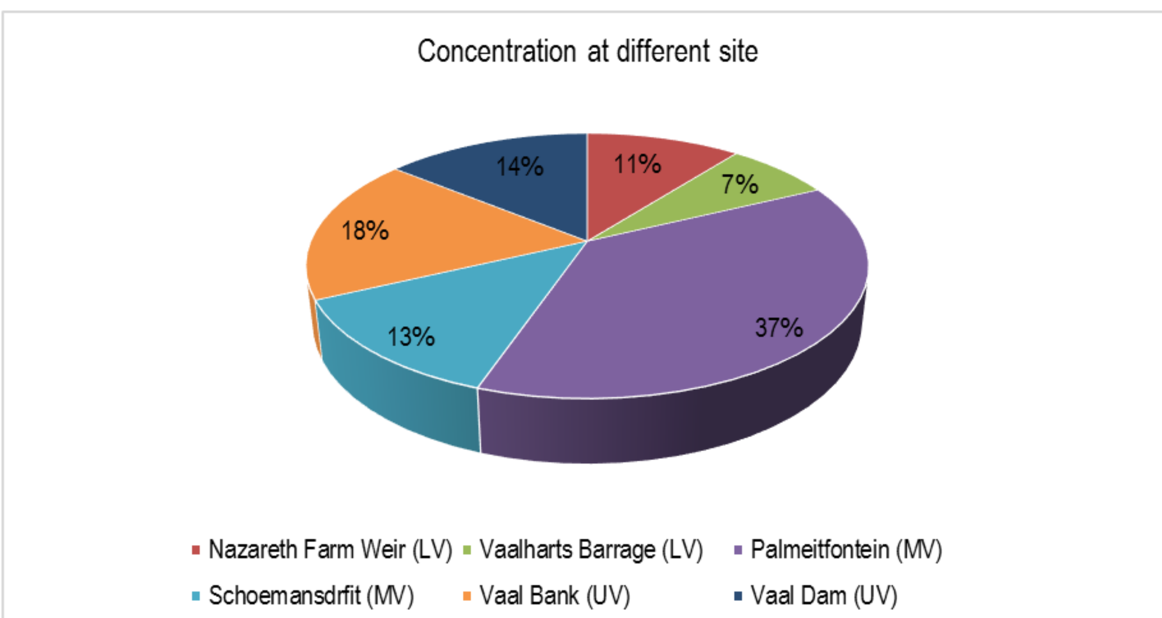

Figure 13: $P0_4^{3-}$ concentration at different sites

The figure above shows Palmietfontein to be the most polluted with phosphorous that could result from agriculture practice taking place from alongside the river bank. Sewage containing detergents with phosphates from near-by urban areas such as Bothaville could be the cause of elevated phosphate.

4.2.1 $P0_4^{3-}$ concentration comparison between the past two decades

$P0_4^{3-}$ data are presented in Appendix A

Vaal Dam

The t-test conducted on the Vaal Dam data showed that $P0_4^{3-}$ has increased in the past decade. Increasing $P0_4^{3-}$ may be due to run-off from surrounding areas such as Oranjeville and Deneysville. Sewage has a high $P0_4^{3-}$. Agricultural activities along the Wilge River drain into the Vaal River and may also contribute to the increasing $P0_4^{3-}$. At the Vaal Dam Group 1 (N=132, M=0.053776, SD=0.032384) and Group 2 (N=113, M=0.104222, SD=0.300205) and P=0.56247. p is greater than 0.05 and therefore the null hypothesis is not accepted indicating that there is a significant difference between group 1 and 2.

Vaal Bank

At the Vaal Bank Group 1 shows that (N=131, M=0.122994, SD=0.789248) and Group 2 (N=115, M=0.115658, SD=0.303912) and P=0.925398. p is greater than 0.05 therefore the null hypothesis is not accepted and there is a difference between group 1 and 2. The results show that $P0_4^{3-}$ concentration has not change in the past decade.

Schoemansdrift

At Schoemansdrift, Group 1 shows that (N=120, M=0.049603, SD=0.039036) and Group 2 (N=134, M=0.38288, SD= 0.044506) and P=0.033073. p is less than 0.05 therefore the null hypothesis is accepted and there is a significant difference between group 1 and 2. The results show that $P0_4^{3-}$ has been decreasing at this site in the Vaal River.

Palmietfontein

At Palmietfontein, Group 1 shows that (N=132, M=0.124563, SD=0.072517) and Group 2 (N=106, M=0.133459, SD=0.110929) and P=0.457306. p is greater than 0.05 therefore the null hypothesis is not accepted and there is a difference between group 1 and 2. $P0_4^{3-}$ concentration has increased in the past decade at this site. Just above this monitoring site, there is agricultural activities taking place on the river bank which increases $P0_4^{3-}$ loading. Also, run-off from Bothaville may be the cause of increasing concentration.

Vaalharts Barrage

At the Vaalharts Barrage, Group 1 shows that (N=84, M=0.031343, SD=0.023650) and Group 2 (N=109, M=0.02145, SD=0.023650) and P=0.036734. p is smaller than 0.05 therefore the null hypothesis is accepted and there is a difference between group 1 and 2. $P0_4^{3-}$ concentration has decreased in the past decade.

Nazareth farm weir

At Nazareth Farm Weir Group 1 shows that (N=80, M=0.049680, SD=0.070798) and Group 2 (N=113, M=0.029261, SD= 0.048916) and P=0.018775. p is less than 0.05 therefore the null hypothesis is accepted and there is a significant difference between group 1 and 2. $P0_4^{3-}$ has decrease over the past decade at this site.

4.3 Chlorophyll-a results and analysis in all sites

According to Griffin (2017), chlorophyll a concentration gives a good indication on trophic status of water bodies. Chlorophyll-a comes from fertilizers, septic tanks, sewage treatment plants and urban-runoff (DWA 2002).

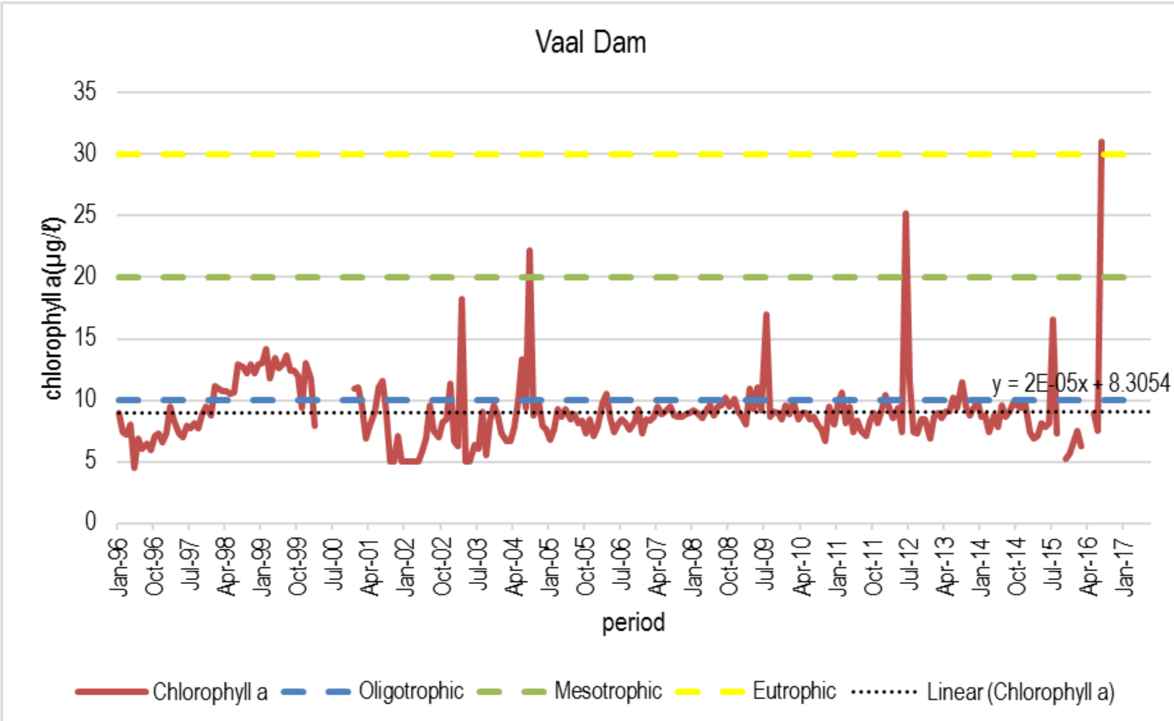

Figure 14: Chlorophyll-a concentration in the Vaal Dam

Chlorophyll-a in the Vaal Dam has mostly occurred at ideal category according to NEMP 2002. Year 1998 to 1999 it has reached the mesotrophic category and peaks in August 2005 and June 2012 are notable that reached the eutrophic level.

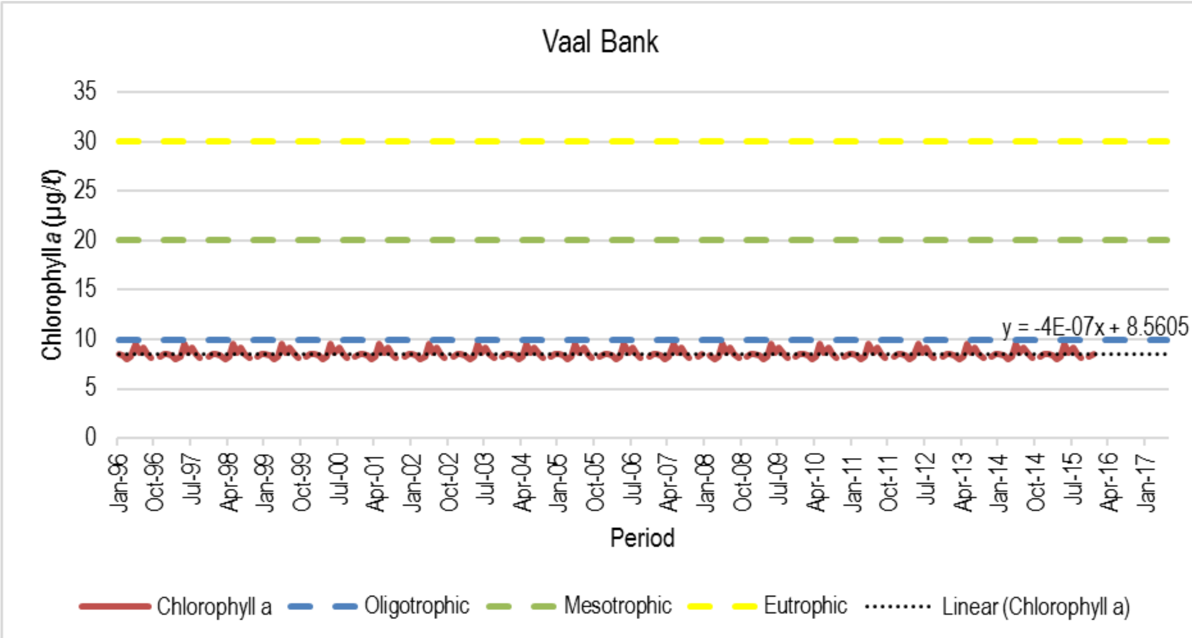

Figure 15: Chlorophyll-a concentration in the Vaal Bank

In the Vaal Bank chlorophyll-a has occurred in the ideal category throughout the monitoring period.

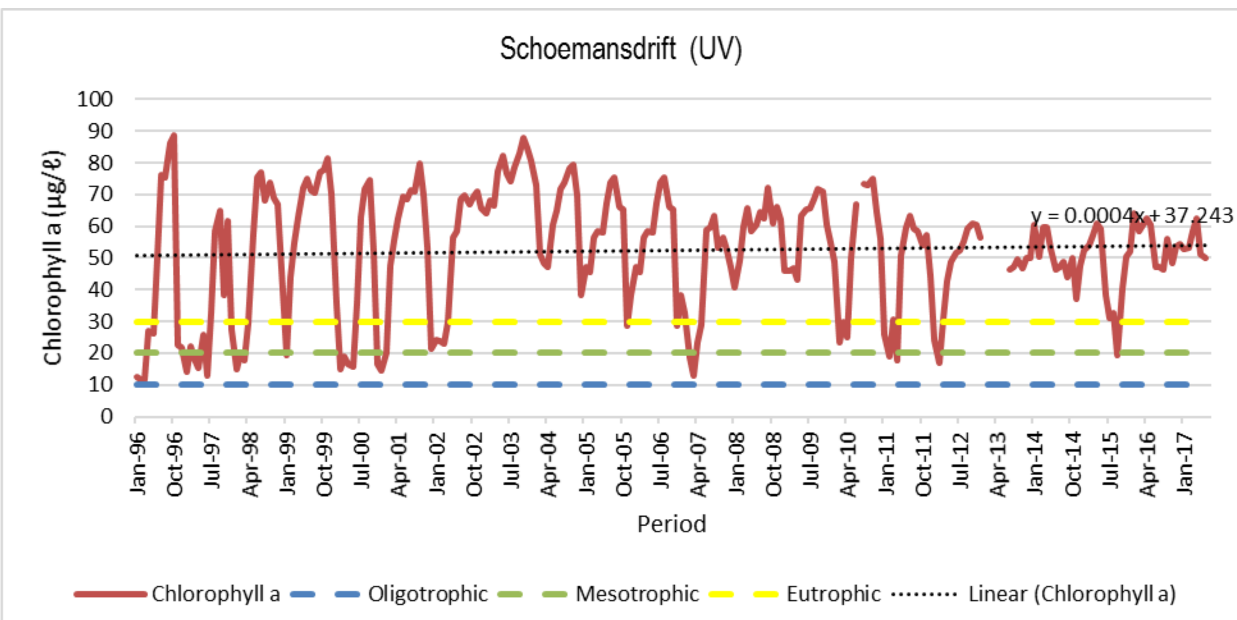

Figure 16: Chlorophyll-a concentration in Schoemansdrift

The graph shows an irregular pattern. Chlorophyll-a in Schoemansdrift is occurring at hypertrophic level and it shows an increasing trend. This could because of urban areas on the upper reaches of Schoemansdrift such as Parys and leachate from agricultural land.

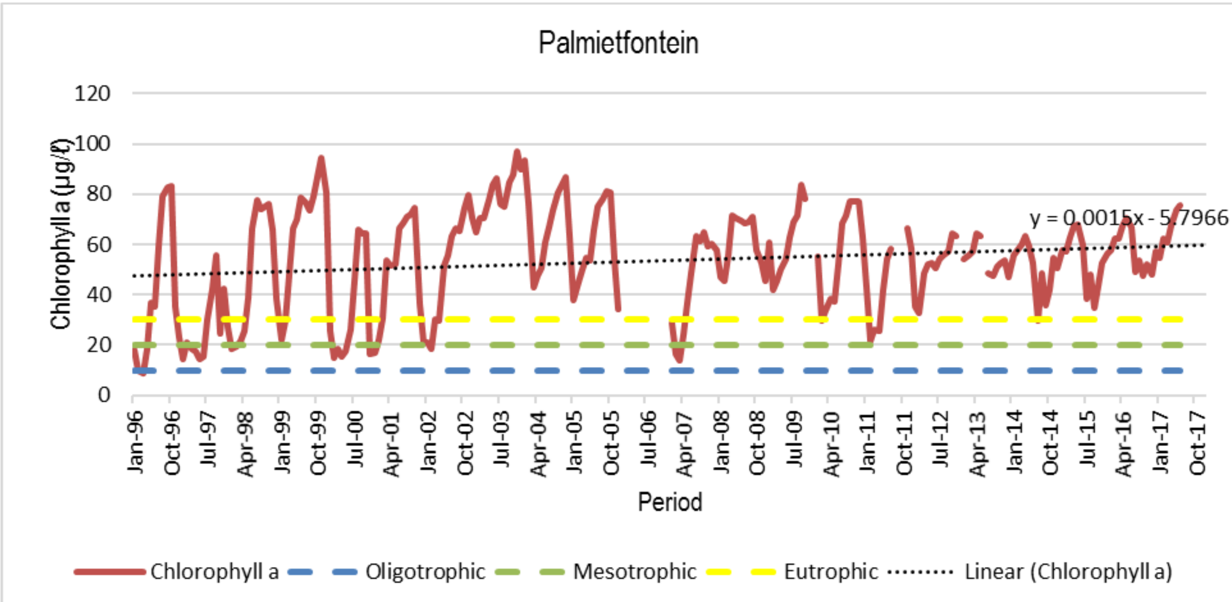

Figure 17: Chlorophyll-a concentration in Palmietfontein

Palmietfontein chlorophyll-a show an irregular pattern and mostly occur at hypertrophic category and shows an increasing trend. Run-off from agricultural activities taking place in the banks of this site may be the cause of elevated chlorophyll-a. Literature state that fertilizers from cultivated pollute water bodies through run-off.

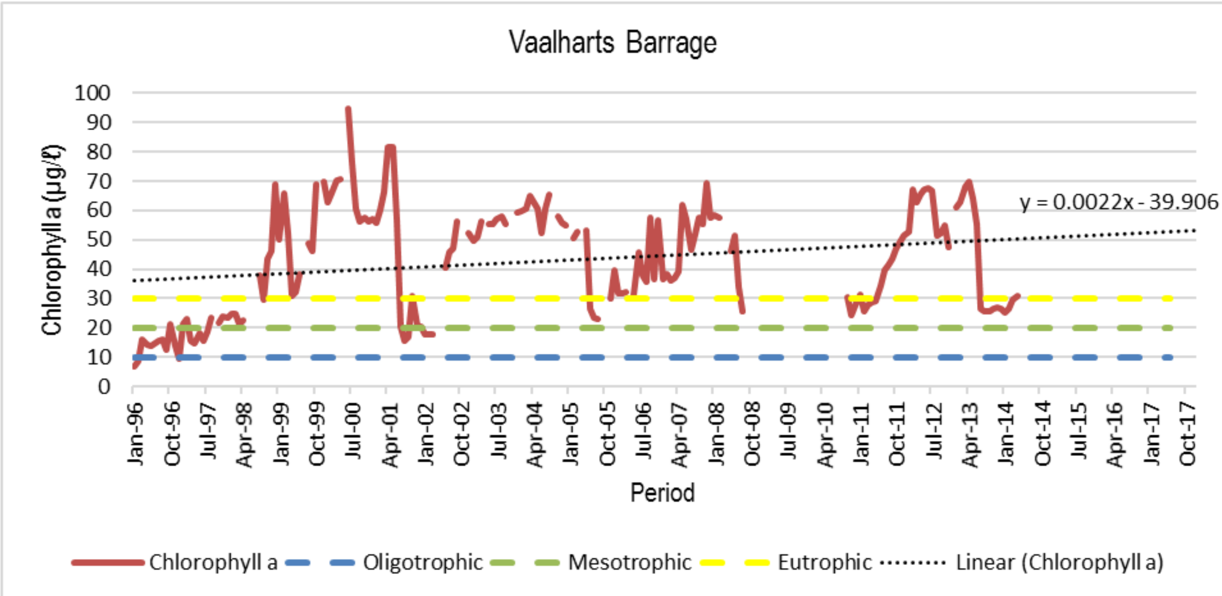

Figure 18: Chlorophyll-a concentration in Vaalharts barrage

At the Vaalharts Barrage chlorophyll-a has reached hypertrophic level almost throughout the monitoring period. Concentration levels occurred at lower levels in the first three years is notable 1999. At the upper reaches of this site, large agricultural activities are taking place which contribute to excessive loading. The graph shows an increasing trend.

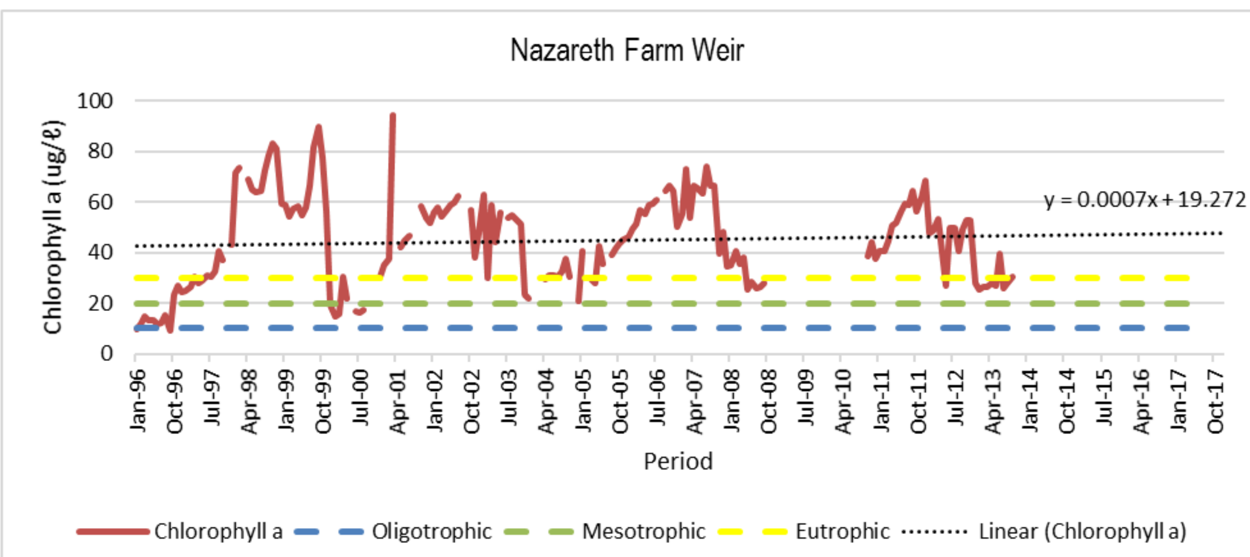

Figure 19: Chlorophyll-a concentration in Nazareth Farm Weir

NB: Chlorophyll a data is missing from 2008 to 2010 and data ended in 2014 in Lower Vaal monitoring sites.

Chlorophyll-a in the Upper Vaal on the chosen sites shows to be occurring at lower concentration levels with the Vaal Bank showing a steady pattern. The Vaal Dam has some cases where chlorophyll-a concentrations showed some peaks. Both the middle and Lower Vaal chlorophyll-a concentration shows an up and down pattern occurring at high concentrations. The high concentrations could be as result of non-point pollutants loads including sediments from surrounding urban areas and nutrients loading form agricultural activities taking place in the Middle and Lower Vaal.

4.4 $N0_3$ results and analysis in all sites

Nitrate in water bodies is introduced mainly through non-point sources such as septic and sewage discharge, leaching of fertilizers from agricultural fields, and animal manure (DWAF 1996a). The graph below shows the nitrate concentration behavior in the Vaal River at selected points over the past two decades.

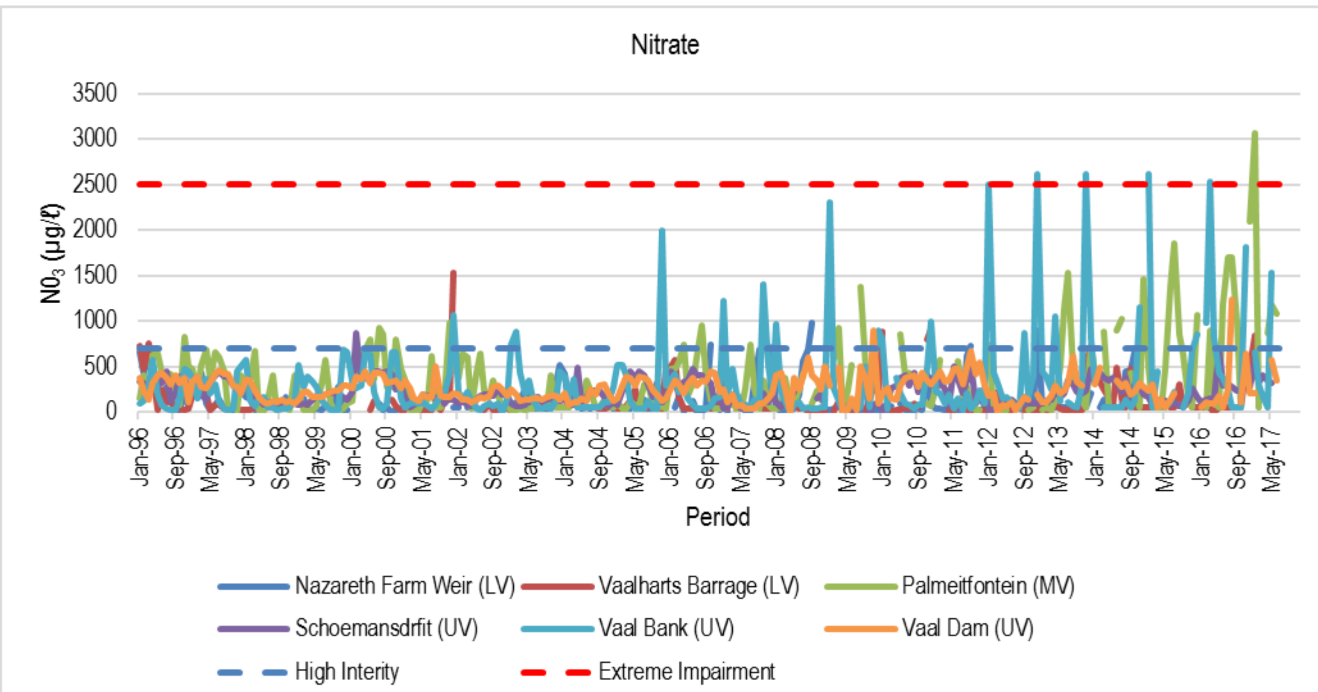

Figure 20: $N0_3$ concentration levels and behavior for all monitoring site

The graph shows that $N0_3$ has mostly occurred at an ideal category according to IWQGES. Even though concentrations occur at lower levels for the first decade, an increase in last decade was noticed with many peaks that reached the impaired category in the Vaal Bank and Palmietfontein. The Vaal Bank and Palmietfontein show many peaks from 2010-2017 monitoring period. This might be due to agricultural activities taking place in the Middle Vaal. Agricultural activities taking place at the banks of the Vaal River in Palmietfontein contribute to nitrate loading. Also, urban areas in the Middle Vaal such as Bothaville may be associated with poor water infrastructure and poor waste-water management which negatively affect the water quality in the Middle Vaal. The Upper Vaal Catchment is characterized by high population, industries and agriculture in the upper reaches of the river. All these activities compromise the quality of the Vaal River. Pollution enters the river through Klip, Riespruit upstream.

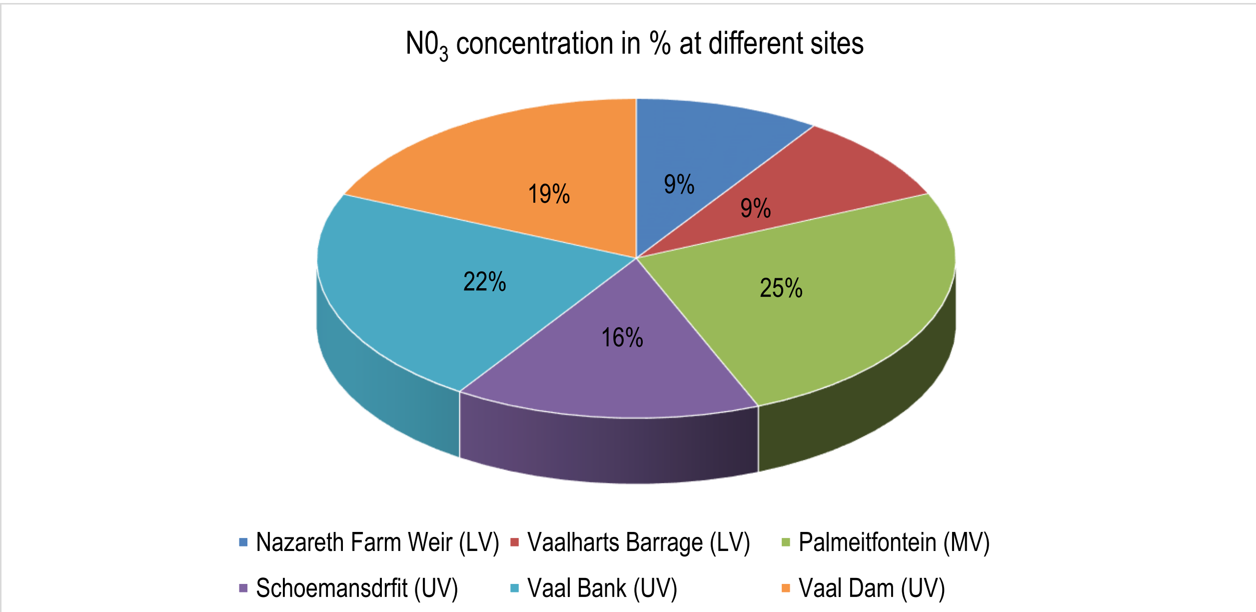

Figure 21: $N0_3$ concentration in %

Palmietfontein is the most concentrated. Run-off from the agricultural activities taking place at the river banks in this area may cause elevated nitrate concentrations. Schoemansdrift in Upper Vaal show high concentration of $N0_3$. Pollution emanating from urban areas such has Potchefstroom and Stilfontein enters the Vaal River through Mooi and Droespruit Rivers causing high concentration. According to Moodley et al (2009), the Vaal Dam supply bulk water to Rand to meet demands for Vereeniging, Vanderbijlpark, Sasolburg and Carletonville. Research literature suggests that excessive water extraction causes water reduction and decrease dilution which results to high concentration of nutrients. Urban areas near the Vaal Dam may contribute to the increased $N0_3$ through urban run-off.

4.4.1 $N0_3$ concentration comparison between the past two decades

$N0_3$ data are presented in Appendix B

Vaal Dam

$N0_3$ concentration in the Vaal Dam shows to be high in last decade. Group 1 showed that (N=132, M=0.250125, SD=0.107103) and Group 2 (N=113, M=0.380714, SD=0.684611) and P=0.31628. p is greater than 0.05 therefore the null hypothesis is not accepted and there is a difference between Group 1 and 2. The results show that N03 has been increasing in this site.

Vaal Bank

In the Vaal Bank Group 1 shows that (N=132, M=0.273598, SD=0.595524) and Group 2 (N=119, M=0.510464, SD=0.865395) and P=0.011486. p is smaller than 0.05 therefore the null hypothesis is accepted and there is a significant difference between Group 1 and 2. The results show that $N0_3$ concentration has increased over the past decade.

The Vaal Dam and Vaal Bank are drained by polluted rivers from Upper Vaal reaches that is heavy industrialized and highly populated. The surrounding towns such as Deneysville are in close proximity with these monitoring sites. Agricultural activities taking place along Wilge and Grootspruit Rivers may be cause of $N0^3$ increase.

Schoemansdrift

In Schoemansdrift Group 1 shows that (N=132, M=0.227278, SD=0.133851) and Group 2 (N=119, M=0.206644, SD= 0.136206) and P=0.227686. p is greater than 0.05 therefore the null hypothesis is accepted and there is a difference between Group 1 and 2. $N0_3$ concentration has decreased the last decade. Agricultural activities are minimal at this site.

Palmietfontein

Group1 shows that (N=132, M=0.270854, SD=0.257583) and Group 2 (N=100, M=0.467249, SD=0.556840) and P=0.000419. p is smaller than 0.05 therefore the null hypothesis is accepted and there is a significant difference between Group 1 and 2. The results show that $N0_3$ has been increasing in the past decade and this could due to agricultural activities taking place at the banks of this site. Sewage returns and urban run-off from urban areas including Bothaville and Leeuwdoornstad may be the cause of elevated $N0_3$ in this site.

Vaalharts Barrage

At the Vaalharts Barrage Group 1 shows that (N=84, M=0.125121, SD=0.218556) and Group 2 (N=110, M=0.126877, SD=0.204201) and P=0.955483. p is greater than 0.05 therefore the null hypothesis is not accepted and there is a slightly difference between Group 1 and 2. When comparing the two decades, the t-test shows that $N0_3$ has not changed much, there is a slightly increase in the past decade.

Nazareth Farm Weir

AT Nazereth Farm Weir Group 1 shows that (N=76, M=0.12996, SD=0.146333) and Group 2 (N=106, M=0.134105, SD=0.21333) and P=0.883990. p is greater than 0.05 therefore the null hypothesis is not accepted and there is no significant difference between Group 1 and 2. The slightly increase in both sites may be due to agricultural run-off from agricultural activities taking place around these sites. According to DEA (2009) the Vaalharts irrigation scheme discharges excess water into the Vaalharts River. Given the South African context, most settlements along streams have a potential to pollute adjacent streams. Sewage discharge and urban run-off from surrounding places such as Christiana and Ganspan may also contribute to the increasing nitrates in these sites.

Although in all the sites $N0_3$ shows to be occurring at acceptable standards, there is concern with in Palmietfontein, Vaal Bank and Vaal Dam as concentration is progressing towards the acceptable limits.

4.5 NH_{4+} results and analysis

Ammonium ions contribute to eutrophication. Commercial agricultural fertilizers contain soluble ammonia which is carried to freshwater systems by run-off, industrial discharge, sewage discharge, mine operation are also source of ammonia (DWA 1996).

The graph below shows the behavior of ammonium at selected points over the past two decades.

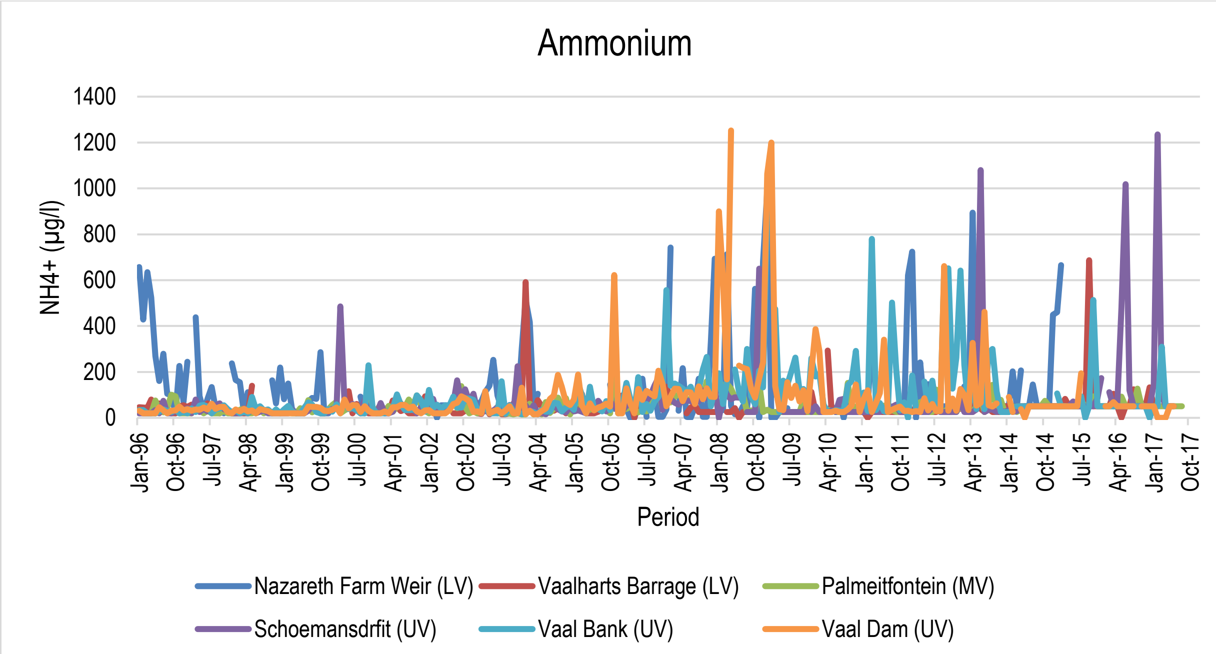

Figure 22: NH_{4+} concentration levels and behavior for all monitoring sites

From the graph above, ammonium levels are occurring at low concentration in the first decade, an increase is noticed in the last decade. Vaal Bank, Dam and Schoemansdrift in the Upper Vaal show high peaks almost throughout the last decade. This might be due to the fact that the Upper Vaal is highly developed and highly populated. Also, industrial, urban, agricultural returns and swage flows from surrounding urban areas may be the cause of concentration increase.

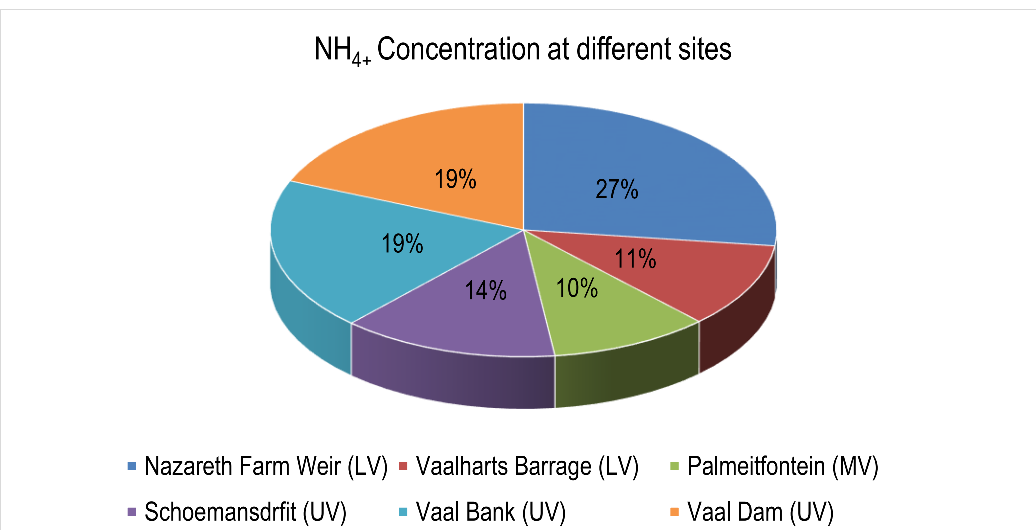

Figure 23: NH_{4+} concentration in all sites

Nazareth, Vaal Bank and the Vaal Dam show to be more concentrated. This could be due to industrial, agricultural and urban run-off carried from upstream. Nazareth and the Vaalharts Barrage receives leachate from the Vaalharts irrigation scheme which contain fertilizers.

4.5.1 NH_{4+} concentration comparison between the past two decades

NH_{4+} data are presented in Appendix C

Vaal Dam

At the Vaal Dam t-test shows that in Group 1 (N=132, M=0.051106, SD=0.0616169) and Group 2 (N=113, M=0.132682, SD=0.216395) and P=0.000048. p is smaller than 0.05 therefore the null hypothesis is accepted and there is a significant difference between Group 1 and 2. In the last decade NH_{4+} concentration was high.

Vaal Bank

At the Vaal Bank Group 1 shows (N=132, M=0.076370, SD=0.296153) and Group 2 (N=119, M=0.0286497, SD=0.880690) and P=0.010325. p is smaller than 0.05 therefore the null hypothesis is accepted and there is a significant difference between Group 1 and 2.

In the Upper Vaal in both sites show that ammonium is increasing. This WMA is heavy industrialized and most of the mining activities occur in this WMA. Also, there is agricultural activities taking place this WMA and is said to be highly populated. Combination of all these factors could be the main reason of increasing ammonium concentration. Sewage spillages from surrounding towns find its way to nearby rivers that feed the Vaal River (Sedibeng District Municipality IDP 2017).

Schoemansdrift

In Schoemandrift Group 1 shows that (N=132, M=0.046740, SD=0.050064) and Group 2 (N=122, M=0.105905, SD= 0.294272) and P=0.023748. p is less than 0.05 therefore the null hypothesis is accepted and there is a significant difference between Group 1 and 2. The t-tests show that NH_{4+} has increased in this site.

Palmietfontein

The t-test conducted this site shows that NH_{4+} has increased in the past decade. Group 1 shows that (N=131, M=0.041105, SD=0.033622) and Group 2 (N=128, M=0.54205, SD=0.034929) and P=0.002330. p is smaller than 0.05 therefore the null hypothesis is accepted and there is a significant difference between Group 1 and

2. Above this monitoring, there is agricultural activities. Leachate from these areas could be the cause of increased NH_{4+}.

Vaalharts Barrage

In the Vaal barrage Group 1 shows that (N=83, M=0.045832, SD=0.065286) and Group 2 (N=110, M=0.056070, SD=0.302594) and P=0.302594. p is greater than 0.05 therefore the null hypothesis is not accepted and there is a difference between group 1 and 2. NH_{4+} has increased in the last decade.

Nazareth Farm Weir

At Nazereth Farm Weir Group 1 shows that (N=66, M=0.125370, SD=0.146336) and Group 2 (N=116, M=0.136361, SD=0.210578) and P=0.705795. p is greater than 0.05 therefore the null hypothesis is not accepted and there is a slightly difference between Group 1 and 2.

The increase in NH_{4+} in both sites in the Lower Vaal is mostly due to agricultural activities such as cultivation of wheat, maize, groundnuts, cotton and many other products in the Lower Vaal catchment area. The returns from the Vaalhart irrigation scheme impact on the Lower Vaal. Sewage discharges and poor managed wastewater treatment also contribute to NH_{4+} loading.

4.6. EC results and analysis

According to DEA (2006), high EC concentration in streams is due to mostly mining deposits, industrial waste and agriculture run-off that enters streams. These activities have a potential to increase conductivity due to chloride, nitrate ions and phosphates associated with these activities. EC indicate nutrients dissolved in water. The Vaal catchment is characterized by heavy industries such as mines in the Upper Vaal, agriculture in the Middle Vaal and livestock faming and agriculture in the Lower Vaal (DWA&F 2009).

The graph below shows the behavior of EC in the Vaal River at selected monitoring sites throughout the entire monitoring period.

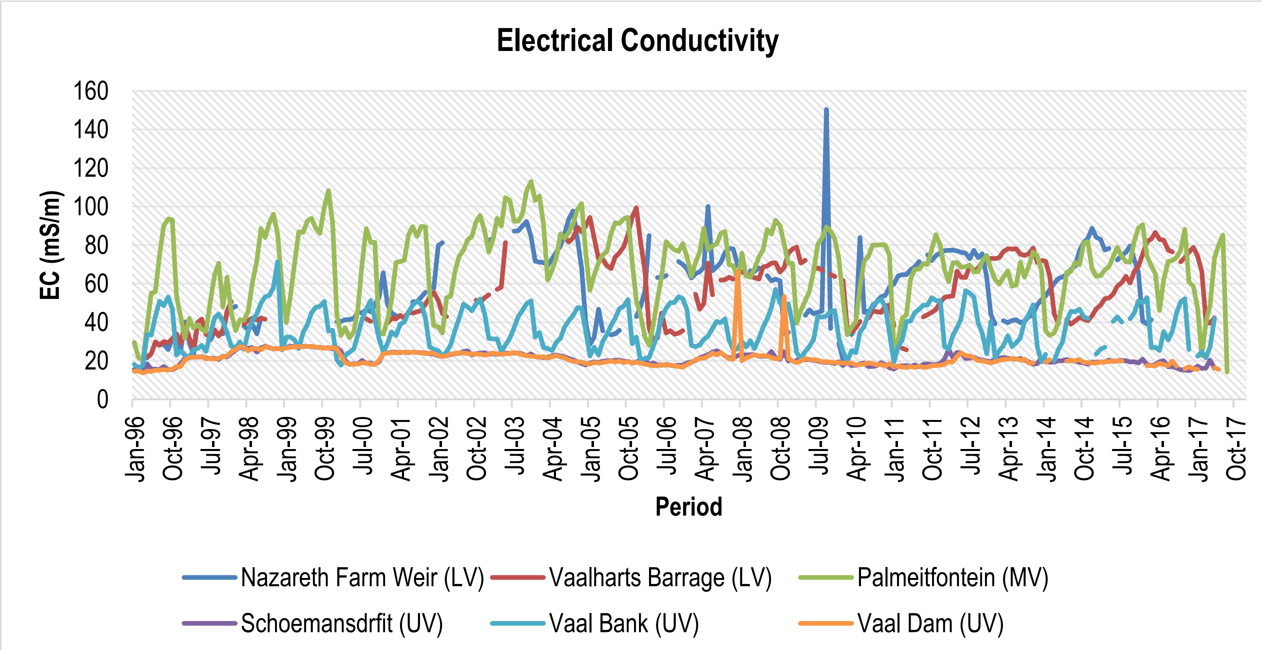

Figure 24: EC concentration level and behavior for all monitoring sites

The graph above shows an irregular pattern in the Middle Vaal at Palmietfontein and in both sites in the Lower Vaal. The Vaal Dam and Schoemansdrift in the Upper Vaal nutrient concentrations occur at lower levels but peak in the Vaal Dam. Palmietfontein and the Vaalharts are highly concentrated and an increase of EC is noticed from both sites between 1999-2005. From 2006-2017 the graph shows a slightly decrease, although concentration still occurs at high levels.

The Middle and Lower Vaal highly depend on the Upper Vaal to meet their water demands (Moddley et al. 2009). The water that is transferred to these WMAs from the Upper Vaal contains industrial, urban, and mining returns from highly developed Upper Vaal WMA. This carries along high concentration of fertilizers and salts. Agricultural activities, urban run-off and industrial discharges in the Middle and Lower Vaal may cause the high concentration of EC in these WMAs (DWA 2009; Moddley et al. 2009).

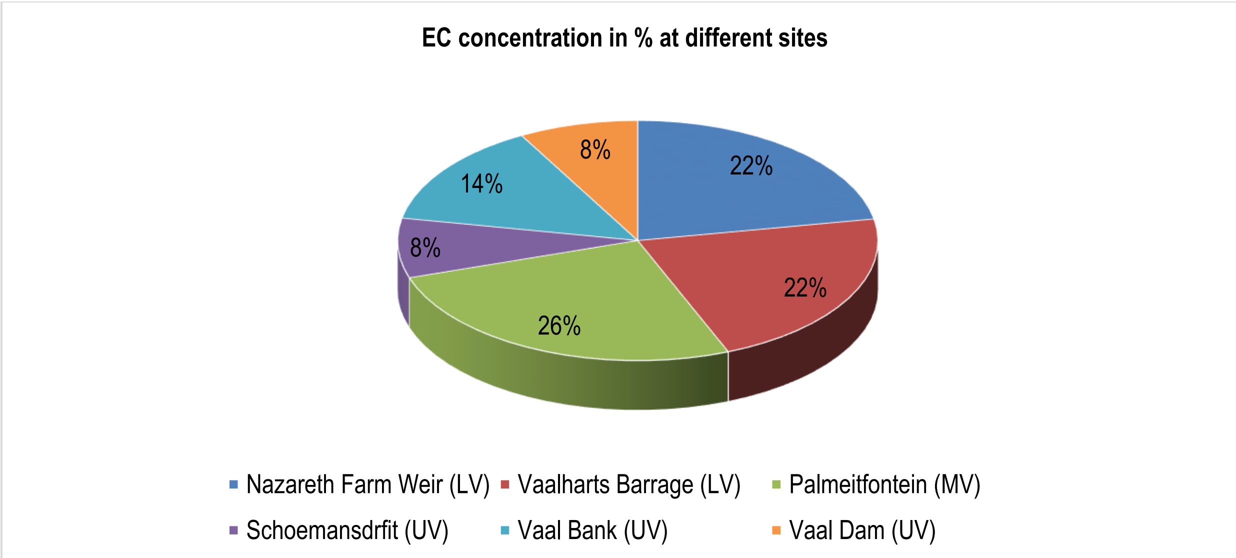

Figure 25: EC Concentration in %

Palmeitfontein in the Middle Vaal is highest at 26%. At the upper reaches of Palmeitfontein there is agricultural activities taking place on the banks of the Vaal River. Urban areas near Palmietfontein include Leeuwdoornstad, Bothaville, and Kanana and Orkney. These surrounding urban areas may contribute to elevated EC concentration through urban run-off that carries pollution. The Vaalharts and Nazereth also show to be highly concentrated. Agricultural and urban run run-off may contribute in nutrient loading in the river which results in increase of EC. Agricultural activities taking place in Hartswater, Pampierstad, Warrenton and Ganspan enters the Harts river through run-off and the Harts River drains the Vaal River and cause pollution.

4.6.1 EC concentration comparison between the past two decades

EC data are presented in Appendix D

Vaal Dam

When comparing the past two decades the t-test shows that in Group 1 (N=134, M=21.7, SD=3.6) and Group 2 (N=144, M=20.2, SD=5.7) and P=0.01. P is smaller than 0.05 therefore the null hypothesis is accepted and there is a difference between group 1 and 2. The results show that EC has decreased at this site over the past decade.

Vaal Bank

In the Vaal bank Group 1 shows that (N=120, M=36.3, SD=10.6) and Group 2 (N=132, M=36.6, SD=10.5) and P=0.8. P is greater than 0.05 therefore the null hypothesis is not accepted and there is a difference between group 1 and 2. The results show that EC concentration has slightly increased in the past decade. The increased concentration in the Vaal Bank could be due to run-off from the industrialized and high populated areas in the upper reaches of the Vaal. Industrial and urban run-off from Johannesburg and surrounding areas enters the Vaal River through the Rietspriuit River and pollute the Vaal River at this point. In South Africa, highly populated areas such as townships are characterized by the lack of sewage infrastructure and poor waste management that is carried to nearby rivers during raining season.

Schoemansdrift

In Schoemansdrift Group 1 shows that (N=132, M=22.03, SD=3.3) and Group 2 (N=124, M=19.8, SD= 2.2) and P=0.00001. P is less than 0.05 therefore the null hypothesis is accepted and there is a significant difference between group 1 and 2. EC concentration has decreased in the past decade at this site.

Palmietfontein

In Palmiefontein Group 1 shows that (N=132, M=69.4, SD=23.4) and Group 2 (N=127, M=67.5, SD=14.9472) and P=0.5. P is greater than 0.05 therefore the null hypothesis is not accepted and there is a difference between group 1 and 2. The results show that EC concentration has been decreasing at this site.

Vaalharts Barrage

In the Vaalharts Barrage Group 1 shows that (N=85, M=102.6, SD=329.9) and Group 2 (N=112, M=60.4, SD=14.5) and P=0.2. p is greater than 0.05 therefore the null hypothesis is not accepted and there is a significant difference between Group 1 and 2.

Nazareth Farm Weir

The t-tests conducted shows a significant difference in EC at Nazareth Farm Weir Group 1 shows that (N=78, M=51.5, SD=21.05) and Group 2 (N=111, M=62.3, SD= 17.7) and P=0.000173. p is less than 0.05 therefore the null hypothesis is accepted and there is a significant difference between Group 1 and 2.

The results show that EC concentration has significantly increased at both monitoring sites in the Lower Vaal. According to DWA (2009), the Lower Vaal receive almost all its surface flow from the Upper Vaal reaches with very little originating for the Lower Vaal itself. The Lower Vaal receives already polluted water from the upper Vaal WMA. Anthropogenic activities taking place in these sites such as irrigation run-off from the Vaalharts irrigation scheme enters the Harts River upstream and pollutes the Vaal River since the Harts drains the Vaal River. This increases nutrient loading and pollutes the Lower Vaal surface water. Also, leachate from the Vaalharts weir enters the Vaal River. This has led to further deterioration of water quality in the Lower Vaal (DWA 2009). Nearby towns such as Ganspan, Warrenton, Pampierstad and Christiana are characterized by agriculture which is one of the causes of nutrients loading through agricultural leachate.

4.7 Summary of results

The study examined nutrient loading in the Vaal River over the past two decades by examining water quality data from six different sites to determine concentration levels using the international and the South African water quality guidelines, trends and significant difference between the two decades in following water quality parameters chlorophyll a, $P0_4^{3-}$, NH_{4+}, $N0_3$ and EC. Table 6 below summarizes the results. The results showed high concentration of nutrients in the Vaal River in general. The results showed a correlation of nutrient loading and land use activities. Where industries, agriculture and urban areas occur, nutrients are elevated. The results also showed an increasing trend in most of the monitoring sites and showed that the last decade had elevated nutrients as compared to the previous decade. Chlorophyll a and $P0_4^{3-}$ showed to be highly concentrated and reach hypertrophic state in downstream of the Upper Vaal, Middle Vaal and the Lower Vaal. The Upper Vaal and the Middle Vaal showed to be the most polluted, and nutrients concentration is reduced in the Lower Vaal in some sites. This shows that even though the Vaal River is highly polluted, it still has an ability to assimilate, however nutrients showed to be elevated in the last decade and increasing trend was notable.

Table 6: Summary of nutrients concentration

Vaal River water quality monitoring points detail, time series data, mean median and maximum [NH_{4+}, $N0_3$, PO_4^{3-} and Chlorophyll] values.												
Sample location	**NH_{4+}**			**$N0_3$**			**PO_4^{3-}**			**Chlorophyll**		
	med	**mean**	**max**	**med**	**mean**	**max**	**med**	**mean**	**max**	**Med**	**mean**	**max**

Site1: Vaal Dam (UV)	47	82	1253	241	258	1236	37	48	515	8	9	31
Site2: Vaal Bank (UV)	50	85	919	144	311	2624	45	61	404	8	9	10
Site3: Schoemansdrift (UV)	36	72	2659	188	217	875	33	43	293	56	52	88
Site4: Palmietfontein (MV)	35	78	8146	181	356	3063	107	127	490	56	54	96
Site5: Vaalharts Barrage (LV)	25	38	687	50	125	1530	15	24	447	46	43	95
Site6: Nazareth Farm Weir (LV)	40	102	990	50	132	990	18	36	530	44	45	95

$P0_4^{3-}$ trend showed to be slightly decreasing in the Upper Vaal except in the Vaal Dam. The Middle Vaal showed an increasing trend and a decreasing trend in the Lower Vaal. The highest average value was recoded in Palmeitfontein and all sites has reached the eutrophic state according to the South African water quality guidelines except the Vaalharts barrage. Elevated nutrients could be caused by poor agricultural activities such as extensive use of fertilizers and pesticides and cultivation on the banks of the river. Also, the settlements on the upper reaches contribute in $P0_4^{3-}$ through poor management of water and sanitation infrastructure. The t-tests confirmed that there is a significant difference between the two decades. The box and whisker graphs show that $P0_4^{3-}$ has increased in the Upper and the Middle Vaal and decreased in the Lower Vaal.

Trend for chlorophyll a showed to be increasing in the Middle and the Lower Vaal and concentration has reached the hypertrophic state. In Middle and Lower Vaal at monitored site agriculture is dominant, this confirms with literature that poor agricultural activities result in elevated chlorophyll a concentration through agricultural run-off that enters freshwater bodies. Surprisingly, the Upper Vaal shows low concentration levels of chlorophyll a and a decreasing trend.

$N0_3$ and NH_{4+} showed a similar pattern. They both showed an increasing trend at all sites except $N0_3$ in Schoemansdrift. High maximum values were recorded in the Upper and the Middle sections of the river. T-tests conducted show that there is a significant difference between the two decades. The box and whisker graphs showed that these nutrients were much elevated in the last decade.

Land use activities, poor management of water and sanitation infrastructure and climate change has led to the deterioration of the Vaal River. Integrated water management strategies that incorporate land use activities, water and sanitation and climate change must be taken into consideration to avoid continuous nutrients loading.

Chapter Five: Conclusion and Recommendations

5.1 Conclusion

Nutrient loading has negatively affected global freshwater systems resulting in eutrophication at the highest order. This has compromised the goods and services of freshwater systems which have affected the ecosystem, the economy and human health. In South Africa more than 62% water bodies have been impacted by nutrients loading (Matthews and Bernard 2014). This has led to further water scarcity as some of the polluted water is not usable for any purpose. This study aimed at understanding how nutrients loading has affected the Vaal River over the past two decades and to see if there was any significant different between the past decades in the Vaal River.

Key findings

The study addressed primary objectives (i) how has nutrient loading affected the Vaal River in the past two decades, (ii) is there a significant different between the two decades. The results showed that nutrient loading has negatively impacted on the Vaal River and caused eutrophication. Overall the quality of the Vaal River is deteriorating with the upper and middle sections being more polluted than the lower section. The results showed that the lower reaches are less polluted although they reach the eutrophic and hypertrophic states at various times. This shows that the Vaal River still has assimilate capacity as it naturally cleans itself from high pollution coming from the upper reaches of the river that is characterized by industries and high population. Most monitoring sites showed that nutrients were much more elevated in the last decade and also showed an increasing trend in nutrient loading in most sites.

The analysis showed that there is correlation between land use and nutrient loading. Where industries, agricultural and urban areas occur, nutrients were much more elevated. Elevated nutrients were recorded in the Upper and the Middle Vaal which include NH_{4+}, $N0_3$ and $P0_4^{3-}$ chlorophyll a. The results showed that the river has reached eutrophic state in all monitoring sites except the Vaalharts barrage in the Lower Vaal. Palmeitfontein in the Middle Vaal showed to be the most polluted site and reached the eutrophic state which recorded a mean value of 127µg/ℓ for $P0_4^{3-}$. It has highly exceeded the required standard of 5 µg/ℓ as per the SAWQGAE 1996 and recorded a mean value of 54 µg/ℓ for chlorophyll a which is more than five times the required standard.

In general, the Vaal River showed an increasing trend in all measured variables except chlorophyll a in the Upper Vaal. Despite the elevated nutrients in the Upper and the Middle Vaal, assimilative capacity of the river was demonstrated by improved water quality in the Lower Vaal. The Lower Vaal showed to be less polluted except with chlorophyll-a which reached hypertrophic state. This raises a concern as the Vaal River continues to deteriorate as Monfrered et al (2017) argue that excessive water pollution from industrial, agricultural and domestic wastewater disposal reduces natural river cleansing and sometimes lead to irreparable damage.

5.2 Recommendations

Nutrient loading in freshwater system is a continuous problem that has led to water quality deterioration globally. This highlight a need to explore how land use activities and climate change should be taken into consideration in the development of water management strategies as results demonstrated a correlation between land use activities and nutrients concentration and literature suggest that climate change also contribute to nutrients loading in freshwater systems.

This research highlighted several aspects to be considered for future research which include:

- There is gap in water quality monitoring of the Vaal River. The DWS water quality data showed to be inconstant. Continuous water quality monitoring using improved technologies to achieve quality data must be considered in informing water management strategies. This will allow managers to understand the depth of water pollution problem and enable them to track progress in managing water resources.

- The study revealed an increasing trend of nutrients loading, visitation of water management strategies and ensuring implementation is necessary to address water pollution problems and restore freshwater systems. This will help in identifying gaps and encourage implementation of water quality management strategies

- Determine the effects of climate change and land-use activities in catchments. Little is known about climate change impacts on water quality. Understanding the effects of climate change and land use activities on water quality is key.

Eutrophication has devastating impacts on ecosystem, economy and human health. A shift toward an integrated eutrophication management that take into consideration hydrology, climate change, socio-economic and land use dynamics is vital. Continuous and effective monitoring is key is toward developing informative water management strategies that will address eutrophication problems.

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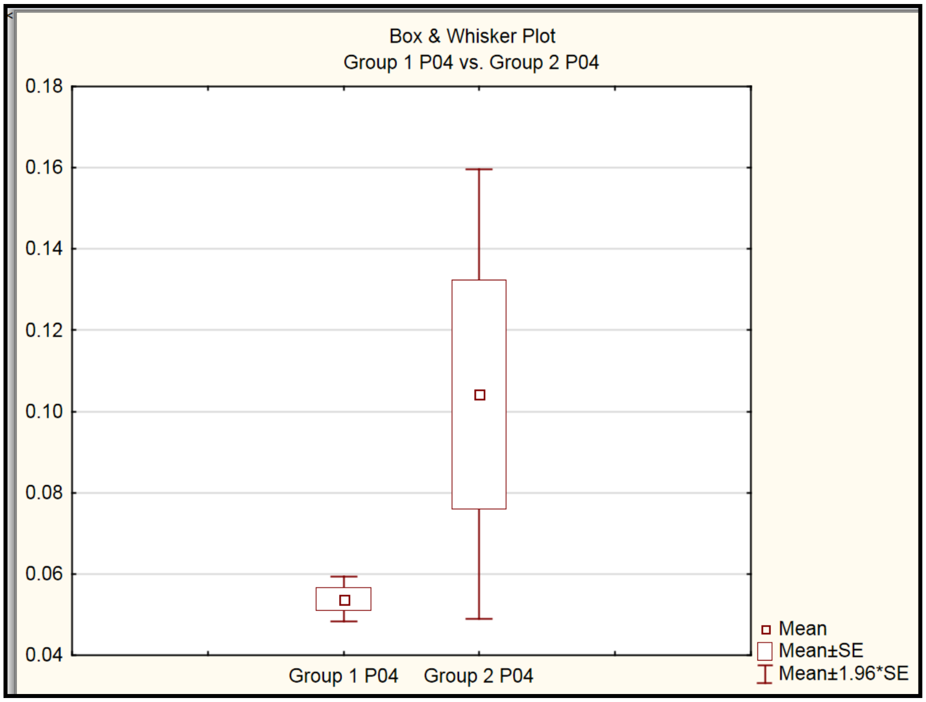
Appendix A: $P0_4^{3-}$ concentration comparison between the past two decades

Vaal Dam

T-test for Independent Samples (Sheet1 in P04)
Note: Variables were treated as independent samples

Group 1 vs. Group 2	**Mean Group 1**	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
Group 1 P04 vs. Group 2 P04	0.053776	0.104222	-1.91829	243	0.056247	132	113	0.032384	0.300205	85.93839	0.00



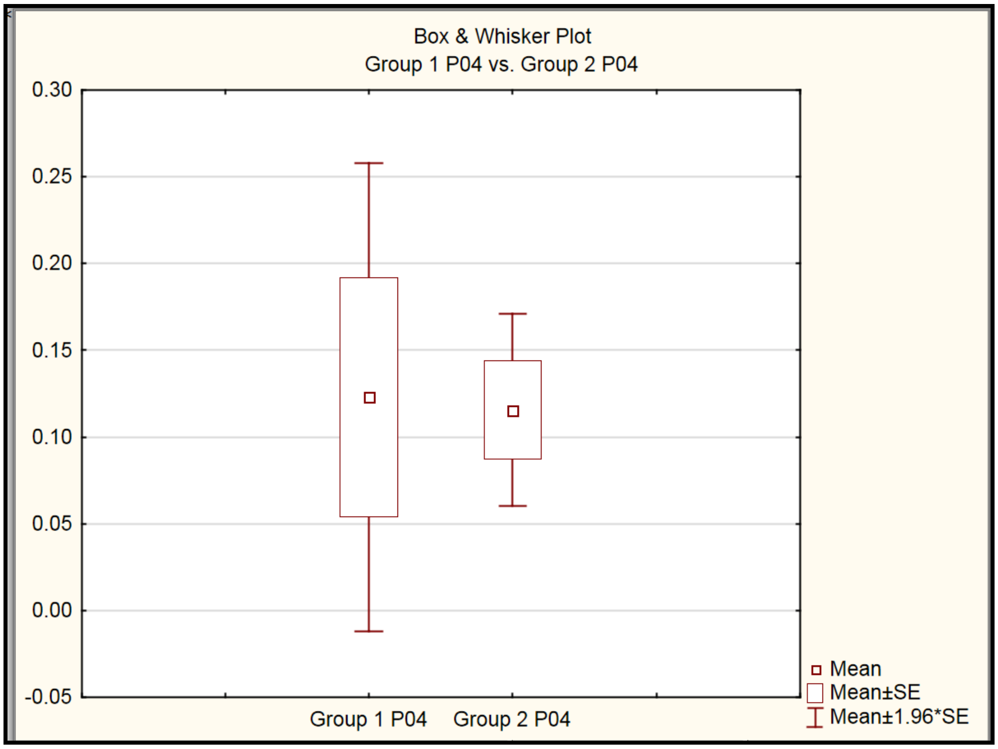
Box and whisker graph for $P0_4^{3-}$ at Vaal Dam

At the Vaal Dam Group 1 (N=132, M=0.053776, SD=0.032384) and Group 2 (N=113, M=0.104222, SD=0.300205) and P=0.56247. p is greater than 0.05 therefore the null hypothesis is not accepted and there is a significant difference between group 1 and 2.

Vaal Bank

T-test for Independent Samples (Sheet1 in P04)
Note: Variables were treated as independent samples

Group 1 vs. Group 2	**Mean Group 1**	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
Group 1 P04 vs. Group 2 P04	0.122994	0.115658	0.093733	244	0.925398	131	115	0.789248	0.303912	6.744202	0.000000



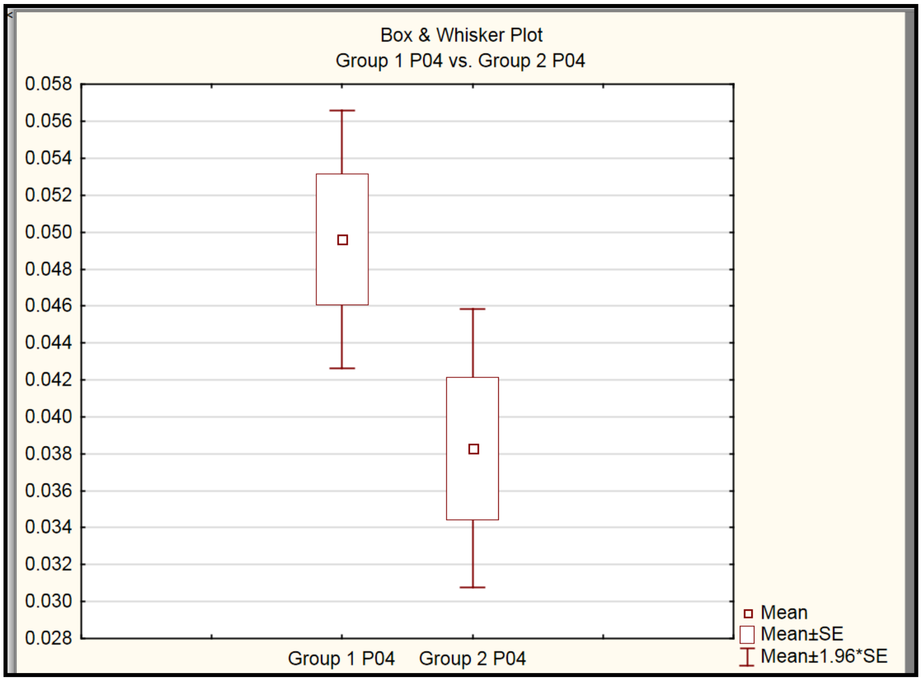
Box and whisker graph for $P0_4^{3-}$ at Vaal Bank

At Vaal Bank Group 1 shows that (N=131, M=0.122994, SD=0.789248) and Group 2 (N=115, M=0.115658, SD=0.303912) and P=0.925398. p is greater than 0.05 therefore the null hypothesis is not accepted and there is a difference between group 1 and 2. The results show that $P0_4^{3-}$ concentration has not change in the past decade.

Schoemansdrift

T-test for Independent Samples (Sheet1 in P04)
Note: Variables were treated as independent samples

Group 1 vs. Group 2	**Mean Group 1**	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
Group 1 P04 vs. Group 2 P04	0.049603	0.038288	2.142977	252	0.033073	120	134	0.039036	0.044506	1.299944	0.144797

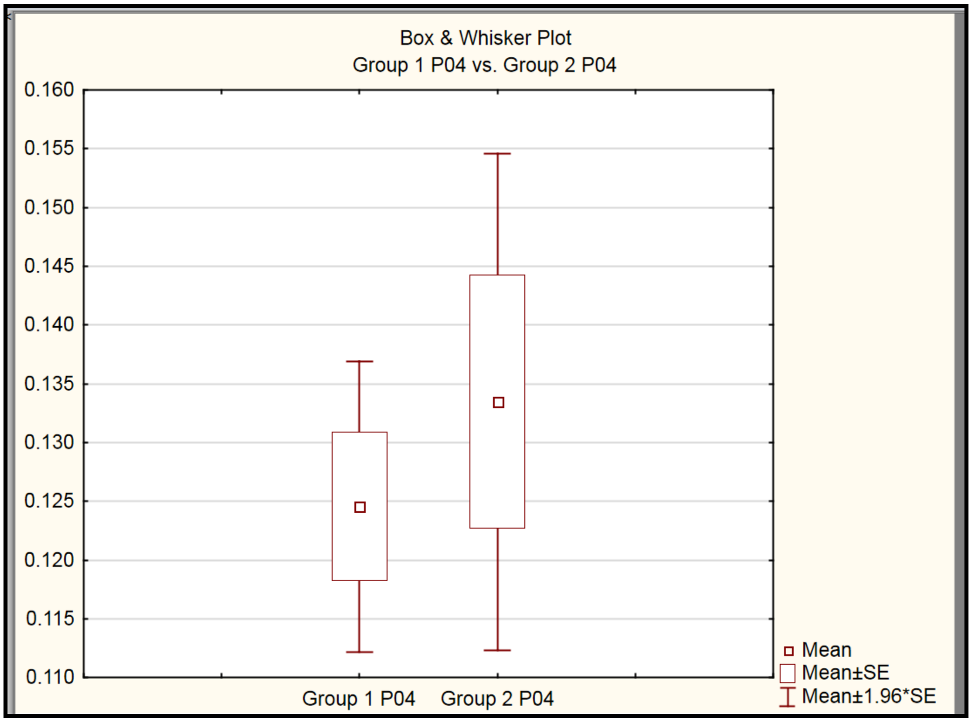


Box and whisker graph for $P0_4^{3-}$ at Schoemansdrift

In Schoemandrift Group 1 shows that (N=120, M=0.049603, SD=0.039036) and Group 2 (N=134, M=0.38288, SD= 0.044506) and P=0.033073. p is less than 0.05 therefore the null hypothesis is accepted and there is a significant difference between group 1 and 2.

Palmietfontein

Group 1 vs. Group 2	T-test for Independent Samples (Sheet1 in P04) Note: Variables were treated as independent samples Mean Group 1	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
Group 1 P04 vs. Group 2 P04	0.124563	0.133459	-0.744514	236	0.457306	132	106	0.072517	0.110929	2.339964	0.000004

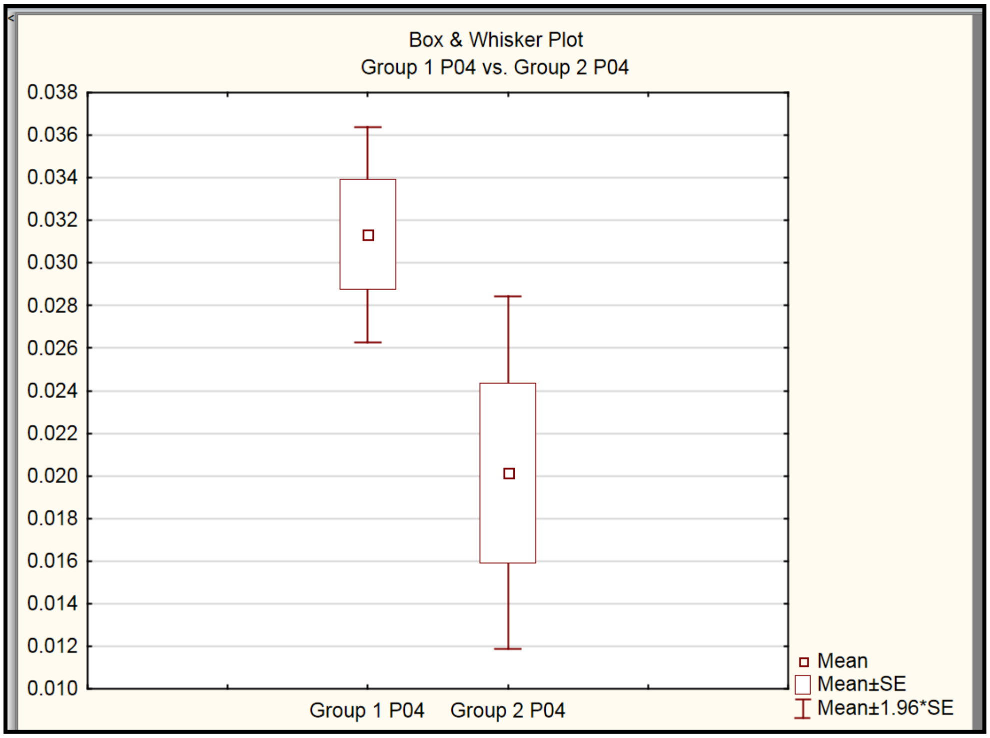


Box and whisker graph for $P0_4^{3-}$ at Palmietfontein

In Palmietfontein Group 1 shows that (N=132, M=0.124563, SD=0.072517) and Group 2 (N=106, M=0.133459, SD=0.110929) and P=0.457306. p is greater than 0.05 therefore the null hypothesis is not accepted and there is a difference between group 1 and 2.

Vaalharts Barrage

	T-test for Independent Samples (Sheet1 in P04) Note: Variables were treated as independent samples										
Group 1 vs. Group 2	**Mean Group 1**	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
Group 1 P04 vs. Group 2 P04	0.031343	0.020145	2.103473	191	0.036734	84	109	0.023650	0.044135	3.482561	0.000000



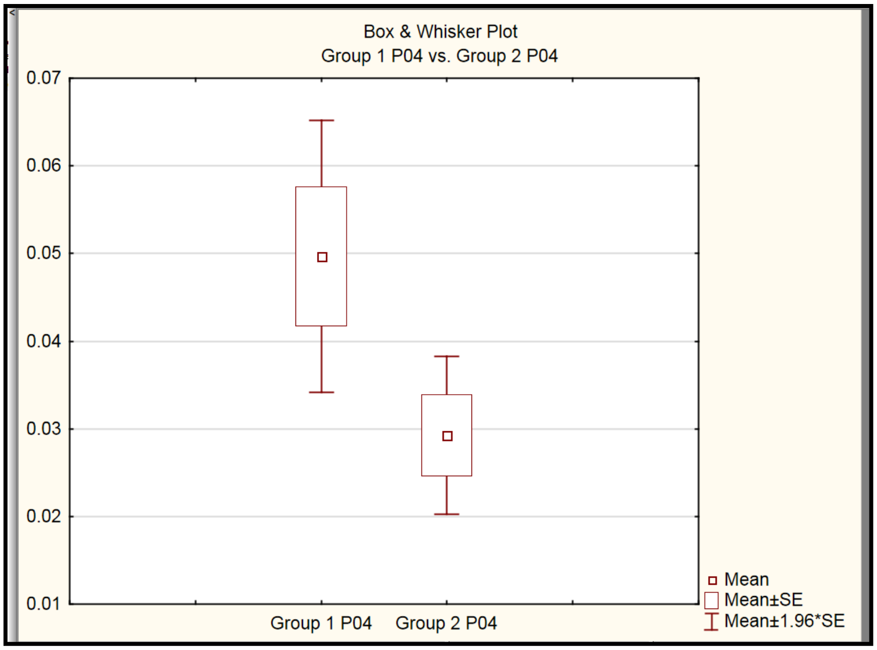
Box and whisker graph for $P0_4^{3-}$ at Vaalharts Barrage

In the Vaalharts Barrage, Group 1 shows that (N=84, M=0.031343, SD=0.023650) and Group 2 (N=109, M=0.02145, SD=0.023650) and P=0.036734. p is smaller than 0.05 therefore the null hypothesis is accepted and there is a difference between group 1 and 2. $P0_4^{3-}$ concentration has decreased in the past decade.

Nazareth farm weir

T-test for Independent Samples (Sheet1 in P04)
Note: Variables were treated as independent samples

Group 1 vs. Group 2	Mean Group 1	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
Group 1 P04 vs. Group 2 P04	0.049680	0.029261	2.370192	191	0.018775	80	113	0.070798	0.048916	2.094756	0.000322



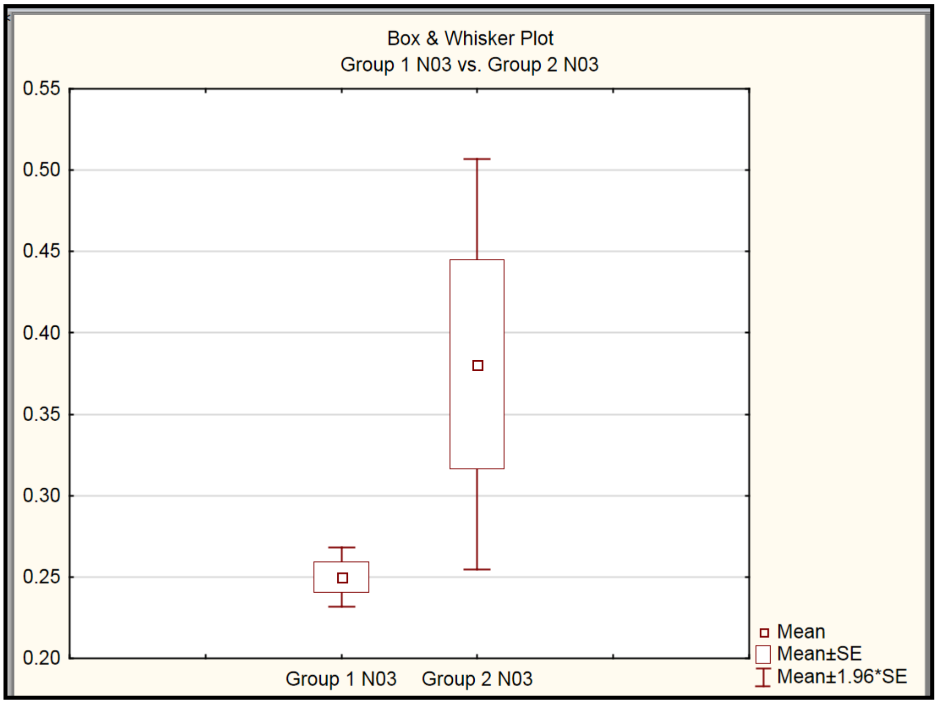
Box and whisker graph for $P0_4^{3-}$ at Nazareth farm weir

At Nazareth Farm Weir Group 1 shows that (N=80, M=0.049680, SD=0.070798) and Group 2 (N=113, M=0.029261, SD= 0.048916) and P=0.018775. p is less than 0.05 therefore the null hypothesis is accepted and there is a significant difference between group 1 and 2.

Appendix B: $N0_3$ concentration comparison between the past two decades

T-test for Independent Samples (Sheet1 in N03)
Note: Variables were treated as independent samples

Group 1 vs. Group 2	**Mean Group 1**	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
Group 1 N03 vs. Group 2 N03	0.250125	0.380714	-2.16157	243	0.031628	132	113	0.107105	0.684611	40.85713	0.00

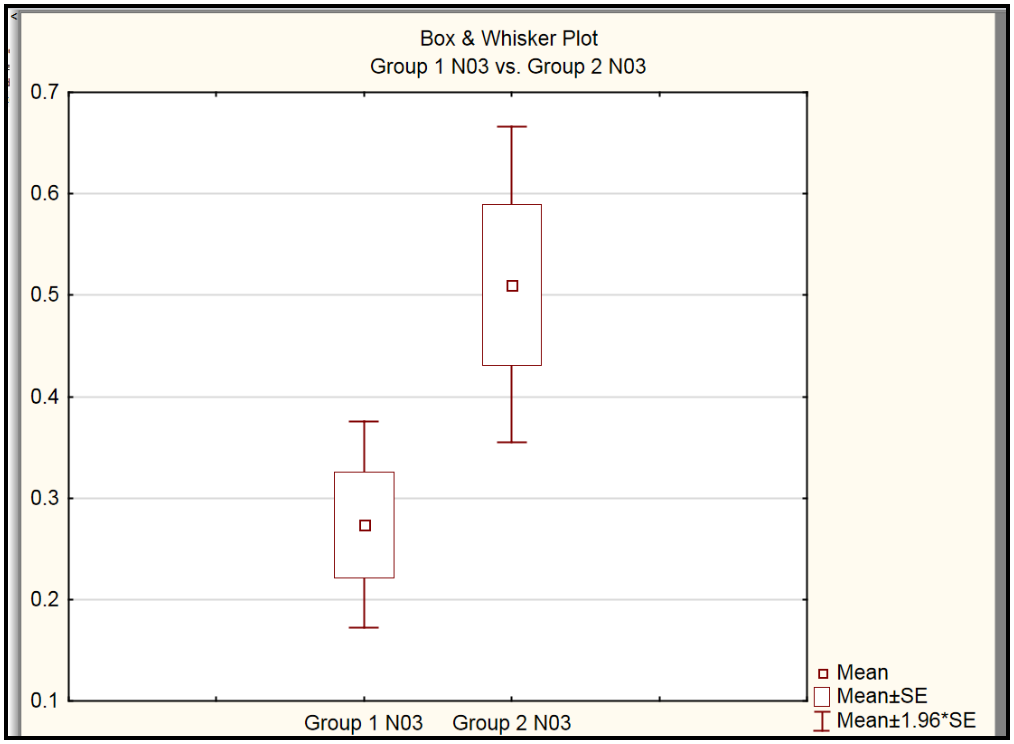


Box and whisker graph for $N0_3$ in the Vaal Dam

$N0_3$ concentration in the Vaal Dam shows to be high in last decade. Group 1 showed that (N=132, M=0.250125, SD=0.107103) and Group 2 (N=113, M=0.380714, SD=0.684611) and P=0.31628. p is greater than 0.05 therefore the null hypothesis is not accepted and there is a difference between Group 1 and 2.

T-test for Independent Samples (Sheet1 in N03)
Note: Variables were treated as independent samples

Group 1 vs. Group 2	**Mean Group 1**	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
Group 1 N03 vs. Group 2 N03	0.273598	0.510464	-2.54644	249	0.011486	132	119	0.595524	0.865395	2.111690	0.000035

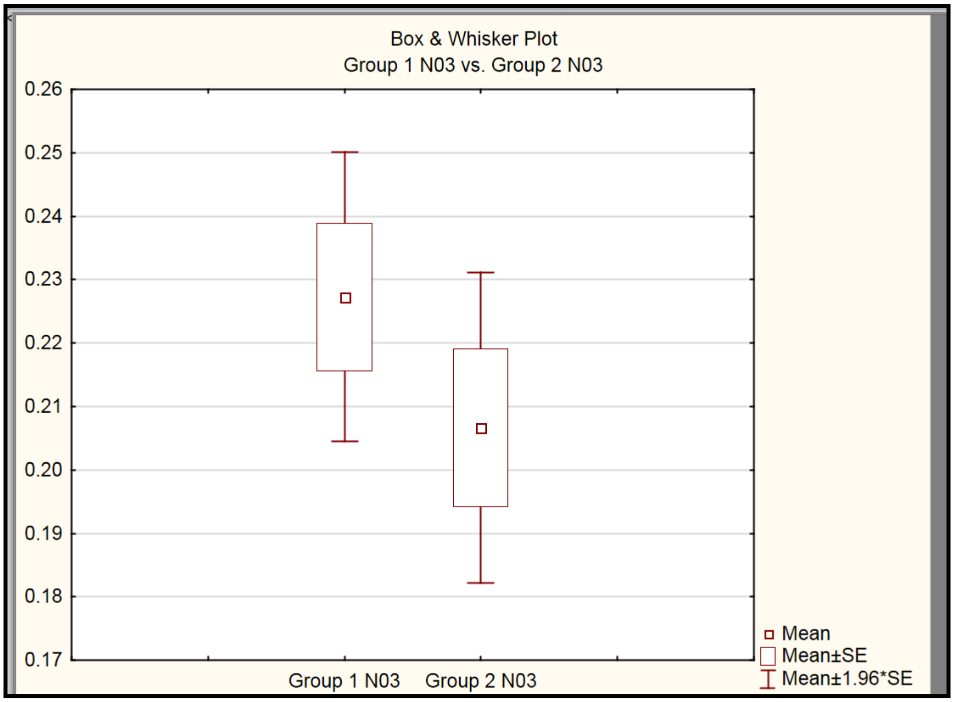


Box and whisker graph for $N0_3$ at Vaal Bank

In the Vaal Bank Group 1 shows that (N=132, M=0.273598, SD=0.595524) and Group 2 (N=119, M=0.510464, SD=0.865395) and P=0.011486. p is smaller than 0.05 therefore the null hypothesis is accepted and there is a significant difference between Group 1 and 2.

T-test for Independent Samples (Sheet1 in N03)
Note: Variables were treated as independent samples

Group 1 vs. Group 2	Mean Group 1	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
Group 1 N03 vs. Group 2 N03	0.227278	0.206644	1.209323	249	0.227686	132	119	0.133851	0.136206	1.035492	0.843748

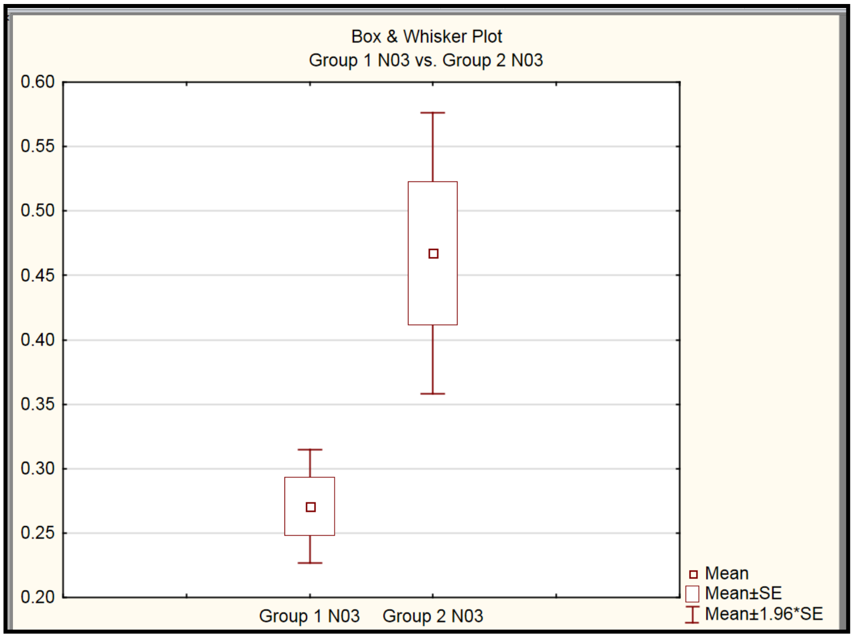


Box and whisker graph for NO_3 at Schoemansdrift

In Schoemansdrift Group 1 shows that (N=132, M=0.227278, SD=0.133851) and Group 2 (N=119, M=0.206644, SD= 0.136206) and P=0.227686. p is greater than 0.05 therefore the null hypothesis is accepted and there is a difference between Group 1 and 2. NO_3 concentration has decreased the last decade. Agricultural activities are minimal at this site.

T-test for Independent Samples (Sheet1 in N03)
Note: Variables were treated as independent samples

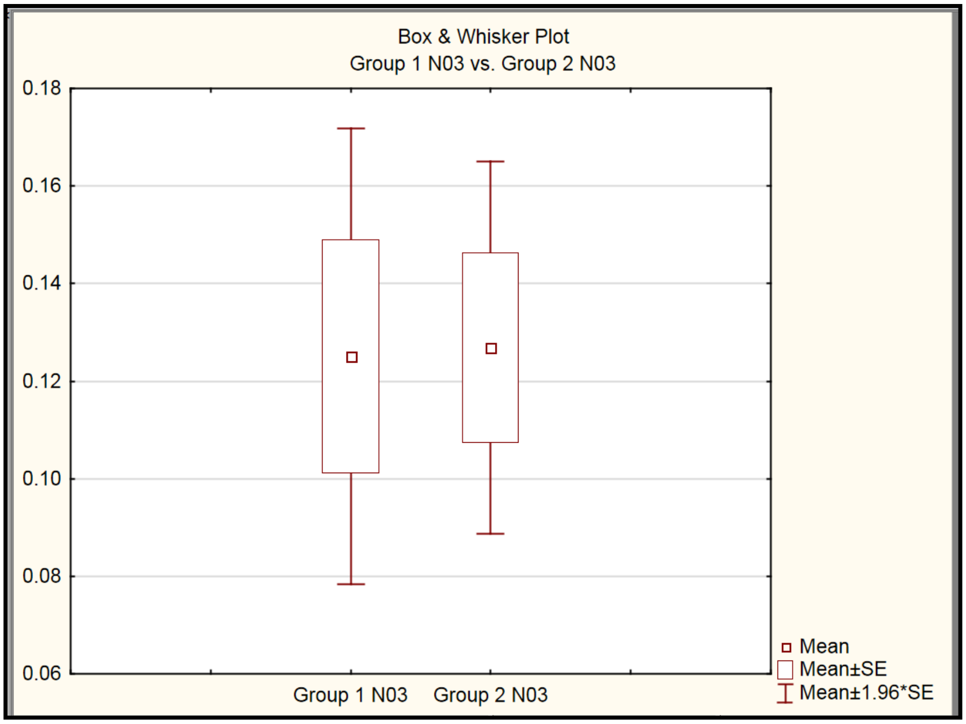
Group 1 vs. Group 2	Mean Group 1	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
Group 1 N03 vs. Group 2 N03	0.270854	0.467249	-3.57975	230	0.000419	132	100	0.257583	0.556840	4.673339	0.000000



Box and whisker graph for $N0_3$ at Palmietfontein

Group1 shows that (N=132, M=0.270854, SD=0.257583) and Group 2 (N=100, M=0.467249, SD=0.556840) and P=0.000419. p is smaller than 0.05 therefore the null hypothesis is accepted and there is a significant difference between Group 1 and 2. The results show that $N0_3$ has been increasing in the past decade and this could due to agricultural activities taking place at the banks of this site. Sewage returns and urban run-off from urban areas including Bothaville and Leeuwdoornstad may be the cause of elevated $N0_3$ in this site.

	T-test for Independent Samples (Sheet1 in N03) Note: Variables were treated as independent samples									
Group 1 vs. Group 2	**Mean Group 1**	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
Group 1 N03 vs. Group 2 N03	0.125121	0.126827	-0.055895	192	0.955483	84	110	0.218556	0.204201	1.145540	0.503572

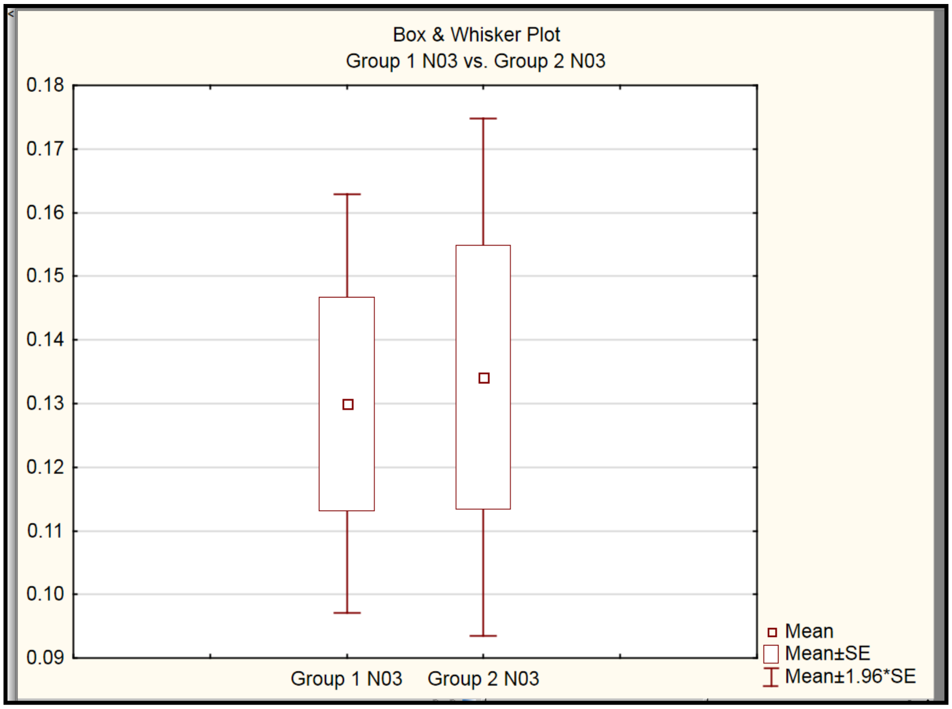


Box and whisker graph for $N0_3$ Vaalharts Barrage

At the Vaalharts Barrage Group 1 shows that (N=84, M=0.125121, SD=0.218556) and Group 2 (N=110, M=0.126877, SD=0.204201) and P=0.955483. p is greater than 0.05 therefore the null hypothesis is not accepted and there is a slightly difference between Group 1 and 2. When comparing the two decades, the t-test shows that $N0_3$ has not changed much, there is a slightly increase in the past decade.

T-test for Independent Samples (Sheet1 in N03)
Note: Variables were treated as independent samples

Group 1 vs. Group 2	**Mean Group 1**	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
Group 1 N03 vs. Group 2 N03	0.129963	0.134105	-0.146121	180	0.883990	76	106	0.146333	0.213725	2.133182	0.000645



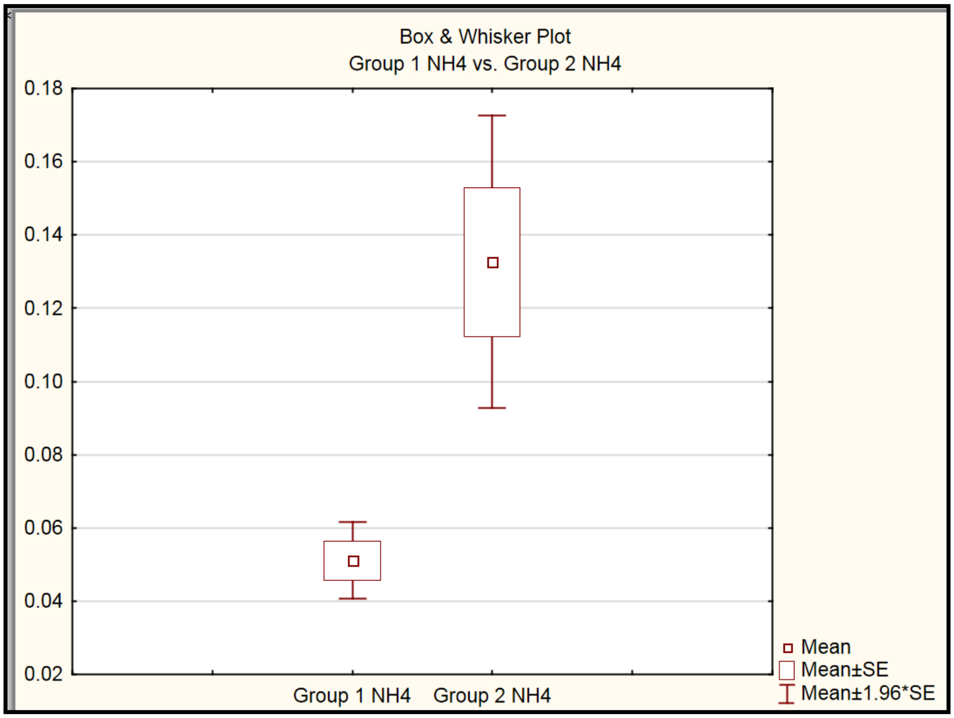
Box and whisker graph for $N0_3$ at Nazareth Farm Weir

Also, at Nazereth Farm Weir Group 1 shows that (N=76, M=0.12996, SD=0.146333) and Group 2 (N=106, M=0.134105, SD=0.21333) and P=0.883990. p is greater than 0.05 therefore the null hypothesis is not accepted and there is no significant difference between Group 1 and 2.

Appendix C: NH_{4+} concentration comparison between the past two decades

T-test for Independent Samples (Sheet1 in NH4)
Note: Variables were treated as independent samples

Group 1 vs. Group 2	Mean Group 1	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
Group 1 NH4 vs. Group 2 NH4	0.051106	0.132682	-4.14072	243	0.000048	132	113	0.061619	0.216395	12.33301	0.00

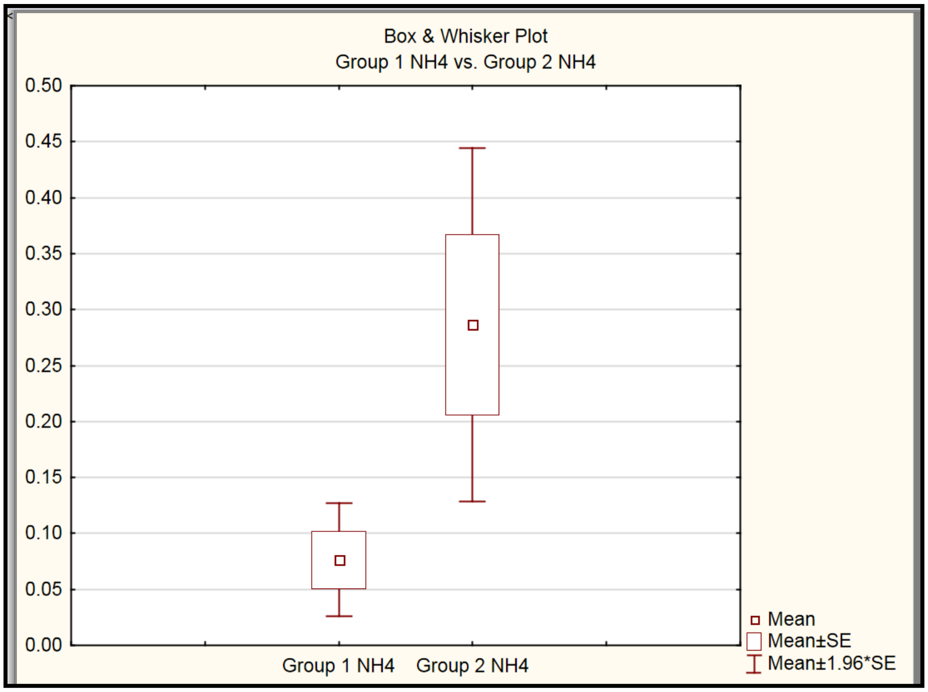


Box and whisker graph for NH_{4+} at Vaal Dam

At the Vaal Dam t-test shows that in Group 1 (N=132, M=0.051106, SD=0.0616169) and Group 2 (N=113, M=0.132682, SD=0.216395) and P=0.000048. p is smaller than 0.05 therefore the null hypothesis is accepted and there is a significant difference between Group 1 and 2.

T-test for Independent Samples (Sheet1 in NH4)
Note: Variables were treated as independent samples

Group 1 vs. Group 2	Mean Group 1	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
Group 1 NH4 vs. Group 2 NH4	0.076370	0.286497	-2.58441	249	0.010325	132	119	0.296153	0.880690	8.843287	0.000000

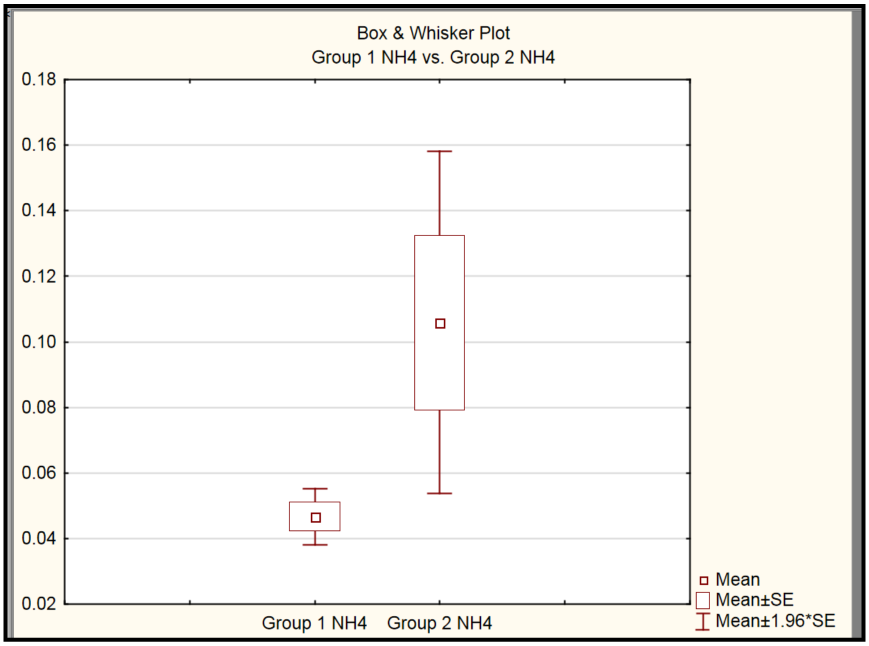


Box and whisker graph for NH_{4+} at Vaal Bank

At the Vaal Bank Group 1 shows (N=132, M=0.076370, SD=0.296153) and Group 2 (N=119, M=0.0286497, SD=0.880690) and P=0.010325. p is smaller than 0.05 therefore the null hypothesis is accepted and there is a significant difference between Group 1 and 2.

T-test for Independent Samples (Sheet1 in NH4)
Note: Variables were treated as independent samples

Group 1 vs. Group 2	**Mean Group 1**	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
Group 1 NH4 vs. Group 2 NH4	0.046740	0.105905	-2.27498	252	0.023748	132	122	0.050064	0.294272	34.55062	0.00

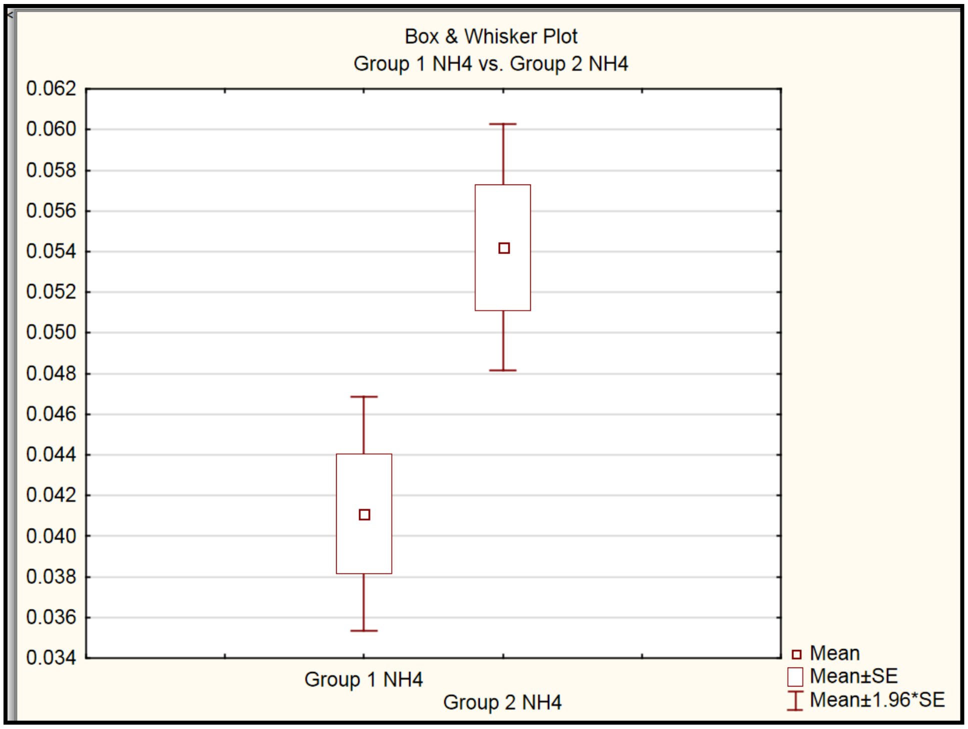


Box and whisker graph for NH_{4+} at Schoemansdrift

In Schoemandrift Group 1 shows that (N=132, M=0.046740, SD=0.050064) and Group 2 (N=122, M=0.105905, SD= 0.294272) and P=0.023748. p is less than 0.05 therefore the null hypothesis is accepted and there is a significant difference between Group 1 and 2.

T-test for Independent Samples (Sheet1 in NH4)
Note: Variables were treated as independent samples

Group 1 vs. Group 2	Mean Group 1	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
Group 1 NH4 vs. Group 2 NH4	0.041105	0.054205	-3.07534	257	0.002330	131	128	0.033622	0.034929	1.079249	0.665673

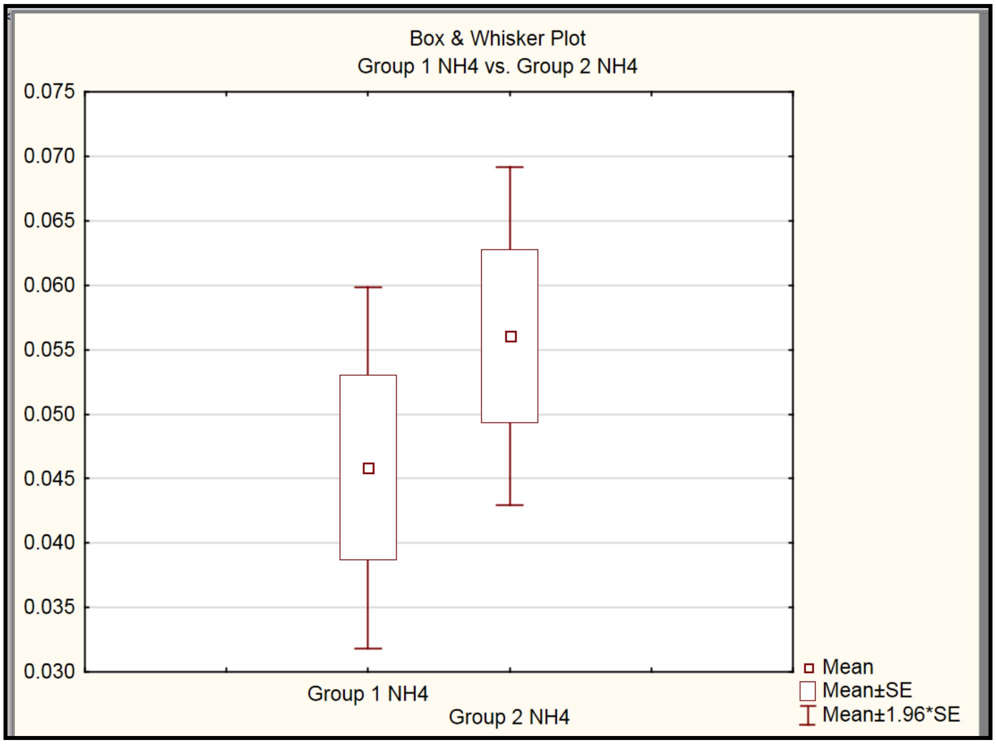


Box and whisker graph for NH_{4+} at Palmietfontein

The t-test conducted this site shows that NH_{4+} has increased in the past decade. Group 1 shows that (N=131, M=0.041105, SD=0.033622) and Group 2 (N=128, M=0.54205, SD=0.034929) and P=0.002330. p is smaller than 0.05 therefore the null hypothesis is accepted and there is a significant difference between Group 1 and 2.

T-test for Independent Samples (Sheet1 in NH4)
Note: Variables were treated as independent samples

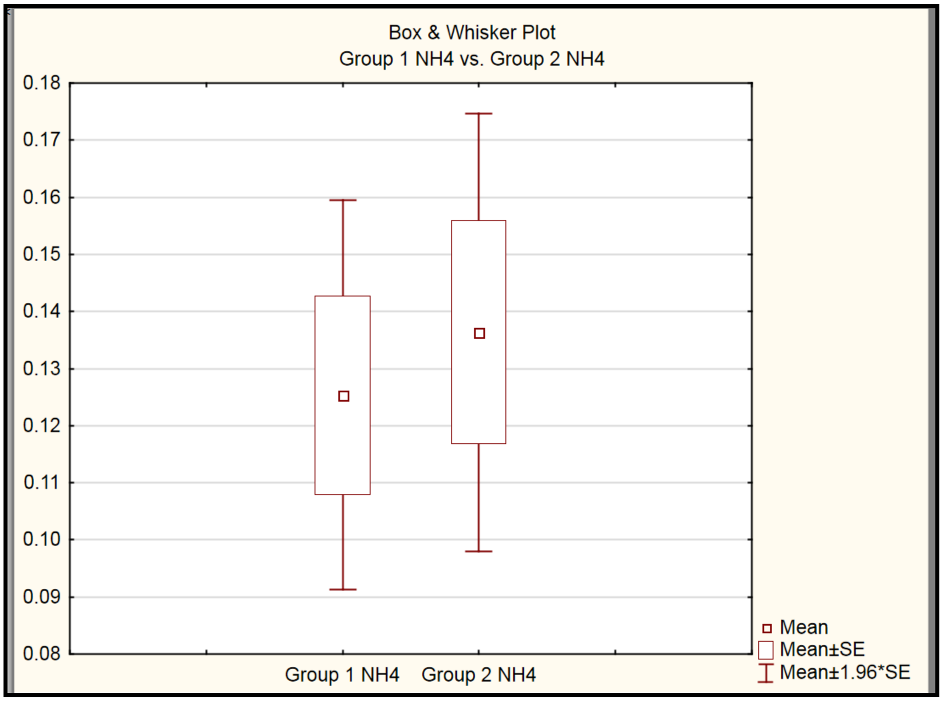
Group 1 vs. Group 2	Mean Group 1	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
Group 1 NH4 vs. Group 2 NH4	0.045832	0.056070	-1.03368	191	0.302594	83	110	0.065286	0.070184	1.155667	0.492988



Box and whisker graph for NH_{4+} at Vaalharts Barrage

In the Vaal barrage Group 1 shows that (N=83, M=0.045832, SD=0.065286) and Group 2 (N=110, M=0.056070, SD=0.302594) and P=0.302594. p is greater than 0.05 therefore the null hypothesis is not accepted and there is a difference between group 1 and 2.

	T-test for Independent Samples (Sheet1 in NH4) Note: Variables were treated as independent samples										
Group 1 vs. Group 2	**Mean Group 1**	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
Group 1 NH4 vs. Group 2 NH4	0.125370	0.136361	-0.378109	180	0.705795	66	116	0.141336	0.210578	2.219842	0.000589



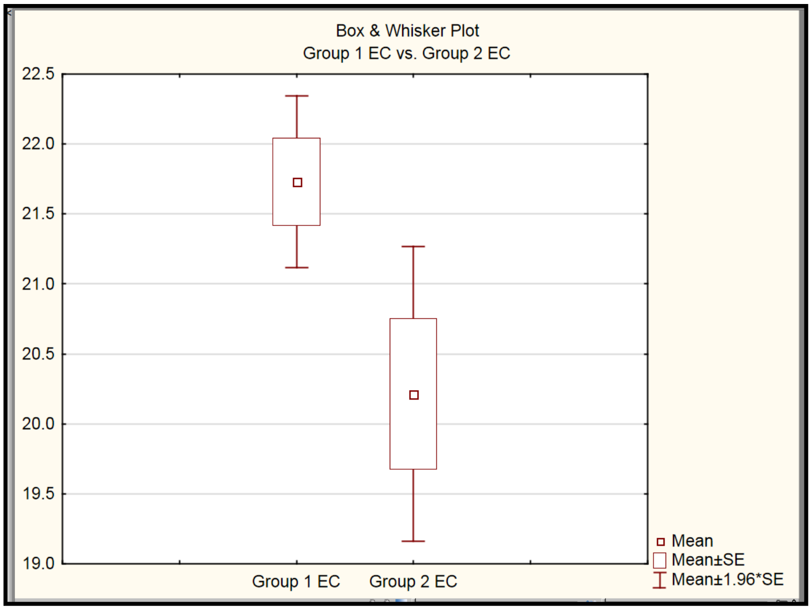
Box and whisker graph for NH_{4+} at Nazareth Farm Weir

At Nazereth Farm Weir Group 1 shows that (N=66, M=0.125370, SD=0.146336) and Group 2 (N=116, M=0.136361, SD=0.210578) and P=0.705795. p is greater than 0.05 therefore the null hypothesis is not accepted and there is a slightly difference between Group 1 and 2.

Appendix D: EC concentration comparison between the past two decades

T-test for Independent Samples (Sheet1 in EC)
Note: Variables were treated as independent samples

Group 1 vs. Group 2	**Mean Group 1**	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
Group 1 EC vs. Group 2 EC	21.73227	20.21422	2.521551	244	0.012322	132	114	3.595964	5.734325	2.542928	0.000000

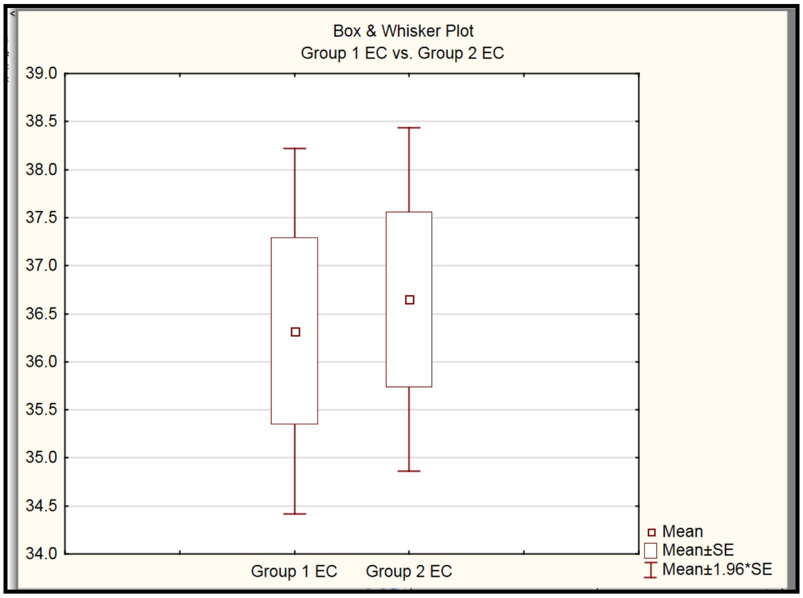


Box and whisker graph for EC at Vaal Dam

When comparing the past two decades the t-test shows that in group 1 (N=134, M=21.73227, SD=3.595964) and group 2 (N=144, M=20.21422, SD=5.734325) and P=0.012322. P is smaller than 0.05 therefore the null hypothesis is accepted and there is a difference between group 1 and 2.

T-test for Independent Samples (Sheet1 in EC)
Note: Variables were treated as independent samples

Group 1 vs. Group 2	**Mean Group 1**	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
Group 1 EC vs. Group 2 EC	36.32008	36.64985	-0.247726	250	0.804549	120	132	10.63607	10.47884	1.030234	0.865883



Box and whisker graph for EC at Vaal Bank

In the Vaal bank group 1 shows that (N=120, M=36.32008, SD=10.63607) and group 2 (N=132, M=36.64985, SD=10.47884) and P=0.804549. P is greater than 0.05 therefore the null hypothesis is not accepted and there is a difference between group 1 and 2.

	T-test for Independent Samples (Sheet1 in EC) Note: Variables were treated as independent samples										
Group 1 vs. Group 2	**Mean Group 1**	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
Group 1 EC vs. Group 2 EC	22.03442	19.77819	6.188576	254	0.000000	132	124	3.399622	2.289242	2.205351	0.000012

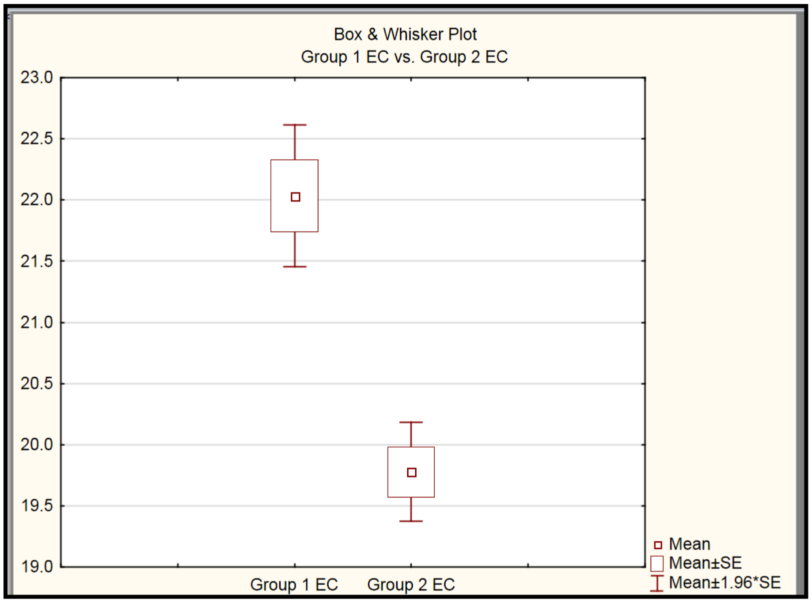


Figure 26: Box and whisker graph for EC at Schoemansdrift

In Schoemansdrift group 1 shows that (N=132, M=22.03442, SD=3.299622) and group 2 (N=124, M=19.77819, SD= 2.205351) and P=0.00001. P is less than 0.05 therefore the null hypothesis is accepted and there is a significant difference between group 1 and 2.

Group 1 vs. Group 2	T-test for Independent Samples (Sheet1 in EC) Note: Variables were treated as independent samples Mean Group 1	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
Group 1 EC vs. Group 2 EC	69.35223	67.53958	0.739941	257	0.460011	132	127	23.38951	14.94972	2.447801	0.000001

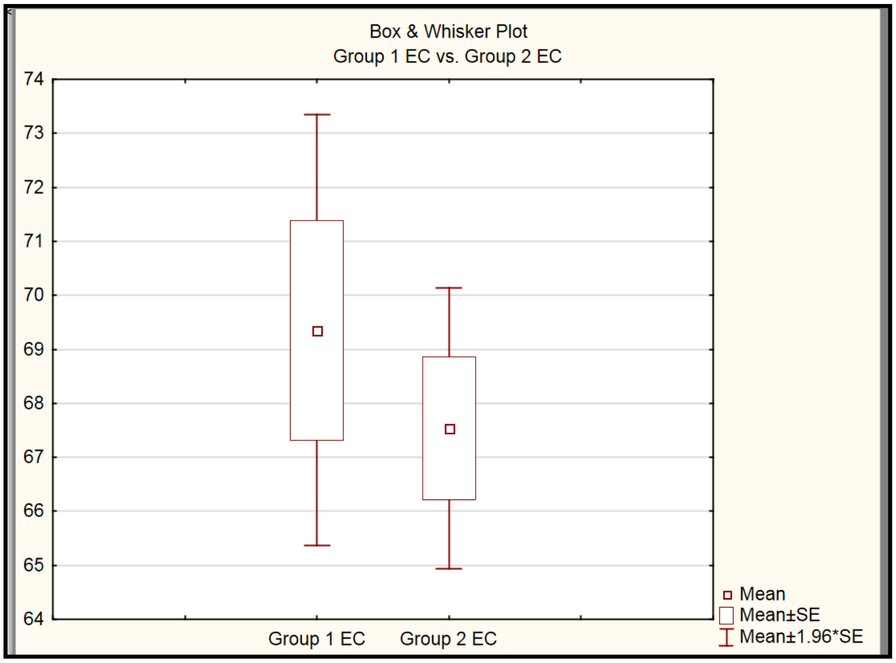
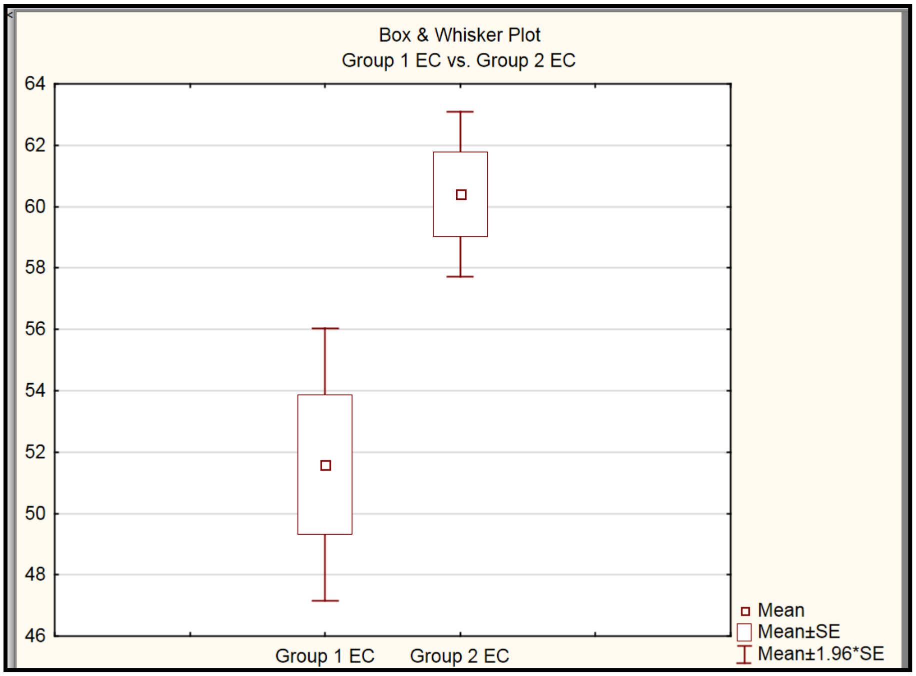


Figure 27: Box and Whisker graph for EC at Palmietfontein

In Palmiefontein group 1 shows that (N=132, M=69.35223, SD=23.38951) and group 2 (N=127, M=67.53958, SD=14.9472) and P=0.46001. P is greater than 0.05 therefore the null hypothesis is not accepted and there is a difference between group 1 and 2.

	T-test for Independent Samples (Sheet1 in EC) Note: Variables were treated as independent samples										
Group 1 vs. Group 2	**Mean Group 1**	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
Group 1 EC vs. Group 2 EC	102.5731	60.40851	1.351834	195	0.177994	85	112	329.9379	14.52520	515.9648	0.00

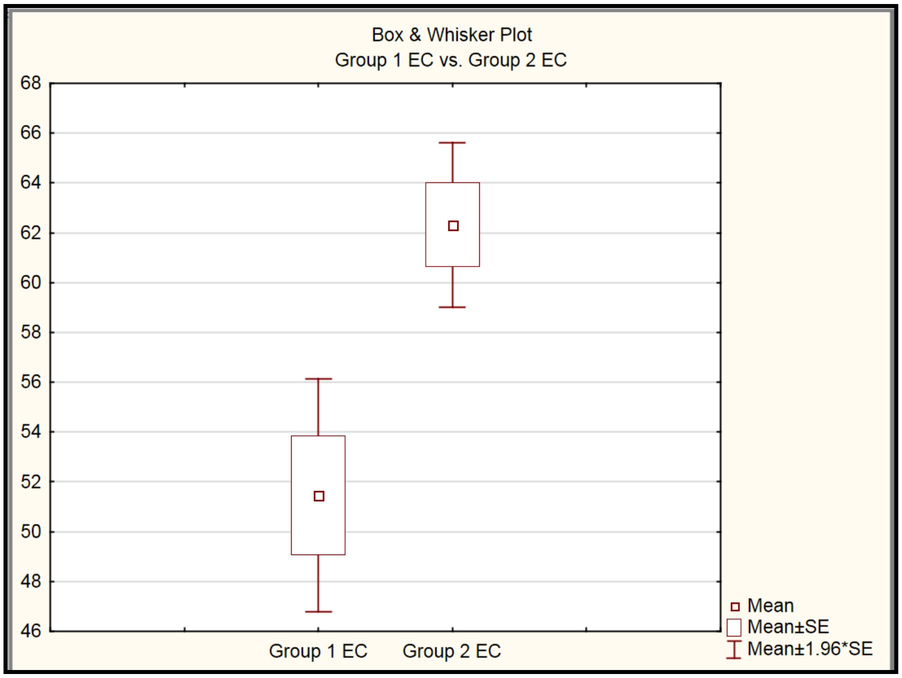


Box and whisker for EC at Vaalharts Barrage

In the Vaalharts Barrage Group 1 shows that (N=85, M=102.5731, SD=329.9379) and Group 2 (N=112, M=60.40851, SD=14.52520) and P=0.177994. p is greater than 0.05 therefore the null hypothesis is not accepted and there is a significant difference between Group 1 and 2.

T-test for Independent Samples (Sheet1 in EC)
Note: Variables were treated as independent samples

Group 1 vs. Group 2	**Mean Group 1**	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
Group 1 EC vs. Group 2 EC	51.46850	62.32074	-3.83281	187	0.000173	78	111	21.05045	17.72389	1.410602	0.097370



Box and whisker graph for EC at Nazareth

The t-tests conducted shows a significant difference in EC at Nazareth Farm Weir Group 1 shows that (N=78, M=51.46850, SD=21.05045) and Group 2 (N=111, M=62.32074, SD= 17.72389) and P=0.000173. p is less than 0.05 therefore the null hypothesis is accepted and there is a significant difference between Group 1 and 2.