COMPARATIVE EVALUATION OF THE IMPACTS OF TWO WASTEWATER TREATMENT WORKS ON THE WATER QUALITY OF ROODEPLAAT DAM IN TSHWANE, GAUTENG

by

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COMPARATIVE EVALUATION OF THE IMPACTS OF TWO WASTEWATER TREATMENT WORKS ON THE WATER QUALITY OF ROODEPLAAT DAM IN TSHWANE, GAUTENG.

I declare that the above thesis is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

I further declare that I submitted the thesis to originality checking software and that it falls within the accepted requirements for originality.

I further declare that I have not previously submitted this work, or part of it, for examination at UNISA for another qualification or at any other higher education institution.

SIGNATURE

08 August 2020

DATE

DEDICATION

This thesis is dedicated to my late father Mr. S.G. Zulu, for his continuous unlimited support and believing in me even when the odds were stacked against me.

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ABSTRACT

Freshwater resources and supplies in South Africa are experiencing severe stress from rising population growth, drought and high urbanization. The stress factors have also exerted pressure on wastewater treatment works leading to the release of partially treated effluent. The study assessed and compared the impact of the two wastewater treatment works effluent discharged into the Roodeplaat Dam. Selected physical parameters (pH, conductivity), chemical parameters (total oxidised nitrogen, phosphate, chemical oxygen demand, chloride, sulphate, sodium) and microbiological parameter (*Escherichia coli*) were evaluated and compared with South African standards. Secondary data (from January 2012 to December 2017) was used to identify parameters that were above or below regulatory standards. The t-test ($p < 0.05$) was used to compare changes between 2012 and 2018 over the same months.The results indicated that aquatic ecosystem quality has not improved, degradation continues as well as a lack of intervention from authorities. The leading parameters in causing stress to Roodeplaat water quality in descending order were *Escherichia coli* (*E. coli*), Phosphate (PO_4^{3-}), Total Oxidized Nitrogen (TON), Chemical Oxygen Demand (COD), Chlorophyll a (Chl a), Ammonia (NH_3), Electrical Conductivity (EC) and Sodium (Na). One of the main reasons why poor effluent was released is limited financial investment to upgrade the treatment facilities. This research provided highlights on the need to enforce extra measures to guarantee compliance of treated effluent quality to the existing guidelines. Moreover it highlights the need for concerned department's authorities to invest in water by allocating enough budget to address the challenge of wastewater treatment works upgrades.

Key Terms

Wastewater treatment works (WWTW), Roodeplaat Dam, Zeekoegat, Baviaanspoort, water quality, Cyanobacteria blooms, *E. coli*, Chlorophyll a, effluent.

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LIST OF ABBREVIATIONS

Abbreviation	Definition
CSIR	Council for Scientific and Industrial Research
CoT	City of Tshwane
EC	Electrical Conductivity
DWAF	Department of Water Affairs& Forestry
DWA	Department of WaterAffairs
DWS	Department of Water& Sanitation
C_2H_5OH	Ethanol
LOQ	Lowest limit of Quantification
LOD	Lowest limit of Detection
RQIS	Research Quality Information Services
SAHRC	South African Human Rights Commission
SANAS	South African National Accreditation System
SAWQ	South African Water Quality Guidelines
TWQGR	Target Water Quality Guidelines Ranges
WCW’s	Water Care Works
WWTW	Wastewater Treatment Works
WHO	World Health Organisation

1 CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Freshwater sources in Southern Africa are experiencing severe stress from rising population growth and growing economies (Vilane & Tembe, 2016; Okeyo *et al.,* 2018). Based on the population growth rate and anticipated change in fiscal growth, South Africa's receiving water bodies will not cope given the current designs of treatment facilities (Council for Scientific and Industrial Research [CSIR], 2010; Angelakis *et al.,* 2018).The entire freshwater resources in South Africa maybe exhausted and fail to meet the public requirements and business around year 2030 (Seckler *et al*., 1999; CSIR, 2010). Blaine (2013), also projected that South Africa might run out of fresh water in 2025, even in areas where rainfall is sufficient due to inconsistency of precipitation. Wastewater recycle contribution is a crucial addition to water supply of semi-arid areas like South Africa and some parts of United States of America's arid areas (Vigneswaran, & Sundaravadivel, 2004; WHO, 2017). The main purpose of wastewater treatment works amongst others is to reutilize wastewater for irrigation. Hence in so doing protects water resources, which is limited in dry and partially dry parts of the world(UNESCO, 2015).

Unfortunately over the last twenty years increasing global water pollution due to human activities have triggered significant alterations in most water ecosystems (Onifadeetal, 2017). Most developing countries have been pronounced as facing the threat of water pollution (Fatoki*, et al*., 2001; Seanego & Moyo, 2013; Yavini & Musa, 2013; Munyati, 2015). Poorly treated sewage effluent flowing into the rivers and dams is a source of declining water quality of the water resources (Wandiga, 2010; Zhang, *et al*., 2010; Seanego & Moyo, 2013; WRC, 2014; Okeyo *et al.,* 2018). South Africa's pollution will increase marginally even if population remains stagnant, contaminants will stay and accumulate in freshwater systems (DWAF, 2004). Hence the need for research to evaluate and improve Wastewater Treatment Works (WWTW) operations is important.

Wastewater Treatment Works reduce pollutants that include Chemical oxygen demand (COD), suspended solids, inorganic nutrients and dissolved solids through physical , chemical and biological processes (Dungeni *et al.*, 2010; Templeton and Butler, 2011;

Okeyo *et al.*, 2018). The aim of pollutants reduction is to guard against danger to humans and avert damage to the environment by ensuring that contaminants released to the receiving water bodies are at an acceptable level (Helen *et al*., 2008; Seanego & Moyo, 2013; Osuolale & Okoh, 2015; Edokpayi *et al.*, 2017; Okeyo *et al*., 2018; Shamimuzzaman *et al*, 2019). Discharged effluent must meet public health and environmental standards. The significance of optimally working WWTW is in the fact that they are the last fence and final border between untreated water and fresh water with a healthy and effective ecosystem (Water Research Commission [WRC], 2017; Angelakis *et al.,* 2018).

Most of the rivers and dams are subjected to severe variation in microbial, physical and chemical parameters due to contaminated water from WWTW (Akpor *et al*., 2014; Mail & Guardian, 2017). Consequently, stringent monitoring processes must be imposed to protect the dams and rivers from pollution by WWTW effluents. The declining conditions of WWTW infrastructure in South Africa is a major cause of several pollution complications experienced in most regions and results in many poor communities experiencing health problems (Mema, 2010; Mail & Guardian, 2017; Okeyo *et al*., 2018).

The leading challenge around many South African impoundments is eutrophication leading to phytoplankton blooms. Cyanobacterial blooms can lead to a nasty taste and odours in drinking waters. Cyanobacteria produce a variety of cyanotoxins that may result in health complications in humans and animals (Conradie & Barnard, 2012; Mbiza, 2014; Berg & Sutula, 2015).

Microbial contamination due to untreated or incompletely treated WWTW effluents flowing into the rivers and dams, pose dangers to receiving water bodies and surrounding areas (Fatoki, *et al.,* 2001; Britz, *et al.,* 2013; US. EPA, 2015; Mail & Guardian, 2017). Most of South African WWTW are struggling to release effluents of consistently high quality which is worrying (Dungeni *et al*., 2010; Mail & Guardian, 2017; Pretoria News, 2019).

Salinity is another challenge in most partially dry parts of the world such as the Southern Africa region. Some of these salts have a tendency to pass through conventional wastewater treatment works unchanged like sodium chloride and potassium sulphate.

Elevated levels of these salts may cause salinity levels to increase in rivers and dams and eventually disturb the ecosystem (Morrison, *et al.,* 2001; Seanego & Moyo, 2013). Ground water contamination is also due to percolation of sodium chloride and potassium sulphate salts. A WWTW that releases waste with parameters outside the required standards will pollute the receiving water resources. Polluted water resource has a low recreation value (Dungeni *et al*., 2010). Discharge of harmful waste, agricultural overflows of fertilizers and pesticides has contributed to severe health fears. As a result, polluted lakes, streams, rivers and groundwater aquifers are regarded as poor quality, and inappropriate for domestic purposes (Ding *et al*., 2015; Sun, *et al.,* 2016).

The maximum volume of Roodeplaat dam is 41.158 million m^3. The Roodeplaat dam is an important recreational resource for Tshwane region. Baviaanspoort and Zeekoegat WWTWs contribute 50% from return flows to the Dam (DWAF, 2008). While Zeekoegat WWTW has been one of the best performing facility in Tshwane, the same cannot be said about Baviaanspoort WWTW (Dungeni *et al*., 2010). Investigation of effluent discharged from WWTWs ensures that water is safeguarded from pollution and resources are properly administered for the benefit of communities who are utilizing it (DWS, 2017).

1.2 PROBLEM STATEMENT

Pollution of water bodies in SA from WWTW is a challenge due to poorly treated wastewater that is discharged into the rivers and dams. The pollution causes impairment of physical, chemical and microbiological parameters impairment (DWS, 2017; Liyanage & Yamada, 2017; Pretoria News, 2019). Roodeplaat Dam is an important resource mainly used for recreational, irrigation and drinking purposes (Van Ginkel, 2002; Silberbauer and Esterhuyse, 2014). Water quality problems in Roodeplaat Dam have been reported as far back as 2004 where fish death problem was indicated. WWTW that discharge into Roodeplaat Dam were found to be the main culprit of the water pollution problems (Hohls & Ginkel, 2004). The poor effluent qualityfrom WWTW was not peculiar to Tshwane, but a countrywide problem. In 2013 about 505 of South Africa’s 824 WWTW could not attain the Green Drop status. Furthermore, 248 (31.1 %) of South Africa’s WWTW scored below 30% on the Green Drop system implying a major crisis looming. About 121 WWTW are identified as in critical risk (Department of Water Affairs [DWA] 2013; Ntombela *et al.*, 2016). It is therefore necessary to ascertain whether the WWTWs are still the main contributors to the challenges experienced and how they impact on water quality of Roodeplaat Dam. All people rely on water for their regular accomplishments and survival; hence the quality of water is extremely important. Water is essential in supporting the social well-being of people (Badu *et al*., 2013; WWAP, 2015; Vilane & Tembe, 2016).

When poorly treated sewage effluent is discharged into the dam, it results in many physical, chemical and microbiological water pollution problems. Phosphates and nitrates (nutrients) in water resources lead to impairment of water quality leading to hyper-eutrophication and consequently excessive zooplanktonic and phytoplanktonic growth (Van Ginkel, 2002; Akpor *et al.*, 2014; Lapointe *et al*., 2015). The death of algae leads to an increase in organic waste which triggers reduction in oxygen levels as a result of decay. This leads to a drop in the diversity of aquatic ecosystem (Gray, 1997; Schreiner & Hassan, 2011; Edokpay, 2016).Discharge of significant amounts of pathogenic microorganisms in South African rivers and dams have caused cholera outbreak in many communities (Samie, *et al.,* 2009; Dungeni *et al*., 2010; WHO/UNICEF, 2015a; UNESCO, 2017). The research is intended to assess and compare the impact of the two WWTWs effluent discharged into the Roodeplaat Dam. Furthermore to pinpoint the leading parameters that cause stress on Roodeplaat water quality status.

1.3 RATIONALE

Deteriorating water quality has become a worldwide cause of distress as human population grows, commercial and farming activities increase. Population growth and economic activities present undesirable alterations to the environment (WHO/UNICEF, 2015b; Vilane & Tembe, 2016; Liyanage & Yamada, 2017; Wall, 2018). Water scarcity is exacerbated by poor planning and mismanagement of the available water resources (Okello *et al*., 2015). The globe is confronted by difficulties associated with wastewater management. Wastewater management challenges are attributed to widespread industrialization, growing population density and highly diverse communities (EPA, 2001; Vilane & Tembe, 2016; UNESCO, 2017; Wall, 2018). The wastewater from domestic and commercial activities is a major contributor of water pollutants. High levels of pollutants burden waste handling facilities resulting in contamination upload (Akpor *et al*., 2014). The extent of the population growth and poor planning, do not give enough space for upgrading of wastewater treatment works (Seanego & Moyo, 2013; Okello *et al*., 2015; Liyanage & Yamada, 2017). The majority of WWTW in Southern Africa treat large amounts of sewage which exceeds their design capacity (Morrison *et al*., 2001; Seanego & Moyo, 2013). The straining of WWTW leads to the release of poor effluent that falls short of stipulated quality standards (Samie *et al*., 2009; Britz *et al*., 2013; Mail & Guardian, 2017). Endless incidences of untreated waste discharges into dams and rivers increase the risk of population exposure to pathogens (Mema, 2010; WHO/UNICEF, 2015a). Microorganisms such as *E. coli*, and faecal *streptococci* are indicators of the presence of faecal pollution in rivers and dams (Akpor & Muchie, 2011; Onifade *et al*., 2017). Water bodies that are heavily polluted with faecal organisms should be used with caution as the water may put community health in danger (Arkermann, 2010; WHO/UNICEF, 2015b; Mail & Guardian, 2017). City of Tshwane has been reported to allow raw or partially treated sewage being discharged from WWTWs to the receiving water bodies (Pretoria News, 2019).

The release of Green Drop reports to the public was in 2013. It is, therefore, necessary to ascertain whether the two WWTW are still the main contributors to the challenges experienced and how they impact on water quality of Roodeplaat Dam. The research assists in identifying gaps which may help improve monitoring program.

1.4 HYPOTHESIS

H_0: The physico-chemical and microbiological parameters from Baviaanspoort and Zeekoegat WWTW do not negatively impact the Roodeplaat Dam’s water quality.

H_1: The physico-chemical and microbiological parameters from Baviaanspoort and Zeekoegat WWTW, negatively impact the Roodeplaat Dam’s water quality.

1.5 RESEARCH QUESTION

The leading research question for this study was:

- Are the parameters from Baviaanspoort and Zeekoegat WWTWs impacting negatively on the water quality of Roodeplaat Dam or within regulatory standards?

The specific research questions of the study were:

- Which physical, chemical and microbiological parameters are above or below regulatory standards?
- Which wastewater treatment works is major contributor of Roodeplaat Dam pollution?
- What are the pollution levels at the discharge points of Baviaanspoort and Zeekoegat WWTWs compared to entrance points of the Roodeplaat Dam?

1.6 AIM AND OBJECTIVES

The aim of the research study was to determine whether the selected water quality parameters from Baviaanspoort and Zeekoegat WWTWs were negatively impacting the water quality of Roodeplaat Dam.

The above aim was fulfilled through the following specific objectives, which were to:

- quantify selected physico-chemical and microbiological variables in effluent from Baviaanspoort and Zeekoegat WWTW and surrounding water bodies;
- compare the effluent quality from Baviaanspoort and Zeekoegat WWTW; and
- determine seasonal and spatial patterns in water quality of Roodeplaat Dam.

1.7 THESIS LAYOUT

The thesis is structured by chapters as follows:

Chapter 1: Includes background; problem statement; rationale; hypothesis, and aim and objectives of the study.

Chapter 2: Comprises of an introduction on wastewater, wastewater definition, water quality parameters description and literature review.

Chapter 3: Research methodology which describes the study area, research design, data collection, research quality, reagents and principle of instruments.

Chapter 4: Focuses mainly on data presentation and discussion. The latter entails theinterpretation of results with the backing of the literature.

Chapter 5: Provides conclusions and recommendations from research based on the reported results.

1.8 CHAPTER SUMMARY

This chapter provided a background to the study through a brief description of the challenges faced in maintaining water quality, rationale and objectives of the study, and the lay out of the thesis. The main issue with water service authorities is to continuously monitor the perfomance of their water and wastewater handling facilities to ensure corresspronding adjustments for maximum public health protection. The next chapter will focus on wider review of literature in wastewater field.

2 CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

Wastewater, water quality and views of other researchers on WWTW studies are discussed in this chapter. The effects of incompletely treated wastewaters or raw sewage discharged into potable water bodies are discussed in this chapter. Moreover, the chapter outlines the importance of effective wastewater treatment processes.

Wastewater is defined according to its origin, composition and treatment processes. Wastewater that is not adequately treated may lead to elevated levels of microbiological, physical and chemical parameters beyond the maximum stipulated regulatory standards. Hence, polluting the receiving water bodies and eventually impairing its water quality (DAE, 2014; Edokpay *et al*., 2017).

Water quality is a term used to define water properties usually regarding its fitness for a range of purposes and for protecting the health and integrity of sustainable dynamic aquatic environments. The chemical, physical, and microbiological properties of water are used to define water quality. Primary standards are for regulating constituents that can bring problems to human safety and aquatic organisms. Secondary standards deal with aesthetic effects, like appearance, smell and flavor (DAE, 2014; Gholizadeh *et al.,* 2016; DWS, 2017).

Water quality may be altered by both natural actions and humans activities that lead to contamination of water receiving bodies (DWS, 2017). Clean, nontoxic and sufficient freshwater is important for the existence of all organisms. Clean water is also necessary for ecosystems and socio-economic sustenance (Vaughn, 2017). Many deaths have been reported all over the world, due to water supply not meeting the health norms in terms of their parameter concentrations (Afifi *et al*., 2015). Improving WWTW management will ensure that receiving water bodies' pollution risk is reduced and the water meets the requirements for both human use and the ecosystem (UNESCO, 2017). Furthermore, poor water quality associated complications can reach the level of catastrophic proportions if is not treated properly (Dusabe *et al*., 2015).

According to Green Drop Report 248 WWTW out of 824 WWTW were found to be in precarious state and required to be closely monitored. A further 161 WWTW were in poor state and required critical care. Since 2013 no data on WWTW has been released to the public. The last data showed that only 60 WWTW received the green drop certificate. Both Zeekoegat and Baviaanspoort WWTW were not amongst those (Ntombela *et al*., 2016).

Hence, wastewater produced from WWTW has many undesirable effects if it is not adequately treated. Acceptable treatment requires different processes to maintain compliance with effluent regulation. It is therefore important to investgate whether processes for wastewater treatment, release effluent which is within legislated water quality guidelines.

2.2 WASTEWATER TREATMENT

Wastewater is regarded as water that ferries waste made from domestic, commercial and industrial sources. Wastewater constituents pose various environmental challenges owing to their chemical, physical and microbiological parameter levels (Naidoo & Olaniran, 2014; DAE, 2014). Wastewater treatment works employ different processes for reducing undesirable parameters from wastewater to yield effluent that is fit for disposal (Naidoo & Olaniran, 2014; Gholizadeh *et al*, 2016, Edokpay, 2016). To be effectively treated, wastewater must be transported to a treatment works by suitable channels. The treatment processes entail solids and chemical removals, and reduction of microbiological load through disinfection. The specific techniques and duration of treatment processes depend on the nature and source of wastes (Naidoo, 2014; Okeyo, 2018). The treatment processes must be monitored using stipulated methods (Aquatech, 2019).

Wastewater treatment has four main phases:

i. Wastewater enters a treatment works through preliminary treatment. Preliminary stage removes wastewater constituents that may cause maintenance or operational problems. These constituents can affect an array of consequent treatment steps, eventually triggering blockages of pumps. The removal of large objects such as rag, toilet tissue and other large foreign objects is executed at this stage. The screens are created from metals labs and vary from sizes. Objects separated by the screens are mostly harmful and need to be disposed of by suitable techniques to a specific treatment works to protect public and environmental health (Naidoo & Olaniran, 2014; Aquatech, 2019).

ii. Primary stage wastewater or sewage is positioned in the holding small pools. Solid materials settle at the foot, and less compact materials like oil and grease hover at the top. These foreign objects are then easily detached (WRC, 2016). Fats are also removed from the top of the reservoir. Throughout primary treatment more than 40% of suspended rigid objects and 20% of amount of dissolved oxygen needed are removed.

iii. Secondary stage entails the removal of liquefied and suspended organic objects. Universally in a secondary stage organic materials are consumed by aerobic microorganisms in the wastewater. Elimination from biological phase outflow of 90% organic nitrogen, organic phosphorus and heavy metals linked to solids which settle at the bottom to form the sludge takes place at secondary phase (Naidoo & Olaniran, 2014).

iv. Tertiary treatment stage is where advanced cleaning of effluent that will ultimately be discharged into delicate surroundings is performed. Tertiary stage can be accomplished by numerous procedures, subject to the remaining pollutants. Special treatment procedures to remove nitrogen, ammonia, phosphorus, trace elements and organic compounds, and residual solids are employed at this stage (Okeyo *et al.,* 2018).

2.3 WATER QUALITY PARAMETERS

Water quality can be defined in terms of levels of physical, chemical, and microbiological parameters in relation to its fitness for a particular usage, such as irrigation, drinking and recreational activities. Water quality is described in terms of quantification parameters and compared against standards set by regulatory bodies to demonstrate their compliance. The parameters reviewed in this section are those under investigation. .Parameters can be grouped into physical, chemical and biological characteristics.

2.3.1 PHYSICAL PARAMETERS

2.3.1.1 POTENTIAL OF HYDROGEN (PH)

The pH is described as the Potential of Hydrogen and serves as an indicator of the magnitude of acid or base in water (EPA, 2001). The pH assessment is done to quantify hydrogen ion movement in a liquid sample. The number of hydrogen ions (H^+) and hydroxyl ions (OH^-) is indication of whether pH is basic or acidic. pH is temperature dependant. If there are equal amounts of H^+ and OH^- in water then the pH is 7, which indicate that the water sample is neutral. Many aquatic processes are influenced by the pH values which depend on the hydrogen ions concentration (Oyhakilome *et al.,* 2012; Subin and Husna, 2013). When there is a higher concentration of H^+ than OH^- the pH will be below 7, hence acidic. Conversely, when there is a higher concentration of OH^- then the pH is more alkaline.

The pH values in an aquatic solution can cause water to be inappropriate for all or specific water uses. Water pH value that is less or equal to four is an example of water that is not suitable for most of aquatic organisms (Nkambule, 2016). The pH of water can have an effect on behaviour and properties of other parameters in water. Heavy metal compounds in low pH have high solubility factor which in turn results in higher toxicity and levels of heavy metals in the receiving water body. Extremes in pH may also affect the taste of drinking water (Xia *et al*., 2016).

2.3.1.2 CONDUCTIVITY

The capacity of water to allow passage of electric flow is called electrical conductivity (EC). The capacity is closely linked to the amount of ions in water. The change in the temperature can also affect conductivity. The recommended EC concentration for dam or river water is less than 1000 μS/cm (EPA, 2001; Rusydi, 2018). Measuring of EC can assist aquatic resources managers to estimate water contamination in terms of the manifestation of pollutants that may render the water unsuitable for intended uses.

2.3.2 CHEMICAL PARAMETERS

2.3.2.1 TOTAL OXIDISED NITROGEN (TON)

This is the sum of nitrate (NO_3) and nitrite (NO_2), but excludes ammonia and organically bound nitrogen. Nitrate may be converted to nitrite which is more toxic to humans. Nitrite can coalesce with haemoglobin in red corpuscle of human beings and results to anaemia (Elshorbagy & Ormsbee, 2006). Domestic wastewater contains high levels of nitrogen which can react in water to form nitrate, thereby causing eutrophication. Higher concentration levels of nitrates limit quantity of oxygen in the brain and which leads to blue baby disease. High nutrients due to untreated or partially treated effluent has added to high deaths rates mainly in under developed and emerging states (Angelakis & Snyder, 2015).

2.3.2.2 AMMONIUM

Ammonium (NH_4^+) can dissolve easily in water and is hence easily moved by surface overflow of water. Ammonium is also found in abundance in raw sewage. Ammonia (NH_3), is formed mostly in basic conditions (pH > 8.5) and is highly toxic to marine life at concentrations above 2.0 mg/l (Spellman, 2017; Chen, 2018).

2.3.2.3 ORTHOPHOSPHATE

Phosphorous is a major element for plant growth hence its abundance in water can promote phytoplankton growth (Van Ginkel, 2002; Griffin, 2017). The upsurge of phosphorus in water bodies is mainly attributed to runoff from agricultural activities (Kgabi, 2015).The recommended limit for phosphorus in surface water is 0.7 mg/l (EPA, 2001).

A combination of high levels of phosphorus and nitrogen accounts for eutrophication in water bodies.

2.3.2.4 CHLORIDES

Chlorides are found as salts of sodium ($NaCl$), potassium (KCl) and calcium ($CaCl_2$). High levels of chloride can make water inappropriate to use for irrigation and drinking. In rivers and dams, the chloride concentration is in the range 15-35 ppm which is significantly lower than the drinking water quality standard levels of 250 ppm (EPA, 2001). Chloride poses no health risks to humans with no underlying conditions, however high concentrations can give the water a salty taste and may affect metabolism in some cases (WHO, 2003).

2.3.2.5 SULPHATES

Sulphates (SO_4^{2-}) are mostly found in aquatic ponds as sulphate anions. Sulphide minerals such as gypsum and pyrite are a major source of sulphates formed from the leaching of these compounds (Kipngetich *et al*., 2013). Sulphur is readily soluble in water in its stable and oxidized form. Substantial amounts of sulphates are added to aquatic environments through industrial discharges and atmospheric precipitation (Georgieva *et al*, 2010; Mosimanegape, 2016). High concentrations of sulphates may lead to a series of serious environmental problems that include water mineralization, corrosion of metal pipes and equipment scaling. High concentrations of sulphates in the water can cause cathartic effects in some animals. The concentration levels in the industrial wastewater and surface water discharge range from 250 ppm to 500 ppm for most countries (Fang *et al.,* 2018).

2.3.2.6 SODIUM

Sodium (Na) is among the most abundant metals on the planet and is highly soluble in water. Sewage and industrial effluents may increase the Na in surface waters. The sodium ions are mainly carried into water bodies from sodium salts percolated from rocks and occasionally due to industrial and domestic activities. Sodium mixtures are used in production and purification of metals, and as a freezing agent in atomic devices. Sodium nitrate is mostly used as an artificial plant stimulant. Sodium is also used in food businesses as a preservative. In sanitary cleansers the element is present as hypochlorite compound. Overdose of Sodium may cause increased blood pressure & arteriosclerosis (Mosimanegape, 2016).

2.3.2.7 CHLOROPHYLL A

Chlorophyll a (Chl a) is the primary pigment for photosynthesis and is present in polyphyletic marine plants. The determination of chlorophyll *a* is used to give an estimation of the phytoplankton biomass present and is widely used to assess the abundance of planktonic (and sometimes benthic) algae present in suspension in natural waters. Chlorophyll *a* is determined using a spectrophotometric method in the laboratory (Portwig, 2009; Johan, *et al*., 2018).

2.3.2.8 CHEMICAL OXYGEN DEMAND

Chemical oxygen demand (COD) is the measure of oxygen required to chemically oxidise waterborne organic matter (Mishra *et al.*, 2009). COD is valuable in finding quality condition of effluent discharged into rivers, ponds and dams in order to minimise their effect. The wastewaters pollution in relations to amount of organic substance is quantified by means of COD concentration. COD approximately relates to the organic material in the sample (Schmitz, 2017).

2.3.3 BIOLOGICAL PARAMETERS

2.3.3.1 *ESCHERICHIA COLI*

There is an array of pathogenic microorganisms that are found in water. These can be bacteria, viruses, fungi and protozoa. Generally, microbiological water contamination focuses on the bacterial species. In most cases the pathogens occur in small numbers and often difficult to detect. Therefore, indicator organisms such as *E. coli* are used as indicator organisms. The name indicator is used as the presence of *E. coli* signifies contamination of water with faecal material and potential presence of pathogens associated with such sources (WRC, 2016). The *E. coli* may not necessarily be pathogenic but possess characteristics that make it relatively easy to detect. *E. coli* are found in the human intestinal tract and warm-blooded organisms and are released by faecal excretion (EPA, 2001; Olorode *et al.*, 2015; Osuolale & Okoh, 2015; Inyinbor *et al*., 2018).

2.4 INTERNATIONAL AND LOCAL RESEARCH

This section details research performed globally around the challenges from malfunctioning and non-optimised WWTW.

2.4.1 INTERNATIONAL RESEARCH ON WWTW AND NUTRIENTS UPLOAD

Lapointe, *et al*., (2015), investigated the existence of unfavourable algal blooms from wastewater in Florida's Indian River Lagoon. The results indicated the elevated concentrations of nutrients upload that caused algal bloom. However, septic tanks were the main non-point source of the pollution, contributing excessive concentration of Nitrogen into the river. The research showed that if WWTW are upgraded, point source pollution can be easily eliminated compared to non-point source (Lapointe *et al.,* 2015).

The case study of state of quality of sewage managing in Shokuhieh industrial park in province of Qom, Iran was undertaken by Fahiminia, *et al.,* (2015). They observed that pre-treatment is not performed in many industries and wastewater recycle is done in few industries. Wastewater management and the sewage treatment services at effluent sites were not conforming to the regulations on wastewater discharge in the rivers and dams. This ultimately affected the water quality and caused nutrient overload in the rivers and dams. The study revealed that WWTW need innovative improvement to advance their treatment interventions to safeguard downstream consumers (Fahiminia *et al*., 2015).

Spångberg, Tidåker & Jönsson (2014) investigated the concept of re-using the nutrients from human waste on agricultural land as fertilizer. They concluded that it could decrease the usage of power and natural resources for creation of biochemical fertilizers. It could also decrease the usage of power and chemicals at WWTW (Spångberg *et al.,* 2014).

Research on characteristics of water quality of municipal wastewater treatment plants in China was done by Sun *et al*., (2016). The data gathered from 3 340 Chinese municipal wastewater treatment works was utilized to increase understanding of the effects of sewage on water quality. After classifying wastewater qualities, researchers resolved that raw waste in Northern China had elevated impurity uploads, but the discharged wastewater to the streams was of great quality due to the extensive implementation of different water recycle approaches. The significance of wastewater as a reserve, and the execution of innovative treatment and assets use in the long-term should be stressed for sustainable ecosystem management (Sun *et al.*, 2016).They also established that nearly 90 % of WWTW have difficulties with TON exclusion, which causes problems like eutrophication downstream. Around half of WWTW nitrogen exceeded the effluent limit standards mostly from less developed regions. The study recommended that the focus should be on upcoming advancement and research (Zhang *et al*., 2016).

Data from three monitoring sites of Lake Geneva were studied by Thevenon *et al.,* (2011). The objective of the study was to reveal robust interrelating outcomes of WWTW and eutrophication on bacterial profusion. The results showed microbial reaction to ordinary or human prompted changing limnology settings. The large amount of sewage treatment water that was released into Vidy Bay caused adverse effect on aquatic animals. This was due to very rich nutrients such as nitrogen and phosphorus. Alarms for the earth's freshwater resources in the view of climate change and the deterioration of marine quality is caused by this threat on water resources. The mixing of inorganic pollutants characterizes an important cause of toxicity for sediment inhabitant organisms. It resulted in unfavourable conditions in relation to water quality management for organisms that live in sediments. The conclusion was that WWTW effluent is not monitored according to set norms, and these require the relevant parties to implement the required remedial action (Thevenon *et al.*, 2011).

The above studies indicate the need for consistent innovation around wastewater treatment to mitigate the ever increasing waste complexity due to human activities. Failure to do so will trigger a vicious cycle of pollution and increased water purification costs that may hinder water purification. The latter will expose the public to health risks. Continous quality monitoring is a critical trigger for timely innovative interventions.

2.4.2 LOCAL RESEARCH ON WWTW AND NUTRIENTS UPLOAD.

Nutrient contamination in many receiving water bodies have been reported in South Africa (Van Ginkel, 2002). Seanego and Moyo (2013) identified high intensities of nitrogen and phosphorus in Sand river as a result of contamination from Polokwane wastewater treatment works. The poor effluent quality was attributed to rapid population growth which exceeded the maximum handling capacity of the plant. Such population growth is not a problem of Polokwane only, but shared by all urban areas (Seanego & Moyo, 2013). The phenomenon is exacerbated by poor planning in infrastructure development and populist approaches by politicians who give people freedom to construct residential properties ahead of waste handling facilities.

The level of Keiskammahoek wastewater treatment works performance in Eastern Cape was investigated by Morrison *et al*., (2001). The parameters that were evaluated include pH, conductivity, COD and nutrients. The research evaluated the influence of the wastewater treatment works on the quality of the receiving Keiskamma river by concurrently monitoring the parameters in the river and Keiskammahoek WWTW. The COD and PO_4^- discharges to the river exceeded the South African Quality Standards guidelines. High levels of contamination received by Keiskamma river were observed for PO_4^-, COD and NH_4^+. The researchers concluded by emphasizing the necessity of regular monitoring of the water quality and that water authorities in the area should demonstrate their willingness to take responsibility. Upgrading the wastewater treatment plant to improve efficiency and compliance was also recommended (Morrison *et al*., 2001).

A study by Munyati (2015) in Mafikeng, South Africa to find the spatial distinction in eutrophication signs in four water resources pointed out that there were other sources of nitrates and phosphates other than municipal sewage from plant. The likely additional source was decomposing organic matter in the resevoirs. Financial constrains were noted as a hindrance to the efforts towards the eradication of eutrophication problem. The community was forced to drink polluted water due to water shortages (Munyati, 2015). The study demonstrated that not only WWTW are the culprits when it comes to water pollution. Therefore, an open mind is necessary when identifying sources of pollution.

Furthermore, consistent monitoring helps in identifying such evolving sources of pollutants.

However, wastewater treatment works have been reported to be the main cause of pollution in many dams and rivers in South Africa. Poor WWTW effluent has been demonstrated to be an emergency that should be attended to (Van Ginkel, 2002; Silberbauer, 2014; Munyati, 2015). The implementation of the Green Drop System has not yielded the much anticipated positive impact. What has made it worse is the fizzling of this incentive-based initiative with the last public report issued in 2013.

2.5 CHAPTER SUMMARY

This chapter touched on water quality parameters that were used in this study and gave a brief overview of the results from local and international research around the area of wastewater treatment. It is important to note that not only the WWTW are the sole culprits for potable water contamination. There is a need for continuous monitoring and improvement of wastewater handling infrastructure and processes to maintain compliance to the relevant regulatory water quality standards for the ultimate protection of the public.

3 CHAPTER 3: STUDY AREA, MATERIALS & METHODS

3.1 THE STUDY AREA

Roodeplaat Dam was constructed in 1959. The dam is located approximately 24 km from Pretoria, east of Moloto Road. The original purpose of the dam was to provide for irrigation to the surrounding areas, but has been used as a source of drinking water for the north metropolitan region of Pretoria (Zambezi, Wonderboom, Magaliesberg Doornpoort).The Roodeplaat Dam, Pienaars River, Upper and Lower Crocodile Rivers share the area of the Crocodile West Marico Water Management Area (WMA). Roodeplaat Dam is a renowned destination for bird watching, angling and assortment of marine sports (Lomberg, 2010).

Approximately ten kilometers up stream of the Roodeplaat Dam on the eastern part of the Pienaars River is where the Baviaanspoort wastewater treatment works is situated. The Baviaanspoort WWTW, situated in the Tshwane Metro, serves Mamelodi Township and Baviaanspoort Correctional Services. It discharges into the Pienaars River. The Zeekoegat wastewater treatment works is situated close to the western side of Moloto Road not far from Roodeplaat dam (Figure 3.1). The Zeekoegat discharges the effluent into the Roodeplaat Dam through a short earth waterway which passes through the Roodeplaat Nature Reserve (Lomberg, 2010).

There are several different groups that are interested in the operations of the dam and activities on the surrounding areas, like associations, government bodies and private proprietors. There are many events on the dam and in the vicinity which include, eco-tourism, camping, canoeing, picnic spots, power boating, rowing, lodging, fishing and meeting amenities (DWAF, 2008).

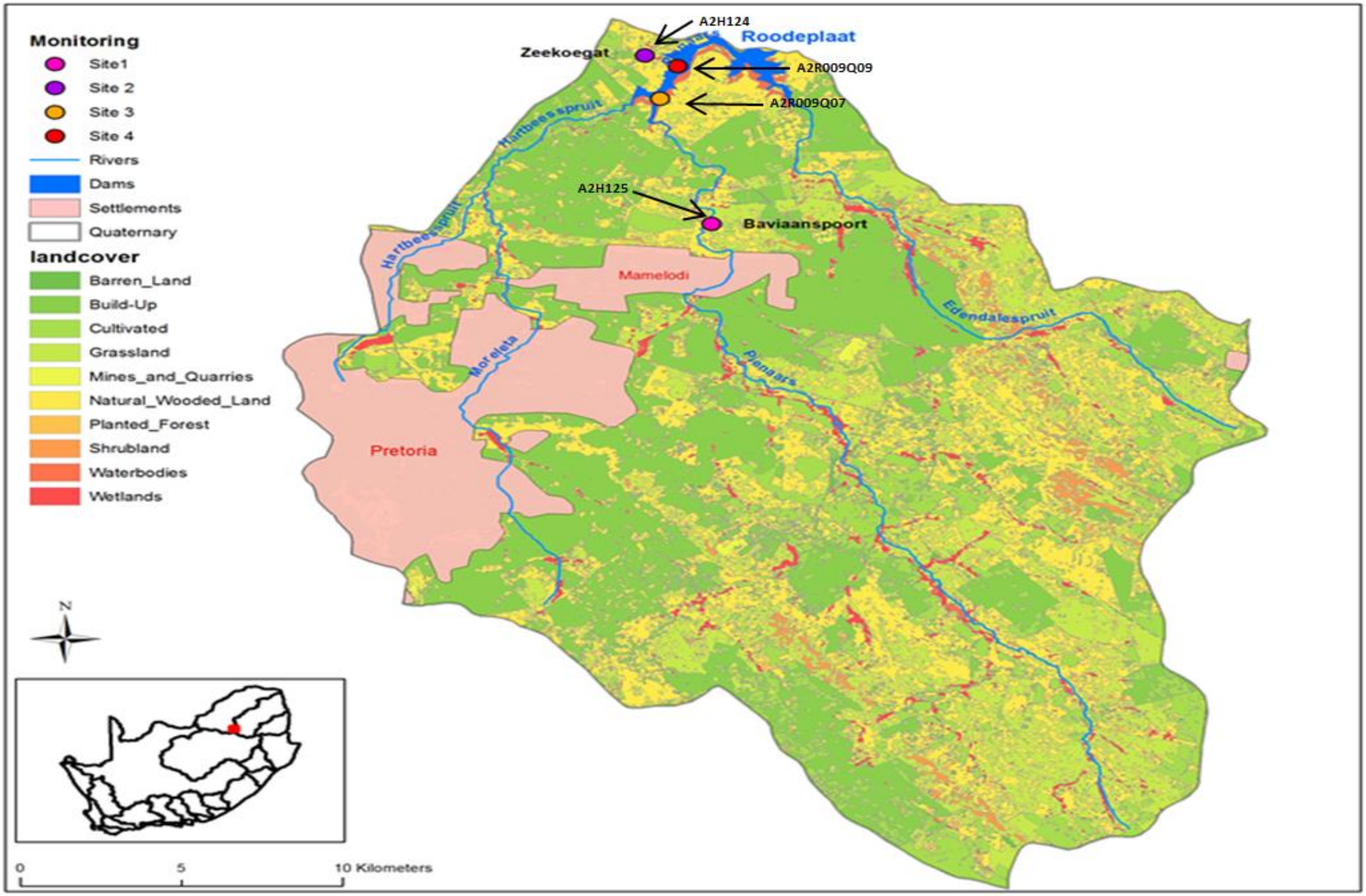

Figure 3-1: Locality of Roodeplaat dam (Prepared by: B. Adie, 2019)

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The landscape proximate to Roodeplaat reservoir is equitably planed and does not cause a restraint to likely expansion near the dam. The landscape permits stress-free entry to the water surface and offers prospects for numerous events that include rowing and fishing (DWAF, 2008).

Moreletaspruit, Pienaars River and Edendalspruit are major tributaries to Roodeplaat Dam, which enter the dam from the south and exit from the north away from the dam wall (Figures 3.2 and 3.3). The average population density in the Roodeplaat Dam's catchment area is above 50 people per square kilometre (DWAF, 2008).

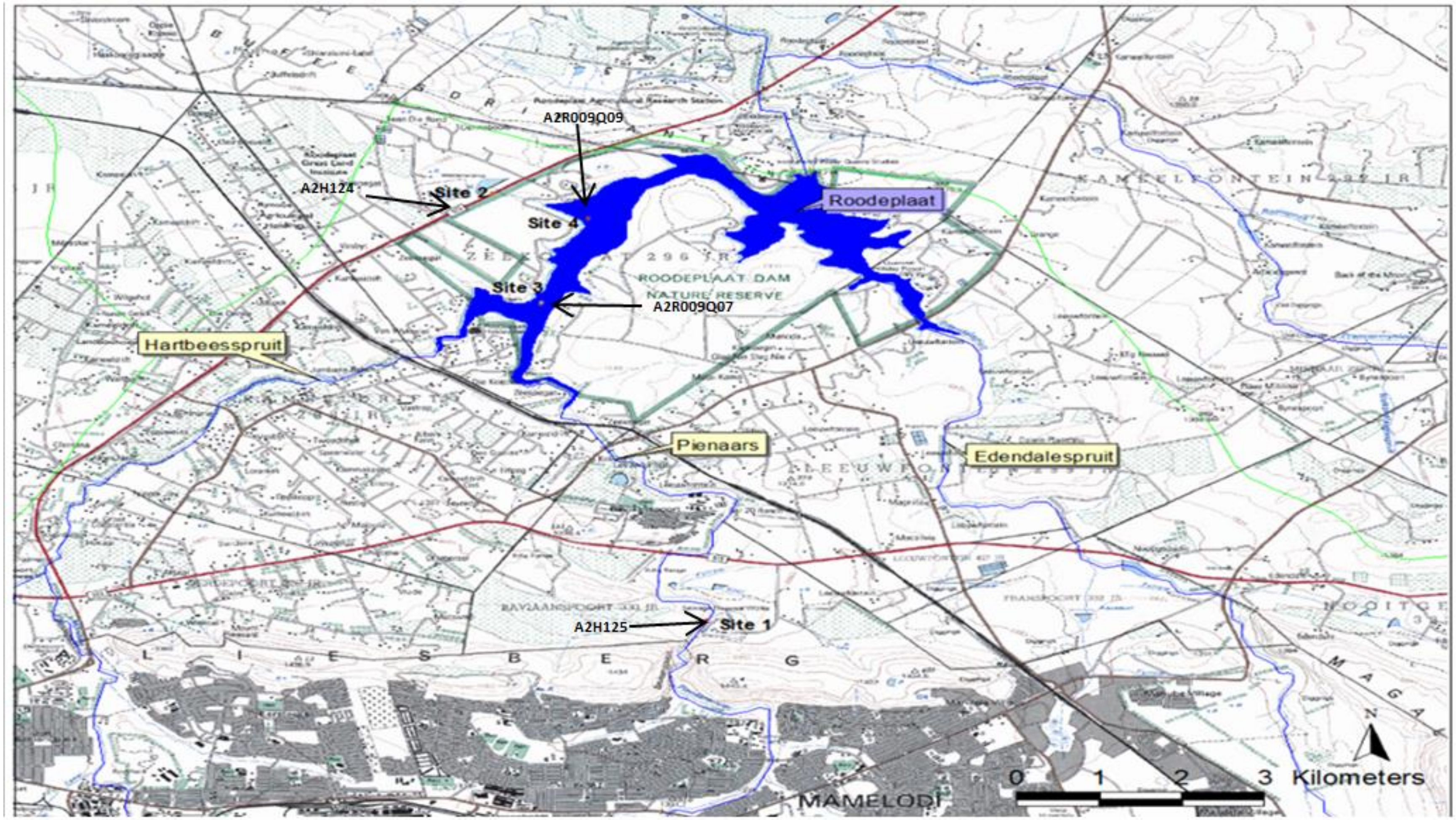

Figure 3-2: Roodeplaat Dam and surroundings (Source: DWAF, 2008)

Monitoring sites were selected based on the intended comparative use of water quality data points. The four monitoring sites were considered for the study:

i. Discharge point of Baviaanspoort site 1 (A2H125Q01);
ii. Discharge point of Zeekoegat site 2 (A2H124Q01);
iii. And at the entrances point of Roodeplaat Dam, site 3 (A2R009Q07); and
iv. Entrance point of Roodeplaat Dam site 4 (A2R009Q09), refer to figure 3.1.

Table 3-1: Description of the selected water quality sampling sites

Description of monitoring sites	DWS sample point	Research study points	Latitude (S)	Longitude (E)	Located on Type
Baviaanspoort WWTW sewage effluent	A2H125Q01	Sample point 1	-25.6886	28.36194	Baviaanspoort WWTW
Zeekoegat WWTW sewage effluent	A2H124Q01	Sample point 2	-25.6232	28.33874	Zeekoegat WWTW
Point in Roodeplaat dam	A2R009Q07	Sample point 3	-25.64	28.344	Dam / Barrage
Point in Roodeplaat dam	A2R009Q09	Sample point 4	-25.627	28.349	Dam / Barrage

Figure 3-3: Aerial map of the study area (Source: Google earth map, 2017)

3.2 RESEARCH DESIGN

Research design allows the researcher to measure and analyse data achieving the high standards of consistency of data collecting owing to controlled interpretations and laboratory tests (Mouton, 2001; Leedy & Ormrod, 2016). The focus was on the collection of primary and secondary data, analyses and interpretation of data. A quantitative research design was used in this study. The quantitative research design is regarded as a suitable method to finalize results and disprove or prove a hypothesis (Leedy & Ormrod, 2016).

3.3 DATA COLLECTION

Data from the Department of Water & Sanitation from 2012 to 2017 were used for comparative evaluation of the impacts of the two wastewater treatment works on water quality of Roodeplaat Dam. The research included collection of raw data where subsurface grab sampling was used. Samples were collected monthly from July 2018 to December 2018. Sample bottles were cleaned and sterilised according to the standard procedures for microbiological and physico-chemical analysis. Before sampling, all cleaned and sterilized bottles were rinsed by same water sample to minimise contamination. (DWAF, 1992).

The samples for inorganic analyses were then placed in a cooler container kept between 2 ºC and 8 ºC during transit to the laboratory where they were analysed (Portwig, 2009). Each sample for nutrients analyses was preserved with one ampoule of Mercury Chloride (HgCl), to avoid deterioration as some volatile nutrients like ammonia. The ampoule was broken and dropped into the water sample. Before analysis the water samples were filtered to avoid instrument breakdown (Portwig, 2009).

Cold transit and storage for microbiology samples was not necessary since analyses were performed within two hours of collection. However, where microbiological analyses within two hours were not possible the samples were stored between 0 ºC to 4 ºC. The length and temperature of storage was recorded (DWAF, 1992). The primary data (July 2018 to

December 2018) was compared with secondary data (July 2012 to December 2012) to determine if the changes were significant or insignificant over six year period.

3.4 PRINCIPLES OF ANALYTICAL INSTRUMENTS

3.4.1 ATOMIC ABSORPTION SPECTROMETER

The Atomic Absorption Spectrometry (AAS) is extensively used for elemental analysis due to its ease of use and cost effectiveness (Skoog, 2013, Tissue 2013). The sample is converted into a gaseous form before it is atomized. The nebulizer is responsible for converting liquid phase into fine aerosol. The flame is responsible for atomization of the sample. The fuel and oxidant determine the amount of heat from the flame. A light source produces a light beam at a specific wavelength that passes through the flame into a monochromator where a narrow band of wavelength is selected. The light then goes to the detector that measures the magnitude of light absorbed by the atomised element in the flame (Figure 3-4). Each element has a unique absorption wavelength. The quantity of energy at the distinctive wavelength absorbed in the flame is relative to the signal of the constituent (Skoog, 2013).

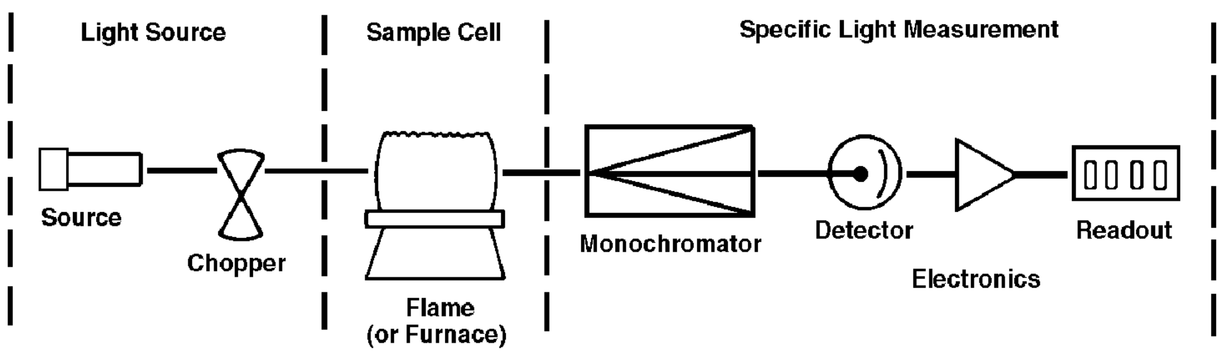

Figure 3-4: Schematic diagram of an AAS principle. Source: (Beaty & Kerbner, 1993)

3.4.2 DISCRETE ANALYSERS

Discrete analyser is ideal for automation and when multiple analyses are performed on one sample. In the automated photometric chemical analyser the device carries out trials on samples that are separated in the cuvettes unlike in a continuous flow analyser where they use a roller pump for uninterrupted flow of blends. Discrete analysers can be bench top devices (Figure 3-5) and other systems require floor space (Figure 3-6) (Thermo Scientific, 2004).

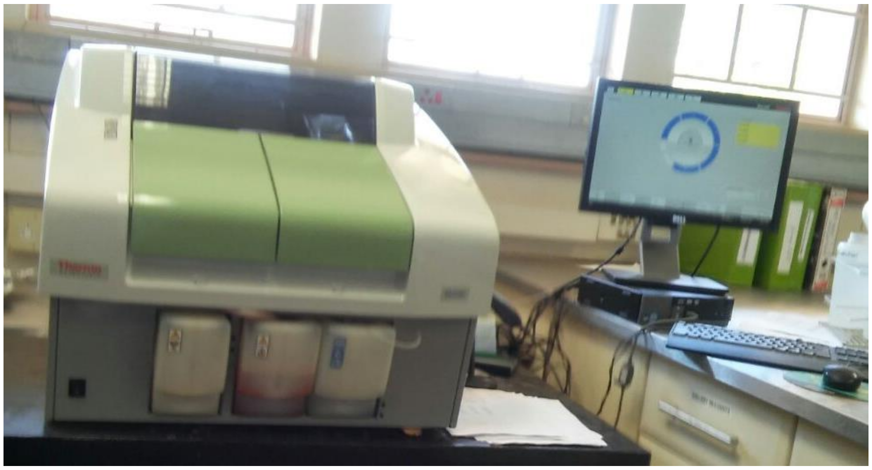

Figure 3-5: Bench top discrete analyser (Gallery instrument)

Figure 3-6: Discrete analyser that uses floor space (Aquakem instrument).

The cuvette is transferred from its original position into an available space in the incubator. There are designated positions around the incubator for dispensing reagents and samples into the cuvettes (Figure 3-7).The dispensing needle allots precise and accurate amounts of trials and chemicals, applicable to the experiment into the cuvettes. The sample is mixed by an oscillating needle in the cuvette to stimulate proficient mixing. After proper mixing, the mixture of the sample and reagents is incubated in the cuvette for a set period after which it is passed over the photometer for readings. The incubator rotates to move the cuvette cells to different positions around the incubator according to the steps in the tests that are run.

In the photometer the beam of light travel from the light source through the abridging lens to the intervention filters. After the filtering the light is transformed into a flow of light beats by the chopper. Then the quartz fibre directs the beam through the converging lens and the slit. After all cells of one whole cuvette strip are used and measured, a new cuvette is loaded to the same slot in the incubator and the used cuvette is discarded to the cuvette waste bin (Thermo Scientific, 2004; Portwig, 2009a).

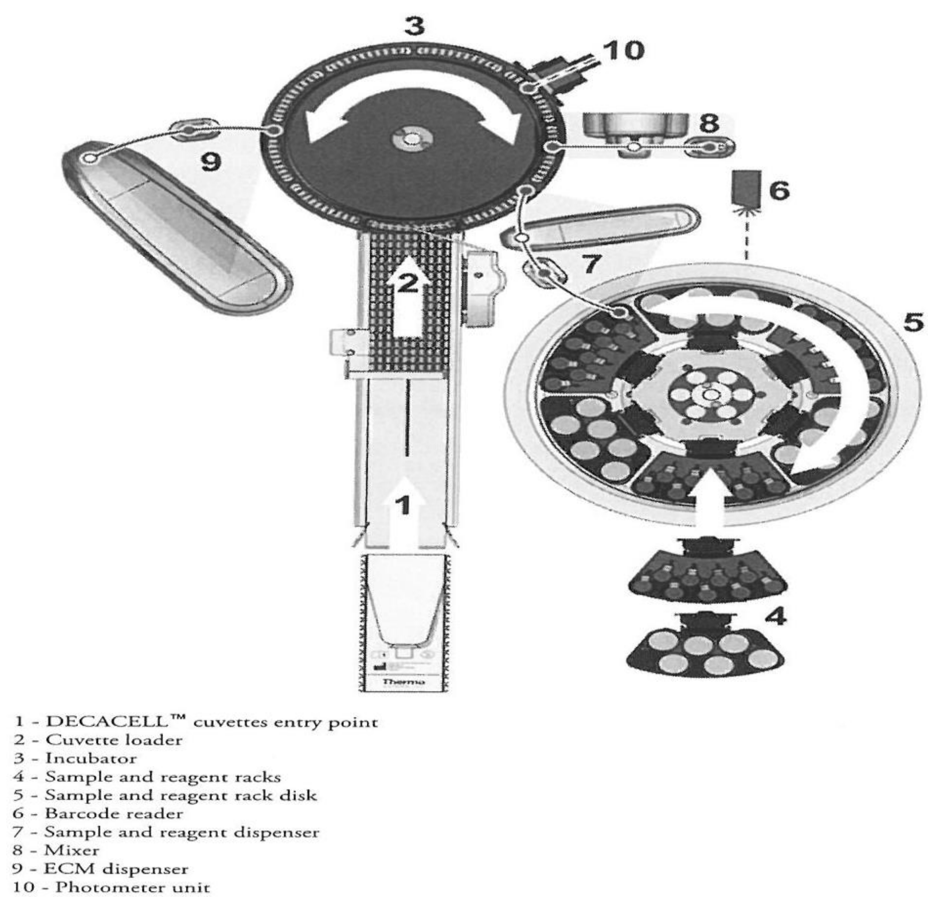

Figure 3-7: Discrete analyser flow system diagram. Source: (Portwig, 2009).

3.4.3 RADIOMETER

Radiometer offers a selection of two-pole conductivity cells for a wide variety of applications including Conductivity and pH. The Radiometer consists of the conductivity probe that determines the capability of a liquid mixture to measure the rate of flow of electrical charge between two conductors. In a liquid the current movement is through ion conveyance. Therefore, conductivity is directly proportional to ion concentration in the solution. This current is converted into voltage. Electrical conductivity of a liquid is also affected by temperature (Portwig, 2009a)

3.4.4 UV-VISIBLE SPECTROPHOTOMETER

UV-Vis spectrometry is a simple, fast and low-cost method to analyse the ratio of solute of a component of interest in a solution. The light wavelength varies between 180 and 1 100 nm travel through a liquid mixture in a cuvette. The blend in the cuvette absorbs this light beam. Each molecule has a specific wave length at which it absorbs maximum light. This absorption characteristic forms the basis for absorbance spectroscopy (Posudin, 2014). The wave length is set at the suitable value for maximum absorbance for as molecule in question. The light absorbed is directly proportional to the concentration of the molecule of interest. The quantity of the molecule is determined with the use of a standard curve. Hence it is important to ensure that the light shone through the cuvette path passes through the sample (Figure 3-8). This technique is however prone to interference by suspended particles and highly turbid solutions.

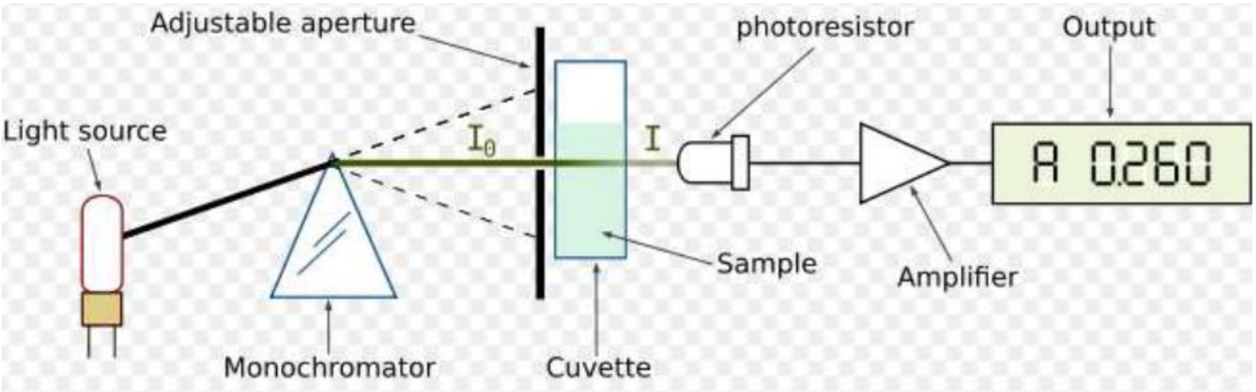

Figure 3-8: Components arrangement in UV/VIS spectroscopy (Source: Wintermans & de Mots, 1965)

3.5 CHEMICALS/REAGENTS

Mercury chloride ($HgCl_2$) is used as a preservative for inorganic samples (PO_4, TON, NH_4-N) which are not analysed within two weeks. A list of reagents used for different parameter determination is given in Table 3-2.

Table 3-2: List of reagents used and concentration range

Parameter	Reagents/Chemicals	Range
Ammonium-N	HNO_3 (Nitric acid), $C_7H_5O_3Na$(reagent 1) NaOH, $Cl_2Na(NCO)_3.2H_2O$	0.050 – 2.0 mg/L
Conductivity	NaCl, EDTA, Conductivity standard,	0.1 – 2000.0 mS/m
Chlorides	Hg $(SCN)_2$, Fe (NO_3), HNO_3 NaCl.	0.09 – 300 mg/l
pH	KCl, EDTA, Buffers	2.0 – 12.0
Nitrite + Nitrate	$NaNO_2$, H_3PO_4 , $HgCl_2$, $C_{12}H_{16}Cl_2N_2$, KNO_3 , $C_6H_8N_2O_2S$	0.025 – 2.00 mg/l

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Parameter	Reagents/Chemicals	Range
Phosphate	$K(SbO)C_4H_4O_6.1/2H_2O$, $(NH_4)_6Mo_7O_{24}.4H_2O$, H_2SO_4, $C_6H_8O_6$.	0.010 – 0.500 mg/l
Sulphate	$BaCl_2.2H_2O$, HCl, NaCl, Gelatin, $NaSO_4$	3.0 – 240 mg/l
Sodium	NaCl, EDTA.	4.0 – 200 mg/l

3.6 ANALYTICAL METHODS

The sample analyses were performed in the Department of Water and Sanitation (DWS) national laboratory Research Quality Information Services (RQIS) and parameters that were analysed include: pH, Conductivity, TON, Ammonia, O- phosphate, Chlorides, Sulphates, Sodium, Chlorophyll a, *E. coli* and COD. These parameters will be discussed below:

3.6.1 PH

The pH provides information regarding acid or base properties of water sample by measuring the H^+ anions in a solution (DWAF, 1992; Portwig, 2009). The Automated instrument used was Radiometer TTT85 Titrate pH meter (Fig. 3-9). The pH is susceptible to variation prior to analysis in the laboratory and, hence preferably should be measured *in situ.* However, this was not possible in this study because the DWS laboratory instrument was too large, delicate and requires electricity. Furthermore, the organisation has challenges with management of field instruments.

The pH 4, 7 and 10 were used to calibrate the meter at 25 ˚C. The sensitivity reading was kept between 97 and 103 %.

Figure 3-9: Radiometer Instrument (Source: Author)

3.6.2 CONDUCTIVITY

Automated instrument for analysis is Radiometer Conductivity Meter model CDM83 (DWAF, 1992; Portwig, 2009, EPA, 2001).Conductivity calibrations for the cell constant was between 0.95 to 1.1 µS/cm. A deviation of 4.0 mS/m was allowed when a newly prepared EC validation standard of 101.15 was tested. TDS/EC ratio was around 0.64 (Nkambule, 2016).

3.6.3 TOTAL OXIDIZED NITROGEN (TON)

In this method hydrazine is used as a reducing agent to convert nitrate to nitrite under basic settings. Pink azo-dye was formed after chemical reaction of nitrite ions with sulphanimide and N-1-naphthylenediamine, dihydrochloride under low pH settings. The absorbance of the solution was measured using Aquakem 250 instrument with wavelength set at 540 nm. Total Oxidized Nitrogen (TON) concentration was determined using a calibration curve (Aquakem Labmedics, 2006). The calibration standards that formed a straight line with regression of $r^2 = 0.995$ or better were accepted. For QC=1 the range between 0.858 and 1.143 was accepted otherwise the calibration was rejected and reanalysis done.

3.6.4 AMMONIA

Aquakem 250 instrument was used for analysis of ammonia. For this method the ammonia reacted with hypochlorite ions to produce monochloramine which further reacted with salicylate and sodium nitroprusside. A blue compound formed at around pH 12.6 and absorbance at 660 nm is measured spectrophotometrically using Aquakem 250 (Aquakem Labmedics, 2006; ALS, 2016). The calibration standards must form linear graph with regression r^2 = 0.995 or more acceptable and QC is within a limit.

3.6.5 ORTHO PHOSPHATE

Aquakem 250 instrument was used for orthophosphate analysis. The reaction of orthophosphate with ammonium molybdate and antimony potassium tartrate which acted as catalyst under acidic conditions resulted to formation of 12-molybdatephosphoric complex. The compound was reacted with ascorbic acid to give a blue colour heteropoly complex. The absorbance of the complex was measured at 880 nm (Aquakem Labmedics, 2006; ALS, 2016). Orthophosphate concentration was read off a calibration curve, r^2 = 0.995.

3.6.6 CHLORIDES

The Gallery instrument was used for samples analysis. Chloride reacts with Hg $(SCN)_2$ to form a soluble covalent compound. The free thiocyanate anions react with iron (III) nitrate at low pH to produce a reddish-brown iron (III) thiocyanate compoundwhose absorbance was measured at 480 nm (Aquakem Labmedics, 2006; ALS, 2016). The concentration in the water samples was read off a standard curve r^2 = 0.995.

3.6.7 SULPHATE

Sulphate ion was precipitated in a strongly acid medium with barium chloride. The resulting turbidity is measured with Gallery instrument at 405 nm. Concentration was read off from an appropriate standard curve with r^2 = 0.995 (Aquakem Labmedics, 2006; ALS, 2016).

3.6.8 SODIUM

GBC Savanta Atomic Absorption Spectrometer (AAS; Figure 3-10) instrument was used for Sodium analysis. The instrument and technique are appropriate for analysis of Na in dam, river, wastewater and water for domestic purpose (GBC Savanta, 1996; Skoog, West, Holler& Crouch, 2004). The wavelength used was set at 330.2 nm and the lamp current at 5.0 mA. The fuel and oxidant used were acetylene and air, respectively, with temperatures range of 2100 – 2400 ^{o}C. The common light source for the AAS is a hollow cathode lamp (Tissue, 2013; Lorris, 2018).The calibration standards formed a linear graph with r^2 = 0.995 and QC within a limit.

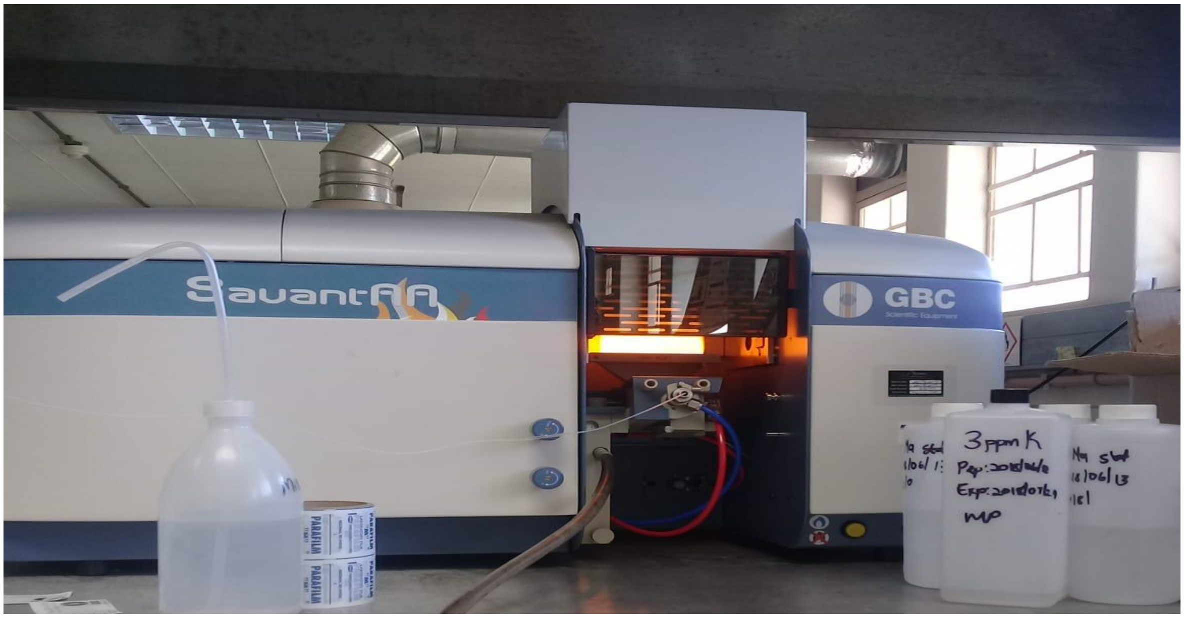

Figure 3-10: GBC Savanta Atomic Absorption Spectrometer (Source: Author)

3.6.9 CHLOROPHYL A

GBC – UV/VIS spectrophotometer (Figure 3-12) was used in the determination of chlorophyll a in the water samples. Water sample filtration was performed within 24 hours of sampling when kept between two and eight degrees Celcius (Portwig, 2004). The volume of sample filtered depended on the visual concentration of planktonic material. For samples that had visibly high algal concentration, between 100 and 500 ml were filtered. One litre was filtered for clearer samples. The volumes were taken into account in the calculations of the final Chl a concentration. Acidification of a sample and aliquot after sample extraction was done. The extract was placed on the centrifuge tube at 4 000 rpm for around ten minutes. The analysis was performed within 30 minutes after centrifugation. The amount of chlorophyll a present in the aliquot was analysed by measuring the absorbance at 665. nm and 750 nm (Wintermans & de Mots, 1965).

Figure 3-11: GBC-UV/VIS instrument for Chlorophyll analysis. Source: (Author).

3.6.10 *ESCHERICHIA COLI*

Membrane filtration technique was used for *E. coli* counts. Water samples were filtered through a 0.22 µm membrane. The membranes where plated on mFC media(with 4-methylumbelliferyl-beta-d-glucuronide [MUG]) – a selective and differential media and incubated for 24 hours at 44.5 ± 0.5 ˚C. *Escherichia coli* colonies exhibited a blue colour on this media. Therefore, all blue colonies were enumerated (Cowan & Steel, 1965; Olorode *et al*., 2015).

3.6.11 CHEMICAL OXYGEN DEMAND (COD)

COD analysis was based on the measurement of electron donor capacity of the organic material in which the electron acceptor is chromium-VI. This was achieved by oxidising the organic material with strong oxidant. COD is measured in terms of colour change when orange potassium dichromate was reduced to green Chromium (Cr) (III) by digestion of water sample in a mixture of sulphuric acid, potassium dichromate, silver (I) sulphate and mercury (II) sulphate. Samples are analysed by UV-Visible Spectrophotometer at 445 nm (DWAF, 1992).

The open reflux method 5220 B was used to determine COD in the samples. The first step was mixing by reflux method where 50ml was transferred by using a pipette into the flask. After weighing, one gram of Mercury (ll) sulphate was transferred into the flask. A few crystal beads were added before 50 ml of H_2SO_4 sulphuric acid was gradually added to dissolve Mercury (ll) sulphate. The blend was chilled as it was mixed to circumvent losing volatile constituents. The mass of 0.02084 mg $K_2Cr_2O_7$ was added to a 500 ml volumetric flask. The 25 ml $K_2Cr_2O_7$ solution was then pipetted to a flask and the flask was positioned to the condenser and cooling water turned on. A 70 ml concentrated H_2SO_4 was added while shaking and blending and was sustained for two hours. Colour change was observed when orange potassium dichromate was reduced to green Cr (III) after digestion. After cooling at room temperature excess of potassium dichromate was titrated. Using blank and deionised water including all reagents except the sample, the same procedure was followed. The data obtained was entered in a computer for COD calculations (APHA, 2005).

3.7 STATISTICAL ANALYSES

Data gathered was summarised by using tables and graphs methods. A student t-test was used to test for significance ($p = 0.05$) difference among sites 1, 2, 3 and 4 mean over six years for the pH, TON, Ammonium, Phosphate, EC, Chlorides, Sulphate, Sodium and *E. coli*.

3.8 RESEARCH QUALITY

The degree to which the instrument accurately measure what is projected to measure in a quantitative study is defined as validity (Leedy & Ormrod, 2016). Analytical methods were validated using standards prepared from ISO 17025 certified chemicals (SANS17025, 2005). Validation of a method established by systematic laboratory analysis that the technique is fit-for-purpose, i.e. its performance characteristics are capable of generating results in line with the needs of the analytical problem as well as the assessment of uncertainty for a particular method (Portwig, 2009).

The validity of data collected was tested by means of quality control standards (samples of known value). A validation standard (samples of known parameter concentration) or as referred to as a check sample was tested after every 9^{th} sample (Figures 3-12 and 3-13). The standards were within the allowed tolerances as described in the method of that particular analysis (Portwig, 2009). The tolerances were determined from three times standard deviations calculations. Depending on the results, the analyst accepted the measurements or reanalyzed the samples where quality control was not within acceptable value.

Microbiological quality control was performed by verifying method of enumeration using a known positive and negative control culture. Aseptic techniques for handling microbiological samples were employed to minimize contamination. The tests were accepted if positive control plates formed clusters of interest and negative control plates formed no progress or different clusters (Portwig, 2009). The laboratory methods were accredited according to ISO 17025 and SANAS requirements. The companies that implement calibrations and validations on instruments and equipment were approved by SANAS (SANS17025, 2015).

Reliability is the degree to which an instrument dependably has the matching outcomes if it is done in the similar condition on repetitive instances in a numerical research (Leedy & Ormrod, 2016; EPA, 2017). The steps which were taken to confirm reliability of results include sample replications and repetitions. The duplicate samples were verified at a minimum of single trial per test run to conclude on the test precision (Portwig, 2009).Control charts were used to check for negative or positive bias in the instrument (Figure 3-13). An increasing trend or decreasing trend as bias would be prominent if seven points validation standards on seven consecutive days are above or below the true value.

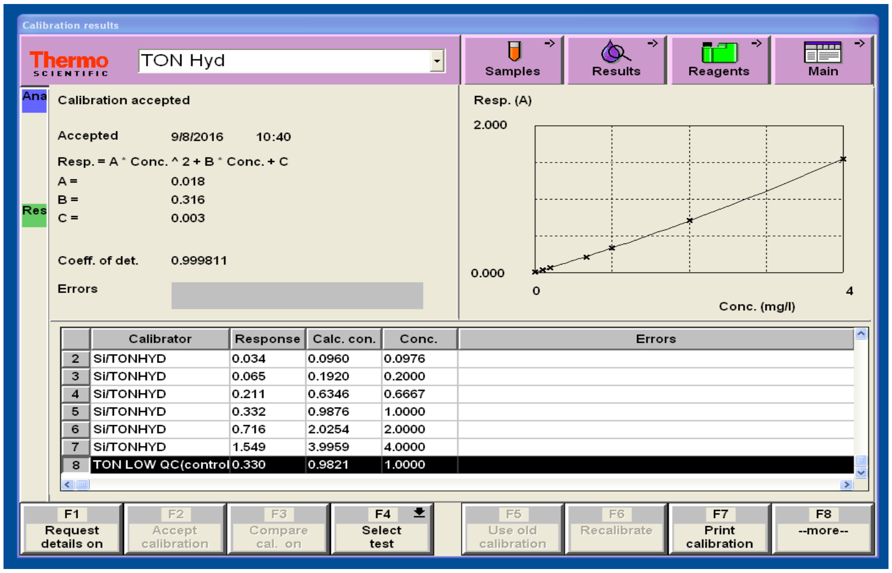

Figure 3-12: QC and Calibration graph for TON (Source: Aquakem 200 print screen, 8 Sept 2017)

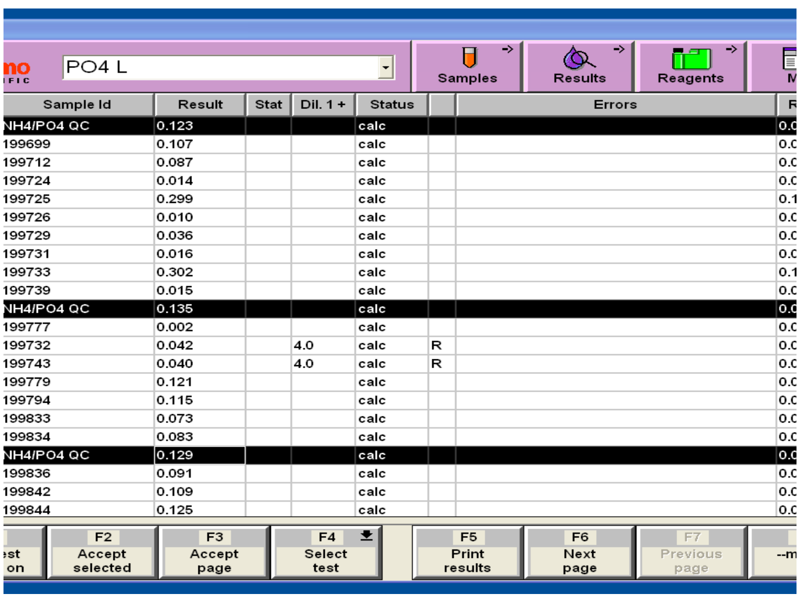

Figure 3-13: QC standards after every 9th sample (Source: Aqua 200 print screen, 8 December 2017)

A Qlikview control chart is a statistical analysis used to monitor changes over time. Control chart has upper line for upper control limit (UL) and lower line for lower control limit (LL). Figure 3-15, below, shows sulphate analyses on different days, no value is outside UL or LL. This shows that the instrument was accurate, hence results were reliable (Portwig, 2009).

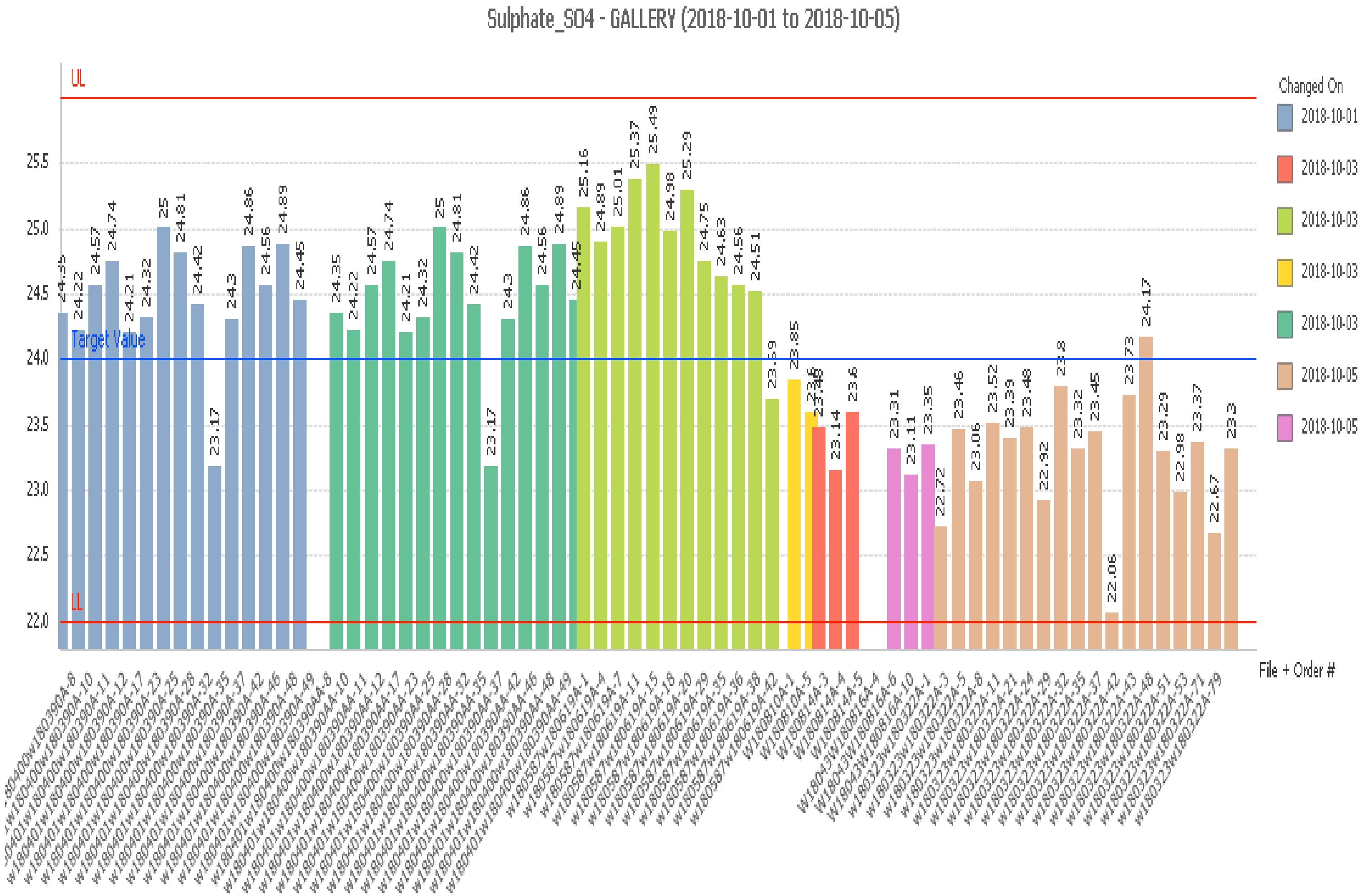

Figure 3-14: Qlikview control chart for SO4 $^{2-}$ (Print screen trends for validation standards)

4 CHAPTER 4: RESULTS AND DISCUSSION

The average values from four selected sites were used for comparative evaluation of the impacts of the two waste waterworks on water quality of Roodeplaat Dam from January 2012 to December 2017. The monthly average values from the four selected sites were used to compare seasonal variation of parameters from January 2012 to December 2017. For each parameter, results are presented at annual and monthly levels. All significant testing was at $P = 0.05$, unless stated otherwise.

4.1 PH

There was a significantly high ($P < 0.05$) pH in Roodeplaat dam for both sites 3 and 4 that correspond to discharge points of Baviaanspoort and Zeekoegat, respectively over the six years (Figure 4.1). However, the average annual pH values at all sites were within the 5.5 – 9.5 range recommended by the regulatory authority for recreational use (DWAF, 1996).

There are other sources of pollution besides the two treatment plants mentioned. Van Ginkel *et al.*, 2000 and Hohls *et al*., 2002 pointed out that pollution of Roodeplaat dam can be attributed to both point and non-point sources. However, 55% of the water in Roodeplaat Dam comes from the two waste water treatment works, so they contribute significantly in polluting the dam. The dam is known to be highly polluted. Thus the effluent is contributing to water quality deterioration (Harding, 2008).

Figure 4-1: Annual pH values for the sampling sites between 2012 and 2017

The pH at discharge points was within the DWA wastewater effluent limit and also at the dam was within DWA ecosystem aquatic standards (Figure 4-2). There was no significant difference within each site over the twelve months (Figure 4-2). Thus it is reasonable to average the annual results without loss of detail. Lomberg, (2010) also observed that the pH around Roodeplaat Dam catchment was not of a concern as water showed neutral to slightly alkalinity. Dissolved salts that enter the dam and non-point sources along Hartebees spruit may have contributed towards alkalinity levels exhibited at sites 3 and 4 at the dam entrance.

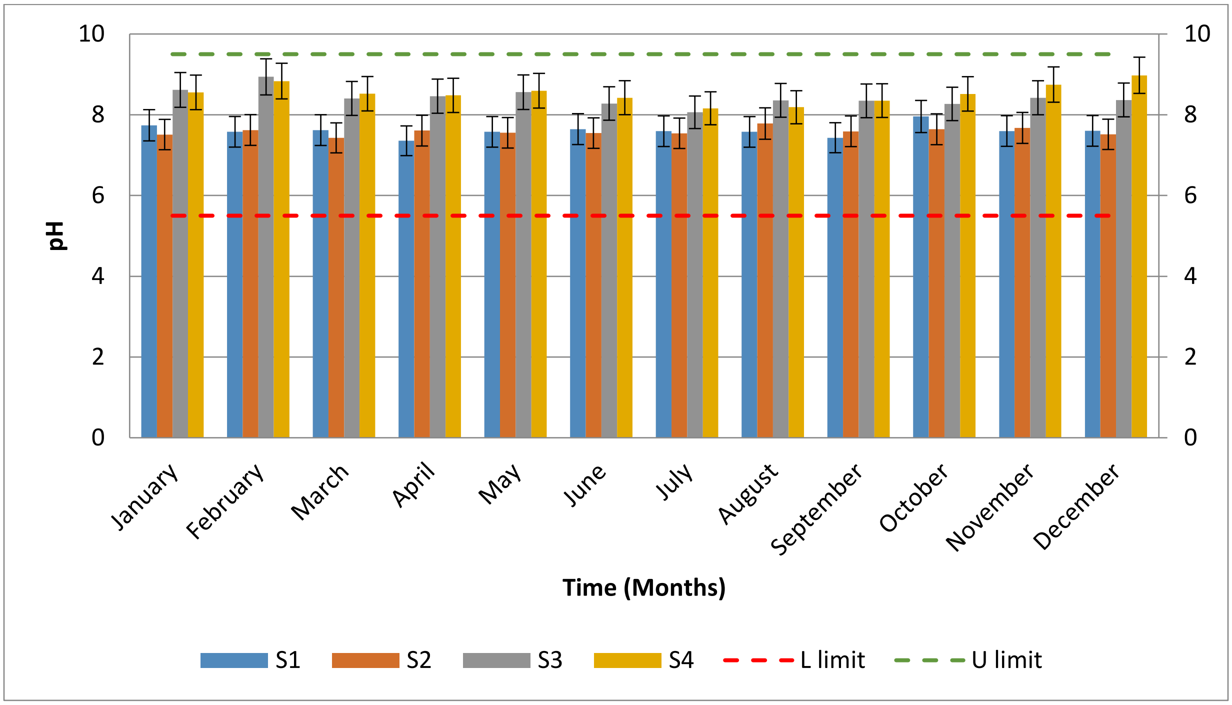

Figure 4-2: Average monthly pH for four sampling sites for six years

4.2 ELECTRICAL CONDUCTIVITY (EC).

Generally the EC from the two treatment plants is higher than that of the respective entry points to Roodeplaat dam (Figure 4-3). Baviaanspoort WWTW had consistently the highest annual average conductivity compared to Zeekoegat WWTW ranging from 62.02 to 93.14 (Figure 4-3). Although the EC conductivity was the highest, only in 2013 and 2016 was above the maximum allowable limit (70 mS/m) by the regulator. The differences in the EC between Baviaanspoort and Zeekoegat can be attributed to the varying efficiencies of the two plants. Zeekoegat has been consistently scoring better compliance points on the Green Drop system than Baviaanspoort from 2010 to 2015 reports (CoT, 2017). Alternatively, the influent composition for the two plants can account for the observed differences in conductivity.

The reduction of EC amongst the dam sites (sites 3 and 4) is expected as the large water body should dilute the contaminants. Dilution is one of the ways pollution can be reduced (Lomberg, 2010; Walakira, 2011).The ideal EC for irrigation is <40 mS/m and the average for all the points were above the limit (DWAF, 1996a). The $t_{crit} > t_{cal}$ (Appendix D) at p = 0.05, shows that the difference is insignificant; therefore there were no major changes over the past six years for EC. Baviaanspoort WWTW capacity is at 60 Ml/day compared to Zeekoegat WWTW which is at 30 Ml/day. The City of Tshwane (CoT) WWTW Master plan put Baviaanspoort WWTW at 312 Ml/d whereas Zeekoegat at 160 Ml/d (CoT, 2017). This shows that the Baviaanspoort WWTW is handling more influent than Zeekoegat WWTW, which maybe one of the reasons why effluent from the plant is consistently non-compliant. The Baviaanspoort WWTW is receiving more water than operational capacity and it takes time to refurbish each of its four modules (MAP Forum, 2019). Baviaanspoort WWTW, Klipgat WWTW and Rooiwal WWTW have been identified as the main critical WWTW that need urgent attention since 2011 but little or nothing has been done (MAP Forum, 2019).

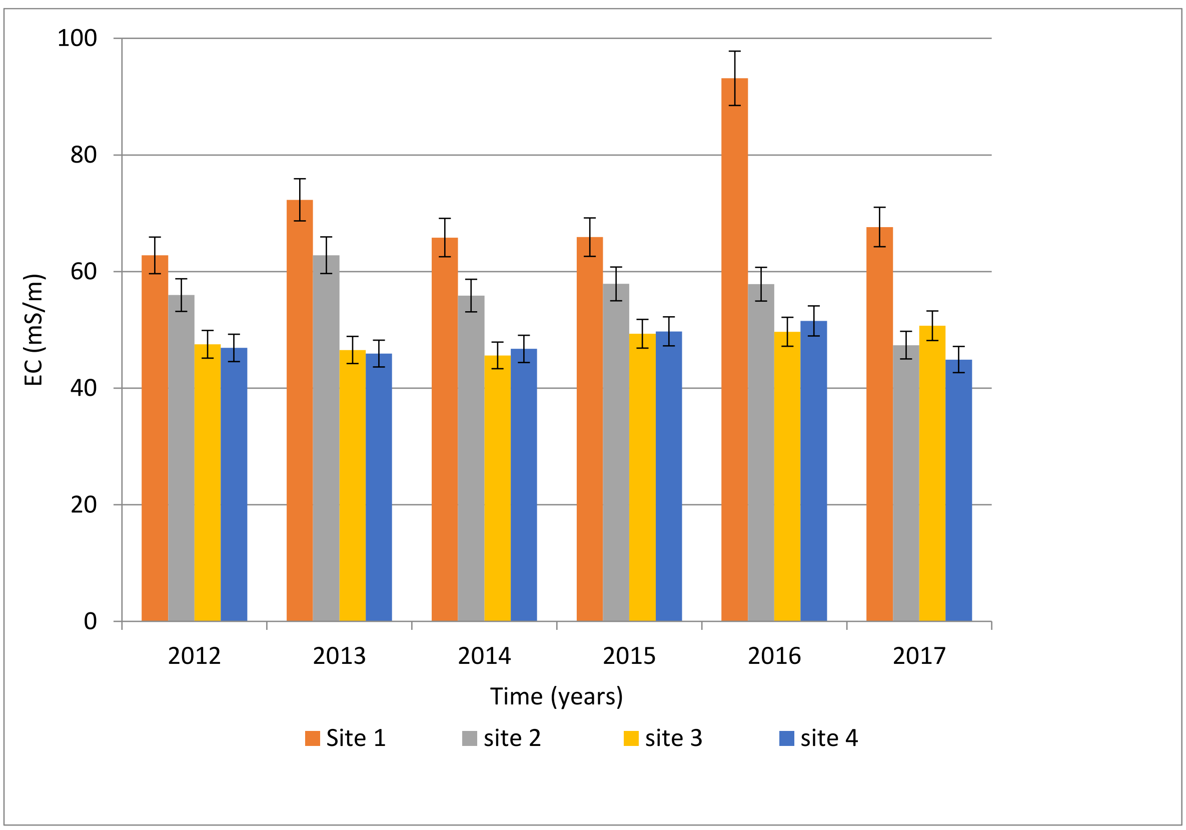

Figure 4-3: Average annual EC values for four sampling sites over six years

The monthly average electrical conductivity at the discharge sites was within the DWA wastewater effluent limit of 70 mS/m for Zeekoegat (site 2). For Baviaanspoort (site 1) the monthly averages were above the limit from June to November, February and April. The highest concentration for site 1 was 103 mS/m in September, point 2 is 67.72 in June, point 3 is 54.6 in August and point 4 is 53.7 in October (Figure 4-4). The points on the dam show high average between August and December which falls under spring and summer season. The high concentration levels may be due to inability to handle influent during that period or the operational problems. The recommended EC for irrigation is <40 mS/m and the average for all the points were also above the limit (Figure 4-4). Baviaanspoort WWTW water quality has prompted South African Human Rights Commission (SAHRC) to investigate the quality of water around Roodeplaat dam. Baviaanspoort WWTW was identified as one of the over capacitated WWTW and discharge effluent that is not in compliance with the license conditions (MAP Forum, 2019). Hardened surfaces due to informal settlement allow for greater levels of surface runoff and subsequently huge introduction of contaminants into the system.

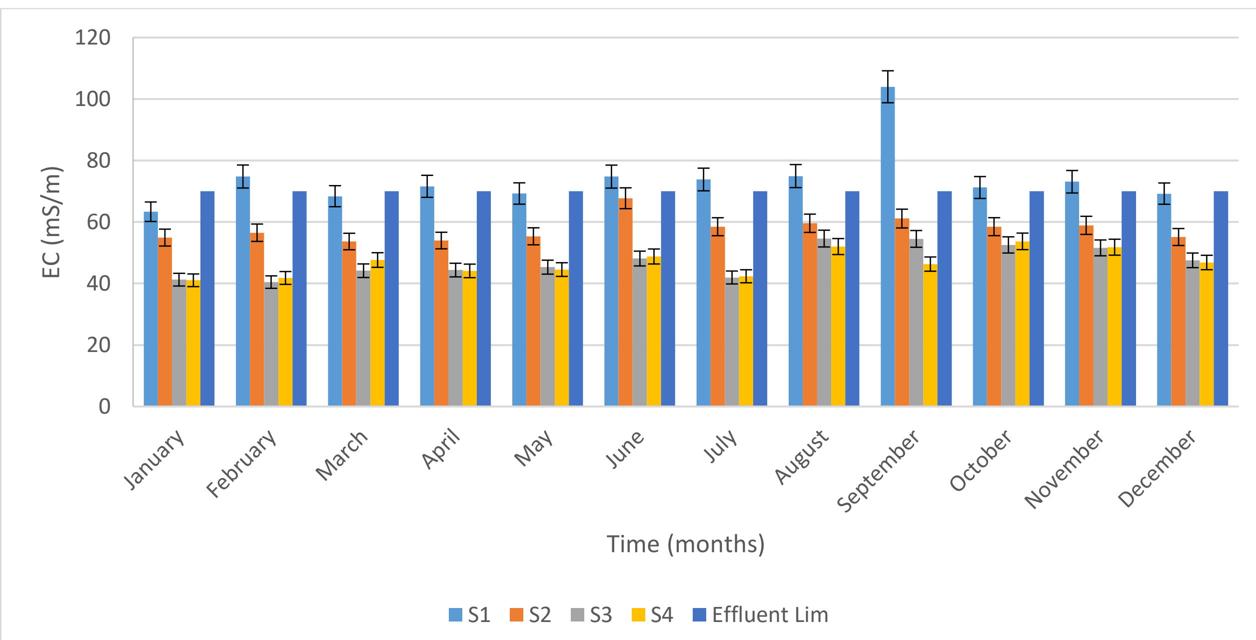

Figure 4-4: Average monthly EC for four sites over six years

4.3 NITRATES + NITRITES (TON)

The annual TON from the two treatment plants was higher than that of the respective entry points to Roodeplaat dam (Figure 4-5). Baviaanspoort (Site 1) consistently had the highest annual average TON ranging from 10.49 to 27.82 (Figure 4-5).The elevated values for site 3 and site 4 particular in 2017 may be due to non-point source around the dam. The TON recommended limits by the regulator was not available, however, some limits that exist recommend the concentration of 15 mg/L for nitrate. Site 1 parameters exceeded 15 mg/l limit. Nitrates are normally soluble in water; they cannot be removed by settling, filtration, flotation or other methods of solid-liquid separation (Henze, 2008). For ideal optimal aquatic system balance, the nitrates + nitrites must not exceed 0.5 mg/l. (DWAF, 1996).The $t_{crit} < t_{cal}$ (Appendix D) at $p = 0.05$, shows that the difference was significant, therefore there were major changes over the past six years for TON. These changes were across all four sites (Figure 4-5). For points on the dam ($t_{crit} < t_{cal}$ at $p = 0.05$) it was observed that the pollution is getting worse inside the dam compared to six years ago, with 2017 quantities almost double those of 2012. There was annual increment of TON from site 1 which may indicate an increasing inability to remove nitrates or an overload of nitrates in influent at Baviaanspoort WWTW. The latter could have been ascertained had the influent been characterized. However, resource limitations did not permit. The study by Edokpay, (2016) established that the nitrates load into the water bodies may cause a risk to poor water quality and also results in eutrophication.

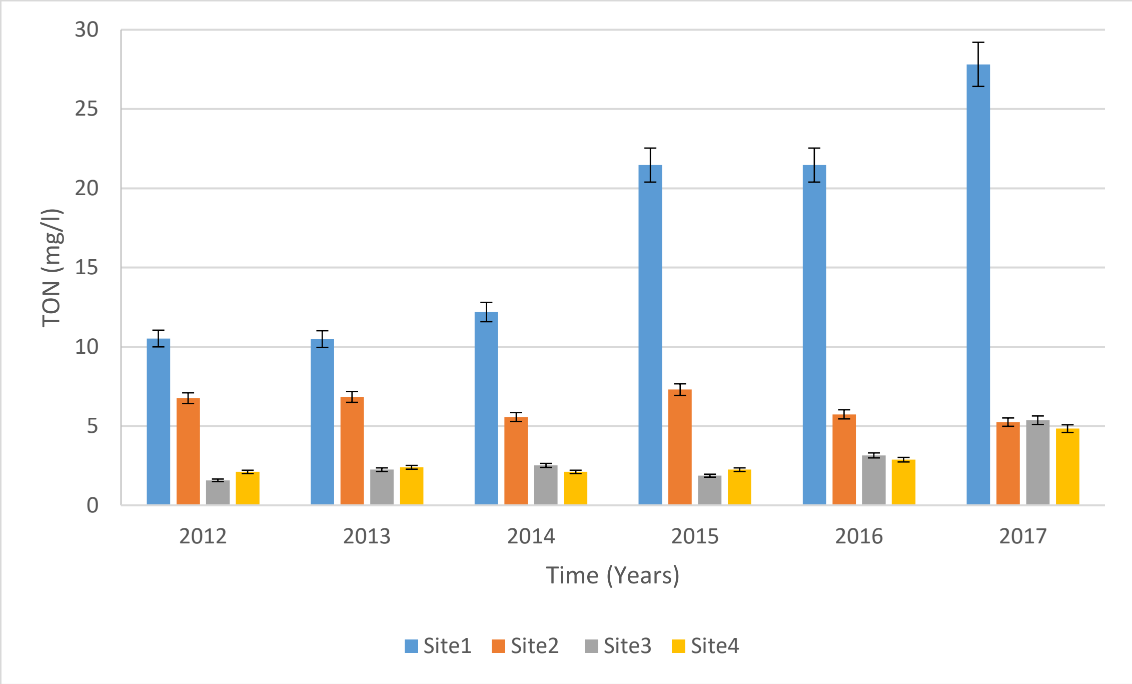

Figure 4-5: Average annual TON for four sites over six years

The highest monthly concentrations for Baviaanspoort was 26.6 mg/l in November; Zeekoegat was 7.03 mg/l in August; site 3 was 4.5 mg/l in September and site 4 was 4.2 mg/lin September (Figure 4-6). The points on the dam show high average between August and November. TON wastewater limit of 15 mg/l at site 1 was exceeded from April onwards. For ideal operational of aquatic system the Nitrates + nitrites inside Roodeplaat Dam must not exceed 0.5 mg/l. The levels around 4 mg/l for TON inside the dam promotes algal bloom, irritating growth of aquatic plants and species that are harmful to humans and wildlife (DWAF, 1996a; Griffin, 2017; Angelakis *et al.,* 2018).

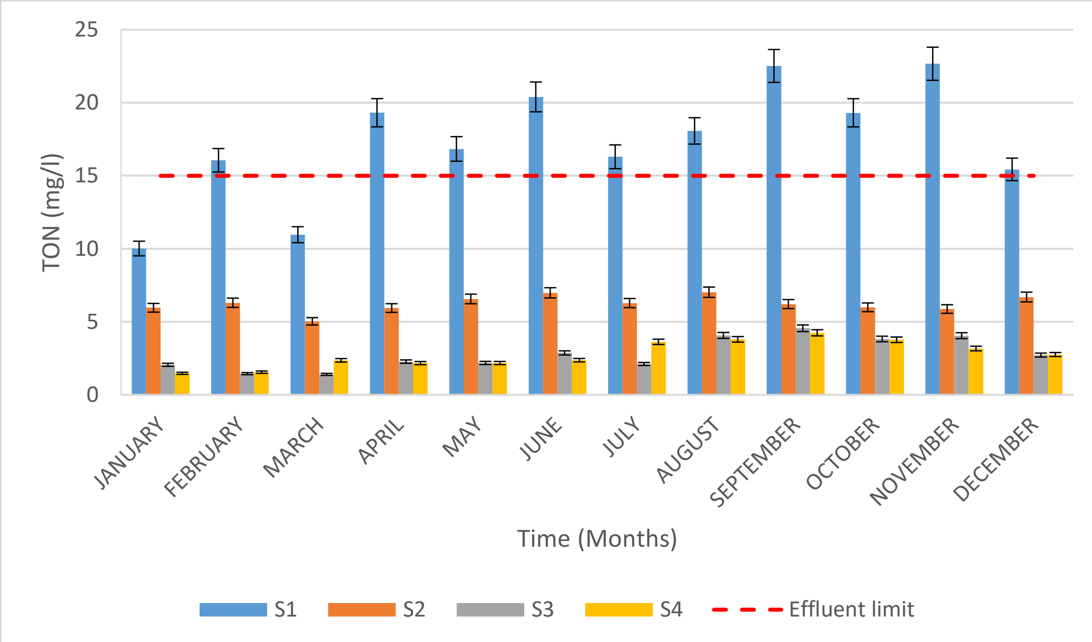

Figure 4-6: Average monthly TON for four sites from 2012 to 2017

4.4 AMMONIA

The Target Water Quality Guidelines Ranges (TWQGR) for Ammonia with respect to Aquatic Ecosystems is 0.007 mg/l. The results for all sites exceeded the TWQGR for Aquatic Ecosystems. Generally the ammonia from the two treatment plants is higher than that of the respective entry points to Roodeplaat Dam (Figure 4-7). The patterns for Baviaanspoort (site 4) ranged from 1.058 to 11.265 mg/l. Interestingly, in 2012 and 2016 ammonial levels in the dam were higher than those at effluent discharge points (site 1 and 2; Figure 4-7). This points to the fact that around Roodeplaat dam there are also non-point sources, like farming activities which also contribute to the pollution of the dam. Similar results where sources of pollution besides WWTW were reported by Munyati (2015). The maximum stipulated ammonia in WWTW effluent is 3mg/l (DWAF, 1996). Baviaanspoort (site 1); was a culprit in breaching the regulatory guidelines (Figure 4-7) (DWAF, 1996). Points inside the dam that recorded more than 1.5 mg/l indicate non-compliance (SANS 241: 2015). Non-compliance was occasionally observed for both site 3 and 4. The low level of ammonia in Zeekoegat effluent (site 2) could be attributed to effective waste treatment process of nitrification and de – nitrification (Agyemang, *et al.,* 2013).

There was progressive decrease in ammonia in effluent from both plants over six years (Figure 4-7), which is commendable. However, the ammonia levels in the dam increased over the six-year period. The elevated ammonia levels in roodeplaat Dam were also reported by Silberbauer and Esterhuyse (2014). The dam water quality is therefore a cause for concern.

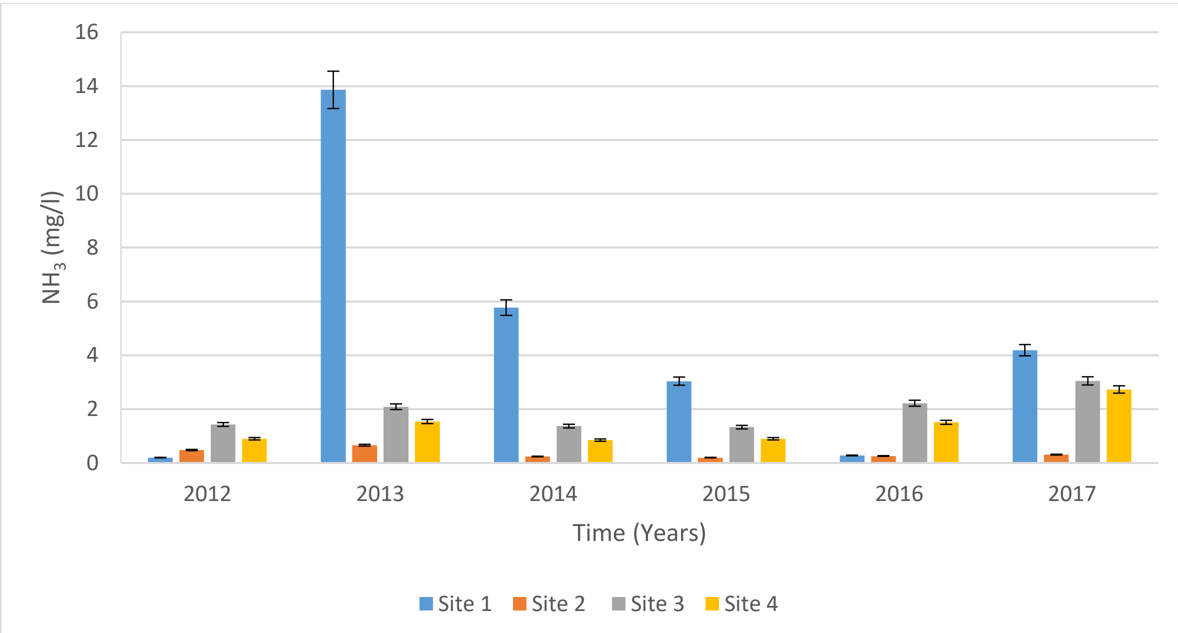

Figure 4-7: Average annual ammonia concentration for the four selected sites between 2012 and 2017

Monthly average ammonia concentrations of Baviaanspoort WWTW effluent consistently exceeded the 3 mg/l regulatory standard while the opposite was true for Zeekoegat WWTW effluent that was consistently lower than the sampling sites inside the dam (Figure 4-8). The sites on the dam showed high averages between July and December. The July and December peaks may be due to non-point source of pollution. The high ammonia at site 1 did not cause immediate spike in the dam. However, the TWQGR for ammonia like in annual results exceeded the limit for Aquatic Ecosystems (0.007 mg/l).

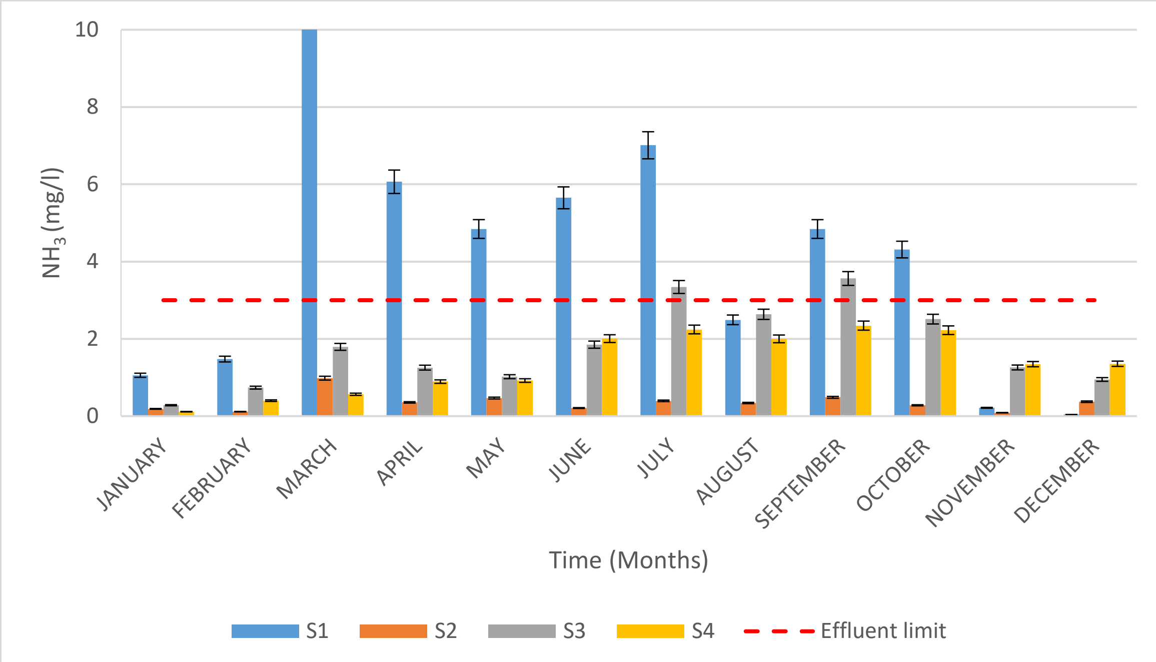

Figure 4-8: Average monthly ammonia concentration at the four sampling sites for six years

4.5 PHOSPHATES

Generally the phosphates from the two treatment plants were higher than that of the respective entry points to Roodeplaat dam (Figure 4-9). Baviaanspoort had consistently the highest mean phosphates ranging from 1.09 to 2.6 mg/l, except in 2017 where Zeekoegat WWTW annual mean was higher (Figure 4-5).The recommend limit of 1.0 mg/l for effluent was exceeded at sites 1 and 2 was exceeded in 2016 and 2017. The TWQGR for phosphates with respects to Aquatic Ecosystems is 0.005mg/l. The results for all sites were significantly higher ($p < 0.05$) than the TWQGR for Aquatic Ecosystems (DWAF, 1996). Baviaanspoort effluent had significantly higher ($P < 0.05$) phosphates than all; sampling sites from 2012 to 2016 (Figure 5-9). There was a significant increase in phosphates in Zeekoegat WWTW effluent from 2016 to 2017. The increase trend from 2016 to 2017 was also reflected on sites 3 and 4 (Figure 4-9). Therefore, there is a need to pay attention to the phosphate removal processes at Zeekoegat WWTW to curb the increase. Baviaanspoort WWTW should continue intensifying efforts to reduce the phosphates further in the effluent. Silberbauer and Esterhuyse, 2014 also observed high effluent offloading from Zeekoegat and Baviaanspoort WWTWs.

The amount of phosphate from phosphorus-based detergents released might be the cause for the unwarranted content of phosphate at both sites 1 and 2. Extreme levels of phosphate in water may resultin negative human health implications such as nausea and diarrhea (Subin and Husna, 2013). These results point to a high possibility of eutrophic processes in the Roodeplaat Dam (Van Ginkel, 2002; Griffin, 2017).

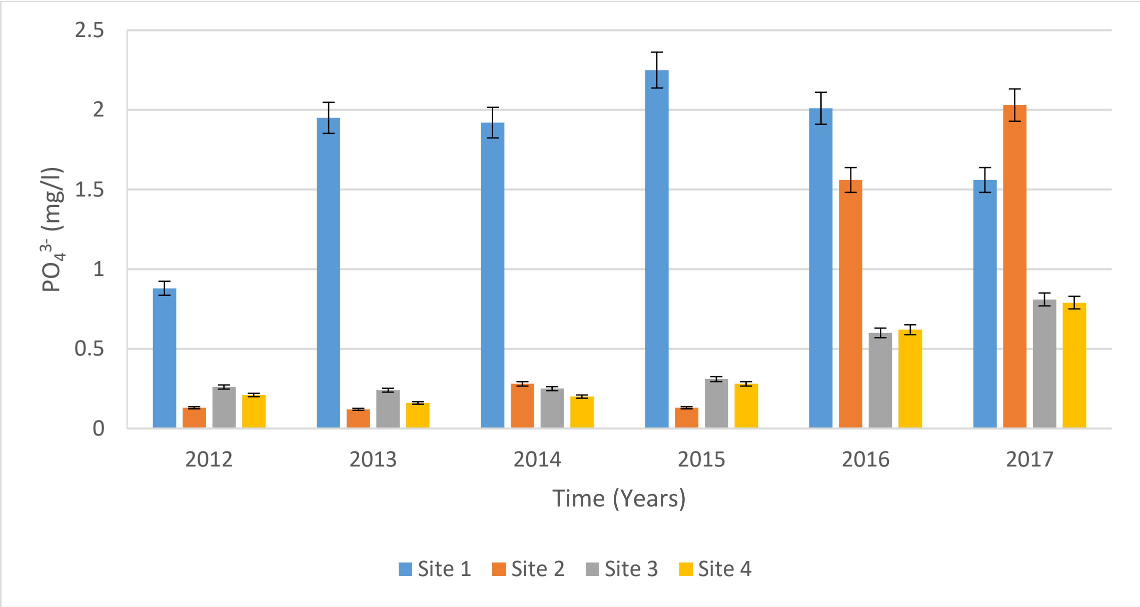

Figure 4-9: Average annual phosphate levels at four sampling sites from 2012 to 2017

Monthly phosphates average concentrations for Baviaanspoort WWTW effluent were highest between February and November, whereas Zeekoegat WWTW peaked in September and October (Figure 4-10). The sites in the dam showed high averages between August and December, the spring and summer season,respectively. Non-point sources could account for the high peaks observed in the dam Generally the variations of phosphates in WWTW effluent did not seem to rely on seasonal patterns like respective sites inside the Roodeplaat dam. The results for all sites significantly exceeded the TWQGR for Aquatic Ecosystems (DWAF, 1996) as was noted for annual averages (Figure 4-9). Elevated levels of phosphates in the Roodeplaat Dam resulted in eutrophication, which was observed by Van Ginkel and Silberbauer (2007). Lomberg (2010) also pointed out that the spikes observed from WWTW would have major repercussions on the rate of Roodeplaat dam's eutrophic status.

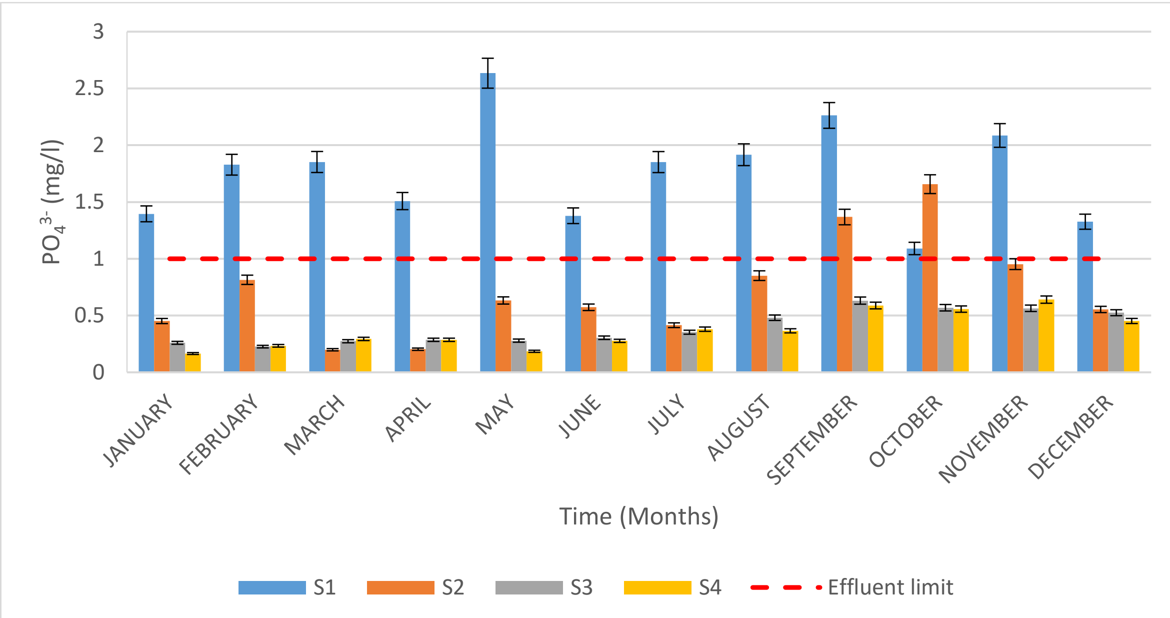

Figure 4-10: Average monthly phosphate levels for the four sites over six years

4.6 CHLORIDE

There was a significantly high ($p < 0.05$) chloride concentration for sites 1 and 2 compared to sites 3 and 4, respectively. Zeekoegat WWTW was consistently higher than Baviaanspoort WWTW ranging from 53.84 to 65.29 mg/l (Figure 4-11). The difference might be due to the increased chlorine dosing during disinfection at Zeekoegat WWTW as opposed to Baviaanspoort WWTW. Alternatively, the differences may be due to high chlorine content in the influent. The latter requires further work for confirmation. The TWQGR for chlorides with respect to Aquatic Ecosystems is 400 mg/l (DWAF, 1996a). Therefore, results for chlorides at all sites complied with the TWQGR. However, sites 1 and 2 levels were above the 50 mg/l threshold for corrosion. The $t_{crit} > t_{cal}$ (Appendix D) for Baviaanspoort WWTW shows that the difference is insignificant over the six-year span.

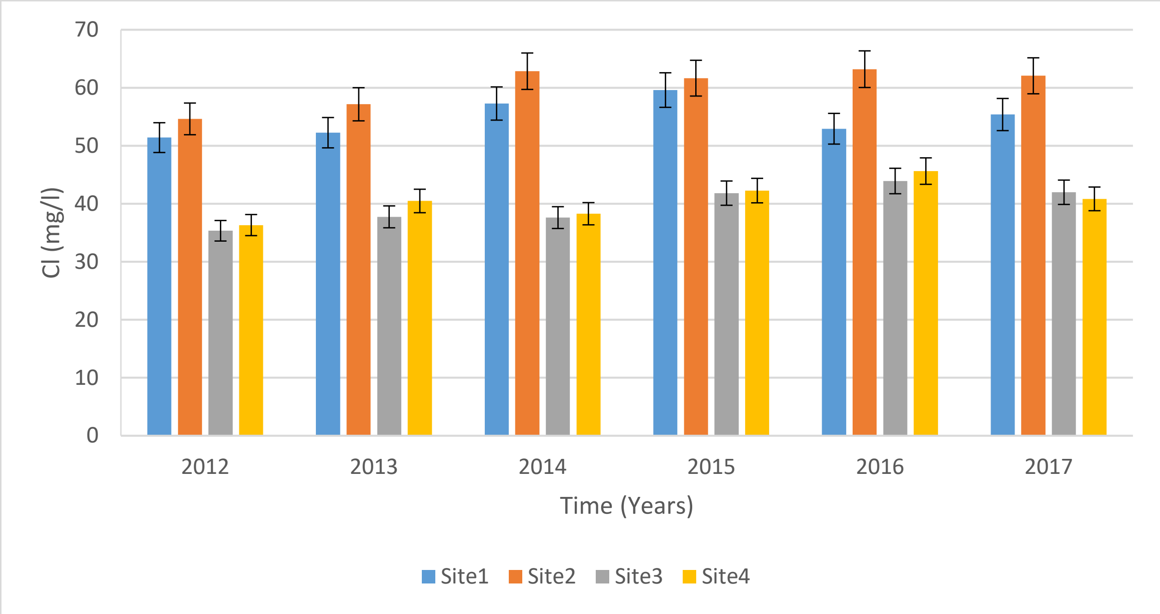

Figure 4-11: Average annual chloride concentration for the four sampling sites over six years

The highest monthly average concentration for site 1 was 60.08 mg/l in August, site 2 is 65.29 mg/l in November, site 3 was 44.9 mg/l in October and site 4 was 44.08 mg/l in November (Figure 4-12). The sites in the dam showed high averages between August and December which were spring and summer season, respectively. The chloride levels were within the limits from the regulator.

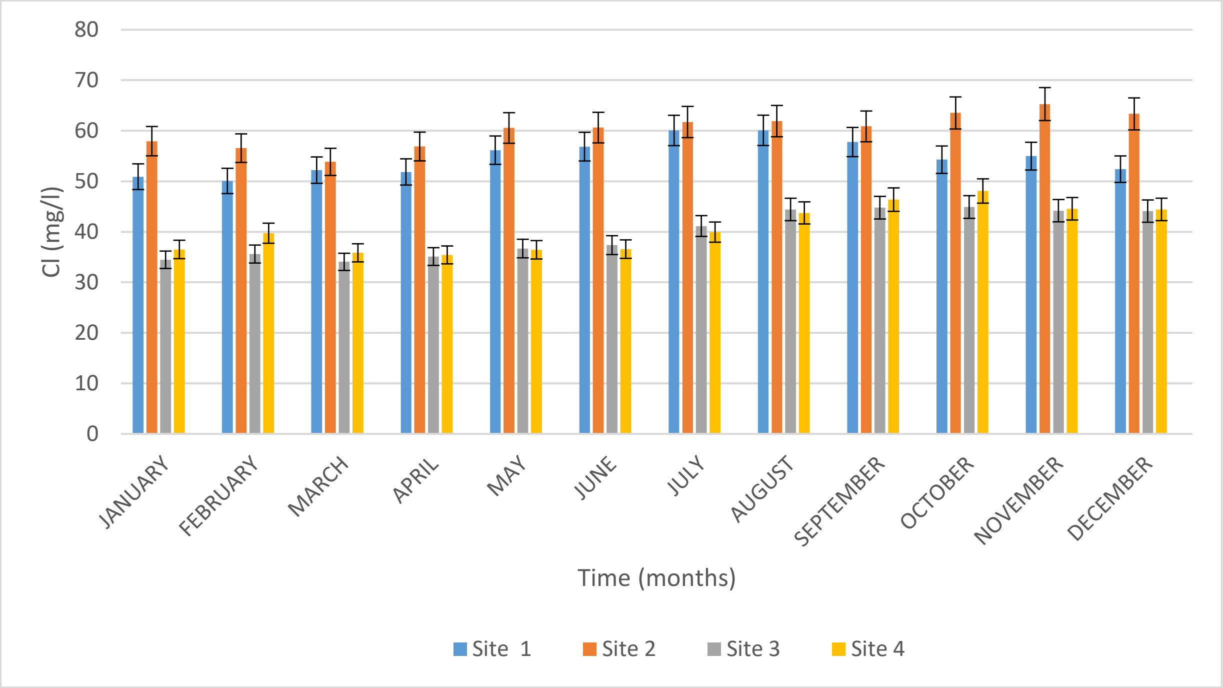

Figure 4-12: Monthly average Cl concentrations over six years for the four sampling sites

4.7 SULPHATES

Generally the sulphates from the two treatment plants was higher than that of the respective entry points to Roodeplaat Dam. Baviaanspoort was consistently higher than Zeekoegat (Figure 4-13). . Cathartic effects due to extreme high levels of sulphates in drinking water may lead to dehydration to humans (WHO, 2017). Presently there are no guidelines limits to be used to evaluate the sulphates effluent discharge effects on receiving water bodies. With regard to drinking water the acceptable sulphate levels with no adverse health effects is less than 200 mg/L (SANS: 241, 2015). Between 200-400mg/L it has a tendency of causing diarrhea in some people, as well as a slight off taste. There were no significant differences (P > 0.05; Appendix D) within each site over the six-year span. The results indicate that the level of sulphates is below the maximum (200 mg/l) for drinking water. Therefore, both plants and the water body pose low risk with respect to sulphates.

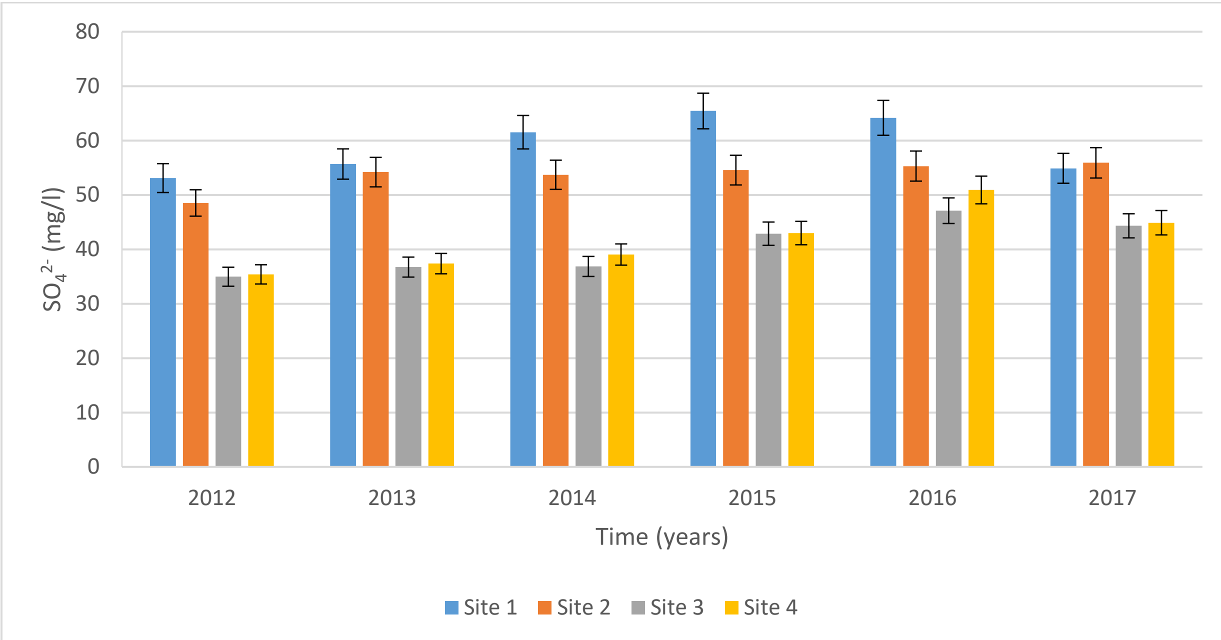

Figure 4-13: Annual average sulphate levels at sampling site from 2012 to 2017

The highest monthly average sulphate for site 1 was 68.7 mg/l in August; site 2 - 56.88 mg/l in November; site 3 - 46.87 mg/l in September; and site 4 - 45.52 mg/l in September (Figure 4-14). The sites in the dam had peak averages between August and December.

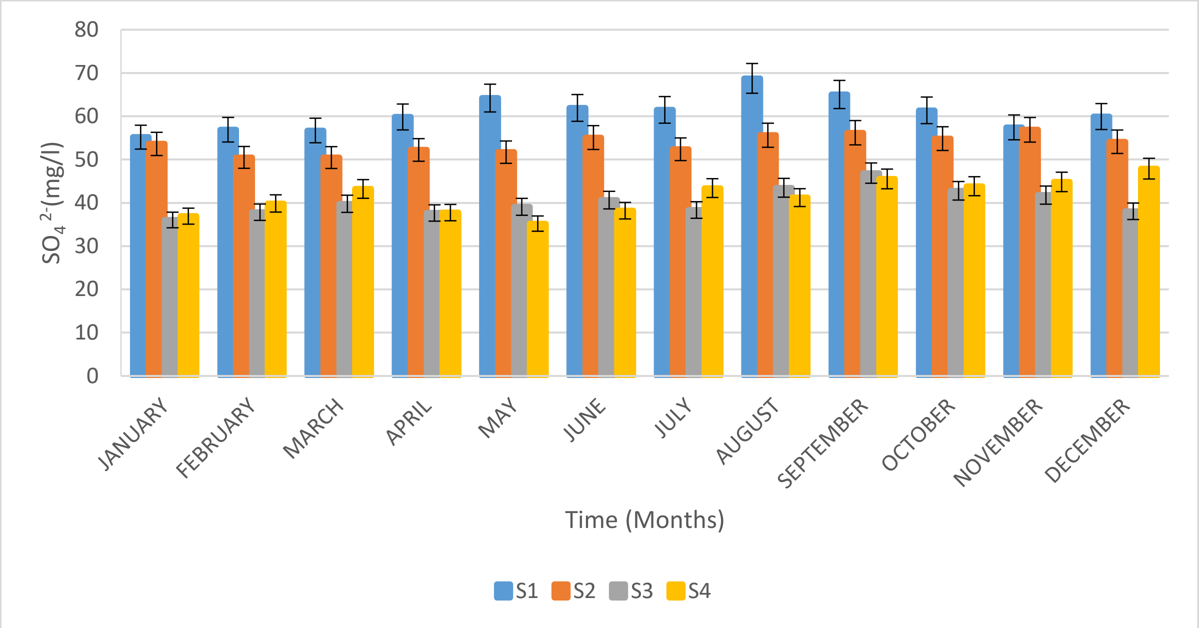

Figure 4-14: Monthly average sulphate levels at the four sampling sites from 2012 to 2017

4.8 SODIUM

The annual sodium levels from the two treatment plants were significantly ($p < 0.05$) higher than that of the respective entry points to Roodeplaat dam. Baviaanspoort WWTW average was consistently high compared to Zeekoegat WWTW except in 2015, ranging from 60.56 to 77.38 mg/l (Figure 4-15). Sodium limit is 200 mg/l (SANS: 241, 2015) and 70 mg/l for irrigation (DWAF; 1996b). Water from Baviaanspoort WWTW was occasionally above the limit for irrigation. Reducing amount of sodium salts in household detergents may help in reducing the effect of saline water to soil (Patterson, 1997). Similar to sulphate results, there were no significant changes to the sodium concentration for each site over the six-year assessment period.

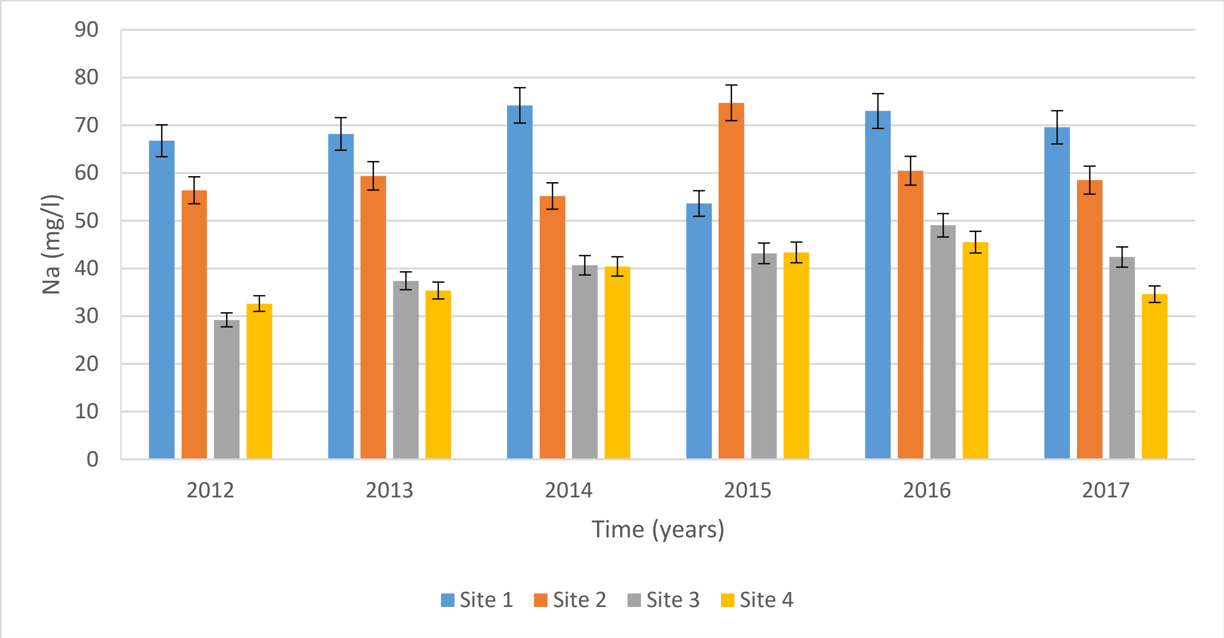

Figure 4-15: Annual average sodium concentrations at four sampling sites between 2012 and 2017

The highest monthly average sodium levels were as follows:

- site 1 - 77.38 mg/l in August;
- site 2 - 66.30 mg/l in August;
- site 3 - 47.43 mg/l in September; and
- site 4 - 47.50 mg/l in October (Figure 4-16).

The sites in the dam showed the highest average between August and December the spring and summer seasons, respectively. There was no distinct pattern for variation when points on the dam are compared to respective points for effluent.

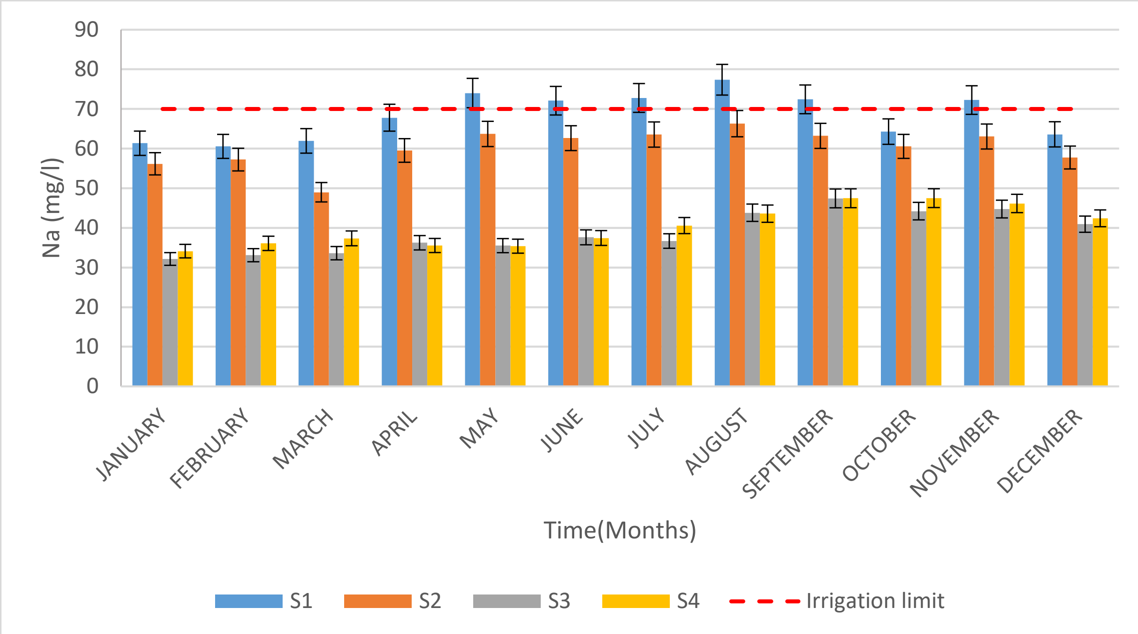

Figure 4-16: Monthly average sodium concentrations for four sites between 2012 and 2017

4.9 ESCHERICHIA COLI

There was significantly high ($p < 0.05$) annual average *E. coli* counts for sites 1 and 2 compared to sites 3 and 4, respectively (Figure 4-17). *E. coli* mean values for site 1 were consistently higher than for site 2 ranging from 2.97 x 10^4 to 2.18 x10^6. The average *E. coli* counts on site 1 exceeded the regulatory limit (1 000 CFU/100 ml) by more than ten times. Therefore this effluent is a high risk to public health and can negatively affect the quality of the Roodeplaat Dam. It is relatively comforting to note a significant decrease in *E. coli* counts in the dam. This decrease suggests death in transit. One should be cognizant of the viable but nonculturable bacteria, hence the reduction in numbers should be cautiously interpreted.

The differences in the microbial counts between the effluent from the two plants can be attributed to the diffrences in the infrastructure designs and the processes. Baviaanspoort WWTW is characterised by the absence of a division tank, the presence of an automatic ventilation system in the two natural reactors and the nonexistence of sand filtration at the end of discharge unlike Zeekoegat WWTW (Dungeni *et al*., 2010). Results from this study suggest a difference in chlorine dosage that could account for the differences in the microbial load of the effluent.

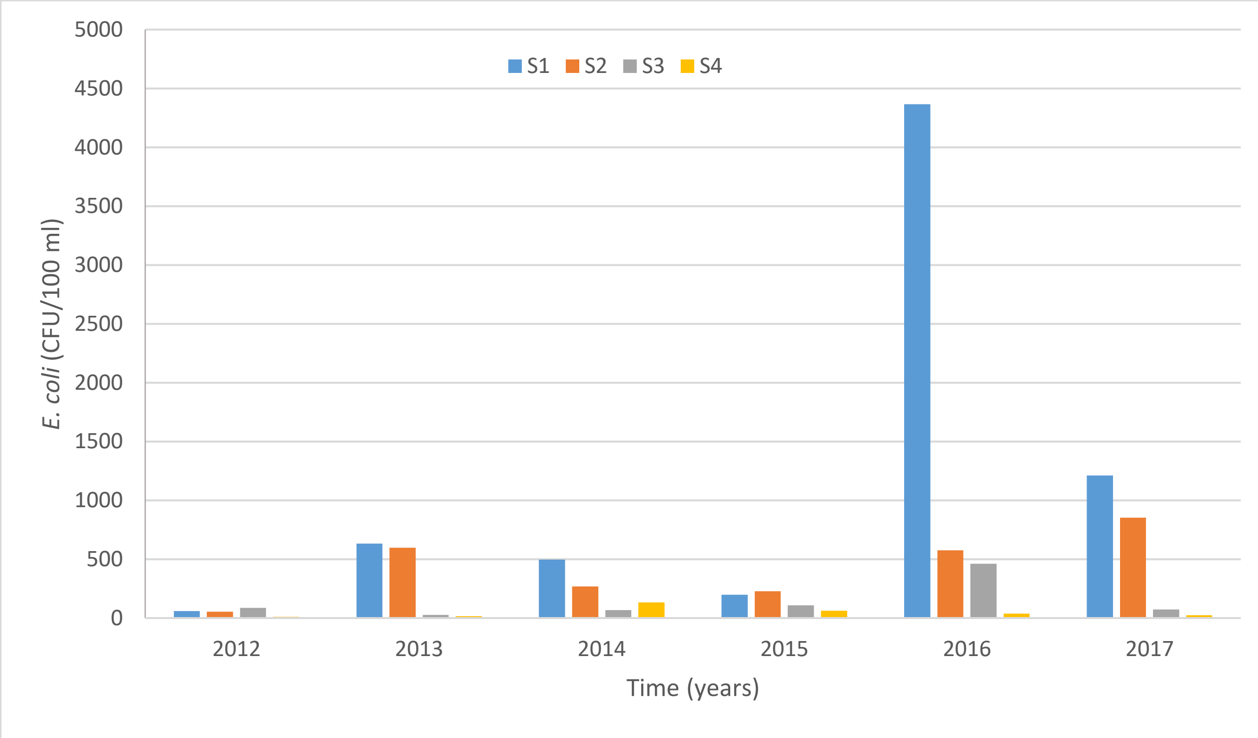

Figure 4-17: Average annual *E. coli* colony forming unit counts at the four sampling sites between 2012 and 2017

Similar to the annual results, the monthly average *E. coli* counts for Baviaanspoort WWTW (site 1) were consistently higher in all seasons compared to Zeekoegat WWTW (site 2) which were within limits except in February and September (Figure 4-18). The highest average count for site 1 was 3.5 x 10^6 in December; site 2 was 1.3 x 10^3 in February; site 3 was 6.02 x 10^2 in October; and site 4 was 2.61 x 10^2 in November. Lomberg (2010), identified poorly managed WWTW as one of the major sources of pollution in South Africa. The results corroborate observations by Hohls & Ginkel (2004) and Dungeni *et al*. (2010) regarding effluent released by Baviaanspoort WWTW that is poorer than the effluent released by Zeekoegat WWTW.

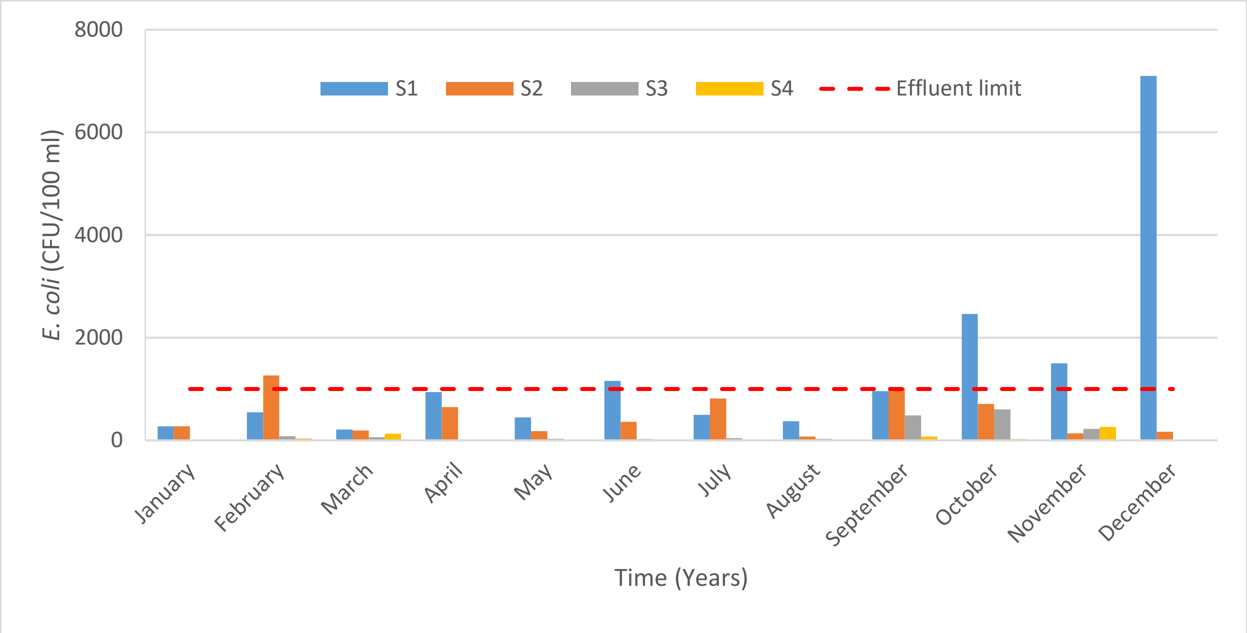

Figure 4-18: Average monthly *E. Coli* counts at four sampling sites from 2012 to 2017(site 1 results have a dilution factor of 500)

4.10 4.1.10. CHLOROPHYLL A

The annual average values were between 49.97 µg/L and 135.28 µg/L for site 3 and between 54.21 µg/L and 96.45 µg/L for site 4 (Figure 4-19). The mesotrophic status is for average between 10 to 20 µg/L and annual that is between 20 to 30 µg/L is eutrophic and more than 30 µg/L a serious hypertrophic case (Balali *et al*., 2013). The results were similar to those observed by van Ginkel *et al.,* 2001 and Balali *et al*., 2013, the occurrence of algal blooms when chlorophyll a parameter is more than 30 µg/L. Matthews and Bernard, 2015 and van Ginkel, 2008 also observed the upwards trend towards cyanobacteria blooms due to hypertrophic status of the dam. Their high nutrients levels promote algal bloom, growth of aquatic plants and species that are toxic to aquatic organisms (Van Ginkel, 2002; Griffin, 2017; Angelakis *et al.,* 2018).

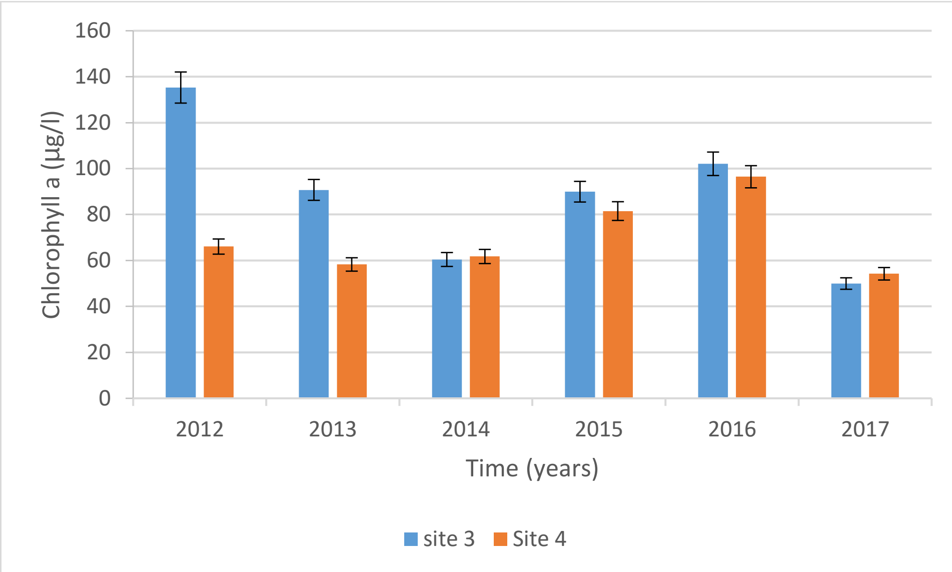

Figure 4-19: Annual average chlorophyll a concentration at sampling sites in Roodeplaat Dam

The sites in the dam showed high monthly averages between October and March (Figure 4-20). Chlorophyll a concentration varied seasonally. Silberbauer and Esterhuyse (2014) observed that the phosphate and nitrogen from effluent contribute to the increased green pigmentation in the dam. The dam is hypertrophic and the occurrence for algal and plant productivity was observed (Van Ginkel and Silberbauer, 2007; Silberbauer and Esterhuyse, 2014; Angelakis *et al.,* 2018). The variations in chlorophylly a concentrations can be attributed to the synergistic effect of temperature and nutrients. At warmer temperatures and high nutrients there is bound to be more planktonic life and activity as opposed to lower temperatures and nutrients.

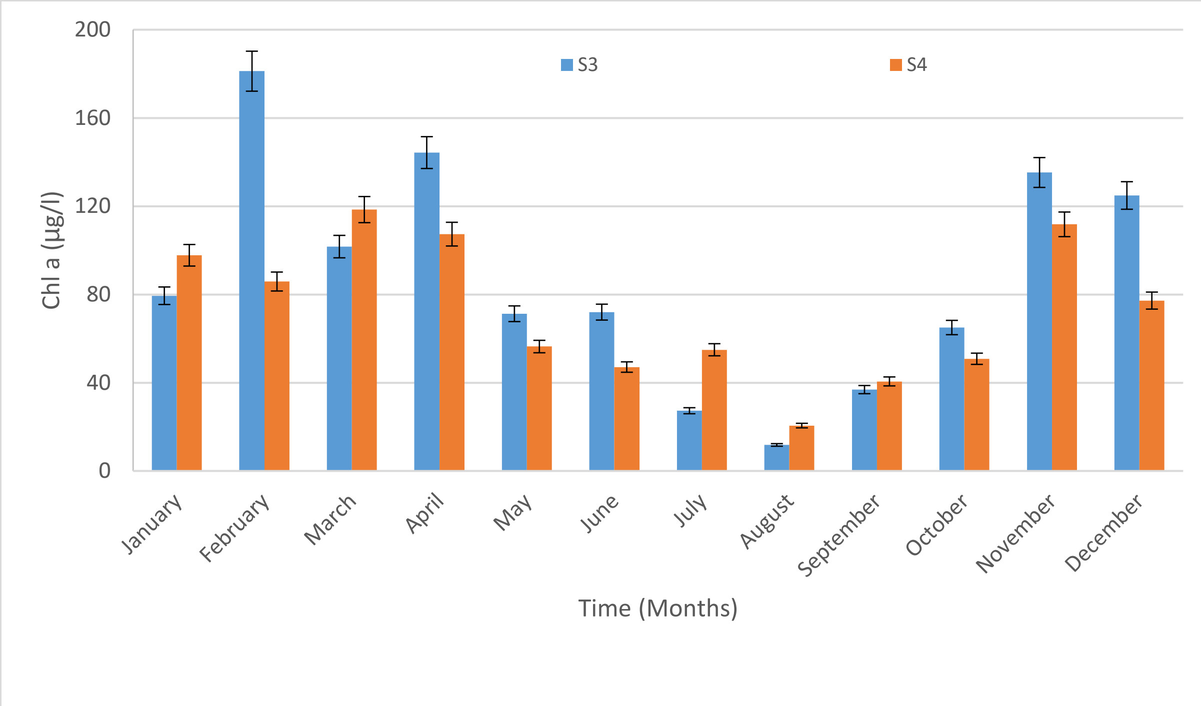

Figure 4-20: Monthly average chlorophyll a concentration at sampling sites in Roodeplaat Dam between 2012 and 2017

4.11 COD

There were no results recorded in the dam however like most of results above, the impact on the dam would not be observed immediately as there was a tendency of parameter concentration decrease in transit to the dam. The effluent COD for site 1 is exceeded 75 mg/l according general requirements for wastewater regulation (DWAF, 1996). The presence of COD (Figure 4-21) could be credited to existence of sulphides, sulphites and chlorides that cause interference to COD (Agyemang *et al*., 2013). Effluent from WWTW is the main provider of organic pollution in dams and rivers in South Africa (Edokpayi *et al*., 2017).

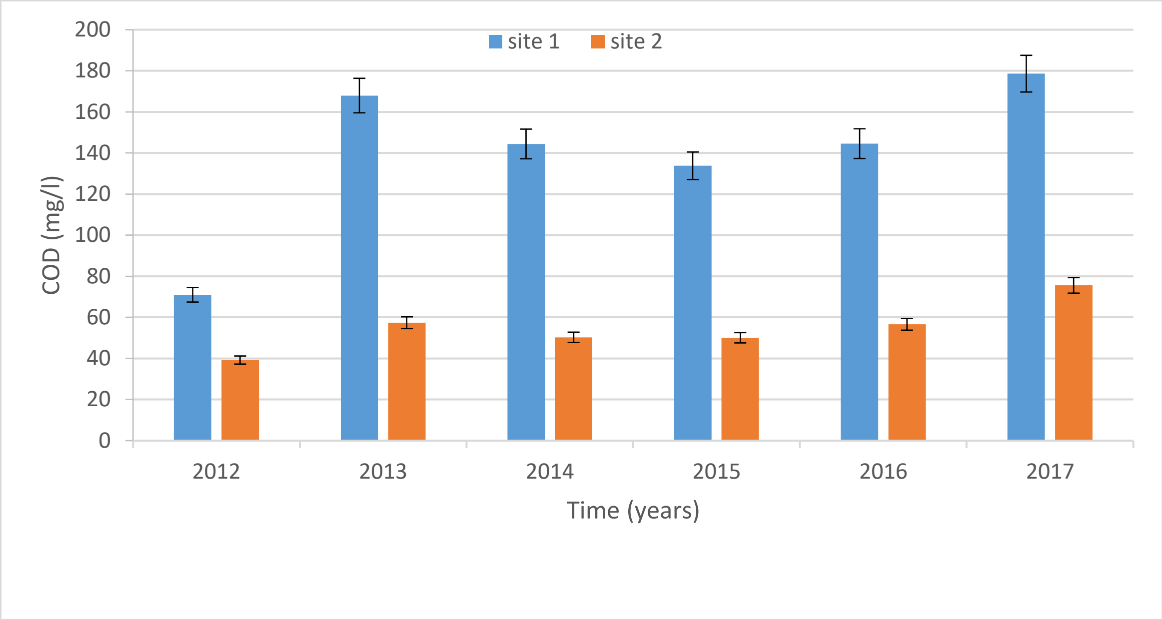

Figure 4-21: Average annual COD levels for the effluent from Baviaanspoort and Zeekoegat WWTW between 2012 and 2017

Monthly average COD values ranges from 66.03 to 168.36 mg/l for site 1 and 31.74 to 100.63 mg/l for site 2 (Figure 4-22). The COD for site 1 is exceeded the 75 mg/l limit for general requirements for wastewater regulation (DWAF, 1996). Site 2 COD was fairly acceptable except for the average for October which went up to 100 mg/l. There was no definitive seasonal pattern observed from the two effluent sites. The elevated levels of COD may point to strain in recipient water bodies that may be rendered unfit for purpose.

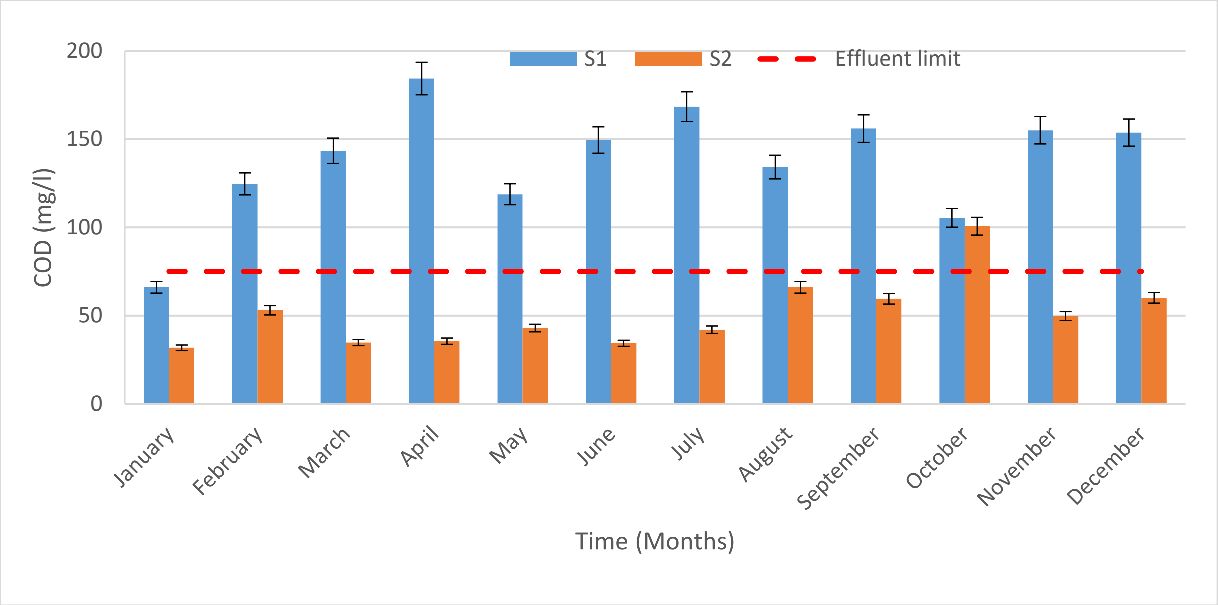

Figure 4-22: Monthly average COD levels for two sites within Roodeplaat Dam over six years

4.12 CHAPTER SUMMARY

The chapter presented and explained the results for the assayed parameters. There was variation in the level of pollutant contribution by the Baviaanspoort and Zeekoegat WWTW. The former was the worst performer. While most of the parameters in the dam were lower than the concentration in the effluent, it was noted that there were other contributors of pollutants besides the WWTW. The next chapter will draw conclusions and recommendations from the observed results.

5 CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The study provided an insight on the role of Baviaanspoort and Zeekoegat WWTW in the pollution of Roodeplaat Dam. There was ample evidence that an increase in parameters concentration in the dam was partly due to effluent from the two WWTW. The parameters that were above regulatory standards from WWTW must not be taken for granted as the two WWTW contribute more than 55 % return flows into the dam. The t-test results (Appendix D) at $p = 0.05$ indicated that there were no evidence for major changes between 2012 and 2017 samples from effluent of both WWTW. Generally this means improvements that were recommended in previous years were not fully implemented.

The results showed that Baviaanspoort WWTW is always releasing effluent which is poorer in quality than Zeekoegat WWTW. Overload capacity of Baviaanspoort WWTW is one of the challenges that are causing poor quality of effluent discharged in the Roodeplaat Dam (MAP Forum, 2019). The leading parameters in causing stress to Roodeplaat Dam water quality in descending order were *E. coli*, Phosphate, TON, Ammonia, Chlorophyll a, Conductivity, COD and Sodium. pH, Chlorides and Sulphates were always below the limit by the regulator. The study results are congruent with other researchers' on the issue of eutrophication on the Roodeplaat Dam and poor state of WWTW effluent released to dams and rivers (Van Ginkel, 2002; Silberbauer and Esterhuyse, 2014; Naidoo, 2014; Angelakis *et. al*., 2018; Map Forum, 2019). The water from the dam needs treatment before usage due to high microbial load that poses a high risk of waterborne diseases. Wastewater treatment works effluent ought to be treated with great care in order not to constitute a health threat to the consumers of water from the dam and adverse environmental effects. Power outages and vandalism also contributed to failure for both Zeekoegat WWTW and Baviaanspoort WWTW (Map Forum, 2019).

The current problems which are costly and exceed the budget are causing long term plans to be overlooked. The budget for 15 WWTW is not enough which causes long term planning not to be addressed, City of Tshwane (CoT) spends R4.4 billion on WWTW annually. The current budget for CoT's annual budget is R32 billion, the estimate for CoT to fix the 15 WWTW is R30 billion (CoT, 2017).

The Null hypothesis is therefore rejected, the physico-chemical and microbiological variables from Baviaanspoort and Zeekoegat WWTW negatively impact the Roodeplaat Dam's water quality. The Baviaanspoort WWTW and Zeekoegat WWTW are still contributing significantly to water contamination. The lesson learnt is that there is no microwaving of upgrading of WWTW despite the high costs involved as this will negatively impact effluent quality. Poor effluent quality is a time bomb that comes with higher costs upon detonation than costs for upgrading facilities. More sample points and other derterminants like trace and organic compounds would make the extent of pollution more clear.

5.2 RECOMMENDATIONS

The following recommendations were made from the study:

- The Baviaanspoort WWTW needs upgrade more urgently than Zeekoegat WWTW by improving its treatment performance and capacity, to ensure sustainable use of water by downstream users;
- Water regulations must be put in practice to protect the environment and public health;
- Prohibitive polluter pays principle must be practiced and maintained through relevant legislation (Edokpayi *et al*., 2017) so that the price for environmental impairment is a deterrent;
- The stake holders must also consider Roodeplaat Dam rehabilitation program due to pollutants entering the dam.
- The Green Drop assessments must be made public, since 2014 results were not made public or assessments were never done (Ntombela *et al*., 2016; FSE, 2018) and the intended incentives be implemented;
- Monitoring must be precise and problems pinpointed and addressed promptly;
- In situ water quality measurements for variables like pH, EC and other determinants like alkalinity are preferable than laboratory analysis. Mercury

chloride preservations should be avoided by laboratories, as it is not good for environment and humans. Investment and instrument maintenance is essential.

- The Government must invest in the water monitoring programs in order to maintain the safety of the community who are using the Roodeplaat Dam for different purposes;
- CoT must seek help from state owned enterprises like Ekurhuleni Water Care Company (ERWAT) and Magalies Water for funding and expertise;
- The CoT must look for other funders and prioritize the WWTW, like Baviaanspoort which has been identified for years to need urgent upgrade (CoT, 2017; MAP Forum, 2019);
- Investing in alternative wastewater treatment methods and water reuse schemes is necessary. Large companies that have a monopoly on wastewater treatment technology must not derail upcoming companies with alternative methods (Map Forum, 2019);
- Political will to end mismanagement of coffers; corruption and inadequate funds allocated to wastewater treatment processes need to be investigated and consequence management approach must be adopted; and
- Future studies for downstream quantification till the entry to the dam would make concentration dynamics more understandable as effluent flows to the dam. The research on trace elements and organic pollutants may give a clearer picture of Roodeplaat Dam pollution status.

5.3 LIMITATIONS

The parameters selected were based on the availability of secondary data to allow comparison. Due to SAHRC investigation it was difficult to get information from CoT and WWTW management.

5.4 CHAPTER SUMMARY

This chapter demonstrated that the objectives of the study were met. The two treatment plants were not fully compliant on all parameters, hence did not obtain the full Green Drop certification. While Zeekoegat still outperforms Baviaanspoort, the rapid population growth and housing infrastructure development requires the local authorities to priorities ugrading of the WWTW so that they have reasonable reserve capacity to accommodate urbanization. There is a need for decisiveness and bravery in mouthing huge bills that come with infrastructure upgrading while saving future costs that will be incurred due to failed wastewater handling. Continuous monitoring coupled to appropriate responses will remain paramount to quality management of water resources.

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7 APPENDICES

7.1 APPENDIX A: ETHICS CLEARANCE

UNISA university of south africa

UNISA HEALTH RESEARCH ETHICS COMMITTEE

Date: 14/05/2018

NHREC Registration # : REC-170616-051
REC Reference # : 2018/CAES/078
Name : Mr MB Zulu
Student #: 30310717

Dear Mr Zulu

Decision: Ethics Approval from 10/05/2018 to 30/04/2019

Researcher(s): Mr MB Zulu
Zulum2@dws.gov.za

Supervisor (s): Dr CA Togo
catogo@gmail.com; 082-362-2431

Working title of research:

Comparative evaluation of the impacts of two wastewater treatment works on the water quality of Roodeplaat dam in Tshwane, Gauteng

Qualification: MSc Environmental Science

Thank you for the application for research ethics clearance by the Unisa CAES Health Research Ethics Committee for the above mentioned research. Ethics approval is granted for a one-year period, **subject to clarification and the submission of the relevant permission letter.** After one year the researcher is required to submit a progress report, upon which the ethics clearance may be renewed for another year.

Due date for progress report: 30 April 2019

Please note the points below for further action:

1. What is the nature of the secondary data mentioned? What are the parameters of the data that will be used?
2. According to the time-plan provided sampling has already started. The researcher is requested to clarify whether sampling has commenced or not.
3. Permission for the use of the laboratory is outstanding. This must be obtained and submitted to the Committee before laboratory work may commence.

University of South Africa
Preller Street, Muckleneuk Ridge, City of Tshwane
PO Box 392 UNISA 0003 South Africa
Telephone: +27 12 429 3111 Facsimile: +27 12 429 4150
www.unisa.ac.za

*The **medium risk application** was **reviewed** by the CAES Health Research Ethics Committee on 10 May 2018 in compliance with the Unisa Policy on Research Ethics and the Standard Operating Procedure on Research Ethics Risk Assessment.*

The proposed research may now commence with the provisions that:

1. The researcher(s) will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.
2. Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study should be communicated in writing to the Committee.
3. The researcher(s) will conduct the study according to the methods and procedures set out in the approved application.
4. Any changes that can affect the study-related risks for the research participants, particularly in terms of assurances made with regards to the protection of participants' privacy and the confidentiality of the data, should be reported to the Committee in writing, accompanied by a progress report.
5. The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study. Adherence to the following South African legislation is important, if applicable: Protection of Personal Information Act, no 4 of 2013; Children's act no 38 of 2005 and the National Health Act, no 61 of 2003.
6. Only de-identified research data may be used for secondary research purposes in future on condition that the research objectives are similar to those of the original research. Secondary use of identifiable human research data require additional ethics clearance.
7. No field work activities may continue after the expiry date. Submission of a completed research ethics progress report will constitute an application for renewal of Ethics Research Committee approval.

Note:

*The reference number **2018/CAES/078** should be clearly indicated on all forms of communication with the intended research participants, as well as with the Committee.*

Yours sincerely,

URERC 25.04.17 - Decision template (V2) - Approve

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Prof EL Kempen
Chair of CAES Health REC
E-mail: kempeel@unisa.ac.za
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Prof MJ Linington
Executive Dean : CAES
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7.2 APPENDIX B: PERMISSION TO CONDUCT RESEARCH AT COT

CITY OF
TSHWANE
IGNITING EXCELLENCE

City Strategy and Organisational Performance

Room CSP23 | Ground Floor, West Wing, Block D | Tshwane House | 320 Madiba Street | Pretoria | 0002
PO Box 440 | Pretoria | 0001
Tel: 012 358 7542
Email: NosiphoH@tshwane.gov.za | www.tshwane.gov.za | www.facebook.com/CityOf Tshwane

My ref: Research Permission/Zulu
Contact person: Pearl Maponya
Section/Unit: Knowledge Management

Tel: 012 358 4559
Email: PearlMap3@tshwane.gov.za
Date: 07 May 2018

Mr Mpumelelo Zulu
4572 Shabangu Str
Mamelodi West
Mamelodi
4031

Dear Mr Zulu,

RE: COMPARATIVE EVALUATION OF THE IMPACTS OF TWO WASTEWATER TREATMENT WORKS ON THE WATER QUALITY OF ROODEPLAAT DAM IN TSHWANE, GAUTENG.

Permission is hereby granted to Mr Mpumelelo Zulu, a MSc Environmental Science candidate at University of South Africa (UNISA), to conduct research in the City of Tshwane Metropolitan Municipality.

It is noted that the aim of your study is to analyse physical, chemical and microbiological parameters in order to assess the impact of Baviaanspoort and Zeekoegat WWTWs, on water quality of Roodeplaat Dam. The City of Tshwane further notes that all ethical aspects of the research will be covered within the provisions of UNISA Research Ethics Policy. You will be required to sign a confidentiality agreement form with the City of Tshwane prior to conducting research.

Relevant information required for the purpose of the research project will be made available upon request. The City of Tshwane is not liable to cover the costs of the research. Upon completion of the research study, it would be appreciated that the findings in the form of a report and or presentation be shared with the City of Tshwane.

Yours faithfully,

PEARL MAPONYA (Ms.)
ACTING DIVISIONAL HEAD: INNOVATION & KNOWLEDGE MANAGEMENT DIVISION

City Strategy and Organisational Performance • Stadstrategie en Organisatoriese Prestasie • Lefapha la Thulaganyo ya Tiro le Togamaano ya Toropokgolo • UmNyango wezokuSebenza namaQhinga aHleliweko kaMasipala • Kgoro ya Leanopeakanyo la Toropokgolo le Bodiragatši bja Mmasepala • Muhasho wa Vhupulani ha Ḓorobo khulwane na Mashumele • Ndzawulo ya Maqhinga ya Dorobakulu na Matirhele ya Masipala • Umnyango Wezeqhinga Ledolobha Nokusebenza Kwesikhungo

3031-071-7

water & sanitation

Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

Enquiries: T. Mthombeni

Telephone: 012 808 9619

Reference: Zulu 30310717

MANAGER: UNIVERSITY OF SOUTH AFRIÇA

APPROVAL FOR Mr MPUMELELO BLESSING ZULU TO PERFOM THE STUDY AT ROODEPLAAT DAM IN PRETORIA, CITY OF TSHWANE.

Mr M.B. Zulu has been granted permission by the Department of Water and Sanitation to perform the study in the Roodeplaat Dam in Pretoria.

The research is on the topic "Comparative evaluation of the impacts of the two wastewater treatment works on the quality of the Roodeplaat Dam in Tshwane, Gauteng".

Yours sincerely,

Director: RESOURCE QUALITY INFORMATION SERVICES (RQIS).

DATE: 05/04/2018

Department Water and Sanitation
PRIVATE BAG X313, PRETORIA, 0001

2018 -04- 05

RESOURCE QUALITY INFORMATION
SERVICE. ROODEPLAAT DAM
Department Water and Sanitation

7.3 APPENDIX C: ANALYTICAL SERVICES PERMISSION

water & sanitation

Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

Enquiries: J. Lekekiso

Telephone: 012 808 9750

Reference: Zulu 61302198

MANAGER: UNIVERSITY OF SOUTH AFRICA

APPROVAL FOR Mr MPUMELELO BLESSING ZULU TO ACCESS DATA AND ANALYSE WATER SAMPLES AT THE LABORATORIES OF DIRECTORATE: RESOURCE QUALITY INFORMATION SERVICES (RQIS).

Mr Zulu has been granted permission to access and analyse water samples at the Inorganic Chemistry and Biology laboratories at RQIS. The water samples are in relation to the project title "**Comparative evaluation of the impacts of BAVIAANSPOORT AND ZEEKOEGAT wastewater treatment works effects on water quality of Roodeplaat Dam in Tshwane"** Mr Zulu will be able to access and analyse samples for the period required by the study.

It should however be noted that some biological methods are accredited. South African National Accreditation System (SANAS) assessed Inorganic Chemistry and Biology laboratories as extension of scope in April 2017. The laboratories are waiting accreditation confirmation of accreditation from SANAS.

Yours sincerely,

Scientific Manager: Analytical Services

DATE: 2017/07/31

7.4 APPENDIX D: T-TEST RESULTS

Baviaanspoort

Critical t = 2.57

Months	pH 2012	pH 2018	EC 2012	EC 2018
July	7.795	7.1	67.16	56.55
August	7.666667	7.235	72.46667	62.7
September	7.706667	7.335	71.45	66.6
October	7.656667	7.333333	64.86667	64.9
November	7.67	7.05	72.4	86
December	7.7025	7.191667	67.7	85.8
Average	7.6996	7.2075	70.425	69.34
t-test calc	**8.3370**		**0.2188**	
Ho	rejected		accepted	

Critical t = 2.57

Baviaanspoort

Months	COD 2012	COD 2018	SO_4 2012	SO_4 2018
July	68.66667	46.33333	54.79	60.05
August	103	60.4	61.187	70.5
September	53.33	60	51.984	68
October	35.33	108	52.4085	68.4
November	153	34	51.56	68.8
December	145.67	71	49.699	77.04
Average	93.167	63.289		
t-test calc	**1.103**		**6.516**	

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Ho	accepted		rejected	

Critical t = 2.57

Baviaanspoort

Months	**Cl 2012**	**Cl 2018**	**TON 2012**	**TON 2018**
July	59.284	44.05	10.454	0.256
August	54.741	53.7	7.9215	0.571
September	54.741	53.8	8.5375	20.28
October	49.5195	57	10.43	16.722
November	48.768	63.413	7.726	19.2785
December	49.037	58.144	9.927	22.7765
Average	52.682	55.018	9.166	13.314
t-test calc	**1.546**		**1.032**	
Ho	accepted		accepted	

Critical t = 2.57

Baviaanspoort

Months	**PO_4 2012**	**PO_4 2018**	**NH_4 2012**	**NH_4 2018**
July	0.902	0.989	4.84	5.087
August	0.602	2.244	12.461	0.05
September	0.794	1.58	5.317	0.05
October	0.685	1.497	0.066	0.05
November	0.939	1.026	0.025	18.219
December	0.968	0.977	0.025	22.135
Average	0.815	1.385	3.789	7.598
t-test calc	**2.1901**		**0.68993**	
Ho	accepted		accepted	

Zeekoegat.

Critical t = 2.57

Months	pH 2012	pH 2018	EC 2012	EC 2018
July	7.40	7.1	54.06667	56.13333
August	7.733	7.235	60.4	58.46667
September	7.340	7.335	61.46667	60.4
October	7.397	7.333	55.76667	60.7
November	7.470	7.05	57.5	61.525
December	7.543	7.192	52.5	61.1125
Average	7.423	7.207	59.72292	56.95
t-test calc	**3.386**		**1.723**	
Ho	rejected		accepted	

Critical t = 2.57

Zeekoegat

Months	COD 2012	COD 2018	SO_4 2012	SO_4 2018
July	50.5	46.33333	44.219	53.5
August	34.33333	60.4	50.421	53.4
September	31.66667	60	47.3285	61.1
October	35.5	108	45.64	51.8
November	27.75	34	45.1535	57.421
December	30.75	71	48.226	54.851
Average	35.0833	63.289	55.34533	46.83133
t-test calc	**2.560**		**1.8501**	
Ho	accepted		accepted	

Months	Cl 2012	Cl 2018	TON 2012	TON 2018
July	54.897	63.85	4.944	3.885
August	56.0715	59.05	8.513	6.14475
September	55.612	59.025	7.7695	6.6735
October	54.3795	59	6.2535	6.8235
November	53.987	58.354	5.2175	8.667
December	59.671	62.997	6.272	6.5085
Average	60.37933	55.76967	6.450375	6.494917
t-test calc	**5.084**		**0.054**	
Ho	rejected		accepted	

Critical t = 2.57

Zeekoegat

Months	PO_4 2012	PO_4 2018	NH_4 2012	NH_4 2018
July	0.1055	1.4575	0.531	0.05
August	0.0675	0.446	0.35	0.272
September	0.144	0.853	0.025	0.05
October	0.138	1.605	0.025	0.106
November	0.0575	0.252	0.4762	0.137
December	0.061	0.319	0.314	0.134
Average	0.0956	0.8221	0.28144	0.123
t-test calc	**3.182**		**1.464**	
Ho	rejected		accepted	

7.5 APPENDIX E: TABLE RESULTS

Table 7-1: Comparison of pH values on site 1, 2, 3 and 4 for 6 years

Year	Site1	Site2	Site3	Site4
2012	7.71	7.42	8.67	8.56
2013	7.65	7.33	8.56	8.45
2014	7.64	7.19	8.63	8.48
2015	7.60	7.93	8.63	8.54
2016	7.69	7.86	8.53	8.59
2017	7.34	7.83	8.29	8.12

Table 7-2: Comparison of EC values on site 1, 2, 3 and 4 for 6 years

Year	Site 1	site 2	site 3	site 4
2012	62.77	55.96	47.52	46.90
2013	72.30	62.80	46.55	45.93
2014	65.83	55.88	45.62	46.73
2015	65.90	57.88	49.33	49.74
2016	93.14	57.83	49.67	51.53
2017	67.64	47.38	50.70	44.91

Table 7-3: Comparison of TON values on site 1, 2, 3 and 4 for 6 years.

Year	Site1	Site2	Site3	Site4	
2012	10.523		6.76	1.58	2.11
2013	10.48888		6.84	2.25	2.40
2014	12.19415		5.57	2.52	2.11
2015	21.46329		7.30	1.87	2.25
2016	21.46329		5.74	3.15	2.88
2017	27.81717		5.25	5.37	4.84

Table 7-4: Comparison Ammonia values on site 1, 2, 3 and 4 for 6 years

Year	Site 1	Site 2	Site 3	Site 4
2012	0.20	0.48	1.43	0.90
2013	13.86	0.66	2.09	1.54
2014	5.77	0.24	1.37	0.85
2015	3.04	0.20	1.33	0.90
2016	0.28	0.26	2.22	1.51
2017	4.19	0.31	3.05	2.73

Table 7-5: Comparison of Phosphates values on site 1, 2, 3 and 4 for 6 years

Year	Zeekoegat	Baviaan	A2R009Q07	A2R009Q09
2012	0.13	0.88	0.26	0.21
2013	0.12	1.95	0.24	0.16
2014	0.28	1.92	0.25	0.20
2015	0.13	2.25	0.31	0.28
2016	1.56	2.01	0.60	0.62
2017	2.03	1.56	0.81	0.79

Table 7-6: Comparison Chloride average values on site 1, 2, 3 and 4 for 6 years

Year	Site1	Site2	Site3	Site4
2012	51.40	54.63	35.34	36.32
2013	52.25	57.15	37.74	40.48
2014	57.28	62.85	37.61	38.28
2015	59.60	61.65	41.83	42.27
2016	52.93	63.20	43.92	45.63
2017	55.38	62.06	41.98	40.84

Table 7-7: Comparison Sulphate average values on site 1, 2, 3 and 4 for 6 years

Year	Site 1	Site 2	Site 3	Site 4
2012	53.10	48.52	34.96	35.39
2013	55.68	54.19	36.73	37.37
2014	61.53	53.70	36.85	39.04
2015	65.43	54.56	42.87	42.99
2016	64.17	55.30	47.10	50.91
2017	54.89	55.90	44.32	44.89

Table 7-8: Comparison Sodium average values on site 1, 2, 3 and 4 for 6 years

Year	Site 2	Site 1	Site 3	Site 4
2012	56.37	66.74	29.22	32.64
2013	59.39	68.18	37.40	35.37
2014	55.17	74.16	40.65	40.42
2015	74.69	53.60	43.15	43.35
2016	60.47	72.97	49.03	45.50
2017	58.50	69.56	42.38	34.60

Table 7-9: Comparison *E.coli* average on site 1, 2, 3 and 4 for 6 years

YEAR	S1	S2	S3	S4
2012	29712	55	88	10
2013	316396	598	28	15
2014	249173	270	68	132
2015	98794	228	108	61
2016	2182767	575	461	39
2017	605999	852	74	25

Table 7-10: Comparison of Chlorophyll a values on site 3 and 4 for 6 years.

Year	site 3	site 4
2012	135.28	66.056
2013	90.73	58.27
2014	60.43	61.74
2015	89.94	81.505
2016	102.09	96.45
2017	49.97	54.21

Table 7-11: Comparison of COD, values on site 1 and 2 for 6 years

Year	site 1	site 2
2012	71.00	39.22
2013	167.95	57.38
2014	144.39	50.28
2015	133.77	50.06
2016	144.55	56.58
2017	178.59	75.55

Table 7-12: pH monthly average on site1, site2, site3 and site4 for 6 years.

	S1	S2	S3	S4
January	7.739313	7.509633	8.615083	8.55425
February	7.577944	7.62225	8.938	8.833917
March	7.619472	7.427083	8.403917	8.520611
April	7.355556	7.606639	8.46025	8.479333
May	7.576528	7.553139	8.558444	8.59475
June	7.644111	7.545444	8.278917	8.422333
July	7.592333	7.540833	8.060917	8.1599
August	7.575306	7.782	8.35675	8.185583
September	7.431111	7.590583	8.344333	8.350333
October	7.956611	7.640444	8.268333	8.5165
November	7.597333	7.673833	8.420833	8.747667
December	7.600583	7.515067	8.367	8.977333

Table 7-13: EC monthly average site1, 2, 3 and 4 for 6 years.

	S1	S2	S3	S4
January	63.33817	54.93	41.24683	41.04683
February	74.79133	56.50556	40.453	41.8045
March	68.39103	53.65278	44.15717	47.63333
April	71.59444	53.96944	44.36667	44.1
May	69.26944	55.34167	45.31667	44.53333
June	74.76417	67.725	48.11667	48.78333
July	73.82111	58.46944	41.95642	42.3525
August	74.93333	59.57833	54.60919	52.01917
September	103.9694	61.11944	54.5	46.30708
October	71.21389	58.48611	52.54722	53.70883
November	73.09583	58.90833	51.58333	51.80833
December	69.22889	55.12333	47.53333	46.83333

Table 7-14: TON monthly average on site1, 2, 3 and 4 for 6 years

	S1	S2	S3	S4
JANUARY	10.01975	5.96225	2.061583	1.477917
FEBRUARY	16.06142	6.306583	1.451583	1.553917
MARCH	10.96339	5.036083	1.401333	2.36575
APRIL	19.31558	5.94375	2.277333	2.174
MAY	16.83658	6.5675	2.183833	2.180583
JUNE	20.3985	6.985583	2.873083	2.375917
JULY	16.29858	6.283361	2.113917	3.630833
AUGUST	18.07133	7.027417	4.071417	3.800083
SEPTEMBER	22.51917	6.21475	4.559083	4.248167
OCTOBER	19.31017	5.993583	3.826667	3.772417
NOVEMBER	22.66925	5.878	4.051417	3.175333
DECEMBER	15.43583	6.697333	2.7235	2.759167

Table 7-15: Ammonia monthly average on site1, 2, 3 and 4 for 6 years.

	S1	S2	S3	S4
JANUARY	1.0582	0.18825	0.283167	0.1155
FEBRUARY	1.4774	0.1168	0.738333	0.401583
MARCH	11.2656	0.9832	1.7935	0.566667
APRIL	6.065	0.3562	1.255833	0.893833
MAY	4.8435	0.4688	1.021	0.9215
JUNE	5.6506	0.21	1.850333	2.006333
JULY	7.010333	0.3958	3.342167	2.242833
AUGUST	2.492167	0.34	2.635667	1.999917
SEPTEMBER	4.843	0.487167	3.562583	2.342833
OCTOBER	4.311667	0.281167	2.510833	2.224333
NOVEMBER	0.215833	0.088	1.26	1.345833
DECEMBER	0.041667	0.3738	0.949	1.356333

Table 7-16: O-PO4 monthly average on site 1, 2, 3 and 4 for six years.

	S1	S2	S3	S4
JANUARY	1.39575	0.4518	0.259833	0.165333
FEBRUARY	1.828333	0.814833	0.2265	0.233667
MARCH	1.85225	0.198944	0.273833	0.294167
APRIL	1.508167	0.203583	0.2865	0.2865
MAY	2.634167	0.632861	0.279	0.185333
JUNE	1.378917	0.57275	0.3045	0.277167
JULY	1.851389	0.414833	0.353167	0.379917
AUGUST	1.91625	0.851417	0.481	0.3655
SEPTEMBER	2.262333	1.367833	0.6315	0.588333
OCTOBER	1.09075	1.657083	0.568833	0.556917
NOVEMBER	2.085917	0.952667	0.564	0.640417
DECEMBER	1.3265	0.5536	0.525	0.452333

Table 7-17: Chlorides monthly average on site 1, 2, 3 and 4 for 6 years

	Site 1	Site 2	Site 3	Site 4
JANUARY	50.91017	57.9475	34.4645	36.509
FEBRUARY	50.07339	56.55825	35.602	39.72467
MARCH	52.21233	53.8405	34.05336	35.84017
APRIL	51.85475	56.88783	35.10683	35.42983
MAY	56.16317	60.55817	36.691	36.43742
JUNE	56.8625	60.62783	37.36317	36.57642
JULY	60.067	61.73281	41.14692	39.94142
AUGUST	60.08525	61.91617	44.43092	43.74442
SEPTEMBER	57.76892	60.86808	44.78183	46.37717
OCTOBER	54.2745	63.528	44.91083	48.08142
NOVEMBER	54.97742	65.28617	44.18442	44.56008
DECEMBER	52.405	63.34233	44.10117	44.4325

Table 7-18: Sulphate monthly average on site 1, 2, 3 and 4 for 6 years.

	S1	S2	S3	S4
JANUARY	55.1783	53.617	36.04083	36.925
FEBRUARY	56.89742	50.50133	37.83833	39.86092
MARCH	56.7195	50.46458	39.78183	43.21325
APRIL	59.84292	52.22192	37.65667	37.7465
MAY	64.20617	51.70942	39.08342	35.20533
JUNE	61.92925	55.08625	40.63008	38.18708
JULY	61.48481	52.38558	38.35267	43.40933
AUGUST	68.76119	55.62317	43.484	41.20875
SEPTEMBER	65.03608	56.20208	46.875	45.5245
OCTOBER	61.37542	54.84317	42.788	43.84283
NOVEMBER	57.43667	56.87708	41.79033	44.838
DECEMBER	59.9378	54.119	38.05433	47.90217

Table 7-19: Na monthly average on site1, site2, site3 and site4 for 6 years.

	S1	S2	S3	S4
JANUARY	61.35	56.17	32.15	34.13
FEBRUARY	60.56	57.23	33.10	36.09
MARCH	61.95	48.99	33.61	37.35
APRIL	67.80	59.53	36.24	35.55
MAY	74.02	63.70	35.52	35.38
JUNE	72.09	62.64	37.61	37.44
JULY	72.78	63.55	36.68	40.58
AUGUST	77.38	66.30	43.82	43.58
SEPTEMBER	72.43	63.21	47.43	47.47
OCTOBER	64.29	60.56	44.22	47.50
NOVEMBER	72.25	63.05	44.75	46.16
DECEMBER	63.60	57.75	40.93	42.41

Table 7-20: ***E. coli* monthly average on site1, site2, site3 and site4 for 6 years.**

	S1	S2	S3	S4
January	1.38E+05	271	2	3
February	2.74E+05	1266	81	37
March	1.05E+05	195	62	132
April	4.70E+05	646	10	6
May	2.25E+05	181	28	5
June	5.80E+05	360	25	3
July	2.49E+05	813	43	5
August	1.86E+05	76	29	4
September	4.81E+05	1024	485	72
October	1.23E+06	711	602	25
November	7.51E+05	139	221	261
December	3.55E+06	166	6	3

Table 7-21: **Chlorophyll a monthly average on site 3 and 4 for six years.**

	S3	S4
January	79.42667	97.76583
February	181.1979	85.86417
March	101.6933	118.47
April	144.3063	107.3446
May	71.26125	56.3975
June	71.99875	47.10417
July	27.3025	54.94167
August	11.80667	20.575
September	36.87333	40.58833
October	65.0125	50.85167
November	135.2858	111.785
December	124.8633	77.22083

Table 7-22: **COD, monthly average on site 1 and site 2 for 6 years.**

COD	S1	S2
January	66.03	31.74
February	124.61	53.00
March	143.38	34.72
April	184.29	35.50
May	118.74	42.94
June	149.46	34.31
July	168.36	42.00
August	134.14	66.03
September	155.92	59.49
October	105.35	100.63
November	155.00	49.75
December	153.67	60.06

7.6 APPENDIX F: TURN-IT-IN SUMMARY

Comparative evaluation of impacts of two wastewater treatment works on the water quality of Roodeplaat dam in Tshwane, Gauten

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