Assessment of water quality and associated impacts of the sewage discharges into the Mooi River Catchment

XNM Dube

orcid.org 0000-0002-1041-742X

Dissertation accepted in partial fulfilment of the requirements for the degree *Master of Environmental Management with Ecological Water Requirements* at the North-West University

Supervisor:	Mr KN van Zweel
Co-supervisor:	Dr CW Malherbe

Graduation May 2020

25604678

DECLARATION

I declare that this dissertation, which I hereby submit at the North-West University for fulfilment of the requirements for the degree of Master of Environmental Management with specialisation in Ecological Water Requirements, is my very own work which has never previously been submitted to any institution for degree purposes.

I declare that all work submitted by other persons and sources used in this mini dissertation are acknowledged.

_________________ __18 February 2020______

XNM Dube Date

DEDICATION

I dedicate my dissertation to my kids Sandisa, Lungelo and Sithelosomusa for their patience when mommy was not always around. They have been my source of strength and motivation. I am very much grateful to my husband Mr Bhekani Dube for the days and weeks he had to go without a wife and the support he provided throughout my studies.

ACKNOWLEDGEMENTS

Firstly, I acknowledge with appreciation God for His guidance and protection in my entire trips to the university and providing me with strength to persevere throughout my studies. I would also like to thank the people who provided valuable contribution and input: my co-supervisor Dr Wynand Malherbe for his motivation, encouragement, his guidance and help without whom this research work would not have been accomplished. I am grateful to Mhlathuze Water and North-West University for the opportunity and their financial contribution. I would also like to extend my heartfelt gratitude to the Department of Water and Sanitation (DWS) staff, Marica Erasmus, Hellen Mathedimosa and Victor Nkuna for the water quality data and other related information used in this study. I would not forget assistance and courage from my mates Zafika Nyongo who had always listened tirelessly and pushed us to move forward and Nditsheni Maliaga and Lethabo Ramashala for their assistance in pressing the right buttons for me to get data. I would also like to thank Dr Allen Mambanda and Dr Brent Newman for their assistance and expertise, who responded to my queries tirelessly. I would not forget my mother Ms Fikile Makhoba and grand-ma Mrs Isabel Makhoba whose words of encouragement pushed me to do well and I appreciate the time they spent looking after my kids without fail while I was away studying, and my friend Nqezu for the support throughout my studies. Lastly, I would like to thank my immediate family for their general support (hubby and kids). Thank you for your patience, love and for being understanding.

ABSTRACT

Population growth in developing cities is putting pressure on the wastewater treatment plants. The improper treated sewage entering the aquatic environment deteriorates the water quality of the receiving water resource. The Mooi River Catchment has been a centre of attention and a number of research studies on significant pollution sources have been undertaken. However, very little has been done about the impacts of sewage discharges into the water bodies in the Mooi River Catchment. The aim of the study was to determine the possible negative impact of pollution injection by sewage treatment plants located within the Mooi River Catchment area. The study looked at how the discharges affect the water quality of the Mooi River system in relation to the regularised discharge of treated water into the receiving water environment.

This study assesses the impact of wastewater discharges from the Kokosi, Flip Human and Potchefstroom Wastewater Treatment Works, on the Loop Spruit; Wonderfontein Spruit and Mooi River, respectively. Data received from Department of Water and Sanitation (DWS) was analysed for the sites upstream and downstream of the wastewater discharges. The results were then analysed using a student's t-test to determine if there is any significant change in water quality between the points upstream and downstream. The data analysed for physico-chemical and microbiological parameters were checked against compliance with the national and international water and wastewater guidelines and standards. Water quality results upstream and downstream of the various wastewater treatment works were evaluated and tested for significant differences between upstream and downstream.

The data on the physico-chemical and the microbiological parameters such as pH, electrical conductivity, suspended solids, ammonia, nitrate, phosphate, chemical oxygen demand, faecal coliforms and *E. coli* of the water of the Loop Spruit, Wonderfontein Spruit and the Mooi River for the period 2015 to 2018 was received from DWS and collated for analysis. Furthermore, included for comparison was data from the period 2001 to 2002 as the reference data. The river water quality data were for samples taken downstream of the discharge points of wastewater treatment works (WWTWs) located in the three rivers. Upstream samples were also included for comparison purposes. To evaluate the quality of the receiving water, the combined data were compared against set national and international water and wastewater guidelines and standards as well as the Water Use Licences for the three wastewater works (Kokosi, Flip Human and Potchefstroom).

Data revealed instances during the period July 2015 to January 2018 at which the concentrations and values of most of the physical, biochemical and microbiological quality indicators were higher than those expected for natural surface water. Comparative analysis of the data at the sampling points located downstream against their respective upstream of the discharge points into the rivers suggested there were occasions where the WWTWs discharged treated wastewater which was of poor quality into the rivers, leading to an increase in the water quality parameters such as conductivity, nitrates, ammonia, orthophosphate, suspended solids, COD, *E. coli* and faecal coliforms.

It is possible that on these occasions, the quality of the treated wastewater from the WWTWs were non-compliant with the guidelines on Water Use Licence for authorised discharge. This could arise if there was incidences of lapse and failure to adhere to the process quality control protocols on the water treatment process at the WWTWs. Thus, the results indicate that discharging treated water from the WWTWs deteriorated the quality of water of the Mooi River and its tributaries. More concerning were the elevated levels of the pathogenic bacteria as was observed by high values in the microbiological quality parameters (total coliform (faecal) count and *E. coli* count) of the receiving water. Ideally, surface water should be free from any form of pathogens (*E. coli* = 0; Faecal less than 0), as these pose a serious health risk, ranging from diarrhoea to sudden death. The results from the t-test statistical analyses indicated that there was significant difference between the upstream and downstream water quality for the following parameters and sites: electrical conductivity at Flip Human (71.8 and 84.6 mS/m) and Potchefstroom (72 and 101 mS/m), nitrates at Kokosi (5 and 6.08 mg/l), ammonia at Kokosi (0.002 and 1.88 mg/l), Flip Human (0.006 and 0.56 mg/l) and Potchefstroom (0.01 and 0.32 mg/l), orthophosphate at Kokosi (1.079 and 2.26 mg/l) and Flip Human (0.07 and and 2.7 mg/l) and *E. coli* at Kokosi (23 and 928.9 cfu/100mL).

Even when the discharge is regularised and planned there might be a long term effect on the self-sustainability of the aquatic ecosystems along the three rivers as well as the attaching a health risk to users, livestock and wild life. Most of the monitored parameters relevant to wastewater discharge in the receiving river system exceeded the National and international quality standards and the water use licence limits set for discharging WWTWs.

Key words

Water quality, Mooi River, faecal pollution, surface water, anthropogenic activities, wastewater treatment works, eutrophication, physico-chemical parameters, and microbiological parameters.

LIST OF ABBREVIATIONS

BOD:	Biological Oxygen Demand
COD:	Chemical Oxygen Demand
CO_2:	Carbon Dioxide
Cu:	Copper
DEA:	Department of Environmental Affairs
DO:	Dissolved Oxygen
DWAF:	Department of Water Affairs and Forestry
DWS:	Department of Water and Sanitation
EC:	Electrical Conductivity
E. coli:	Escherichia coli
EPA:	Environment Protection Agency
***et al.*:**	et alia (and others)
Fe:	Iron
GA:	General Authorisation
GDP:	Green Drop Program
H_2O:	Water
NEMA:	National Environmental Management Act
NH_3:	Ammonia
NO_3:	Nitrate
NW:	North West
NWA:	National Water Act (No. 36 of 1998)
NWRS:	National Water Resource Strategy
PCA:	Principal Component Analysis
PO_4^{3-}:	Orthophosphate
pH:	Power of Hydrogen
REC:	Recommended Ecological Category
RQO:	Resource Quality Objective
SANS:	South African National Standard
SAWQG:	South African Water Quality Guidelines
SS:	Suspended Solids
TDS:	Total Dissolved Oxygen
TCC:	Total Coliform Count
TWQR:	Target Water Quality Range
WEPA:	Water Environment Partnership in Asia
WHO:	World Health Organisation
WUL:	Water Use Licence

WWTW: Wastewater Treatment Works

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION

1.1. BACKGROUND

Water quality is an essential aspect in meeting basic human needs. Water quality is a measure of the condition of water resources relative to the requirements of the living organisms and human needs. It is defined as the physical, chemical and biological characteristics of water (United Nations, 2007). Water supports all forms of animal and plant life. Human settlements, including modern urban cities, have always been located strategically closer to reliable sources of water such as rivers or dams (Fisher *et al.*, 2000). This is because humans and their livestock all need water for hydration (drinking). In addition, humans need water for almost all their domestic activities such as cooking, washing, bathing and tidying. Further, water is also used for non-domestic purposes like agricultural irrigation (a key component to reliable food supply for mankind) and numerous industrial processes. As a result, the growth of settlements (urban or rural) has always been intertwined to a reliable supply of fresh water. The water reserves further contribute as watersheds for recharging of groundwater (Hemamalini *et al.*, 2017).

The use of water for both domestic and commercial activities has also presented challenges due to its possible pollution, especially in urban centres where industrial activities are taking place and rapid growth of population coupled with climate change effects have presented water pollution risks (Nriagu, 1996; Carpenter *et al.*, 1998). Pollution results in water shortages faced for many countries (Cheng *et al.,* 2009). Water pollution decreases the usefulness of water and it poses risks to human heath and to the aquatic environment (James, 2008). Thus, water that is of good quality is a basic and important need for all living things to survive. Therefore, water pollution is not only a challenge to mankind but also to these aquatic ecosystems, with potential adverse effects of their ecological balance and self-sustainability.

Pollution of water resources especially in the urban metropolitans and towns deteriorates the quality of fresh surface and ground water resources. This problem has become more severe in the Southern Africa region (Amadi, 2010). Most of the wastes which may contaminate water are of industrial and agricultural origins and are laden with synthetic and usually non-biodegradable chemical wastes and residues. Domestic and industrial activities often result in the discharge of various contaminants into the water environment thereby deteriorating the quality of the water (Dickens and Graham, 1998). The known contaminants include organic and inorganic chemicals, nutrients, radioactive materials, pathogens, colloidal wastes (sludge, sediments soil, organic matter, forms, oils and gels) (Feng *et al.*, 2004). These anthropogenic activities also threaten the health balance of the ecosystem and diversity of the aquatic species (Imoukhuede and Afuye, 2016, Moyo and Mtetwa, 2002). The complexity and composition of wastewater also make the cost of the biochemical treatment of such polluted water very high (Schölzel and Bower, 1999).

The negative impact of water pollution is exacerbated in urban settlements due to their rapid growth in population and industrialisation. This normally is not matched be an up-scaling of service delivery and provision of sanitation and amenities. These urban centres are attractive destinations for rural folks who flock to them to seek employment in the industries. This skewed growth pattern in demand and supply of sanitation services creates a fertile ground for pollution of urban water resources as well as poor town planning (Dan-Hassan *et al.*, 2012). This has also led to the generation of huge volumes of raw water effluents and wastes whose composition is usually varied and complex (Amadi, 2010). As a result, most treatment plants servicing major cities of South Africa are overloaded beyond their capacity, leading in most cases to partially and poorly treated wastewater. This creates a problem in respect to safe disposal of partially treated wastes.

If the effluent still contains elevated amounts of nutrients, then the receiving water basin may experience eutrophication (Nriagu, 1996). This triggers anaerobic conditions which leads to the formation of reduced chemical products, the majority of which are acutely toxic to aquatic life as well as animals and humans (Li *et al.*, 2011). If elevated amounts of metals remains (majority of which are toxic and persistent in the environment), then this may have a synergetic adverse effect on the biodiversity of the aquatic ecosystem (Carpenter *et al.*, 1998). Improperly treated and disposed waste contains elevated concentration of nitrates which might not be eliminated during water treatment for drinking purposes, and usually the technology is expensive and energy consuming (Rocca *et al.,* 2007). Exposure to drinking water of such quality is known to cause methaemoglobinaemia (blue baby syndrome) in infants and it also kills livestock (Canter, 1996).

Pollution related to treatment, handling and disposal of wastewater has become a challenging environmental problem in most urban settlements worldwide (Ensink *et al.*, 2010). South Africa is not an exception to this, especially in respect to leakage of sewer wastes due to dilapidated and poorly maintained infrastructure, poor wastewater treatment and disposal practices thus posing health risks to humans and the environment (Slabbert and Venter, 1999; DWAF, 2002). However, only properly treated wastewater should be directed into the natural water ways as failure to do so can pose a health risk to human, animals and the natural aquatic ecosystems in general (De Villiers and Graham, 2016; Mdamo, 2001). Both untreated and treated wastewater have a potential negative effect on the receiving aquatic bodies since these can potentially inject contaminants and toxins that would negatively alter the quality of the receiving water bodies (De Villiers and Graham, 2016).

The issue of overpopulation in most urban settlements of South Africa is evident in the frequent occurrence of informal settlements (NMMP, 2000). These settlements are usually located along the periphery of planned housing suburbs and townships and are in most cases located along the banks of strategically located rivers or their tributaries. In most cases, there is no provision of safe portable water nor is there proper conveyance of wastes (both solids and liquids) through a laid out sewerage system. As a result, there is rampant illegal dumping and disposal of domestic wastes and acid mine drainage directly into the river systems, which are ironically also the sources of portable water for the cities (Dudgeon *et al.*, 2006). One such stretches of informal settlements are dotted in urban centres along the canal system of the Mooi River Catchment. The quality of water had been affected significantly by the encroachment of illegally dumped domestic wastes (Sibanda *et al.*, 2015). Literature data for work done along the Mooi River also suggests widespread contamination of the area close to where mines are located (Manyatshe *et al.*, 2017). The discharge of improperly treated wastewater into river systems has been a common practice in developing countries (Nhapi and Tirivarombo, 2004). Assessing and monitoring of water quality of the rivers is important in order to identify rivers that have been vulnerable and exposed to pollution impacts as a result of rapid urbanization (Pantshwa *et al.*, 2009).

The Mooi River Catchment is known to provide farmers with water for irrigation, mining activities and for other agricultural purposes. Wastewater discharges in the Mooi River and in its tributaries is regulated, yet the same water is a source of drinking water for communities and their livestock who are located within the study area (Venter *et al.*, 2013). The Upper Vaal Water Management Area’s water quality status is affected by the mining activities and excessive volumes of substandard treated sewage that is being discharged into the environment. The Mooi River has water quality problems that affects recreation and other activities emanating from physical interruptions and changes to the river channel, urban runoff, sewage disposal and mining activities (DWA, 2012b). If the issues around the Mooi River are not attended to they could affect the ecosystem integrity as well as pose health risk (Wade *et al.,* 2000).

1.2. PROBLEM STATEMENT

South Africa has been classified as water scarce country (Otieno and Ochieng, 2004) and hence proper management of the water resources and its distribution became a priority. (Annandale and Nealer, 2011). The country once experienced little and even no rains as a result of drought. Major rivers ran dry thus affecting the livelihood of the people and livestock since rivers depend on adequate rainwater in their watersheds or confluences. There were increasing number of industries and agricultural sectors that were adversely affected by scarcity of water in South Africa (Smakhtin *et al*., 2004). Projections are that by the year 2025, most regions and countries will suffer from water scarcity (Seckler *et al.,* 1999). The issue of non-availability of water and even shortages of water are not only faced by South Africa; it is a global concern (Naidoo, 2013a; Seckler, 2003; Smakhtin *et al.*, 2004). It has been projected that in the near future, demand of clean water will be higher than what would be supplied, causing recession of economies (Blaine, 2013).

Contamination of surface and underground water is caused by human (domestic and industrial) activities (Masere *et al.*, 2012). The wastewater that is generated from these activities should be treated to quality standards of water that is safe to discharge back into the watercourse (Dickens and Graham, 1998; Corcoran *et al.*, 2010; USEPA, 2004; Dube *et al.*, 2010). However, most of the municipality wastewater treatment works (WWTW) are old and overburdened with high volumes of sewage, resulting in partial removal of waste particulates. . The wastes that are directed to these plants have become costly to treat as their sources are quite variable and complex. This come at the back of reduced budgets from national treasury. Illegal dumping of solid wastes in undesignated places or directly into the rivers occurs on a frequent basis (Helmer *et al.*, 1997). In developing and developed countries, untreated faecal matter (human as well as non-human) is a major contributor towards the deterioration of water quality of rapidly growing cities (Harwood *et al.*, 2000; USEPA, 2004).

Apart from the local sources, the Mooi River also receives pollution burdens from its tributaries namely: Wonderfontein Spruit and Loop Spruit that also contribute to water pollution challenges faced by the Mooi River Catchment. The far West-Rand of Gauteng is known for its mining activities that have an impact on the catchment resources. Areas around the Wonderfontein Spruit has a number of abandoned mineral tailings (IWQS, 1999; Annandale and Nealer, 2011; Barnard *et al.,* 2013). Leaching from these impoundments contaminate underground water which feeds pollution (including uranium wastes) into the catchment area (van der Walt *et al.*, 2002; Coetzee, 2004; Fosso-Kankeu *et al.*, 2015). The agricultural practices around the Mooi River as well as along its tributaries and urban related activities associated with Potchefstroom and other small towns have also been identified as sources of pollution (DWA, 2012b). The Mooi River has been classified as a class III water resource, indicating that the resource is heavily affected by human activities though still categorised as ecologically sustainable. The Mooi River's recommended ecological category is C/D, thus suggesting the resources is moderately to largely modified (DWA, 2016).

The intention of the study is to understand water quality issues specifically the impacts of sewage discharges into the Mooi River Catchment.

1.3. RESEARCH QUESTIONS

- How are the activities/operations of the sewage treatment plants located within the catchment area along the Mooi River and its feeding tributaries impacting negatively on the quality of the receiving water resources downstream of the WWTW plants?
- What pollutants (possibly derived from sewage treatment plants) dominate the pollution of the Mooi River?
- Is the pollution from sewage treatment works affecting the water quality and its suitability for drinking purposes from the Mooi River?

1.4. AIMS AND OBJECTIVES OF THE STUDY

The study aimed to look at how discharges affected the water quality of the Mooi River system in relation to the regularised discharge of treated water into the receiving water environment from the following WWTW:

- Kokosi WWTW into Loop spruit
- Flip Human WWTW into Wonderfonteinspruit
- Potchefstroom WWTW into Mooi River

This will be evaluated against national and international water and wastewater standards in order to establish whether there is any significant of pollution emanating from the sewage discharged into the river from the wastewater treatment plants discharging into the Mooi River Catchment.

This will be achieved through the following study objectives:

- Assessing the trends in the concentrations of selected chemical parameters and the values of physical and microbiological water quality indicators as a result of direct discharge of treated wastewater into the Mooi River and its tributaries.
- Comparing the values of these water quality indicators against set national and other international regulatory standards so as to determine the potential risk of direct discharge of treated wastewater into Mooi River and its tributaries.
- Determining the pollution impact and change in water quality over the years from 2015 to 2018 at a single historical water quality monitoring station of the Mooi River Catchment.

1.5. HYPOTHESIS

The sewage treatment plants treat raw sewage to a quality level where it can be discharged safely into the Mooi River without posing a risk to downstream users and aquatic ecosystems.

1.6. LAYOUT OF THE STUDY

The mini-dissertation consist of five chapters and is organised as follows:

Chapter 1: Introduction, justification of the study, aims and objectives of the study including the hypothesis.

Chapter 2: A literature review of similar work that has been done locally (South Africa and within the SADC region) as well as globally in respect to wastewater treatment, disposal and its potential impact on receiving water basins.

Chapter 3: Discusses materials and methods adopted in this research study. It further outlines the environmental setting of the study area.

Chapter 4: Discusses findings and results of the research study.

Chapter 5: Conclusions and recommendations drawn from the study.

CHAPTER 2: LITERATURE REVIEW

2.1. WATER QUALITY

Water quality is an attribute which relates to its fitness for an intended use. Humans use water for domestic purposes, commercial, agricultural purposes and for industrial purposes, hydrogeneration of power, washing in synthetic processes and food processing. The fitness for intended use is assessed in terms of its chemical composition and potential effects thereafter, hence the importance to develop catchment water quality plans (Helmer *et al.*, 1997). Therefore, it is imperative and important to measure these water quality indicators for surface water before it can be utilised for its intended use. The main concern on the quality of surface water is its safety from any pathogens *i.e.* it should be free from disease-causing pathogens that can potentially affect human health. It is recommended that microbiological examination is undertaken to monitor the quality of water (Barell *et al.*, 2000).

One of the growing challenges facing South African urban settlements is the ever deterioration in the quality of water of major water resources due to changes exacerbated by changes in land use and thus compromising the livelihoods of people and the ecosystem's (O'Keeffe *et al.*, 1992). This has put pressure on the country's capability to supply sufficient portable water at a standard that meet the current needs of the population as well as ensuring sustainability in its re-use in the near future (Otieno and Ochieng, 2004). It is therefore critical to undertake continuous monitoring studies on the quality of water of key South African water resources so as to assess the pollution impact and to detect trends (EEA, 1996) coming out of strategically located treatment plants, including the disposal of such treated water. One of the normal customs is to discharge the treated water back into the water resources. It is premised that the water is authorised to discharge treated water back into the natural water environment (Helmer *et al.*, 1997).

Water being a universal medium, dissolves a wide range of solutes, be it under natural conditions or in human specific use and activity. As a result, water is usually chosen as convenient medium to convey waste streams from processes that ranges from agricultural, chemical synthetic and sewerage systems (Chapman, 2002). Disposal of such wastewater can have an adverse impact on quality of the water in the receiving water resources. In addition, the disposal of such wastes put a risk to the use of water from the receiving water body due to possible injection of contaminants derived from the effluent. A good management practice is to monitor the impact of such treatment and disposal activities.. Quality parameters that should be checked to assess the extent of artificial injection of contaminants should include physico and bio-chemical characteristics. Apart from the adverse effects of waste disposal and other generated waste streams abetted by human activities in most urban built environment, climate change and changes in land use practices have had a long-term negative impact on the quality, suitability and availability of fresh water (Naidoo, 2013b).

The major challenges that lie in the treatment of wastewater for direct discharge back into river systems is that industries also convey their wastes, some of which are quite hazardous directly into their domestic sewer systems (CSIR, 2010). This makes the complete treatment of the wastewater very difficult and costly as all of the varied contaminants have to be removed to levels that would make the water safe for disposal through direct discharge. Those industries that divert their wastes to storage ponds or storage dams also risk contaminating soil and underground water. Old and decaying sewerage infrastructure, malfunctioning wastewater treatment works are the major sources of contaminant leakages into the natural water bodies servicing most urban settlements in South Africa (Mwangi, 2014). Unsecured sewerage systems, leaks of raw wastes and partially treated wastes into river and wetland systems also contributes to the pollution of these resources (Canada Gazette, 2010; Baloyi *et al*., 2014). The inefficiency of the sewage treatments works results in failure to eliminate persistent chemicals which is a cause for concern on water quality and human health. Previous impact assessment studies on water treatment and disposal activities at some wastewater treatment plants have recommended urgent upgrading of the treatment technology operational at most metropolitan treatment plants across South Africa (Hendricks, 2011).

2.1.1. Water Quality Parameters

Water is considered the most essential and valuable commodity (Das and Acharya, 2003). Its assessment and monitoring of its quality especially at the loop at which wastes are conveyed by water and later removed by physico-biochemical treatment processes for subsequent discharge back into natural waterways for reuse downstream is key to its sustainable management (Helmer *et al.*, 1997). Such water quality assessment studies contribute towards establishing national data sources or banks for pollution abatement campaigns. The data can thus be used for policy formulation and regulation so as to curb avoidable contamination and illegal discharge of wastes.

The monitoring and assessment usually involves measuring the values of the water quality parameters (physical, chemical and microbiological) (Meybeck and Helmer, 1992) and comparing the values with regulatory Standards. South Africa has stipulated standards and guidelines to ensure compliance and these also guide on the intended use of water. Examples include the South

African National Standard (SANS) 241:2015 for drinking water and South African Water Quality Guidelines for different user type (such as industrial, domestic, recreation).

Water quality monitoring is dependent on the intended use of water. There are certain parameters of concern in wastewater discharges such as power of hydrogen (pH), dissolved oxygen (DO), suspended solids (SS), chemical oxygen demand (COD) and biological oxygen demand (BOD), phosphate, metals, nitrates, nitrite and ammonia (Tufekci *et al.*, 1998). Any changes in these variables indicate potential pollution in water quality as they can easily influence biochemical reactions in water. Other variables may also change due to natural processes or any other human induced activities such as turbidity and temperature and *Escherichia coli* (*E. coli)*. The presence of pollutants thus resulting in exceedances of regulated specifications and parameters is not considered acceptable in the receiving environment as they pose risks to human health and to the aquatic species (EPA, 2000; DWA 1996a, 1996c).

Of the above discussed parameters conductivity, suspended solids, dissolved oxygen, ammonia, phosphates, COD, nitrates and *E. coli* count are recommended as key indicator of the quality of a wastewater and its potential risk in the receiving water (Akpor and Muchie, 2011).

2.2. SOURCES OF POLLUTION

Water is referred to as polluted when it is impaired by anthropogenic contaminants and either is not suitable for human consumption and or cannot support its biotic communities (Imoukhuede and Afuye, 2016; Pegram *et al.*, 2001). Water pollution is one of the major environmental issues worldwide. Water pollution refers to the disturbance of the physical and chemical characteristics of water resources (Dragicevic *et al.*, 2010). In simple terms it means the introduction or discharges of foreign substances into rivers and lakes thus affecting the functioning of the ecosystem (Helmer *et al.*, 1997). Pollution has indeed become a major threat that is continuously becoming critical because of lack and inefficient measures to protect surface water quality *(*Dube *et al.*, 2010; Halder and Islam, 2015). Water pollution affects drinking water, rivers, lakes and oceans worldwide which consequently affect human health and the environment (Ensink *et al.*, 2010; Juneja and Chaudhary, 2013).

The main cause of poor water quality are the contamination by human and other animal waste, chemicals, heavy metals, oils (Dube *et al.*, 2010; Drabowski and De Klerk, 2013; Esshaimi, 2013), rising populations, industrialisation (Muruven and Tekere, 2013) and agricultural activities leading pollution (Moss, 2007; de Clerq *et al.*, 2010). Figure 2.1 shows land use activities that contribute to pollution of water bodies.

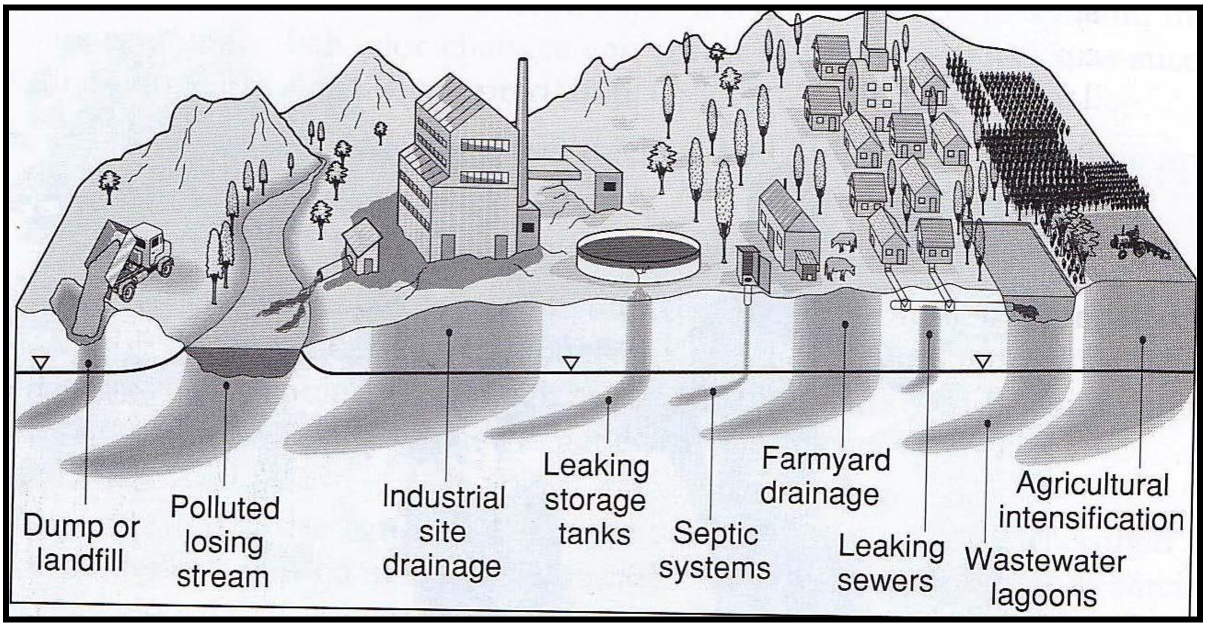

Figure 2. 1: Land use activities (Kresic, 2009)

There are several sources of water pollution as discussed above, but the key potential ones relevant to the study area of the Mooi river catchment are as follows:

- Soil erosion leading to sediments into the rivers;
- High nutrients loads from fertilizers, animal waste, and from sewage-treatment works;
- Pesticides;
- High salts from domestic and industrial effluents;
- Mine residues; and
- Toxic chemicals from manufactured products (Davies *et al.*, 1998 Frost and Sullivan, 2010)

2.2.1. Non-point source pollution

Nonpoint source pollution is a combination of pollutants from a large area rather than from specific identifiable sources such as discharge pipes. The key sources of non-point pollution emanate from urban developments, surface runoff and agricultural activities. Non-point source water pollution is distinct and it gets spread over a wider area thus affecting the aquatic environment at any time and point (Vink *et al.*, 1999). Their introduction into water resources makes monitoring and measurement very difficult since they are emanating from different points of entry. They are not easy to regulate (Hagedorn, 1999). Examples include but not limited to surface runoff originating from household activities such as washing from vegetable and animal products discharges from the swimming pool, oils and fuel from cars, building rubble; runoff from fertilizers and pesticides, acid rain; and seepage water from mines (Moses, 2005).

Non-point sources of pollution are often intermittent and linked to seasonal agricultural activities (International Labour Organisation, 2010). Non-point sources of pollution often emanate from extensive areas inland and are transported overland, underground, and through the air to receiving water environment (Holm, 2004). The developments closer to the river banks and other activities such as clearance of riparian vegetation, canalization, stormwater drainage inflows, spillages, and illegal dumping have proven to have an impact on the country's water resources (Mwangi, 2014). Ever growing informal settlements within the Mooi River Catchment is one of the potential negative impact affecting the system from the non-point source of pollution point of view (Labuschagne, 2017).

2.2.2. Point source pollution

Point sources are defined as originating points such as pipes from industries or treatment works and, or feedlots with specific points of discharge. These include WWTWs which release their final effluent into the aquatic environment (Huang and Xia, 2001). More examples include the discharge of effluent into water resources by factories, the emission of fluids, the spillage of toxic chemicals from industries such as pulp-and-paper mills including textile factories, and oil and fuel spillages from any operation or transportation. Point-source pollution refers pollutants or emissions which enter water receiving environment from an easily identifiable single source (Spulber *et al.*, 1998; Hanley *et al.*, 2001).

Point sources are therefore easier to measure, monitor and manage than non-point sources because emissions emanate from a known single point and water quality can be sampled at the outlet, upstream and also downstream to assess the level of impact on that water body (Muller, 2013; Moses, 2005; Holm, 2004). The only way to ensure that point source pollutants are managed is through regulating the quality and quantity of volumes of what is being disposed into the environment (Muller, 2013). Unregulated point source pollution interrupts the functioning of the aquatic ecosystem and makes river water unsafe for human consumption (Chimuriwo, 2016). Point source pollution especially from the sewage and industrial effluents is believed to have noticeable acute impact in water bodies in developing countries (Daniel *et al.*, 2002).

2.2.3. Indicators of sewage contamination

Improperly treated wastewater potentially contains high levels of the nutrients, nitrogen, phosphorus and faecal coliform. Levels of nitrates are used to indicate the nutrient status of water resources. High levels are related to influences from agricultural and urban activities in particular sewage discharges. Phosphates are also used to indicate the nutrient status of water resources. High levels are normally related to activities such as use of detergents and fertilisers. Faecal coliform levels are then used to illustrate levels of microbiological pollution, which poses potential risks to human health and in recreational activities (Chapman, 2002).

a) Suspended Solids (SS)

Suspended solids are particles that can enter surface water bodies from land-use practices, human induced activities, erosion, disturbance of riparian vegetation and from industrial and/ or domestic discharges carrying suspended sediment loads (DEAT, 2006). Impacts of sediment pollution include alteration of the habitat for the aquatic species resulting to changes in the species diversity in a water resource. The feeding capacity of fish are affected as suspended solids impair visibility and food then becomes buried in silt, respiration process is also impaired (Kazunga *et al.,* 2002). SS as particles found suspended in the wastewater are removed through sedimentation and filtration during the treatment process.

b) Electrical Conductivity (EC)

Electrical conductivity (EC) is defined as a measure of the ability of water to conduct an electric current (Dallas & Day 2004; (DWAF, 1996a). EC measures the total amount of material that is dissolved in a sample of water and is therefore often used in the general characterisation of water quality (Dallas & Day 2004). The value of EC is directly propotional to total dissolved solutes (TDS) in the water. Changes in TDS concentrations can be toxic since the density of the water determines the flow of water into and out of the organism's cells (Mitchell and Stapp, 1992; Du Preez *et al.*, 2000). In the natural environment, concentration levels of the EC accumulate naturally and also due to anthropogenic activities such as domestic and industrial wastewater discharges and surface run-off (Du Preez *et al.*, 2000). Elevated levels of EC in isolated water bodies can also be an indication of excessive evaporation especially during drought seasons and even gives water a brackish taste and that affects the aquatic life in that receiving water environment (Morrison *et al*., 2001). Alternatively, high salt content may arise from agricultural activities, particularly in the presence of chlorine and sulphate (Walsh and Wepener, 2009).

c) pH

The pH is a measure of the concentration of protons as a negative logarithm on concentration in a scale than range from 0 -14. It is an indicator of the acidity or alkalinity of water. Safe water has a pH, which is almost neutral water to ensure support to plant and animal life. A change in stream water pH can also affect aquatic life indirectly by altering other aspects of water chemistry. High pH values are toxic to plant and animal species as well as corrosive to natural and synthetic materials (Morrison *et al*., 2001). Low and high pH affect both plant and animal life as some fish will not even survive at low pH, acidic pH increases the gill permeability in fish (Wright and Welbourn, 2002). For example, low pH levels can increase the solubility of certain heavy metals. This allows the metals to be more easily absorbed by aquatic organisms. During the chemical treatment of wastes in the treatment plants, pH is manipulated so as to separate wastes by coagulation; removal of ammonia; disinfection and preventing some biochemical related reactions (Naidoo, 2013b). High pH of fresh water is also toxic and corrosive due to artificial addition of alkaline wastes and sometimes this may be due formation of ammonia from nutrient ions and reducing conditions.

d) Nutrients

Nutrients are those chemicals needed for plant growth and reproduction (Davies *et al.*, 1998). There are those nutrients that occur naturally which are vital for normal growth of living species. The same nutrients, however can be harmful if found in certain unacceptable levels and could pose risk to human and animals. Nitrogen originates mainly from raw faeces and untreated sewage and it has been discovered that nutrients loads result to reduced concentrations of dissolved oxygen in the receiving environment and negatively affecting the ecosystem (Morrison *et al.*, 2001). Nutrients are not the only issue associated with sewage discharges, also the microbiological contamination as a result of runoffs from informal settlements and sewage works has also posed a risk to the aquatic system (Fatoki *et al.,* 2001). The presence of nutrients in rivers often encourages excessive plant growth. Nutrient enrichment provides conditions that promotes the growth of waterweeds such as water hyacinth and water lettuce (Degner and Howat, 1997).

The two common nutrients found in water environment are nitrogen and phosphorus mostly originating from anthropogenic activities such as agricultural runoffs (fertilizers), untreated domestic sewage and industrial effluent discharges. Elevated nutrient loads result in eutrophication in river systems and thus stimulating algal blooms (Masere *et al.*, 2012). Eutrophication refers the unnaturally enhanced primary productivity and loading of organic matters in water environment as a result of increased concentrations of nutrients emanating from unregulated and improper disposal of municipal sewage (Chapman, 1996). Eutrophication emanating from nutrient enrichment has been identified as the most serious risk to the aquatic life (Pieterse *et al.*, 2003).

Nutrients such as ammonia and nitrates are known to be fatally toxic to aquatic species when concentration levels are excessive and could lead to excessive production of plants and problematic algal blooms (Chapman, 1996). The known ecological impacts of eutrophication include release of toxins causing deaths in animals due to decayed algae; human health risk due to inadequate water treatment; and economic impacts as a result of livestock deaths, elevated water treatment costs. Continuous loading of effluents into the river affects the self-purification capacity of the systems as well as the natural flow of river waters and thus endangering aquatic life (Seanego and Moyo, 2013). Nitrogen exposure has been reported and implicated in adverse health effects. The naturally occurring of nitrogen ions that are part of water cycle combined with haemoglobin result in methaemoglobinemia, an illness that affects bottle-fed babies (Fewtrell, 2004).

The common forms of nitrogen are mainly ammonia and nitrate. Ammonia is volatile and can be injected from external source e.g. alkaline cleaning products or can be formed in equilibrium with ammonium salts from fertilizers; and in sewage and industrial discharges. Ammonia is toxic to fish and can be oxidised to form nutrients ions which causes eutrophication of natural aquatics (Naidoo, 2013b). Nutrient ions in wastewater come from inorganic fertiliser as well as from domestic sewerage effluent. Failure to completely remove these nutrients poses a serious risk of algal blooms in water bodies receiving the waste (Odjadjare and Okoh, 2009).

I. Ammonia

Ammonia is a good indicator for water quality especially for land use where agricultural activities dominate as nitrogen is fixed by plants and soil microbes in soil and water and thus can end up in aquatic systems (Rounsevell & Reay, 2009). Ammonia may be found in household detergents and in industrial chemicals. Ammonia and nitrates are said to be positively correlated to wastewater treatment works because high levels of ammonia and/or nitrates are usually experienced. Ammonia is oxidised then forms nitrite which is further oxidised to form nitrate, and on the other side; in areas where COD levels are high, nitrates are reduced to form nitrites and then ammonia (Sanchez *et al*., 2007). Ammonia, pH and COD are closely related to each other, and all can be seasonally influenced individually.

II. Nitrate

Nitrate is strongly related to the presence of nitrites and ammonia in water bodies as these are either oxidised or reduced respectively and change from one form to another. Nitrate is an important nutrient for plant growth. Most farmers use nitrogen rich fertilizers for the stimulation of the crop growth (Schröder *et al*., 2004). Nitrogen production may also occur naturally from atmospheric deposition during lightning storms. Elevated levels of nutrient loading in water resources cause eutrophication which results to a decline in water quality. Nitrates are often present as a result of agricultural runoff and/ or from sewage and effluent (Wade *et al*., 2008). The presence of nitrate in the WWTWs may also be an indication of inefficiency of the WWTWs.

III. Phosphates

Phosphate is an indicator of many factors that affect water quality. Elevated levels of phosphate concentration indicate urban land use as it arises from domestic detergents, industrial and human wastewater. It may also indicate the use impacts from agricultural land uses (fertilisers and nutrients) into water resources. Phosphorous is an vital nutrient necessary for plant growth (Schröder *et al*., 2004) it further stimulates algal blooms and promotes growth to unwanted aquatic vegetation which may have a potential to cause oxygen depletion and thus affecting species. Phosphate is known for its effect on water quality, as it causes eutrophication due to nutrient loading from agricultural run-off and wastewater discharges. This may also affect the flow of water, drainage and the earation (Paul, 2011). Orthophosphate comes from both sewage waste (organic) and fertilisers (inorganic) and the known major sources of pollution include industrial effluent, domestic detergents and human wastewater (Verheul, 2012).

e) Chemical Oxygen Demand (COD)

Chemical oxygen demand (COD) is a measure of the oxidation of reduced chemicals in water (King *et al*, 2003; Lee *et al*., 2009). The higher the COD detected in water, the higher the presence of the oxidisable contaminants in the water (Naidoo, 2013b). It is commonly used to indirectly measure the amount of organic compounds in water and is useful as an indicator of organic pollution in surface water. A rise in COD may be caused by an excessive urban land use activities from agriculture to wastewater which causes nutrient loading in the water environment; thus afftecting Dissolved Oxygen (DO) (Bere & Tundisi, 2011). Nutrient loading from WWTWs and urban runoff causes increased nutrients and reactions between ammonia and nitrate in turn causes an increase in COD (Verheul, 2012).

f) Microbiological Parameters

Microbiological assessments in water are critical and are used to identify the presence of microorganisms related to the transmission of water-borne diseases and possibly the presence of faecal contamination. Ashbolt *et al.,* 2001). Faecal contamination in water is a worldwide issue and more especially with the rural communities who still rely on untreated water for consumption (Naidoo, 2013b). There are health related risks that have been associated with the use of microbiologically contaminated water which is of great concern (Pandey, 2006). The common indicator organisms in waste water receiving environment are total and faecal coliforms. These coliforms indicate faecal pollution in water which than makes water not suitable for consumption purposes and disinfectants need then to be used to kill the bacteria and microorganisms.

The bacterial indicators currently used world-wide in water quality as well as during health risks assessments include but not limited to *E. coli*, enterococci, total and faecal coliforms (DWAF, 1996a). These indicators are subjected to set government rules (limits) to ensure compliance. *E. coli* is used as an indicator of faecal contamination in water quality environment (Meays *et al.,* 2004). Total and faecal coliforms in water indicates the general quality of water and potentially faecally contaminated source and basically indicating the presence of pathogens in water and the efficiency of wastewater treatment facilities (Ashbolt *et al.,* 2001). It has been proven that coliform bacteria are in abundance on warm blooded mammals and then used to indicate sanitary quality of water resources since their presence indicates faecal contamination.

I. *E. coli*

Escherichia coli (*E. coli)* has been used as the most precise indicator of feaecal coliforms and has been certified as a dependable and best bacterial indicator of faecal contamination in the drinking water sector (Odonkor and Ampofo, 2013). *E. coli* falls under the faecal coliform group and has been commonly regarded as the first microorganisms of relevance in water monitoring programs since it serves as a primary indication of faecal pollution in water (Naidoo, 2013b). There are health risks as a result of exposure to infections from the pathogens such as diarrhoea (cholera), urinary tract infections, typhoid, hepatitis and cryptosporidiosis and others (WHO, 1993). Presence of *E. coli* pathogens results to the deterioration in water quality due to unsecured faecal wastes (DWAF, 1996b). These are released by humans and animals, or sewage leakages into water (DWAF, 1996a)**.** The *E. coli*, may be released into aquatic environment as a result of poorly functioning and overloaded WWTWs, informal settlements as well as agriculture land-use. The high concentrations of *E. coli* present at any influent, upstream and downstream points could be associated with the wastewater containing sewage and sanitary wastes and runoff into the river, respectively (Chapman, 1996).

II. Total coliforms and faecal coliforms

Faecal coliforms have been mainly used to indicate the microbiological quality of surface and ground waters (Colford *et al.,* 2007). Faecal coliforms are thus used as an indicator of potential faecal pollution of surface water. This indicator is normally used when evaluating the quality of waste water effluents into water resources (DWAF, 1996b). Coliforms are a group of bacteria which are rod-shaped Gram-negative non-spore forming and motile or non-motile bacteria which ferment lactose resulting into the formation of acidic gases in the bowels of warm blooded mammals. The known and common are the faecal coliforms examplified by *E. coli*. These have the ability to multiply rapidly even at an elevated temperature (WHO, 2008). Total coliforms are found in both sewage and natural water environment through human and animals faecal waste. Total coliforms are known to be sensitive to disinfection as compared to other bacteria and viruses and they disappear immediately after disinfection is used (Naidoo, 2013b).The coliforms can grow in water and survive other conditions, hence they are mainly useful for indicating the effectiveness of the WWTWs (WHO, 2008).

g) Metal pollution

The metals have been identified as common pollutants, which are widely distributed in the natural environment with sources mainly from soils and mineral weathering. The metals would naturally occur at low concentrations that have been proven to be non-toxic to the aquatic life (Dallas and Day, 2004). The elevated concentrations in metal contamination is a threat as these metals accumulate in the tissues of various aquatic species such as fish and thus affecting the species richness, diversity and distribution (Milenkovic *et al*., 2005). There are people that still rely on raw water for consumption, their lives are threatened by heavy metal pollution in water. In all pollutants found on the aquatic system, metals form a vital group of hazardous substances to the environment (Chimuriwo, 2016). The presence of metals in wastewater is influenced by the physical and chemical conditions of the effluent and the receiving environment (Gagnon *et al*., 2006). Accumulation of metals in an aquatic environment has negative impact to both man and the system itself. Most metals are removed from the liquid wastes during the treatment process and end up in the solids formed as a result of the treatment process. Population growth does impact on the removal of metals in wastewater treatment as the plant will be forced to ensure more volumes of influents are treated than what it is actually designed for (Manugufala *et al.,* 2011). Hardness mitigates metals toxicity, because Ca2+ and Mg2+ help keep fish from absorbing metals such as lead, arsenic, and cadmium into their bloodstream through their gills. The greater the hardness, the harder it is for toxic metals to be absorbed through the gills (Jaishankar *et al*., 2014).

The presence of metals in surface water can occur naturally or as a result of anthropogenic activities. Metal element contamination in water from anthropogenic sources includes discharges of untreated domestic and industrial wastewater, fuel spillages and illegal dumping of solid waste. Metals are also known and associated with cell damages in humans and animals. Some metals are essential nutrients that are needed for various biochemical and physical functions. Inadequate supply of these nutrients may result in a variety of deficiency diseases and/ or syndromes (WHO, 1996). Zinc is a known trace metal essential for human health and is vital for the functioning of the tissues and regulates key processes, though excessive zinc may cause serious health problems, such as nausea, stomach cramps, vomiting, skin irritations and anemia (Oyaro *et al.*, 2007). Lead can damage central nervous system, kidneys, liver, reproductive system and brain cells. The symptoms are weakness of muscles, anemia, insomnia, headache, dizziness and renal damages (Naseem and Tahir, 2001; Duruibe *et al.*, 2007). Mercury is a metal that has a potential to affect the central nervous system. Elevated levels of mercury cause impairment of kidney functioning and cause chest pain (Namasivayam and Kadirvelu, 1999). Copper is good for animal metabolism though excessive exposure to this metal may cause vomiting, cramps and/ or even fatality (Paulino *et al*., 2006). High concentrations of nickel may cause serious lung and kidney failures aside from gastrointestinal disorders and skin problems (Borba *et al*., 2006). Prolonged exposure to some of these heavy metals in particular the cadmium can lead to deaths (Hemdan *et al.*, 2006).

2.3. LAND AND WATER USE IN THE MOOI RIVER CATCHMENT

Mining activities commenced around the 1930's in the Wonderfontein sub-catchment. The mines are mostly around the Krugersdorp and Carletonville areas. They affected the quality of water in the upper and middle catchment of the Wonderfontein Spruit, as well as the upper reaches of the Loop Spruit. Effluent, wastewater and storm water, including effluent from various urban developments and industries as well as informal settlements are discharged into the Wonderfontein Spruit, thus contaminating the water environment (van de Walt *et al.*, 2002). The river systems and dolomitic compartments are polluted due to leaching from mining tailings dams and slimes dams. These mining facilities most of the time are in a poor state and thus contribute to pollution of water in the area (Tlokwe City Council, 2011). In the Lower Wonderfontein Spruit, farming activities and large-scale mining have been identified as major land uses resulting in the formation of the sinkholes and causing the water table to drop. This has had a major impact on the farmers mostly. The confluence of the Wonderfontein Spruit and the Mooi River takes place just upstream of the Boskop Dam (van de Walt *et al.*, 2002).

Land-uses around the Loop Spruit sub-catchment are mainly crop farming and grazing. There are a couple of goldmines, around the watershed between the Loop Spruit and the Wonderfontein Spruit sub-catchments which also discharge wastewater into the Loop Spruit. The Loop Spruit then joins the Mooi River downstream of Potchefstroom. The predominant land-uses in the Mooi River sub-catchment are crop farming and grazing, although a few small-scale diamond mines occur along the Mooi River between the Klerkskraal and Boskop Dams. These mining activities are affecting the floodplain and riparian habitats and have caused silting of the Mooi River upstream of Boskop Dam. This poses a risk to farmers using the water for irrigation and stock watering (van de Walt *et al.,* 2002).

The WWTWs mainly contribute to phosphates, nitrates and in some cases organic chemicals because of the discharge of sewage sludge and or untreated sewage (Henze, 2008). The agricultural practices along the Mooi River may potentially contribute towards nitrogen and phosphate loads in the system. Indications are that both farming practices and WWTWs contribute to high faecal bacterial contamination into the rivers. (Tlokwe City Council, 2011). Water from the Boskop Dam is used around Potchefstroom for some industrial, agricultural and recreational purposes.

2.4. CHALLENGES FACING WATER QUALITY IN SOUTH AFRICA

The South African national government is aware and concerned about the state of rivers in terms of quality and the status of the WWTWs in and around the country. The deteriorating water quality of the rivers is one of the major threats to South Africa's capability to provide sufficient water of appropriate quality to meet its population's need and to ensure environmental sustainability (Singh and Lin, 2015). Water of poor quality not only reduces its usefulness; it also affects the society economically. The more polluted the water sources the higher the costs for treating that particular water. This is evident in most part of South Africa where health risks and outbreaks have occurred (Griesel *et al.,* 2006). In South Africa pollution of water is not as a result of change in the environment only but also contribution from societal related external factors. During the apartheid era, mine labour forces were sourced from rural communities in different parts of the country where they were either forced to create their temporary homesteads closer to work or accommodated in mine constructed hostels. In most of these residential areas there were hardly proper ablution facilities. As a result, there was rapid growth in population of most urban or industrial settlements with no upgrade in handling incapacity to match the overpopulation in cities, leading to challenges into their wastewater systems (Grobicki *et al.*, 2001).

Most South African river systems are polluted with faecal coliforms. The faecal contamination in rivers can be attributed to the disposal of improperly treated sewage. These coliforms are mainly bacteria and viruses which are indicators of pollution. Coliforms, *E. coli*, and faecal streptococci are used worldwide as indicators of faecal pollution in water systems (Akpor and Muchie, 2011). Literature has revealed that another cause of water pollution in South Africa is the poor operational state and improper maintenance of the municipal WWTWs which poses a health and economic risk to those that still rely on raw water from the rivers. When substandard or inadequately treated sewage is discharged into the rivers, the oxygen demand and nutrients load in a source is affected and thus leading to eutrophication creating instability to the aquatic species (Ogunfowokan *et al.,* 2005).

The following are some of the common and key issues facing the wastewater treatment industry internationally and locally:

- The wastewater treatment works including their associated facilities have aged and are worn out, thus requiring improvements, repairs and replacement of some of the equipment to ensure sustainability and longevity of use;
- The composition and volumes of effluent with contaminants have introduced serious and complex problems now compared to the historical challenges; and
- The population growth is affecting current wastewater treatment infrastructure thus demanding new or highly refurbished plants because of capacity issues (EPA, 2004).

The identified common issues facing South African WWTWs are the following:

- Power failures;
- Mechanical failures or process failures;
- Flooding: stormwater ingress;
- Storage in sludge dams: contamination of ground water;
- Chlorine overdosing; and
- Shock load over school holiday seasons (in particular during Christmas breaks) (WIN-SA, 2011);
- Poor plant designs, inadequate capacity due to overload, poor operation and lack of maintenance and faulty WWTWs equipments (Mema, 2010)

2.5. EFFECTS OF WATER POLLUTION

2.5.1. Effects on the receiving environment

The wastewater from the municipal treatment works contains certain amount of pollutants in the form of pathogenic organisms, which results to deterioration of water quality of the aqualitic environment they are discharged into (Akpor and Muchie, 2011). Pathogenic microorganisms are known to pose the health associated risks. These pollutants enter the water resources through the release of partial treated wastewater and/ or through sewage pipe leakages; leaching of substandard septic tanks. It is therefore required to monitor the effluents quality discharged into the water sources in order to maintain the ecosystem (NEMA, 1998).

Healthy river systems are important to humans as they provide various services to meet human needs (De Villiers and Graham, 2016). Any changes in physical water variables such as temperature, turbidity and TDS, or changes in chemical variables such as salinity, pH, salinity, inorganic and organic nutrients, DO, inorganic salts, and toxic matters, such as cyanide and lead, pose a serious threat to the environment (Palmer *et al.*, 2004). Sewage discharged in water resources has been identified as the major source of pollution in many systems. The deposition of organic matters and nutrients has been discovered to have an effect on the micro-and-macro-fauna present in the surrounding environment (Naidoo, 2013b).

Apart from the environmental and natural process disturbances, sewage discharge has always been a point source potentially containing heavy metals and pathogens (Daniel *et al.*, 2002). Other sources of potential anthropogenic risks negatively impacting on the Mooi River Catchment are the mine closures affecting the groundwater and the surface water quality (Coetzee, 2009). The Mooi River sub-catchment within the Mooi River Catchment is categorised as a class III water resource, which indicates major impacted area as a result of human activities but it is also considered ecologically sustainable. Its recommended ecological category is C/D, which basically indicates that the system is moderately to largely modified (DWA, 2016). These impacts leading to such ecological status are as a result of human activities and sewage discharges being one of them. The license holders (or wastewater plant operators) responsible for discharging sewage or effluent into the water resources are then required to monitor both upstream and downstream of the receiving environment as part of their permit conditions to ensure compliance and sustainability of the resources.

2.5.2. Health risks associated with water pollution

Water pollution has been one of the major impacts affecting water bodies. Water pollution resulting from industrial and sewage discharges has contributed greatly to human health risks in the developing countries. The communities located downstream of the municipal sewage discharge point or where contaminated water environment are at risk of due to increased microbial bacteria and deteriorating physical and chemical indicators (Wakelin *et al.*, 2008) They are also the cause for many diseases such as gastrointestinal infections. Other infections associated with wastewater include dysentery, typhoid, cancer human enteritis, and stomach ulcers (Liang *et al.,* 2006). The greatest concern related to microbial pollution is mainly the risk of human and livestock related illnesses after prolonged exposure to contaminated water from the systems (Naidoo, 2013b). The water bodies used as recreational facilities may serve as a source of infectious diseases which may be transmitted through body contact or even through ingestion of contaminated water (DWAF, 1996d).

It is also known a variety of skin and ear infections may be caused by contaminated waters coming directly into contact with the broken skin and also when that water penetrates the ear. The discharge of poorly treated wastewater often results in increased number of bacterial, viruses and pathogens which may be a cause of waterborne related diseases and infections (Okoh *et al.*, 2010). There are indirect health risks identified such as the presence of mosquito, chemical contaminants which may lead to more human health risks (Coetzee, 2003). Some chemicals are either found occurring naturally in land or are introduced by human activities and usually dissolve in the water, contaminating it and causing various infectious diseases (Moses, 2005). Studies were carried out in 5 catchments of the North West Province which included the Mooi River to determine the presence of pathogenics such as *E. coli*, *Salmonella*, *Klebsiella* and *Shigella* species of which it was positive due to wastewater discharges into the system. Indications were that though they may be minimal direct human consumption of water from the water resources but indirectly they were consuming these pathogens through fish. Eating the fish raw or undercooked poses human health concerns (Sibanda *et al.*, 2015).

2.5.3. Effect of sewage effluent on the suitability of water for drinking purposes

Water for drinking purposes is abstracted from surface waters such as rivers, dams and sometimes ground water sources are considered such as boreholes. Because of urban development and human activities along the catchments which may affect the quality and quantity of the resource, it is therefore it is important that these resources are assessed and monitored. Polluted resources not only threaten public health as some of the communities still rely on the resources directly but it also affects them economically and aesthetically (Water Research Commission, 2002). In most parts of South Africa, many communities still use untreated water from surface and groundwater for their daily needs and it is usually contaminated with faecal matters due to wastewater discharges. Any form of contact with contaminated waters, either through mural activities or consumption is a health risk (Farasat *et al.*, 2012).

Water quality can be classified according to its intended use and purpose. There are cases polluted water could not be used for human consumption but still be useful in other activities by industrial and agricultural sectors. Studies have revealed that anthropogenic activities do affect natural processes and resulting into poor water quality, such as agriculture and effluent or wastewater discharges (Chimuriwo, 2016). As a result of poor water quality aesthetic impacts such as bad taste and odours in drinking water are evident (Moses, 2005). Within the Mooi River Catchment, Mooi River system is considered the key source of potable water for the people living in and around the Potchefstroom town, its worsening water quality will affect most communities (Venter *et al.,* 2013). Apart from the system being used for drinking purposes, the Mooi River is largely used for industrial purposes and mostly around Potchefstroom, and is also used for angling and other for other recreational purposes (Labuschagne, 2017). The main land-use activities in the north of the sub-catchment are crop farming as well as grazing (van der Walt *et al*., 2002).

2.6. SOUTH AFRICAN WATER LEGISLATION AND MANAGEMENT

The environmental impacts emanating from municipal wastewater disposal are controlled by various legislations and policies. South Africa has developed these guidelines, standards and policies to safeguard the national water resources and to ensure water needs are met. This is done through Department of Water and Sanitation (DWS), who are the custodian of the country's water resources. The pieces of legislation developed by DWS are aimed at ensuring that water entering the national water bodies meets the set standards for the protection of human health and aquatic life. Over time, challenges on water quality have been experienced, hence DWS then has imposed specific quality limits as part of the legislative requirements to prevent and curb pollution issues (Smethurst, 1988).

The legislations governing the water management and wastewater discharges into water resources in South Africa is very broad and focuses on different aspects of water protection and use**.** The National Water Act (No. 36 of 1998) (DWAF, 1998) and the Water Services Act (No. 108 of 1997) (DWAF, 1997) provides comprehensive coverage of the different aspects of wastewater treatment. The challenge with water and wastewater related laws and policies is that they have been identified in different documents and thus making it difficult and time-consuming to access, hence a need for a comprehensive document that will consolidate all these laws and policies into one user friendly and easily accessible document (Muller, 2013).

The National Water Act (NWA) covers regulatory issues on resource management whereas the Water Services Act (WSA) sets the mandate on water services provision and setting licence criteria for discharge (Muller, 2013). The challenge with the two frameworks is that they only make provision for general authorisations for discharging into streams and rivers but there is no mention of the compliance levels of the treatment. This then calls for the real need to have a single set of regulations and standards specifically for discharges of wastewater from the treatment works into water resources (Gaydon *et al.,* 2007).

2.6.1. National Water Policy

The National Water Policy was developed and adopted in 1997. The key principles driving the policy are equal availability of water for all citizens considering the current and future generations. The policy further affords all citizens a right to clean water whilst maintaining the ecological sustainability. The principles of the Constitution are embedded in this policy (Mosoa, 2013). Water policy requires that households should receive up to 6000 liters of water free of charge every month. Improper management of wastewater was identified as priority; however, deteriorating water quality has adverse effects on human health in other areas, activated by the lack of sanitation and the non-functioning of water supply schemes (Mackintosh and Colvin, 2003). The National Water Policy requires that water resources be developed and managed in such a manner as to allow all water user sectors to gain equitable access to the desired volumes, quality and reliability of water (DWAF, 1997).

2.6.2. Constitution of Republic of South Africa

The Constitution of the Republic of South Africa (Act no. 108 of 1996) states thus everyone has the right to a protected and safe environment through legislations that ensure pollution prevention, promote conservation and sustainability, and degradation prevention (Parliament of RSA, 1996). Water is considered a scarce resource that requires all measures to ensure it is protected and used wisely. Over and above the protection of water for human consumption and benefit, the aquatic environment is also entitled to the same rights and benefits (Naidoo, 2013b). The Constitution has allocated the management of the water resources to the National Government as custodian, and the management of water and sanitation services to local government. In line with the provision in the Constitution (Act 108 of 1996) that national government is the custodian of the sources of water, such as rivers, groundwater and dams; and the Minister of the Department of Water was given the mandate by the National Water Act to act on behalf of the nation, to protect, use, develop, conserve, manage and control water resources as a whole (DWAF, 2013).

2.6.3. National Water Act (NWA)

The NWA’s mandate is to promote the implementation of an Integrated Water Resource Management (IWRM) framework, which serves as a guide to achieve a balance between water resource use and resource protection in an integrated, economically and environmentally sustainable manner (RSA, 1998). The NWA is based on the principles of equity; efficiency and sustainability (Muller, 2013). The NWA is aimed at promoting the sustainable use and protection of water resources, making the management and monitoring of sewage treatment plants so mandatory. The Act requires a licence discharging any form of treated wastes back into the water system and where such practice is done there should be consistent monitoring of the quality of water and records kept of such since some people still rely on untreated water from the resources for their daily supply. In the case of wastewater treatment plants this implies that the right technology and plans on maintenance of the works, as well as emergency measures be put in place to prevent pollution from treated water effluents as well as the solid sludge up to its safe disposal (WRC, 2002).

The licences approved and issued by DWS are either in a form of a General Authorisation (GA) or Water Use Licence. The Government Notice (DWAF, 2013) published qualifies specific water use activities related to wastewater discharges as those requiring the GA as opposed to the full licence requirements depending on the extent and nature of a particular discharge activity. The Act further provides for Water Use Licence requirements in terms of Section 22 (3) for certain wastewater discharging activities where DWS as the authority grants the applicant approval where the requirements and the purpose of the Act have been met (Belcher and Grobler, 2014).

Kokosi, Flip Human and Tlokwe WWTWs are currently operated in terms of different water use licences issued by DWS, which permit them for the treated wastewater to be discharged into the Loopspruit, Wonderfontein Spruit and Mooi River systems respectively. Chapter 3 of NWA focuses on pollution prevention with certain requirements for the users whose activities may impact negatively on the resources that those individuals should implement (Hendricks, 2011). The definition not only focuses on the physical, chemical and biological changes due to pollution, but it also covers the potential impacts on the users thus making it easy to assess and quantify pollution at different levels. In this way the sources of pollution should be easily identified; with the origins and sources of water pollution are identified in the subsequent section (Moses, 2005).

The NWA has developed effluent quality standards for the discharges of effluent into the water resources as described in Government Gazette No. 20526 (RSA DWAF, 1999) which superseded previous General and Special Effluent Standards (SA Government Gazette, 1984). These latest standards are based on the quality of the receiving environment which allows for a determined quality of effluent to be discharged. Table v and vi (in Appendix 3) show discharge limits (General and Special Effluent standards) for different elements including *E. coli,* ammonia and nitrate, on which this study focuses. General Limit are normally applied unless wastewater is being discharged into sensitive or protected areas, then the special limits apply (Government Gazette, 1984). Special limits are used when the effluent arising in the catchment area is discharged into any river or tributary at any place between the source and the river. General Limits are then applied on effluent arising in any area other than the special standard is applicable, e.g. protected areas (SA Government Gazette, 1984). These limits are applied to wastewater works who have not been granted a GA or WUL.

The NWA also makes provision for the development and implementation of the Resource Quality Objectives (RQO) in order to ensure that the country's water resources are protected for future and used sustainably. The aim of the RQO is to set distinct goals with regards to the quality of water resources. The act further indicates the need to balance between the need protection and utilization a water resource (DWA, 2014). The classes and RQOs were determined for all significant water resource of the Upper Vaal Water Management Area, of which the Mooi River Catchment is part. The Mooi River was classified as class III and Recommended Ecological Category (REC) and water quality category D (indicating the system is largely modified) and RQOs indicating the need to improve the salts and nutrients in order to ensure the ecosystem’s heath and suitability for different uses (DWS, 2016).

2.6.4. Water Services Act (WSA)

The discharge of industrial effluent and wastewater is done in accordance with the requirements of the NWA and the WSA where local authorities have the responsibility to treat before disposing wastewater as per the requirements of the Act and other environmental legislations. Each user or discharger is required and expected to ensure effluent discharged into the resource meets the set and legislated standards (Bekal *et al.*, 2003). The WSA requires that the drinking water and sanitation provisions be managed by local government and municipalities (RSA, 1997). It contains rules and regulations to municipalities on how they should provide water services. The main users of the Water Services Act are institutions, such as municipalities, who are focused on water service provision to water users. It is crucial that the Water Services Act be read in conjunction with the NWA as the NWA is considered “the key legal instrument relating to accessibility and provision of water services (LHR Publication Series, 2009). The focus of this research was the discharges of sewage into the water environment.

2.6.5. The National Water Resources Strategy (NWRS)

The National Water Resource Strategy (NWRS) was initiated to promote integrated water resources management in the country through developed strategies aimed at protecting, developing, conserving, utilizing, controlling and managing the South African’s water resources in accordance with the legislative requirements and Section 5 (4)(a) of NWRS (Nomquphu, 2005; Naidoo, 2013b). The key objective of this initiative was to fairly manage water resources in a way that ensures enough water of appropriate quality will be available to sustain a strong economy, high quality life and healthy aquatic ecosystems for many generations. A vital element of the NWRS is the delegation of responsibility and authority for water resources management to catchment management agencies and water user associations (local level) to allow effective management of water resources in their respective areas (DWAF, 2013). The NWRS indicates that RQO provides numerical limits on the chemical, biological and physical attributes while considering the class and requirements different uses of a particular resource. RQO provides description of the condition and character of the habitat and aquatic biota, the water quality and quantity, and river flow pattern and timing (Dickens *et al.,* 2011).

2.6.6. The South African Water Quality Guidelines (TWQR)

The then Department of Water Affairs and Forestry (DWAF) developed target ranges for water quality in response to the increasing degradation of the country's rivers and streams. The approach that DWA followed was based on the capacity and tolerance levels of each water resource to any foreign material (Naidoo, 2013b). The water quality guidelines include quality criteria target ranges to ensure fitness of water for any intended use is assessed and treatment options provided. Legislations are enforced to ensure that the recommended guidelines are achieved and complied with. In order to limit effluent releases from municipalities and industrial sources into the water environment water quality criteria and standards are worldwide used to prevent damage to human health and aquatic species. Quality standards are considered a regulatory instrument that enlist specific quality parameters attached to specific uses and are usually based on a scientific and observations (Perry and Vanderklein, 1996).

2.6.7. The National Environmental Management (NEMA), Act No. 107 of 1998

The NEMA (Act no. 107 of 1998) serves as a blanket legislation through established principles and procedures for co-ordinated environmental activities by different organs of state. The NEMA as the umbrella legislation makes provision for co-operative governance to environmental management issues though its established principles for decision makers (Naidoo, 2013a). NEMA emphasizes on the importance of avoiding the disturbance of the ecosystems and loss of biodiversity. This is applicable to wastewater discharge into the water environment which may change water quality of that resource and possibly cause death of aquatic species due to the concentration of those pollutants. The Act also requires that the quality of domestic wastewater disposed be monitored on certain intervals and that it adheres with the effluent standards before discharge. According to the schedule 3 of the Act, any person who commits an offence relating to endangering species would be fined as much as three times the value of that species affected. This includes discharging improperly treated effluents which would affect the aquatic species (Mothetha, 2016).

2.6.8. Green Drop System

The Green Drop Certification Programme was first launched in 2008 and is aimed at providing the Department of Water and Sanitation with an information on how municipal WWTWs are complying with relevant licence conditions as set in terms of the NWA and the WSA (Muller, 2013). This program attempts to regularly measure, monitor and improve the wastewater industry. The Green Drop program (GDP) provides local municipalities with an opportunity to generate their information and data pertaining to their treatment plant efficiency and effluent composition, in order to monitor and ensure they report back on their wastewater management systems (Naidoo, 2013b). The GDP assesses the entire wastewater treatment process, from the source up until wastewater is discharged into the water environment (Figure 2.2). It also looks at operational processes, maintenance works and emergency response plans in place. The results of each municipality's performance are published for continuous improvement and for members of the public to comment and put pressure where there are issues. The programme ensures that wastewater discharged from the treatment works complies with the requirements of the discharge licence (Muller, 2013).

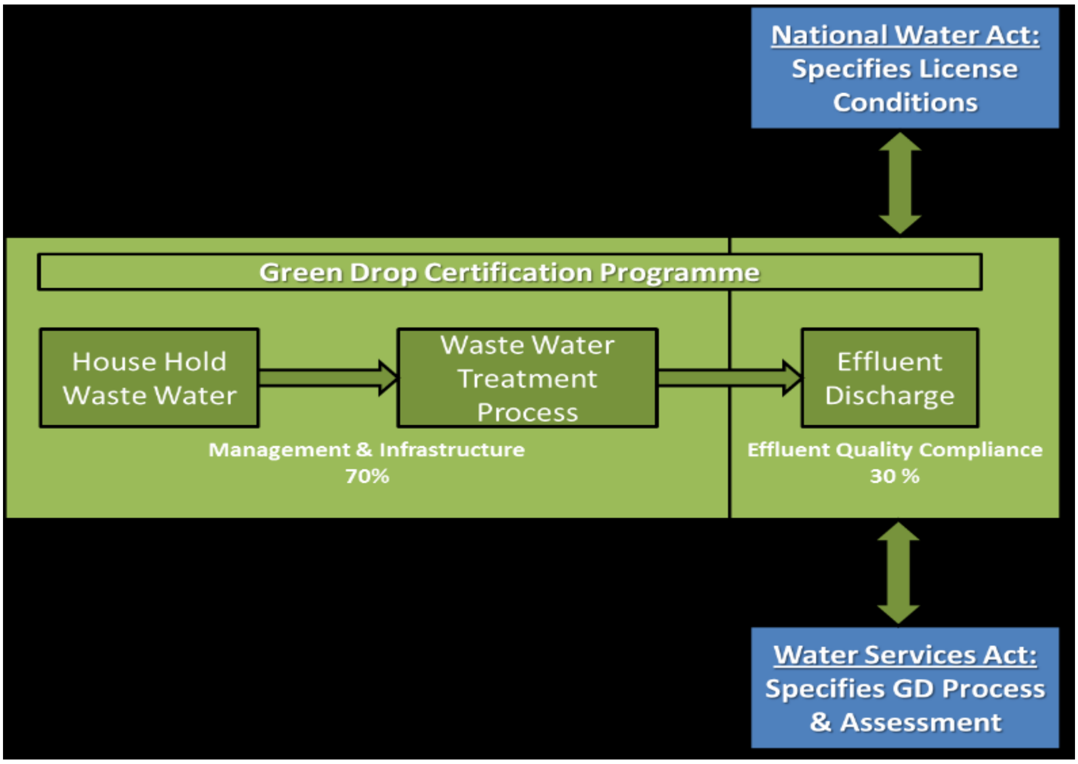

Figure 2. 2: Diagram showing the Green Drop (GD) process from source to discharge into the water resource (Muller, 2013).

2.6.9. National Eutrophication Monitoring Programme (NEMP) and National Microbial Monitoring Programme (NMMP)

Due to deterioration of water quality of the water resources as a result of development, DWS (the then DWAF) developed water quality monitoring programmes, e.g. National Eutrophication Monitoring Programme (NEMP) and National Microbial Monitoring Programme (NMMP). The NEMP and NMMP provides status of all rivers and dams and the impact of human and industrial activities on the water resources. In these monitoring programmes all quality parameters are assessed seasonally and over a certain period of time (Nomquphu, 2005).

2.7. WASTEWATER DISCHARGES

Wastewater is defined as a mixture of liquid waste removed from the industrial establishments, residences and storm water from both ground and surface water (Tchobanoglous *et al.*, 2004; Naidoo, 2013b). The domestic wastewater is then defined as sewage which normally consists of black water composed of faecal matters from human and animal wastes as well as grey water originating from household activities (Naidoo, 2013b). Wastewater is further defined as any water whose quality has been disturbed by the introduction materials from anthropogenic activities.

One of the critical issues around sewage treatment is the inequality from the authorities in the provision of the services. Literature has revealed that developed countries have reached their goals of achieving basic phases of wastewater treatment and have worked towards achieving relevant Standards. The developing countries are still trying to establish the basics of wastewater treatment while at the same time trying to meet international standards in order to protect the receiving water environment (Muller, 2013).

Table 2.1 indicates the WWTWs in the study area and the rivers they discharge their wastewater into.

Table 2. 1: Wastewater works in the study area and rivers they are discharging into

Wastewater works	Rivers the WWTW is discharging into
Final Effluent From Kokosi WWTW at Kokosi	Loop Spruit
Flip Human WWTW Final Effluent	Wonderfontein Spruit
Potchefstroom Final Effluent From Pochefstroom WWTW	Mooi River

2.7.1. Wastewater composition

Wastewater is defined as any water whose quality has affected by anthropogenic activities. These waste products can be in liquid and/ or solid forms. Wastewater comprises of liquid waste collected from domestic residential, commercial, industrial, or agricultural areas and has potential to contain contaminants depending on the volumes discharged (Henze, 2008). Municipal wastewater is a combined by-product of human waste (domestic sewage), debris, waste chemicals, suspended solids, and a diverse waste types from residences, commercial, and industrial sectors (Holm, 2004). It may include urban run-off. Figure 2.3 illustrates municipal wastewater components. Municipal wastewater is mainly constituted of 99.9% water with minor concentrations of suspended and dissolved solids. Over and above the organic substances found in sewage there are fats, soaps, carbohydrates, proteins as well as other natural synthetic organic chemicals from different processes in industries (Metcalf and Eddy, 2003). A number of substances contained in any municipal wastewater effluents are known to pose a threat on aquatic environment including nutrients, such as nitrogen and phosphorus; pathogens, antibiotics, endocrine disrupting substances (Holm, 2004).

The composition of the municipal wastewater varies notably from one place to another due to volumes discharged (Henze, 2008). Wastewater can be further characterised by its main contaminants as per the list in Table 2.2 which may have potential negative impacts on the receiving water environment. The level of contaminants in the river system results in an increases in BOD, COD, total dissolved solids (TDS), TSS, metals and faecal coliforms and thus make the water unsuitable for its intended purposes (Kanu and Achi, 2011). In rural settings the wastewater issues are usually linked to bacteria-carrying faecal matter as a result of uncontrolled discharges. In rural areas pollution arises from agricultural plots that carries fertlizers, livestock manure and pesticides, and this combined with overflowing sewer during rainfall season result to diffuse urban pollution (Helmer *et al.,* 1997).

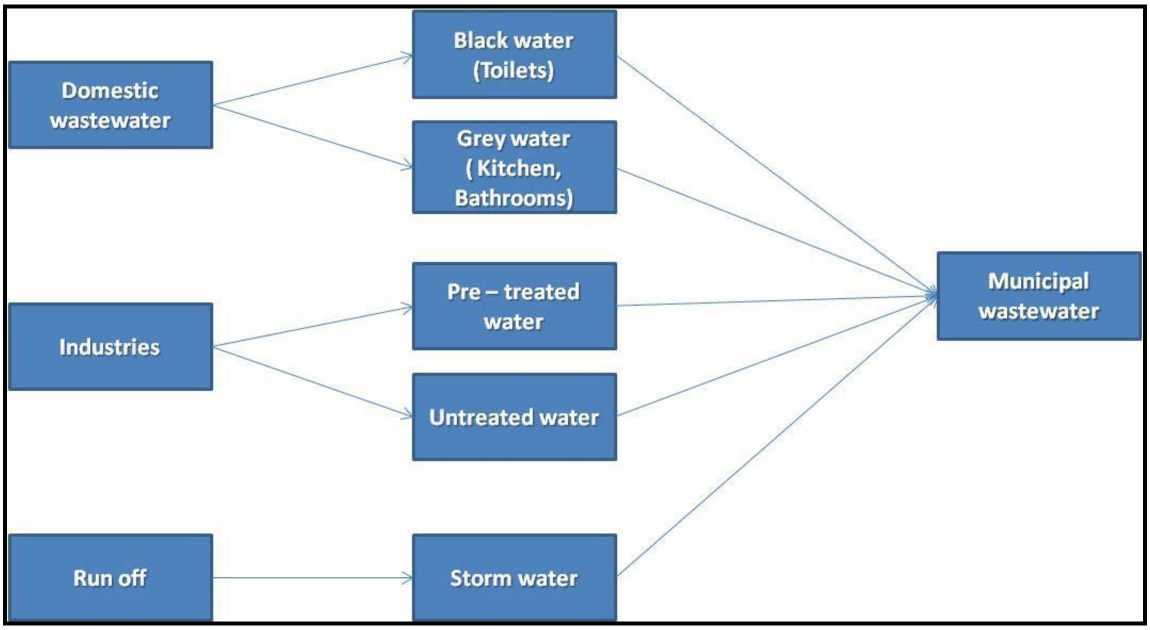

Figure 2. 3: Diagram illustrating municipal wastewater components (Source: Mothetha, 2016)

Table 2. 2: Main classes of the contaminants of the municipal wastewater and their significance and origin (Source: Metcalf and Eddy Inc., 1991)

Contaminant	Significance	Origin
Settleable solids (sand, grit)	Settleable solids may create sludge deposits and anaerobic conditions in sewers, treatment facilities or open water	Domestic, run-off
Organic matter (BOD); Kjeldahl-nitrogen	Biological degradation consumes oxygen and may disturb the oxygen balance of surface water; if the oxygen in the water is exhausted anaerobic conditions, odour formation, fish kills and ecological imbalance will occur	Domestic, industrial
Pathogenic microorganisms	Severe public health risks through transmission of communicable water borne diseases such as cholera	Domestic
Nutrients (N and P)	High levels of nitrogen and phosphorus in surface water will create excessive algal growth (eutrophication). Dying algae contribute to organic matter (see above)	Domestic, rural run-off, industrial
Micro-pollutants (heavy metals, organic compounds)	Non-biodegradable compounds may be toxic, carcinogenic or mutagenic at very low concentrations (to plants, animals, humans). Some may bioaccumulate in food chains, e.g. chromium (VI), cadmium, lead, most pesticides and herbicides, and PCBs	Industrial, rural run-off (pesticides)
Total dissolved solids (salts)	High levels may restrict wastewater use for agricultural irrigation or aquaculture	Industrial, (salt water intrusion)

2.7.2. The importance of sewage treatment

Sewage treatment, and/ordomestic wastewater treatment, is defined as the process of the removal of contaminants from domestic and industrial effluents. The treatment process (Figure 2.4) includes physical, chemical and biological processes to remove physical, chemical and biological contaminants conveyed in the water. Majority of these contaminants are organic and inorganic compounds and acutely toxic and hazardous to health (Greenberg *et al.,* 1998). One of the key focuses of wastewater treatment is the removal of pathogens in order to protect the health of the public by making sure effluent discharged complies with the set quality limits and standards (Bekal *et al.*, 2003). Wastewater treatment is a vital component in any community without which water-borne pathogens can spread resulting in diseases and degradation of receiving water bodies (Akpor, 2011). Treatment is broadly categorized into the following stages: preliminary treatment; primary treatment; secondary treatment; tertiary treatment and solids treatment (Naidoo, 2013b). Table 2.3 explains briefly what each of the treatment stages involve.

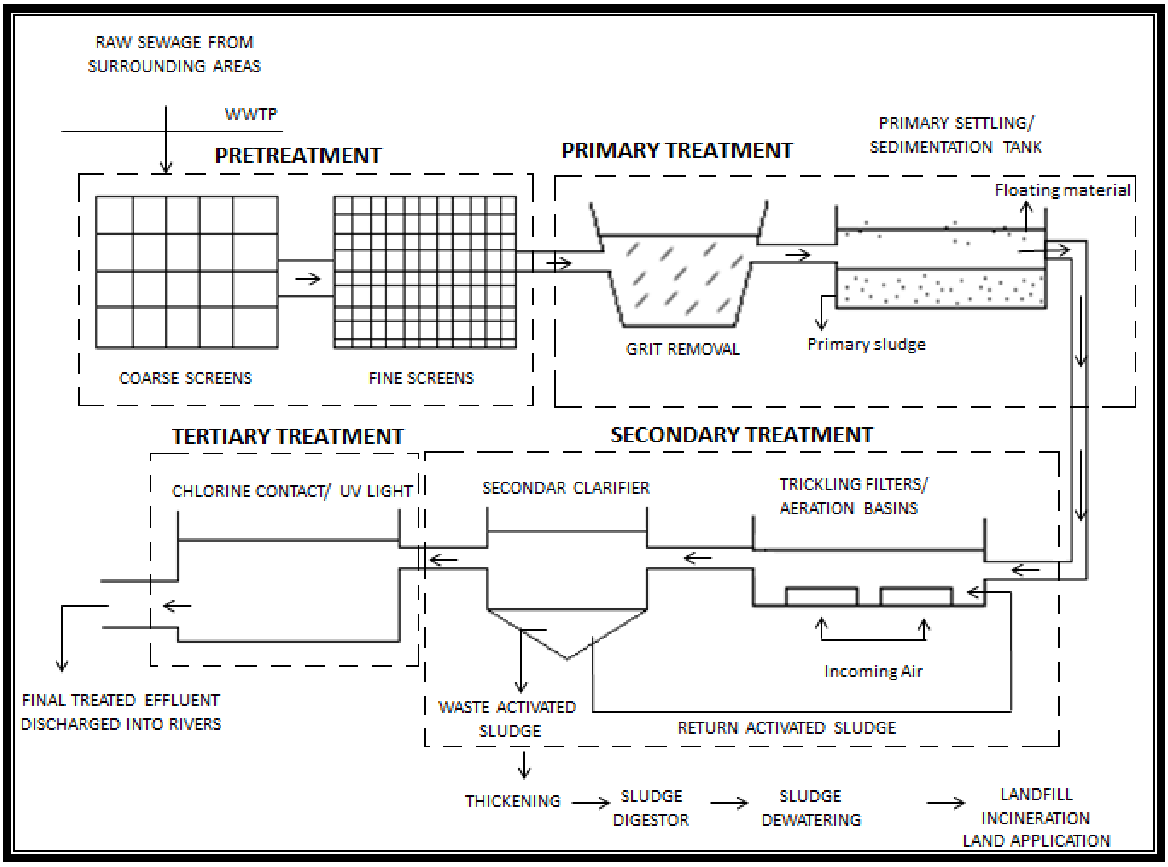

Figure 2. 4: A general overview of treatment stages within a wastewater treatment plant (Naidoo, 2013b)

Table 2. 3: Brief details on the stages of the treatment process (Mothetha, 2016)

Stages of the treatment process	Brief details of the process
Preliminary Treatment	This is the first stage in a process where large solids and grit are removed. These large materials are disposed of in landfills
Primary Treatment	Waste is passed through settling/ sedimentation tank to remove solids through settling.
Secondary Treatment	At this stage dissolved and suspended organic material is broken down by naturally occurring microorganisms and is called the activated sludge process.
Tertiary Treatment	Wastewater is disinfected to reduce disease causing pathogens. This is done through the use of chlorine, ultraviolet ponds and micro filtration and biological detention ponds.
Sludge Treatment	This is done with the help of anaerobic microorganisms in sludge digester tanks.

The main aim of treating wastewater is to ensure it is discharged safely, without being a nuisance to public health and without degrading watercourses. Wastewater treatment is critical process in the management and monitoring of water resources because it is the only way to minimise the potential pollutants entering the rivers and streams as a result of discharged effluents (Lester, 1983). The wastewater treatment is not only critical for human health only but also to ensure the ecosystem's health is not compromised. Inadequate and improper treatment could possibly affect the ecosystem once released with insufficient treatment (Naidoo, 2013b) by affecting the levels of Dissolved Oxygen (DO) and causing increased nutrient loads and algal blooms as a results of elevated phosphorous and nitrates levels (Morrison *et al.*, 2001) as well as faecal coliforms. There are number of plant associated risks identified as a result of improper and insufficient treatment of wastewater that have implications on the increased high maintenance costs and thus requiring frequent monitoring of water quality.

Tourism sector is also affected as a result of reduced number of tourists' visits to the water resources due to deteriorated conditions at the site (Schölzel and Bower, 1999). Literature revealed that most WWTWs in the North West province do not practice adequate treatment of water to ensure removal of microbes from the water (DWA, 2012a). Development and proper implementation of the management strategies and monitoring programmes will ensure the protection of the water quality of water resources, thus reducing the cost of drinking water treatment, and at the same time preventing waterborne disease (Bekal *et al.*, 2003). The routine treatment of wastewater reduces the load of unwanted organisms and organic nutrients entering the water resources. Often a times limitations such as lack of trained or negligent personnel and or faulty machinery during treatment process can lower removal efficiency and non-complying wastewater could be released into the environment. It is known that if normal treatment fails, effluents of poor quality could pose associated health risks to human and could possibly also affect aquatic species (Mema, 2010).

Despite the technologies applied to treat wastewater in WWTWs, there is still a necessity that its physical and chemical composition still needs to be assessed. Any change on the parameters may be an indicator of changes in water quality. The assessment and monitoring of those parameters is done to protect water resources from potential pollution and negative impact as a result of possible poor maintenance and other operational issues at the plants (Kukier *et al.*, 2004). Discharged wastewater into natural waters remain a major source of viruses and bacteria as the wastewater discharged contains human and animal faecal matters hence the importance to ensure monitoring is done to avoid potential public health risks and exposure. This then means domestic wastewater treatment and management requires treating untreated domestic wastewater up to acceptable levels where municipalities ensure that they prevent deterioration in the receiving aquatic environment, minimising possible risk of waterborne disease and protection of the ecosystem services provided by the surrounding ecosystem. Consequently, improperly managed domestic wastewater can possibly result in significant risks to human and aquatic environment health (De Villiers and Graham, 2016). Wastewater pollution has always been seen as a major threat worldwide (Okpor, 2011).

CHAPTER 3: MATERIALS AND METHODS

3.1. STUDY SITE DESCRIPTION

The Mooi River Catchment runs along the Western Gauteng and North West Provinces of South Africa. The catchment has a total area of approximately 1800 km^2 (Figure 3.1). The Mooi River Catchment falls under the Vaal River Water Management Area. The Mooi River originates from the Boons area before it flows into three impoundments namely Klerkskraal, Boskop and Potchefstroom Dams (van der Walt *et al.*, 2002). The main tributaries of the Mooi River are the Loop Spruit and the Wonderfontein Spruit. The Loop Spruit originates from Fochville and is fed by springs and excess water from the various mining activities. There are two major impoundments on the Loop Spruit namely the Klipdrift and Modder Dams. The Wonderfontein Spruit originates from Krugersdorp and flows into Donaldson dam, from which its water is pumped into pipeline of approximately 32 km to the Carletonville area (Tlokwe City Council, 2014).

The Mooi River Catchment has three sub-catchments, namely the Wonderfontein Spruit, the Mooi River proper and the Loop Spruit. These are shown in Figure 3.1. Each of these three sub-catchments falls within different local municipalities. The Mooi River falls within the Tlokwe Municipality in Potchefstroom, whereas its tributaries, the Loop and Wonderfontein Spruit fall under Merafong City and Mogale City municipalities, respectively. The WWTWs of these municipalities hold licences to discharge their treated wastewater into the Mooi River and its tributaries at different points. The water of these same rivers are used for irrigation for commercial agriculture and serve also as a source of drinking water.

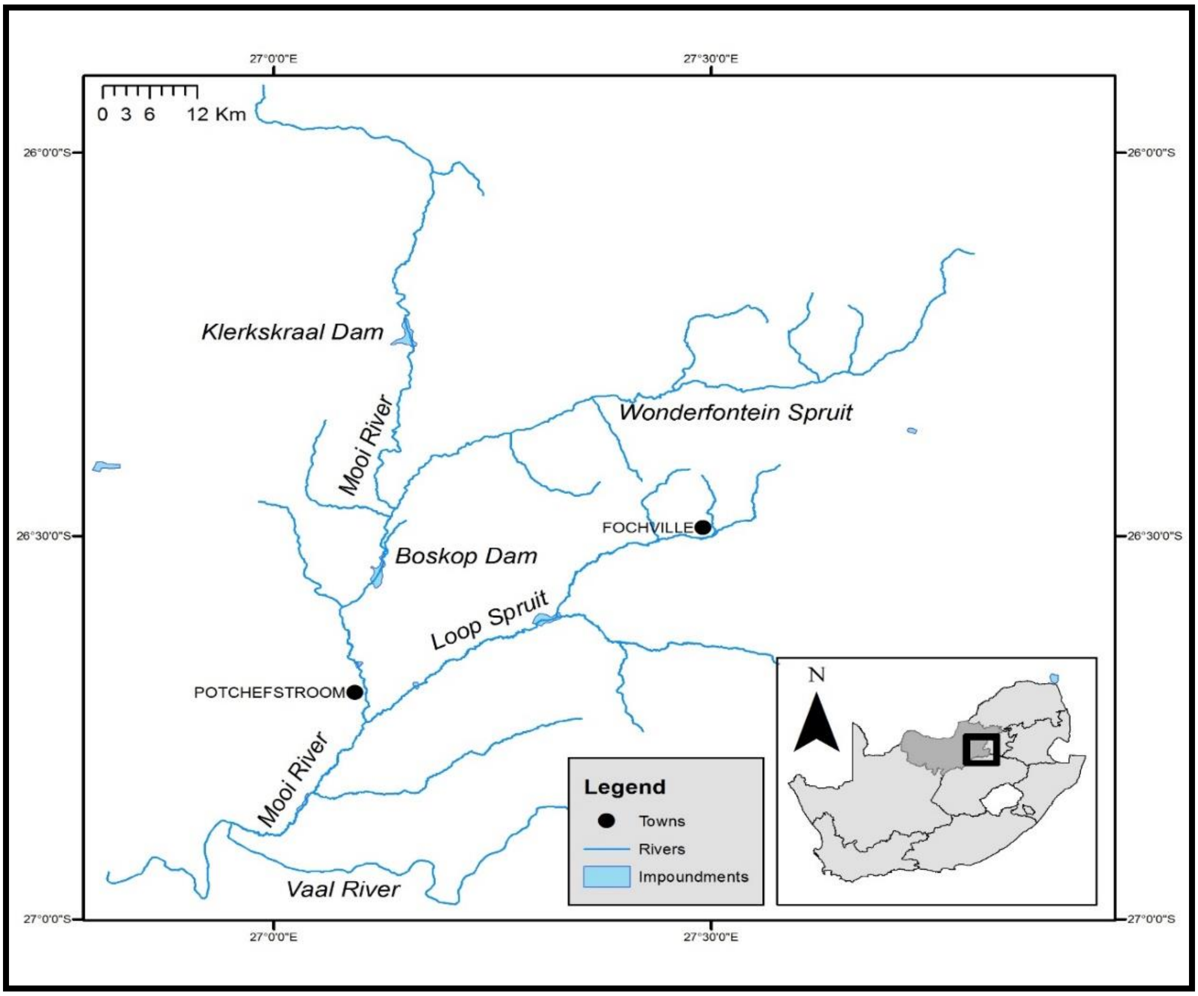

Figure 3. 1: Map showing Mooi River Catchment and its major tributaries in the catchment

The three sub-catchments of the Mooi River run through six districts, namely Krugersdorp, Randfontein, Westonaria, Oberholzer, Fochville and Potchefstroom (Malan, 2002). The Mooi River Catchment is further delineated into eight quaternary catchments known as C23D, C23E, C23F, C23G, C23H, C23J, C23K and C23L (see Figure 3.2).

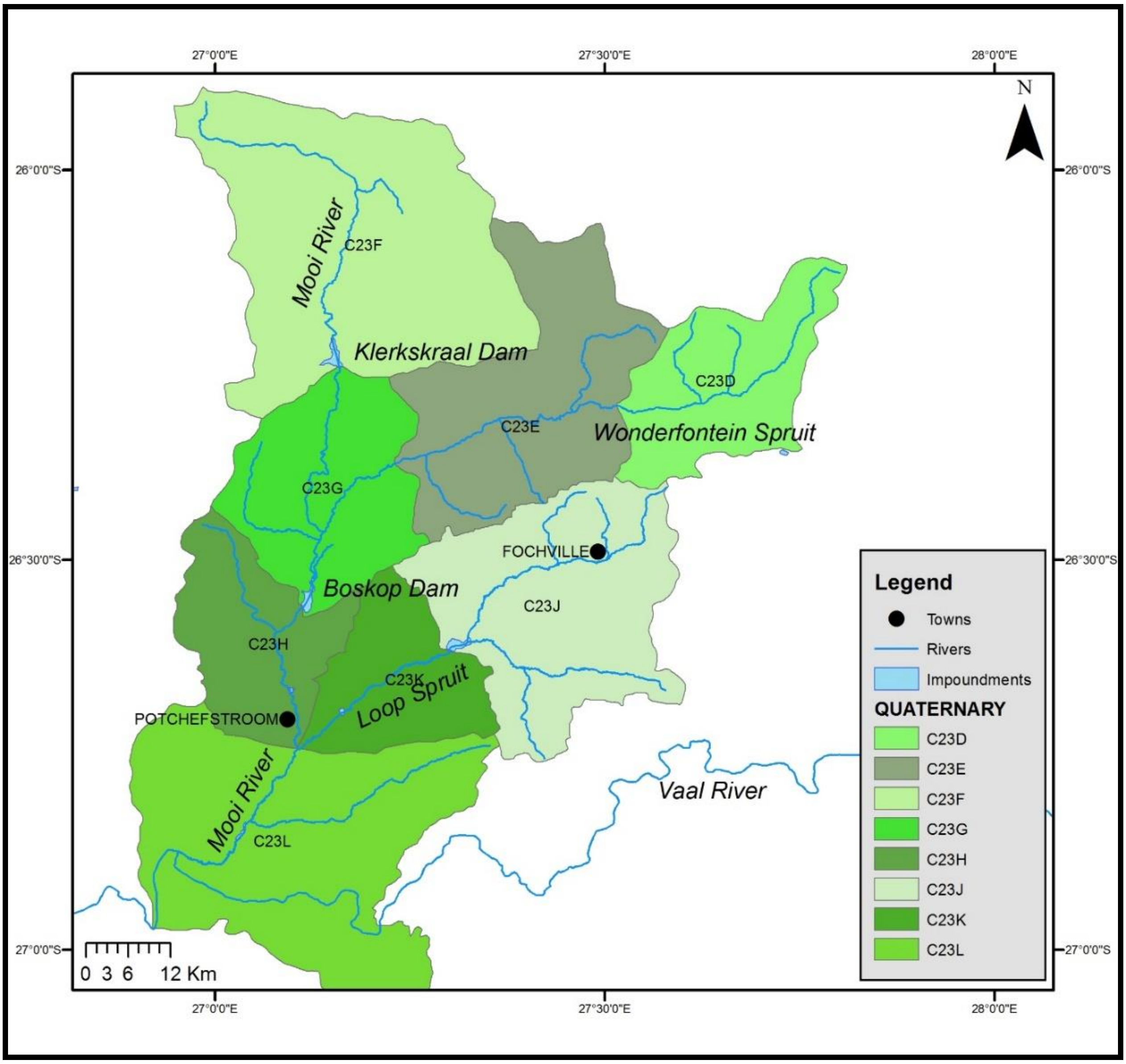

Figure 3. 2: The quaternary catchments of the Mooi River Catchment

The three WWTWs namely; Kokosi, Flip Human and Potchefstroom that discharge into the Loop Spruit, Wonderfontein Spruit and Mooi Rivers, respectively were selected for this study. The water quality data of the receiving environment downstream of each of these WWTWs were analysed and compared to their upstream points. The data used was received from DWS. The chosen sites enable one to assess the impact on the quality of the water of the receiving rivers as a result of discharging treated wastewater from the WWTWs. The GPS coordinates of the discharge points of wastewater from the WWTWs into the rivers within the study area are presented in Table 3.1. Reference sampling points which are located far upstream of most of the discharge points were also included for comparison purposes. The sites from which DWS collected samples whose data was collated and analysed in this study are shown in Figure 3.3.

Table 3. 1: Sampling locations along the Catchment area of the Mooi River

Sample location	Quaternary catchment	WWTWs	Reason for sampling	Latitude	Longitude
C2H246	C23J	Upstream of Kokosi WWTW	Upstream point of C2H257	26°26'01"	27°33'14"
C2H257	C23J	Kokosi WWTW	To determine the contribution of Kokosi WWTW to the pollution of the water of Loop Spruit as part of the Mooi River Catchment	26°29'52"	27°27'36"
C2H153	C23D	Upstream of Flip Human WWTW	Upstream point of C2H237	26°09'54"	27°46'01"
C2H237	C23D	Flip Human WWTW	To determine the contribution of Flip Human Water Care works to the pollution of the water of Wonderfontein Spruit as part of the Mooi River Catchment.	26°10'54"	27°46'15"
C2H254	C23L	Upstream of Potchefstroom WWTW	Upstream point of C2H255	26°45'07"	27°05'58"
C2H255	C23L	Potchefstroom WWTW	To determine the contribution of the Potchefstroom Water Care Works to the pollution of water of Mooi River as part of the Mooi River Catchment.	26°45'04"	27°05'39"

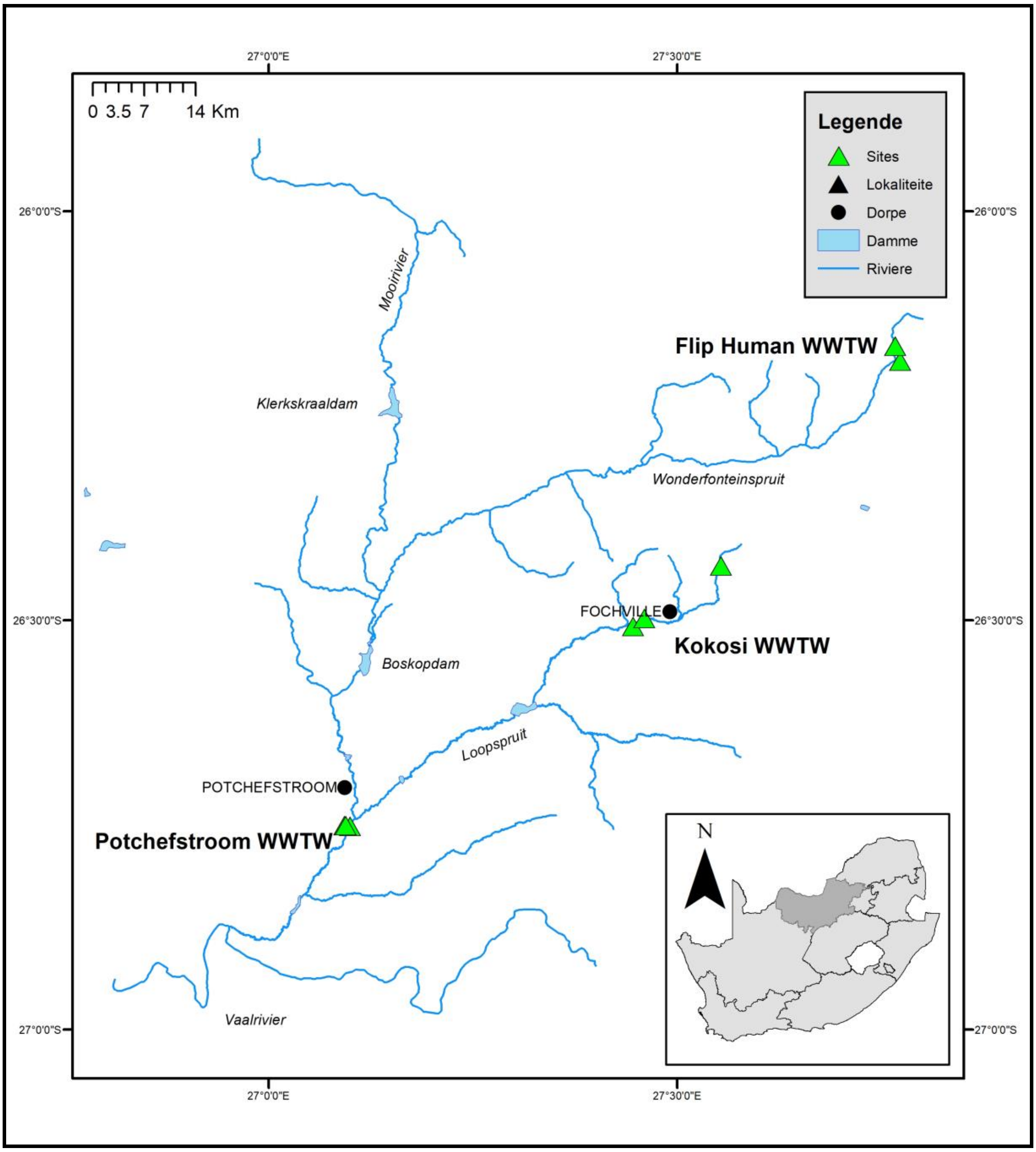

Figure 3. 3: Map showing all the selected DWS points from the study area.

3.1.1. Vegetation

The catchment is situated in the Highveld Ecoregion 11 (Ecoregion Level 1) (Kleynhans *et al.,* 2005). Three of the eight quaternary catchments fall into different Level 2 ecoregions (Figure 3.4). In this region grasslands are dominant, and may likely be influenced by frost, veld fires and overgrazing. The region is widely degraded as a result of growing population, intensive grazing of the grasslands, and other important vegetation types, agricultural activities and mining activities (Low and Rebelo, 1998). A portion of the Mooi River system is situated in Ecoregion 7 which is dominated by Waterberg moist mountain and mixed bushveld (Kleynhans *et al.*, 2005). The vegetative habitat along the Mooi River is in a moderately modified state (DWS, 2016). At Boskop Dam, the river has been extensively modified to an E category. Downstream of the Klerkskraal Dam (approx. 30 km upstream of the study area), the upper reaches of the river are dominated by wetland areas. Around these locations the river has undergone bed and bank modifications. Alien vegetation also dominates the river below Boskop Dam. The habitat integrity become sparse around the Potchefstroom area and below the Potchefstroom Dam. The city of Potchefstroom is situated at the lower end of the Mooi River Catchment.

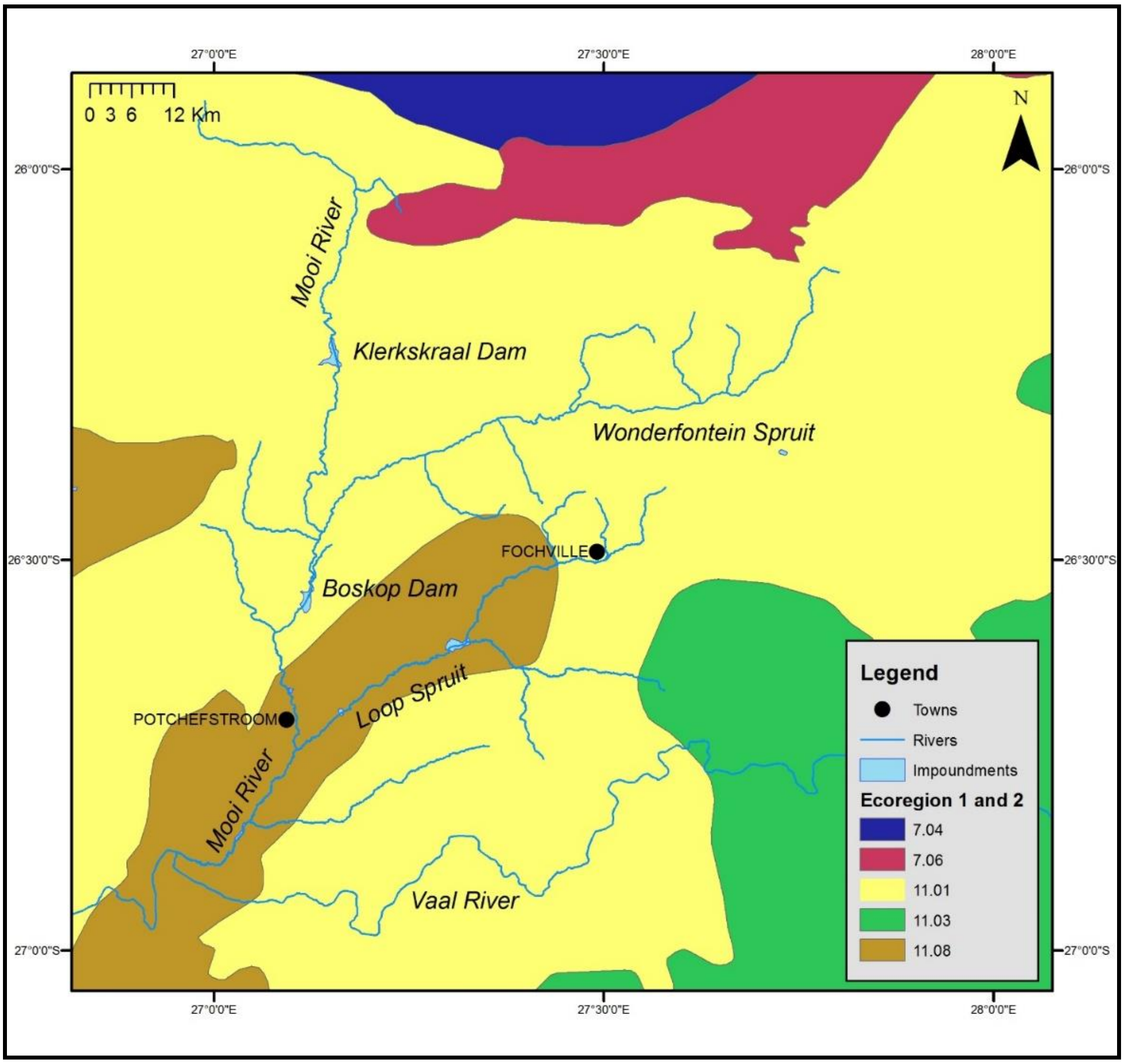

Figure 3. 4: Map of the Mooi River Catchment indicating ecoregions.

3.1.2. Rainfall

Climate is a measure of the weather conditions over a long period of time. It is known to influence certain aspects such as vegetation, soil type, land uses and water quality. The catchment has a mean evaporation potential of 1 650 mm (van der Walt *et al*., 2002) and temperatures ranging from -1 ˚C during extended winter cold spell (May to September) to higher than 32 ˚C during October to January (Cilliers and Bredenkamp, 2000), see also Figure 3.5. The hydrology of the river system is strongly influenced by the rainfall from October to March. The dry season is normally from April to September. Rainfall may be highly variable, both in space and time, often resulting in severe droughts or flooding (Pantshwa *et al.,* 2009).

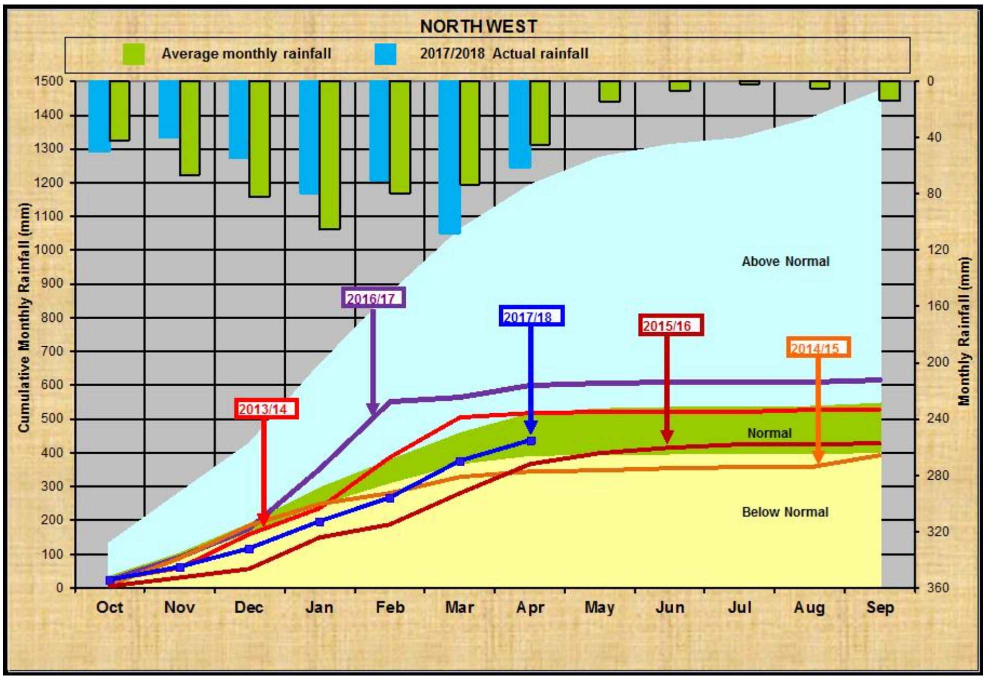

Figure 3. 5: Mean monthly and annual rainfall for North West Province (DWS website, 2018)

3.1.3. Geology

The geology of the study area is dominated by dolomites and there are large-scale gold mining operations across the upper reaches of the catchment (DWS, 2014a). The geology of the Mooi River Catchment is underlain with dolomite and the Wonderfonteinspruit contains three dewatered dolomite compartments, the three dams in the Wonderfonteinspruit catchment are also heavily contaminated with raw dolomite dewatering effluent, having an alkaline effect on the water downstream (Winde, 2010) The dolomitic characteristic of the Mooi River Catchment changes the chemical composition of the river, resulting into elevated pH and electrical conductivity levels including elevated calcium and magnesium levels as the Mooi River flows downstream

(Henderson-Sellers, 1991). The Boskop Dam within the catchment originates on complex geology which consist of a quartzite ridge, lava, shale, dolomitic limestone, and a diabase dyke (Annandale and Nealer, 2011). The source of water of the Boskop Dam is from dolomite underground compartments, whose main sources are Boskop-Turffontein Compartment and Gerhard Minnebron (DWAF, 1999).

3.1.4. Demography

There are currently eight formal settlements within Merafong City namely; Carletonville-Oberholzer, Khutsong, Welverdiend, Blybank, Fochville, Kokosi and Greenspark (Merafong City, 2016). Of the eight formal settlements the Kokosi Wastewater works services the Fochville, Kokosi, Greenspark and the Losberg Industrial Area (which is part of Fochville). These small towns of the Merafong City have a combined population of about 38 970 (Stats SA, 2011).

The Flip Human Wastewater works provides services to the following settlements namely; Krugersdorp, Kagiso, Azaadville and Lusaka. The combined population of the areas serviced by the Flip Human WWTW is estimated at about 10 000 (Stats SA, 2011).

Potchefstroom town had a population of about 250 000 according to the Stats SA (2011), sustaining North-West University, residential areas and several other large industries. The town's supply of drinking water is from the Boskop and Potchefstroom Dams (Annandale and Nealer, 2011). Table 3.2 below provides a summary of the Local municipalities that each wastewater works falls under, with the areas they service and their population statistics.

TableTable 3. 2: Population statistics and projections of the key towns within the study area (StatsSA, 2011).

Wastewater works	Sampling stations	Local Municipality	Villages served	Population served
Final Effluent From Kokosi WCW at Kokosi	C2H257	Merafong City	Fochville, Kokosi, Greenspark, Losberg Industrial Area	38 970
Flip Human WCW Final Effluent	C2H237	Mogale City	Krugersdoro, Kagiso, Azaadville, Lusaka	10 000
Potchefstroom Final Effluent From Potchefstroom WCW	C2H255	JB Marks (Previously Tlokwe)	Potchefstroom	250 000

3.1.5. Hydrology

The catchment receives a mean annual precipitation of 683 mm (van der Walt *et al.*, 2002). Some of the rainfall seeps into the ground and serves as the ground water source which recharges the tributaries of the Mooi River and its tributaries through several dolomitic bedrocks (hydrological eyes). The mean annual loss of water by evaporation is estimated at 1650 mm (van der Walt *et al.*, 2002). The catchment area is known to have a relatively flat topography, with altitudes ranging between 1520 m in the north to 1300 m in the southwest (Tlokwe City Council, 2014). About 55.8% of the total runoff within the catchment area contributes to the surface water of the Mooi River (van der Walt *et al.*, 2002).

The Mooi River system and its two tributaries (Mooi River Catchment), are recharged through various known dolomitic eyes (Winde and van der Walt, 2004). The dolomitic eye known as the Bovenste Oog as well as surface water from the Wonderfontein Spruit provides the Mooi River with water. The Boskop-Turffontein compartment and Gerhard Minnebron eye also feeds the Mooi River through underground dolomitic compartments (Labuschagne, 2017). The tributary of the Mooi River upstream from Boskop Dam namely the Mooirivierloop, is fed by water from the Wonderfontein Spruit when high rainfall conditions are high. The Wonderfontein Spruit originates in the Tudor and Lancaster areas which is from south of Krugersdorp, where it then drains portion of the Krugersdorp area on the south of the Indian and Atlantic watershed. On the upper Wonderfontein Spruit there is also Donaldson Dam which receives water from several sources, such as mining facilities, sewage works, and informal settlements (Barnard *et al.*, 2013).

The lower Wonderfontein Spruit, further downstream of the Donaldson Dam is a combined artificial and natural drainage system. Most of the water received is conveyed through a pipeline till it reaches the Oberholser underground compartment. From the compartment then the water flows naturally to a streambed in a canal. If cases where the stormwater drainages exceed the capacity of the pipeline, water then spills over the actual Wonderfontein Spruit feeding the Mooiriverloop (Barnard *et al.*, 2013).

There are activities undertaken with the catchment impacting on the hydrology of the Mooi river system. The widely known and dominant land-use in the catchment is the agricultural practices in the form of crop farming and grazing (van der Walt *et al.*, 2002) thus contributing to elevated salts inputs, erosion and topsoil loss due to run-off (DWAF, 1986). Peat mining formed from the Gerhard Minnebron dolomitic eye has also caused reduction in the habitat integrity of the catchment (DWA, 2009). Mining activities involving small-scale diamond diggings have been evident occur in the system of the Mooi River between Klerkskraal Dam and Boskop Dam. These have destroyed the floodplain and riparian habitats, and caused silting of the Mooi River system upstream of the Boskop Dam (van der Walt *et al.*, 2002).

3.2. METHODOLOGY

This section explains the methodology adopted for this research, how the data was sourced and analysed. It further evaluates the results obtained against the national and internal water and wastewater guidelines and standards.

3.2.1. Data collection

The quantitative research technique was applied for collection of all types of data used throughout the study.

A request to supply monitoring data records for the selected sampling sites along the Mooi River catchment was made to the Department of Water and Sanitation (DWS). Data on water quality for the Loop Spruit, Wonderfontein Spruit and the Mooi River for the period 2015 to 2018 was used as well as historical reference data taken during the period 2001 to 2002. Water samples were collected and analysed by DWS. For the purpose of this study, the already existing data obtained from DWS was used. There was very little data available for the specific sites identified in Table 3.1. Data from before 2001 / 2002 was mainly once-off sampling data or the data for the variables identified for this study were not available. Although an inorganic dataset for South Africa is available between 1972 and 2011, the sites and WWTW of interest had minimal data included with the majority being used for the reference period from 2001 / 2002 (Huizenga *et al*., 2011).

The received data included the sampling records, quality indicators which are routinely monitored, their physico-chemical and the microbiological methods of analysis that were used, as well as the measured data. The records on the concentration of each parameter (received as monthly Excel reports) were analysed and collated into tables of variation data of each parameter during the study period. The data was used to draw up graphs to depict the trends and variation in the concentrations of each measured parameter in water at each sampling site as a function of time. The figures also depict the set control limits (national and international set standards limits) for averting pollution of receiving surface water due to disposal of treated wastewater. Thus, out-of-limit (non-compliant) data for each measured parameter could be identified easily. Effectively the figures serve as a check of each measured parameter against the Water Use Licences for the three wastewater works (Kokosi, Flip Human and Potchefstroom), and other South African and international standards and guidelines. In order to investigate and determine the potential impacts on quality of the water of Mooi River as a result of sewage discharges from sites located within its catchment area, the following analytical approaches were undertaken:

- Pre analysis of potential pollution problem on the Mooi River and its tributary by:
  - ✓ surveying literature on the human activities likely to impact the Mooi River from its catchment area.
  - ✓ reviewing green drop data and reports obtained from DWS;
  - ✓ reviewing Water Use Licences for the selected wastewater works; and
  - ✓ obtaining rainfall data for the area from South African Weather Services.

3.2.2. Data preparation

Raw data received from DWS for each parameter at each site were used to construct tables of monthly data. The sampling points at each site were downstream of the point of WWTWs discharge of their treated water into the Mooi River and its tributaries. Points further upstream of all wastewater discharging points were also included for comparison purposes. Once the data for each parameter was collated it was used to draw up control charts to show variations in the levels of each parameter as a function of time.

Only parameters which are characteristic of pollution derived from wastewater handling, treatment and disposal were considered for data analysis. These were pH, electrical conductivity, suspended solids (SS), ammonia, nitrate, phosphate, chemical oxygen demand (COD), Total faecal coliforms count (TCC) and *E. coli* count (see Table 3.3).

Table 3. 3: Water quality parameters that were chosen for data analysis in this study.

Parameter Group	Water quality indicator Parameter
Physical	pH, EC, SS
Nutrients	Ammonia (NH_3), Nitrates (NO_3), Orthophosphate (PO_4^{3-})
Organic matter	Chemical Oxygen Demand (COD)
Microbiological	*E. coli*, Total Faecal coliforms count (TCC)

3.2.3. Water quality standards and guidelines

To evaluate the potential environmental impact of the activities of the WWTWs within the catchment of the Mooi River on the quality of the receiving water, the collated data were compared against set national and international water and wastewater guidelines and standards. The guidelines were used to determine if the quality of water was within the set specifications for discharging the treated water into the river system. The national guidelines which were used included DWS wastewater limits (DWAF, 2013); South African Water Quality Guidelines for Domestic use, volume 1 and for Agricultural use (irrigation), volume 4 (DWA, 1996a; 1996b); RQOs for the Upper Vaal (DWA, 2016) and the Water Use Licences for the three WWTWs which were issued in terms of Section 39 of NWA (DWAF, 2013). Table 3.4 indicates the issued Water Use Licences' limits for the three WWTWs. The international standards included Water Environment Partnership in Asia (WEPA, 2013) and the Environment Protection Act standards for effluent regulation (EPA, 2003). The assessment of data against international and national standards and guidelines was done to provide an indication of the fitness for use and possible impacts on the aquatic system.

Table 3. 4: Water Use Licence limits for the Tlokwe, Flip Human and Kokosi WWTWs

Concentration/ value of Substance/Parameter	Tlokwe WUL	Flip Human WUL	Kokosi WUL
Faecal coliforms	0	0	0
Chemical oxygen demand (mg/l)	75	75	75
pH	5.5-9.5	5.5-9.5	5.5-9.5
Ammonia (mg/l)	10	10	10
Nitrate/nitrite as nitrogen (mg/l)	3	15	15
Suspended solids (mg/l)	25	25	25
Electrical conductivity (mS/m)	75	75	75
Orthophosphorous (as phosphorous (mg/l))	3	10	1

3.3. DATA ANALYSIS PROCEDURE

The selection of data analysis method is a a critical factor in achieving the aims and objectives of the study. This research method allowed the comparison of indicators, categories and theories that have been developed with primary data to achieve a perfect fit between categories and data.

Control charts for each parameter at each sample points (discharge points), sites located upstream of the discharge points as well as from historic data (2001 - 2002) were plotted from the collated data (Figures 4.1 - 4.30). These graphs show the variation of each parameter as well as against set limits from the standards, licences and guidelines in the study area. From this comparative analysis, statements on the quality of the water of the three river were made. Percentage compliance for the parameters analysed in this research was obtained by taking the number of samples passed, divided it by the total number of samples analysed for that parameter then multiplied by 100.

3.4. STATISTICAL ANALYSIS

Data collated from DWS was analysed quantitatively. The statistical analysis for all physico-chemical and microbiological parameters were conducted using data from the study period 2015 - 2018 and the historical data from 2001 - 2002. The statistical analysis was a challenge as there were many data gaps. A student's t-test (univariate) was conducted for two reasons: (I) to determine whether water quality parameters of a particular WWTW were contaminated or not, and (II) also to compare the water quality of the two monitoring sites (Singh and Kumar, 2011). Statistical significance was set at $p < 0.05$, which indicates there is a statistically significant difference between the two data sets being compared but if $p > 0.05$ then this means there is no significant difference. For each variable there were three tests done to compare between the different WWTW. Furthermore, a linear mixed model approach was used to determine what the influence of sampling site, year and the interaction between site and year were for each of the water quality variables. All analyses were completed using SPSS Version 25.

Principal Component Analysis (PCA) (multivariate) statistical technique was applied using Canoco version 5. It attempted to explain the correlations between observations and to identify possible sources that influence water quality (Gvozdić *et al.*, 2012). Multivariate statistical analyses in the form of a principal component analysis (PCA) were carried out to determine whether any spatial differences were evident in the sediment results based on the average total metal concentrations at each site, irrespective of the time of the sampling survey. Furthermore, a PCA was used to determine if there were any spatial or temporal trends within the water quality variables between sites as well as between different sampling surveys (van den Brink *et al.*, 2003). In this case, sampling site and sampling year were used as co-variates in the PCA analysis. All of the data were log transformed prior to analyses.

CHAPTER 4: RESULTS AND DISCUSSION

Chapter 4 presents and discusses the trends in the water quality characteristics of the Mooi River and its tributaries at each chosen monitoring sites for the period 2015 to 2018. Variation in the levels of each parameter is also graphically presented followed by a brief discussion on the quality of the water.

4.1. PRESENTATION OF THE RESULTS

The tables of collated data are given in the various appendices. Each figure in this section has horizontal solid lines, indicating the critical limit (over which the water quality is regarded as poor and possibly causing a risk) of the specific water quality parameter. The variations in the measured values of each parameter at each downstream and its respective upstream sampling point as a function of time are shown as red and blue solid lines, respectively. The figures also include data of the measured parameters for the river water samples which were taken upstream of the discharge points. This enabled assessment of the impact on the water quality to be made before sewage is released into water environment.

4.2. POWER OF HYDROGEN

During the study period, the power of hydrogen (pH) from Loop Spruit (Figure 4.1), Wonderfontein Spruit (Figure 4.2) and the Mooi River (Figure 4.3) ranged within 6 to 8.5, except for one or two occasions at one or two of the sites. Overall, the variation in pH of the water of the three rivers was within normal limits. The pH of fresh surface water varies between 6 - 8.5. This pH range is influenced by the nature of the geological bedrock of the water body via the carbonate/ bicarbonate buffer pump derived from the solubility of limestone and shale rocks. The geology of the study area maintains a pH ranging from 6 - 9.5. Outside this range, the pH of the water has a significant effect on other water parameters such as the redox potential of solutes. This in turn controls the solute solubility equilibria, especially the bioavailability of metal ions and their complexes as well as nutrients (Paul, 2011; Agoro *et al.,* 2018). Furthermore, the pH varied within the limits of the Target Water Quality Range (TWQR).

By comparison of the average values, the pH downstream of the discharge points of the WWTWs into the rivers were not significantly different ($p > 0.05$) from those measured upstream of the WWTW. Since there is no difference, it can be concluded that the release of wastewater from the three WWTWs did not have a significant influence on the pH of the water. However, an out of limit value of around 5.9 was measured only in July 2015 for water sampled downstream of the Kokosi WWTW. The value of 5.9 was below the TWQR for domestic use and for agricultural (irrigation) purposes which are 6 and 6.5, respectively (DWAF, 1996a and 1996b). In most cases fresh waters in South Africa are normally more or less neutral, with pH ranges between 6 and 8 (Day and King, 1995). Surface water with very low pH (pH < 4.5) is considered acidic and toxic to animals (Naidoo, 2013a). This is usually an indication of artificial contamination due to discharge of industrial or wastewater effluents (Swanson and Baldwin, 1965). High pH of fresh water (8.5) is also toxic and corrosive. This results from artificial addition of alkaline wastes such as those from non-neutralised alkaline cleaning reagents. This may also be a result of formation of ammonia from nutrient ions and reducing conditions.

The pH in the natural water environment is mainly influenced by various factors such as discharge of effluents, leachate of acidic metal ions acidic precipitation (rainfall), other microbial activity (Naidoo, 2013b). An out-of-limit pH value of 8.9 was observed in the Mooi River in November 2017. This was an indication of addition of wastes that may have been alkaline or the formation of ammonia under reducing or anaerobic conditions. The value was above the TWQR for agricultural (irrigation) purposes and WEPA upper limits of 8.4 and 8.7, respectively.

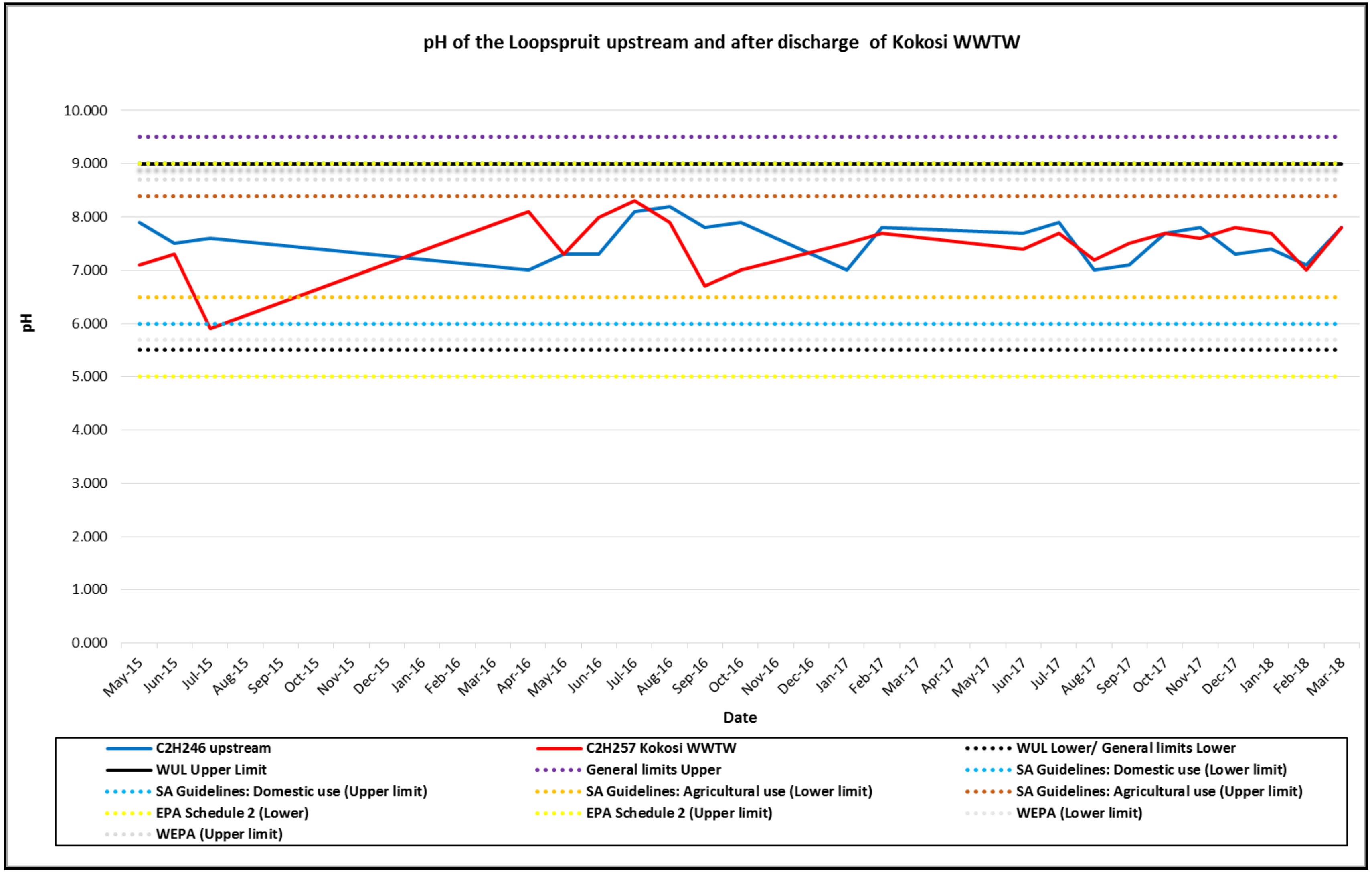

Figure 4. 1: pH of the Loop Spruit upstream and downstream of the Kokosi WWTW for the period May 2015 – March 2018.

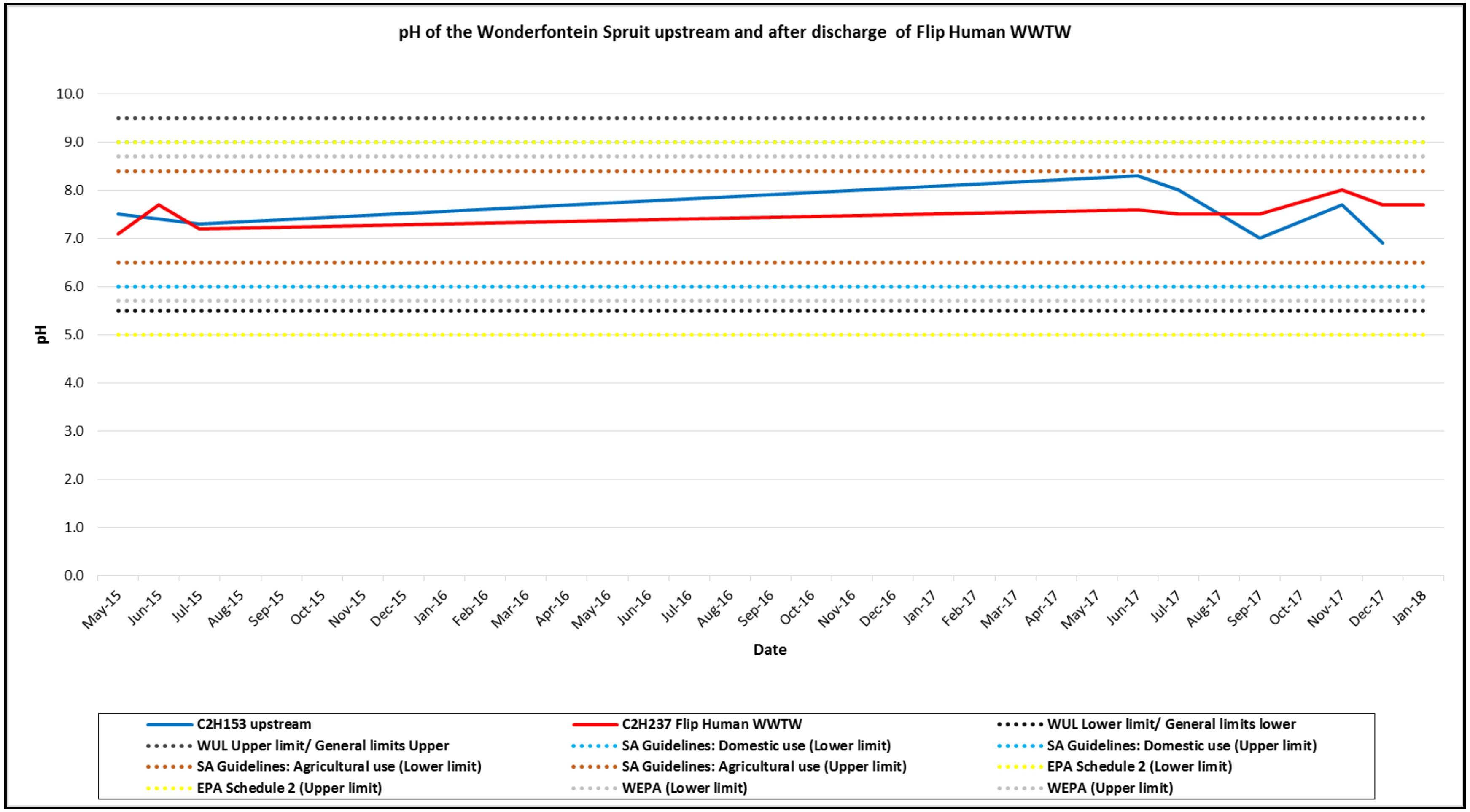

Figure 4. 2: pH of Wonderfontein Spruit upstream and downstream of the Flip Human WWTW for the period May 2015 – March 2018.

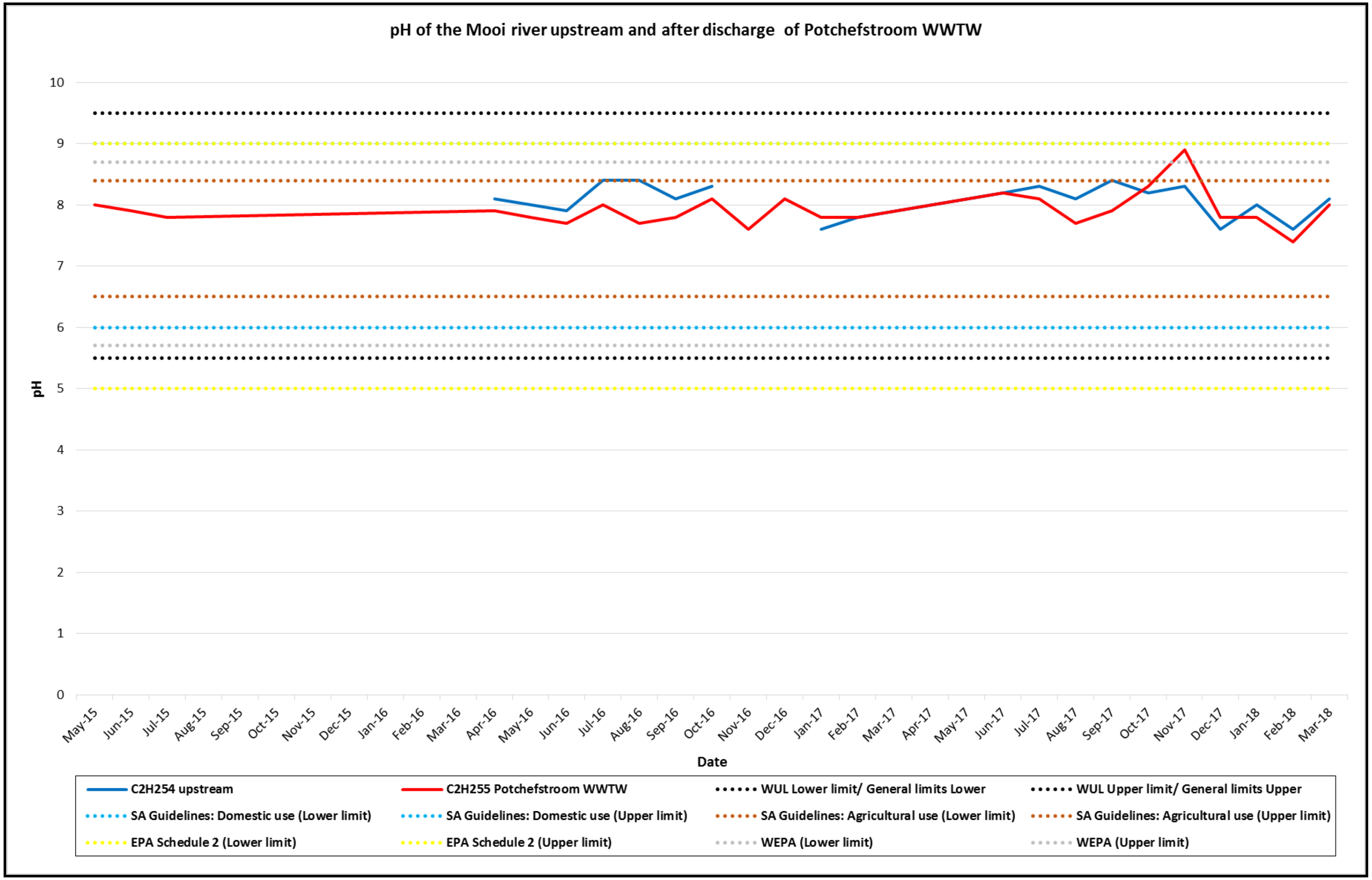

Figure 4. 3: pH of the Mooi River upstream and downstream of the Potchefstroom for the period May 2015 – March 2018.

4.3. ELECTRICAL CONDUCTIVITY (EC)

The electrical conductivity (EC) concentrations ranged from 33.4 to 108 mS/m at the upstream points of the Kokosi WWTW and ranged from 41.7 to 71.8 mS/m for the downstream site of the Kokosi WWTW. At the Flip Human upstream points, the EC concentration ranged from 45.3 to 92.3 mS/m and after discharge it ranged from 65.3 to 104.8 mS/m. At the Potchefstroom WWTW, the upstream EC concentration ranged from 58.2 to 90.6 mS/m and after discharge of the WWTW it ranged from 69.4 to 117 mS/m (Figures 4.4 to 4.6).

The Kokosi WWTW upstream and downstream points complied fully with the RQO limits as well as the WUL limit but only at the discharge point of the WWTW. The upstream point of the Kokosi WWTW did not meet the WUL limit with only 59% compliance. The General limit compliance was 50% for the upstream and 96% after discharge of the WWTW, this then indicates some level of improvement on the water quality from upstream to downstream. The Flip Human WWTW complied fully with the RQO limits at the upstream points and after discharge of the Flip Human WWTW. The upstream points' compliance was at 63% for the WUL and 25% for the General Limits. Compliance after discharge of the WWTW was 22% for both the WUL and the General Limits. The Potchefstroom WWTW compliance to the limits at the upstream points were 60% for the WUL, 100% for the RQO and 35% for the General Limits. After discharge of the WWTW compliance was 4% for the WUL and General Limits, and 20.8% for the RQO limit.

The p-value for the comparison between the EC concentrations measured at the point upstream of Kokosi and Potchefstroom WWTWs and at the sites after the two WWTWs discharge were less than 0.05 ($p = 0.02$ and 0.000 respectively). Since there is a difference, it can be concluded that the release of wastewater from the Potchefstroom WWTWs was having a significant influence on the EC concentrations downstream. Pelser, 2015 also discovered that Potchefstroom was the largest contributer of pollution to the Mooi River as a result of various sources of pollution entering the Mooi River and very high concentrations of water quality variables were measured and phosphates being one of them, which indicate pollution and impact. This is not the case with Kokosi WWTW. Although the difference is significant, the EC upstream of this WWTW was higher than just after the WWTW. Therefore, the WWTW in fact appears to result in an improvement in EC compared to the upstream site. Figure 4.4 indicates that this trend is only seen in 2017. The p-value for the comparison between the EC concentration measured at the point upstream of Flip Human and at site after discharge is = 0.08 which is greater than 0.05. This then means there is no statistically significant difference between the EC concentration upstream and at the Flip Human WWTW. It should be noted that the average EC upstream is still lower than that at Flip Human

WWTW. Even though there is no significant difference, there might still be an impact of the WWTW. However, many data gaps existed for these monitoring points (Figure 4.5).

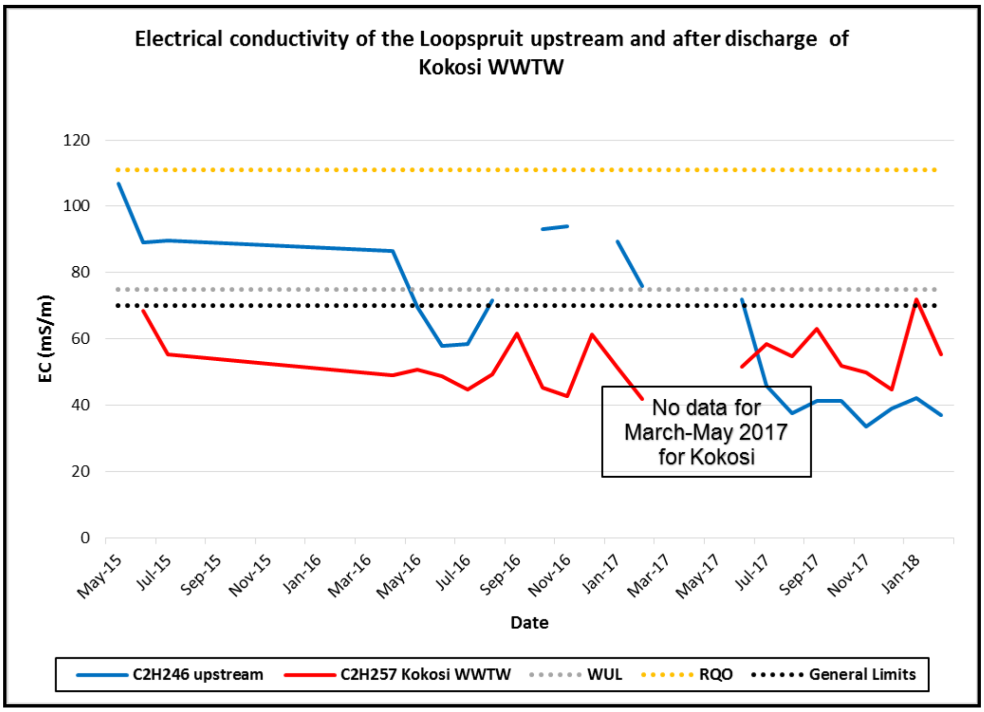

Figure 4. 4: Electrical conductivity in the Loop Spruit upstream and downstream of the Kokosi WWTW for the period May 2015 – March 2018.

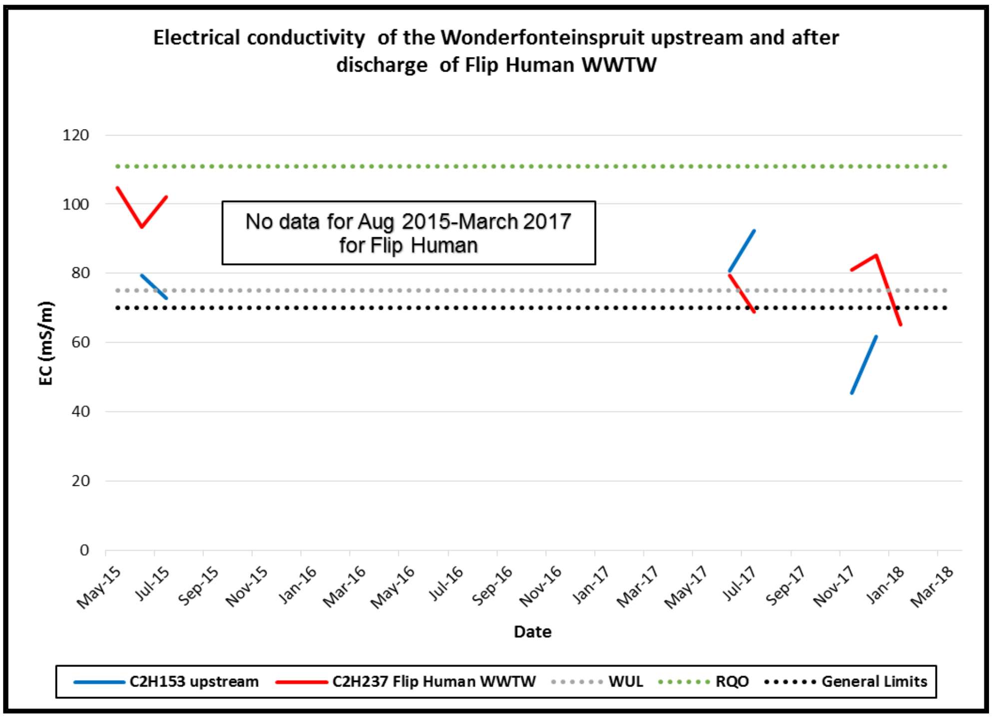

Figure 4. 5: Electrical conductivity in the Wonderfontein Spruit upstream and downstream of Flip Human WWTW for the period May 2015 – March 2018.

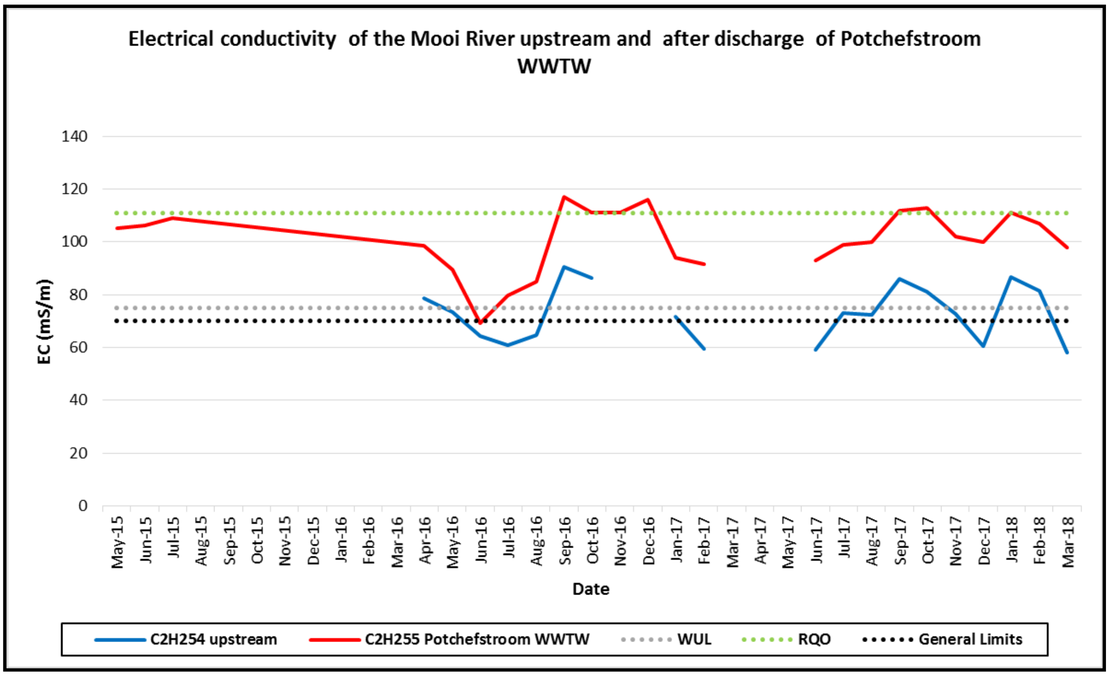

Figure 4. 6: Electrical conductivity In the Mooi River upstream and downstream of Potchefstroom WWTW for the period May 2015 – March 2018.

The EC data of the water within the catchment area during the period 2001 - 2002 was also analysed for its compliance as a comparative historic reference data to the current study period. The EC concentration for the WWTWs ranged from 51 to 69 mS/m (Kokosi), 69.8 to 82.3 mS/m (Flip Human) and 108 to 137 mS/m (Potchefstroom) (Figure 4.7). The EC of water from the Loop Spruit, Wonderfontein Spruit and Mooi Rivers downstream of the discharge points of the respective WWTWs established that only water downstream of the Kokosi was compliant with set General, RQO and WUL Limits. The EC of the water from Mooi River downstream of the Potchefstroom WWTW exceeded all the set limits and quality targets. Water after the discharge point of the Flip Human WWTW were within the RQO, but exceeded the General and WUL limits. Compared to 2015-2018 data only the Potchefstroom WWTW indicated some level of improvements on the EC concentration in water with averages from 120 to 100 mS/m. The other WWTWs there are variations though there is some kind of improvement though only slightly.

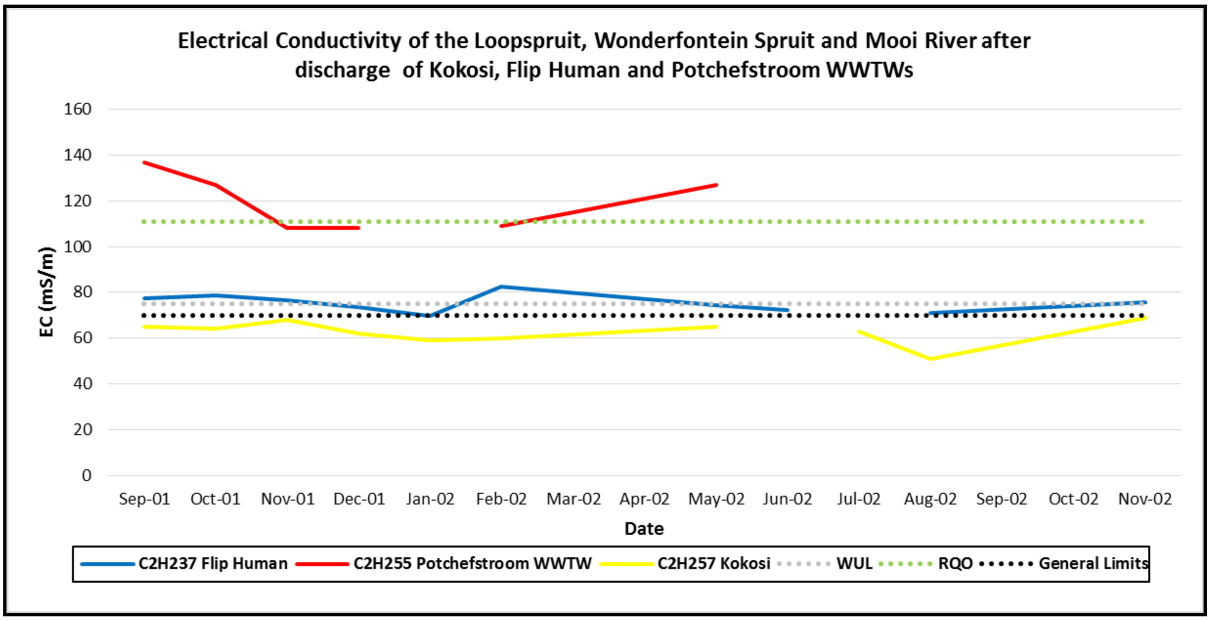

Figure 4. 7: Historical data (2001- 2002) electrical conductivity from the Loop Spruit, Wonderfontein Spruit and Mooi River after discharges of the Kokosi, Flip Human and Potchefstroom WWTWs.

4.4. SUSPENDED SOLIDS (SS)

The SS concentration of water at the Kokosi WWTW ranged from 5 to 149 mg/l (Figure 4.8). Only the WEPA limits were complied with fully. Compliance to TWQR for agricultural use (irrigation) was at 84%, EPA was 75% and the WUL and General limits were 70%. The SS concentration at Flip Human WWTW ranged from 1.5 to 308 mg/l and 29 to 388 mg/l both upstream and downstream respectively (Figure 4.9). Compliance with the TWQR for agricultural use (irrigation), WUL, EPA, WEPA and General Limits was about 83% for the upstream point. The downstream point could meet the WUL and General Limits, and compliance with TWQR for agricultural use (irrigation) was 50%, EPA was 33% and WEPA was 83%. The SS concentration at Potchefstroom WWTW ranged from 1.5 to 422 mg/l (Figure 4.10). Compliance was at 90.5% with the WUL, General Limits and EPA Limits. Compliance with TWQR for agricultural use (irrigation) and WEPA was 95%. However, as can be seen in Figure 4.8 to Figure 4.10 the amount of data points for the SS was extremely limited. The noticeable highest SS results were 308 and 388mg/l both upstream and downstream of the Flip Human as well as 422 mg/l at the Potchefstroom WWTWs. These could be attributed to the solids accumulated from the inadequate treatment process as well as any other potential human induced activitivies (such as agriculture) that could have introduced solids the upstream points of the Flip Human WWTW.

Only the t-test for the Flip Human WWTW could be completed as there were no upstream data for the Kokosi and Potchefstroom WWTWs. The p-value for the comparison between the SS concentration measured at the point upstream of Flip Human and at site after discharge was 0.54 which is greater than 0.05. This result indicates there was no statistically significant difference between the SS concentration upstream and at the Flip Human WWTW.

The SS of settled surface water is the mass of colloidal particulate matter (both or organic or inorganic origins) that remains suspended after attaining a settling equilibrium per unit volume of water (Venkatesharaju *et al.*, 2010). Sources of SS pollution includes discharges from WWTWs and industrial processes and agricultural runoff. The higher the SS concentration, the poorer the water quality is of the water resource. Elevated concentrations Sediments decreases water suitability for different uses especially in urban/ industrial areas, for recreational activities and for aquatic life. The SS has a potential to impact on the benthic fauna and also affect gill functioning in fish (Dallas and Day, 2004).

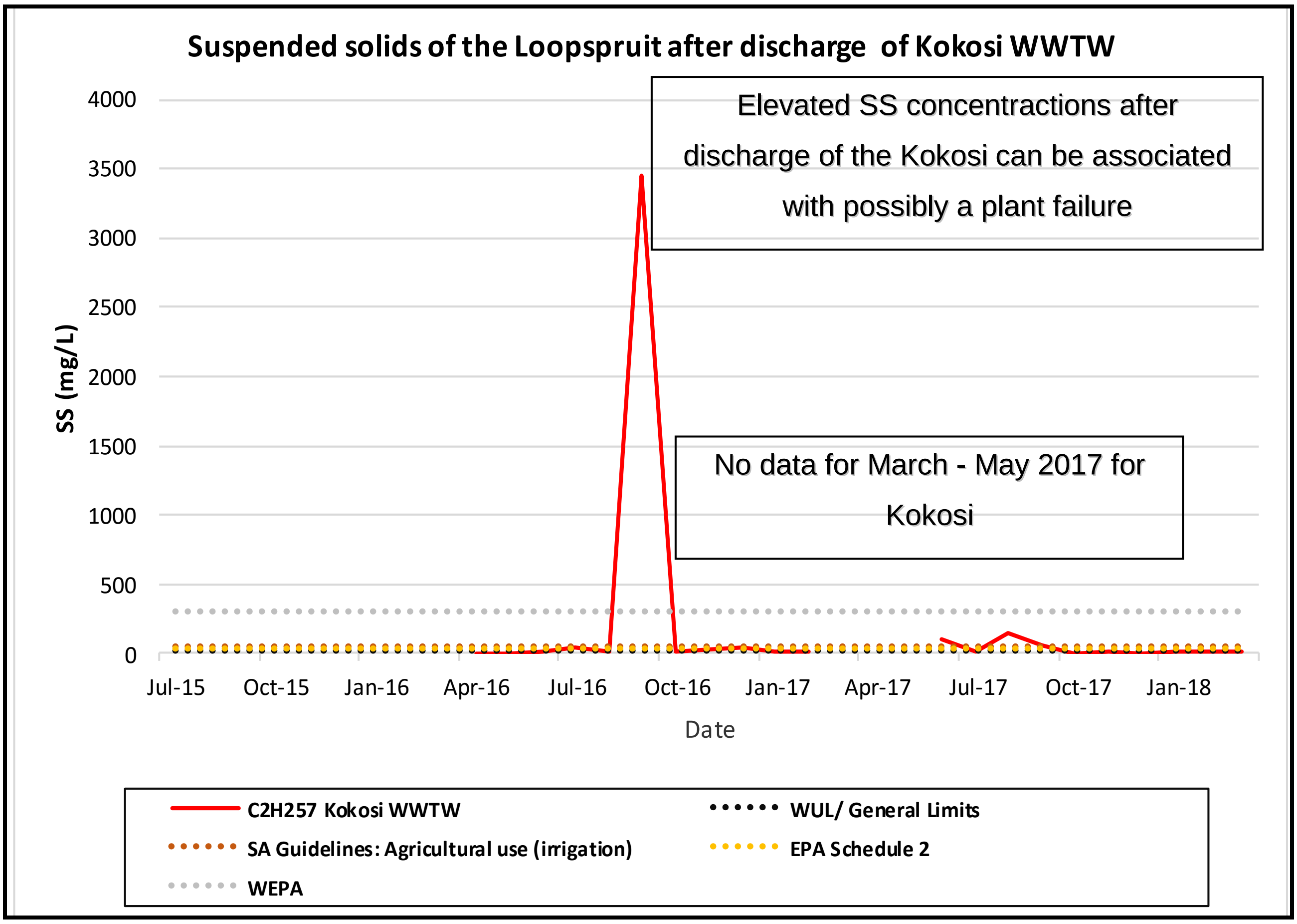

Figure 4. 8: Suspended solids in the Loop Spruit downstream of the Kokosi WWTW for the period July 2015 – March 2018.

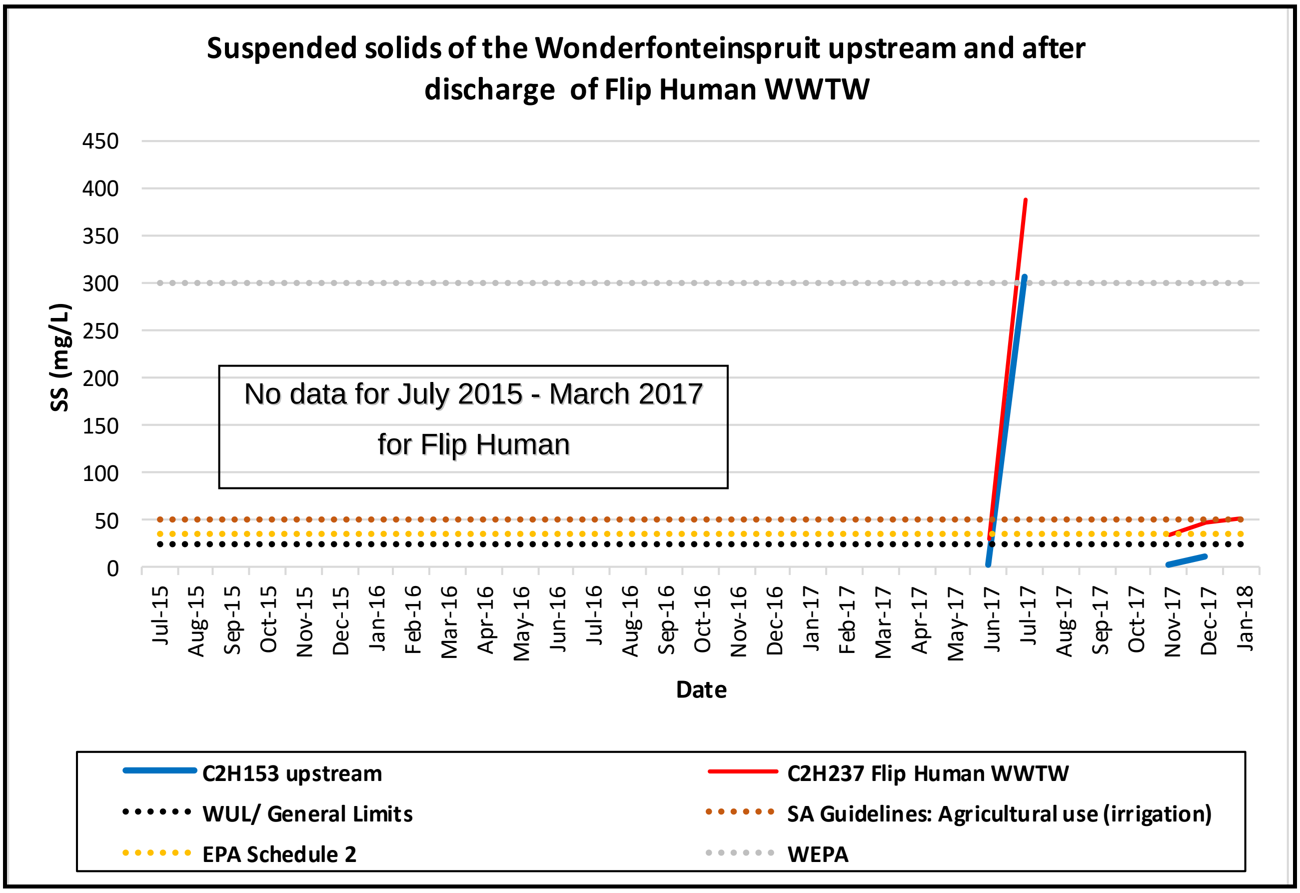

Figure 4. 9: SS in the Wonderfontein Spruit upstream and downstream of the Flip Human WWTW for the period July 2015 – March 2018.

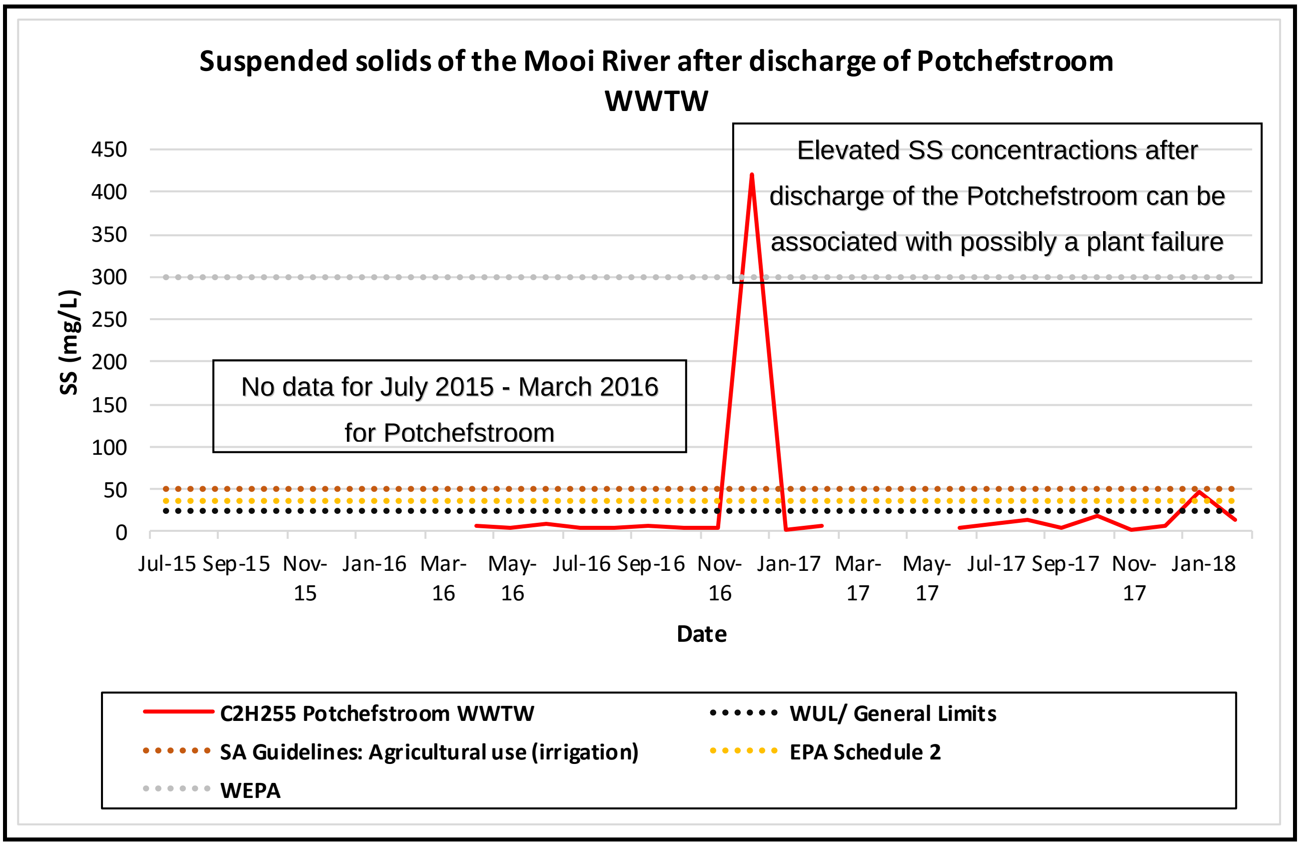

Figure 4. 10: SS in the Mooi River downstream of the Potchefstroom WWTW for the period July 2015 – March 2018.

4.5. NITRATES

The nitrate (NO_3) concentrations ranged from 1.0 to 8.2 mg/l at the upstream points of the Kokosi and Flip Human WWTWs. There was no data for the Potchefstroom WWTW upstream points. Both the highest and the lowest concentrations were recorded at the Flip Human upstream point (Figures 4.11 – 4.13). In addition, the nitrate values in the upstream points of Kokosi and Flip Human WWTWs were within the permissible limits of the WUL, General Limits and EPA schedule 2. Only a few points recorded exceeded the TWQR for domestic use, whilst other points exceeded the RQO limits. None of the upstream points for Kokosi and Flip Human met the TWQR for agricultural use (irrigation) limits. This could indicate that nitrate contamination reaching the Loop Spruit may be from a combination of sources such as discharge of water as well as agricultural runoff. These nitrate concentrations could also be as a result of mining activities which are known to occur along the Mooi River system.

The nitrate concentrations ranged from 0.1 to 31.3 mg/l at the downstream points for Kokosi, Flip Human and Potchefstroom WWTWs, where the maximum value was recorded at Kokosi while the lowest value was recorded in Flip Human WWTW. The points recorded after discharge of the Flip Human and Potchefstroom WWTWs complied fully with the EPA Schedule 2 limits whilst compliance at Kokosi was 83%. The WUL and General Limit requirements were not met at the Kokosi and Potchefstroom whilst the Flip Human WWTW complied fully. The TWQR for domestic use was met fully after the discharge of Flip Human whilst compliance for the points after discharge of Kokosi and Potchefstroom was sitting at 65% and 38% respectively. The points downstream of Potchefstroom did not meet the TWQR for the agricultural use (Irrigation) whilst compliance at the Kokosi and Flip Human WWTW was 9% and 67% respectively. Compliance to the RQO limits were 52%, 89% and 8% for the Kokosi, Flip Human and Potchefstroom respectively. Pelser, 2015 discovered that Potchefstroom was the largest contributer of pollution to the Mooi River as a result of various sources of pollution entering the Mooi River and very high concentrations of water quality variables were measured and nitrates being one of them, which indicate pollution and impact.

The p-value for the comparison between the nitrate concentration measured at the point upstream of Kokosi and at the downstream site was greater than 0.05 ($p > 0.54$). Since there was no difference, it can be concluded that the release of wastewater from the Kokosi WWTW is not having a significant influence on the nitrate concentration of the water (again noting that there are limitations in the data, and on occasion the nitrate concentration at the Kokosi WWTW is in fact quite high - 31.3 mg/l; Figure 4.11). This periodic higher measurement potentially reflects an impact of the WWTW, but based on all the measurements, there was no statistically significant difference. For the comparison of the nitrate concentration measured at the site upstream of the Flip Human WWTW, and at point at Flip Human WWTW, the p value was 0.003. Thus, there was a statistically significant difference between the upstream and downstream sites.

Two major sources of nitrate pollution of surface water include agricultural run-off laden with residues of inorganic fertilizers as well untreated animal and human wastes. Elevated amounts of nitrates in river water can also be due to discharge of semi treated sewage wastes from WWTWs (Naidoo, 2013b). Nitrates are known to induce eutrophication which poses a threat to the aquatic life (Pieterse *et al*., 2003; de Villiers and Thiart, 2007). Reduced sunlight penetration and depletion of dissolved oxygen due to a high demand of DO for aerobic bio-oxidation of the organic matter resulting from the decay of plant blooms triggers anaerobic conditions (Odjadjare and Okoh, 2010; Abbaspour, 2011). The nitrates are reduced to produce ammonia, which is toxic to fish, and related species. These conditions also produce noxious and odorous volatile compounds such methane, halomethanes and hydrogen sulphide (Agora *et al.*, 2018). In addition, high concentration of nitrates is toxic to humans.

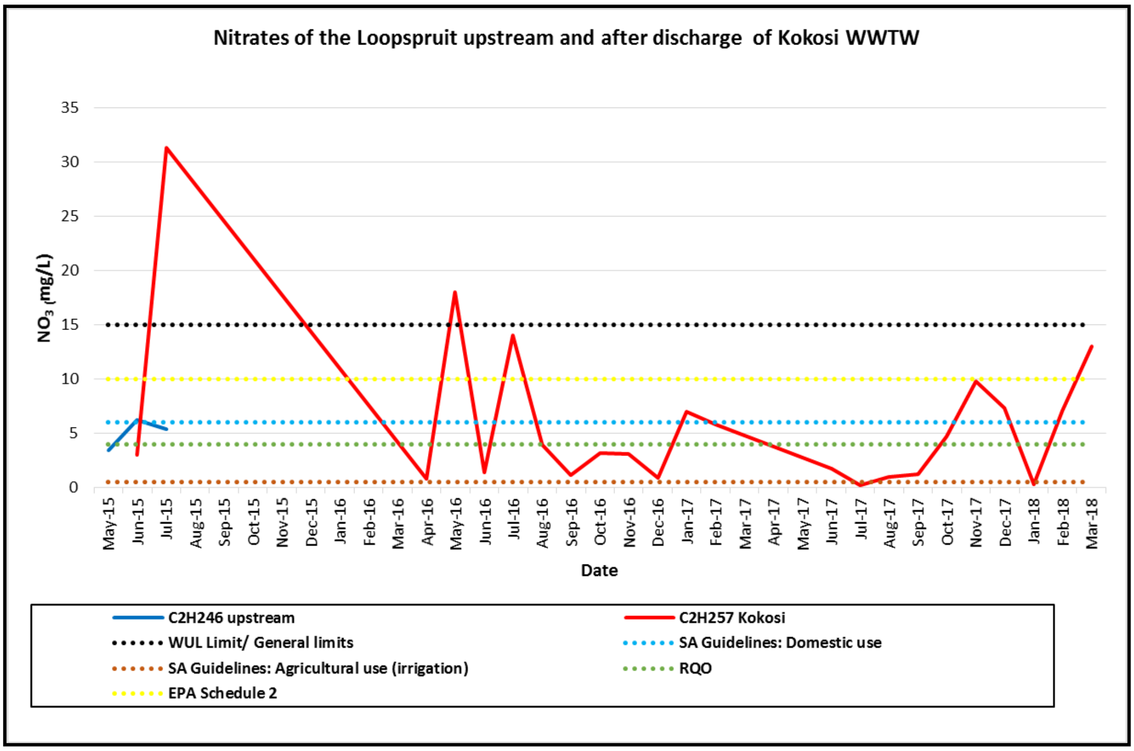

Figure 4. 11: Nitrate concentrations in the Loop Spruit upstream and downstream of the Kokosi WWTW for the period May 2015 – March 2018.

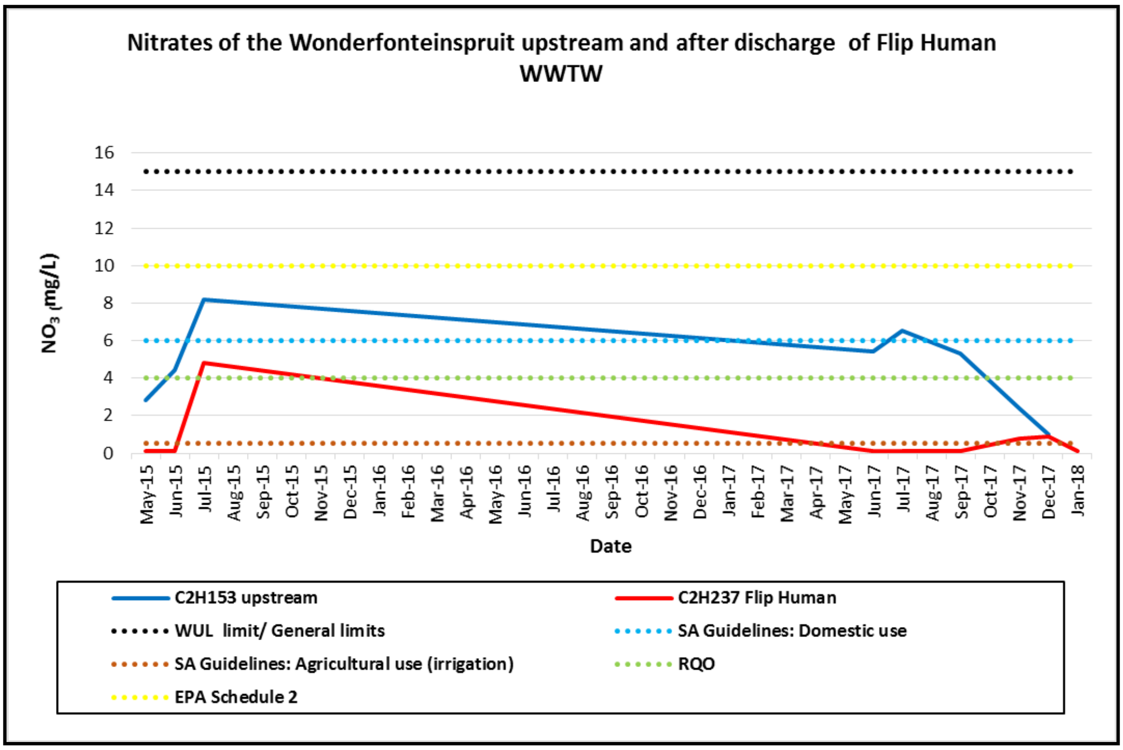

Figure 4. 12: Nitrate concentrations in the Wonderfontein Spruit upstream and downstream of the Flip Human WWTW for the period May 2015 – March 2018.

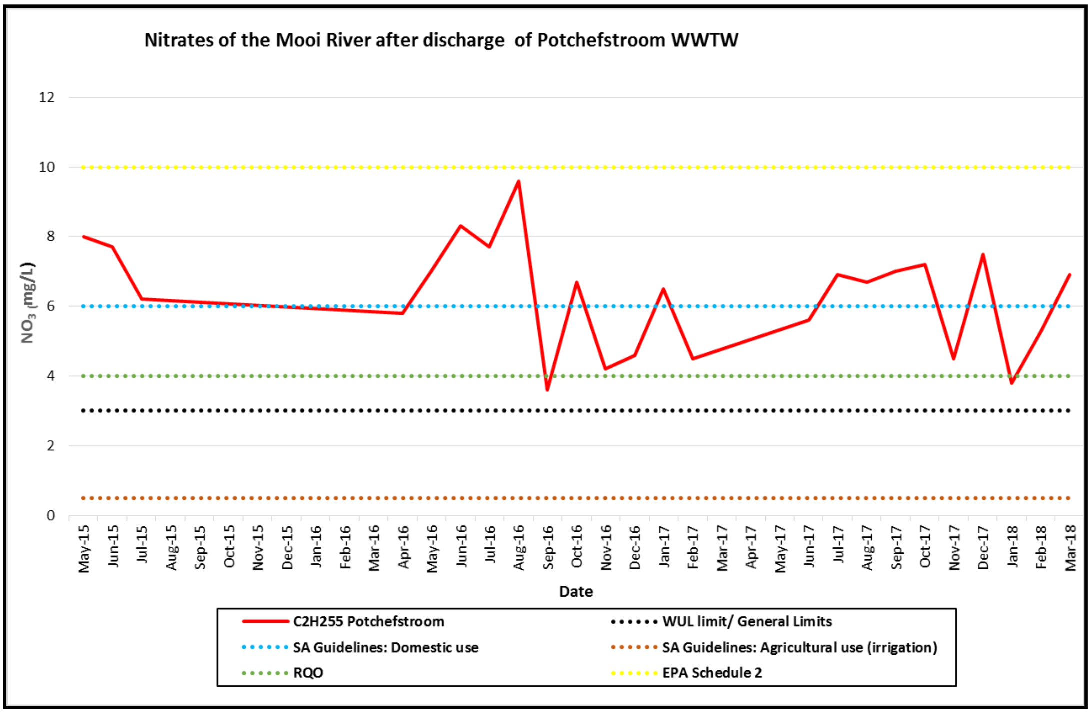

Figure 4. 13: Nitrate concentrations in the Mooi River upstream and downstream of Potchefstroom WWTW for the period May 2015 – March 2018.

4.6. AMMONIA

The ammonia (NH_3) concentrations ranged from 0 to 0.004; 0.001 to 0.015 and 0.062 mg/l at the upstream points of the Kokosi, Flip Human and Potchefstroom WWTWs respectively. After the discharge of the three WWTWs, the ammonia concentrations ranged between 0 and 15 mg/l for Kokosi, 0.3 to 1 mg/l for Flip Human and 0.001 to 3.3 mg/l for Potchefstroom WWTW (Figures 4.14 – 4.16). There were gaps on the data received from DWS, with noticeably missing analysis results between August 2015 to March 2016 which was found to be common amongst all 3 WWTWs (see Figure 4.14). The upstream points for the Kokosi WWTW complied and met all the ammonia limits for the WUL, TWQR for domestic use, EPA schedule 2 and the General Limits. For the points after the discharge of the Kokosi WWTW, only the WUL limit was met. Compliance for other limits was at 74% for both the TWQR for domestic use and EPA schedule 2 whereas General limit compliance was at 84%.

From the data received for the Flip Human WWTWs there were missing analysis results from August 2015 to January 2015. Indications were there issues with the appointment of the service providers in most of the months' prior to the year 2017, hence there was no monitoring done of the resources. The the upstream point, compliance was 100%, meaning all the WUL, TWQR for domestic use, EPA schedule 2 and the General Limit requirements were met. The upstream points of Potchefstroom complied with all the WUL, TWQR for domestic use, EPA schedule 2 and the

General Limits. After the discharge of the WWTW only the WUL was complied with. The TWQR for domestic use, EPA schedule 2 and the General Limit compliance were at 92%, 92% and 96% compliance respectively.

The p-value for the comparison between the ammonia concentrations measured at the point upstream of Kokosi, Flip Human and Potchefstroom and at the sites after the three WWTWs discharge were less than 0.05. Since there is a difference, it can be concluded that the release of wastewater from the three WWTW was having a significant influence on the nitrate ammonia concentration of the water. To examine this further the averages of the concentrations at each site were calculated. The average ammonia concentration upstream of the three WWTWs were far lower than at the WWTWs. This then confirms that the WWTWs is having a statistically significant influence on the ammonia concentration in the water.

The major sources of ammonia into the surface water could be associated with the release and discharge of human and animal excreta, effluent from industries and agricultural fertilisers (DWAF, 1996c; Agora *et al.*, 2018). Most of the domestic wastewater contains ammonia and ammonium salts which are used as cleansing agents and some as food additives. Ammonia as a gas is known to be toxic to fish and other aquatic species (WHO, 2003).

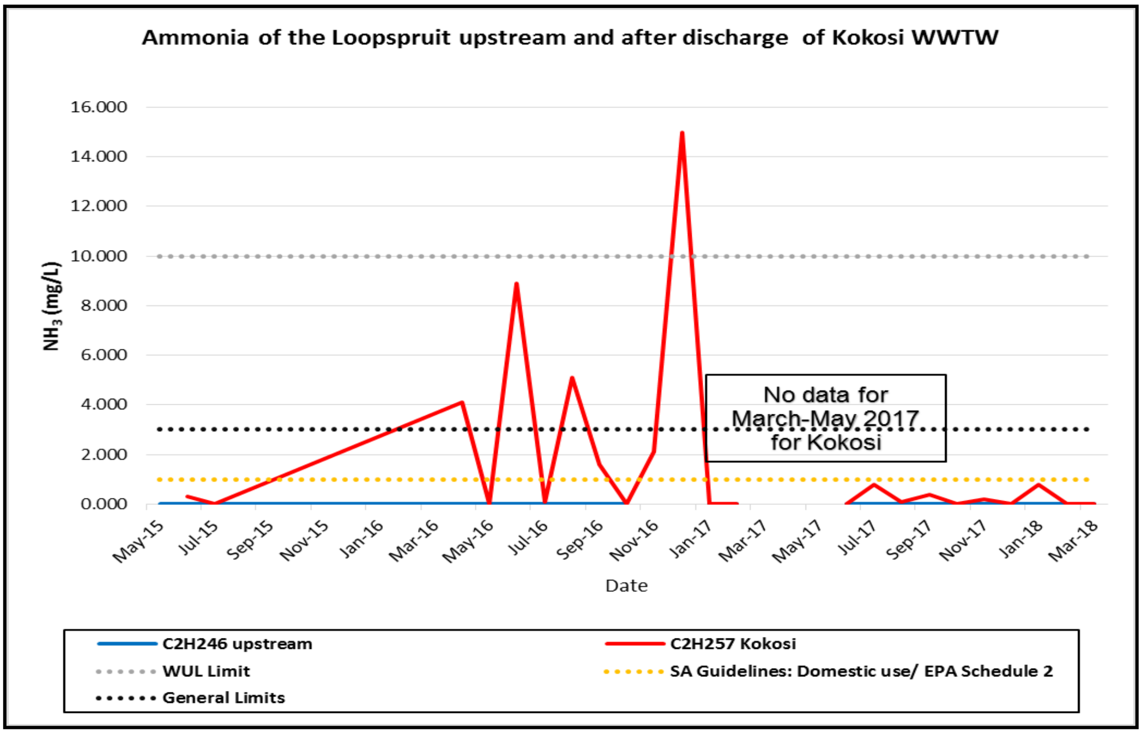

Figure 4. 14: Ammonia concentrations in the Loop Spruit upstream and downstream of the Kokosi WWTW for the period May 2015 – March 2018.

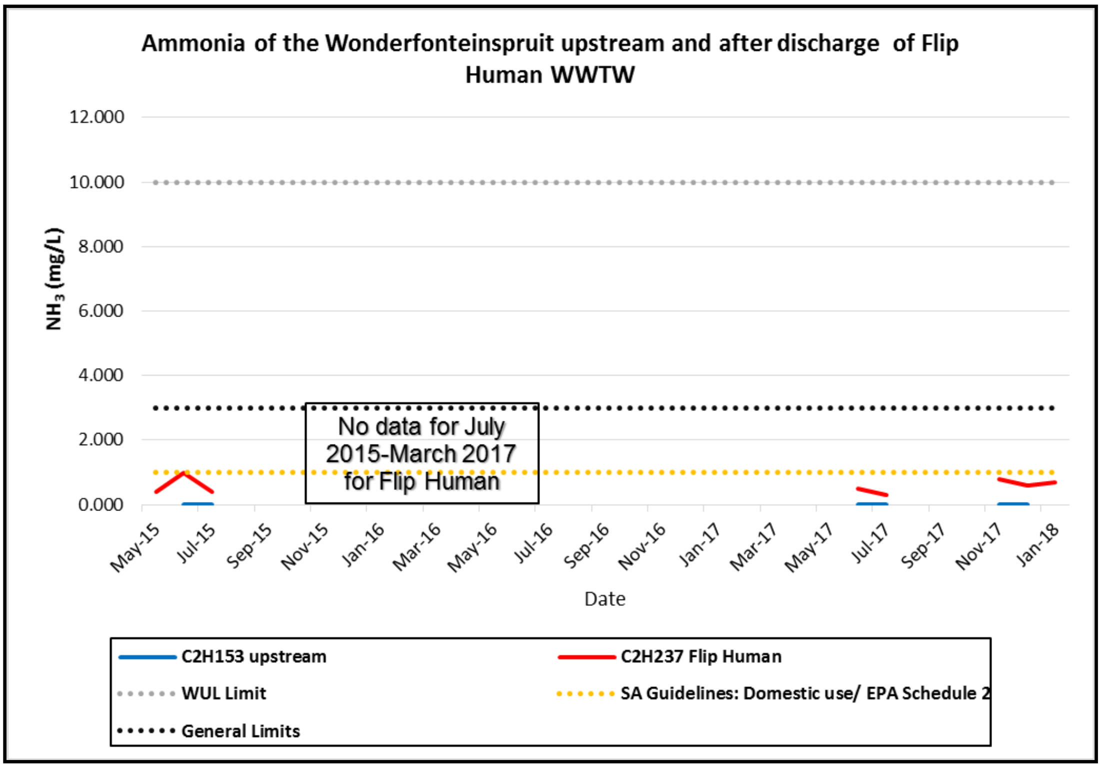

Figure 4. 15: Ammonia concentrations in the Wonderfontein Spruit upstream and downstream of the Flip Human WWTW for the period May 2015 – March 2018.

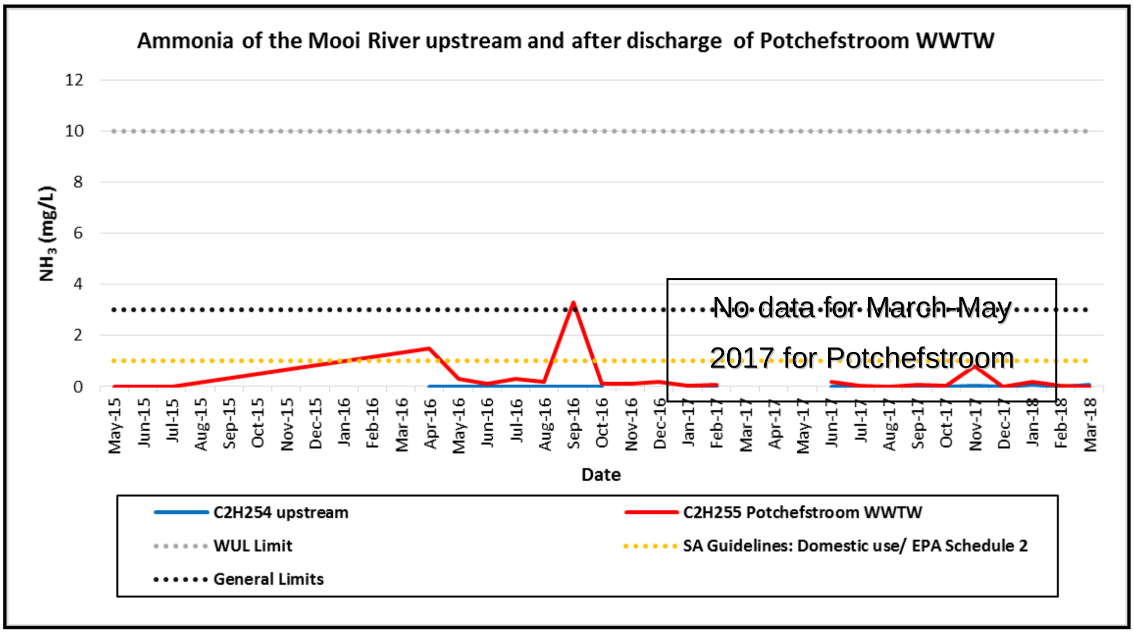

Figure 4. 16: Ammonia concentrations in the Mooi River upstream and downstream of the Potchefstroom WWTW for the period May 2015 – March 2018.

4.7. ORTHOPHOSPHATE

The orthophosphate (PO_4^{3-}) concentrations ranged from 0.460 to 2 mg/l in the upstream points and ranged from 0.1 to 9.8 mg/l for the downstream points of the Kokosi WWTW. At the Flip Human

WWTW upstream, the PO_4^{3-} concentration ranged from 0.01 to 0.1 mg/l and after discharge it ranged from 0.3 to 7 mg/l. At the Potchefstroom WWTW, the PO_4^{3-} concentration ranged from 0.2 to 6 mg/ L after discharged of the WWTW (Figures 4.17 - 4.19). The upstream data for Potchefstroom was unavailable.

The Kokosi WWTW complied entirely with the General Limits in both upstream and downstream points. The upstream points did not comply with the RQO limits (0%) whereas after the discharge of the WWTW, compliance was at 29%. The WUL compliance upstream was 63.6% and after discharge of the Kokosi WWTW was 58%. The Flip Human WWTW upstream and downstream points complied with all the WUL, RQO and General Limits except the downstream point which did not comply with the RQO limits (0%). The Potchefstroom WWTW complied entirely with the General Limits. Compliance to WUL was 96% and the WWTW did not comply to the RQO limits (0%).

The p-value for the comparison between the PO_4^{3-} concentrations measured at the upstream and downstream points for Kokosi WWTW was greater than 0.05 ($p = 0.10$). Since there is no difference, it can be concluded that the release of wastewater from the Kokosi WWTW was not having a significant influence on the PO_4^{3-} concentration in the water. The p-value for the comparison between the PO_4^{3-} concentration measured at the point upstream of Flip Human and at the point downstream was less than 0.05 ($p = 0.04$). Therefore, there was a statistically significant difference between the PO_4^{3-} concentration upstream and downstream of the Flip Human WWTW. The statistical analysis for the Potchefstroom could not be done since there was no upstream data. Pelser, 2015 discovered that Potchefstroom was the largest contributer of pollution to the Mooi River as a result of various sources of pollution entering the Mooi River and very high concentrations of water quality variables were measured and phosphates being one of them, which indicate pollution and impact. The high orthophosphate levels are very harmful to the river, as it encourages eutrophication (Morisson *et al.,* 2001).

Phosphates enter water resources from human and animal waste, some from phosphate rich bedrock, wastewater from laundry cleaning and from other industrial processes, and fertilizer runoff (Mosley *et al.,* 2004). Elevated amounts of orthophosphates can also be due to discharge of semi-treated sewage effluent from WWTWs. Orthophosphates are known to induce eutrophication, which poses a threat to the aquatic life (Morrison *et al.*, 2001). Depletion of dissolved oxygen due to a high demand of DO for aerobic bio-oxidation of the organic matter results in the rapid growth of plant, algae and phytoplankton. Other causes of elevated levels of orthophosphates could be operational issues during the treatment process such as free or bound oxygen in anaerobic zone, and or under or over aeration (WIN-SA, 2011).

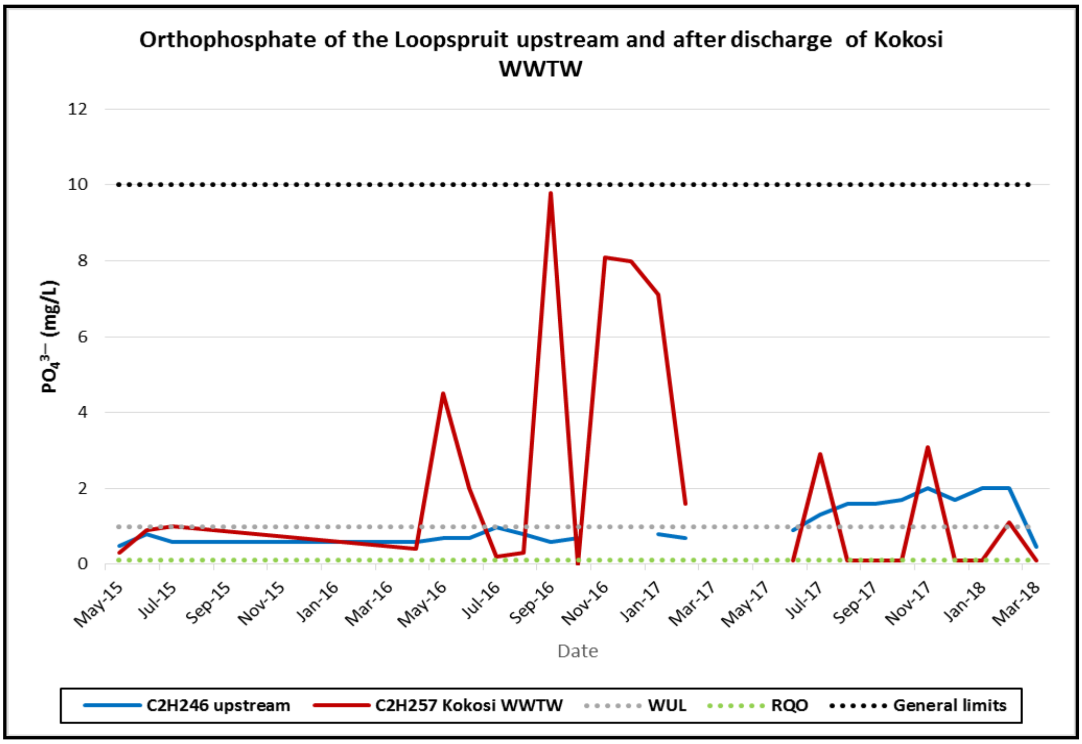

Figure 4. 17: Concentrations of orthophosphate in the Loop Spruit upstream and downstream of the Kokosi WWTW for the period May 2015 – March 2018.

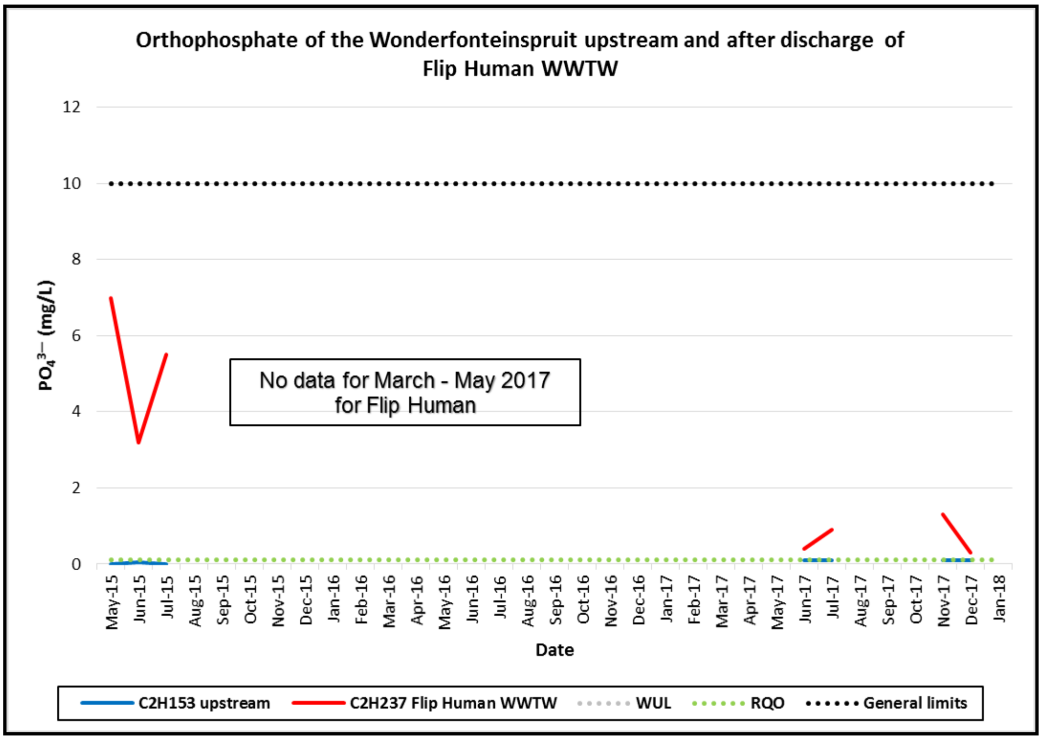

Figure 4. 18: Concentrations of orthophosphate in the Wonderfontein Spruit upstream and downstream of the Flip Human WWTW for the period May 2015 – March 2018.

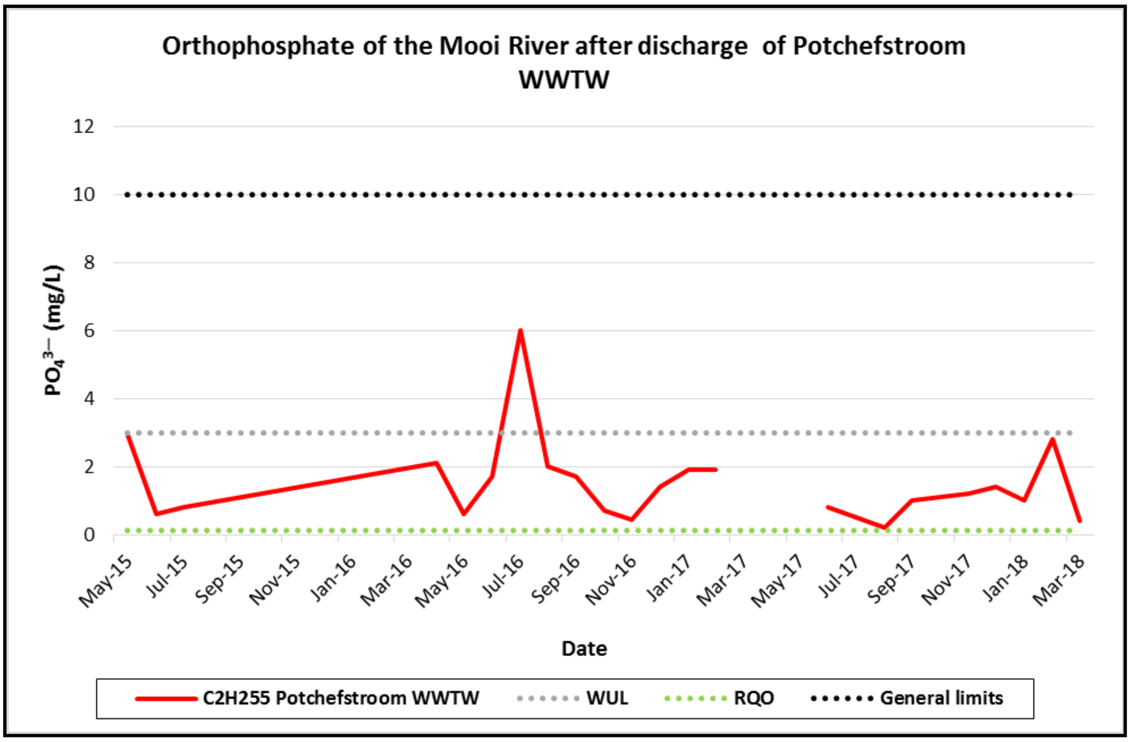

Figure 4. 19: Concentrations of orthophosphate in the Mooi River downstream of the Potchefstroom WWTW for the period May 2015 – March 2018.

4.8. CHEMICAL OXYGEN DEMAND (COD)

The Chemical Oxygen Demand (COD) concentrations at the Loopspruit ranged between 5 to 24 mg/l and 5 to 4740 mg/l for the upstream points and Kokosi WWTW respectively (Figure 4.20). Only the upstream points complied fully with the WUL, General Limit and EPA Schedule 2 limits. For the Kokosi WWTW site (downstream) compliance to WUL and General Limits were at 80.9% and EPA was 85.7%. The COD concentrations at the Wonderfonteinspruit ranged from 5 to 16 mg/l and 89 to 1420 mg/l respectively (Figure 4.21). Only the upstream points complied fully with the WUL, General Limit and EPA Schedule 2 limits. The downstream points at Flip Human did not meet the requirements of the WUL and General limits. Compliance to EPA was at 33.3%. There was no data on the COD concentration for the upstream points of the Potchefstroom WWTW. The COD concentration for the Potchefstroom WWTW ranged between 5 and 61 mg/l which complied with the WUL, General Limits and EPA Schedule 2 requirements (Figure 4.22).

The p-values for the comparison between the COD concentration measured at the point upstream of Kokosi and at the site downstream was found to not be statistically significant for either Kokosi WWTW and Flip Human WWTW ($p = 0.25$ and $p= 0.19$, respectively). Since there is no difference, it can be concluded that the release of wastewater from the Kokosi and Flip Human WWTW was not having a significant influence on the COD concentration of the water. The statistical analysis for the Potchefstroom WWTW could not be completed since there was no upstream data.

Chemical Oxygen Demand is an indicator of the equivalent amount of oxygen that would be required to chemically oxidise all the oxidisable matter of a water sample (Naidoo, 2013b). The higher the COD detected in water, the higher the presence of oxidisable contaminants in the water. High COD values are due to discharges from wastewaters from municipal and industrial waste streams (pulp processing, food (dairy and meat processors) (Paul, 2011; Agora *et al.*, 2018).

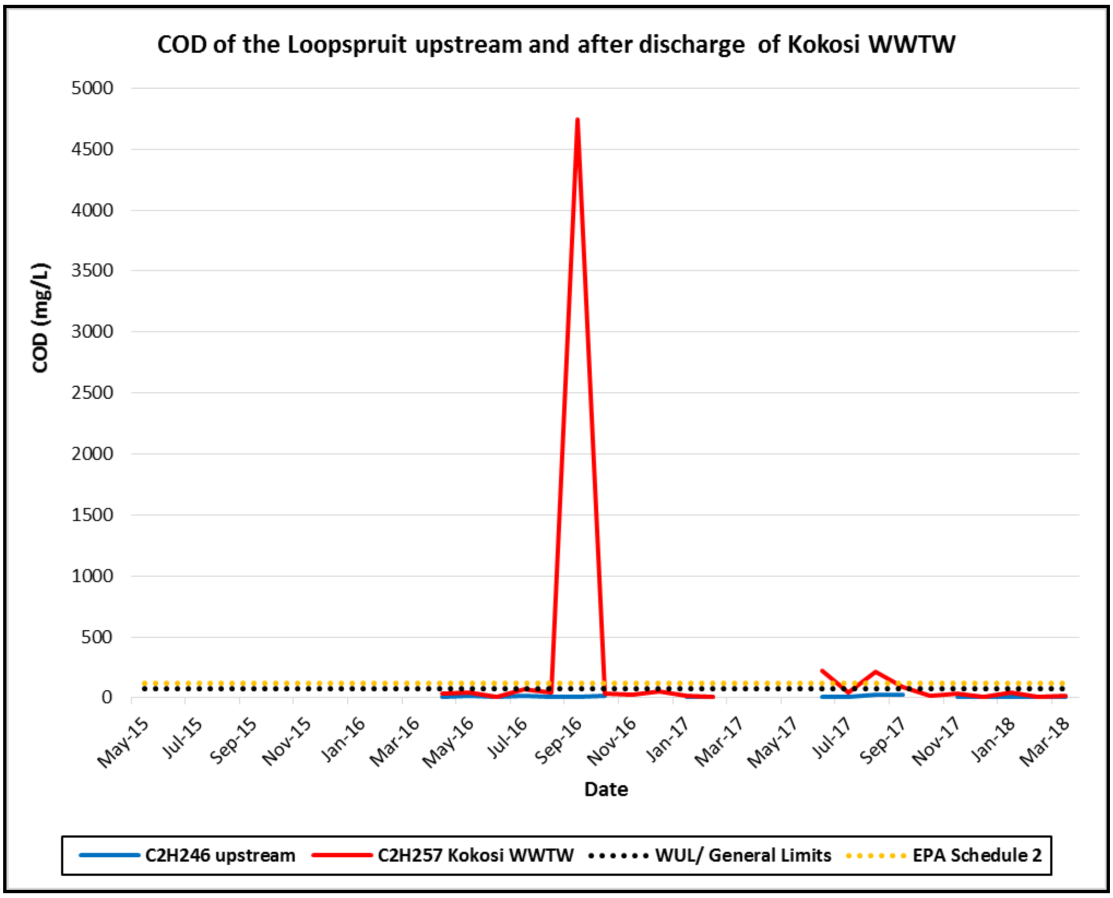

Figure 4. 20: COD concentrations in the Loop Spruit upstream and downstream of the Kokosi WWTW for the period May 2015 – March 2018.

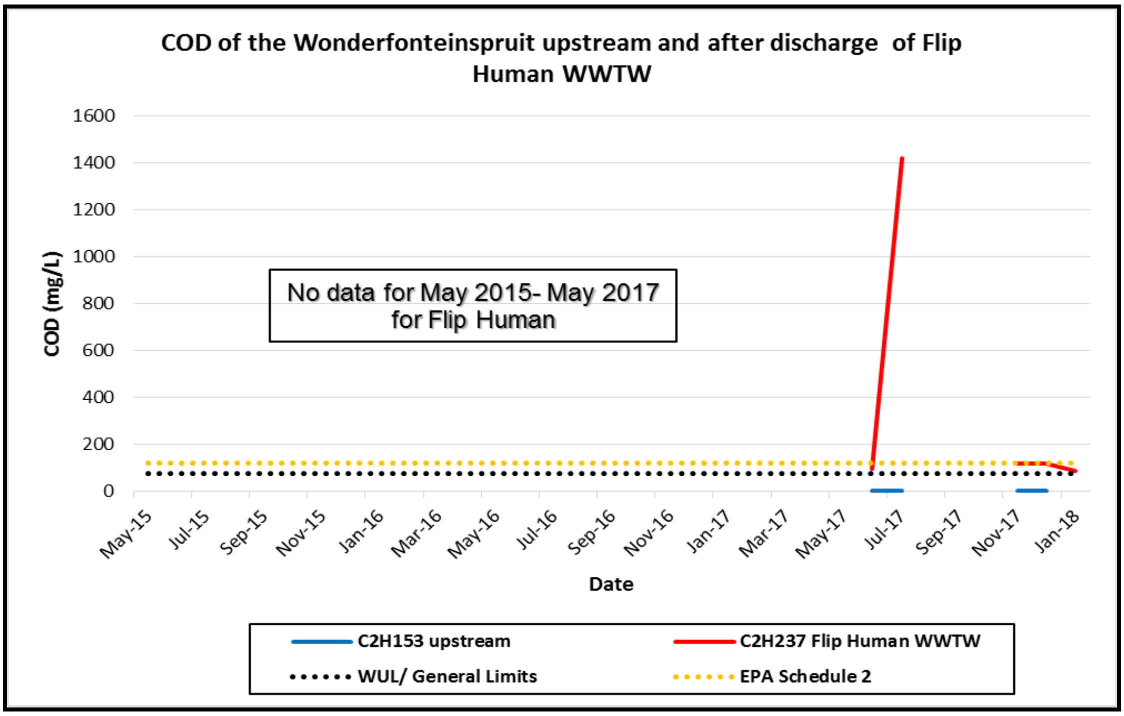

Figure 4. 21: COD concentrations in the Wonderfontein Spruit upstream and downstream of the Flip Human WWTW for the period May 2015 – March 2018.

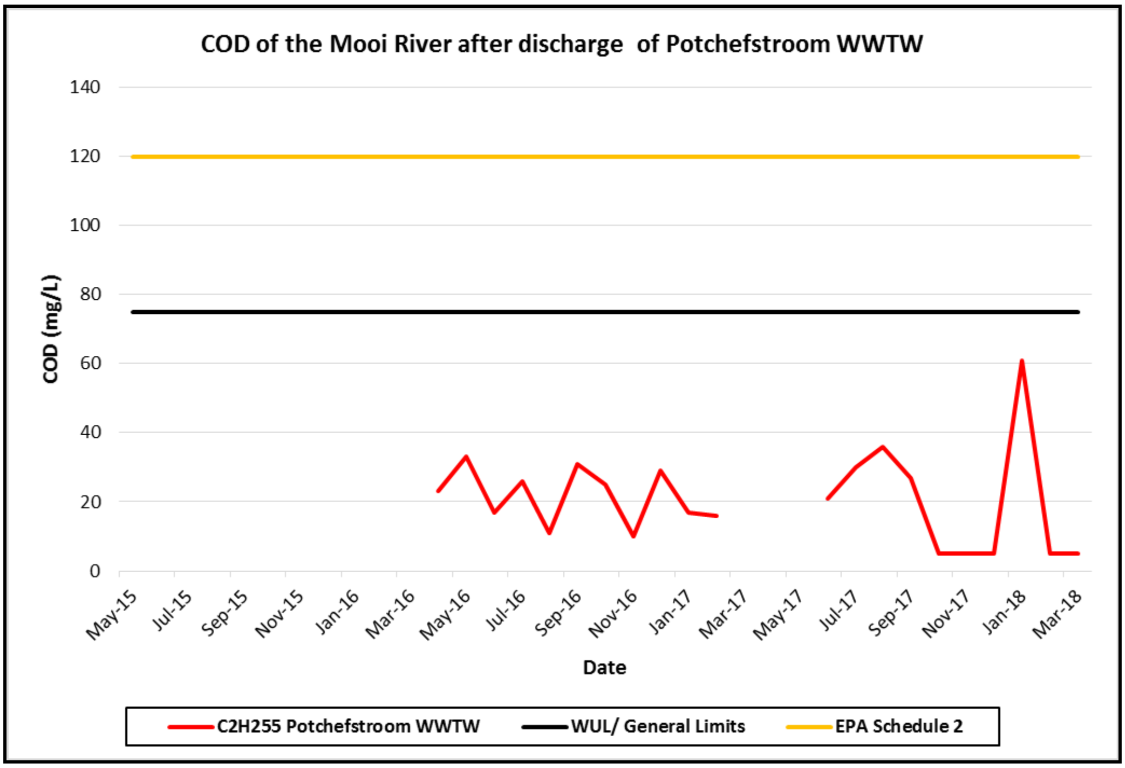

Figure 4. 22: COD concentrations in the Mooi River downstream of the Potchefstroom WWTW for the period May 2015 – March 2018.

The historical data for the period 2001 to 2002 indicated that the COD concentration ranged from 5 to 976 mg/l, 27 to 124 mg/l and 28 to 465 mg/l for the Kokosi, Flip Human and Potchefstroom WWTWs respectively (Figure 4.23). The data indicates that downstream of the discharge point of

Kokosi, the COD were within the WUL, General and EPA limits except in November 2002 where a spike of 163 mg/l was noted which exceeded all the water quality targets. The Wonderfontein Spruit results only exceeded the limits once in September 2002 with the results of 124 mg/l but it was then within the water quality targets afterwards. The results of the Mooi River after the discharge of Potchefstroom WWTW were within all the water quality targets through out, though there were some gaps in the data received from DWS. When looking at the downstream historical data and comparing it with the current study data, one can draw a conclusion that there has not been an improvement on the COD concentration of the water in Loopspruit, Wonderfontein Spruit and Mooi River as a result of the discharge of the WWTWs instead the potential impacts have increased.

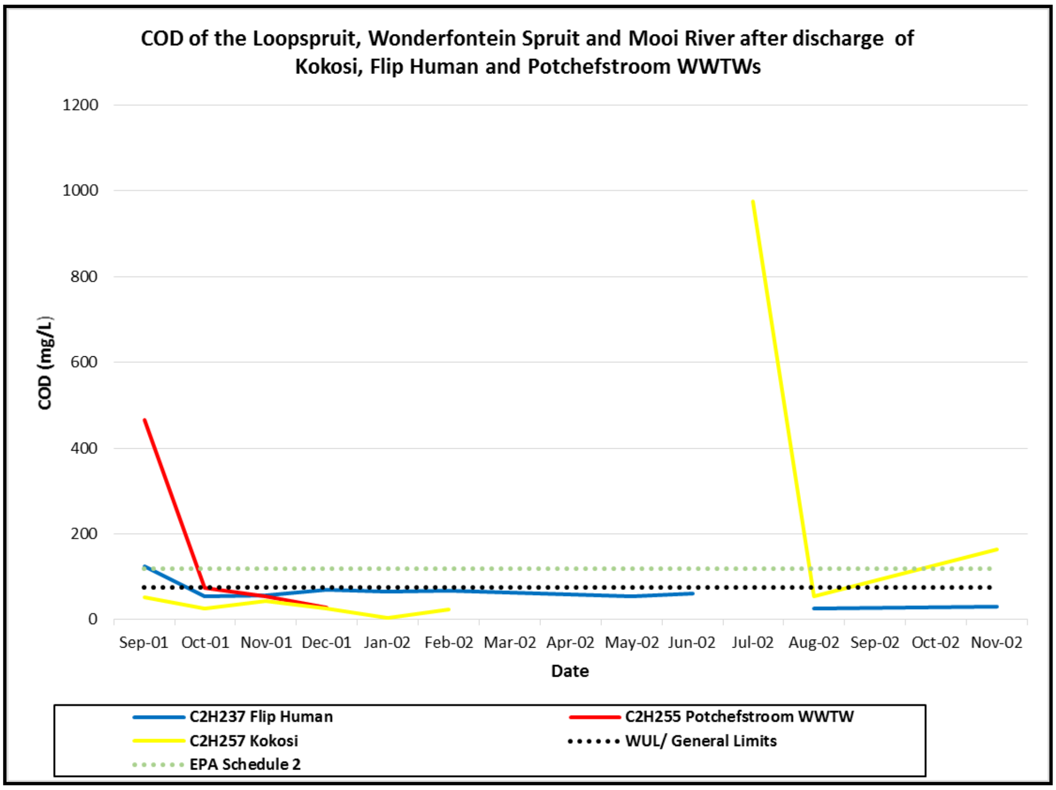

Figure 4. 23: Historical COD data for the Loop Spruit, Wondefontein Spruit and Mooi Rivers, downstream of their respective discharge points at Kokosi, Flip Human and Potchefstroom WWTWs during 2001-2002 period.

4.9. TOTAL FAECAL COLIFORM COUNT (TCC) AND *E. COLI COUNT*

The faecal coliform concentration for the Kokosi WWTW ranged from 1 to 100 cfu/100mL at the upstream point and between 1 to 300 cfu/100mL at the downstream discharge point (though only two months' data were available). The faecal coliform concentration for the Flip Human WWTW ranged from 46 to 3200 cfu/100mL at the upstream point and between 1 to 690 cfu/100mL at the discharge point. The faecal coliform concentration for the Potchefstroom WWTW ranged from 2 to

7600 cfu/100mL at the upstream point and between 1 to 4800 cfu/100mL at the discharge point (Figures 4.24 - 4.26).

The results of the faecal coliform counts at the Kokosi, Flip Human and Potchefstroom WWTWs (both upstream points and after discharge) did not comply with the WUL and TWQR (domestic use). Only the General Limits were complied with at the Kokosi WWTW (both upstream and after discharge), and compliance at the Flip Human WWTW was 83% for upstream point and 100% downstream, and the Potchefstroom WWTW compliance was 75% upstream and 95% downstream. The Flip Human and Potchefstroom WWTWs upstream points did not comply with the TWQR (agricultural use) whereas downstream points were 67% and 28.6% respectively. At the Kokosi WWTW compliance with TWQR (agricultural use) was 0% downstream and 26% upstream.

The p-values for the comparison between the faecal coliform concentrations measured at Kokosi, Flip Human and Potchefstroom WWTWs were greater than 0.05 (p = 0.55, 0.38 and 0.17 respectively). This result indicates there was no statistically significant difference between the faecal coliform concentration upstream and downstream of the WWTWs. However, the data availability was extremely poor and as such this result has a low confidence. A study by Pantshwa et.al, 2009 also revealed the existence of faecal pollution gradients along the Mooi River system.

Coliforms are a group of bacteria (inclusive of faecal and the enterococci genera) which are rod-shaped, gram-negative, non-spore forming and motile or non-motile bacteria which ferment lactose resulting in the formation of acidic gases in the bowels of warm blooded animals (WHO, 2001, 2008). The most common types are the faecal coliforms exemplified by *E. coli*. These have the ability to proliferate even at an elevated temperature (WHO, 2008). Total coliforms are prevalent in both sewage and natural water systems through human and animals' faeces. This poses a health threat due to high chances of water contamination through untreated sewerage waste. Total coliforms count (TCC) (cfu per volume) is used as reliable indicator of hygienic quality of water for drinking water purposes (DWAF, 1996b). Faecal coliforms are thus used as an indicator of potential faecal pollution of surface water. This indicator is normally used when evaluating the quality of wastewater effluents into water resources (DWAF, 1996b).

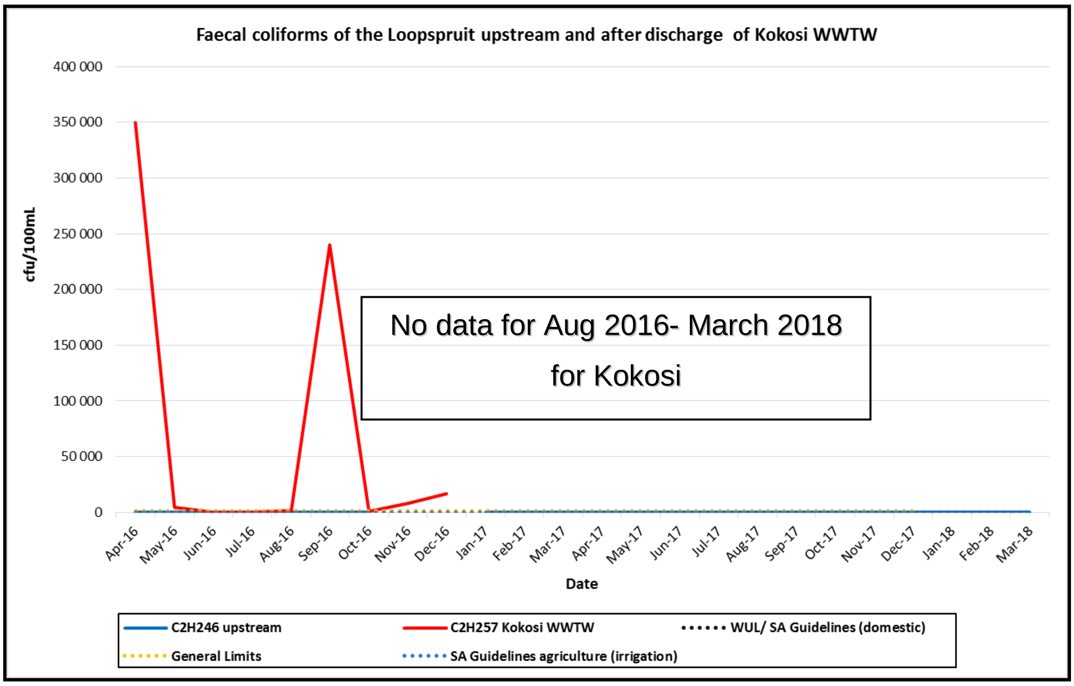

Figure 4. 24: Faecal coliforms count (cfu/100 mL) from the Loop Spruit upstream and downstream of the Kokosi WWTW for the period April 2016 – March 2018.

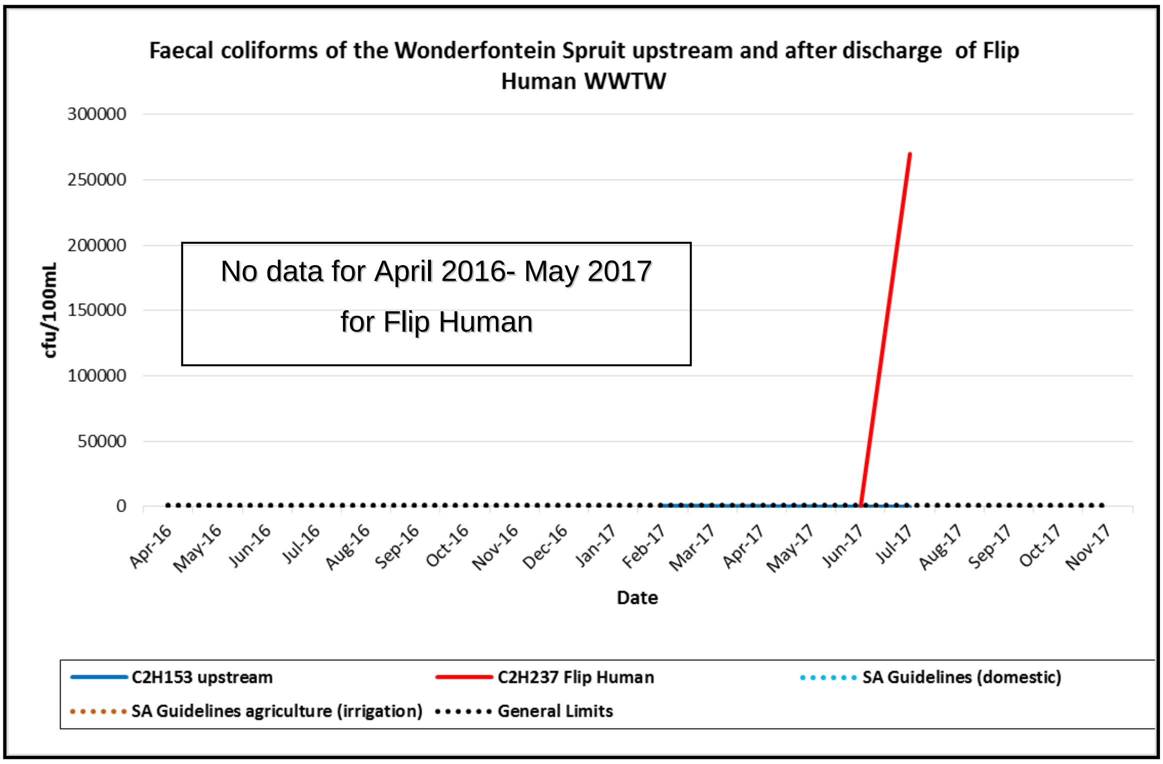

Figure 4. 25: Faecal coliform counts from the Wonderfontein Spruit upstream and downstream of the Flip Human WWTW for the period April 2016 – December 2017.

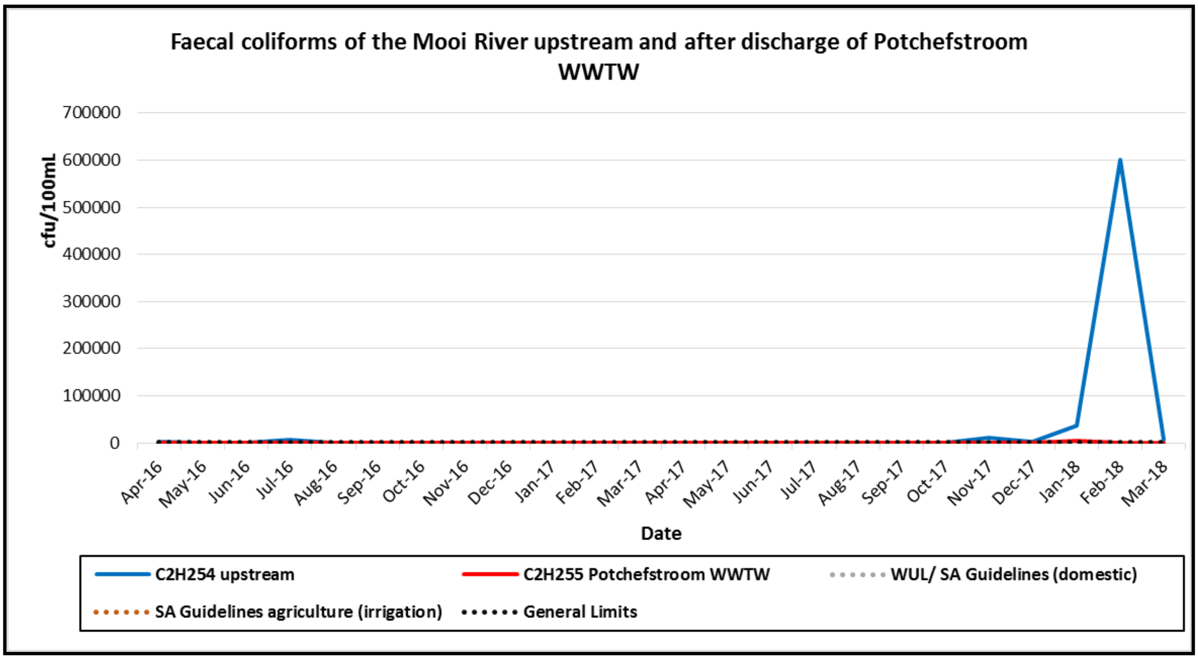

Figure 4. 26: Faecal coliform counts from the Mooi River upstream and downstream of the Potchefstroom WWTW for the period April 2016 – March 2018.

During the reference period (2001-2002), data was only available during the period January 2002 to May 2002 (Figure 4.27). The faecal coliform count of water from the Loop Spruit, downstream of the Flip Human WWTW was consistently higher in values of coliforms and was non compliant to all the water quality targets except in May and November 2002, where at least the General Limit was not exceeded. Water from the Mooi River was heavily contaminated with coliforms and values exceeded all water quality targets throughout the study period (2001 - 2002). The Loop Spruit results showed variation in compliance. In October and November 2001 the General Limit was met but in February and May 2002 there were exceedences on the General Limit where the results were 25 000 and 81 000 cfu/100 mL, respectively. When looking at the downstream points historical data (2001 - 2002) and comparing it with the current study data (2015 - 2018), the conclusion can be drawn that there has been an improvement on the faecal coliform concentration of the water in the Mooi River catchment as a result of the discharge of the WWTWs.

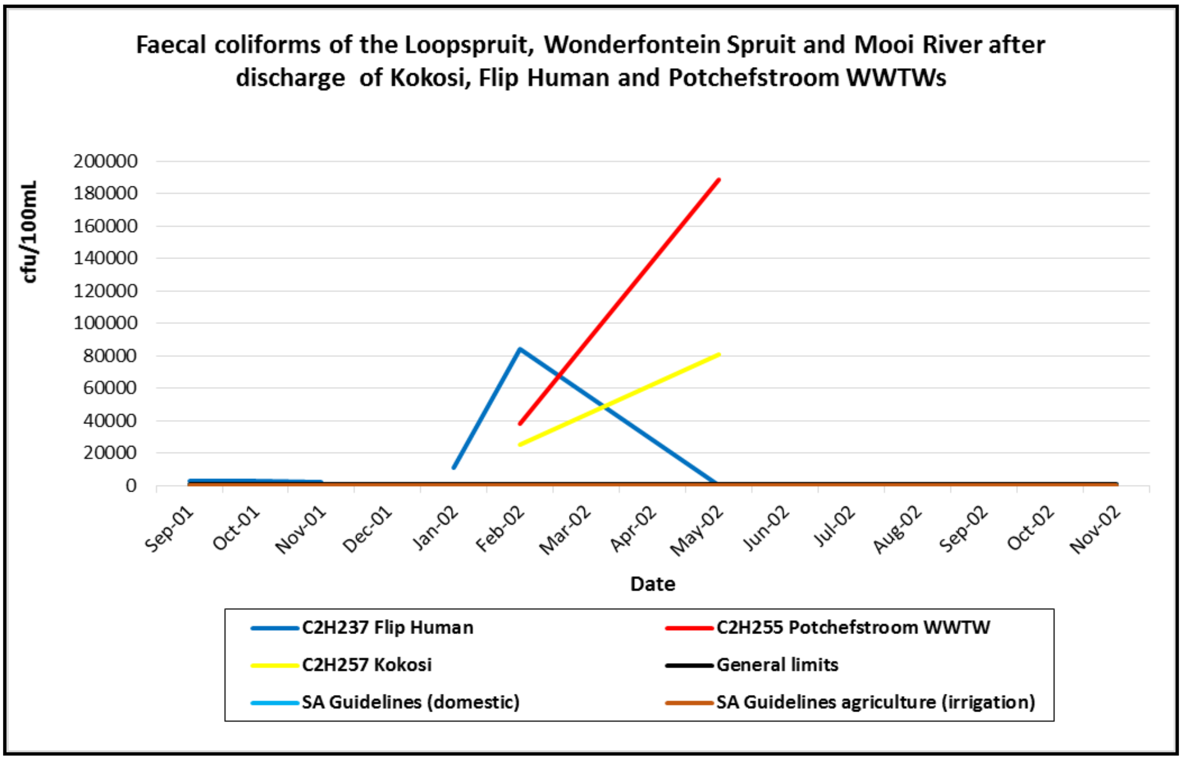

Figure 4. 27: Faecal coliform counts from the Loop Spruit, Wonderfontein Spruit and Mooi River downstream of the respective discharge points at Kokosi, Flip Human and Potchefstroom WWTWs in the period 2001-2002.

The *E. coli* concentrations at the points upstream of Kokosi WWTW ranged from 1 to 100 cfu/100mL (Figure 4.28). After the discharge of the Kokosi WWTW the *E. coli* concentration ranged from 1 to 315 000 cfu/100mL.The concentrations at the Flip Human WWTW, both at the upstream and downstream points ranged from 1 to 1600 cfu/100mL and 1 to 690 cfu/100mL, respectively (Figure 4.29). The *E. coli* concentration at the Potchefstroom WWTW ranged from 2 to 2300 cfu/100mL and 1 to 1920 cfu/100mL, respectively (Figure 4.30).

The upstream points of the Kokosi WWTW complied fully with the RQO and EPA schedule 2 limits and the downstream points' compliance was 13% with the RQO and 25% with EPA schedule 2. Compliance at the upstream points of the Flip Human WWTW was 33% for both RQO and EPA schedule 2 limits. However, the WUL limit was not met. Compliance at the downstream point was 67% for the RQO and EPA limits. The WUL limit was not met at the downstream points at the Flip Human WWTW. Compliance at the upstream points of the Potchefstroom WWTW was 46% for the RQO and 69% for the EPA Schedule 2 limits. After discharge of the Potchefstroom WWTW compliance to the RQO and EPA limits was 89% for both limits.

The p-value for the comparison between the *E. coli* concentrations measured at Kokosi WWTW was less than 0.05 (p=0.03). This means that there were statistically significant differences between the *E. coli* concentration upstream and downstream of the Kokosi WWTW. The release of wastewater from the WWTW was therefore potentially having a significant influence on the E. coli concentration in the water. The p-values for the Flip Human and Potchefstroom were greater than 0.05 (p = 0.52 and 0.37 respectively). Therefore, there was no statistically significant difference between the *E. coli* concentration upstream and downstream of the WWTWs.

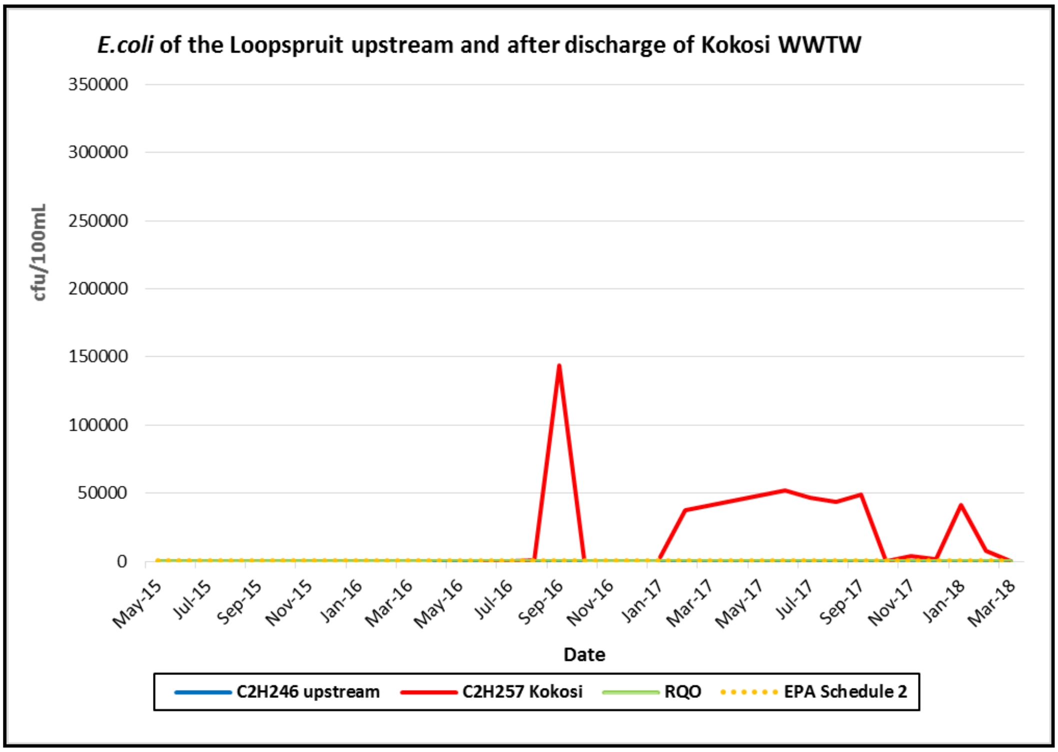

Figure 4. 28: *E. coli* concentrations in the Loop Spruit upstream and downstream of the Kokosi WWTW for the period May 2015 – March 2018.

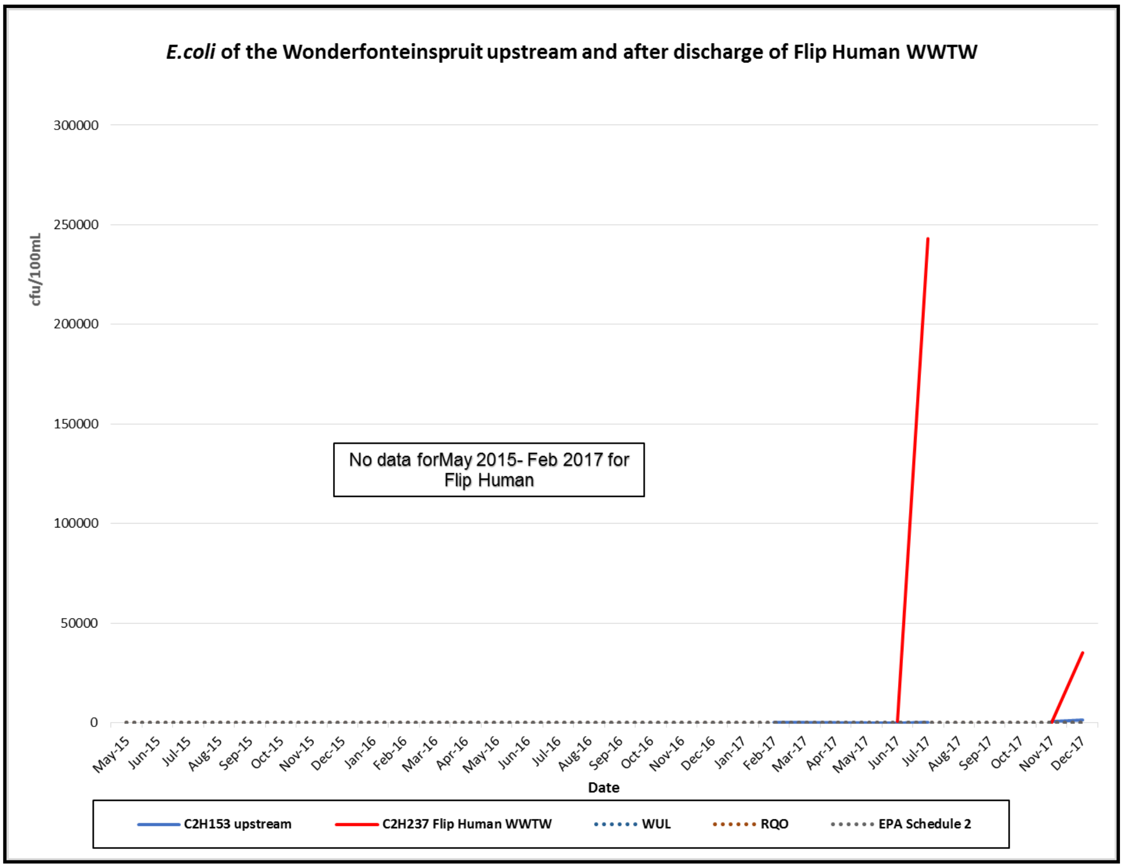

Figure 4. 29: *E. coli* concentrations in the Wonderfontein Spruit upstream and downstream of the Flip Human WWTW for the period May 2015 – March 2018.

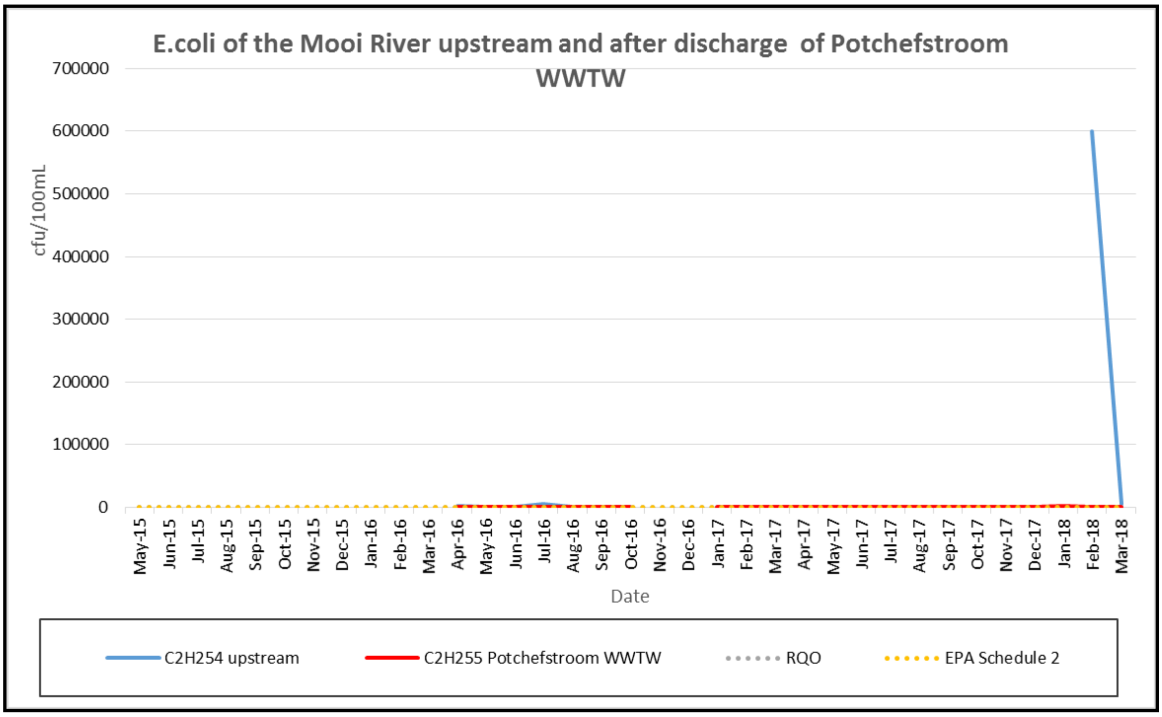

Figure 4. 30: *E. coli* concentrations in the Mooi River upstream and downstream of the Potchefstroom WWTW for the period May 2015 – March 2018.

4.10. STATISTICAL ANALYSIS

4.10.1. Mixed Models

The results of the linear mixed models (LMM) are presented in Table 4.1 for the comparison between the specific water quality variables, sites and sampling year. The results compared the four sampling sites (S2, S3, S4 and S6) and the sampling years (2016, 2017 and 2018) for each of the various water quality variables. The sites represented the following: S2 = upstream Kokosi WWTW; S3 = upstream Flip Human WWTW; S4 = downstream Flip Human WWTW; S6 = downstream Potchefstroom WWTW. In addition, the combination effects of site and year were also investigated. The LMM results showed significant results for the E. coli (site * year) interaction effect while no significant differences where seen between sites or years on its own. The COD, phosphate and pH indicated no significant differences. The EC results indicated significant differences were present between sites (spatial variation) while the ammonia indicated there was significant differences between sampling years (temporal variation). The nitrate results indicated a significance for spatial differences (sites) as well as for the interaction effect between sampling site and sampling years.

Table 4. 1: Linear mixed model results for the three WWTWs, water quality variables and sampling year. Significance indicated by shaded blocks were determined based on P < 0.05.

	Type III Tests of Fixed Effects			
	Source	**Numerator df**	**F**	**Sig.**
E. coli	Site	3	2.31	0.10
	Year	2	0.60	-
	Site * Year	2	4.75	0.02
COD	Site	3	0.27	0.85
	Year	2	0.75	-
	Site * Year	2	1.22	0.31
Phosphate	Site	3	0.75	0.53
	Year	2	0.57	0.57
	Site * Year	2	0.44	0.65
Ammonia	Site	3	0.51	0.68
	Year	2	4.73	0.02
	Site * Year	2	2.33	0.12
EC	Site	3	25.24	0.00
	Year	2	0.28	0.76
	Site * Year	2	0.07	0.93
Nitrates	Site	3	4.89	0.01
	Year	2	2.56	0.09
	Site * Year	2	4.27	0.02
pH	Site	3	0.98	0.41
	Year	2	0.31	0.73
	Site * Year	2	0.34	0.72

4.10.2. Multivariate analyses

In Figure 4.31, the sites represent the following: S2 = upstream Kokosi WWTW; S3 = upstream Flip Human WWTW; S4 = downstream Flip Human WWTW; S6 = downstream Potchefstroom WWTW. The *E. coli* was strongly grouped with sites S2 and S3 while the EC and pH was higher at site S6 during summer. Temperature has been used as a useful measurement that indicates various biological and chemical activities (Wattoo, *et al*., 2004). The *E. coli* survival rates are known to be dependent on temperature (Jamieson *et al*., 2004). The *E. coli* concentrations are usually higher when the temperatures are warmer, but in this study *E. coli* was high at the upstream sites (during winter). This might be due to the rainfall season in South Africa which occurs in winter months (May, June ad July) and the river flow is often low, thus causing water to become stagnant and The EC and pH were higher downstream at S6 potentially due to the sewage outfalls.

The COD seemed to indicate higher concentrations was found at S2 during winter while the nitrates seemed to be higher during at S3 sites in the summer. High COD levels can be associated with decomposition of organic materials in the municipal sewage and effluents. Nitrate concentration was higher during the summer period due to high decomposition rates of organic matter by anaerobic bacteria at high temperatures (Kumar, 2002). In addition to that, in this study it could have been as a result of higher sewage loads discharged into the system. Ammonia and phosphates were higher in S4 during winter. The increased concentrations in phosphate is mainly due to sewage contamination (Nebel and Wright, 1998). Both the increased ammonia and phosphate levels could also be as a result of agricultural activities taking place within the catchment.

Table 4. 2: Eigenvalues and cumulated variance percentage of components obtained

Sites	Eigenvalues	Explained variation (cumulative)
S2	0.7353	73.53
S3	0.1768	91.21
S4	0.0366	94.87
S6	0.0295	97.83

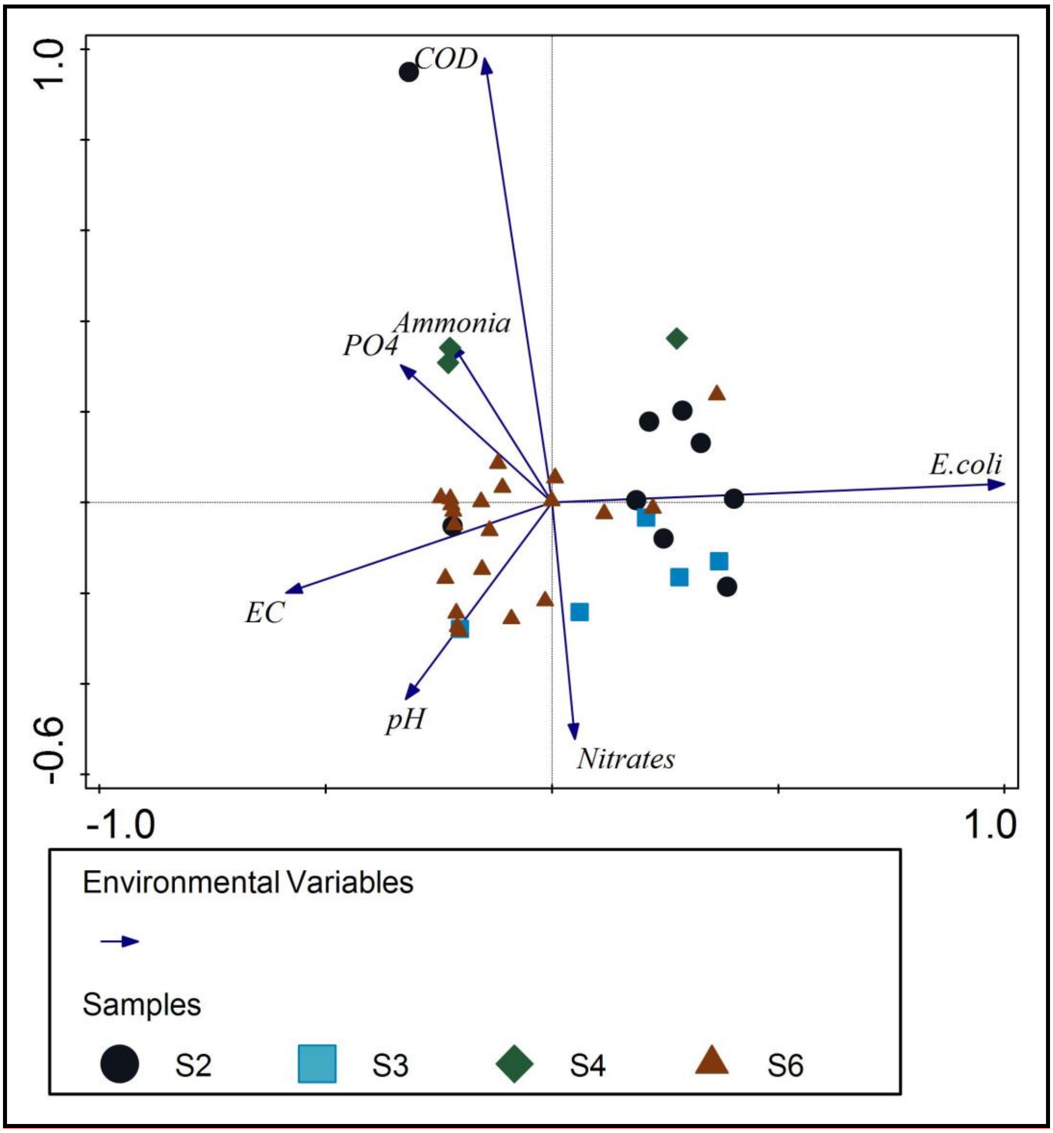

Figure 4. 31: Principal component analysis (PCA) of measured water quality parameters and sampling sites for the sampling period 2015 – 2018. S2 = upstream Kokosi WWTW; S3 = upstream Flip Human WWTW; S4 = downstream Flip Human WWTW; S6 = downstream Potchefstroom WWTW.

In Figure 4.32 the PCA with covariates for sampling year (2016-2018) and sampling sites (S2, S3, S4, S6) removes the effect of the covariables on the water quality dataset. This PCA described 91.3% of the variation in the data with 75.5% on the first axis and 15.8% on the second axis. In comparison with Figure 4.31, the sampling sites are strongly grouped together with little discrimimation between sampling sites. The variation at sampling site S6 is also evident here. The outliers from S2 is indicative of high values for COD and pH that was present at this site at this. The site groupings are defined by the influence of *E. coli* on axis 1 and the COD on axis 2.

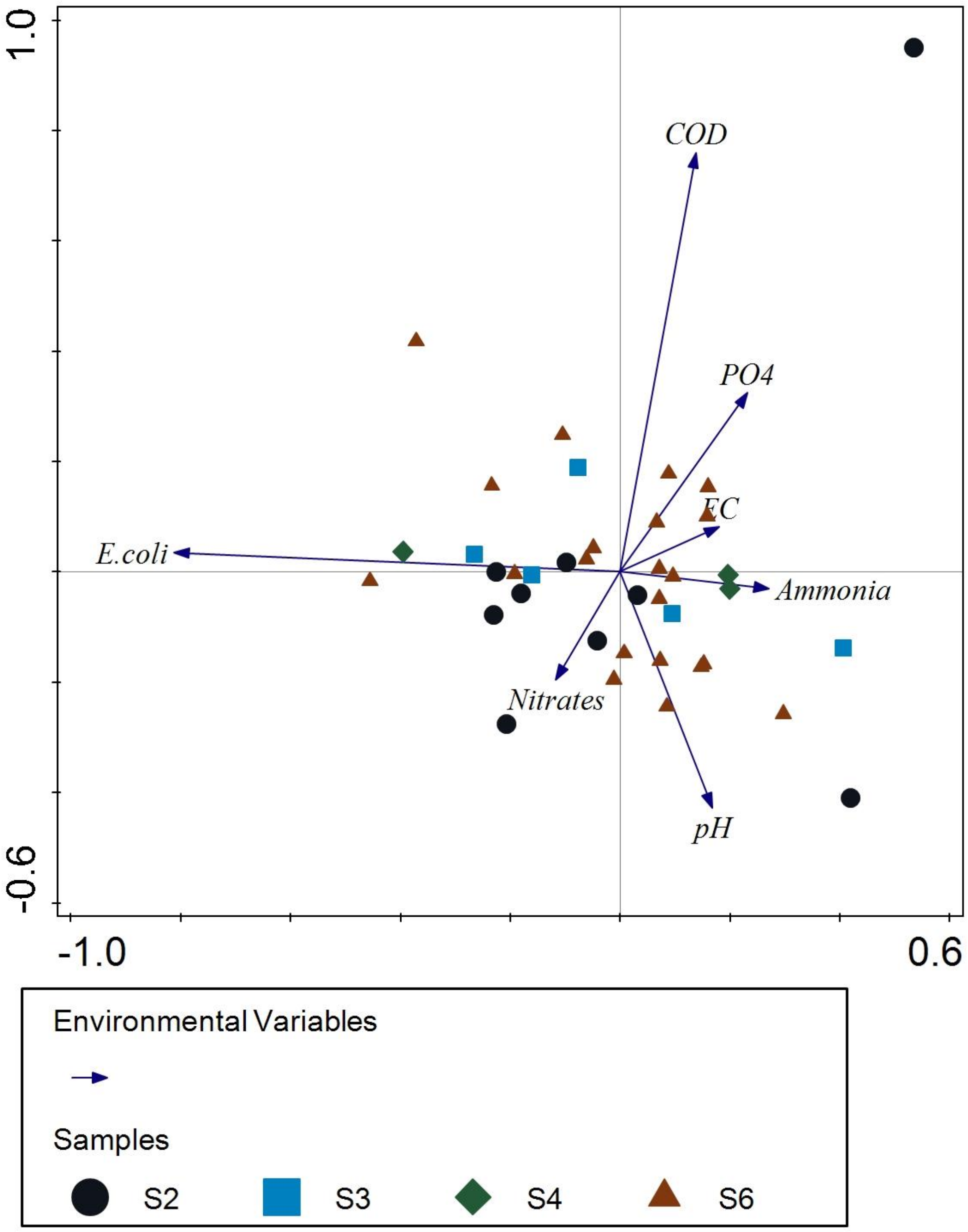

Figure 4. 32: Principal component analysis (PCA) with covariables for sampling year (2016 – 2018) and sampling site (S2, S3, S4 and S6) for measured water quality parameters and sampling sites for the sampling period 2015 – 2018. S2 = upstream Kokosi WWTW; S3 = upstream Flip Human WWTW; S4 = downstream Flip Human WWTW; S6 = downstream Potchefstroom WWTW.

4.11. DISCUSSION

There were noticeable gaps on the data acquisition from the Department of Water (DSW) and Sanitation. The DWS is scheduled to take samples once every month from these designated points within the study area. However, the collated data had gaps due to either failure by DWS to collect samples or their failure to analyse the samples for some months. In some months there were incomplete sets of data for all the selected sites (stations), which made it difficult to compare individual stations and wastewater works. The NEMA and NWA encourages continuos monitoring to ensure the sustainability for the water resource management. It is very difficult in most cases to make informed decisions and even the determination of the impact based on poor water quality data.

Although the data received from the DWS had gaps, the available data indicated that the water from the Mooi River and its tributaries in most instances exceeded critical quality indicators of water quality, as set by the various national guidelines or standards for a healthy aquatic ecosystem. From the data analysed, one can conclude that the Mooi River water and its tributaries were occasionally polluted by poorly treated effluent from WWTWs that are located in close proximity to the sampling points on the river were. The high concentration of parameters such as suspended matter, pH, nitrate, ammonia, COD, total coliform counts and *E. coli* counts which were evident downstream of the WWTWs were an indication of pollution to the water resources.

It should also be considered that there are other activities other than WWTWs discharges that has the potential to contribute to the overall pollution of the Mooi River system. Agricultural runoff within the catchment of the Mooi River and its tributaries could be another important contributor to water quality. Agricultural practices along the Mooi River Catchment contribute towards phosphate loads, ammonia and high faecal contamination. There are mines along the Loop Spruit and Wonderfontein Spruit sub-catchments which also contribute salt loads (which in turn is directly proportional to EC) and also elevated pH concentrations.

A comparison of the results against quality guidelines for different uses (agricultural, domestic purposes, aquatic ecosystem), including international standards, show that the water quality downstream of the discharge points occasionally exceeded the limits, which is an environmental concern along the stretch of the river in terms of its support of a healthy aquatic ecosystem as well as its general use. The discharges of the WWTWs into the Mooi River system have impacted negatively by increasing the concentration of nutrients and solids as well as the organic matter loads. The Flip Human WWTW seems to be the most pollution contributor in the tributary of the Mooi River.

A critical and worrying aspect related to encroachment of untreated wastewater is the positive detection of coliforms in the Mooi River and its tributaries. In some instance and some points on the rivers, these coliforms were detected in numbers that far exceeded the limits for safe and general hygienic water. That poses a high heath risk to humans and warm blooded animals who uses this water. Both the total faecal coliforms and *E. coli* counts confirm the presence of pathogenic microorganisms downstream of the discharge points of the WWTWs, in numbers that varied from plant to plant.

Coliform contamination of water of the Mooi River had been reported previously in the 2013/14 Green Drop Reports (DWS, 2014b) where complete non-compliance with the microbiological standards were noted over the years (see Appendix 4). The report pointed to elevated concentration levels of nutrients (ammonia, and phosphates) and TDS (corroborated by high COD values) as factors that risk eutrophication of the river system leading to a higher demand for dissolved oxygen for biological degradation of organic matters (DWS, 2014b). Kokosi WWTW seemed to pose the least risk to contaminate the water of the Mooi River within this catchment area although scope for improvement was noted. The Green Drop Report for the Tlokwe City indicated improved compliance to the microbiological standards though there were few instances of exceedances to the guidelines and standards when comparing with the data received from DWS (DWS, 2014b).

Similar studies on the water quality impact from WWTW were undertaken in other parts of South Africa (Limpopo, Eastern Cape, Durban) and it was discovered that for most parameters the water and wastewater guidelines and limits have been exceeded, which correspond to what was found in this study. A study conducted by Gitari *et al.(*2017) on the physico-chemical appraisal of an effluent receiving stream (Mvudi River) revealed the following:

- the pH of the river water at the downstream point after discharge ranged between 7 – 7.95.
- The EC of the river water was found to be between 39.4 and 316 mS/m, which is also evident in the Mooi River catchment where the EC also varied from 41.7 – 117 mS/m exceeding set guidelines.
- The COD of river water downstream was found to be from 83 to 195 mg/l whereas upstream point varied between 16 and 30 mg/l.
- The nitrate profile at the downstream point ranged from 0.8 to 23.4 mg/l and the upstream point varied from 0.63 to 16.27 mg/l.
- The orthophosphate levels at downstream point were from 1.37 to 13.63 mg/l with upstream point ranging from 0.37 to 3.2 mg/l.

Another similar study on the assessment of the impact of wastewater discharges on river water quality in eThekwini (Durban) undertaken by Naidoo (2013a) revealed the following:

- The results showed a difference between the upstream and downstream points in river water quality where the elevated levels pH at the downstream point is associated with the discharge of wastewater. The same applied to EC, nitrate, *E. coli* and faecal coliforms where there were high levels noted at downstream points compared to upstream.

There was another investigation of faecal pollution and occurrence of antibiotic resistant bacteria in the Mooi River System done by Bezuidenhout (2013) where the following was discovered:

- Indications are that cumulative inputs from several sources were the main cause of the elevated bacteria indicators at both upstream and especially downstream localities. This then serves as confirmation of the presence of faecal pollution within the Mooi River catchment.

Another study by Morrison *et al*. (2001), an assessment of the impact of point source pollution from the Keiskammahoek Sewage Treatment Plant on the Keiskamma River, studied the pH, EC, oxygen-demanding substance (COD) and nutrients. This study found the following:

- The pH results were found to be within the SA guidelines.
- This limit was not exceeded in the river water samples and the parameter does not give cause for concern, but the effluent discharge doubled the electrical conductivity in the river (compared to values at the reference site), which indicates a large impact.
- The COD values were high indicating the inability of the WWTW to remove chemical oxygen-demanding substances in the incoming effluent. The results for COD in the river water were varied between 32.0 mg/l and 74.0 mg/l.
- Nitrate values varied on different samples, but 87% of the sampling period the guidelines were met.
- Orthophosphate levels downstream of the dam (discharge point) were exceeded in most occasions.
- Ammonium concentrations were lower at the upstream site compared to the downstream site with concentrations exceeding the old South African guideline for wastewater discharge for ammonia in effluent was 1.5 mg/l at pH > 8.5 (*Government Gazette*, 1984) and the TWQR for domestic use with a limit of 1.

The Wonderfonteinspruit is the first major source of pollution in the Mooi River catchment as a results of the impact from the mines in the West Rand area, after the Wonderfonteinspruit joins the Loop Spruit then Mooi River. The impact of agricultural activity is clearly evident with higher concentrations of water quality variables measured than at Boskop Dam. Potchefstroom had the largest contribution of pollution to the Mooi River with several sources of pollution entering the Mooi River. Very high concentrations of measured water quality variables, especially phosphates, nitrate, EC and sulphates indicating pollution and impact (Pelser, 2015).

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1. CONCLUSION

The aim of the study was to determine the possible negative impact of pollution as a result of sewage treatment plants discharging into the Mooi River catchment. The study seeked to assess the trends in the concentrations of selected chemical parameters, physico-chemical and microbiological water quality indicators as a result of direct discharge of treated wastewater into the Mooi River and also into its tributaries. The study further compares the values of these water quality indicators against set National and other International regulatory standards so as to determine the potential risk of direct discharge of treated wastewater into Mooi River and its tributaries. Lastly, the study seeked to determine the pollution impact and change in water quality from 2015 to 2018 at a single historical water quality monitoring station of the Mooi River catchment.

The concentration and or values of some of the selected water quality indicators for water sampled from Loop Spruit, Wonderfontein Spruit and Mooi Rivers at points downstream of the respective WWTWs namely, Kokosi, Flip Human and Potchefstroom were measured by DWS between July 2015 to January 2018. Though the discharge is regulated, it does affect the sustainability of the aquatic ecosystems along the three rivers as well as posing a potential health risk to users, livestock and wildlife. The collated DWS data was checked against the relevant guidelines and set out quality standards namely:

- Water Use Licence – authorised discharge for each WWTWs
- General Limit for wastewater discharges
- South African Water Quality Guidelines (Domestic and Agricultural Use)
- RQOs for the Upper Vaal
- International water and wastewater standards (EPA and WEPA)

Data revealed instances when the concentrations of the physical, biochemical and microbiological quality indicators (highest averages were suspended solids (191 mg/l), electrical conductivity (100.7 mS/m), nitrates (6.3 mg/l), ammonia (1.88 mg/l), phosphate (2.66 mg/l), chemical oxygen demand (332.8 mg/l), total faecal (69 211 cfu/100mL) and *E. coli* (55 738 cfu/100mL) counts) in the water of the Mooi River and its two tributaries were significantly higher than those expected for natural surface water. Comparative analysis of the data at the sampling points downstream and upstream of the discharge points into the rivers suggested there were occasions where WWTWs discharged treated wastewater which was of poor quality into the rivers, leading to the increase in the concentration and values of the water quality indicators. It is possible that on these occasions, the quality of the treated wastewater from the WWTWs were non-compliant with the wastewater guidelines and Water Use Licence for authorised discharge. This could arise if there was incidences of lapses and failures to adhere to the protocols for process quality control of the water treatment process at the WWTWs. Thus, these results indicate that discharging treated water from the WWTWs deteriorated significantly the quality of water of the Mooi River and its tributaries. More worrying was the high level of the bacteriological quality parameter (total coliform faecal count and *E. coli* count) of the receiving rivers. This is because this parameter indicates prevalence of potential pathogens that cause various forms of diseases such as diarrhoea.The Mooi River system has high levels of organic pollution with a high faecal pollution load. The faecal pollution needs intervention as it renders water unfit for any use.

The Mooi River system is mostly used for irrigation and for drinking purposes. The average pH measured for the Mooi River system (dowstream of all WWTWs) is 7.9. This falls within the target water quality guidelines set out in the South African Water Quality Guidelines for agricultural purposes but exceeds the one for drinking purposes and it does not present major problems. Other variables measured during this study that might have an effect on crop irrigation is; electrical conductivity and nitrates. The SS was within the TQWR for adricultural purposes thus indicating no impact on the irrigation activities.

Statistical procedures were useful for environmental data to determine whether monitoring sites were contaminated or not and also used to compare the monitoring points' quality. In this study both the univariate (student t-test) and multivariate (PCA) analysis were used to determine water quality of two monitoring points. These analyses indicated that there were significant differences between the upstream and downstream water quality for the following parameters and sites; EC at Kokosi and Potchefstroom, nitrates at Flip Human, ammonia at Kokosi, Flip Human and Potchefstroom, orthophosphate at Flip Human and *E. coli* at Kokosi. The PCA also indicated a cumulative increase in pH and EC downstream in the Mooi River, thereby pointing at cumulative potential effects on the aquatic ecosystem in the Mooi River. The LMM indicated some significant influences of sampling site and sampling year were present. This potentially relates to changes in rainfall, flows and general climate as having an influence on the water quality of the Mooi River as well as an impact on the potential quality of discharges from the WWTW.

Some of the key parameters in the receiving river water exceeded the set limits and the licence target limits for discharging treated wastewater. Thus, the hypothesis that the discharge of treated wastewater from the WWTWs into the Mooi River and its tributaries was not significantly affecting the quality of the Mooi River was not accepted.

5.2. RECOMMENDATIONS

Based on the occasional high values in key quality characteristics of water sampled from Loop Spruit, Wonderfontein Spruit and Mooi Rivers at points downstream of the WWTWs, there has been a decline in water quality of water of these rivers which has potential to reduce its usefulness as well as pose a health risk to users. This necessitates firm interventions by DWS as well as the local authorities in the respective sections of the rivers in order to safeguard the aquatic ecosystems as well as reduce health risks to users of the water.

The following are the recommendations for improving the downstream river water quality of the Loop Spruit, Wonderfontein Spruit and Mooi Rivers which include:

- There is a need to identify the cause of the occasional lapses in the quality of treated water which is being discharged into the river. The quality of the treated water should be checked regularly before discharge is made, more so with respect to absence of strong monitoring data on microbiological indicators. Partially treated wastewater especially of sewerage and food processing plant origins may contain residual pathogenic microorganisms that could result in negative health risks when poorly treated and discharged into river systems.
- A similar study by Naidoo, 2013a looked at the assessment of the impact of wastewater treatment plant discharges and other anthropogenic varaibles on river water quality in the eThekwini Metropolitan area recommended an urgent upgrade of the WWTW discharging into the rivers to ensure DWS discharge requirements are met. In this studu though no assessment was done on the WWTWs themselves, but because of the water quality results a conclusion a can be drawn that there might be challenges with the treatment process leading to substandard effluent being discharged. For the Mooi river catchment if the problem is related to inadequate capacity to handle influent volumes, it is recommended that the WWTWs should be expanded and upgraded with better treatment technology so that the WWTWs meet their authorised discharge limits and consequently improving the poor water quality of the rivers.
- There is also a need for consistent and regular sampling and data collection and monitoring within the catchment area of the Mooi River by DWS on key parameters related to assessing the quality of treated wastewater from the WWTWs. Improve monitoring to pick up failures from WWTW is recommended. Sampling can be done fortnightly to increase frequency of detection of non-compliance and thus force the WWTWs to take immediate corrective actions. The DWS should enforce stringent penalties on municipalities and Licence holders whose WWTWs fail to meet stipulated standards for discharging treated wastewater into receiving water bodies.

- Follow up studies should consider chemical analysis of metal ions and persistent organic pollutants. The sampling should be completed in all the four seasons of the year in order to ascertain the impact on the levels on rainfall (dilution effects) and runoff on water quality.
- Future investigations should not only consider the measurement of concentrations or levels, but they also look at the determination of loads in order to determine the exact contribution of the WWTWs to the amount of microbial, nutrients and chemicals nutrients discharged into the Mooi River catchment.

REFERENCES

Abbaspour, S. 2011. Water quality in developing countries, south Asia, South Africa. Water Quality Management and Activities that cause Water Pollution. *IPCBEE*, *15*, pp.94-102.

Agoro, M.A., Okoh, O.O., Adefisoye, M.A. and Okoh, A.I. 2018. Physicochemical Properties of Wastewater in Three Typical South African Sewage Works. *Polish Journal of Environmental Studies*, *27*(2), pp.491-499.

Akpor, O.B. 2011. Wastewater effluent discharge: Effects and treatment processes. *Int. Conf. Chem. Biol. Environ. Eng* (Vol. 20, pp. 85-91).

Akpor, O.B. and Muchie, M. 2011. Environmental and public health implications of wastewater quality. *African Journal of Biotechnology,* 10 (13): 2379-2387.

Amadi, A. N. 2010. Effects of urbanization on groundwater quality: A case study of Port-Harcourt, Southern Nigeria. *Natural Applied Science Journal*, 11(2): 143-152.

Annandale, E. and Nealer, E.J. 2011. Exploring aspects of the water history of the Potchefstroom region and the local management of it. New Contree. 62 (2011) 111 - 124.

Ashbolt, N.J., Grabow, W.O.K. and Snozzi, M. 2001. Indicators of microbial water quality, p. 289-316. In Fewtrell, L. and Bartram, J. (ed.), Water Quality: Guidelines, Standards and Health: Assessment and Risk Management for Water-Related Infectious Disease, World Health Organization, Geneva, Switzerland.

Baloyi, C., Gumbo, J.R. and Muzerengi, C. 2014. Pollutants in sewage effluent and sludge and their impact on downstream water quality: a case study of Malamulele sewage plant, South Africa. *Water Pollution XII*, *182*, p.15.

Barnard S., Venter A. and Van Ginkel, C.E. 2013. Overview of the influences of mining-related pollution on the water quality of the Mooi River system's reservoirs, using basic statistical analyses and self organised mapping. *Water SA.* Vol. 39 No. 5: 655-662.

Barrell, R.A., Hunter, P.R. and Nichols, G.C.D.P.H. 2000. Microbiological standards for water and their relationship to health risk. *Commun Dis Public Health*, *3*(1), pp.8-13.

Bekal, S., Brousseau, R., Masson, L., Prefontainel, G., Fairbrother, J. and Harel, J. 2003. Rapid Identification of *Escherichia coli* Pathotypes by Virulence Gene Detection with DNA Microarrays. *J.Clin.Microbiol.* 41(5): 2113-2125.

Belcher, M.T. and Grobler, D. 2014. Freshwater Assessment for the Proposed Expansion of the Existing Kraaifontein Waste WWTWs. Cape Town.

Bere, T. and Tundisi, J.G. 2010. Influence of Land-Use Patterns on Benthic Diatom Communities and Water Quality in the Tropical Monjolinho Hydrological Basin, Sao Carlos-SP, Brazil. *Water SA , 37*, 93-102.

Bermudez-Couso A., Arias-Esteves M., Novoa-Munoz J.C., Lopez Periago E., Soto-Gonzalez B. and Simal-Gandara J. 2007. Seasonal distributions of fungicides in soils and sediments of a small river basin partially devoted to vineyards. *Water Research.* Vol. 31: 4515-4525.

Bezuidenhout, C.C. 2013. A Large-scale Study of Microbial and Physico-chemical Quality of Selected Groundwaters and Surface Waters in the North West Province, South Africa: A Report to the Water Research Commission. Water Research Commission.

Blaine, S. 2013. Agriculture is putting South Africa in deep water. Accessed online [www.bdlive.co.za]. Date of access: 19 Aug. 2018.

Borba, C.E., Guirardello, R., Silva, E.A., Veit, M.T. and Tavares, C.R.G. 2006. Removal of nickel (II) ions from aqueous solution by biosorption in a fixed bed column: experimental and theoretical breakthrough curves. *Biochemical Engineering Journal*, *30*(2), pp.184-191.

Canada Gazzette, 2010. Wastewater Systems Effluent Regulations. *Regulatory Impact Analysis Statement*, 144: 12.

Canter, L. W. 1996. Nitrates in groundwater. New York: Lewis Publishers, Chelsea, MI, USA.

Carpenter, S.R., Caraco, N.F., Correll, D.L., Howarth, R.W., Sharpley, A.N. and Smith, V.H. 1998. Non-point pollution of surface waters with phosphorus and nitrogen. Ecol. Appl. 8 (3) 559–568.

Chapman, D. 1996. Water quality assessments: A Guide to Use of Biota, Sediments and Water in Environmental Monitoring. 2nd ed., UNESCO, World Health Organization, United Nations Environment Programme, Chapman and Hall, London, UK.

Chapman, D.V. 2002. Water quality assessments: a guide to the use of biota, sediments and water in environmental monitoring. CRC Press.

Cheng, H., Hu, Y. and Zhao, J. 2009. Meeting China's water shortage crisis: current practices and challenges. Environmental Science and Technology: 43, 240 – 244.

Chimuriwo, B. 2016. An assessment of water quality along Mukuvisi River, Harare, Zimbabwe. Doctoral dissertation. University of South Africa.

Cilliers, S.S. and Bredenkamp, G.J. 2000. Vegetation of road verges on an urbanisation gradient in Potchefstroom, South Africa. *Landscape and Urban Planning*, 46: 217-239.

Coetzee, M.A.S. 2003. Water pollution in South Africa: its impact on wetland biota. Centre for water in the environment. Department of botany. University of the Witwatersrand.

Coetzee, H. 2004. An assessment of sources, pathways, mechanisms and risks of current and potential future pollution of water and sediments in gold-mining areas of the Wonderfonteinspruit catchment WRC Report No 1214/1/06, Pretoria, 266 pp.

Coetzee, H. 2009. (*In* Merkel, B.J. and Schipek, M.). Mining and Water. *DAAD Alumni Expert Seminar - Proceeding .Freiberg Online Geology, 24: 25 – 31*. Available online [http://www.geo.tu-freiberg.de/fog/FOG_Vol_24.pdf#page=2]. Accessed on 19 Aug. 2018.

Colford, J.M., Wade, T.J., Schiff K.C, Wright C.C, Griffith, J.F. Sandhu, S.K. Burns, S., Sobsey M.D., Lovelace, G. and Weisberg, S.B. 2007. Water quality indicators and the risk of illness at beaches with nonpoint sources of faecal pollution. Epidemiology 18:27-35.

Corcoran, E., Nellemann, C., Baker, E., Bos, R., Osborn D, Savelli, H. (eds). 2010. Sick Water: The central role of wastewater management in sustainable development. A Rapid Response Assessment. United Nations Environment Programme, UN-HABITAT, GRID-Arendal.

CSIR. 2010**.** A CSIR Perspective on Water in South Africa-2010. CSIR Report No. CSIR/NRE/PW/IR/2011/0012/A. ISBN: 978-0-7988-5595-2.

Dabrowski, J.M. and De Klerk, L.P. 2013. An assessment of the impact of different land use activities on water quality in the upper Olifants River catchment. *Water SA*, *39*(2), pp.231-244.

Dallas H. F. and Day J.A. 2004. The effect of water quality variables on aquatic ecosystems: a review. *Report No. TT 224/04. Water Research Commission.* Pretoria, South Africa.

Dan-Hassan, M.A., Olasehinde, P.I., Amadi, A.N., Yisa, J. and Jacob, J.O. 2012. Spatial and Temporal Distribution of Nitrate Pollution in Groundwater of Abuja, Nigeria. International Journal of Chemistry, 4(3); 104-113.

Daniel, M.H., Montebelo, A.A., Bernardes, M.C., Ometto, J.P., De Camargo, P.B., Krusche, A.V., Ballester, M.V., Victoria, R.L. and Martinelli, L.A. 2002. Effects of urban sewage on dissolved oxygen, dissolved inorganic and organic carbon, and electrical conductivity of small streams along a gradient of urbanization in the Piracicaba river basin. Water, Air, and Soil Pollution, 136(1-4), pp.189-206.

Das, J. and Acharya, B.C. 2003. Hydrology and assessment of lotic water quality in Cuttack City, India, *Water, Air, and Soil Pollution*, vol. 150, no. 1–4, pp. 163–175.

Davies, B.R., Day, J.A. and Douie, C. 1998. Vanishing waters*,* University of Cape Town Press Cape Town.

Day, J.A. and King, J.M. 1995. Geographical patterns and their origins, in the dominance of major ions in South African rivers. S. Afr. J. Sci. 91: 299-306.

De Clerq, W., Jovanovic, N. and Fey, M. 2010. Land use impacts on salinity in Berg River water. Water Research Council, Pretoria.

Degner, S.M. and Howat, R.F. 1997. Water Hyacinth Control at Inanda Dam Kwazulu Natal. Msinsi Holdings Management Report, South Africa.

Department of Environmental Affairs and Tourism (DEAT). 2006. South Africa Environment Outlook, p. 371. A report on the state of the environment. Department of Environmental Affairs and Tourism, Pretoria, SA.

Department of Water Affairs and Forestry. 1986. Management of the Water Resources of the Republic of South Africa. Department of Water Affairs, Pretoria.

Department of Water Affairs and Forestry. 1996a. South African Water Quality Guidelines (second edition). Volume 1: Domestic Use. (2nd edn.). Pretoria.

Department of Water Affairs and Forestry. 1996b. South African Water Quality Guidelines: Agricultural use - irrigation. 2nd ed. (Report Volume 4). Pretoria.

Department of Water Affairs and Forestry. 1996c. South African Water Quality Guidelines: Volume 7: Aquatic Ecosystem. (1st edn.). Pretoria.

Department of Water Affairs and Forestry. 1996d. South African Water Quality Guidelines. Volume 2: Recreational Use. Pretoria. RSA.

Department of Water Affairs and Forestry. 1997. White Paper on a National Water Policy for South Africa. Pretoria.

Department of Water Affairs and Forestry. 1999. General Authorisations No. 1191 as Set out Government Gazette No. 20526.

Department of Water Affairs and Forestry. 2002. Guideline for the management of waterborne epidemics, with the emphasis on cholera. Water Quality Management Series. Guideline Document U1.5. Edition 1.

Department of Water Affairs. 2009. Adopt-a-River Programme Phase II: Development of an Implementation Plan. Water Resource Quality Situation Assessment. Resource Quality Services Project Number WP 9583. Available online [http://www.dwaf.gov.za/iwqs/rhp/xtra/Water_Quality_Situation_Assessments.pdf] Accessed July 2011).

Department of Water Affairs. 2012. Classification of Significant Water Resources (River, Wetlands, Groundwater and Lakes) in the Upper, Middle and Lower Vaal Water Management Areas (WMA) 8, 9, 10: Management Classes of the Vaal River Catchment Report. DWA Report No. RDM/WMA8,9,10/00/CON/CLA/0212.

Department of Water Affairs. 2012a. Green drop progress report. Pretoria, South Africa: Government Printer.

Department of Water Affairs. 2012b. Classification of Significant Water Resources (River, Wetlands, Groundwater and Lakes) in the Upper, Middle and Lower Vaal Water Management Areas (WMA) 8, 9, 10: Management Classes of the Vaal River Catchment Report.

Department of Water Affairs and Forestry. 2013. Revision of General Authorizations in terms of section 39 of the National Water Act 1998 (Act No. 36 of 1998)—engaging in a controlled activity. Government Gazette 36820, No 665. Pretoria

Department of Water Affairs and Forestry. 2013. National water resource strategy. Water for an equitable and sustainable future. Second edition. Pretoria.

Department of Water and Sanitation. 2014a. Determination of Resource Quality Objectives in the Upper Vaal Water Management Area (WMA8): SUB-COMPONENT PRIORITISATION AND INDICATOR SELECTION REPORT. Report No.: RDM/WMA08/00/CON/RQO/0114. Chief Directorate: Water Ecosystems. Study No.: WP10535. Prepared by the Institute of Natural Resources (INR) NPC. INR Technical Report No.: INR 493/14 (v). Pietermaritzburg, South Africa.

Department of Water and Sanitation. 2014b. Green Drop Reports for North West and Gauteng. Pretoria.

Department of Water and Sanitation. 2016. Classes and Resource Quality Objectives of Water Resources for Catchments of the Upper Vaal. Government Gazette No. 39943. Pretoria.

Department of Water and Sanitation. 2017. National Norms and Standards for Domestic Water and Sanitation Services. Government Gazette, 8 September 2017. No. 982 No. 41100.

Department of Water and Sanitation. 2018. Rainfall data. Available online [http://www.dwa.gov.za/Hydrology/Provincial Rain/Default.aspx-Provincial Rainfall] Accessed on 02 August 2018.

De Villiers, S. and Thiart, C. 2007. The nutrient status of South African rivers: concentrations, trends and fluxes from the 1970s to 2005. *South African Journal of Science,* 103: 343-349.

De Villiers, A. and Graham, M. 2016. Scoping investigation into the cumulative impacts of point source discharge from Low Volume Privately Owned Treatment Works on river health in the eThekwini Metropolitan Municipality. Ground Truth. WRC Report No: KV 355/16.

Dickens, C.W.S., Graham, P.M. 1998. Biomonitoring for effective management of wastewater discharges and the health of the river environment. Aquatic Ecosystem Health and Management, 1(2), pp.199-217.

Dickens, C., Pringle, C. and Macfarlane, D. 2011. Procedures to Develop and Implement Resource Quality Objectives. Department of Water Affairs, Pretoria, South Africa. p12 -42.

Dragicevic, S., Nenadovic, S., Jovanovic, B. Milanovic, M., Novakovic, I., Pavic, D. and Ljesevic, M. 2010. Degradation of Topciderska river water quality (Belgrade). Carpathian Journal of Earth and Environmental Sciences, 5, (2), 177.

Dudgeon, D., Arthington, A.H., Gessner, M.O., Kawabata, Z.I., Knowler, D.J., Lévêque, C., Naiman , R.J., Prieur-Richard, A.H., Soto, D., Stiassny, M.L.J. and Sullivan, C.A. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. Biological Previews, 81(2):163-182.

Du Preez, C.C., Strydom, M.G., Le Roux, P.A.L., Pretorious, J.P., Van Rensburg, L.D. and Bennie, A.T.P. 2000. Effect of Water Quality on Irrigation Farming along the Lower Vaal River: The influence on soils and crops. WRC Report No. 740/1/00.

Duruibe, J. O., Ogwuegbu, M. O. C. and Egwurugwu, J. N. 2007. Heavy metal pollution and human biotoxic effects. *International Journal of Physical Sciences.* Vol 2 (5):112-118.

Ensink, J.H., Scott, C.A., Brooker, S. and Cairncross, S. 2010. Sewage disposal in the Musi-River, India: water quality remediation through irrigation infrastructure. *Irrigation and drainage systems*, *24*(1-2), pp.65-77.

Environmental Protection Agency. 2000. Proposed ground water rule. EPA 815 F-00–003. Office of Ground Water. *Environmental Protection Agency,* Washington, D.C. Available online [http: //www.epa.gov/305b/2000report/]. Accessed on 11 November 2018.

Environment Protection Act. 2003. Standards for Effluent Discharge Regulations. Ministry of Environment and Sustainable Development: Port Louis, Port Louis District, Mauritius.

Erasmus, J.H. 2017. The macroinvertebrate diversity, chemical and physical factors in the Loop Spruit and Mooi River. North-West Province (Doctoral dissertation, North-West University (South Africa), Potchefstroom Campus.

Esshaimi, M., Ouazzani, N., El Gharmali, A., Berrekhis, F., Valiente M. and Mandi, L. 2013. Speciation of Heavy Metals in the Soil and the Tailings, in the Zinc-Lead Sidi Bou Othmane Abandoned Mine, J. Environ. Earth Sci. 3(8):2224 – 3216.

Fatoki, O.S., Muyima, N.Y.O. and Lujiza, N. 2001. Situation analysis of water quality in the Umtata River catchment. *Water SA*, 4 (27): 0378-4738.

Feng, Q., Liu, W., Su, Y.H., Zhang, Y.W. and Si, J.H., 2004. Distribution and evolution of water chemistry in Heihe River basin. *Environmental Geology*, 45: 947-956.

Fewtrell, L. 2004. Drinking-Water nitrate, Methemoglobinemia, and Global Burden of Disease: A discussion. Environmental Health Perspective 112:1371-1374.

Fisher, D.S., Steiner, J.L., Endale, D.M., Stuedemann, J.A., Schomberg, H.H., Franzluebbers, A.J. and Wilkinson, S.R. 2000. The relationship of land use practices to surface water quality in the Upper Oconee Watershed of Georgia. *Forest Ecology and Management*, *128*(1-2), pp.39-48.

Fosso-Kankeu, E., Van der Berg, D.P., Waanders, F., Manyatshe, A., Lemmer, N. and Tutu, H. 2015. Mapping of surface water quality in the vicinity of Potchefstroom based on mining pollutants. In *7th International Conference on Latest Trends in Engineering and Technology (ICLTET'2015)*.

Frost and Sullivan. 2010. Eutrophication Research Impact Assessment. Water Research Council, Pretoria.

Gagnon, C., Gagne, F., Turcotte, P., Saunier, I., Blaise, C., Salazar, M.H., and Salazar, S.M. 2006. Exposure of caged mussels to metals in a primary-treated municipal wastewater plume. Chemosphere, 62(6), pp. 998-1010.

Gaydon, P., McNab, N., Mulder, G., Pillay, I., Sahibdeen, M. and Thompson, P. 2007. Evaluation of the domestic wastewater treatment package plants for rural, peri-urban and community us. WRC report No 1539/1/06.

Gitari, W.M., Tshikovhi, F.P. and Akinyemi, S.A. 2017. Physicochemical Appraisal of Effluents Receiving Stream: A Case Study of Mvudi River. South Africa. *Adv Environ Pollut Res*, pp.25-31.

Government Gazette No. 9225. 1984. Regulation No. 991: Requirements for the Purification of Wastewater or Effluent. Government Printers, Pretoria.

Greenberg A.E., Clesceri L.S. and Eaton A.D. 1995. Standard methods for the examination of water and wastewater (19th ed.). Washington, D.C.: American Public Health Association (APHA), American Water Works Association, and Water Pollution Control Federation.

Griesel, M., Kuhn, A., Kempster, P., Mamabolo, M. and Silberbauer, M. 2006. Report on an integrated water quality monitoring programme conducted in the town of Delmas, November 2005 to June 2006. Pretoria: DWAF.

Grobicki, A., Males, R., Martinez, I., Matika, S., and Archibald, S. 2001. Integrated Catchment Management in an Urban Context*: The Great and Little Lotus Rivers, Cape Town.* (Cape Town: Water Research Commission Report No. 864/1/01).

Gvozdić, V., Brana, J., Malatesti, N. and Roland, D. 2012. Principal component analysis of surface water quality data of the River Drava in eastern Croatia (24 year survey). *Journal of hydroinformatics*, *14*(4), pp.1051-1060.

Hagedorn, C., Robinson, S.L., Filtz, J.R., Grubbs, S.M., Angier, T.A. and Reneau, R.B. 1999. Determining sources of fecal pollution in a rural Virginia watershed with antibiotic resistance patterns in fecal streptococci. *Appl. Environ. Microbiol.*, *65*(12), pp.5522-5531.

Halder, J. N. and M. N. Islam. 2015. Water pollution and its impact on the human health. *Journal of environment and human* 2(1): 36-46.

Hanley, N., Shogren, J.F., and White, B. 2001. Introduction to Environmental Economics. 1st ed. (New York: Oxford University Press).

Harwood, V.J., Whitlock, J. and Withington, V. 2000. Classification of antibiotic resistance patterns of indicator bacteria by discriminant analysis: use in predicting the source of faecal contamination in subtropical waters. *Applied and Environmental Microbiology*, *66*(9), pp.3698-3704.

Helmer, R., Hespanhol, I. and World Health Organization. 1997. Water pollution control: a guide to the use of water quality management principles. E & FN Spon, London, Great Britain.

Hemamalini, J., Mudgal, B.V. and Sophia, J.D. 2017. Effects of domestic and industrial effluent discharges into the lake and their impact on the drinking water in Pandravedu village, Tamil Nadu, India. *Global Nest Journal*, *19*(2), pp.225-231.

Hemdan, N.Y.A., Emmrich, F., Sack, U., Wichmann, G., Lehmann, J., Adham, K., and Lehmann, I. 2006. The *in vitro* immune modulation by cadmium depends on the way of cell activation. Toxicology 222:37-45

Henderson-Sellers, B. 1991. Water quality modelling, Decision support techniques for lakes and reservoirs. Volume 4. CRC Press. United States. Boston.

Hendricks, R. 2011. Assessment of the biological quality of raw and treated effluents from three sewage treatment plants in the Western Cape, South Africa. Doctoral dissertation, University of the Western Cape.

Henze, M. 2008. Biological Wastewater Treatment: Principles, Modeling, and Design. International Water Association.

Holm, J. K. 2004. The water quality of the wood river and the effects of land use. Masters Dissertation. University of Saskatchewan.

Huang, G.H. and Xia, J. 2001. Barriers to sustainable water-quality management. *Journal of environmental management,* vol. 61, no. 1, pp. 1-23.

Huizenga, J.M., Silberbauer, M., Dennis, R. and Dennis, I. 2013. An inorganic water chemistry dataset (1972–2011) of rivers, dams and lakes in South Africa. *Water SA*, *39*(2), pp.335-340.

Imoukhuede, O. and Afuye, G. 2016. Water Pollution and its Effect on Water Consumption in Akure. International Journal of Environmental & Agriculture Research (IJOEAR) ISSN:[2454-1850] Vol-2, Issue-5.

Insitute For Water Quality Studies. 1999. Report on the radioactivity monitoring programme in the Mooi River (Wonderfonteinspruit) catchment. Report No. N/C200/00/RPQ/2399, April 1999. Department of Water Affairs and Forestry, Pretoria. 26 pp. plus appendices.

International Labour Organisation (ILO). 2010. *Safety Health in Agriculture* ISBN, 71, 77- 108.

Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B.B. and Beeregowda, K.N. 2014. Toxicity, mechanism and health effects of some heavy metals. *Interdisciplinary toxicology*, *7*(2), pp.60-72.

James, P.N. 2008: Water quality for ecosystem and human health. 2nd Edition. United Nations Environmental Programme, Global Environment Monitoring Systems. GEMS.

Jamieson, R.C., Joy, D.M., Lee, H., Kostaschuk, R. and Gordon, R.J. 2004. Persistence of enteric bacteria in alluvial streams. Engineering and Science 3, 203-212.

Juneja, T. and Chaudhary, A. 2013. Assessment of water quality and its effects on the health of residents of Jhunjhunu district, Rajasthan: A cross sectional study. Journal of Public Health and Epidemiology 5(4): 186-191.

Kazunga, J.M., Munga, D., Mwaguni, S.M. and Ochiewo, J. 2002. Development and protection of the coastal and marine environment in sub-Saharan Africa: Kenya National Report Phase 1: Integrated Problem Analysis. March 2002. GEF MSP Sub-Saharan Africa Project (GF/6010-0016).

Kanu, I. and Achi, O. 2011. Industrial effluents and their impact on water quality of receiving rivers in Nigeria. Journal of Applied technology in Environmental sanitation, 1(1), pp. 75-86.

Kleynhans, C.J., Thirion, C. and Moolman, J. 2005. A level 1 River Ecoregion classification System for South Africa. Lesotho and Swaziland. *Department of Water Affairs and Forestry*. South Africa. Report No. N/0000/00/REQ0104. Resource Quality Services, Department of Water Affairs and Forestry, Pretoria, South Africa.

Kresic, N. 2009. Groundwater Resources: Sustainability, Management and Restoration. Mcgraw-Hill. USA.

Kukier, U., Peters, C. A., Chaney, L. R. and Angel, A. J. 2004. The effect of pH on metal accumulation in two ayssum species. Journal of Environmental Quality 33: 2090 – 2102.

Kumar, A. 2002. Biomonitoring of Sewage Pollution. New Delhi: A P H publishing Corporation. Inc. pp. 39-103.

LaBrie, H.M. 2016. The potential impacts of the Nogales International Wastewater Treatment Plant on the Santa Cruz River. The University of Arizona.

Labuschagne, L. 2017. Water quality of the Mooi River North-West Province: a supporting study for the determination of resource quality objectives (Doctoral dissertation, North-West University (South Africa), Potchefstroom Campus).

Lee, S.W., Hwang, S.J., Lee, S.B., Hwang, H.S., and Sung, H.C. 2009. Landscape Ecological Approach to the Relationships of Land Use Patterns in Watersheds to Water Quality Characteristics. *Landscape and Urban Planning , 92*, 80-89.

Lester, J.N. 1983. Significance and Behaviour of Heavy Metals in Wastewater Treatment Processes, Sewage Treatment and Effluent Discharge. *The Science of the Total Environment*. 30: 1-44. The Netherlands: Elsevier Ltd.

LHR Publication Series. 2009. Environmental Accounts and Municipal Accountability. 1st edn, Water Supply and Sanitation in South Africa, Pretoria.

Li, S., Li, J. and Zhang, Q. 2011. Water quality assessment in the rivers along the water conveyance system of the Middle Route of the South to North Water Transfer Project (China) using multivariate statistical techniques and receptor modeling. *Journal of hazardous materials*, *195*, pp.306-317.

Low, A.B. and Rebelo, A.G. 1998. Vegetation of South Africa, Lesotho and Swaziland. Dept. of Environmental Affairs & Tourism, Pretoria.

Mackintosh, G. and C. Colvin. 2003. Failure of rural schemes in South Africa to provide potable water. Environmental Geology 44:101-105.

Malan, J.D. 2002. The impacts of Gold Mining Industry on Water Quality of the Kromdraai Catchment. Masters Dissertation. Rand Afrikaans University.

Manyatshe, A., Fosso-Kankeu, E., Van der Berg, D., Lemmer, N., Waanders, F. and Tutu, H. 2017. Dispersion of inorganic contaminants in surface water in the vicinity of Potchefstroom. *Physics and Chemistry of the Earth, Parts A/B/C*, *100*, pp.86-93.

Manungufala, T.E., Chimuka, L., Cukrowska, E. and Tutu, H. 2011. Evaluation of the performance of rural wastewater treatment plants using chemical measurements in combination with statistical techniques: a case study. Toxicological & Environmental Chemistry, 93(6), pp. 1123-1134.

Masere, T.P., Munodawafa, A. and Chitata, T. 2012. Assessment of human impact on water quality along Manyame River. International Journal of Development and Sustainability. Vol. 1 No. 3, pp. 754-765.

Mdamo, A. 2001. Accumulation of Nutrients and Heavy Metals in plants at Kagondo natural Wetland (Draft Paper).

Meays, C.L.K. Broersma, R. Nordin and Mazumder, A. 2004. Source tracking faecal bacteria in water: a critical review of current methods. Journal of Environmental Management 73:71-79.

Mema, V. 2010. Impact of poorly maintained wastewater and sewage treatment plants: Lessons from South Africa. *ReSource 12*, 60–65.

Merafong City. 2016. Municipal Spatial Development Framework 2016 – 2021 (Annexure C). Available online [http://www.merafong.gov.za/datafiles/pdf/IDP/2019/Annexures/MSDF/MSDF%202016-21%20Annexure%20C%20Local%20Spatial%20Development%20Directives.pdf]. Accessed on 20 February 2019.

Metcalf Inc. and Eddy, I.S.M. 2003. Wastewater Engineering Treatment and Reuse. *Metcalf & Eddy, Inc.,* 4th Edition.

Meybeck, M. and Helmer, R. 1992. An introduction to water quality. In: Chapman, D. (ed) Water quality assessments, Great Britain, pp 1–17.

Milenkovic, N., Damjanovic, M. and Ristic, M. 2005. Study of Heavy Metal Pollution in Sediments from the Iron Gate (Danube River), Serbia and Montenegro. *Polish Journal of Environmental Studies*, 14 (6): 781-787.

Mitchell, M.K., and Stapp, W.B. 1992. *Field manual for water quality monitoring: An environmental education program for schools*. Dexter, Mich: Thomson-Shore, Inc.

Morrison, G., Fatoki, O.S., Persson, L. and Ekberg, A. 2001. Assessment of the impact of point source pollution from the Keiskammahoek Sewage Treatment Plant on the Keiskamma River-pH, electrical conductivity, oxygen-demanding substance (COD) and nutrients. *Water SA 27*(4), pp.475-480.

Moses, M. 2005. An investigation into the negative external impact of water pollution, public policy options and coping strategies with specific references to the Lotus River Catchment area. Doctoral dissertation, University of the Western Cape.

Mosley, L., Sarabjeet, S. and Aalbersberg, B. 2004. Water quality monitoring in Pacific Island countries. Handbook for water quality managers & laboratories, Public Health officers, water engineers and suppliers, Environmental Protection Agencies and all those organizations involved in water quality monitoring (1st Edition). 43 p; 30 cm, ISSN: 1605-4377: SOPAC. The University of the South Pacific. Suva - Fiji Islands.

Mosoa, M.W. 2013. Assessment of approaches to determine the water quality status of South African catchments. Masters dissertation. University of Pretoria.

Moss, B. 2007. Water pollution by agriculture. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1491), pp.659-666.

Mothetha, M.L. 2016. Evaluation of the impacts of municipal wastewater treatment on the receiving environment: a case study of the Olifantsvlei wastewater treatment plant in the Gauteng Province, South Africa (Masters dissertation).

Moyo, N. and Mtetwa, S. 2002. Water quality management and pollution control. Hirji, R., Johnson, P., Maro, P. and Chiuta, TM. Defining and Mainstreaming Environmental Sustainability in Water Resources Management in southern Africa. *SADC, IUCN, SARDC, IBRD. pp137-176*.

Muller, M.J. 2013. Linking institutional and ecological provisions for waster water treatment discharge in a rural municipality, Eastern Cape, South Africa. Masters Thesis. Rhodes University.

Muruven, D. and Tekere, M. 2013. An evaluation of the cumulative surface water pollution on selected areas within the consolidated main reef area, Roodepoort, South Africa. Air, Soil and Water Research 6: 121.

Mwangi, F.N. 2014. Land use practices and their impact on the water quality of the Upper Kuils River (Western Cape Province, South Africa). Doctoral dissertation, University of Western Cape.

Naidoo, J. 2013a. Assessment of the Impact of Wastewater Treatment Plant Discharges and Other Anthropogenic Variables on River Water Quality in the EThekwini Metropolitan Area. Doctoral dissertation, University of KwaZulu-Natal, Durban.

Naidoo, S. 2013b. Impact of Microbial and Physico-chemical Qualities of Treated Wastewater Effluent on Receiving Water Bodies in Durban. Doctoral dissertation, University of KwaZulu-Natal, Durban.

Namasivayam, C. and Kadirvelu, K. 1999. Uptake of mercury (II) from wastewater by activated carbon from an unwanted agricultural solid by-product: coirpith. *Carbon*, *37*(1), pp.79-84.

Naseem, R. and Tahir, S.S. 2001. Removal of Pb (II) from aqueous/acidic solutions by using bentonite as an adsorbent. *Water Research*, *35*(16), pp.3982-3986.

Nebel, B.J. and R.T. Wright. 1998. Environmental Science*:* The Way the World Works. (2nd ed). Prentice-Hall. Inc. pp. 296-298.

Nhapi, I. and Tirivarombo, S. 2004. Sewage discharges and nutrient levels in Marimba River, Zimbabwe. Water SA, 30(1), pp.107-113.

Nriagu, J.O. 1996. A history of global metal pollution. Science 272: 223–224.

NMMP (National Microbial Water Quality Monitoring Programme). 2000. Identification and prioritisation of areas in South Africa with a potentially high health risk due to faecally polluted surface water. Department of Water Affairs Forestry, Pretoria, DWAF Report N/0000/00/EE/Q/4399.

Odjadjare, E.E. and Okoh, A.I. 2010. Physicochemical quality of an urban municipal wastewater effluent and its impact on the receiving environment. Environmental monitoring and assessment, 170(1-4), pp. 383-394.

Odonkor, S.T. and Ampofo, J.K. 2013. *Escherichia coli* as an indicator of bacteriological quality of water: an overview. Microbiology Research; 4: e2.

Ogunfowokan, A.O., Okoh, E.K., Adenuga, A.A. and Asubiojo, O.I. 2005. An Assessment of the Impact of Point Source Pollution from a University Sewage Treatment Oxidation Pond on a Receiving Stream-A Preliminary Study. Journal of Applied Sciences 5 (1): 36-43.

O'Keeffe, J.H., Uys, M. and Bruton, M.N. 1992. Freshwater Systems. In Fuggle, R.F. and Rabie, M.A. (eds.). *Environmental Management in South Africa*. Juta. Cape Town.

Okoh, A.I., Sibanda, T. and Gusha, S.S. 2010. Inadequately Treated Wastewater as a Source of Human Enteric Viruses in the Environment. International Journal of Environmental Research and Public Health. 7:2620-2637.

Osuolale, O. and Okoh, A. 2015. Assessment of the physicochemical qualities and prevalence of *Escherichia coli* and Vibrios in the final effluents of two wasteWWTWs in South Africa: ecological and public health implications. International journal of environmental research and public health, 12(10), pp.13399-13412.

Otieno, F.A.O. and Ochieng, G.M.M. 2004. Water management tools as a means of averting a possible water scarcity in South Africa by the year 2025. *Water SA*, 30: 668-672.

Oyaro, N., Ogendi, J., Murago, E.N. and Gitonga, E. 2007. The contents of Pb, Cu, Zn and Cd in meat in nairobi, Kenya. Journal of Food, Agriculture & Environment Vol.5 (3&4) : 119-121. 2007.

Palmer C.G., Muller W.J. and Hughes D.A. 2004. Water quality in the ecological Reserve. In: SPATSIM, an integrating framework for ecological reserve determination and implementation: Incorporating water quality and quantity components for rivers. *Hughes D.A. (ed). WRC Report No. TT 245/04. Water Research Commission.* Pretoria, South Africa.

Pandey, S. 2006. Water pollution and health. Kathmandu University Medical Journal 4:128-134.

Pantshwa, M.J., Van Der Walt, A.M., Cilliers, S.S. and Bezuidenhout, C.C. 2009. Investigation of faecal pollution and occurrence of antibiotic resistant bacteria in the Mooi River system as a function of a changed environment. North West University. WISA Paper.

Parliament, South Africa. 1996. Constitution of the Republic of South Africa Act No. 108. Pretoria.

Paul, W.A. 2011. Impact of industrial effluents on water quality of receiving streams in Nakawa-Ntinda, Uganda. MSc Thesis, Makerere University, Kampala, Uganda.

Paulino, A.T., Simionato, J.I., Garcia, J.C., Nozaki, J., 2006. Characterization of chitosan and chitin produced from silkworm chrysalides. Carbohydrate Polymers. 64: 98-103.

Pawari, M.J. and Gavande, S.M. 2013. Assessment of Water Quality Parameters: A Review. International Journal of Science and Research (IJSR) ISSN, pp.2319-7064.

Pegram, G. C. and Görgens, A. H. M. 2001. A Guide to Non-Point Source Assessment: To Support Water Quality Management of Surface Water Resources in South Africa. Pretoria: Water Research Commission Report No. TT 142/01.

Pelser, E.L.C. 2015. *Ecosystem health and water quality of the Mooi River and associated impoundments using diatoms and macroinvertebrates as bioindicators* (Doctoral dissertation, North-West University (South Africa), Potchefstroom Campus).

Perry, J. and Vanderklein, E. 1996. Water Quality Management of a Natural Resource. Blackwell Science, Inc. 639pp.

Pieterse, N.M., Bleutena, W. and Jørgensen, S.E. 2003. Contribution of point sources and diffuse sources to nitrogen and phosphorus loads in lowland river tributaries. *Journal of Hydrology*, 271: 213-225.

Redeker, M. 2011. Impact of wastewater treatment works on the stream water quality in the upper Stör catchment. Masterarbeit in der Abteilung Hydrologie und Wasserwirtschaft der CAU Kiel.

Republic of South Africa. 1997. Water Services Act. Act No. 108 of 1997. Government Gazette, 18522.

Republic of South Africa. 1998. National Water Act (Act No. 36 of 1998). *Government Gazette*, (19182).

Rocca, C.D., Belgiorno, V. and Meric, S. 2007. Overview of in-situ applicable nitrate removal processes. pp. 46-62.

Rounsevell, M. D., and Reay, D. S. 2009. Land Use and Climate Change in the UK. *Land Use Policy , Supplement*, 160-169.

Sanchez, E., Colmenarejo, M. F., Vincente, J., Rubio, A., Garcia, M. G., Travieso, L., et al. (2007). Use of the Water Quality Index and Dissolved Oxygen Deficit as Simple Indicators of Watersheds Pollution. *Ecological Indicators , 7*, 315-328.

Schölzel, H. and Bower, R. 1999. Small Scale Wastewater Treatment Plant Project: Report on project criteria, guidelines and technologies. SOPAC Technical Report 288.

Schröder, J. J., Scholefield, D., Cabral, F., & Hofman, G. 2004. The Effects of Nutrient Losses from Agriculture on Ground and Surface Water Quality: The Position of Science in Developing Indicators for Regulation. *Environmental Science and Policy , 7*, 15-23.

Seanego, K.G. and Moyo N.A.G. 2013. The effect of sewage effluent on the physico-chemical and biological characteristics of the Sand River, Limpopo, South Africa. Physics and Chemistry of the Earth 66 (2013) 75–82.

Seckler, D., Molden, D. and Barker, R. 1999. Water Scarcity in The Twenty-first Century. International Journal of Water Resources Development, 15 (1/2), 29–42.

Seckler, D., Molden, D. and Sakthivadivel, R. 2003. The concept of efficiency in water resources management and policy. *Water productivity in agriculture: Limits and opportunities for improvement*, *1*, pp.37-51.

Sibanda, T., Selvarajan, R. and Tekere, M. 2015. Urban effluent discharges as causes of public and environmental health concerns in South Africa's aquatic milieu. *Environmental Science and Pollution Research*, *22*(23), pp.18301-18317.

Singh, A. and Lin, J. 2015. Microbiological, coliphages and physico-chemical assessments of the Umgeni River, South Africa. *International journal of environmental health research*, *25*(1), pp.33-51.

Singh, Y. and Kumar, M. 2011. Application of Statistical Methods to Analyse Groundwater Quality. Journal of Earth Sciences and Geotechnical Engineering, vol. 1, no.1, 1-7. International Scientific Press.

Slabbert, J.L. and Venter, E.A. 1999. Biological assays For Aquatic Toxicity Testing. *Wat. Sci. Tech*. 39(10): 367-373. Great Britain: Pergamon Press.

Smakhtin, V., Revenga, C. and Döll, P. 2004. A pilot global assessment of environmental water requirements and scarcity. *Water International*, *29*(3), pp.307-317.

Smethurst, G. 1988. Basic Water Treatment. 2nd ed. Thomas Telford, Ltd., London.

South Africa. 1998. National Environmental Management Act (No 107 of 1998) (NEMA). Government Printers, Pretoria.

Spulber, N. and Sabbaghi, A. 1998. *Economics of Water Resources: From Regulation to Privatization,* 2nd ed. (Massachusetts: Kluwer Academic Publishers).

Statistics South Africa. 2011. Census for 2011. Available online [http://www.statssa.gov.za/?page_id=993&id=tlokwe-city-council-municipality]. Accessed 28 October 2018.

Swanson, H.A. and Baldwin, H.L. 1965. A primer on Water Quality: Water Properties and Measurements. Survey. Available online [http://water.usgs.gov/edu/characteristics.html]. Accessed May. 24, 2019.

Tlokwe City Council. 2011. Wastewater Risk Abatement Plan. Potchefstroom.

Tchobanoglous, G. Burton, F.L. and Stensel, H. D. 2004. Wastewater Engineering Treatment and Reuse. Mc-Graw Hill. New York.

Tufekci, N., San, H.A., Aydın, S., Ucar, S. and Barlas, H. 1998. Wastewater Treatment Problems in the Operation of Woven and Knit Fabric Industry, FEB, 7: 795-802.

United States Environmental Protection Agency (USEPA). 2004. Primer for Municipal Wastewater Treatment Systems. EPA 832-R-04-001. Available online [https://www.epa.gov/sites/production/files/2015-09/documents/primer.pdf]. Accessed on 17 January 2019.

United Nations. 2007. Glossary of the Environment Statistics, Studies in Methods. New York.

Valentukeviciene, M., Gytautas, I. and Amosenkiene, A. 2011. The sustainable development assessment of drinking water supply system/Geriamojo vandens tiekimo sistemos darnaus vystymo vertinimas. Technological and Economic Development of Economy 17.4. 688.

Van den Brink, P.J., Van den Brink, N.W. and Ter Braak, C.J. 2003. Multivariate analysis of ecotoxicological data using ordination: demonstrations of utility on the basis of various examples. *Australasian Journal of Ecotoxicology*, *9*(2), pp.141-156.

Van der Walt, I.J., Winde, F. and Nell, B. 2002. Integrated Catchment Managemnt: The Mooi River (North West Province, South Africa) As a Case Study. Cuadernos de Investigacion Geografica.pp 109 – 126.

Venter, A., Barnard, S., Dickinson, M.A., van Vuuren, S.J., Levanets, A. and Taylor, J.C. 2013. Planktonic algae and cyanoprokaryotes as indicators of ecosystem quality in the Mooi River system in the North-West Province, South Africa. *Water SA*, *39*(5), pp.707-720.

Verheul, J.K. 2012. Assessing the effects of different land uses on water quality in the Upper Wilge River Catchment. Doctoral dissertation, University of Johannesburg.

Vink, R., Behrendt, H. and Salomons, W. 1999. Point and diffuse source analysis of heavy metals in the Elbe drainage area: comparing heavy metal emissions with transported river loads. *Hydrobiologia,* vol. 410, pp. 307-314.

Wade, P.W., Woodbourne, S., Morris, W.M., Vos, P. and Jarvis, N.V. 2000. Tier 1 Risk Assessment of Radionuclides in Selected Sediments of the Mooi River. WRC-Project No K5/lO95.

Wade, A. J., Jackson, B. M., & Butterfield, D. 2008. Over-Parameterised, Uncertain 'Mathematical Marionettes'- How Can we Best Use Catchment Water Quality Models? An Example of an 80-Year Catchment-Scale Nutrient Balance. *Science of the Total Environment , 400*, 52-74.

Wakelin, S.A., Colloff, M.J. and Kookanal, R.S. 2008. Effect of wastewater treatment plant effluent on microbial function and community structure in the sediment of a freshwater stream with variable seasonal flow. Applied and Environmental Microbiology. 74:2659-2668.

Walsh, G. and Wepener, V. 2009. The influence of land use on water quality and diatom community structures in urban and agriculturally stressed rivers. *Water SA.* 35(5).

Water Environment Partnership in Asia. 2013. Emission Standards. Available online http://www.wepa-db.net/policies/law/laos/Standards.htm.

Water Information Network-South Africa. 2011. Achieve Green Drop status Lessons from Bitou and Tlokwe Local Municipalities. Available online: [https://www.slabbert-associates.com/storage/files/WINSA-greendrop.pdf]. Accessed on 22 February 2019.

Water Institute of South Africa, Water Research Commission and East Rand Water Care Company. 2002. *Handbook for the operation of wastewater treatment works*. Water Institute of South Africa.

Wattoo, M.H.S., Wattoo, F.H., Kazi, T.G., Tirmizi, S.A., Bhanger, M.I., Mahar, R.B. and Iqbal, J. 2004. Quality Characterization of Phulali canal water for irrigation purposes. *The Nucleus*, 41: 69-75.

Winde, F. 2010. Uranium pollution of the Wonderfonteinspruit, 1997-2008 Part 1: Uranium toxicity, regional background and mining-related sources of uranium pollution. *Water SA.* Vol. 36 No. 3: 239-256.

World Health Organization (WHO). 1993. *Guidelines for drinking-water quality*. World Health Organization. Geneva

World Health Organization (WHO). 1996. *Guidelines for drinking-water quality*. World Health Organization. Geneva

World Health Organization (WHO). 2001. Water Quality: Guidelines, Standards and Health. Edited by Lorna Fewtrell and Jamie Bartram. Published by IWA Publishing, London, UK. ISBN: 1 900222 28 0.

World Health Organization (WHO). 2003. Ammonia in drinking-water. Background document for development of WHO Guidelines for Drinking-water Quality. Geneva, World Health Organization (WHO/SDE/WSH/03.04/01).

World Health Organization (WHO). 2008. Guidelines for Drinking-water Quality [electronic resource]: incorporating 1st and 2nd addenda, Vol. 1. Recommendations.

Wright, D.A. and Welbourn, P. 2002. Environmental Toxicology. Cambridge University Press.

APPENDICES

Appendix 1: Water Quality Data obtained from DWS for the period 2015 - 2018

Table i: Water quality data of the selected sites, WWTWs and their upstream points sorted per parameter

		Selected sites					
Parameters	**Dates**	**C2H246 (Upstream)**	**C2H257**	**C2H153 (Upstream)**	**C2H237**	**C2H254 (Upstream)**	**C2H255**
pH	May-15	7.9	7.1	7.5	7.1		8
	Jun-15	7.5	7.3	7.4	7.7		7.9
	Jul-15	7.6	5.9	7.3	7.2		7.8
	Apr-16	7.0	8.1			8.1	7.9
	May-16	7.3	7.3			8	7.8
	Jun-16	7.3	8			7.9	7.7
	Jul-16	8.1	8.3			8.4	8
	Aug-16	8.2	7.9			8.4	7.7
	Sep-16	7.8	6.7			8.1	7.8
	Oct-16	7.9	7			8.3	8.1
	Nov-16		7				7.6
	Dec-16		7.7				8.1
	Jan-17	7.0	7.5			7.6	7.8
	Feb-17	7.8	7.7	7.8		7.8	7.8
	Jun-17	7.7	7.4	8.3	7.6	8.2	8.2
	Jul-17	7.9	7.7	8.0	7.5	8.3	8.1
	Aug-17	7.0	7.2			8.1	7.7
	Sep-17	7.1	7.5	7.0	7.5	8.4	7.9
	Oct-17	7.7	7.7			8.2	8.3
	Nov-17	7.8	7.6	7.7	8	8.3	8.9
	Dec-17	7.3	7.8	6.9	7.7	7.6	7.8
	Jan-18	7.4	7.7		7.7	8	7.8
	Feb-18	7.1	7			7.6	7.4
	Mar-18	7.8	7.8			8.1	8
Conductivity	May-15	106.8			104.8		105.1
	Jun-15	89.0	68.4	79.3	93.4		106.4
	Jul-15	89.7	55.3	72.8	102.2		108.9
	Apr-16	86.6	49.1			78.8	98.5
	May-16	69.7	50.8			73.3	89.6
	Jun-16	57.8	48.8			64.3	69.4
	Jul-16	58.5	44.6			60.9	79.7
	Aug-16	71.7	49.3			64.8	85

	Sep-16		61.6			90.6	117
	Oct-16	93.0	45.2			86.5	111.2
	Nov-16	94.0	42.8				111
	Dec-16		61.3				116
	Jan-17	89.5	51.2			71.7	94.1
	Feb-17	75.8	41.7	70.7		59.4	91.7
	Jun-17	72.0	51.5	80.7	79.3	59.1	92.9
	Jul-17	45.9	58.4	92.3	69	73.1	98.8
	Aug-17	37.4	54.6			72.3	100
	Sep-17	41.2	63.1	71.1	81.3	86	112
	Oct-17	41.4	51.9			81.1	113
	Nov-17	33.4	49.9	45.3	81.1	72.9	102
	Dec-17	39.0	44.7	61.8	85.2	60.4	99.9
	Jan-18	42.0	71.8		65.3	86.7	111
	Feb-18	36.9	55.3			81.6	107
	Mar-18	108.0	53.8			58.2	97.9
Nitrates	May-15	3.4		2.8	0.1		8
	Jun-15	6.2	3	4.4	0.1		7.7
	Jul-15	5.4	31.3	8.2	4.8		6.2
	Apr-16		0.8				5.8
	May-16		18				7
	Jun-16		1.4				8.3
	Jul-16		14				7.7
	Aug-16		3.9				9.6
	Sep-16		1.1				3.6
	Oct-16		3.2				6.7
	Nov-16		3.1				4.2
	Dec-16		0.9				4.6
	Jan-17		7				6.5
	Feb-17		5.8	7.1			4.5
	Jun-17		1.7	5.4	0.1		5.6
	Jul-17		0.24	6.5	0.1		6.9
	Aug-17		1				6.7
	Sep-17		1.2	5.3	0.1		7
	Oct-17		4.7				7.2
	Nov-17		9.8	2.4	0.8		4.5
	Dec-17		7.3	1.0	0.9		7.5
	Jan-18		0.3		0.1		3.8
	Feb-18		7.1				5.3
	Mar-18		13				6.9
Faecal coliforms	Apr-16	45.0	350 000			2300	1
	May-16	3.0	4200			43	6
	Jun-16	25.0	1			41	330
	Jul-16	5.0	300			6000	1
	Aug-16	1.0	1900			140	3

	Sep-16	4.0	240 000			350	19
	Oct-16	13.0	1100			2	24
	Nov-16		8400				720
	Dec-16		17 000				54
	Jan-17	33.0				160	5
	Feb-17	3.0		300		38	450
	Jun-17	51.0		46	690	340	1
	Jul-17	39.0		48	270 000	270	3
	Aug-17	1.0				110	29
	Sep-17	1.0		260	1	59	1
	Oct-17	1.0				171	7
	Nov-17	1.0		620	1	10000	380
	Dec-17	64.0		3200	35 000	1820	1
	Jan-18	21.0				37000	4800
	Feb-18	20.0				600000	32
	Mar-18	100.0				7600	1
Ammonia	May-15	0.0			0.4		0.003
	Jun-15	0.0	0.3	0.005	1		0.002
	Jul-15	0.0	0	0.001	0.4		0.002
	Apr-16	0.0	4.1			0.003	1.5
	May-16	0.0	0,1			0.003	0.3
	Jun-16	0.0	8.9			0.002	0.1
	Jul-16	0.0	0.1			0.007	0.3
	Aug-16	0.0	5.1			0.007	0.2
	Sep-16	0.0	1.6			0.014	3.3
	Oct-16	0.0	<0,1			0.006	0.1
	Nov-16		2.1				0.1
	Dec-16		15				0.2
	Jan-17	0.0	0.006			0.009	0.02
	Feb-17	0.0	0.002	0.002		0.002	0.08
	Jun-17	0.0	0.004	0.015	0.5	0.004	0.2
	Jul-17	0.0	0.8	0.003	0.3	0.006	0.04
	Aug-17	0.0	0.1			0.004	0.001
	Sep-17	0.0	0.4	0.004	0.5	0.006	0.08
	Oct-17	0.0	0.002			0.004	0.02
	Nov-17	0.0	0.2	0.001	0.8	0.036	0.8
	Dec-17	0.0	0.002	0.015	0.6	0.007	0.01
	Jan-18	0.0	0.8		0.7	0.062	0.2
	Feb-18	0.0	0.02			0.012	0.02
	Mar-18	0.0	0.002			0.06	0.003
Orthophosphate	May-15	0.5	0.3	0.01	7		2.9
	Jun-15	0.8	0.9	0.045	3.2		0.6
	Jul-15	0.6	1	0.01	5.5		0.8
	Apr-16	0.6	0.4				2.1
	May-16	0.7	4.5				0.6

	Jun-16	0.7	2				1.7
	Jul-16	1.0	0.2				6
	Aug-16	0.8	0.3				2
	Sep-16	0.6	9.8				1.7
	Oct-16	0.7	<0,20				0.7
	Nov-16		8.1				0.44
	Dec-16		8				1.4
	Jan-17	0.8	7.1				1.9
	Feb-17	0.7	1.6	0.1			1.9
	Jun-17	0.9	0.1	0.1	0.4		0.8
	Jul-17	1.3	2.9	0.1	0.9		0.5
	Aug-17	1.6	0.1				0.2
	Sep-17	1.6	0.1	0.1			1
	Oct-17	1.7	0.1				1.1
	Nov-17	2.0	3.1	0.1	1.3		1.2
	Dec-17	1.7	0.1	0.1	0.3		1.4
	Jan-18	2.0	0.1				1
	Feb-18	2.0	1.1				2.8
	Mar-18	0.5	0.1				0.4
COD	Apr-16	5.0	36				23
	May-16	16.0	47				33
	Jun-16	5.0	10				17
	Jul-16	16.0	70				26
	Aug-16	5.0	43				11
	Sep-16	5.0	4740				31
	Oct-16	17.0	34				25
	Nov-16		27				10
	Dec-16		51				29
	Jan-17	5.0	13				17
	Feb-17	5.0	5	5			16
	Jun-17	5.0	225	5	97		21
	Jul-17	5.0	45	5	1420		30
	Aug-17	24.0	210				36
	Sep-17	22.0	87	16	149		27
	Oct-17		20				5
	Nov-17	5.0	31	5	121		5
	Dec-17	5.0	5	5	121		5
	Jan-18	5.0	41		89		61
	Feb-18	5.0	5				5
	Mar-18	5.0	14				5
	Apr-18						
Suspended solids	Apr-16		6				6
	May-16		5				3
	Jun-16		15				9
	Jul-16		37				3

	Aug-16		19				3
	Sep-16		3448				7
	Oct-16		8				3
	Nov-16		31				4
	Dec-16		39				422
	Jan-17		12				1.5
	Feb-17		7	1.5			6
	Jun-17		101	1.5	29		5
	Jul-17		9	308.0	388		9
	Aug-17		149				13
	Sep-17		62	4	84		4
	Oct-17		6				19
	Nov-17		10	1.5	33		1.5
	Dec-17		6	11	48		7
	Jan-18		15		51		47
	Feb-18		15				14
	Mar-18		8				16
E. coli	Apr-16	45.0	315 000			2300	1
	May-16	3.0	3360			43	6
	Jun-16	25.0	1			41	330
	Jul-16	5.0	300			6000	1
	Aug-16	1.0	760			140	3
	Sep-16	4.0	144 000			350	6
	Oct-16	13.0	1100			2	24
	Jan-17	33.0	2790			160	96
	Feb-17	3.0	37 600	300		38	4
	Jun-17	51.0	52 000	1	690	340	1
	Jul-17	39.0	47 000	43	243 000	270	3
	Aug-17	1.0	44 000			110	26
	Sep-17	1.0	49 000	260	1	59	1
	Oct-17	1.0	200			171	7
	Nov-17	1.0	3920	558	1	10000	1
	Dec-17	64.0	1890	1600	35 000	6 400	1
	Jan-18	21.0	41 000			37000	1920
	Feb-18	20.0	8 000			600000	19
	Mar-18	100.0	390			4560	1

Appendix 2: Available reference or historical data obtained from DWS for the 3 WWTWs sorted per parameters for the period 2001 – 2002

Table ii: Reference data used for COD

Chemical Oxygen Demand					
Dates	**C2H237 Flip Human WWTW**	**C2H255 Potchefstroom WWTW**	**C2H257 Kokosi WWTW**	**WUL/ General Limits**	**EPA Schedule 2**
Sep-01	124		52	75	120
Oct-01	55	75	25	75	120
Nov-01	57.3	54	43	75	120
Dec-01	69.2	28	25	75	120
Jan-02	65		5	75	120
Feb-02	68	42	23	75	120
May-02	55			75	120
Jun-02	60			75	120
Jul-02		70		75	120
Aug-02	27		55	75	120
Nov-02	30		163	75	120

Table iii: Reference data used for EC

Electrical Conductivity						
Dates	**C2H237 Flip Human WWTW**	**C2H255 Potchefstroom WWTW**	**C2H257 Kokosi WWTW**	**WUL**	**RQO**	**General Limits**
Sep-01	77.3	137	65	75	111	70
Oct-01	78.5	127	64	75	111	70
Nov-01	76.5	108	68	75	111	70
Dec-01	73.6	108	62	75	111	70
Jan-02	69.8		59	75	111	70
Feb-02	82.3	109	60	75	111	70
May-02	74.5	127	65	75	111	70
Jun-02	72.1			75	111	70
Jul-02		126	63	75	111	70
Aug-02	71		51	75	111	70
Nov-02	75.5		69	75	111	70

Table iv: Reference data used for faecal coliforms

Faecal coliforms						
Dates	C2H237 Flip Human	C2H255 Potchefstroom WWTW	C2H257 Kokosi	General limits	SA Guidelines (domestic)	SA Guidelines agriculture (irrigation)
Sep-01	2671			1000	0	1
Oct-01	2950	28000	5	1000	0	1
Nov-01	1900		238	1000	0	1
Dec-01				1000	0	1
Jan-02	11100			1000	0	1
Feb-02	84000	38000	25000	1000	0	1
May-02	40	189000	81000	1000	0	1
Jun-02	228			1000	0	1
Jul-02				1000	0	1
Aug-02	12			1000	0	1
Nov-02	676			1000	0	1

Appendix 3: Water and Wastewater standards and guidelines

Table v: South African Wastewater limit values applicable to discharge of wastewater into a water resource

PARAMETER/SUBSTANCE	GENERAL LIMIT	SPECIAL LIMIT
Faecal Coliforms (per 100 ml)	1000	0
Chemical Oxygen Demand (mg/l)	75	30
pH	5.5-9.5	5.5-7.5
Ammonia as Nitrogen (mg/l)	3	2
Nitrate/Nitrite as Nitrogen (mg/l)	15	1.5
Free Chlorine (mg/l)	0.25	0
Suspended Solids (mg/l)	25	10
Electrical Conductivity (mS/m)	70 mS/m above intake to a max of 150 mS/m	
Orthophosphate as P (mg/l)	10	1
Fluoride (mg/l)	1	1
Soap, oil or grease (mg/l)	2.5	0
Arsenic (mg/l)	0.02	0.01
Cadmium (mg/l)	0.005	0.001
Copper (mg/l)	0.01	0.002
Cyanide (mg/l)	0.02	0.01
Iron (mg/l)	0.3	0.3
Lead (mg/l)	0.01	0.006
Manganese (mg/l)	0.1	0.1
Mercury(mg/l)	0.005	0.001
Selenium (mg/l)	0.02	0.02
Zinc (mg/l)	0.1	0.04
Boron (mg/l)	1	0.5
Chromium (mg/l)	0.05	0.02

Source: National Water Act wastewater discharge standards DWAF, 1999 guidelines

Table vi: Standards for effluent discharge (National Norms and Standards, 2017)

Determinant	Unit	General Limit	Special Limit
Faecal Coliforms	cfu /100 mL	1000	0
Chemical Oxygen Demand	mg /L	75	30
pH		5.5 -9.5	5.5 -7.5
Ammonia (as Nitrogen)	mg /L	6	2
Nitrate /Nitrite as Nitrogen	mg /L	15	1.5
Chlorine as Free Chlorine	mg /L	0.25	0
Suspended Solids	mg /L	25	10
Electrical Conductivity	mS /m	(70 mS/m above intake) Max: 150 mS/m	(50 mS/m above intake) Max: 100 mS /m
Ortho- Phosphate as phosphorous	mg /L	10	1 (min)- 2.5 (max)
Soap, oil or grease	mg /L	2.5	0

Table vii: The numerical limits for the RQO variables as listed in the government gazette 39943 for the Upper Vaal

Variable	Units	Limit (GG No. 39943)
Nitrate and Nitrite	mg/l	≤ 4
Orthophosphate	mg/l	≤ 0.125
Electrical Conductivity	mS/m	≤111
Sulphate	mg/l	≤ 500
Magnesium Dissolved	mg/l	≤ 33
pH at 25°C	pH units	>5.8
pH at 25°C	pH units	≤ .88
Dissolved manganese	mg/l	≤ .31
Dissolved uranium	mg/l	≤0.015
E. coli	cfu /100 mL	≤ 130

Table viii: South African Water Quality guidelines for agriculture (irrigation) and for domestic use (DWAF, 1996)

Parameters	Domestic use	Agriculture (irrigation)
pH	6 – 9	6.5 – 8.4
Nitrates	0 – 6	0.5
Ammonia	0 – 1	-
EC	-	-
PO_4	-	-
COD	-	-
E. coli	-	-
SS	-	50
Feacal coliforms	0	1 - 1000

(DWAF, 1996a, 1996b)

Appendix 4: Green drop data for the period 2017 to 2018

Table ix: Kokosi data 2017-2018

Works Compliance: Kokosi for Period: January 2018									
Category	Microbiological	Physical			Chemical				
Determinants	*E. coli*	pH	EC	SS	COD (Unfiltered)	COD (Filtered)	NH_3	PO_4	NO_3
Limits	0	9	150	25	Not Measured	75	10	1	15
Units	cfu/100ml	pH Units	mS/m	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
February - 2017	4.0	8.1	54.7	8.8		36.0	9.6	0.2	1.5
March - 2017	0.0	7.8	62.7	0.4		32.0	4.0	0.2	3.6
April - 2017	0.0	7.1	56.0	3.2		37.0	10.2	0.1	0.8
May – 2017	0.0	8.6	79.9	14.8		51.0	21.7	0.1	0.1
June - 2017	0.0	8.1	72.0	8.4		40.0	25.6	0.1	0.1
July – 2017	0.0	7.9	62.0	4.2		38.0	15.7	0.1	1.1
August – 2017	0.0	7.2	72.1	0.2		31.0	30.7	0.3	0.1
September - 2017	0.0	7.5	67.7	16.8		28.0	15.9	0.2	5.1
October – 2017	0.0	7.9	75.1	1.6		36.0	0.2	0.1	3.2
November – 2017	0.0	7.6	59.5	6.0		30.0	12.9	0.5	0.3
December – 2017	0.0	7.6	52.7	1.2		20.0	0.2	10.0	0.1
January – 2018	0.0	7.7	71.5	4.8		41.0	19.6	0.3	0.1
Total Number of samples per determinant	12	12	12	12	0	12	12	12	12
Total Number of compliant samples per determinant	11	12	12	12	0	12	4	11	12
% Compliance per Determinant	92	100	100	100	0	100	33	92	100
% Compliance per Category	92	100	100	100	81	81	81	81	81

Table x: Flip Human data 2017 – 2018

Works Compliance: Flip Human for Period: January 2018									
Category	Microbiological	Physical			Chemical				
Determinants	*E. coli*	pH	EC	SS	COD (Unfiltered)	COD (Filtered)	NH_3	PO_4	NO_3
Limits	0	0	0	0	0	75	0	0	0
Units	cfu/100ml	pH Units	mS/m	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
February - 2017	245600.2	7.4	82.8	149.8		283.2	28.2	1.7	0.1
March - 2017	429900.0	7.6	83.4	79.3		225.1	23.1	0.9	0.2
April - 2017	154952.0	7.5	70.5	68.6		191.9	24.4	0.5	0.2
May - 2017	16180.0	7.8	84.6	46.6		150.8	25.2	0.6	0.2
June - 2017	28540.0	7.9	91.4	221.0		312.4	24.1	0.7	0.1
July - 2017	27561.0	8.0	84.4	32.2		78.5	28.9	0.5	0.3
August - 2017	148.5	8.0	74.4	49.2		108.8	17.3	0.5	0.2
September - 2017	656.6	8.1	75.4	89.0		128.0	17.9	0.6	0.2
October - 2017	257.0	8.0	133.9	50.6		71.5	13.2	0.4	0.4
November - 2017	19990.8	8.0	118.2	77.5		126.3	19.7	1.4	0.3
December - 2017	8010.0	7.9	74.4	90.0		59.0	22.9	0.5	0.4
January - 2018	263.3	7.8	89.7	95.0		159.3	28.7	0.6	0.4
Total Number of samples per determinant	59	96	96	96	0	96	96	96	96
Total Number of compliant samples per determinant	14	96	25	7	0	17	4	95	96
% Compliance per Determinant	24	100	26	7	0	18	4	99	100
% Compliance per Category	24	44	44	44	55	55	55	55	55

Table xi: Potchefstroom data 2017-2018

Works Compliance: Potchefstroom for Period: September 2018									
Category	Microbiological	Physical			Chemical				
Determinants	*E. coli*	pH	EC	SS	COD (Unfiltered)	COD (Filtered)	NH_3	PO_4	NO_3
Limits	0	9.5	170	25	75	Not Measured	10	3	3
Units	cfu/100ml	pH Units	mS/m	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
October - 2017									
November - 2017	9.1	7.8	102.5	5.2	21.2		1.8	1.2	2.1
December - 2017	37.8	7.8	99.5	8.0	25.3		1.1	2.5	2.9
January - 2018	15.4	7.7	97.4	8.3	25.3		1.6	2.5	2.8
February - 2018	21.6	7.8	96.4	5.8	25.3		0.9	2.4	2.6
March - 2018	15.2	8.0	91.8	6.4	12.7		1.1	1.4	2.8
April - 2018	29.9	7.6	90.0	5.7	11.4		0.6	1.1	2.8
May - 2018	12.8	7.5	93.5	4.9	21.9		1.9	0.8	1.5
June - 2018	7.3	7.5	90.8	3.6	24.9		1.5	1.0	3.5
Total Number of samples per determinant	276	276	276	276	276	0	276	276	276
Total Number of compliant samples per determinant	96	276	276	276	276	0	276	242	197
% Compliance per Determinant	35	100	100	100	100	0	100	88	71
% Compliance per Category	35	100	100	100	90	90	90	90	90