Cape Peninsula University of Technology

IMPACT OF WASTEWATER TREATMENT EFFLUENT ON THE WATER QUALITY OF THE CROCODILE RIVER, EHLANZENI DISTRICT, MPUMALANGA

By

TERRY TAKALANI PHUNGELA

Dissertation submitted in partial fulfilment of the requirements for the degree

Master of Environmental Management

Faculty of Applied Science, Department of Environmental and Occupational studies

Cape Peninsula University of Technology

Supervisor: Mr T Maphanga

Co-supervisor: Prof K Shale

Cape Town Campus

December 2020

DECLARATION

I, Terry Takalani Phungela, declare that the contents of this dissertation represent my own unaided work, and that the dissertation/thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

Signed **Date**

ABSTRACT

Rapid water resource depletion and pollution have led to the decline of available water for human consumption and the sustenance of ecological integrity. There is only 3% of freshwater on the planet, of which 77% is found in icecaps and glaciers and 22% found in groundwater, leaving 1 % of the fresh water, which is readily available in rivers, dams, and lakes which is not evenly distributed. Excessive discharge of poorly treated wastewater effluent has impacted global water resource systems intensely. Globally, around 80% of wastewater flows back into the environment either as untreated or partially treated, which poses risks to downstream ecosystems and people relying on the rivers and streams as a water source. The study aimed at assessing the impact of wastewater treatment effluent on the quality of Crocodile River within Ehlanzeni District in Mpumalanga Province. Sampling was conducted at six sampling Sites located within the study area in Mbombela Local Municipality and Nkomazi Local Municipality. These included three wastewater treatment plants discharging effluent into the Crocodile River, the sampling points were as follows: White river wastewater treatment works (WWTW) (Site 1), White river – Crocodile River (Site 2), Kanyamazane WWTW (Site 3), Kanyamazane N4 Bridge (Site 4), Matsulu WWTW (Site 5) and Downstream Komatipoort WWTW (Site 6). Parameters such as water temperature (Tem, °C), pH, electrical conductivity (EC, μs/cm), and dissolved oxygen (DO, mg/L) were analysed onsite using a portable meter Hach multi-probe meter Model HQ40d which was calibrated before use. Chemical Oxygen Demand (COD), phosphates, nitrates, ammonia, total suspended solids, and *E. coli* were analysed in a SANAS accredited laboratory and were conducted according to the SANAS accredited LP-ZAM Hach water analysis methods and SANS 5221 methods.

The study revealed that Site 1 was not complying with the effluent standards set out in their Water Use Licence (WUL). This was evidenced by the effluent's Ammonia, Nitrate-Nitrite, *E. coli,* and COD concentration that were frequently above limit during the period of study. The effect of the pollution loading from the WWTW's effluent was observed from a downstream sampling Site (Site 2) water quality whereby seasonal fluctuations in *E. coli* were observed which can be attributed to the discharged. However, assimilation of the discharged effluent was also noted since there is no other WWTW discharging effluent. Water Quality Index (WQI) undertaken downstream of the WWTW at Site 2 showed that there is a discharge of poorly treated effluent, although the water quality of the river is still acceptable, with an index of 31.27. The study further revealed that Site 3 and Site 5 were generally compliant with the effluent standards set out in their WULs, except for phosphate which was non-compliant during the duration of the study. Regression and bivariate statistical analysis of the historic effluent quality for both WWTWs (Site 3 and 5) show a steady increase in phosphate concentration in the discharged effluent as time progresses.

The results of the WQI conducted at Site 4, which is located downstream of site 3 reflected that the quality of the river at this point was very poor, with an index of 101.18, which was mainly attributed to high *E. coli* (overall mean of $2x10^3$ counts per ml). These water quality trends and spatial distribution of nutrients and *E. coli* specifically at site 4 gives information on non-point sources of pollution mainly during wet seasons, specifically from settlements around the Kanyamazane area situated next to the water resource. Downstream Komatipoort WWTW (Site 6) water quality also showed that there is a point source pollution specifically from poorly treated discharged effluent. Concentrations of constituents were frequently non-compliant to the resource quality objectives (RQO) .

Regression and bivariate statistical analysis of historic water quality for this site indicated a steady increase of nitrite-Nitrate and phosphate over time. Water Quality Index (WQI) conducted at this site also illustrated that water quality is very poor, with an index value of 501.05, and based on the water quality trend analysis, poor water quality at this site is mainly attributed to high *E. coli* counts frequently recorded throughout the study. The results obtained in the present study indicated that there is pollution in the Crocodile River concerning WWTW effluent related constituents which were studied. Based on the results of the study, the pollution of the Crocodile River can be attributed to, amongst others non-point sources, poor quality effluent discharged unto the water resource. In addition, poorly treated effluent from wastewater treatment plants discharged into the water resources has a significant impact on the functioning, integrity, and quality of the water resource and associated ecosystem. Several studies also reported the impact of wastewater effluent on the receiving environment and they confirm that there is still a lot of work that needs to be undertaken with regards to improving effluent quality to protect water resources. Actions and measures must be taken by relevant governing authorities to mitigate the pollution of water bodies through the implementation and enforcement of laws and regulations relating to effluent discharge for the protection of South Africa’s water resources.

ACKNOWLEDGEMENTS

I wish to thank:

- Yeshua HaMashiach, my sovereign Lord for giving me the strength and courage to successfully undertake and complete this task.

- My supervisor, Mr. Thabang Maphanga for his continued support, guidance, and motivation during the study, you believed in me, pushed me to never give up even though it was tough, and always guiding me in the right direction.

- My co-supervisor, Prof. Karabo Shale for his willingness to participate in the study that I conducted and his guidance, support, and mentorship throughout the study, is highly appreciated.

- Inkomati Usuthu Catchment Management Agency for granting me permission and access to their information and data for the successful undertaking of this study.

- My family for the support they provided throughout my studies.

DEDICATION

This work is dedicated to:

Yeshua HaMashiach, my Lord and master

My parents Takalane Amos Phungela and Livhuwani Phungela

GLOSSARY

Activated sludge	The biomass produced in wastewater by the growth of organisms in the presence of organic matter.
Aerobic	Conditions where oxygen acts as electron donor for biochemical reactions.
Anaerobic	Conditions where biochemical process occurs in complete absence of oxygen.
Anoxic	Conditions where oxyanion instead of oxygen acts as an electron donor for biochemical reactions.
Aquatic ecosystem	An ecosystem in a body of water
Biochemical oxygen Demand (BOD)	The amount of oxygen required or consumed for the decomposition of microbial reactions within wastewater.
Chemical oxygen Demands (COD)	The amount of oxygen required to chemically oxidise substances in the wastewater.
Electrical Conductivity	The measure of the ability of a solution to conduct electricity.
Total suspended solids (TSS)	The total number of particles that are in suspension in water/wastewater.
Total dissolved solids (TDS)	The combined content of all inorganic and organic substances contained in a liquid which are present in a molecular, ionized or micro-granular suspended form.
Water quality	The condition of water , including chemical , physical and biological characteristics with respect to its suitability for a particular purpose such as drnking or irrigating

LIST OF ACRONYMS

BNR	Biological Nutrient Removal
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
EC	Electrical conductivity
DWA	Department of Water Affairs
NWA	National Water Act
NO_2^-	Nitrite
NO_3^-	Nitrate
NH_3	Ammonia
IUCMA	Inkomati Usuthu Catchment Management Agency
P	Phosphorus
pH	Potential of Hydrogen
SS	Suspended Solids
SANAS	South African National Accreditation System
SPSS	Statistical Product and Service Solution
RQO	Resource Quality Objectives
TDS	Total dissolved solids
WQI	Water Quality Index
WUL	Water Use Licence
WWTW	Wastewater Treatment Works

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDICES

CHAPTER ONE: INTRODUCTION

1.1. Background to study

Rapid water resource depletion and pollution of available water resources have led to the decline of available water resources for human consumption and the sustenance of ecological integrity. There is only 3% of fresh water on the planet, of which 77% is found in icecaps and glaciers and 22% found in groundwater, leaving 1 % of the freshwater, which is readily available in rivers, dams, and lakes which is not evenly distributed (Jackson et al., 2001). Water is an essential component in the existence of every living organism; hence the protection of water resources is of utmost importance. Major contributors to water quality deterioration in South Africa’s water resources are agricultural runoff, extensive coal mining activities, industrial activities combined with a general decline in the operation and management of wastewater treatment infrastructure, especially sewage treatment (DWA,2011). Adequate amounts of suitable quality water resources provide a precondition for economic development and ecological integrity (Wu et al, 2017).

Rivers are the main water source for domestic, industrial, and irrigation purposes, however, they are easily polluted because of their critical role in transporting municipal and industrial pollution and runoff from agricultural land (Singh et al., 2005). Poorly treated effluent has a detrimental impact on the aquatic ecosystem, agriculture, and the local community, and their economy. Monitoring effluent from wastewater treatment works (WWTW) and the impact it has on the water quality of water resources is of utmost importance. Water quality monitoring, assessment, and evaluation are important for pollution mitigation, control, and water resource management. Water quality assessment is critical for identifying the major role players and contributors to spatial and temporal variations in quality, which can be beneficial with regards to integrated water resource management (Wu et al., 2017). Based on the information from the effluent quality assessment, the government in co-operation with the public can implement protective measures to improve the condition of the water resource.

Surface water resources such as rivers and streams receive contaminants from domestic, industrial wastewater, and agricultural effluent, which increase the degradation of the freshwater ecosystem mainly through eutrophication and heavy metal inputs (Qadir et al., 2010; Belabed et al., 2017). Discharge of poorly treated and untreated wastewater furthermore introduces a complex mixture of toxic substances into aquatic environments degrading water quality to the extent that the resultant surface water is not suitable for human consumption and agricultural irrigation (Qadir et al., 2010; Ouali et al., 2018).

1.2. Problem Statement

The declining state of municipal wastewater treatment facilities and infrastructure is one of the largest contributors to pollution in water resources especially surface water resources. Globally, around 80% of wastewater flows back into the environment as untreated or partially treated, which poses risks to downstream ecosystems and people who rely upon the river as a drinking water source (Wang et al., 2017). Deterioration of the quality of a water resource especially one such as the Crocodile River has a detrimental impact on socio-economic development because such water cannot be used for bathing, drinking, industry, or agriculture.

1.3. Research Questions

The following questions are addressed regarding the research:

- How is the effluent from wastewater treatment works discharged into the Crocodile River affecting the water quality?
- To what extent has the Crocodile River been enriched with nutrients from discharged effluents?
- What mitigation measures can be employed to improve the quality of both the catchment and the effluent discharged into the River

1.4. The aims and objectives of the research

The main aim of the study was to assess the impact of the effluent from wastewater treatment plants on the quality of the Crocodile River and establish measures to improve the quality of the discharged effluent and the quality of the catchment. To achieve the aims of the research the following objectives were determined:

- To monitor the quality of the effluent in comparison with the Resource quality objectives (RQO) set for the catchment and/or with the Water Use Licence.
- Analyse historical water quality data for the catchment and establish a trend of whether the quality is improving or not.
- Determine the concentration of parameters such as Ammonia, Nitrates, Phosphate, Chemical Oxygen Demand, pH, conductivity, and *E. coli.*

1.5. Hypothesis

Poorly treated effluent from wastewater treatment plants within Mbombela and Nkomazi Local Municipality have a significant impact on the quality of water in the Crocodile River.

1.6. Delimitation

Aspects that will not be investigated in the study include:

- Assessment of the impact on the groundwater in the study area.
- Assessment of the ecological status of the river through biomonitoring.
- Assessment of the water quality on human health.

1.7. Description of the study area

Crocodile River catchment has an area of about 10500 Km^2 and is located roughly 300 km east of Johannesburg in the Mpumalanga Province. It is the largest tributary of the Komati River, which joins shortly before the border with Mozambique. Crocodile River catchment has been divided into tertiary sub-catchments namely Elands River, Upper Crocodile, Kaap River, Middle Crocodile and Lower Crocodile. Approximately 20 % (a north-eastern portion of the catchment) lies within the southern sector of the Kruger National Park. Crocodile River is a slow-flowing river with main bedrock or sandy pools, it has an average width of 45 m and a low gradient. The Lowveld area has developed rapidly, and agricultural activities have greatly increased. These developments abstract large volumes of water from the river, resulting in a decline of the flow, especially during dry seasons. Extensive reeds dominate most of the river's riparian zone. The lowest reaches of the Crocodile River are considered to have poor water quality due to agricultural runoff as well as additional mining activities and poorly treated effluent from wastewater treatment plants.

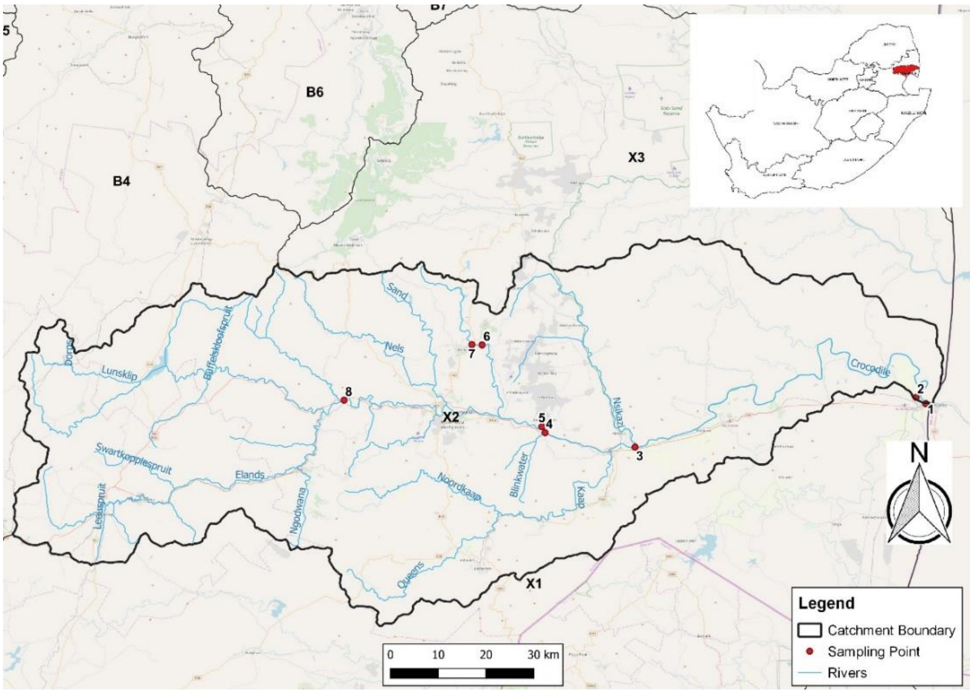

Figure 1.1 (QGIS,2020): Map of the study area with sampling points

CHAPTER TWO: LITERATURE REVIEW

2. Introduction

The quality of water is impacted by a variety of human and natural influences and is declining due to the rise of urbanization, population growth, industrial production, climate change, non-compliance of wastewater treatment plants, agricultural waste, and other factors. The subsequent water pollution poses a major threat to the well-being of both the environment and the population. Globally, around 80% of wastewater flows back into the environment either as untreated or partially treated, which poses risks to downstream ecosystems and people relying on the rivers and streams as a water source.

2.1. The legal regime governing effluent discharge in South Africa

The bill of rights enshrined in the Constitution of the Republic of South Africa outlines that everyone has the right to an environment that is not harmful to their health or wellbeing, and to have their environment protected, for the benefit of present and future generations through reasonable legislative and other measures to prevent ecological degradation (Republic of South Africa, 1996). Clean and clear water links closely with an environment that is not harmful and the need to prevent pollution (Kanamugire, 2008). Water is essential for human health and the environment, and measures must be taken to ensure that it is not polluted to an unacceptable level (Kanamugire, 2008). From this, the National Water Act (Act 36 of 1998) was promulgated deriving directly from the fundamental principles and objectives for the New South African Water Law and the National Water policy's proposal for managing water resources (Department of Water and Forestry, 2004). The act is the principal legal instrument relating to water resources management in South Africa and contains comprehensive provisions for the protection, use, development, conservation, management, and control of South Africa's water resources.

According to the National Water Act, water use is defined not only as including consumptive uses but also includes activities that pollute or have the potential to pollute or degrade a water resource (Republic of South Africa, 1998). Those activities include discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit controlled by another person authorized to undertake the purification, treatment or disposal of waste or water containing waste, subject to the approval of the person controlling the canal, sea outfall or other conduits. To exercise the above-mentioned water use activities, authorization by the relevant authority has to be granted through a Water Use License (WUL) or a General Authorisation (GA) for water use. Water Use authorization granted to a water user for the discharge of wastewater effluent unto a water resource contains stipulated conditions, guidelines, and water quality limits in which the water use activity must be exercised.

Wastewater poses a significant pollution threat to water resources and the environment hence its discharge and management must be controlled (Okoh et al., 2007). The National Water Act stipulates limits for certain parameters especially effluent disposal in catchment areas as shown in the table below of wastewater limit values applicable to the discharge of wastewater into South Africa’s water resources.

Table 2.1: Wastewater limit values applicable to the discharge of wastewater into a water source according to the National Water Act (DWAF, 1999)

Substance /Parameter	General limit	Special limit
Faecal coliforms per 100ml	1 000	0
Chemical Oxygen Demand (mg/l)	75	30
pH	55-9.5	5.5-7.5
Ammonia (ionized and un-ionized) as Nitrogen (mg/l)	3	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 to a maximum of 150 mS/m	50 mS/m above background receiving water to a maximum of 100 mS/m
Orthophosphate as phosphorus (mg/l)	10	1 (median) and 2.5 (maximum)
Fluoride (mg/l)	1	1
Soap, oil or grease (mg/l)	2.5	0
Dissolved arsenic (mg/l)	0.02	0.01
Dissolved cadmium (mg/l)	0.005	0.001
Dissolved chromium (VI) (mg/l)	0.05	0.02
Dissolved copper (mg/l)	0.01	0.002
Dissolved cyanide (mg/l)	0.02	0.01
Dissolved Iron (mg/l)	0.3	0.3
Dissolved Lead (mg/l)	0.01	0.006
Dissolved Manganese (mg/l)	0.1	0.1
Mercury and its compound (mg/l)	0.005	0.001
Dissolved Selenium (mg/l)	0.02	0.02
Dissolved Zinc (mg/l)	0.1	0.4
Boron (mg/l)	1	0.5

2.2. State of Wastewater Treatment and Sanitary infrastructure

South Africa has built a substantial wastewater management industry that comprises approximately 850 municipal wastewater treatment plants, extensive pipe networks, and pump stations, transporting, and treating wastewater daily (DWA, 2009). The municipal wastewater services business is generally considered to be far from acceptable when compared to the required national standards and international best practices (DWA, 2009). Wastewater treatment infrastructures and sanitation systems have been placed under significant pressure in South Africa due to alarming population growth and rapid urban migration. Present conventional systems were designed to cater to a given population size, however, the population is surpassing the maximum carrying capacity of the existing treatment plants (Masindi and Dunker, 2016). The operation of a wastewater treatment works beyond its design capacity compromises the treatment process thus reducing its effectiveness to remove pollutants in the wastewater. Financial provisions related to maintenance and refurbishment of sanitation infrastructure have been neglected, which is evident in continuous service delivery failures across the country today (Masindi and Dunker, 2016).

The quality of effluent discharged into the water resources mostly indicates that there are several operational problems within the treatment plants, either in a form of plant breakdown, poor or delayed maintenance, plants operating above their design capacities, and aging infrastructure which has reached its end of useful life. The government through the Department of Water and Sanitation established an incentive-based regulatory program in 2008 named Green Drop and the results of the program have demonstrated the extent of maintenance challenges in South Africa. High volumes of untreated sewage flowing into the water resource, non-functional unit processes within the treatment work, pipe leakages demonstrate a lack of planning, implementation, and management of the existing infrastructure by Water Services Authorities. This was published in a report in 2013. The report also revealed that only 50.4 % of the wastewater treatment plants scored more than 50% in 2012/13, by implication, 49,6 % (almost half or 409 WWTW) in South Africa were issued with a purple drop (indicating a score less than 30%) during 2012/13 (Ntombela et al., 2016), which states that these treatment works are performing poorly. Also, 121 WWTW were in critical risk positions and need to be put under surveillance as 'hot spots' to ensure that risk mitigation and compliance measures are 'fast-tracked and upscaled' (DWA, 2013). In April 2015 there have been at least 19 reported cases of WWTW overflowing into water bodies (Ntombela et al., 2016).

Figure 2.1A

Figure 2.1B

Figure 2.1 A & B: State of a wastewater treatment plant in Emfuleni Local Municipality, Gauteng Province (Vaal army, 2018)

2.3. **Impact of wastewater effluent on water resources quality**

Evidence of water resource quality deterioration caused by effluent discharge has been well documented since the anthropogenic impact on natural environments and especially on aquatic ecosystems is currently a topic of increasing concern. Urban wastewater treatment plant effluent as reclaimed water provides an alternative water resource especially for urban rivers; however, the effluent has the potential to influence the quality of the rivers. Singh et al., (2004) undertook a study to assess the impact of effluent and sludge from wastewater treatment plants in Jajmau, Kanpur (5 MLD), and Varanasi (80 MLD) located in India on health, agriculture and environmental quality in receiving areas. Raw, treated and mixed treated urban wastewater samples were collected from the inlet and outlet points of the two plants during peak hours (morning and evening) and non-peak hours (noon). The impact of treated wastewater pollutants (metals and pesticides) was assessed with regards to levels in different sample media such as water, soil, crops, vegetation, and food grains. Water quality data generated showed that there are elevated levels of metals and pesticides in all environmental samples including water samples from the water body which suggests that there is a serious impact on the receiving environment. The study also found that these pollutants in crops and food grains suggest that there might be adverse health impacts on communities consuming the crops.

In South Africa, water resources quality has also deteriorated drastically due to the constant disposal of industrial and domestic waste into the river (Jordaan and Bezuidhout, 2013). Salination, eutrophication, and microbiological pollution are currently the main problem affecting water quality (DWAF, 2009). Vaal River is one of the longest rivers in South Africa and it is considered the hardest working river in South Africa because of its role as a primary source of water to the economic heartland of South Africa. The river supplies water to the most important industries situated around Gauteng Province (Tempelhoff et al., 2007). Vaal River flows through areas (Vereeniging, Vanderbijlpark and Sasolburg) which are major industrial areas in South Africa (Dikio, 2010). Due to such activities taking place within the catchment, the river has been subjected to massive pollution from wastewater treatment works, runoff from mines, industrial effluents and agriculture runoff. In 2006, there were two events of pollution from sewage flowing in the Vaal River Barrage which caused significant fish deaths (Tempelhoff et al., 2007). There have been warnings from past years that pollution from wastewater treatment effluent in the Vaal River Barrage could lead to the outbreak of a water-related epidemic, similar to the typhus outbreak at Delmas in Mpumalanga in 2005.

According to a report written by Rand water (2011), Secunda Sewage Works which discharge effluent into a tributary of the Vaal River was found operating above design capacity and the discharged effluent had problems in complying with parameters such as; ammonia, conductivity, nitrate, sulphate, and Chemical Oxygen Demand. The report also outlined that Embalenhle Sewage Works which is also discharging into a tributary of Vaal River was operating above its design capacity by 2.4 ML/day, which indicated that there would be a constant overflow of raw sewage which would have a significant impact on both microbiological and physicochemical parameters of the receiving water (Rand water, 2011). According to the water quality data obtained for the discharged effluent, it was also observed that it was not compliant with the standards set for parameters such as ammonia, nitrate, chemical oxygen Demand, conductivity and alkalinity. This can be concluded that poorly treated effluent from WWTW discharged unto the Vaal River has a negative impact on the quality of the water resource hence the river is in this poor state. Below is an image showing sewage flowing into the Rietspruit River which is one of the major tributaries to the Vaal River.

Figure 2.2: Sewage flowing into the Rietspruit River which is one of the major tributaries to the Vaal River (Ndovu, 2018)

According to a Saturday Star newspaper article written by Sheree Bega (2017), the main source of pollution of the Vaal River is highly saline acid mine drainage effluent pumped into the river, and raw or partially treated sewage effluent from wastewater treatment systems of local municipalities that are often non-compliant. The article also reveals that Rand Water water quality results confirmed unacceptable levels of *E. coli* which is the main indicator of faecal pollution in Vereeniging where the Klip River joins Vaal River, *E. coli* counts of 6570 per 100 ml were measured on 1 November 2017, declining to 411 counts per ml on 8 November 2017. Emfuleni Local Municipality, which is the responsible local authority acknowledged the challenges it has with sewer spillages onto the Vaal River.

Awofolu et al., (2007) conducted a study to assess the influence of discharged effluent on the quality of Blaauwbankspruit which is used for agricultural purposes. Blaaubankspruit forms part of the Limpopo Catchment Area as demarcated by the Department of Water Affairs and Forestry. The stream turns eastwards and flows into the Crocodile River. Also, as a tributary of the Crocodile River, the spruit has a significant impact on the quality of water of the Hartebeespoort Dam which is regularly infested with blooming algae resulting in pressing environmental concern. The water resource receives effluent mostly from wastewater treatment plants and decants water from gold mines around the West Rand district. The study revealed that there is a high concentration of metals in water and sediment samples specifically Lead and Cadmium. High values of determinants obtained from sampling points close to the wastewater treatment plant and mine exit channels strongly reveal their influence on the quality of the stream. The detection of toxic metals such as Cd and Pb above stipulated limits for water intended for irrigational purposes gave cause for concern because ruminants that feed on grasslands irrigated with this water might be at risk of bioaccumulation. Table 2.2 gives an overview of the water quality situation of South Africa's water resources and the main contributors to their pollution.

Table 2.2: An assessment of the overall water quality situation in various provinces in South Africa (Ashton, 2009)

Province	River System	Impact detected/described	Source of pollution
Eastern Cape	Mthatha area	-Rivers contain large numbers of pathogenic organisms and high concentrations of nutrients, salts and endocrine-disrupting compounds (EDCs)	Treated, partially treated and untreated urban and industrial effluent
	Buffalo River system	-Elevated concentrations of dissolved salts and metal ions in the lower reaches of the river -Large numbers of pathogenic organisms; high concentrations of nutrients, salts, and EDCs -Frequent toxic blooms of cyanobacteria Microcystis aeruginosa in the major downstream reservoirs	-Saline effluents discharged from tanneries -Discharges of treated, partially treated and untreated urban and industrial effluent
Kwazulu Natal	Umngeni River system	-Elevated concentrations of pesticides and nutrients -Large numbers of pathogenic organisms and high concentrations of nutrients, salts, and EDCs	-Return flows and seepage from agricultural lands -Contaminated runoff from urban centres and informal settlements, combined with discharges of treated, partially treated and untreated urban and industrial effluent
	Thukela River system	-Large numbers of pathogenic organisms and high concentrations of nutrients, salts, and EDCs -Elevated concentrations of pesticides and nutrients reaching the river -Lowered pH values and elevated concentrations of total dissolved salts, especially sulphate.	-Discharges of treated, partially treated and untreated urban and industrial effluent, contaminated runoff from urban centres and informal settlements -Return flows and seepage from agricultural lands (principally livestock ranching, dairy farming, cultivation of crops, sugar cane) and forestry -Operating and defunct coal mines contribute large volumes of acid mine drainage (AMD) to the river system

Free State	Caledon and Modder river systems	-Large numbers of pathogenic organisms, high concentrations of nutrients and salts and moderately high concentration of EDCs -Periodic blooms of toxic cyanobacteria Microcystis aeruginosa have been recorded from the Krugerdrift Dam	-Discharges of treated, partially treated and untreated urban effluent, as well as contaminated runoff from urban centres and informal settlements -Return flows and seepage from agricultural lands result in elevated concentrations of pesticides and nutrients reaching the rivers
Gauteng/ North West / Free state	Vaal River System	-Lowered pH values and elevated concentrations of metal ions and total dissolved salts, dominated by sulphate, as well as relatively high levels of radioactivity in certain tributary rivers -Large numbers of pathogenic organisms and high concentrations of nutrients and salts, as well as low to moderately high concentrations of EDCs -Blooms of toxic cyanobacteria (Microcystis aeruginosa)	-Numerous active and defunct gold and uranium mines in the Witwatersrand complex contribute large volumes of AMD -Discharges of urban and industrial effluents, as well as contaminated runoff from larger cities, smaller urban centres and informal settlements
Mpumalanga / Limpopo	Eastern River systems; upper Olifants River system	-Lowered pH values (sometimes to <3.0) and elevated concentrations of metal ions (especially aluminium, iron, cadmium, zinc and cobalt) and total dissolved salts, dominated by sulphate v -Large quantities of inorganic and organic compounds in the Olifants River -Large numbers of pathogenic organisms and high concentrations of nutrients, salts and low to moderate concentrations of EDCs	-Operating and defunct coal mines contribute large volumes of AMD -Heavy industries in the Witbank and Middelburg area (mainly iron and steel works) -Discharges of urban and industrial effluents, as well as contaminated runoff from larger towns, smaller urban centres and informal settlements (many lacking proper and/or functioning sanitation systems)
North West	Crocodile (West) River system	-Large numbers of pathogenic organisms and high concentrations of nutrients, salts and low to moderately high concentrations of EDCs (all these substances pose health risks to humans and livestock that may consume the water)	-Discharges of large volumes of treated, partially treated and untreated urban effluent, especially from the northern areas of the Witwatersrand, as well as contaminated runoff from urban centres and informal settlements
Western Caper	Cape Town urban rivers	-Receiving urban rivers contain large numbers of pathogenic organisms and high concentrations of metal ions, nutrients, salts and EDCs	-Contaminated runoff from urban areas and informal settlements: discharges of treated, partially treated and untreated domestic and industrial effluent

Rapid population growth in urban areas puts pressure on the existing wastewater treatment plants, leading to improper treatment of sewage which ultimately flows into a water resource deteriorating the ecological integrity and the quality of the receiving water body. Seanego and Moyo, (2013) conducted a study to assess the effect of sewage effluent on the physicochemical and biological characteristics of the Sand river situated in Limpopo, South Africa. Polokwane Wastewater treatment works (WWTW) discharges effluent into the Sand River and the river is used extensively by farmers downstream for irrigation. Polokwane is generally a water-scarce area and to conserve water, artificial recharge of the local Polokwane aquifer using treated effluent is practiced. Sand River sub-catchment is a major tributary of the Sabie River catchment and is a right-hand tributary of the Limpopo River (Seanego and Moyo, 2013). The city of Polokwane has situated 200 km up the stream of its mouth was Polokwane Pasveer Activated Sludge WWTW discharges its effluent into the Sand River and Seshego WWTW discharges into the Blood River which is a tributary of Sand River. Eight sampling sites were established whereby two of the sites were situated upstream of the Polokwane Pasveer WWTW, and the remaining six sites are situated downstream of the wastewater treatment plant.

Total phosphorus and total nitrogen at each of the sampling sites were determined using colourimetric methods adapted from APHA (1995). Temperature, salinity pH, and dissolved oxygen from each sampling site were measured monthly using a YSI meter. Suspended solids, *E. coli,* chemical oxygen Demand (COD) of the samples were determined according to Standard Methods procedures (APHA, 1989). Nitrite and ammonia were also analysed according to the Standard Methods procedures using an ammonia selective electrode (APHA, 1989). Coliform counts were determined using the Membrane Filtration Method (WHO, 1996), total coliform, faecal coliforms, and faecal streptococcus coliforms were isolated using M-Endo, m-FC, and K-F agar respectively. The results revealed that suspended solids, ammonia, chemical oxygen Demand, and *E. coli* in the Polokwane WWTW maturation ponds were above the license limits. Analysis of variance also indicated that there are no significant differences for temperature, conductivity, salinity, pH, oxygen, and flow rate between the upstream and downstream sites. There was however significant difference in phosphorus and nitrogen at the sites downstream due to effluent discharge. The study indicated that, due to increased urbanization, Polokwane WWTW is discharging effluent of compromised quality. High coliform levels also pose a potential threat to the downstream water users and also compromise the quality of the artificially recharged aquifer

2.4. International impact of wastewater effluent on water quality

In Nigeria, many abattoirs discharge their effluents directly into the streams and rivers without prior treatment. A study was conducted by Osibanjo and Adie, (2007) to assess the impact of effluent from Bodija abattoir on the quality of the Oshunkaye stream, Nigeria. The qualities of the effluent and stream water (before and after mixing with the effluent) were studied using basic water quality parameters. Five effluent samples were collected to depict different activities within the abattoir while two samples were collected upstream and downstream of the Oshunkaye stream into which the abattoir effluent is discharged. Parameters that were determined include pH, temperature, total solids, total suspended solids, chemical oxygen Demand, oil and grease, nitrates, phosphates, chloride, lead, cadmium, nickel, copper, and zinc according to the Standard Methods of Examination of Water and effluent, 20^{th} edition of 1998. The study revealed that there is pollution generated by Bodija Abattoir effluent which is deteriorating the quality of the water resource. The physiochemical parameters showed the negative impact of the abattoir effluent onto the stream thus rendering the water not suitable for domestic, agricultural, or industrial use.

Ngwira and Lakudzala (2018) conducted a study to assess the quality of industrial effluent from a soft drink manufacturer in Lilongwe, Malawi to determine the impact of pollution in the Nankhaka River. Both affluent and river water samples from the different locations were analysed for pH, suspended solids, total dissolved solids, phosphate, nitrates, chemical oxygen Demand, biochemical oxygen Demand, and faecal coliform using standard methods. It was observed that the parameters analysed from effluent samples were non-compliant to the Malawi Standard recommended for effluents discharged into the inland waters. The study suggests that effluent from the industry pollutes water in the river rendering it unfit for human consumption and has an impact on the aquatic ecosystem.

Awofolu et al., (2007) conducted a study to assess the influence of discharged effluent on the quality of Blaauwbankspruit which is used for agricultural purposes. The water resources effluent from wastewater treatment plants and decants water from gold mines around the West Rand district. Water and sediment samples were collected at four different sampling sites. The study revealed that there is a high concentration of metals in water and sediment samples. High values of determinants obtained from sampling points close to the wastewater treatment plant and mine exit channels strongly reveal their influence on the quality of the stream.

A study was conducted by Wang et al., (2017) to investigate and predict percentages and trends of effluent discharge throughout the Yangtze River (China) watershed to understand the relative contribution of wastewater discharges into the river and its tributaries towards preventing water scarcity concerns. The study established that there is a strong interdependence between dense urban population, water Demand, industrial output, and wastewater discharges that impact downstream communities. The dense population and associated high water Demand in the Han River Basin led to potential stresses on the amount and quality of water in the river. Since the contribution of wastewater effluent and associated pollutants pose health issues and water quality degradation, it would be cost-effective to improve the quality of the effluent at the local wastewater treatment plants before discharge into the river. Chemical pollutants and pathogens in the wastewater are not only diluted when discharged in the river, but some undergo transformations, absorb and accumulate in sediments or be inactivated, thus the predictions of the study identified regions of the Yangtze River at potential risks for impacts to both aquatic organisms in the river and drinking water quality at a downstream location.

Medeiros *et al.*, (2017) conducted a study to assess the water quality of the Murucupi River located in an urban area in Brazil. The study was motivated by intense industrial activity in Barcarena City, Brazil. Arapiranga River in Abaetetuba City was used as a control or as a benchmark, water quality was assessed using a Water Quality Index (WQI) based on nine variables that were analysed (Temperature, pH, total dissolved solids, total suspended solids, dissolved oxygen, BOD, thermotolerant coliforms, total nitrogen, total phosphorus, and turbidity). The quality of the river is mostly influenced by anthropogenic activities taking place, such as the discharge of effluents from urban wastewater treatment works and also industrial waste tailings upstream of the river. The study showed that due to its less inhabited environment and further away from the urban area and the industries, Arapiranga River was more preserved. The study also revealed that Murucupi River was more affected by anthropogenic activities. It was also highlighted that there is an increasing need to generate information relating to water quality in the Amazon Region in which the above-mentioned rivers drain into because the riverside population uses untreated water. A study to investigate the impact of wastewater effluent containing pharmaceutically active compounds (PhACs) was conducted by Mandaric et al., (2019) in small, rural and effluent-dominated tributaries of the lower Ebro River located in North-Eastern Spain (Catalonia). Pharmaceutically active compound represents a group of emerging environmental contaminants whereby treated and untreated (raw) wastewater discharges are the main route of the entrance. Continuous release of PhACs into the aquatic environment may cause unexpected and unwanted effects on the living organisms. Eleven sampling sites where established situated on a series of small to medium-sized tributaries of the lower Ebro River Basin.

This system shows a typical Mediterranean international variation and seasonal flow reductions in summer and floods in spring and autumn. These sampling sites were defined with a control (upstream) and impact (downstream) reaches of the wastewater discharge. Three sites received treated wastewater effluent from nearby wastewater treatment plants while the other eight were impacted by discharge of raw (untreated) wastewater. Pharmaceutically Active Compounds analysis in water was conducted using an offline solid-phase extraction (SPE) followed by ultra-high-performance liquid chromatography coupled to triple quadrupole linear ion trap tandem mass spectrometry (UHPLC-QqLIT-MS/MS). The results reveal that in all samples collected, 60 different PhACs out of 68 monitored were detected. Non-steroidal anti-inflammatory drugs were the most present, together with psychiatric drugs, lipid regulators, and antibiotics. PhACs concentration in treated wastewater was 12 times less compared to untreated wastewater. The results also showed that concentration levels of detected PhACS were generally low on control sites except in the Sec River where relatively high concentrations could be related to the discharges from a town 2 km upstream. The occurrence of PhACs in the Mediterranean aquatic ecosystems is associated with the seasonal variation of the streamflow (flow reduction in summer and floods in spring and autumn), while in the case of the medium-sized tributaries of the lower Ebro River results showed evidence of the strong urban impact on the river quality.

Chen et al., (2009) conducted a study on the evaluation of the impact of treated discharges with a specific focus on the fate of organic matter and disinfection by-product precursors on the downstream water quality in an effluent-dominated stream in the southwest of the USA. Wastewater treatment plant effluent discharge is also a source of contamination such as disinfection by-products (when chlorine disinfection is used). These disinfection by-products (DBPs) occur when chlorine oxidizes amino acids resulting in the formation of aldehydes and nitrites, with subsequent or concomitant chlorine substitution to form chloral hydrate (trichloroacetaldehyde) and dichloroacetonitrile (C_2HCl_2N), respectively (Trehy et al., 1986). These disinfection by-products can pose risk to aquatic organisms and also impact the health of consumers drinking water from treatment plants located downstream. Samples were collected in 10 established sampling sites with the Santa Crus River (Arizona) in June 2004 and February 2005.   During the sampling periods, there was no river flow above the point of discharge at the Nogales International Wastewater Treatment Plant.

Thus, the research was conducted on a 100 percent effluent-dominated stream. Samples were analysed for parameters such as Carbonaceous Biochemical Oxygen Demand (CBOD), chemical oxygen Demand (COD), Total Kjeldahl Nitrogen (TKN), turbidity, electrical conductivity, ammonia, nitrite, and nitrate. Overall, the results for conductivity, chloride, phosphate, and primidone were consistent and reinforced the assumption that no dilution from other unknown surface waters was occurring along the reach. Ammonia, nitrite, and nitrate concentrations have significantly changed along the length of the river. Instream ammonia was oxidized to nitrate and ultimately to nitrate. Dissolved oxygen concentrations over the reach decreased from 4 to 2-3 mg\L. Nogales WWTP discharged organic matter that was biodegradable in the stream and in the biodegradable dissolved organic carbon (BDOC) reactor which underwent some nitrification. Urban rivers are always influenced by the anthropogenic activities taking place around the area coupled with biodiversity decrease due to land clearing, decreasing habitat heterogeneity which causes the decrease of the river system’s self-purification ability. Polycyclic aromatic hydrocarbons (PAHs) are a type of pollutants founds in water relevant to the anthropogenic activities in industrialization which reflects the urbanization process.

A study was conducted by Qiao et al., (2018) to assess the impact of secondary effluent from wastewater treatment plants on urban rivers in Beijing, China with a specific focus on pollutants such as aromatic hydrocarbons and derivatives. Urban rivers in Beijing are special because they are all artificial rivers originating from the city with the water source being mainly reclaimed water in recent years (Qiao et al., 2018). Because the construction of the wastewater treatment plants lags behind the increasing urban population, some untreated wastewater might also be discharged into the rivers. In the study, five urban rivers directly receiving effluent from five major wastewater treatment plants in Beijing were selected to investigate pollution levels of polycyclic aromatic carbons in the urban rivers, to identify the impact of wastewater treatment plant effluent on the corresponding river, and to find effective ways to reduce these pollutants from the rivers. Samples were collected from two sites upstream of the WWTP effluent discharge, two sites downstream of the WWTP effluent discharge, and the WWTP effluent in the river. The distance between the two neighbouring sites was 200 m. Samples were collected in April and November in 2015, representing no heating season and heating season respectively, a total number of 50 samples were collected. Samples were analysed for Methyl Polycyclic Aromatic Hydrocarbons, Oxygenated Polycyclic Aromatic Hydrocarbons, and Chlorinated Polycyclic Aromatic Hydrocarbons. Chemical Oxygen Demand (COD) and Total Organic Carbon were also analysed representing the total organic matter in the water. Nutrients including Phosphorus and Nitrogen were also analysed. The results indicated the existence of PAHs in urban rivers. It was also noted that there were variations with regards to the concentration's PAHs and its derivatives between no heating season (April) and heating season (November). This may be caused by the decommissioning of half of the major coal-fired power stations in Beijing in 2015.

Yu et al., (2019) conducted a study to assess the influence of municipal wastewater effluent on dissolved organic matter quality and microbial community composition on Xiaohe River, which is an urbanized stream located in Hebei Province, Northern China. Xiahe River is approximately 86 Km long and it originates from the Wufengshan, receiving sewage effluent as its major water source. The river ultimately flows into the Fyang River where it merges with Hai River making it the biggest basin in Northern China (Yu et al., 20190. There are four wastewater treatment plants namely Qiaodong, Qiaoxi, Douyu and Zhaoxiam wastewater treatment plants discharging tailing water into the Xiaohe River. Ten sampling sites were established along the main rivers of the Xiaohe River, and three parallel samples were taken from each sampling site. Sampling site S1 was located downstream of Qiaodong WWTP, sampling site S2 was downstream of the Qiaoxi WWTP, sampling site S3 was downstream of Douyu WWTP and sampling S8 was downstream of Zhaoxian WWTP. Ammonia nitrogen was determined by Nessler's reagent method; nitrate ammonia was determined by phenol disulfonic acid spectrophotometry, nitrite nitrogen was determined by ion chromatography (ICS-2000, Dionex USA), and total nitrogen was digested by alkaline potassium persulfate and measured by ultraviolet spectrophotometry. Chemical Oxygen Demand was determined by titration with potassium dichromate and total phosphorus was determined by ammonium molybdate spectrophotometry. The results of the study show that in general, total nitrogen was observed to be high and total phosphorus was relatively low. It is worth noting that sections with heavy pollution indexes (COD and nitrogen species) were downstream of the sewage effluent outflow. Results also indicate that wastewater treatment plant effluent has a great influence on the quality of the receiving water resource because it exerts significant effects on receiving water dissolved organic quantity and quality, and then influences the microbial communities' structure and function.

2.5. Impact of discharged effluent on the aquatic ecosystem

Ecotoxicology incorporates ecology into the studies of the injurious effects of stressors such as chemicals on living organisms by assessing the impact of stressors not only on individual organisms but also populations and the whole ecosystem (Weperner and Chapman, 2012). Some effects of wastewater discharge into aquatic bodies cut across the whole spectrum of the biological organization while others are felt at molecular, individual, species, or population levels (Sibanda et al., 2015). Habitat destruction through sedimentation and debris deposition is one of the examples of the effect that is felt at the ecosystem level (Sibanda et al., 2015).

Effluent discharge has the potential to significantly alter many different aspects of the aquatic systems including nutrient uptake efficiency, organic carbon content, bacterial levels, and hydrologic characteristics (Carey and Migliaccio, 2009). One characteristic of wastewater treatment plant effluent that often impacts receiving water is its nutrient content (Carey and Migliaccio, 2009). Domestic wastewater generally consists of high concentrations of nitrogen in either organic or inorganic form. Organic fraction coexists with the dissolved inorganic nitrogen (nitrate, nitrite, and ammonium) and the gaseous forms (N_2 and NxOy).

The transformations among the different pools of nitrogen in the wastewater and aquatic ecosystems are mainly mediated by biological processes. However, abiotic processes and ambient conditions concur to regulate nitrogen cycling, because they influence the activity and abundance of living organisms and the structure of their communities. Bacterial activity and hydrolysis convert organically bound nitrogen such as urea and protein to ammonia and ammonium nitrogen (Sperling, 2007). Both inorganic and organic nitrogen in the aquatic environments exists in continuous size distribution, from dissolved organic compounds to macro heterotrophs.

An excessive amount of nitrogen particularly nitrate has a significant impact on the quality of water and the health of an aquatic ecosystem. Nitrogen, one of the critical limiting nutrient for plants and cyanobacteria and one of concern for the eutrophication of fresh water systems. Excessive growth algae in response to nutrient increases on the water body can result in a bloom of single or multiple species depending on variables such as pH, temperature, dissolved oxygen which has some negative impacts on the aquatic ecosystem. Such occurrence is called algal bloom and variously encompass red tides, brown tides, and toxic and noxious blooms (Rabalais, 2002). Toxic forms such as cyanobacteria can have a serious direct impact on a variety of life forms such as invertebrates, vertebrates and cause hypoxia, foul odour, tainted fish products and also depletes dissolved oxygen in water resource. In rivers receiving nutrient inputs from wastewater, ammonia nitrogen can directly affect dissolved oxygen concentration(Carey and Migliaccio, 2009) and wastewater discharges to receiving water characterized by alkaline pH values could exacerbate ammonia nitrogen toxicity and threaten the viability of various fish species (Carey and Migliaccio, 2009).

Phosphorus is an essential nutrient for plant growth in fresh water systems and is often a limiting nutrient in water bodies. Since it is a limiting nutrient to fresh water systems, its input can cause the proliferation of algae. It has been found as the main contributor to eutrophication in freshwater systems. The high concentration of orthophosphate causes blooms of blue-green algae (Kirke, 2001). Major sources of total phosphorus are sewage treatment plant effluent, agriculture, urban development, and industrial effluents. Orthophosphate is a measure of the inorganic oxidized form of soluble phosphorus. This form of phosphorus is readily available for algal uptake during photosynthesis and energy production.

. Just like nitrogen, an excessive amount of phosphorus on a water resource has a negative impact since it also stimulates excessive growth of algae and certain alien aquatic plants. Depending on the assimilative capacity of a water body, the algal population can reach very high values which cause a series of problems such as the depletion of dissolved oxygen in water, mortality of aquatic lifeforms, bad odour especially in lakes and reservoirs. Anaerobic conditions in the bottom of a lake or a dam may occur due to the rise in heterotrophic bacteria, which feed on organic matter from algae and other dead organisms, consuming dissolved oxygen in the water.

Wastewater consists of pathogenic bacteria and viruses which have a detrimental impact on both human health and the health of an aquatic ecosystem. Coliform bacteria such as *E. coli* are mostly used as indicator organisms of the presence of pathogenic bacteria in water. The detection, isolation, and identification of different types of microbial pollutants in wastewater are always difficult, expensive, and time-consuming hence indicator organisms are always used to determine the relative risk of the possible presence of a particular pathogen in wastewater (Sperling, 2007). A water body receiving treated effluent from wastewater treatment works may incorporate into itself a wide range of pathogenic microorganisms. This may not generate a direct impact on the aquatic organisms themselves but may affect some of the prevailing uses of water resources such as potable water supply, irrigation, and bathing (Sperling, 2007).

Bacteria and other organisms in freshwater such as lakes and rivers utilize oxygen to metabolize the sewage they accompany. While breaking down biodegradable solids in the wastewater, these microorganisms can cause hypoxic (oxygen-depleted) dead zones. These dead zones lack sufficient oxygen needed by aquatic lifeforms such as fish to survive.
Ecological impacts of wastewater treatment plant effluents on the river ecosystem are of great concern however it is difficult to assess these effects as most rivers and streams receiving wastewater treatment effluents are also affected by other stressors. Pereda et al. (2019) conducted a study whereby a whole-system manipulation experiment following a Before-After/Control-impact design to assess the impact of wastewater treatment plant effluent on a stream. Exclusion of the influence of other potentially confounding factors was done by diverting part of the effluent of Apraitz wastewater treatment plant into a small, unpolluted stream and studies its effect on the ecosystem structure and functioning for over two years (i.e. one year before and one year after the effluent diversion). Apraitz wastewater treatment plant consists of a sequential biological reactor that treats wastewater of a population that is greater than 90 000 derived from urban and industrial sources. the resulting effluent is released into the Depa River with a mean discharge flow of 10.9 m3/s. Ten meters downstream from the WWTP effluent release point, the Depa River receives the water of the Apraitz Stream, a small unpolluted stream draining a 7 km^2 catchment over sandstone and shale with a mean discharge of 0.12 m3/s. To conduct the study, two 100 m long reaches in the Apraitz stream were defined: a control (upstream) and an impact (downstream). Both reaches were studied every month for 2 years (04/04/2016 to 30/06/2018), one year before and another year after diverting part of the WWTP effluent to the impact reach.

Physiochemical parameters of the water were analysed at the downstream and end of both reaches and directly at the effluent outflow during periods of effluent release. The pH, temperature, electrical conductivity and dissolved oxygen saturation were measured using handheld probes (WTW multi 350 and WTW 340i SET, WTW Wissenschaftlich, Weilheim, Germany, YSI ProODO handled; YSI Incorporated, Yellow Springs, OH, USA). Samples were collected and immediately filtered by 0.7 µm pre combusted Whatman glass fiber filters.

The concentration of soluble reactive phosphorus was determined using the molybdate method, ammonium was determined using the salicylate method on a spectrophotometer.

Concentrations of nitrate, nitrite, chloride, and sulphate were determined using capillary ion electrophoresis. The concentration of inorganic nitrogen was calculated as the sum of nitrate, nitrite, and ammonium concentration. Dissolved organic carbon and total dissolved nitrogen were measured by catalytic oxidation. Additionally, the concentration of the main groups of emergent pollutants was measured including herbicides, hormones, lifestyle products, industrial chemicals, and pharmaceuticals during the first month after diversion. The results showed that the effluent was 3 °C warmer than the stream water, with electrical conductivity three times higher than the stream, dissolved oxygen concentration two times lower, nutrients (phosphorus, nitrogen) and dissolved organic carbon with concentrations of 4 and 90 times higher than the stream respectively. Additionally, the effluent also showed a high concentration of emergent pollutants mostly pharmaceutical products used to treat hypertension. The study shows that even well treated and highly diluted wastewater treatment plant effluents can cause significant effects on the ecosystem structure, quality, and function of a water resource. Despite high dilution, the intermittent effluent diverted to Apraitz Stream significantly affected water characteristics during release periods, reducing pH and dissolved oxygen while increasing electrical conductivity and concentrations of nutrients and emergent pollutants. Similar effects of effluent inputs on stream water quality have been reported in other water resources systems (Marti et al., 2009). Dissolved organic matter from wastewater treatment plants poses a threat to the receiving water bodies and their microbial community.

Hartbeespoort Dam is one of the most important dams in South Africa due to the magnitude of activities the dam support. Water from Hartbeespoort Dam is mainly used for domestic consumption (12%) and irrigation (82%) with 6 % released ecological requirements (Botha, 2015). The dam was constructed between 1921 and 1923 for storage of water draining from a catchment of approximately 4120 square kilometres in areal extent, mainly providing water to large government irrigation schemes situated in Brits (Botha, 2015). The dam is located downstream of Gauteng Province, South Africa's economic hub, and for this reason, the dam has become highly eutrophic (Mitchell and Crafford, 2016). The dam is situated downstream of the largest wastewater treatment plants in Johannesburg (Rimayi et al., 2018), thus contaminating the receiving streams and ultimately contaminating the Hartbeespoort dam with poorly treated effluent. The water quality of the Hartbeespoort Dam has been a concern since the 1950s, and it was referred to as a maturation pond, implying that the dam could be perceived as a large waste stabilization pond to conclude wastewater treatment started in the upstream sewage plants (Botha, 2015). Several scientific reports have concluded that phosphorus and nitrogen originating from wastewater treatment plants in the catchment were the main nutrients involved in the eutrophication of the dam, with phosphorus the main cause of eutrophication in fresh water (Botha, 2015). The image in Figure 2.3 shows excessive growth of the hyacinth due to nutrient enrichment at Hartbeespoort Dam.

Figure 2.3: Excessive growth of water hyacinth at Hartbeespoort dam (The Citizen, 2018)

CHAPTER THREE: METHODOLOGY

3. Introduction

This chapter describes the research design and methodology selected for the study in Crocodile River within Ehlanzeni District. It further shows every step, in detail, that was taken in collecting the data. The chapter presents the methods adopted in this research, research procedures and data collection techniques utilized, and the type of research practices used to answer the study's research objectives. It also outlines sample times, sampling procedure and parameters, sample points, and the plan for data analysis.

3.2 Materials and methods

All equipment, chemicals/reagents, and facilities for the analysis of samples were readily available at a laboratory accredited in terms of the South African National Accreditation System (SANAS), which is utilized by the Inkomati Usuthu Catchment Management Agency (IUCMA).

3.2.1 Sample collection

The sampling was conducted on Six Sampling Site located in the study area within Mbombela Local Municipality and Nkomazi Local Municipality, which included three wastewater treatment plants discharging effluent into the Crocodile River, the sampling points were as follows:

Table 3.1: Sampling sites with co ordinates

Sampling sites	Co ordinates
White River WWTW (Site 1)	S -25.31591 ; E31.04669
White river – Crocodile River (Site 2)	S -25.31522 ; E31.02539
Kanyamazane WWTW (Site 3)	S -25.48649 ; E31.17166
Kanyamane N4 Bridge (Site 4)	S-25.49912 ; E31.17834
Matsulu WWTW (Site 5)	S-25.52907 ; E31.36631
Downstream Komatipoort WWTW (Site 6)	S -25.42271 ; E31.93726

Samples were collected monthly over a period of 36 months (Jan 2017 – Dec 2019). All the necessary samples about the research were collected at the respective plants where effluent is discharged into the river, downstream of the discharge points and at the confluence of tributaries. The samples were collected in sterilized containers at the specified points and were being stored in a cooler box at 4°C and transported to the laboratory for analysis. All glassware and plastic materials used were treated for 24 hr in 2 M nitric acid and 2 M hydrochloric acid solutions, be rinsed with deionized water. Each bottle will be labelled with a unique identity (numbers). This procedure was conducted at each sample location to avoid contamination of samples.

3.2.2 Water Quality analysis

Onsite analysis of parameters

Parameters such as water temperature (°C), pH, electrical conductivity (EC, µs/cm), and dissolved oxygen (DO, mg/L) were analysed onsite using a portable meter Hach multi-probe meter Model HQ40d which was calibrated before use. All the onsite measurement data were recorded on prepared sheets.

Laboratory analysis of parameters

The parameters such as ammonia, nitrite-nitrate, phosphate, chemical oxygen demand, total suspended solids (TSS), *E. coli* were analysed at a laboratory accredited by the South African National Accreditation System (SANAS) as per standard methods by American Public Health Association (APHA, 2012)

Phosphate:

Phosphate in the water samples was analysed using the Hach Ascorbic acid method 10209. Reagents such as sulphuric acid, ammonium molybdate solution, ascorbic acid were used during the determination of phosphate. The determination of phosphate using the ascorbic method is a colorimetric method hence a spectrophotometer with infrared phototube at 880 nm was used.

Ammonia:

Ammonia was determined using a Hach Nessler method. Reagents such as methyl orange indicator, boric acid, Polyvinyl Alcohol Dispersing agent, Nessler Reagent were used. Preliminary distillation of the sample was undertaken before analysis. spectrophotometer at wavelength 425 nm will be used.

Nitrate:

The nitrate concentration of the water samples was determined using the Cadmium Reduction method as described in the Hach Water analysis handbook. Reagents such as copper cadmium, ammonium chloride, EDTA, Hydrochloric acid, copper sulphate solution were used in the determination of nitrate. A spectrophotometer at the wavelength of 543 nm was used since it is a colorimetric method.

Chemical oxygen Demand:

Analysis of Chemical Oxygen Demand was conducted using Potassium Dichromate as an oxidizing agent. The sample was digested in which the dichromate oxidises COD material in the sample. Reagents such as potassium dichromate, Sulphuric acid, Potassium hydrogen phthalate were used spectrophotometer was used to analyse the sample at wavelength 610 nm.

Total suspended solids:

Total suspended solids were analysed using Hach gravimetric method 8158. A glass fiber filter disc was used as a filter in a filtering flask. Deionized water was pulled with a vacuum through the filter. The fibre filter disc was dried to a constant weight in an oven at 102-105 °C (217–221 °F) to determine the weight of the empty disc. A well-mixed filtered sample was dried in the same fibre filter disc to a constant weight in an oven at 102-105 °C (217–221 °F). The weight difference between the empty disc and the disc with the remaining materials showed the Total Suspended Solids.

Microbial analysis:

Escherichia coli

Escherichia coli was determined using Hach USEPA membrane filtration method 8367 m-TEC Agar. The m-TEC method detects *E. coli* in recreational freshwater samples with a two-step process. First, membrane filters were incubated on m-TEC Agar for 2 hours at 35 °C to resuscitate injured organisms. The thermos tolerant organisms were then selected by fermentation of lactose at an elevated temperature of 44.5 °C. The second step uses a substrate medium containing urea to distinguish urease-negative *E. coli* from other thermotolerant coliforms that hydrolyse urea. Yellow or yellow-brown urease-negative colonies are positive for *E. coli.*

3.2.3 Statistical analysis

The results presented in the regression analysis and correlation are the averages of the three years (2017 - 2019) water quality data at different sampling sites for water samples. The IBM SPSS statistic version 26 package was used for statistical analysis. Regression analysis and Pearson's correlation at a 5 % significance level was used to establish the relationship between concentrations of analysed parameters over time. The study further analysed the relationship between the analysed parameters in different sampling sites.

3.2.4 Water quality index calculation

The water quality index was used to establish the quality of the water resource and its suitability in supporting aquatic life, social and economic development. Water quality parameters analysed for three different sampling sites (Site 2, Site 4 and Site 6) were used to calculate the water quality index. These water quality parameters are transformed to a scale of 1 - 100 through mathematical equations and assigned a weight based on their apparent effect on river health and ecosystem. Based on the water quality index, water quality will be classified into five grades: Good quality water (1 - 25), acceptable water quality (26 - 50), regular water quality (51 - 75), poor water quality (76 - 100) and very poor water quality (> 100) (Madalina and Gabriela, 2014; Tian et al, 2019). The water quality index was calculated using the equation below.

1. Calculation of the unit weight (Wn) factors for each parameter by using the formula:

$$\mathrm{Wn} = \frac{\mathrm{K}}{\mathrm{Sn}}$$

Where

$$\mathrm{K} = \frac{1}{{}^{1}/_{\mathrm{S1}} + {}^{1}/_{\mathrm{S2}} + {}^{1}/_{\mathrm{S3}} + \dots + {}^{1}/_{\mathrm{Sn}}} = \frac{1}{\Sigma \frac{1}{\mathrm{Sn}}}$$

Sn = Standard desirable value of the $\mathrm{n^{th}}$ parameters

On summation of all selected parameters unit weight factors, $Wn = 1$ (Unity)

2. Calculation of the Sub-index ($Qn = \frac{[(Vn-V0)]}{[(Sn-V0)]}\ x\ 100$

Where

Vn = mean concentrations of the $\mathrm{n^{th}}$ parameters

Sn = Standard desirable value of the $\mathrm{n^{th}}$ parameters

Vo = Actual values of the parameters in pure water (generally Vo=0 , for most parameters except for pH

$$\mathrm{QpH} = \frac{\mathrm{K[\ (\ vpH\ \text{-}7)\}}}{\mathrm{[(8.5\text{-}7)]}}\ \mathrm{x\ 100}$$

3. Combining Step 1 & step 2, WQI is calculated as follows :

$$\text{overall WQI} = \frac{\sum \text{WnQn}}{\sum \text{Wn}}$$

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This chapter discusses the results which were obtained during the research. The results were obtained by following the method and procedure which are stated in chapter three, which were guided by the objectives of this study. The study deployed various statistical analyses to interpret the results following the main aim and the objectives.

4.2 The compliance status of the water quality to the resource quality objectives (RQO) and the Water Use Licence Limit

The tables below depict the relevant limits of water quality as reported by the Department of Water Affairs.

Table 4.1: Resource Quality Objectives (RQO) set for the Crocodile River Water (DWS, 2016)

Constituents	Limits
Electrical conductivity (ms/m)	70
Nitrite and Nitrates (mg/l)	6
Phosphate (mg/l)	0.125
Ammonia-N (mg/l)	6
***E- coli* (count per ml)**	130
pH	6.5-8.5

4.2.1 Whiteriver WWTW (Site 1)

Table 4.2: Effluent Quality Limits as per Whiteriver WWTW Water Use Licence (DWA, 2009)

Constituents	Limits
Electrical conductivity (ms/m)	75
Nitrite and Nitrates (mg/l)	15
Phosphate (mg/l)	1
Ammonia-N (mg/l)	1
Chemical Oxygen Demand (COD) (mg/l)	75
***E- coli* (count per ml)**	0
Suspended Solids (mg/l)	25
pH	5.5-9.5

Table 4.3: Table showing water quality data for the 2017 wet and dry season at Site 1

2017 WET SEASON WATER QUALITY DATA								
MONTHS	pH	COD (mg/l)	NO2 + NO_3^- (mg/l)	NH3 (mg/l)	PO4 (mg/l)	*E.coli*	Suspended Solids (mg/l)	Electrical Conductivity (ms/m)
January	7.40	66	1.53	11.40	2.17	0	14.4	56.5

February	7.00	602	1.27	5.70	3.59	184200	221	58.2
March	7.18	76	1.65	20.70	4.13	0	19.2	61.7
October	7.52	47	4.46	0.20	0.13	0	6.8	45.8
November	6.95	80	0.33	12.30	1.80	0	27.2	51.4
December	7.66	55	0.11	11.10	1.99	0	17.2	48.9
Mean	**7.3**	**154.3**	**1.55**	**10.2**	**2.30**	**30700**	**51.0**	**63.2**
2017 DRY SEASON WATER QUALITY DATA								
April	7.30	88	0.96	21.70	4.47	282800	71.2	63.4
May	8.11	47	0.39	15.20	5.85	484000	6	64.3
June	7.24	38	4.03	7.53	1.54	0	8.4	62.8
July	7.35	59	0.11	12.20	5.22	0	20.80	64.0
August	7.28	48	0.75	16.30	0.66	484000	19.6	68.0
September	7.07	46	4.14	5.32	3.43	25	11.20	90.5
Mean	**7.4**	**54.3**	**1.73**	**13.04**	**3.53**	**208470.8**	**22.9**	**68.8**
Resource quality objectives	**5.5-9.5**	**75**	**15**	**1**	**1**	**0**	**25**	**75**

Table 4.4: Table showing water quality data for 2018 wet and dry season at Site 1

2018 WET SEASON WATER QUALITY DATA								
MONTHS	pH	COD (mg/l)	NO2 + NO_3^- (mg/l)	NH3 (mg/l)	PO4 (mg/l)	*E.coli*	Suspended Solids (mg/l)	Electrical Conductivity (ms/m)
January	6.74	34	1.69	3.29	0.62	2	8.00	44.6
February	7.07	69.0	4.79	2.32	1.47	5800	51.6	39.8
March	6.99	49.0	0.22	1.61	0.36	0	21.2	45.0
October	7.12	127.0	3.25	10.7	1.13	0	53.2	52.8
November	7.33	116.0	0.18	12.2	0.82	5000	98.8	54.1
December	7.17	40.0	1.92	2.80	0.55	0	12.8	48.7
Mean	**7.07**	**72.5**	**2.01**	**5.49**	**0.825**	**1800**	**40.9**	**47.5**
2018 DRY SEASON WATER QUALITY DATA								
April	7.16	46.0	2.01	6.67	4.31	58	18.4	43.8
May	6.55	64.0	9.25	0.36	4.43	2400	23.6	39.2
June	6.98	44.0	1.88	4.84	0.18	0	8.00	46.6
July	7.11	44.0	3.35	7.83	0.66	0	12.4	59.2
August	7.67	59.0	2.26	7.81	0.34	0	14.4	51.5
September	6.51	32.0	1.92	2.33	0.08	21600	15.2	41.7
Mean	**7.00**	**48.2**	**3.44**	**4.97**	**1.67**	**4010**	**15.3**	**47**
Resource quality objectives	**5.5-9.5**	**75**	**15**	**1**	**1**	**0**	**25**	**75**

Table 4.5: Table showing water quality data for 2019 wet and dry season at Site 1

2019 WET SEASON WATER QUALITY DATA								
MONTHS	pH	COD (mg/l)	NO2 + NO_3^- (mg/l)	NH3 (mg/l)	PO4 (mg/l)	*E.coli*	Suspended Solids (mg/l)	Electrical Conductivity (ms/m)
January	7.6	28	42.6	0.20	0.55	35600	35.2	42.6
February	7.04	237	44.5	5.57	8.68	209200	198.0	44.5
March	6.86	58	57.4	4.66	5.84	5800	16.0	57.40
October	8.10	36	58.9	13.20	1.80	-	4.80	58.9
November	7.70	134	50.2	0.02	5.92	-	52.0	50.2
December	7.3	105	65.5	27.9	3.20	-	6.40	65.5
Mean	**7.4**	**100**	**53.2**	**8.59**	**4.33**		**52.07**	**53.2**
2019 DRY SEASON WATER QUALITY DATA								
April	7.31	54.0	55.7	5.54	0.72	0	22.0	55.7
May	6.82	138.0	53.2	11.9	0.04	397200	112.0	53.2
June	7.02	156.0	61.1	18.0	1.71	184200	102.0	61.1
July	7.64	38.0	46.9	7.99	0.17	154000	12.8	46.9
August	7.37	90.0	63.6	12.2	1.46	0	50.0	63.6
September	6.8	208	72.63	26.6	6.10	0	42.4	72.63
Mean	**7.2**	**114**	**58.9**	**13.7**	**1.7**	**122567**	**56.9**	**58.9**
Resource quality objectives	**5.5-9.5**	**75**	**15**	**1**	**1**	**0**	**25**	**75**

The tables above (table 4.3-4.5) show water quality data for site 1 over three years (2017, 2018, 2019). Data revealed that the effluent was not compliant with the set limits for parameters outlined on the Water Use Licence (see table 4.2). The data which was collected from 2017 to 2019 dry season shows that the *E. coli* count was low in 2018 which was recorded as 2400 counts per ml compared to the same period in 2017 and 2019 where the *E. coli* count was higher, recorded as 48400 and 397200 counts per ml respectively. This was way above the limits which are set in the Water Use Licence. Wastewater consists of pathogenic bacteria and viruses which have a detrimental impact on both human health and aquatic ecosystems (sperling, 2007). Coliform bacteria such as *E. coli* are mostly used as indicator organisms of the presence of pathogenic bacteria in water. The detection, isolation, and identification of different types of microbial pollutants in wastewater are always difficult, expensive, and time-consuming hence indicator organisms are always used to determine the relative risk of the possible presence of a particular pathogen in wastewater (Sperling, 2007; Tripathi & Sharma, 2011). These results show that treated effluent discharged into the water resource had an impact on its microbial quality, which can be impacted significantly by pathogenic microorganisms.

According to sperling, (2007), High *E. coli* counts present in the discharged effluent impact negatively on the microbial quality of a water resource since it indicates a potential for faecal pollution and the presence of pathogens in the river. The results from table 4.3 to 4.5 which were obtained during this research are in line with other studies which were conducted in South African rivers such as the Mhlathuze River, Vaal River and Klip River (Bezuidenhout et al., 2002; Pegram et al., 1998). The results of this study observed the same trend during the wet season that the *E. coli* counts were lower in 2018 compared to 2017 and 2019 levels.

Phosphate concentration was frequently non-compliant to the set limit as evidenced in the water quality data of the wet season period from 2017 to 2019 (table 4.3-4.5), with a low mean concentration of 0.825 mg/l in 2018 compared to the same period in 2017 and 2019 whereby Phosphate mean concentration was higher, recorded as 2.30 mg/l and 4.33 mg/l respectively. The results of this study also observed the same trend during the dry season whereby a lower mean concentration of Phosphate was recorded in 2018 compared to 2017 and 2019 mean concentrations. Major sources of phosphorus as phosphate are sewage treatment plant effluent, agriculture, urban development, and industrial effluents (Kirke, 2001). Phosphate is an essential nutrient for plant growth in freshwater systems, which is often considered as a limiting nutrient in water bodies, thus its excessive input can cause the proliferation of algae. Water quality guidelines for phosphorus as phosphate vary in South African water resources based on the ecological status of the water resource, in this study, it is evident that the mean phosphate concentrations for the WWTW in the period of 2017 to 2018 exceeded the limit set out for the Crocodile River. These results are in line with the conclusion made in a study by Mema (2007) that most of South Africa's wastewater treatment works are discharging effluent which is not compliant with set guidelines.

A higher mean concentration of Chemical Oxygen Demand (COD) was observed during the wet season of the period 2017 to 2019. The results showed that 2018 had a recording of 72.5 mg/l, which was compliant to the limit of 75 mg/l (see table 1), compared to the same period in 2017 and 2019 whereby the mean COD concentrations were higher, recorded as 154.3 mg/l and 100 mg/l respectively, exceeding the set limit as per the guideline. The same trend was observed with regards to water quality data during the dry season whereby COD concentrations were lower in 2018 compared to 2017 and 2019 concentrations. Van der Hoek et al., (2016) outlines that organic matter present in wastewater which is measured as chemical oxygen demand (COD) originates from urine, faecal matter, toilet paper and greywater, with greywater and faecal matter with the highest contributions (36 % and 34 % respectively), urine contributing 7%. Most of the organic matter in wastewater treatment plants is removed as sludge.

4.2.2 Whiteriver – Crocodile confluence (Site 2)

Table 4.6: Table showing water quality data for 2017 wet and dry season at Site 2

2017 WET SEASON WATER QUALITY DATA						
MONTHS	pH	NO2 + NO_3^- (mg/l)	NH3 (mg/l)	PO4 (mg/l)	*E.coli*	Electrical Conductivity (ms/m)
January	7.54	0.1	0.2	0.1	65	35.20
February	-	-	-	-	-	-
March	7.48	0.97	0.20	0.10	1533.00	31.10
October	7.43	0.10	0.22	0.01	4400.00	39.9
November	7.82	0.10	0.20	0.01	19.00	38.10
December	7.89	0.11	0.20	0.01	45.00	31.30
Mean	7.6	0.2	0.2	0.04	1212	35.12
2017 DRY SEASON WATER QUALITY DATA						
April	7.82	0.29	0.20	0.10	315.00	34.1
May	8.23	0.18	0.20	0.10	88.00	31
June	7.85	0.10	0.20	0.10	28.00	31.1
July	7.70	0.10	0.20	0.10	15.00	-
August	6.99	0.12	0.20	0.10	158.00	23.9
September	7.51	0.10	0.20	0.01	1153.00	32.8
Mean	7.68	0.15	0.20	0.085	293	30.58
Resource quality objectives	**6.5-8.5**	**6**	**6**	**0.125**	**130**	**70**

Table 4.7: Table showing water quality data for 2018 wet and dry season at Site 2

2018 WET SEASON WATER QUALITY DATA						
MONTHS	pH	NO2 + NO_3^- (mg/l)	NH3 (mg/l)	PO4 (mg/l)	*E.coli*	Electrical Conductivity (ms/m)
January	7.29	0.10	0.20	0.01	35.00	34.50
February	7.87	0.10	0.20	0.01	145.00	33.80
March	7.51	0.00	0.20	0.02	260.00	29.70
October	7.64	0.10	0.20	0.01	55.00	31.10
November	7.82	0.10	0.20	0.12	75.00	34.20
December	7.65	0.10	0.20	0.01	78.00	33.70
Mean	7.63	0.083	0.20	0.03	108	33.7
2018 DRY SEASON WATER QUALITY DATA						
April	7.40	0.10	0.20	0.02	388.00	27.60
May	7.65	0.10	0.20	0.08	50.00	23.30
June	7.38	0.10	0.20	0.01	140.00	29.00
July	7.38	0.10	0.20	0.01	48.00	29.00

August	7.98	0.10	0.20	0.01	78.00	29.80
September	7.61	0.10	0.20	0.01	78.00	27.80
Mean	7.6	0.10	0.20	0.023	130.3	29.9
Resource quality objectives	**6.5-8.5**	**6**	**6**	**0.125**	**130**	**70**

Table 4.8: Table showing water quality data for 2019 wet and dry season at for Site 2

2019 WET SEASON WATER QUALITY DATA						
MONTHS	pH	NO2 + NO_3^- (mg/l)	NH3 (mg/l)	PO4 (mg/l)	*E.coli*	Electrical Conductivity (ms/m)
January	7.92	0.10	0.20	0.01	50.00	33.00
February	7.75	0.10	0.20	0.01	65.00	34.50
March	7.52	0.13	0.20	0.03	90.00	34.40
October	7.70	0.10	0.01	0.07	-	28.80
November	7.90	0.10	0.02	0.02	-	21.40
December	7.90	0.10	0.02	0.10	-	41.90
Mean	7.78	0.105	0.04	0.04	68.3	32.3
2019 DRY SEASON WATER QUALITY DATA						
April	7.72	0.11	0.20	0.01	170.00	39.20
May	7.27	0.10	0.20	0.02	23.00	24.60
June	7.31	0.10	0.20	0.01	55.00	23.90
July	7.86	0.10	0.20	0.01	8.00	23.40
August	7.61	0.10	0.20	0.02	25.00	22.80
September	7.67	0.15	0.05	0.02	-	28.33
Mean	7.57	0.11	0.175	0.015	56.2	27.03
Resource quality objectives	**6.5-8.5**	**6**	**6**	**0.125**	**130**	**70**

The tables above (table 4.6-4.8) show water quality data for Site 2 over three years (2017, 2018, 2019). Two parameters namely COD and Suspended Solids which were analysed on samples from the effluent of the WWTW were not analysed in samples taken from this site because the site is situated within the water resource (White River) and there is no set limit for such parameters on the Resource Quality Objectives (RQO). Data revealed that water resources quality at this site was compliant in most of the months with the set limits for parameters outlined on the Resource Quality Objectives (see table 4.1). The data which was collected from 2017 to 2019 dry season shows that the *E. coli* count was low in 2019 which was recorded as 8 counts per ml compared to the same period in 2017 and 2018 where *E. coli* counts were the higher, recorded as 1153 and 388 counts per ml respectively, which is above the compliance limit. The site is situated downstream of the Whiteriver WWTW, ideally, since the effluent from the WWTW had high *E. coli* counts during 2017 and 2019 of the same periods, it is expected that this site would exhibit higher *E. coli* counts during these months, however higher *E. coli* counts were only noted in 2017 only. It was also noted during a period between April and May 2019, the area received slight rainfall of between 100-200 mm (SAWS. 2019). These results contradict the study conducted by Abia et al., (2015) which outlined that runoff from the storm influenced the concentration of *E. coli* in the water resource since runoff carries sediments containing microorganisms into the river.

The phosphate concentration of samples collected on this site were mostly compliant to the set limit as evidenced in the water quality data of the wet season period from 2017 to 2019 (table 4.5-4.7), with a lowest mean concentration of 0.03 mg/l in 2018 and a mean concentration of 0.04 mg/l during 2017 and 2019. The results of this study also observed the same trend during the dry season whereby a lower mean concentration of Phosphate was recorded during 2017, 2018, 2019. These results are in line with the study conducted by Turumen et al., (2020), which revealed a lower concentration of constituents observed downstream of the effluent discharge point which is attributed to the dilution and assimilative capacity of the water resource, which is majorly influenced by the discharge point of the effluent, and the concentration of the pollutants present in the effluent. As observed, the phosphate concentration of Whiteriver WWTW (Site 1) was generally low even though it was not compliant with the resource quality objectives, hence dilution was effective.

A low mean concentration of Nitrate and Nitrite during the dry season of the period 2017 to 2019 was observed in 2018 with a recording of 0.10 mg/l, compared to the same period in 2017 and 2019 where the mean concentration was higher, recorded as 0.20/mg/l and 0.11 mg/l respectively, however, the mean concentration throughout the study period was compliant to the limit of 6 mg/l (see table 4.1). The same trend was also observed with the mean concentration of Nitrate and Nitrite in the wet season of the same period whereby they were compliant with the set limit. An excessive amount of nitrogen particularly nitrate has a significant impact on the quality of water and the health of an aquatic ecosystem. Nitrogen one of the critical limiting nutrient for plants and cyanobacteria and one of concern for the eutrophication of freshwater systems. Excessive growth algae in response to nutrient increases on the water body can result in a bloom of single or multiple species depending on variables such as pH, temperature, dissolved oxygen which has some negative impacts on the aquatic ecosystem (Rabalais, 2002).

4.2.3 Kanyamazane WWTW (Site 3)

Table 4.9: Effluent Quality Limits as per Kanyamazane WWTW Water Use Licence (DWA,2009)

Constituents	Limits
Electrical conductivity (ms/m)	75
Nitrite and Nitrates (mg/l)	15
Phosphate (mg/l)	1
Ammonia-N (mg/l)	6
Chemical Oxygen Demand (COD) (mg/l)	75
***E- coli* (count per ml)**	0
Suspended Solids (mg/l)	25
pH	5.5-9.5

Table 4.10: Table showing water quality data for the 2017 wet and dry season at Site 3

2017 WET SEASON WATER QUALITY DATA								
MONTHS	pH	COD (mg/l)	NO2 + NO_3^- (mg/l)	NH3 (mg/l)	PO4 (mg/l)	*E.coli*	Suspended Solids (mg/l)	Electrical Conductivity (ms/m)
January	6.81	28.00	16.70	0.20	1.09	0.00	2.4	50.70
February	7.40	25.00	14.80	0.20	0.26	22000.00	4.4	52.10
March	7.36	33.00	8.94	3.18	0.84	0.00	8.4	52.20
October	7.32	46.00	13.90	2.47	2.86	0.00	2	59.10
November	7.60	34.00	15.00	0.69	4.02	0.00	3.2	57.80
December	7.79	40.00	12.10	0.21	3.73	0.00	0.4	53.90
Mean	**7.38**	**34.3**	**13.6**	**1.158**	**2.13**	**3666.7**	**3.47**	**54.3**
2017 DRY SEASON WATER QUALITY DATA								
April	7.37	20.00	13.90	1.07	0.87	0.00	0.4	51.50
May	7.76	38.00	17.20	1.00	0.41	0.00	6.8	55.10
June	7.47	46.00	10.70	5.25	0.94	0.00	**15.6**	57.20
July	7.37	20.00	13.90	4.62	0.84	0.00	14.8	63.60
August	7.30	51.00	15.30	4.56	1.05	0.00	10.4	64.80
September	7.44	44.00	17.40	0.36	3.33	0.00	6.4	61.40
Mean	**7.45**	**36.5**	**14.7**	**2.81**	**1.24**	**0.00**	**9.07**	**58.93**
Resource quality objectives	**5.5-9.5**	**75**	**15**	**6**	**1**	**0**	**25**	**75**

Table 4.11: Table showing water quality data for 2018 wet and dry season at Site 3

2018 WET SEASON WATER QUALITY DATA								
MONTHS	pH	COD (mg/l)	NO2 + NO3 (mg/l)	NH3 (mg/l)	PO4 (mg/l)	*E.coli*	Suspended Solids (mg/l)	Electrical Conductivity (ms/m)
January	7.33	28.00	12.8	0.20	3.47	0.00	3.60	53.90
February	7.42	25.00	14.1	0.20	3.70	0.00	0.40	53.90
March	7.39	33.00	12.5	0.20	3.50	0.00	1.20	50.30

October	7.66	46.00	15.3	0.22	3.88	0.00	0.40	59.10
November	7.63	34.00	13.1	1.64	3.82	0.00	6.00	54.90
December	7.55	40.00	15	0.94	4.26	0.00	6.40	56.60
Mean	**7.49**	**34.3**	**13.8**	**0.57**	**3.77**	**0.00**	**3.00**	**54.78**
2018 DRY SEASON WATER QUALITY DATA								
April	7.49	20.00	14.1	0.20	3.71	0.00	0.40	51.60
May	7.53	38.00	14.8	1.19	3.36	0.00	2.40	49.70
June	7.36	46.00	16.5	0.69	2.89	0.00	0.80	52.80
July	7.46	20.00	18	1.15	3.07	0.00	4.00	61.00
August	7.31	51.00	18.4	0.20	3.57	0.00	3.20	63.70
September	7.46	44.00	15.8	1.40	3.34	2420.00	8.00	61.50
Mean	**7.44**	**36.5**	**16.26**	**0.805**	**3.32**	**403.3**	**3.13**	**56.7**
Resource quality objectives	**5.5-9.5**	**75**	**15**	**6**	**1**	**0**	**25**	**75**

Table 4.12: Table showing water quality data for 2019 wet and dry season at Site 3

2019 WET SEASON WATER QUALITY DATA								
MONTHS	pH	COD (mg/l)	NO2 + NO3 (mg/l)	NH3 (mg/l)	PO4 (mg/l)	*E.coli*	Suspended Solids (mg/l)	Electrical Conductivity (ms/m)
January	7.42	25	14.10	0.2	3.7	0	0.4	53.90
February	7.39	33	12.50	0.2	3.5	0	1.2	50.30
March	7.49	20	14.10	0.2	3.71	0	0.4	51.60
October	7.63	34.00	13.10	1.64	3.82	0	6.00	54.90
November	7.55	40.00	15.00	0.94	4.26	0	6.40	56.60
December	7.80	10.00	13.80	0.20	3.55	0	0.80	52.90
Mean	**7.54**	**27.0**	**13.8**	**0.56**	**3.76**	**0**	**2.53**	**53.4**
2019 DRY SEASON WATER QUALITY DATA								
April	7.53	38	14.80	1.19	3.36	0	2.4	49.70
May	7.36	46	16.50	0.69	2.89	0	0.8	52.80
June	7.46	20	18.00	1.15	3.07	0	4	61.00
July	7.31	51	18.40	0.2	3.57	0	3.2	63.70
August	7.46	44	15.80	1.4	3.34	2420	8	61.50
September	7.66	46	15.30	0.22	3.88	0	0.4	59.10
Mean	**7.46**	**40.8**	**16.5**	**0.808**	**3.35**	**403.3**	**3.13**	**58.00**
Resource quality objectives	**5.5-9.5**	**75**	**15**	**6**	**1**	**0**	**25**	**75**

The tables above (table 4.10-4.12) show water quality data for site 3 over three years (2017, 2018, 2019). Data revealed that the effluent was generally compliant with the set limits for parameters outlined on the Water Use Licence (see table 4.9), however, reoccurring non-compliance was noted with phosphate, since it was frequently above the limit. The data which was collected from 2017 to 2019 dry season shows that the *E. coli* count was not detected throughout the season in 2017 which was recorded as 0 counts per ml compared to the same period in 2018 and 2019 where the *E. coli* count was higher, recorded as 2420 counts per ml in both periods. These *E. coli* counts were noted in the effluent only during August and September of 2018 and 2019, respectively. This was way above the limits which are set in the Water Use Licence. It can be noted from the trend of the effluent quality that the occurrence of *E. coli* in the effluent can be a result of lack of disinfectant during a particular period, maintenance of disinfectant dosing system or scheduled maintenance at the plant, hence *E. coli* failure is observed once in a year.

Phosphate concentration was frequently non-compliant to the set limit as evidenced in the water quality data of the wet season period from 2017 to 2019 (table 4.10-4.12), with a lower mean concentration of 2.13 mg/l in 2017 compared to the same period in 2018 and 2019 whereby Phosphate mean concentrations were higher, recorded as 3.77 mg/l and 3.76 mg/l respectively. The results of this study also observed the same trend during the dry season whereby a lower mean concentration of Phosphate was recorded in 2017 compared to 2018 and 2019 mean concentrations.

A low mean concentration of Chemical Oxygen Demand (COD) was observed at site 4 during the wet season of a period 2017 to 2019. The results showed that 2019 had a mean concentration of 27 mg/l, compared to the same period in 2017 and 2018 whereby the mean COD concentrations were higher, recorded as 36.5 mg/l and 34.3 mg/l respectively, however, all the mean COD concentration were compliant to the limit of 75 mg/l (see table 4.9)

4.2.4 Kanyamazane N4 Bridge (Site 4)

Table 4.13: Table showing water quality data for 2017 wet and dry season at Site 4

2017 WET SEASON WATER QUALITY DATA						
MONTHS	pH	NO2 + NO3 (mg/l)	NH3 (mg/l)	PO4 (mg/l)	*E. coli*	Electrical Conductivity (ms/m)
January	7.85	0.74	0.20	0.1	570,00	18.4
February	7.99	0.79	0.20	0.1	815,00	23.4
March	7.54	0.72	0.20	0.1	1153,00	15.1
October	7.69	1.03	0.20	0.097	440,00	23.9
November	8.05	1.03	0.20	0.103	3065,00	24.4
December	7.78	0.97	0.20	0.103	5230,00	21.3
Mean	7.81	0.88	0.20	0.10	1879	21.1

2017 DRY SEASON WATER QUALITY DATA						
April	7.91	0.94		0.1	8800,00	21.7
May	8.17	0.96		0.1	11400,00	26.1
June	8.13	1.49		0.12	730,00	28.1
July	8.19	1.51		0.1	3065,00	31.8
August	7.54	1.67		0.12	605,00	30,00
September	7.88	0.87		0.11	115,00	29.2
Mean	7.97	1.24		0.108	4119	27.8
Resource quality objectives	**6.5-8.5**	**6**	**6**	**0.125**	**130**	**70**

Table 4.14: Table showing water quality data for 2018 wet and dry season at Site 4

2018 WET SEASON WATER QUALITY DATA						
MONTHS	pH	NO2 + NO3 (mg/l)	NH3 (mg/l)	PO4 (mg/l)	*E.coli*	Electrical Conductivity (ms/m)
January	6,32	1,09	0,2	0,09	2440	25,4
February	8,08	0,80	0,2	0,06	2055	22,90
March	7,54	0,86	0,2	0,1	1380	21,00
October	7,85	1,08	0,2	0,15	545	27,10
November	7,88	0,93	0,2	0,13	525,00	23,50
December	7,82	0,94	0,2	0,18	9930,00	23,40
Mean	7.6	0.95	0.2	0.12	2812	23.9
2018 DRY SEASON WATER QUALITY DATA						
April	7,67	0,94	0,2	0,11	575	0,90
May	7,63	1,32	0,2	0,16	895	22,50
June	7,69	0,96	0,2	0,16	4900	26,30
July	7,82	1,31	0,2	0,22	5230	31,50
August	7,76	0,89	0,2	0,16	595	30,80
September	7,91	1,14	0,2	0,17	1050	32,40
Mean	7.7	1.09	0.2	0.16	2207	24.06
Resource quality objectives	**6.5-8.5**	**6**	**6**	**0.125**	**130**	**70**

Table 4.15: Table showing water quality data for 2019 wet and dry season at Site 4

2019 WET SEASON WATER QUALITY DATA						
MONTHS	pH	NO2 + NO3 (mg/l)	NH3 (mg/l)	PO4 (mg/l)	*E.coli*	Electrical Conductivity (ms/m)
January	7,68	0,80	0,2	0,05	3245,00	22,30
February	7,85	0,77	0,2	0,11	4330,00	21,10
March	7,55	1,08	0,2	0,11	655,00	23,60
October	7,60	1,54	0,02	0,35	-	33,40
November	8,70	1,20	0,10	0,04	-	21,40
December	-	13,00	0,02	0,40	-	33,00
Mean	7.65	3.07	0.123	0.176	2743	25.8
2019 DRY SEASON WATER QUALITY DATA						
April	7,88	1,09	0,2	0,07	1935,00	25,70
May	7,69	1,02	0,2	0,12	135,00	28,50
June	8,08	1,14	0,2	0,11	140,00	31,70
July	8,09	0,88	0,2	0,12	153,00	31,50
August	8,09	1,03	0,2	0,17	235,00	32,90
September	7,96	1,19	0,02	0,20	-	31,14
Mean	7.70	1.92	0.17	0.13	519	30.24
Resource quality objectives	**6.5-8.5**	**6**	**6**	**0.125**	**130**	**70**

The tables above (table 4.13-4.15) show water quality data for Site 4 over three years (2017, 2018, 2019). The site is located approximately 300 m downstream of Site 3 and data collected from 2017 to 2019 dry season shows that the mean *E. coli* count was low in 2019 which was recorded as 519 counts per ml compared to the same period in 2017 and 2018 where the mean *E. coli* counts were the higher, recorded as 4119 and 2207 counts per ml respectively. The overall status of the quality of the water resource reveals that it is not compliant with the set limit (see table 4.1). A Similar trend was also observed from site 2 whereby higher *E. coli* counts were observed during the 2017 and 2018 periods and lower counts were noted in samples collected in 2019. This sampling site is situated in a densely populated area in the township called Kanyamazane, the site is also situated approximately 300 m downstream of Kanyamazane WWTW discharge point. The results are in line with the study conducted by Amoah et al., (2020) which outlined that in addition to the treated effluent discharged into the river, informal settlements situated near the water resources has an impact on the microbial quality of the water resources, as indicated mostly by the presence of *E. coli* as observed in the results.

The phosphate concentration of samples collected on this site were mostly compliant to the set limits as evidenced in the water quality data of the wet season period from 2017 to 2019 (table 4.13-4.15), with a lowest mean concentration of 0.10 mg/l in 2018 and a higher mean concentration of 0.12 mg/l and 0.176 mg/l during 2017 and 2019 respectively, which exceeded the limit. A steady increase in phosphate concentration during the wet season period is observed from 2017 to 2019, which can result in the proliferation of algae in downstream water impoundment since conditions are favourable for algal growth during spring-summer (wet season) (Ericke et al., 2018)

A low mean concentration of Nitrate and Nitrite during the dry season of the study period was observed in 2018 with a recording of 1.09 mg/l, compared to the same period in 2017 and 2019 where the mean concentration was higher, recorded as 1.24 /mg/l and 1.92 mg/l respectively, however, the mean concentration throughout the study period was compliant to the limit of 6 mg/l (see table 4.1).

4.2.5 Matsulu Wastewater treatment plant (Site 5)

Table 4.16: Effluent Quality Limits as per Matsulu WWTW Water Use Licence (DWA,2009)

Constituents	Limits
Electrical conductivity (ms/m)	70
Nitrite and Nitrates (mg/l)	15
Phosphate (mg/l)	1
Chemical Oxygen Demand (mg/l)	75
Ammonia-N (mg/l)	3
***E- coli* (count per ml)**	0
Suspended Solids (mg/l)	25
pH	5.5-9.5

Table 4.17: Table showing water quality data for 2017 wet and dry season at Site 5

2017 WET SEASON WATER QUALITY DATA								
MONTHS	pH	COD (mg/l)	NO2 + NO3 (mg/l)	NH3 (mg/l)	PO4 (mg/l)	*E.coli*	Suspended Solids (mg/l)	Electrical Conductivity (ms/m)
January	7.63	10,00	4.72	0.2	1.82	0,00	1.6	50.6
February	7.71	26,00	7.29	0.2	1.73	0,00	3.6	57.4
March	7.7	10,00	5.12	0.2	0.53	0,00	0.4	54.4
October	7.38	27,00	6.11	0.2	1.78	0,00	0.8	59.4
November	7.8	10,00	6.51	0.2	1.91	46,00	1.2	56.4
December	7.79	12,00	5.58	0.2	1.77	0,00	0.4	59.7
Mean	7.6	15.8	5.9	0.2	1.59	7.67	1.33	56.3
2017 DRY SEASON WATER QUALITY DATA								
April	6.99	12,00	6.93	0.2	0.36	0,00	0.4	52.5
May	8.26	18,00	6.7	0.2	1.12	0,00	0.4	57.8
June	7.53	41,00	8.55	0.2	1.78	0,00	4,00	58.8
July	7.53	16,00	7.86	0.2	2.72	0,00	0.4	64.9

August	7.58	31,00	7.1	0.2	2.72	0,00	1.2	62.5
September	7.51	10,00	8.35	0.2	5.32	0,00	4.4	63.6
Mean	7.6	31.3	7.58	0.2	2.34	0	1.36	60.3
Resource quality objectives	**5.5-9.5**	**75**	**15**	**3**	**1**	**0**	**25**	**70**

Table 4.18: Table showing water quality data for 2018 wet and dry season at Site 5

2018 WET SEASON WATER QUALITY DATA								
MONTHS	pH	COD (mg/l)	NO2 + NO3 (mg/l)	NH3 (mg/l)	PO4 (mg/l)	*E.coli*	Suspended Solids (mg/l)	Electrical Conductivity (ms/m)
January	7.51	10	8,01	0,2	2,56	0	0,4	60,1
February	7.69	10	5,78	0,2	2,56	0	0,4	54,4
March	7.46	16	5,00	0,2	1,66	0	0,4	55,8
October	7.67	42	7,68	0,2	2,62	1	2	62,70
November	7.82	20,00	7,99	0,2	3,02	0,00	0,40	66,50
December	7.62	14,00	4,36	0,2	2,84	0,00	2,00	60,60
Mean	7.6	18.7	6.47	0.2	2.54	0.167	0.933	60.02
2018 DRY SEASON WATER QUALITY DATA								
April	7.58	26	6,23	0,2	2,38	0	0,4	61,3
May	7.03	14	7,41	0,2	1,91	0	0,4	55,30
June	6.97	22	7,23	0,2	2,65	0	0,4	58,00
July	7.56	10	11,70	0,2	2,63	0	0,4	65,60
August	7.69	23	8,28	0,2	1,83	0	1,2	68,80
September	7.98	14	5,19	0,2	0,88	0	0,4	69,60
Mean	7.5	18.2	7.67	0.2	2.05	0	0.53	63.0
Resource quality objectives	**5.5-9.5**	**75**	**15**	**3**	**1**	**0**	**25**	**70**

Table 4.19: Table showing water quality data for 2019 wet and dry season at for Site 5

2019 WET SEASON WATER QUALITY DATA								
MONTHS	pH	COD (mg/l)	NO2 + NO3 (mg/l)	NH3 (mg/l)	PO4 (mg/l)	*E.coli*	Suspended Solids (mg/l)	Electrical Conductivity (ms/m)
January	7.63	10,00	5,36	0,2	2,04	0,00	0,40	60,90
February	7.80	12,00	6,36	0,2	2,57	0,00	0,40	59,20
March	7.68	14,00	6,48	0,2	1,59	0,00	4,40	60,80
October	7.70	12,00	8,14	4,9	4,70	-	0,80	78,20
November	7.50	-	6,33	0,02	0,70	-	0,40	57,50
December	7.60	61,00	7,25	0,1	2,00	-	0,40	77,20
Mean	7.7	21.8	6.65	0.94	2.27	0	1.13	65.6

2019 DRY SEASON WATER QUALITY DATA								
April	8.04	22,00	7,60	0,2	2,32	1,00	0,40	66,90
May	7.64	14,00	6,70	0,2	1,83	0,00	0,40	64,60
June	7.44	24,00	5,36	0,2	2,97	0,00	0,40	71,10
July	8.18	21,00	11,60	0,2	2,63	0,00	0,40	80,60
August	7.70	16,00	7,35	0,2	1,91	184,00	1,20	79,50
September	7.77	-	8,77	0,02	0,80	-	2,00	67,35
Mean	7.8	19.4	7.90	0.17	2.08	37.00	0.8	71.68
Resource quality objectives	**5.5-9.5**	**75**	**15**	**3**	**1**	**0**	**25**	**70**

The tables above (table 4.17-4.19) show water quality data for site 5 over three years (2017, 2018, 2019). Data revealed that the effluent was generally compliant with the set limits for parameters outlined on the Water Use Licence (see table 4.16). The water quality data from the 2017 to 2019 dry season shows that the mean *E. coli* count was low in 2017 and 2018 which was recorded as 0 counts per ml compared to the same period in 2019 where the *E. coli* count was higher, recorded as 184 counts per ml during August. This was above the *E. coli* limit set in terms of the Water Use Licence. Disinfection plays a major role in the removal of pathogenic organisms in the effluent, hence the non-detection of *E. coli* in the effluent can be attributed mainly to disinfection, which in this site (site 4) is achieved through chlorination using chlorine gas. Comparing the mean *E. coli* count on the effluent discharged from site 4 with the mean *E. coli* count in the effluent discharged from site 1, it is evident that the plant is effective in removing pathogens from the effluent, thus complying with its Licence limits. The removal of pathogens in wastewater treatment effluent is very important for the protection of receiving water bodies, and this can be achieved through disinfection. Gheethi et al., (2018) outlined that treated sewage needs to undergo further treatment (disinfection) to reduce the density of pathogenic bacteria present, thus achieving a favourable sanitary effluent quality. The results obtained are in line with the study conducted by Tree et al., (2003) which revealed that disinfection of treated effluent using Chlorine is effective in removing pathogens present in the water.

Phosphate concentration was frequently non-compliant to the set limit as evidenced in the water quality data of the wet season period from 2017 to 2019 (table 4.17.-4.19), with a low mean concentration of 1.59 mg/l in 2017 compared to the same period in 2018 and 2019 where the mean Phosphate concentration was higher, recorded as 2.30 mg/l and 4.33 mg/l respectively. Non-compliance was also noted from water quality data during the wet season of the same period. Phosphorus removal in Activated Sludge systems such as Matsulu WWTW (site 4) relies mainly on Phosphorus Accumulating Organisms (PAO) for enhanced biological phosphorus removal. Bunce et al., (2018) outline that operating conditions, including prerequisites for metabolism such as carbon, glycogen and electron acceptor requirements are very important for the growth of such organisms hence the adjustment of such factors must be undertaken to promote the proliferation of PAOs and ultimately removing phosphorus from wastewater. The results from the study conducted by Bunce et al. (2018) show that the plant does able phosphorus present in wastewater, however, the system is unable to produce an effluent with a phosphate concentration of less than 1 mg/l as per the WUL limit (Table 4.16). The results are in line with a study conducted by Cai et al., (2020) which revealed that biological nutrient removal (BNR) systems do not remove phosphorus present in wastewater completely, however they remove around 60 % of the total influent phosphorus.

COD for this site was generally compliant to the specified limit during the wet season of the period 2017-2019, with the highest mean COD concentration of 21.8 mg/l observed in 2019 and the lowest mean COD concentration observed in 2017. The same trend was also observed during the dry season whereby the effluent was compliant, with the highest mean concentration of 31.1 mg/l in 2017 and the lowest mean concentration of 18.2 mg/l observed in 2018. Fluctuation in effluent quality was observed and the study conducted by Niku and Schroeder, (1981) outlined that variation in the effluent quality from an activated sludge process such as Site 1 is a result of several internal and external factors influent variables such as flow, influent organic load, inflow suspended solids, environmental conditions such as the temperature of wastewater and the size of the plant.

4.2.6 Downstream Komatipoort WWTW (Site 6)

Table 4.20: Table showing water quality data for 2017 wet and dry season at Site 5

2017 WET SEASON WATER QUALITY DATA								
MONTHS	pH	COD (mg/l)	NO2 + NO3 (mg/l)	NH3 (mg/l)	PO4 (mg/l)	*E.coli*	Suspended Solids (mg/l)	Electrical Conductivity (ms/m)
January	8.25	-	5.83	0.2	0.10	415.00	-	130.00
February	8.26	-	6.86	0.2	0.21	38825.00	-	128.20
March	8.18	-	6.69	0.2	0.22	590.00	-	129.00
October	7.9	-	7.64	0.2	0.73	2040.00	-	130.00
November	8.11	-	8.71	0.2	0.16	345.00	-	131.00
December	8.15	-	8.6	0.2	0.04	288.00	-	136.00
Mean	**8.15**		**7.39**	**0.2**	**0.242**	**7083.8**	**-**	**130.7**
2017 DRY SEASON WATER QUALITY DATA								
April	8.3		7.87	0.2	0.10	233.00		126.00
May	8.32	-	8.96	0.2	0.10	430.00	-	126.00
June	8.3	-	7.37	0.64	0.42	278.00	-	127.00

July	8.32	-	8.04	1.05	0.33	158.00	-	129.00
August	7.84	-	10,00	0.2	0.64	278.00	-	121.60
September	8.24	-	9.01	0.2	0.02	98.00	-	128.00
Mean	**8.22**	**-**	**8.25**	**0.415**	**0.267**	**245.8**		**126.3**
Resource quality objectives	**6.5-8.5**	**-**	**6**	**6**	**0.125**	**130**	**-**	**70**

Table 4.21: Table showing water quality data for 2018 wet and dry season at Site 6

2018 WET SEASON WATER QUALITY DATA								
MONTHS	pH	COD (mg/l)	NO2 + NO3 (mg/l)	NH3-N (mg/l)	PO4 (mg/l)	*E.coli*	Suspended Solids (mg/l)	Electrical Conductivity (ms/m)
January	8.11	-	9.59	0.20	0.04	295.00	-	128
February	7.97	-	5.15	0.68	1.34	6050.00	-	127.00
March	8.20	-	9.74	0.20	0.05	1028.00	-	123.70
October	7.80	-	9.13	0.36	0.52	650.00	-	138.00
November	8.05	-	8.47	0.42	1.56	295.00	-	138.00
December	8.20	-	11.00	0.20	0.02	1153.00	-	139.00
Mean	**8.05**	**-**	**8.85**	**0.343**	**0.588**	**1578.5**		**132.3**
2018 DRY SEASON WATER QUALITY DATA								
April	8.19	-	10.20	0.20	0.03	570.00	-	137.00
May	8.22	-	9.41	0.20	0.53	193.00	-	128.00
June	7.98	-	9.93	0.35	0.47	270.00	-	127.00
July	8.00	-	9.20	0.20	0.22	463.00	-	125.70
August	8.58	-	9.49	1.09	0.60	1153.00	-	132.00
September	7.97	-	11.10	0.20	0.47	1028.00	-	134.00
Mean	8.15	-	9.89	0.373	0.387	612.8		130.6
Resource quality objectives	**6.5-8.5**	**75**	**6**	**6**	**0.125**	**130**	**25**	**70**

Table 4.22: Table showing water quality data for 2019 wet and dry season at Site 6

2019 WET SEASON WATER QUALITY DATA								
MONTHS	pH	COD (mg/l)	NO2 + NO3 (mg/l)	NH3 (mg/l)	PO4 (mg/l)	*E.coli*	Suspended Solids (mg/l)	Electrical Conductivity (ms/m)
January	7.78	-	6.84	0.20	1.21	4965.00	-	140.00
February	8.28	-	9.66	0.20	0.90	475.00	-	135.00
March	8.06	-	8.33	0.20	0.49	680.00	-	126.00
October	7.40	-	12.40	4.10	3.80	-	-	66.50

November	7.90	-	14.20	0.02	0.19	-	-	12.30
December	8.20	-	9.79	0.02	5.10	-	-	135.90
Mean	**7.94**		**10.2**	**0.79**	**1.94**	**2040**	**-**	**102.6**
2019 DRY SEASON WATER QUALITY DATA								
April	7.89	-	9.30	0.65	1.13	3.00	-	132.00
May	8.16	-	4.82	0.20	0.25	4965.00	-	92.40
June	8.18	-	9.90	1.43	0.81	0.00	-	133.00
July	8.15	-	11.50	1.45	0.75	0.00	-	137.00
August	8.07	-	11.30	1.13	0.52	403.00	-	145.00
September	8.12	-	12.90	0.02	0.02	-	-	136.00
Mean	**8.095**	**-**	**9.95**	**0.813**	**0.58**	**917.8**	**-**	**129.2**
Resource quality objectives	**6.5-8.5**	**75**	**6**	**6**	**0.125**	**130**	**25**	**70**

The tables above (table 4.16-4.19) show water quality data for Site 6 over three years (2017, 2018, 2019). Data collected during the dry season shows that the mean *E. coli* count was low in 2017 which was recorded as 98 counts per ml compared to the same period in 2018 and 2019 where the mean *E. coli* counts were higher, recorded as 1153 and 4965 counts per ml respectively. The overall status of the quality of the water resource reveals that it is not compliant with the set limit (see table 4.1). This sampling site is also situated in a populated area in the town called Komatipoort and is also situated approximately 200 m downstream of Komatipoort WWTW discharge point.

The phosphate concentration of samples collected on this site were mostly non-compliant to the set limits as evidenced in the water quality data of the wet season period from 2017 to 2019 (table 4.16-4.19), with a lowest mean concentration of 0.242 mg/l in 2017 and a higher mean concentration of 0.588 mg/l and 1.94 mg/l during 2018 and 2019 respectively. A steady increase in phosphate concentration during the wet season period is observed from 2017 to 2019, a similar trend was also observed during the wet season period of site 4 whereby a steady increase in phosphate concentration was noted, which has a potential to cause eutrophication especially in downstream water impoundments.

A lower mean concentration of Nitrate and Nitrite during the dry season of the study period was observed in 2017 with a recording of 8.25 mg/l, compared to the same period in 2018 and 2019 where the mean concentration was higher, recorded as 9.89 /mg/l and 9.95 mg/l respectively. The mean concentration throughout the study period non-compliant to the limit of 6 mg/l (see table 4.1).

4.3 Regression analysis of the historical water quality data

A regression analysis technique was employed to develop and analyse the relationship between the concentration of parameters and time using the historical water quality data. The coefficient of determination (R- squared value) and Pearson's correlation coefficient (r) of various water quality parameters of WWTW effluent and surface water of the study area during a period of 2017 to 2019 was calculated using the pair of variables. These showed significant and insignificant correlation as shown in the tables below (table 4.19- 4.23).

4.3.1 Whiteriver WWTW (site 1)

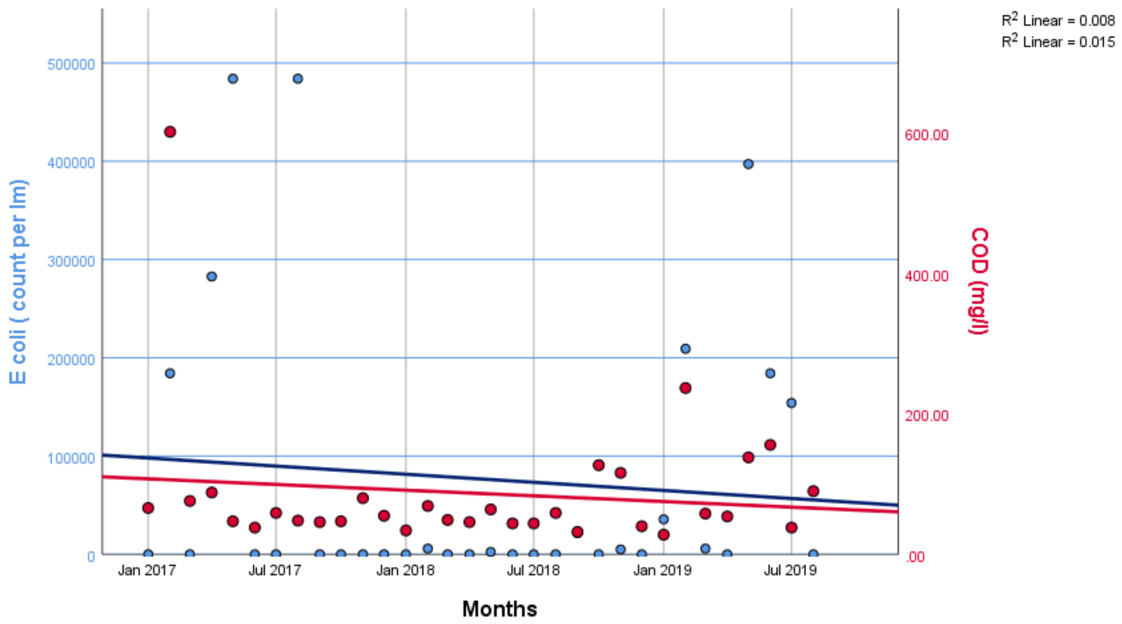

Figure 4.1: Historical Regression of Site 1 *E. coli and* COD

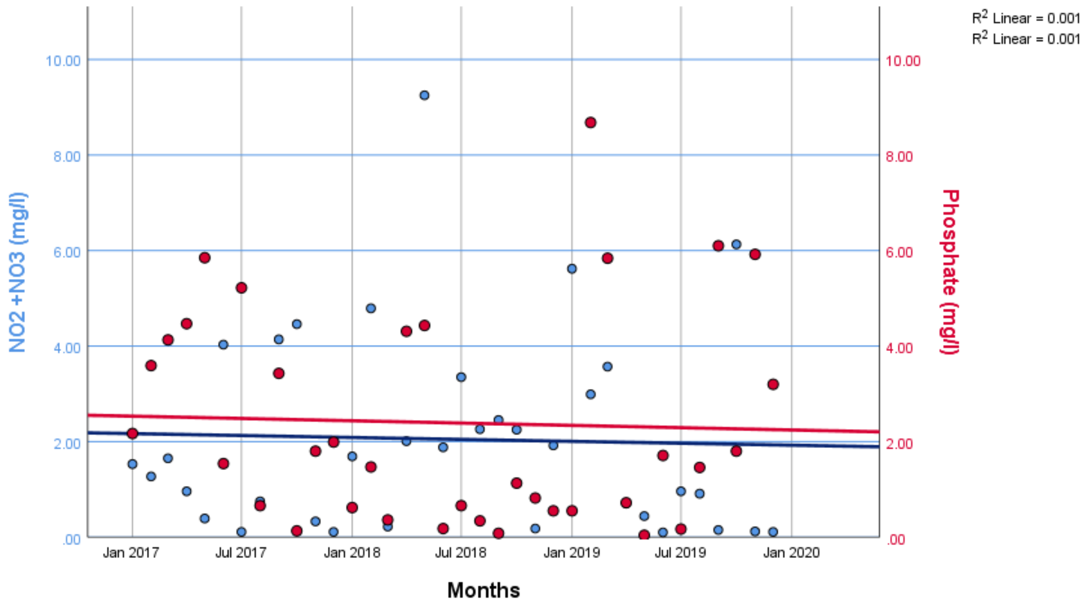

Figure 4.2: Historical Regression of Site 1 Nitrite -Nitrate and Phosphate

Table 4.13: Table showing site 1 Pearson's correlation coefficient and significance.

Correlations

		Time (Months)	NO2 +NO3 (mg/l)	Phosphate (mg/l)	COD (mg/l)	E coli (count per ml)
Time (Months)	Pearson Correlation	1	-.034	-.038	-.043	-.089
	Sig. (2-tailed)		.845	.827	.803	.629
	N	36	36	36	36	32
NO2 +NO3 (mg/l)	Pearson Correlation	-.034	1	-.013	-.199	-.310
	Sig. (2-tailed)	.845		.938	.246	.084
	N	36	36	36	36	32
Phosphate (mg/l)	Pearson Correlation	-.038	-.013	1	.326	.206
	Sig. (2-tailed)	.827	.938		.052	.258
	N	36	36	36	36	32
COD (mg/l)	Pearson Correlation	-.043	-.199	.326	1	.238
	Sig. (2-tailed)	.803	.246	.052		.191
	N	36	36	36	36	32
E coli (count per ml)	Pearson Correlation	-.089	-.310	.206	.238	1
	Sig. (2-tailed)	.629	.084	.258	.191	

N	32	32	32	32	32

Figures 4.1 & 4.2 above show a graph plotting the concentrations of Site 1 constituents (*E. coli,* Chemical Oxygen Demand, Phosphate and Nitrate & Nitrite) over time. Both graphs indicate a negative regression of constituent concentration. A low coefficient of determination (R- squared value) however was observed which ranged between 0.1 % to 1.5 %, indicating no variability of the response data around the mean. Table 4.19 above shows the Pearson (Bivariate) correlation of *E. coli*, COD, Phosphate, Nitrite-Nitrate and time (months between 2017- 2019). The results show that the observed bivariate correlation between Nitrite-Nitrate and time, phosphate and time is statistically insignificant ($r = -0.034$; $P = 0.845$) and ($r = -0.038$; $P = 0.827$) respectively. This shows that there is no relationship between the concentration of these constituents and time. The results also show that the bivariate correlation between Phosphate and Nitrite-Nitrate is statistically insignificant ($r = -0.013$, $P = 0.938$). These results are in line with the study conducted by Osode and Okoh, (2009) assessing the impact of discharged wastewater final effluent on the physicochemical qualities of a receiving watershed which showed that the correlation between phosphate and nitrate was statistically insignificant, and the study further suggests that since the concentrations of nitrate and phosphate were observed to be high, eutrophication is intensified in the vicinity of the effluent discharge points.

4.3.2 Whiteriver-crocodile confluence (Site 2)

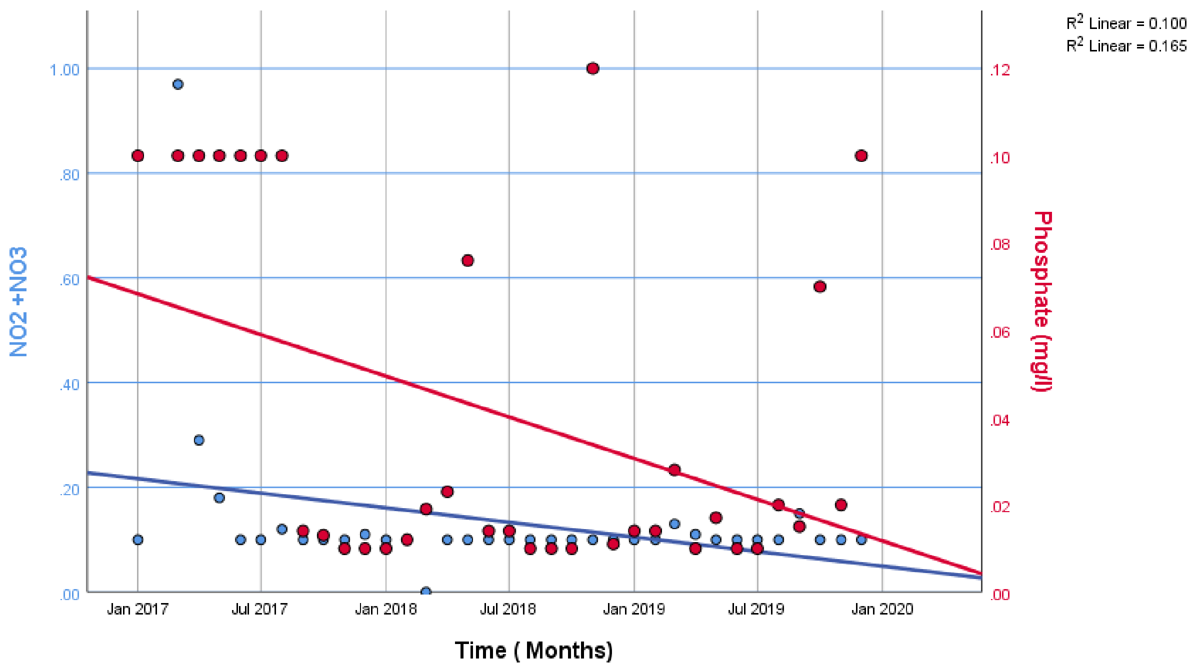

Figure 4.3 Historical Regression of Site 2 Nitrite-Nitrate and Phosphate

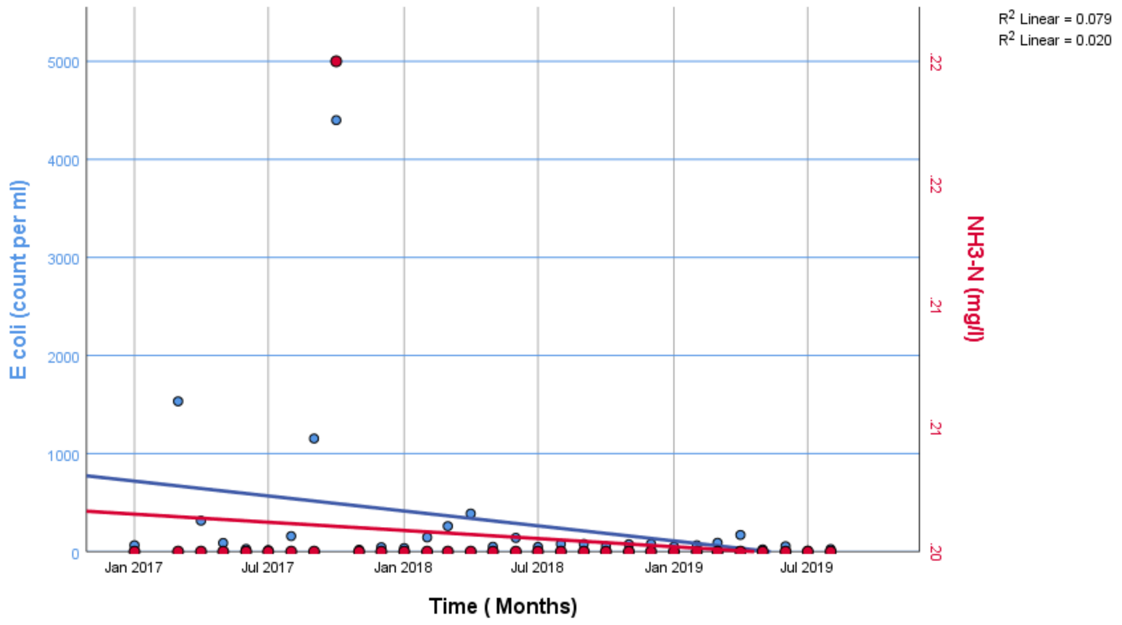

Figure 4.4: Historical Regression of Site 2 *E. coli* and Phosphate

Table 4.24: Table showing site 2 Pearson's correlation coefficient and significance.

Correlations

		Time (Months)	NO2 +NO3	E coli (count per ml)	NH3-N (mg/l)	Phosphate (mg/l)
Time (Months)	Pearson Correlation	1	-.317	-.281	-.556	-.406*
	Sig. (2-tailed)		.064	.125	.001	.015
	N	36	35	31	35	35
NO2 +NO3	Pearson Correlation	-.317	1	.260	.052	.339*
	Sig. (2-tailed)	.064		.150	.764	.043
	N	35	36	32	36	36
E coli (count per ml)	Pearson Correlation	-.281	.260	1	.643**	-.041
	Sig. (2-tailed)	.125	.150		.000	.825
	N	31	32	32	32	32
NH3-N (mg/l)	Pearson Correlation	-.556**	.052	.643**	1	-.125
	Sig. (2-tailed)	.001	.764	.000		.467
	N	35	36	32	36	36

Phosphate (mg/l)	Pearson Correlation	-.406*	.339*	-.041	-.125	1
	Sig. (2-tailed)	.015	.043	.825	.467	
	N	35	36	32	36	36

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Figures 4.3 & 4.4 above show a graph plotting the concentrations of Site 2 constituents (*E. coli,* Ammonia, Phosphate and Nitrate & Nitrite) over time. Both graphs indicate a negative regression of constituent's concentration over time, which signified that the concentration of these constituents is gradually decreasing. Coefficient of determination (R^2 value) ranging between 2 % to 16.5 % was observed, indicating partial variability of the response data around the mean.

Table 4.20 above shows the Pearson (Bivariate) correlation of *E. coli*, Ammonia, Phosphate, Nitrite-Nitrate, and time (months between 2017 to 019). The results show a negative Pearson's correlation coefficient for all the constituents with time, which signifies a negative linear correlation. The results also show that the observed bivariate correlation between Ammonia and time is statistically significant ($r = -0.556$, $P < 0.05$), showing a negative linear relationship between the concentration of Ammonia and time. This signifies that there is a steady decrease in the concentration of Ammonia in the water resource. A similar study was conducted by Mattikali (1995) analysing historical surface water quality data of River Glen Catchment using both graphical analysis and statistical analysis and the study shows an increasing trend in the Nitrogen (total oxidised nitrogen) in the water resource. The study area is dominated by agricultural land use with small urban areas. These results are contrary to the current study since a decrease in oxidised nitrogen (nitrite and nitrate) was observed in the water quality of the water resource.

4.3.3 Kanyamazane WWTW (Site 3)

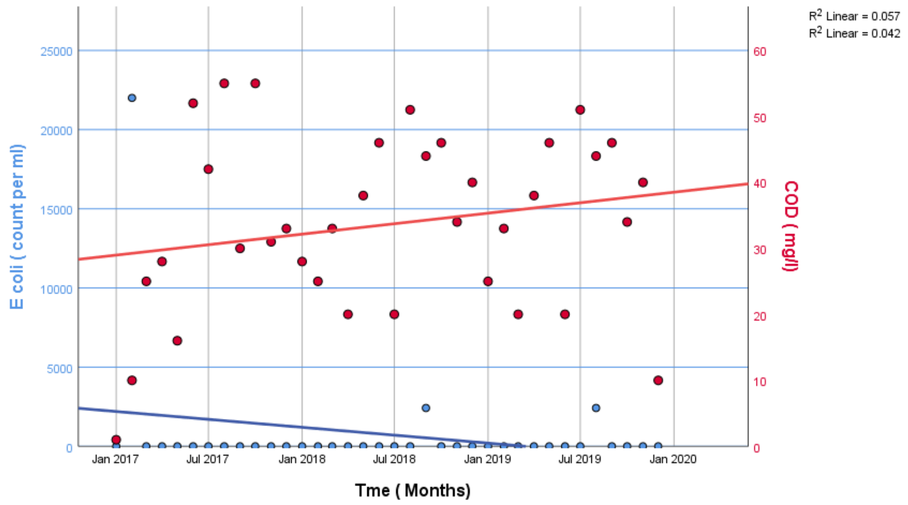

Figure 4.5: Historical Regression of Site 3 *E. coli* and COD

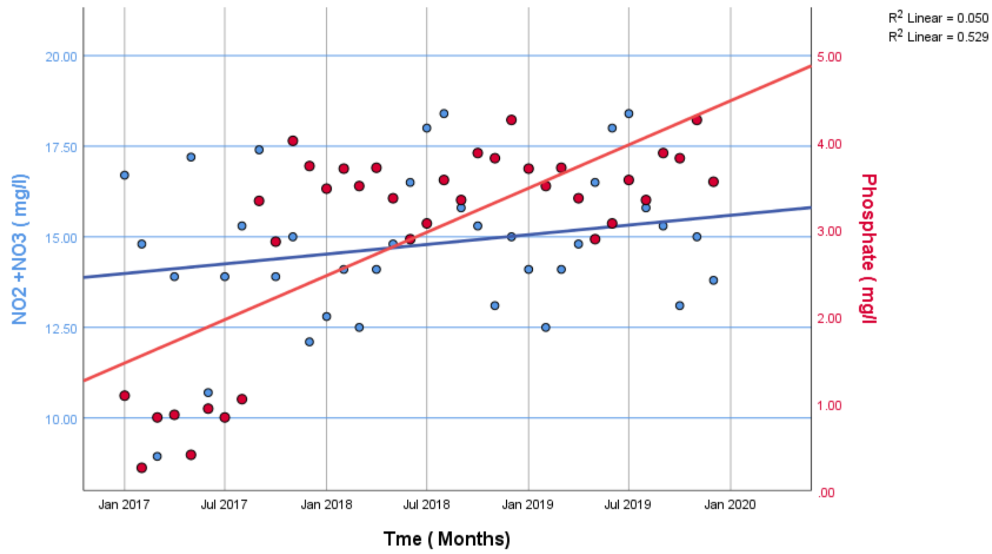

Figure 4.6: Historical Regression of Site 2 NO2+NO3 and Phosphate

Table 4.25: Table showing site 3 Pearson's correlation coefficient and significance.

Correlations

		Time (Months)	NO2 +NO3 (mg/l)	Phosphate (mg/l)	COD (mg/l)	E coli (count per ml)
Time (Months)	Pearson Correlation	1	.223	.727**	.206	-.238
	Sig. (2-tailed)		.191	.000	.228	.163

	N	36	36	36	36	36
NO2 +NO3 (mg/l)	Pearson Correlation	.223	1	.123	.035	.021
	Sig. (2-tailed)	.191		.476	.840	.903
	N	36	36	36	36	36
Phosphate (mg/l	Pearson Correlation	.727**	.123	1	.199	-.362*
	Sig. (2-tailed)	.000	.476		.244	.030
	N	36	36	36	36	36
COD (mg/l)	Pearson Correlation	.206	.035	.199	1	-.269
	Sig. (2-tailed)	.228	.840	.244		.113
	N	36	36	36	36	36
E. coli (count per ml)	Pearson Correlation	-.238	.021	-.362*	-.269	1
	Sig. (2-tailed)	.163	.903	.030	.113	
	N	36	36	36	36	36

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Figure 4.5 & 4.6 above show a graph plotting the concentrations of Site 3 constituents (*E. coli,* Chemical Oxygen Demand, Phosphate and Nitrate & Nitrite) over time. The graph in figure 4.6 indicates a positive regression of constituent's concentration whereas, figure 4.5 shows positive regression (COD and time) and negative regression (*E. coli* and time). A low coefficient of determination (R- squared value) however was observed which ranged between 4.2 % to 5.7 %, indicating low variability of the response data around the mean. Table 4.19 above shows the Pearson (Bivariate) correlation of *E. coli*, COD, Phosphate, Nitrite-Nitrate, and time (months between 2017- 2019). The results show that the observed bivariate correlation between Phosphate and time is statistically significant ($r = 0.727$, $P < 0.01$), showing a strong relationship between the concentration of Phosphate and time.

The results also show that the bivariate correlation between Phosphate and nitrate is statistically insignificant ($r = 0.123$, $P = 0.476$), showing no relationship between the variables These results are in line with the study conducted by Osode and Okoh, (2009) assessing the impact of discharged wastewater final effluent on the physicochemical qualities of a receiving watershed which showed that the correlation between phosphate and nitrate was statistically insignificant, and the study further suggests that since the concentrations of nitrate and phosphate were observed to be high, eutrophication is intensified in the vicinity of the effluent discharge points.

4.3.4 Kanyamazane N4 Bridge (Site 4)

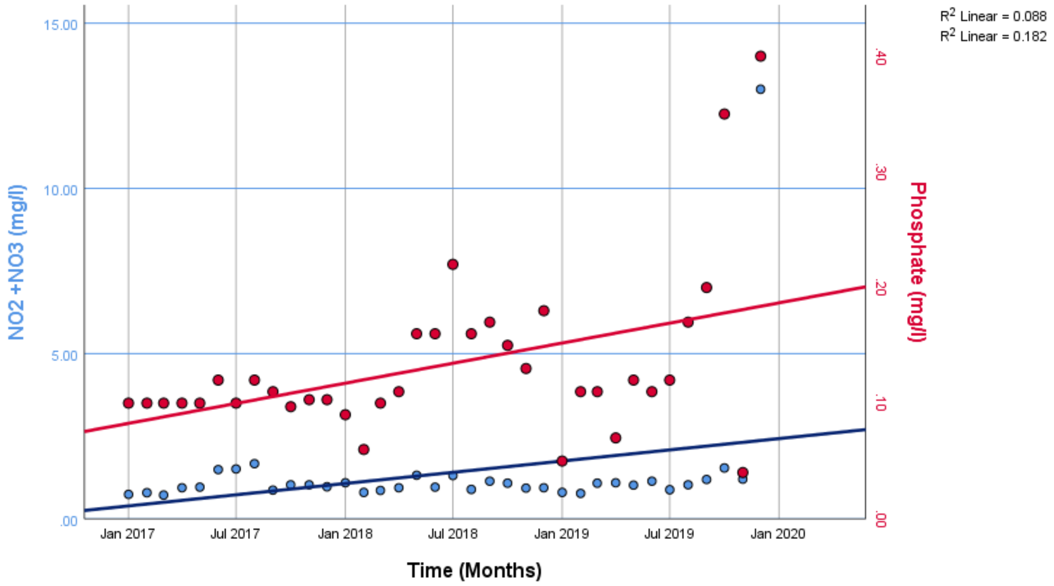

Figure 4.7 Historical Regression of Site 4 Nitrite-Nitrate and Phosphate

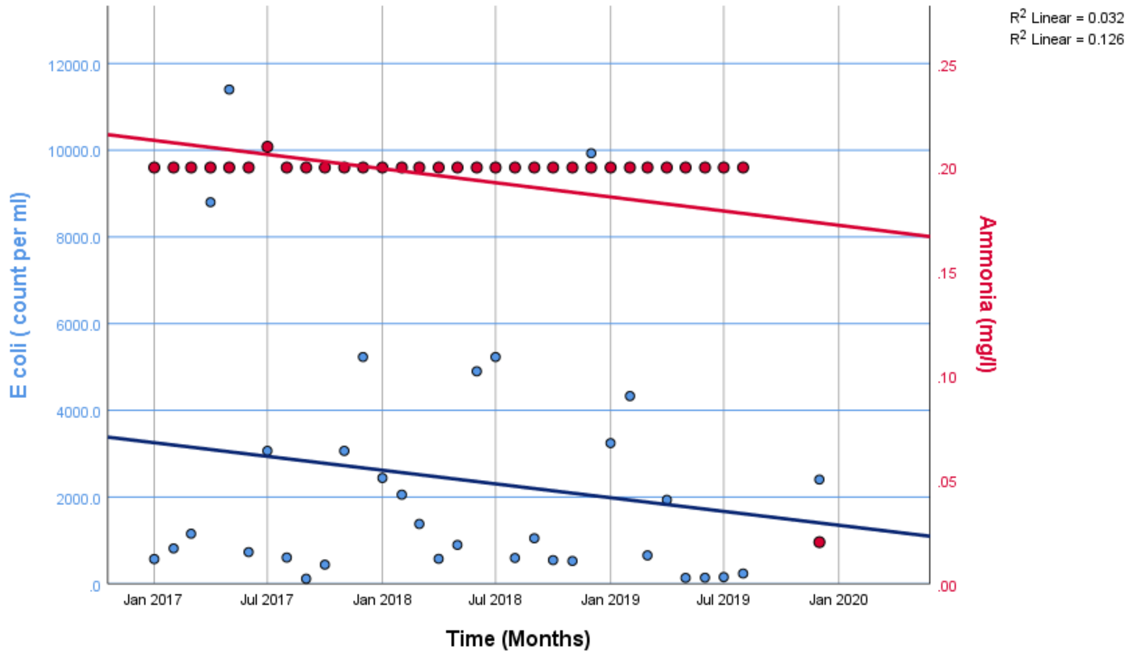

Figure 4.8: Historical Regression of Site 4 *E. coli* and Ammonia

Table 4.26: Table showing site 4 Pearson's correlation coefficient and significance.

Correlations

		Time (Months)	NO2 +NO3 (mg/l)	Phosphate (mg/l)	Ammonia (mg/l)	E coli (count per ml)
Time (Months)	Pearson Correlation	1	.297	.427**	-.534**	-.179
	Sig. (2-tailed)		.078	.009	.001	.320
	N	36	36	36	36	33
NO2 +NO3 (mg/l)	Pearson Correlation	.297	1	.674**	-.561**	-.010
	Sig. (2-tailed)	.078		.000	.000	.957
	N	36	37	37	37	33
Phosphate (mg/l)	Pearson Correlation	.427**	.674**	1	-.687**	.049
	Sig. (2-tailed)	.009	.000		.000	.787
	N	36	37	38	37	33
Ammonia (mg/l)	Pearson Correlation	-.534**	-.561**	-.687**	1	.002
	Sig. (2-tailed)	.001	.000	.000		.990
	N	36	37	37	37	33
E Coli (count per ml)	Pearson Correlation	-.179	-.010	.049	.002	1
	Sig. (2-tailed)	.320	.957	.787	.990	
	N	33	33	33	33	33

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 4.5 & 4.6 above show graphs plotting the concentrations of Site 3 constituents (*E. coli,* Ammonia, Phosphate and Nitrate & Nitrite) over time. Figure 4.5 reveals the graph indicating a positive regression of the concentration of Nitrite-Nitrate and Phosphate, showing a gradual increase in concentration over time and Figure 4.6 shows the graph indicating a negative regression of the concentration of Ammonia and *E. coli* signifying a gradual decrease of the concentration over time. An R^2 value ranging between 3.2 % to 18.2 % was also observed, indicating partial variability of the response data around the mean.

Table 4.21 above shows the Pearson (Bivariate) correlation of *E. coli*, Ammonia, Phosphate, Nitrate-Nitrate, and time (months between 2017 to 2019). The results show a positive Pearson's correlation coefficient for Nitrite-Nitrate and Phosphate with time, which signifies a positive linear correlation. The results also show a negative Pearson's correlation coefficient for Ammonia and *E. coli* with time, which signifies a negative linear correlation. A Pearson's correlation coefficient of r = -0.534 was observed between Ammonia and time which reveals a high statistical significance (P < 0.05). This signifies that there is a steady decrease in the concentration of Ammonia in the water resource. The results also show that the bivariate correlation between ammonia and Nitrite-Nitrate is statistically significant (r = -.561, P < 0.01), showing a strong relationship between the variables.

A study was conducted by Alam et al (2015) to assess water quality parameters and their correlation in two wetland beels situated in Bangladesh and the results revealed that there was a positive and highly significant correlation between ammonia and nitrate (r = 0.724; P< 0.01). The study further revealed that the wetlands were concentrated with ammonia and nitrate which is mainly attributed to agricultural runoff. This study is contrary to the results obtained in site 4 which showed a negative highly significant correlation between ammonia and nitrate. This further reveals that as the concentration of ammonia increases, there is a steady decrease in the concentration of nitrate within the water resource.

4.3.5 Matsulu WWTW (Site 5)

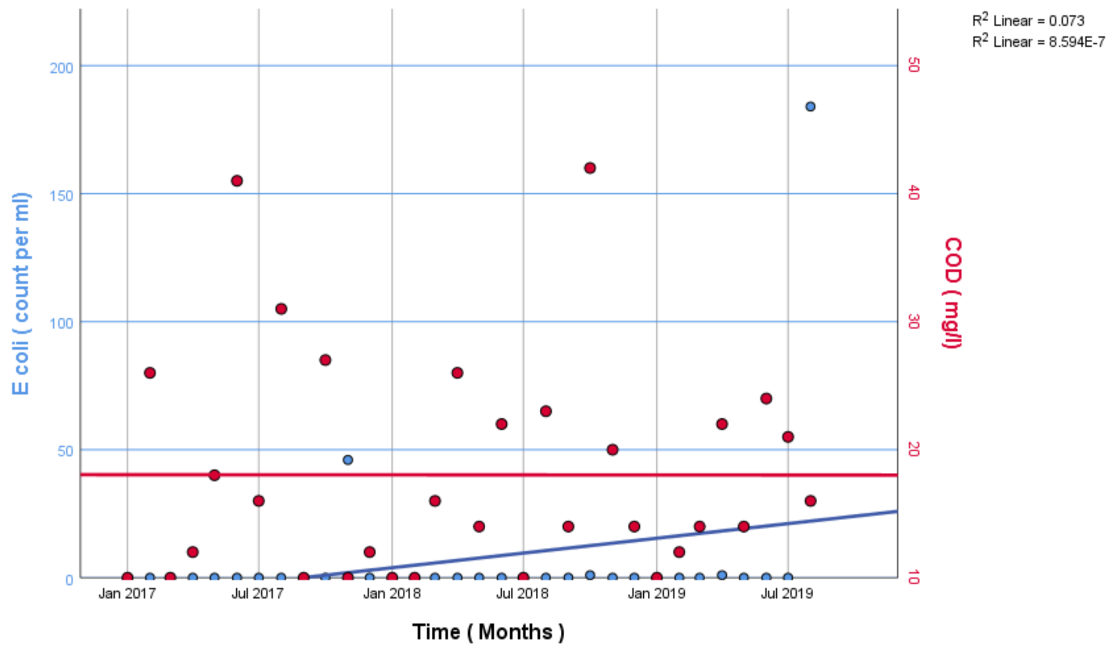

Figure 4.9: Historical Regression of Site 5 *E. coli* and COD

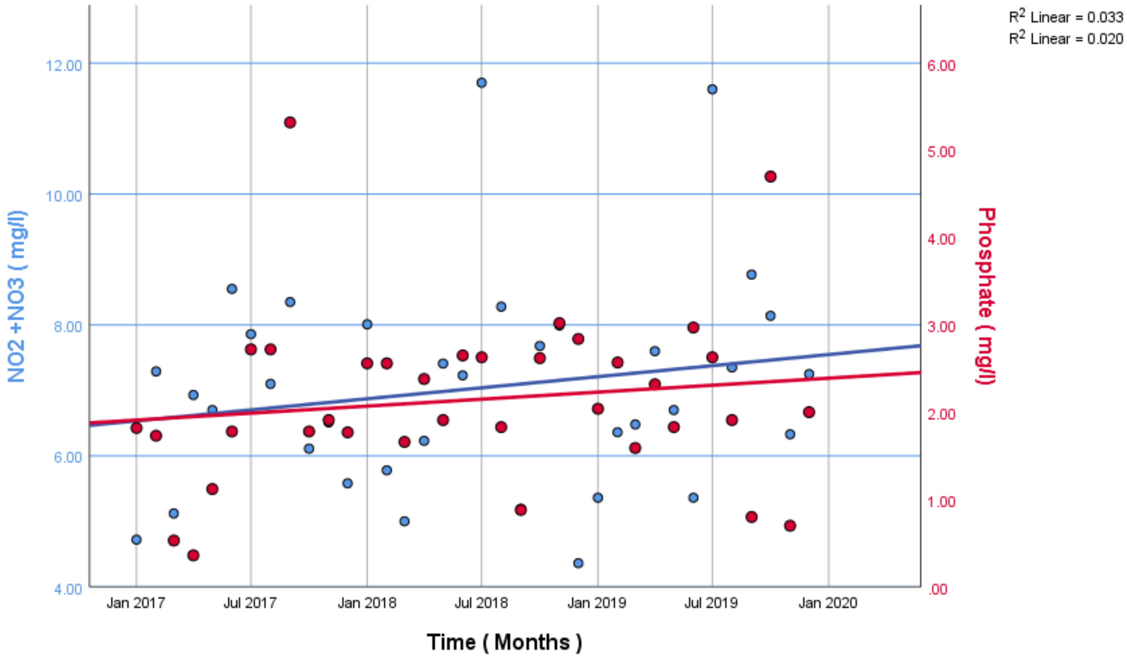

Figure 4.10: Historical Regression of Site 5 Nitrite- Nitrate and Phosphate

Table 4.27: Table showing site 5 Pearson's correlation coefficient and significance.

Correlations

		Time (Months)	NO2 +NO3 (mg/l)	Phosphate (mg/l)	COD (mg/l)	E coli (count per ml)
Time (Months)	Pearson Correlation	1	.182	.141	.185	.271
	Sig. (2-tailed)		.287	.412	.296	.134
	N	36	36	36	34	32
NO2 +NO3 (mg/l)	Pearson Correlation	.182	1	.286	.162	.031
	Sig. (2-tailed)	.287		.090	.359	.865
	N	36	36	36	34	32
Phosphate (mg/l)	Pearson Correlation	.141	.286	1	-.028	-.061
	Sig. (2-tailed)	.412	.090		.877	.740
	N	36	36	36	34	32
COD (mg/l)	Pearson Correlation	.185	.162	-.028	1	-.081
	Sig. (2-tailed)	.296	.359	.877		.661
	N	34	34	34	34	32
E coli (count per ml)	Pearson Correlation	.271	.031	-.061	-.081	1
	Sig. (2-tailed)	.134	.865	.740	.661	
	N	32	32	32	32	32

Figures 4.7 & 4.8 above show a graph plotting the concentrations of Site 5 constituents (*E. coli,* Chemical Oxygen Demand, Phosphate and Nitrate & Nitrite) over time. Figure 4.7 indicates a positive regression of *E. coli* count, the figure also shows a zero regression of COD's concentration over time. A low coefficient of determination (R- squared value) however was observed which ranged between 0.0 % to 7.3 %, indicating no variability of the response data around the mean. It can also be observed in figure 4.7 & 4.8 that a lower coefficient of determination was established due to the concentration fluctuation of all the constituents between the period of 2017-2019. This trend was also observed from Site 1 and it was established that fluctuations in effluent quality are a result of influent variables such as flow, influent organic load, inflow suspended solids, environmental conditions such as the temperature of wastewater and the size of the plant (Niku and Schroeder,1981).

Table 4.19 above shows the Pearson (Bivariate) correlation of *E. coli*, COD, Phosphate, Nitrite-Nitrate, and time (months between 2017- 2019). The results show a positive Pearson's correlation coefficient for all the constituents with time, which signifies a positive linear correlation. The results also show that the bivariate correlation between Phosphate and time (r = 0.141, P = 0.412), Nitrite-Nitrate and time (r = 0.182, P = 0.487) is statistically insignificant. Similar to results in Site 1, these results are also in line with the study conducted by Osode and Okoh (2009) assessing the impact of discharged wastewater final effluent on the physicochemical qualities of a receiving watershed which showed that the correlation between phosphate and nitrate was statistically insignificant.

4.3.6 Downstream Komatipoort WWTW (site 6)

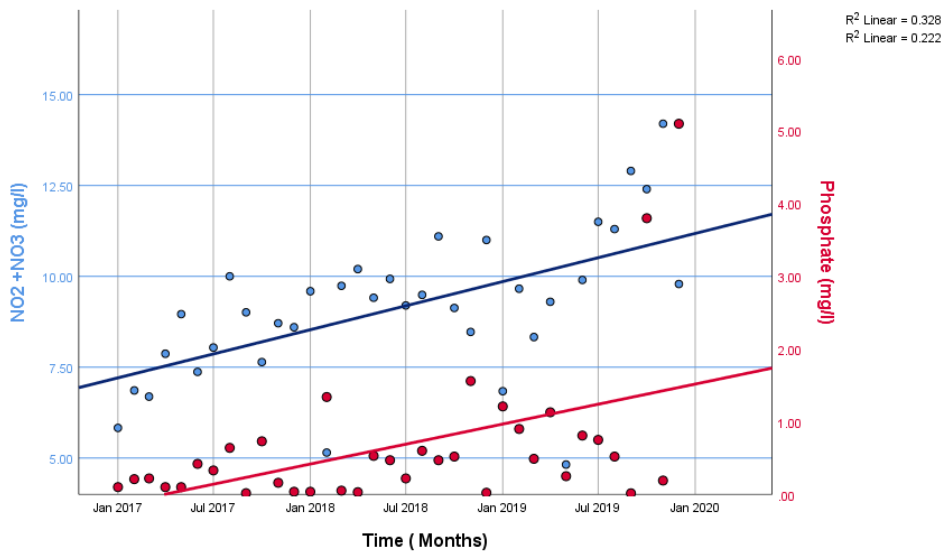

Figure 4. 11: Historical Regression of Site 6 Nitrite -Nitrate and Phosphate

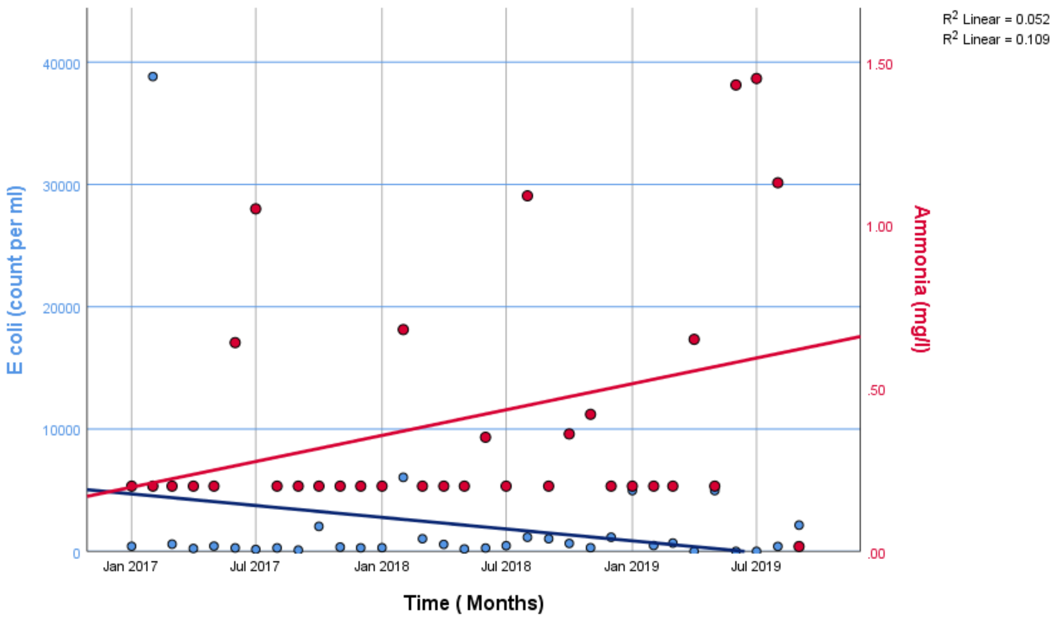

Figure 4. 12: Historical Regression of Site 6 *E. coli* and Ammonia

Table 4. 28: Table showing site 5 Pearson correlation coefficient and significance.

Correlations

		Time (Months)	NO2 +NO3 (mg/l)	Phosphate (mg/l)	Ammonia (mg/l)	E coli (count per ml)
Time (Months)	Pearson Correlation	1	.573**	.471**	.311	-.229
	Sig. (2-tailed)		.000	.004	.065	.200
	N	36	36	36	36	33
NO2 +NO3 (mg/l)	Pearson Correlation	.573**	1	.121	.264	-.302
	Sig. (2-tailed)	.000		.474	.115	.087
	N	36	37	37	37	33
Phosphate (mg/l)	Pearson Correlation	.471**	.121	1	.459**	-.034
	Sig. (2-tailed)	.004	.474		.004	.850
	N	36	37	37	37	33
Ammonia (mg/l)	Pearson Correlation	.311	.264	.459**	1	-.124
	Sig. (2-tailed)	.065	.115	.004		.492
	N	36	37	37	37	33
E Coli (count per ml)	Pearson Correlation	-.229	-.302	-.034	-.124	1
	Sig. (2-tailed)	.200	.087	.850	.492	
	N	33	33	33	33	33

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 4.9 & 4.10 above show graphs plotting the concentrations of Site 6 constituents (*E. coli,* Ammonia, Phosphate and Nitrate & Nitrite) over time. Figure 4.9 reveals the graph indicating a positive regression of the concentration of Nitrite-Nitrate and Phosphate over time, indicating a gradual increase in concentration over time and Figure 4.10 reveals the graph indicating a negative regression of the concentration *E. coli* over time signifying a gradual decrease of the concentration and a positive regression of the concentration of Ammonia. A coefficient of determination (R- squared value) ranging between 5.2 % to 32.8 % was observed, indicating partial variability of the response data around the mean.

Table 4.21 above shows the Pearson (Bivariate) correlation of *E. coli*, Ammonia, Phosphate, Nitrate-Nitrate, and time (months between 2017 to 019). The results show a positive Pearson's correlation coefficient for Nitrite-Nitrate, Ammonia and Phosphate with time, which signifies a positive linear correlation. The results also show a negative Pearson's correlation coefficient for *E. coli* with time, which signifies a negative linear correlation. A Pearson's correlation coefficient of $r = 0.573$ and $P < 0.05$ was observed between Nitrite-Nitrate and time which shows a strong correlation, furthermore a positive linear relationship between the concentration of Nitrite-Nitrate and time signifying that there is a steady increase of the concentration of Nitrite-Nitrate in the water resource over time. The results also show that the bivariate correlation between Phosphate and Ammonia is statistically significant ($r = 0.459$, $P < 0.05$), showing a moderate correlation between the variables. These results are in line with the study conducted by Liu et al., (2018) to assess surface water quality in the Gem River Basin in Korea using multivariate statistical techniques and the results of the study revealed a strong correlation between Phosphate and Ammonia (Total reduced nitrogen) ($r = 0.701$) within the Kanwol lake. Based on the statistical analysis of the water quality of the water resource, the study further concluded that that eutrophication from excessive algal growth is a complex function of various water quality parameters that were also analysed (COD, total phosphorus, pH, total nitrogen).

4.4 Water Quality Index

Classification of the water quality of the water resource concerning the weighted arithmetic WQI is shown in table 4.24 below and the computed WQI for different sites (Site 1 3, 5) Is shown in tables 4.25 – 4.27. The present index is based on the desirable and permissible limits of *E. coli.* , pH, EC, phosphate, Nitrite- nitrate and ammonia defined by the resource quality objectives of Crocodile River.

Table 4.29: classification of the water quality concerning the weighted arithmetic WQI (Brown et al, 1972; Banda & Kumarasamy , 2020)

Water Quality Index	Water Quality Status / Classification
0-25	Class 1 – Good water quality
26-50	Class 2 – Acceptable water quality
51-75	Class 3 – Regular water quality
76-100	Class 4 – poor water quality
>100	Class 5- Very poor water quality

Table 4.30: Calculation of the water quality index (WQI) of the crocodile river in Site 1

Parameters	Standard Value (Sn)	1/Sn	∑1/Sn	K=1/(∑1/Sn)	Wi=K/Sn	IDEAL VALUE (Vo)	MEAN CONC. VALUE (Vn)	Vn/Sn	Qn=Vn/Sn*100	WnQn
E.Coli	130	0.007692	8.472958	0.118022531	0.0009079	0	314.03	2.4156154	241.5615385	0.219305417
pH	8.5	0.117647	8.472958	0.118022531	0.013885	7	7.64	0.42	42	0.583170155
Electric Conductivity	70	0.014286	8.472958	0.118022531	0.001686	0	30.83	0.4404286	44.04285714	0.07425785
Phosphates	0.125	8	8.472958	0.118022531	0.9441803	0	0.0401	0.3208	32.08	30.28930244
Nitrate + Nitrite	6	0.166667	8.472958	0.118022531	0.0196704	0	0.1331	0.0221833	2.218333333	0.043635553
Ammonia	6	0.166667	8.472958	0.118022531	0.0196704	0	0.1803	0.03005	3.005	0.059109618
Sum (∑)					1					**WQI= 31.27**

Table 4.31: Calculation of the water quality index (WQI) of the crocodile river in Site 4

Parameters	Standard Value (Sn)	1/Sn	∑1/Sn	K=1/(∑1/Sn)	Wi=K/Sn	IDEAL VALUE (Vo)	MEAN CONC. VALUE (Vn)	Vn/Sn	Qn=Vn/Sn*100	WnQn
E.Coli	130	0.007692	8.472958	0.118022531	0.0009079	0	2404	18.492308	1849.230769	1.678853049
pH	8.5	0.117647	8.472958	0.118022531	0.013885	7	7.82	0.53	53	0.735905195
Electric Conductivity	70	0.014286	8.472958	0.118022531	0.001686	0	25.48	0.364	36.4	0.061371716
Phosphates	0.125	8	8.472958	0.118022531	0.9441803	0	0.13	1.04	104	98.19474608
Nitrate + Nitrite	6	0.166667	8.472958	0.118022531	0.0196704	0	1.38	0.23	23	0.452419703
Ammonia	6	0.166667	8.472958	0.118022531	0.0196704	0	0.18	0.03	3	0.059011266
Sum (∑)					1					**WQI= 101.18**

Table 4.32: Calculation of the water quality index (WQI) of the crocodile river in Site 6

Parameters	Standard Value (Sn)	1/Sn	∑1/Sn	K=1/(∑1/Sn)	Wi=K/Sn	IDEAL VALUE (Vo)	MEAN CONC. VALUE (Vn)	Vn/Sn	Qn=Vn/Sn*100	Wn Qn
E.Coli	130	0.007692	8.472958	0.118022531	0.0009079	0	2144	16.492308	1649.230769	1.497279924
pH	8.5	0.117647	8.472958	0.118022531	0.013885	7	8.1	0.73	73	1.013605269
Electric Conductivity	70	0.014286	8.472958	0.118022531	0.001686	0	125.3	1.79	179	0.301800473
Phosphates	0.125	8	8.472958	0.118022531	0.9441803	0	0.67	5.36	536	506.0806144
Nitrate + Nitrite	6	0.166667	8.472958	0.118022531	0.0196704	0	9.14	1.5233333	152.3333333	2.996460935
Ammonia	6	0.166667	8.472958	0.118022531	0.0196704	0	0.488	0.0813333	8.133333333	0.159986098
Sum (∑)					1					**WQI= 512.05**

4.4.1 Whiteriver – Crocodile River confluence (Site 2)

Table 4.25 above shows the calculation of water quality index (WQI) of water quality of Crocodile River in site 2 and the standard value (Sn) of the selected six water quality parameters is according to the Resource Quality Objective of the catchment (see table 4.1). Based on the classification of the water quality concerning the weighted arithmetic WQI method as shown in Table 4.24, it was observed that the water quality index value for site 2 was recorded as 31.3, which indicates acceptable water quality. These results are in line with a study conducted by Sener et al., (2017) to evaluate the water quality of Aksu River using a Water Quality Index (WQI). The study included 21 sampling sites located within the river and it was observed that the WQI value sampling sites located mostly in the middle region ranged between 37.6 – 62.9 during both dry and wet season, showing water of good quality.

4.2.2 Kanyamazane N4 bridge (Site 3)

Table 4.26 above shows the calculation of the water quality index (WQI) of Crocodile River in Site 3 and based on the classification of the water quality shown in Table 4.24, the water quality index value of this Site was recorded as 101.2, which indicates very bad water quality. It can be observed that the bad water quality can be attributed to high *E coli* counts present in the water. These results are in line with the study conducted by Ewaid and Abed (2017) which outlined that WQI values showing poor water quality as observed from Site 3 can be attributed to natural phenomena and anthropogenic activities such as wastewater discharge occurring along the river. Medeiros et al., (2017) also conducted a similar study on the quality index of surface water of Amazonian rivers and it was noted that WQIs determined for the water resources flowing through or located to urban centres or populated areas is impacted by domestic and industrial untreated effluents and highlighted that lack of adequate of sanitation services and treatment processes has been the main reason for water quality deterioration in these water resources.

4.4.3 Downstream Komatipoort WWTW (Site 5)

Table 4.27 above shows the calculation of the water quality index (WQI) of Crocodile River in Site 5. The quality index value of the site was recorded as 501.05 and based on the classification of the water quality (table 4.24), it was observed that the quality of the water was very poor. This site is situated downstream Komatipoort wastewater treatment works approximately 50 meters downstream. These results are also in line with a study conducted by Sener et al., (2017) to evaluate the water quality of Aksu River using a Water Quality Index (WQI) and it was observed that the WQI value for certain sampling sites located in the upper regions of Aksu River reached a maximum of 304.51 during the dry season and 304.33 during the wet season, which represent extremely poor water quality. From tributaries, the study further outlined that the reason for such poor water quality was the input of municipal and industrial wastewater discharged at the banks of the river (Sener et al., 2017), which also supports the high water quality index noted in Site 5.

4.5. Operational analysis of the Wastewater treatment works.

4.5.1 Whiteriver Wastewater Treatment Plant

Figure 4.13: A google image showing the location and layout of White River WWTW (google earth, 2021)

White River Wastewater treatment plant has a design capacity of 6 Mega litres per day (ML/d) and the type of process technology utilized is activated sludge process, treating only domestic wastewater from White River town. During the period study, there was no measuring device present hence the operating flowrate Is unknown. The plant is authorised in terms of the National Water Act (Licence no. 24089442) to discharge treated effluent into White River and also classified as class B (02/07/2012) in terms of regulation 2834 (IUCMA, 2014). From water quality data of the study period (2017- 2019), it is evident that the plant was frequently not compliant with the limits set as per the water use licence. Parameters that were mostly above the limit in the effluent were chemical oxygen Demand, phosphate, ammonia and *E. coli.* The removal of carbonaceous material and nutrients (nitrogen and phosphorus) from wastewater using an activated sludge process requires three bioreactors or bioreactor zones in series (anaerobic, anoxic, and aerobic) in which their conditions are different and complicated (Mujtaba et al, 2017). Nitrogen removal is achieved through nitrification and denitrification using aerobic and anoxic zones respectively, phosphorus is removed through the coupling of anaerobic and aerobic zones. Removal of organics takes place in the aerobic zone, its availability is necessary for the concurrent removal of nitrogen and phosphorus since denitrifying bacteria (nitrogen removing bacteria) and phosphate accumulating bacteria (phosphorus removing bacteria) need organic carbon as a substrate for their metabolism (Mujtaba et al, 2017). Figure 4.12 below show the green drop score rating of the performance of wastewater treatment works in South Africa, and it can be noted from figure 4.13 below that Whiteriver WWTW had a score less than 70 % which indicate that the plant is performing poorly based on the green drop assessment undertaken in 2009, 2011 and 2013.

Color Codes	***Percentage***	***Appropriate Action by Municipality***
GREEN	90 - 100%	Excellent
ORANGE	70 - <89%	Good Status
YELLOW	40 - <69%	Poor Performance
RED	0 - <39%	Critical State

Figure 4.14: Table showing green drop score rating of the performance of the wastewater treatment works (DWA, 2013)

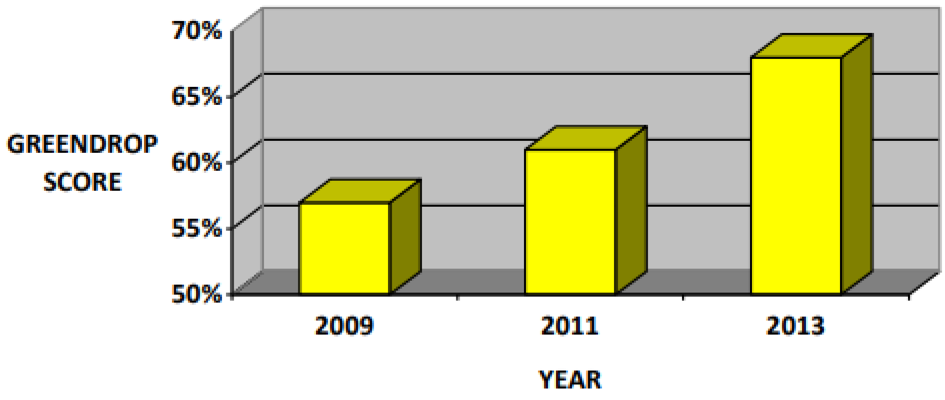

Figure 4.14: Graph showing green drop score for White River Wastewater Treatment Works (DWA, 2013)

For the wastewater treatment to be compliant with the effluent limits especially with regards to the non-compliant parameters, White river WWTW should take note of the following:

a. Ensure that there is sufficient oxygen transfer taking place in the aerobic zone, which is achieved through surface aeration, the concentration of oxygen should be at least 2 mg/l in the aerobic zone (WRC, 1984), for the complete oxidation of ammonia to nitrite, then to nitrate (nitrification) by *Nitrosomonas* and *Nitrobacter* respectively. It is evident from the effluent quality that oxidation of ammonia is not properly undertaken hence ammonia concentration is above the limit. Frequent repair and maintenance of plant equipment and machinery such as aerators must be undertaken to ensure sufficient transfer of oxygen into the water. Removal of Nitrogen from wastewater cannot be achieved if there is a partial conversion of ammonia to nitrate, because the removal of nitrogen as gas is based on the methodology that nitrate is reduced through a series of multiple biochemical reactions to Nitrogen gas by heterotrophic bacteria (WRC, 1984; Azimi et al, 2007; Mujtaba et al., 2017)
b. Biological phosphorus removal is achieved through excessive phosphorus release and uptake by phosphorus accumulating organisms (PAO) under anaerobic and aerobic conditions respectively. The plant should ensure there is no oxygen present in the anaerobic zone (Barnard et al.,1985; Randall et al., 1998; Goel and Motlagh, 2013). pH also plays an important role in biological phosphorus removal since the organisms responsible have an optimum level. PH must be maintained between 7.5 – 8.5. This is in line with studies conducted by Liu et al. (1996) and Converti et al. (1995) which concluded that an acidic pH had a negative impact on both organic carbon uptake and phosphate release in an anaerobic stage which is crucial for excessive phosphorus removal process taking place in the following process in the aerobic zone. These

studies also concluded that it is essential to stabilize pH because when the pH reduced from 7.2 to a weakly acidic value of 6.3, the phosphorus removal efficiency was affected drastically and it required 15 days to re-establish steady-state condition effective for biological nutrient removal.

c. Removal of pathogenic microorganisms from wastewater treatment effluent is of great importance for the protection of public health and also for the protection of ecological integrity. *E. coli* is mostly used as an indicator organism of the presence of pathogenic microorganisms present in water. It is important to note that the removal of pathogens does not occur only in the disinfection process, but also occurs simultaneously during the removal of particulate and insoluble organic matter during primary treatment. White River WWTW needs to take note that for successful removal of pathogens, primary treatment should also be effective.

Figure 4.15 A & B: State of a wastewater treatment plant in white River WWTW

Figure 4.16 A & B: Poor aesthetic quality of treated effluent from white River WWTW (2019)

4.5.2 Matsulu Wastewater Treatment Plant

Figure 4.17: A google image showing the location and layout of Matsulu WWTW (google earth, 2021)

Matsulu Wastewater treatment plant is situated approximately 30 km east of Mbombela City and has a design capacity of 6 Mega litres per day (ML/d) and the type of process technology utilized is activated sludge process, treating only domestic wastewater from the Matsulu location. The plant is authorised in terms of the National Water Act to discharge treated effluent into the Crocodile River and also classified as class C in terms of regulation 2834 (IUCMA, 2014). From water quality data of the study period (2017- 2019), It is evident that the plant was frequently compliant to most parameters set as per the water use licence. Parameter observed that was not compliant to the set limit (limit of 1 mg/l) was phosphate, its concentration ranged between 2- 5 mg / l. Matsulu WWTW should take note of the following:

a. For successful removal of phosphorus from wastewater and to ensure compliance with phosphate limit, a minimum readily biodegradable COD concentration in the anaerobic zone to stimulate phosphorus release by PAO is about 25 mg COD/l (WRC, 1984), and the degree of release increase as the concentration of biodegradable COD increases. Excessive phosphorus uptake by PAO is only obtained only when phosphorus release has taken place and tend to increase with increasing biodegradable COD (WRC, 1984). Mulkerrins et al (2004) noted that the biological phosphorus removal process is also sensitive to disturbances such as dilution of wastewater by heavy rainfall, with prolonged disturbances leading to recovery after 4 weeks. Matsulu WWTW should ensure that sufficient biodegradable COD is present in the anaerobic zone to stimulate P release since the plant receives influent containing low to medium biodegradable COD. Changes in organic composition from Volatile Acids (VFA) to sugars, such as glucose may induce accumulation of glycogen accumulating organisms (GAO's) (Mulkerrins et al (2004), which can effectively aid in the removal of phosphorus in the water.

b. However, it should also be noted that higher COD – suspended solids (600 mg/l) can lead to cessation of anaerobic P release and P removal capability.

Figure 4.18 A & B: State of a wastewater treatment plant in Matsulu WWTW

Figure 4.19 A & B: Good aesthetic quality of treated effluent from white River WWTW (2019)

4.5.3 Kanyamazane Wastewater Treatment Plant

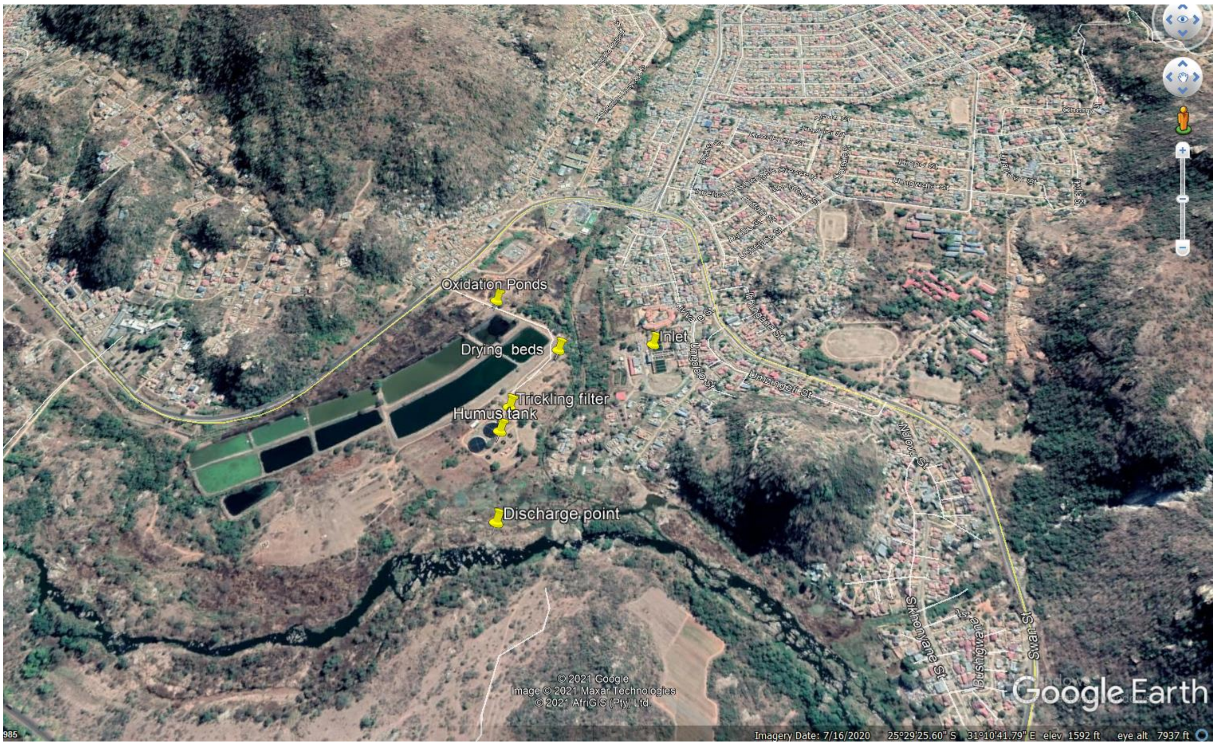

Figure 4.20: A google image showing the location and layout of Kanyamazane WWTW (google earth, 2021)

Kanyamazane WWTW was commissioned in 1972 with a design capacity of 12 Mega litres per day (ML/d), operating at 5 Ml/day. The type of process technology utilized is the oxidation pond system, treating only domestic wastewater from Kanyamazane Township. The plant is authorised in terms of the National Water Act to discharge treated effluent into the Crocodile River and also classified as class D in terms of regulation 2834 (IUCMA, 2014). From water quality data of the study period (2017- 2019), it is evident that the plant was frequently compliant to the limits set as per the water use licence. Parameter observed that was not compliant to the set limit (limit of 1 mg/l) was phosphate, its concentration ranged between 1.5 – 4.7 mg / l. The municipality should conduct a feasibility study and assess the cost and benefit of installing a secondary treatment process to specifically remove phosphate from the effluent and to ensure complete compliance to the requirement of the WUL since it is evident from the water quality trend that the current treatment technology cannot meet the phosphate limit requirement.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Protection of water resources is of utmost importance, not only to safeguard human health but also to sustain the integrity and functioning of the aquatic and terrestrial ecosystem. This study focus was to assess the impact of Wastewater treatment effluent on the quality of Crocodile River with the aim to monitor compliance of selected WWTWs with issued Water Use licences and to analyse and establish a trend of water resources pollution accumulation. The study revealed that Site 1 was not complying with the effluent standards set out in their WUL This was evidenced by the effluent's Ammonia, Nitrate-Nitrite, *E. coli* and COD concentration frequently above limit during the period of study. The effect of the pollution loading from the WWTW's effluent can be observed from a downstream sampling Site (Site 2) water quality whereby seasonal fluctuations in *E. coli* were observed which can be attributed to the discharged, however, assimilation of the discharged effluent can also be noted since is no other WWTW discharging effluent. WQI Undertaken downstream of the WWTW at Site 2 however concludes that even though there is a discharge of poorly treated effluent, the water quality of the river is still acceptable, with an index of 31.27.

The study also revealed that Site 3 and Site 5 were generally compliant with the effluent standards set out in their WULs, except for phosphate whereby It was non-compliant during the duration of the study. Regression and bivariate statistical analysis of the historic effluent quality for both WWTWs show a steady increase in phosphate concentration in the discharged effluent as time progresses. The results of the WQI conducted at Site 4, which is located downstream of site 3 revealed that the quality of the river at this point was very poor, with an index of 101.18, which was mainly attributed to high *E. coli* counts (overall mean of 2000 counts per ml). Such water quality trends and spatial distribution of nutrients and *E. coli* especially at site 4 provides information on non-point sources of pollution mainly during wet seasons, specifically from settlements around the Kanyamazane area situated next to the water resource.

Downstream Komatipoort WWTW (Site 6) water quality reveals information relating to point source pollution specifically from the discharged effluent. Concentrations of constituents were frequently non-compliant to the RQO. Regression and bivariate statistical analysis of historic water quality for this site reveal a steady increase of nitrite-Nitrate and phosphate over time. WQI conducted at this site also revealed that water quality is very poor, with an index value of

501.05, and based on the water quality trend analysis, poor water quality at this site is mainly attributed to high *E. coli* counts frequently recorded throughout the study.

The results obtained in the present study indicated that there is pollution in the Crocodile River concerning WWTW effluent related constituents studied. Based on the results of the study, the pollution of the Crocodile river can be attributed to, amongst other non-point sources, poor quality effluent discharged unto the water resource. poorly treated effluent from wastewater treatment plants discharged into the water resources has a significant impact on the functioning, integrity, and quality of the water resource and associated ecosystem. Several studies were also conducted on the impact of wastewater effluent on the receiving environment, and they confirm that there is still a lot of work that needs to be undertaken with regards to improving effluent quality to protect our water resources.

5.2 Recommendations

- A call to vigilance and aggression by responsible authorities with regards to compliance monitoring and enforcement of effluent discharge laws and regulations to ensure minimal pollution in rivers and streams.
- A comprehensive and detailed study including all WWTWs located within the Crocodile River catchment, covering a wide period of water quality data (15 to 20 years) should be undertaken to successfully assess the overall impact.
- A public awareness and education programme especially in densely populated areas situated next to a water resource is needed to educate the public on the importance of water resources and measures that can be taken by settlers to reduce non-source pollution.
- A scheduled continuous operations and maintenance program for wastewater treatment works and related infrastructure must be put in place to ensure effective operation.
- The local government should conduct a feasibility study, assess, and invest in post treatment technologies that can be integrated into current process technology to enhance the operation and ensure compliance of discharged effluent with set standards.

REFERENCES

Al – Gheeti , A.A., Efaq, A.N. , Bala, J.D., Norli, I. , Abdel-Monem, M.O. & Kadir, M.O.A. 2018. Removal of pathogenic bacteria from sewage -treated effluent and biosolids for agricultural purposes. *Applied Water Science* (2018) 8:78.

Akaahan, T.J.A., Eneji, I.S., & Azua, E.T. 2016. The relationship between surface water temperature and dissolved oxygen in river Benue at Makuedi. *European Journal of Basic and Applied Sciences*, 3(1): 52-60.

Abia , A.L., Ubombo-Jaswa, E. & Momba , M.N.B. 2015. Impact of seasonal variation on Escherichia coli concentrations in the riverbed sediments in the Apies River, South Africa. *Science of Total Environment*, 537: 462-469.

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

American Public Health Association. 2012. Standard Methods for Examination of Water and wastewater 22nd edition. New York*, United State of America: American Public Health Association.*

Amoah, D.I., Kumari, S. & Bux, F. 2020. Impact of informal settlements and Wastewater treatment plants on helminth egg contamination of urban rivers and risks associated with exposure. *Environmental Monitoring and Assessment*. (2020) 192: 713.

Ashton, P.J., 2009. An overview of the current status of water quality in South Africa and possible future trend of change. CSIR, DMS report no. 192725. Council for Scientific and Industrial Research, Pretoria.

Awufolu, O.R., Du Plessis,R. & Rampedi, I. 2007. Influence of discharged effluent on the quality of surface water utilized for agricultural purposes. *African Journal of Biotechnology*, Vol 6 (19), pp 2251-2258.

Balance, A., Hill, L., Roux, D., Silberbauer, M. & Strydom, W. 2001. State of the river report: Crocodile, Sabie-Sand and Olifants River Systems. Resource Quality Services, DWAF, Pretoria, South Africa.

Banda, T.D. & Kumarasamy. 2020. Development of a Universal Water Quality Index (UWQI) for South African River catchments. *Water,* 12, 1534.

Barnard, J., Stevens, G. & Leslie,P.J. 1985. Design Strategies for Nutrient Removal Plant.*Water Science and Technology,* 17(11-12): 233-242.

Bate, R., Tren, R. & Mooney, L. (1999). An econometric and institutional economic analysis of Crocodile River catchment, Mpumalanga Province, South Africa. WRC report No 855/1/99.

Barrow, C.J. 2006. *Environmental Management for Sustainable Development*. 2nd Ed. New York: Routledge

Bega , S., 2018. "Pollution of Vaal River at crisis point ," *Saturday Star*, Johannesburg, 02-Jan 2018.

Bougherira, N., Hani, A., Djabri, L., Toumi, F., Chaffai, H., Haied , N. ,Nechem, D. & Derati, N., 2014. Impact of the urban and industrial wastewater on surface and ground water, in region of Annaba, (Algeria). *Energy Procedia*, 50 (2014), 692-701.

Botha, F.J., 2015. Nutrient reduction options in Hartbeespoort Dam catchment to lower in-dam eutrophication status. Magister Scientiae Dissertation, North West University.

Bouaroudj, S., Menad, A., Bounamous, A., Ali-Khodja, H., Gherib , A.,Weigel , D.E. & Chenchouni, H. 2019. Assessment of water quality at the largest dam in Algeria (Beni Haroun Dam) and effects of irrigation on soil characteristics of agricultural lands. *Chemosphere*, 219(2019): 76-88.

Bougherira, N., Hani, A., Djabri, L., Toumi, F., Chaffai, H., Haied , N. ,Nechem, D. & Derati, N. 2014. Impact of the urban and industrial wastewater on surface and ground water, in region of Annaba, (Algeria). *Energy Procedia* 50 (2014), 692-701.

Brown, R.M., McClelland,N. I., Deininger, R.A. & O'Connor , M.F. 1972. A water quality index – crashing the psychological barrier.*Indicators of environmental quality ,* 173-182.

Bunce, J.T., Ndam, E. & Graham,D.W. 2018. A Review of phosphorus Technologies and Their Applicability to Small Scale Domestic Wastewater Treatment Systems. *Frontiers in Environmental Science,* 6:8.

Carey,R.O. & Migliaccio, K.W., 2009. Contribution of Wastewater Treatment Plant Effluents to Nutrient Dynamics in Aquatic Systems: A Review. *Environmental Management*, 44 (2009) , 205-217.

Chen, B., Nam, S. & Westerhoff, P.K., 2009. Fate of effluent organic matter and DBP precursors in an effluent-dominated river: A case study of wastewater impact on downstream water quality. *Water Research*, 43(2009) 1755-1765.

Chinyama, A., Ochieng, G.M., Snyman, J. & Nhapi, I., 2016. Occurrence of cyanobacteria genera in the Vaal Dam: implication for potable water production. Water SA Vol 42, No.3.
Department of Water Affairs., 2012. Report on the Status of Sanitation services in South Africa, Pretoria, South Africa.

Crossman, J., Futter, M.N., Elliot, J.A., Whitehead, P.G., Jin , L. & Dillon , P.J. 2019 . Optimizing land management strategies for maximum improvement in lake dissolved oxygen concentrations. *Science of the Total Environment*, 652(2019): 382-397.

Dadi, D., Mengistie, E., Terefe, G. , Getahun , T. , Haddis , A., Birke , W., Beyene , A., Luis , P. & Van Der Bruggen , B. (2018). Assessment of the effluent quality of wet coffee processing wastewater and its influence on downstream water quality. *Ecohydrology & Hydrobiology*, 18 (28): 201-211.

Deksissa, T., Ashton, P.J. & Vanrolleghen, P.A. 2003. Control options for river water quality improvement: A case study of TDS and inorganic nitrogen in the Crocodile River (South Africa). *Water SA*, 29(2): 209-218.

DWAF (Department of Water Affairs and Forestry). 2004. National Water Resource Strategy. Department of Water Affairs and Forestry, Pretoria. https://cer.org.za/wp-content/uploads/2017/10/NWRS-2004.pdf.

Department of Water Affairs. 2012. Report on the Status of Sanitation services in South Africa, Pretoria, South Africa.

Department of Water and Affairs. 2011. Planning level Review of water quality in South Africa: Sub series No: WQP 2.0. Pretoria, South Africa

Department of Water Affairs (DWA). 2013. Water requirements and availability Reconciliation strategy for Mbombela Municipal Area Water Quality Report. Pretoria, South Africa, Department of Water Affairs.

Department of Water and Sanitation (2013) Green drop progress executive summary , . Pretoria.

DWA (Department of Water Affairs). 1999. *Wastewater limit values applicable to discharge of wastewater into a water resource*. http://hwt.co.za/downloads/NWA%20General%20and%20Special%20Authorisations.pdf (Accessed 17 February 2021)

Dikio, E.D., 2010. Water Quality Evaluation of Vaal River, Sharpeville and Bedworth Lakes in the Vaal Region of South Africa. *Research Journal of Applied Sciences*, Engineering and Technology, 2(6): 574-579.

Ewaid, S.H. & Abed, S.A. 2017. Water quality index for Al – Gharraf River, southern Iraq. *Egyptian Journal of Aquatic Research. ,* 43(2017)117-122.

Fricke, A. & Magialojo, L. 2018. Multiple stressors and benthic harmful algal blooms (BHABs): Potential effects of temperature rise and nutrient enrichment. *Marine Pollution Bulletin,* Volume 131 , pp 552- 564.

Goel,R.K. & Motlagh, A.M. 2013. Biological phosphorus Removal. *Comprehensive Water Quality and Purification,* Vol 3.

Gray, N.F. (2004). Biology of wastewater treatment Vol.4. Imperial College Press.,London , England.

Hach, (2013). Water Analysis Handbook. https://www.hach.com/wah#W. [20 June 2019]

Inkomati-Usuthu Catchment Management Agency. (2014). Annual water quality status report for Inkomati water management area, Mpumalanga Province, South Africa.

Jackson, R.B., Carpenter, S.R., Dahm, C.N., McKnight,D.M., Naiman, R.J., Postel, S.L. & Running, S.W. 2001. Water in a Changing World. *Issues in Ecology*, Number 9, Spring 2001.

Jordaan K. & Bezuidhout, C.C. 2013. The impact of physico- chemical water quality parameters on bacterial diversity in the Vaal River, South Africa. Vol 39: No 3 (2013) *WISA Special Edition*.

Kanamugire, J.C . 2008. Offenses and penalties for water pollution in South Africa – A comprehensive analysis of South Africa, British, American and Australian legislation. Dissertation, University of Kwazulu Natal

Liu, Z., Joo, J.C., Choi, S.H., Jang,N.H.J., Hur, J.W. 2018. Assessment of Surface Water Quality in Geum River Basin, Korea using Multivariate Statistical Techniques. *International Journal of Applied Engineering Research,* vol 13, No 9(2018) pp 6723- 6732.

Machibya, M, Mwanuzi, F. 2006. Effect of Low Quality Effluent from Wastewater Stabilization Ponds to Receiving Bodies, Case of Kilombero Sugar Ponds and Ruaha River, Tanzania. *Int Environ Res Public Health*, 3(2), 209-216.

Madalina, P. & Gabriela, B. I. 2014. Water quality index- an instrument for water resource management. *International Journal of Sustainable Development and Planning*, 10(6): 781-794.

Mandaric, L., Mor, J., Sabater, S. & Petrovic, M., 2017. Impact of urban chemical pollution on water quality in small rural and effluent – dominated, Mediterranean streams and rivers. *Science of the Total Environment*, 613-614 (2018), 763-772.

Marti, E., Riera, J.L., & Sabater, F. 2010. 'Effects of wastewater treatment plants on stream nutrient dynamics under water scarcity conditions.' In Sabater, S., Barcelo, D., Eds. *Water Scarcity in the Mediterranean: Perspectives under Global Change*. Berlin/Heidelberg, Germany: Springer, 173–196, 2010.

Masindi, V. & Dunker, L.C., 2016. State of Water and Sanitation in South Africa, Built Environment, Council of Scientific and Industrial Research, Pretoria, South Africa.

Mattikalli, N.M. 1996. Time Series Analysis of Historical Surface Water Quality Data of the River Glen Catchment, U.K. *journal of Environmental Management* , Vol 46 , issue 2, pp 149-172.

Medeiros, A.C., Faial, K.R.F., Faial, K.C.F., Lopez, I.D.S., Lima, M.O., Guimaraes, R.M. & Mendonca, N.M., 2017. Quality index of the surface water of Amazonian rivers in industrial areas in Para, Brazil. *Marine Pollution Bulletin*, 123(2017), 156-164.

Mema, V.2009. Impact of poorly maintained wastewater sewage treatment plants: Lessons from South Africa. Council for Scientific and Industrial Research (CSIR) Pretoria, South Africa

Mitchell, S.A. and Crafford, J.G., 2016. Review of the HartbeespoortDam integrated biological remediation programme (Harties Metsi a me). *Water Research Commission* Report No. KV 357/16.

Nayak, S.K. 2020. Assessment of Water Quality of Brahmani River using Correlation and regression analysis. Magister Technologiae Thesis , Department of Civil Engineering , VSSUT , India.

Ndovu,S, (2018). Sewage can be seen flowing into the Rietspruit River that feeds into the Vaal River system, which supplies water to 50% of Gauteng households. [image] Available at: https://www.sowetanlive.co.za/news/south-africa/2018-11-12-restoration-of-polluted-vaal-river-system-will-take-a-year-army/php [Accessed 17 Jul. 2020].

Ngwira, L. & Lakudzala, D., 2018. Assessment pf the quality of SOBO industrial wastewater and its impact on the water quality in Nankhaka River. *Physics and Chemistry of the Earth*, Volume 108, Pages 9-12.

Niku, S. & Schroeder, E.D. 1981. Stability of Activated Sludge Processes based on statistical Measures . *Water Pollution Control Federation,* 457-470.

Ntombela, C., Funke , N., Melssner, R. ,Steyn , M. & Masangane, W., 2016. A critical look at South Africa’s Green Drop Programme, *Water SA*, Vol 42, No 4. DOI: 10.4314/wsa.v42i4.21

Okoh,A.I. , Odjadjarre, E.E., Igbinosa , E.O. & Osode , A.N., 2007. Wastewater treatment plants as a source of microbial pathogens in receiving watersheds. *African Journal of Biotechnology*, Vol. 6(25) , pp. 2932-2944.

Ogundiran, M.A. & Fawole, O.O. 2014. Assessment of the Impacts of Industrial Effluent Discharge on the Water Quality of Asa River, Ilorin, Nigeria. *IOSR Journal of Environmental Science, Toxicology and Food Technology*, 8(7): 2319-2402.

Osibanjo , O. & Adie , G. U. 2007. Impact of effluent from Bodija abattoir on the physio-chemical parameters of Oshunkaye stream in in Ibadan City, Nigeria. *African Journal of Biotechnology*, Vol 6(15) , pp.1806-1811.

Osode, A.N. & Okoh, A.I. 2009. Impact of Discharged Wastewater Final Effluent on the Physiochemical Qualities of a receiving Watershed in a Suburban community of the Eastern Cape Province. *CLEAN – Soil Air Water,* 37(12) 938 -944.

Prasse, C., Stalter, D., Schulte- Oehlamann,U. & Oehlmann, J. 2015. Spoit of choice: A critical review on the chemical and biological assessment of current wastewater treatment technologies. *Water Research*, 87 (2015): 237-270.

Pereda, O., Salagaistua,L., Atristain , M., Guzman, L., Larranaga, A., Schiller,D. and Elosegi, A., 2019. Impact of wastewater effluent pollutin on the stream functioning: Awhole-ecosystem manipulation experiment. *Environmental Pollution*.

Qadir, M., Wichelns, D., Raschild-Sally, L., McCornick, P.G., Drechsel,P., Bahri, A. & Minhas, P.S. 2010. The challenges of wastewater irrigation in developing countries. *Agricultural Water Management*, 97(4): 561-568.

Qiao, M., Bai, Y., Cao, W., Huo, Y., Zhao, X., Liu ,D. & Li, Z., 2018. Impact of secondary effluent from wastewater treatment plants on urban rivers: Polycyclic aromatic hydrocarbons and derivatives. *Chemosphere*, Vol 211, pp 185-191.

Rabalais, N.N. 2002. Nitrogen in Aquatic Ecosystems. *AMBIO: A Journal of the Human Environment*, Vol 31 No.2, March 2002.

Republic of South Africa .1998. National Water Act. Act 36 of 1998. *Parliament of the Republic of South Africa*, Cape Town.

Republic of South Africa. .1998. Constitution of the Republic South Africa. Act No.108 of 1996. Parliament of the Republic of South Africa, Cape Town

Rimayi , C., Odusanya,D., Weiss,J.M., de Boer, J. & Chimuka,K., 2018. Comtaminants of emerging concern in the Hartbeespoort Dam catchment and the uMngeni River estuary 2016 oullution incident, South Africa. *Science of Total Environment*, 627 (2018), 1008-1017.

Randall,C.W., Stensel, H.D. & Barnard , J.L. 1992. Design of Activated Sludge Biological Nutrient Removal Plants. In Design and retrofit of Wastewater Treatment Plants for Biological Nutrient Removal. Technomic Publishing Co. Inc, Lancester.

Rand Water. 2011. *Climate change*. https://www.randwater.co.za/Annual%20Reports/Annual%20Reports/2011-2012%20Annual%20Reports/RW%20IAR%202011-12%20part%202.pdf

Roux, D.J., Kleynhans, C.J., Thirion, C., Hill, L., Engelbrecht, J.S., Deacon, A.R., & Kempen, N.P. 1999. Adaptive assessment and management of riverine ecosystems: The Crocodile/Elands River case study. *Water SA*, 25(4): 501-512.

Sener, S., Sener, E. & Davraz, A. Evaluation of water quality using water quality index (WQI) method and GIS in Aksu River (SW- Turkey). Science *of the Total Environment.* 584-585 (2017) 131-144.

Struyf, E., Bal, K.D., Backx, H., Vrebos, D., Casteleyn, A., De Deckere , E. , Schoelynck , J. , Brendonck , L. , Raitt, M. & Meire , P. 2012. Nitrogen, phosphorus, and silicon in riparian ecosystems along the Berg River (South Africa): The effect of increasing human land use. *Water SA*, 38(4): 597-606.

Singh, K.P., Mohan, D., Sinha, S. & Dalwani, R. 2004. Impact assessment of treated/untreated wastewater toxicants discharged by sewage treatment plants on health, agriculture, and environmental quality in the wastewater disposal area. *Chemosphere*, 55(2004): 227-255.

Singh, K.P., Malik, A. & Sinha, S. 2005. Water quality assessment apportionment of pollution sources of Gomti river (India) using multivariate statistical techniques- a case study. *Analytica Chimica Acta*, 538(1): 355-374

Szabo, A. & Engle, O., 2010. Upgrading alternatives for a wastewater treatment pond in Johor Bahru. Mala Pysia, Lund university.

Sibanda, T., Selvarajan, R., & 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 (2015), 18301-18317.

Tempelhoff, J., Munnik, V. & Viljoen, M., 2007. The Vaal River Barrage, South Africa's hardest working water way: an historical contemplation. *The Journal for Transdisciplinary Research in Southern Africa*, Vol 3 no.1, July 2007, pp 107- 133.

The Citizen, 2018.Hartbeespoort Dam during water hyacinth removal . [image] Available at: https://citizen.co.za/news/south-africa/environment/2119777/coca-cola-invests-r25m-towards-hartbeespoort-hyacinth-removal/amp/ [Accessed 17 Jul. 2020].

Tian, Y., Liu , Q., Dong, M. , Xu, D. & Xu, X. 2019. Using a water quality index to assess the water quality of upper and middle streams of the Luanhe River, Northern China. *Science of the Total Environment*, 667 (2019): 142-151

Turumen, K., Rasanen. & Nieminen S.P. 2020. Analysing Contaminant Mixing abd Dilution in River Waters influenced by Mine Water Discharges. *Water, Air & Soil Pollution,* (2020) 231: 317

Tree, J.A., Adams, M.R. & Lees, D.N. 2003. Chlorination of indicator Bacteria and Viruses in Primary Sewage Effluent. *Applied and Environmental Miccrobiology,* p. 2038-2043.

Tripathi, K. & Sharma, A.K 2011. Seasonal variation in bacterial contamination of water soures with antibiotic resistant faecal coiforms in relation to pollution. *Journal of Applied and Natural Science,* 3(2): 298 -302.

Von Sperling, M.2007. Wastewater Characteristics, Treatment and Disposal*. IWA Publishing*. London, United Kingdom.

Vaal Army, (2018). State of wastewater treatment works in Emfuleni Municipality, Gauteng. [image] Available at: http://vaalarmy.co.za/photos-and-videos/ [Accessed 24 Jul. 2020].

Von Sperling, M. 2007. Wastewater Characteristics, Treatment and Disposal. Biological Wastewater Treatment Volume 1 , IWA publishing.

Yu, M., Liu,S.,Li , G., Zhang , H., Xi, B. & Tian , Z., 2019. Municipal wastewater effluent influences dissolved organic matter quality and microbial community composition in an urbanized stream. *Science of the Total Environment*.

Water Institute of Southern Africa. 2002. Handbook for the operation of Wastewater Treatment Works 1st Edition. Pretoria, South Africa.

Water Research Commision. 1984. Theory, design and operation of Nutrient Removal Activated Sludge Processes. Pretoria

Wang,Z . , Shao , D. & Westerhoff , P. 2017. Wastewater discharge on drinking water sources along Yangtze River (China). *Science of the Total Environment*, 599600(2017), 1399-1407.

Wu, J., Xae, C., Tian, R. & Wang, S. 2017. Lake water quality assessment: a case study of Shahu lake in semi arid loess area of northwest china. *Environmental Earth Sciences,* 76 (5).

Xenarios, S. and Bithas, K. 2012. 'The Use of Environmental Policy Instruments for Urban Wastewater Control: Evidences From an International Survey,' *Environmental Policy and Governance,* 22 (1), 14-26.

Zhaoshi, W., Wang,X. , Chen ,Y. , Cai , Y. & Deng, J. 2018. Assessing river water quality using water quality index in Lake Taihu Basin, China. *Science of the Total Environment*, 612(2018), 914-922.

APPENDICES

Appendix 1 : Resource quality objectives for Crocodile River catchment

4 No. 40531 GOVERNMENT GAZETTE, 30 DECEMBER 2016

GOVERNMENT NOTICES • GOEWERMENTSKENNISGEWINGS

DEPARTMENT OF WATER AND SANITATION

NO. 1616 30 DECEMBER 2016

NATIONAL WATER ACT, 1998
(ACT NO.36 OF 1998)

CLASSES OF WATER RESOURCES AND RESOURCE QUALITY OBJECTIVES FOR THE CATCHMENTS OF THE INKOMATI

I, Sifiso Mkhize, in my capacity as Acting Director-General of the Department of Water and Sanitation, and duly authorised in terms of sections 13(1) and 63(1)(a) of the National Water Act, 1998 (Act No.36 of 1998), hereby publish the notice for the classes of water resources and the resource quality objectives for the catchments of the Inkomati.

Director: Water Resource Classification
Attention: Ms Lebogang Matlala
Department of Water and Sanitation
Ndinaye Building 5046
178 Francis Baard Street
Private Bag x 313
Pretoria
0001
E-mail: matlalal@dws.gov.za Facsimile: 012 336 6712

MR. SIFISO MKHIZE
ACTING DIRECTOR-GENERAL OF THE DEPARTMENT OF WATER AND SANITATION
DATE: 24/11/2016

SCHEDULE

DESCRIPTION OF WATER RESOURCE

The classes and resource quality objectives are determined for all or part of every significant water resource within the catchments of the Inkomati as set out below:

Water Management Area:	Inkomati-Usuthu
Drainage Region:	X Primary Drainage Region
River(s):	Komati (X1), Crocodile (X2), Sable-Sand (X3), and X4 river systems

CLASSES OF WATER RESOURCES AS REQUIRED IN TERMS OF SECTION 13(1)(a) OF THE NATIONAL WATER ACT, 1998

1. A summary of the water resource classes for Integrated Units of Analysis (Figure 1.1-1.4) and Ecological Categories (ECs) per biophysical node is set out in Table 1 to Table 4.

2. Integrated Units of Analysis (IUA) are classified in terms of their extent of permissible utilisation and protection as either Class I: indicating high environmental protection and minimal utilisation; or Class II indicating moderate protection and moderate utilisation; and Class III indicating sustainable minimal protection and high utilisation.

3. Table 1 to Table 4 provides the IUA, its Water Resource Classes and its respective catchment configuration. The catchment configuration consists of a number of biophysical nodes representing river reaches or resource units. The target EC for each unit in the IUA is provided.

RESOURCE QUALITY OBJECTIVES OF WATER RESOURCES AS REQUIRED IN TERMS OF SECTION 13(1)(b) OF THE NATIONAL WATER ACT, 1998

1. Resource Quality Objectives (RQO) are defined for each prioritised resource unit (RU) for every IUA in terms of water quantity, habitat and biota, and water quality, as shown in Table 5 – 20 respectively.

2. Where specified, the ecological category or Recommended Ecological Category (REC) means the assigned ecological condition by the Minister to a water resource that reflects the ecological condition of that water resource in terms of the deviation of its biophysical components from a predevelopment condition.

3. Resource quality objectives will apply from the date signed off as determined in terms of Section 13(1) of the National Water Act, 1998, unless otherwise specified by the Minister.

SCHEDULE

DESCRIPTION OF WATER RESOURCE

The classes and resource quality objectives are determined for all or part of every significant water resource within the catchments of the Inkomati as set out below:

Water Management Area:	Inkomati-Usuthu
Drainage Region:	X Primary Drainage Region
River(s):	Komati (X1), Crocodile (X2), Sable-Sand (X3), and X4 river systems

CLASSES OF WATER RESOURCES AS REQUIRED IN TERMS OF SECTION 13(1)(a) OF THE NATIONAL WATER ACT, 1998

1. A summary of the water resource classes for Integrated Units of Analysis (Figure 1.1-1.4) and Ecological Categories (ECs) per biophysical node is set out in Table 1 to Table 4.

2. Integrated Units of Analysis (IUA) are classified in terms of their extent of permissible utilisation and protection as either Class I: indicating high environmental protection and minimal utilisation; or Class II indicating moderate protection and moderate utilisation; and Class III indicating sustainable minimal protection and high utilisation.

3. Table 1 to Table 4 provides the IUA, its Water Resource Classes and its respective catchment configuration. The catchment configuration consists of a number of biophysical nodes representing river reaches or resource units. The target EC for each unit in the IUA is provided.

RESOURCE QUALITY OBJECTIVES OF WATER RESOURCES AS REQUIRED IN TERMS OF SECTION 13(1)(b) OF THE NATIONAL WATER ACT, 1998

1. Resource Quality Objectives (RQO) are defined for each prioritised resource unit (RU) for every IUA in terms of water quantity, habitat and biota, and water quality, as shown in Table 5 – 20 respectively.

2. Where specified, the ecological category or Recommended Ecological Category (REC) means the assigned ecological condition by the Minister to a water resource that reflects the ecological condition of that water resource in terms of the deviation of its biophysical components from a predevelopment condition.

3. Resource quality objectives will apply from the date signed off as determined in terms of Section 13(1) of the National Water Act, 1998, unless otherwise specified by the Minister.

SCHEDULE

DESCRIPTION OF WATER RESOURCE

The classes and resource quality objectives are determined for all or part of every significant water resource within the catchments of the Inkomati as set out below:

Water Management Area:	Inkomati-Usuthu
Drainage Region:	X Primary Drainage Region
River(s):	Komati (X1), Crocodile (X2), Sable-Sand (X3), and X4 river systems

CLASSES OF WATER RESOURCES AS REQUIRED IN TERMS OF SECTION 13(1)(a) OF THE NATIONAL WATER ACT, 1998

1. A summary of the water resource classes for Integrated Units of Analysis (Figure 1.1-1.4) and Ecological Categories (ECs) per biophysical node is set out in Table 1 to Table 4.
2. Integrated Units of Analysis (IUA) are classified in terms of their extent of permissible utilisation and protection as either Class I: indicating high environmental protection and minimal utilisation; or Class II indicating moderate protection and moderate utilisation; and Class III indicating sustainable minimal protection and high utilisation.
3. Table 1 to Table 4 provides the IUA, its Water Resource Classes and its respective catchment configuration. The catchment configuration consists of a number of biophysical nodes representing river reaches or resource units. The target EC for each unit in the IUA is provided.

RESOURCE QUALITY OBJECTIVES OF WATER RESOURCES AS REQUIRED IN TERMS OF SECTION 13(1)(b) OF THE NATIONAL WATER ACT, 1998

1. Resource Quality Objectives (RQO) are defined for each prioritised resource unit (RU) for every IUA in terms of water quantity, habitat and biota, and water quality, as shown in Table 5 – 20 respectively.
2. Where specified, the ecological category or Recommended Ecological Category (REC) means the assigned ecological condition by the Minister to a water resource that reflects the ecological condition of that water resource in terms of the deviation of its biophysical components from a predevelopment condition.
3. Resource quality objectives will apply from the date signed off as determined in terms of Section 13(1) of the National Water Act, 1998, unless otherwise specified by the Minister.

Table 13: RQOs for RIVERS for water quality (ecological and user) in priority Resource Units of the CROCODILE RIVER System (X2)

IUA	RU	Target EC	Sub-Component	Narrative RQO	Numerical RQO
IUA X2-1	MRU CROC A (EWR C1) (Crocodile River)	A	Nutrients (phosphate)	Acceptable	50th percentile of the data must be less than 0.015 mg/L PO_4-P (aquatic ecosystems: driver).
			Electrical Conductivity (salts)	Ideal	95th percentile of the data must be less than or equal to 30 mS/m (aquatic ecosystems: driver).
			Faecal coliforms and *E.coli*	Recreation (full contact)	Meet the TWQR of 0-120 counts per 100 ml (DWAF, 1996b).
IUA X2-1	MRU CROC A (EWR C2) (Crocodile River)	C	Nutrients (phosphate)	Acceptable	50th percentile of the data must be less than 0.025 mg/L PO_4-P (aquatic ecosystems: driver).
			Electrical Conductivity (salts)	Ideal	95th percentile of the data must be less than or equal to 30 mS/m (aquatic ecosystems: driver).
			Faecal coliforms and *E.coli*	Recreation (full contact)	Meet the TWQR of 0-130 counts per 100 ml (DWAF, 1996b).
IUA X2-2	MRU CROC B (EWR C3) (Crocodile River)	C	Nutrients (phosphate)	Acceptable	50th percentile of the data must be less than 0.015 mg/L PO_4-P (aquatic ecosystems: driver).
			Electrical Conductivity (salts)	Ideal	95th percentile of the data must be less than or equal to 30 mS/m (aquatic ecosystems: driver).
			Toxics	Ideal	95th percentile of the data must be within the TWQR for toxics (1996a) or the upper limit of the A category in DWAF (2008).
IUA X2-9	MRU CROC D (EWR C4) (Crocodile River)	C	Nutrients (phosphate)	Tolerable	50th percentile of the data must be less than 0.125 mg/L PO_4-P (aquatic ecosystems: driver).
			Electrical Conductivity (salts)	Acceptable	95th percentile of the data must be less than or equal to 70 mS/m (aquatic ecosystems: driver).
			Faecal coliforms and *E.coli*	Recreation (full contact)	Meet the TWQR of 0-130 counts per 100 ml (DWAF, 1996b).
			Toxics	Ideal	95th percentile of the data must be within the TWQR for toxics (1996a) or the upper limit of the A category in DWAF (2008).
IUA X2-11	MRU CROC E (EWR C5) (Crocodile River)	C	Nutrients (phosphate)	Tolerable	50th percentile of the data must be less than 0.075 mg/L PO_4-P (aquatic ecosystems: driver).
			Electrical Conductivity (salts)	Acceptable	95th percentile of the data must be less than or equal to 70 mS/m (aquatic ecosystems: driver).
			Faecal coliforms and *E.coli*	Recreation (full contact)	Meet the TWQR of 0-130 counts per 100 ml (DWAF, 1996b).

			Temperature	Acceptable	A moderate change to instream temperatures should occur infrequently, i.e. vary by no more than 2-C (aquatic ecosystems: driver).
			Turbidity	Acceptable	Not available (aquatic ecosystems: driver).
			Toxics	Acceptable	95th percentile of the data must be within the CEV for toxics (DWAF, 1996a) or the upper limit of the B category in DWAF (2008).
IUA X2-11	MRU CROC E (EWR C6) (Crocodile River)	C	Nutrients (phosphate)	Tolerable	Phosphate: 50th percentile of the data must be less than 125 mg/L PO_4-P (aquatic ecosystems: driver).
			Electrical Conductivity (salts)	Acceptable	95th percentile of the data must be less than or equal to 70 mS/m (aquatic ecosystems: driver).
			Faecal coliforms and *E.coli*	Recreation (full contact)	Meet the TWQR of 0-130 counts per 100 ml (DWAF, 1996b).
			Temperature	Acceptable	A moderate change to instream temperatures should occur infrequently, i.e. vary by no more than 2-C (aquatic ecosystems: driver).
			Turbidity	Acceptable	Not available (aquatic ecosystems: driver).
			Toxics	Acceptable	95th percentile of the data must be within the CEV for toxics (DWAF, 1996a) or the B category in DWAF (2008).
IUA X2-10	MRU KAAP A (EWR C7) (Kaap River)	B	Nutrients (phosphate and Total Inorganic Nitrogen)	Tolerable	50th percentile of the data must be less than 0.125 mg/L PO_4-P (aquatic ecosystems: driver). 50th percentile of the data must be < 4.0 mg/L TIN-N (aquatic ecosystems: driver)
			Electrical Conductivity (salts)	Acceptable	95th percentile of the data must be less than or equal to 200 mS/m (Aquatic ecosystems: driver).
			Toxics	Ideal	95th percentile of the data must be within the TWQR for toxics (1996a) or the upper limit of the A category in DWAF (2008).
				Ideal	As levels: 95th percentile of the data must be less than 0.020 mg/L As (aquatic ecosystems: driver).
				Ideal	Cn (free) levels: 95th percentile of the data must be less than 0.004 mg/L Cn (aquatic ecosystems: driver).

Not available: no numerical guideline.
TWQR = Target Water Quality Range (DWAF, 1996a).
CEV = Chronic Effects Value (DWAF, 1996a).
DWAF (1996a): South African Water Quality Guidelines: Volume 7: Aquatic Ecosystems.
DWAF (1996b): South African water quality guidelines. Volume 2: Recreational Use.

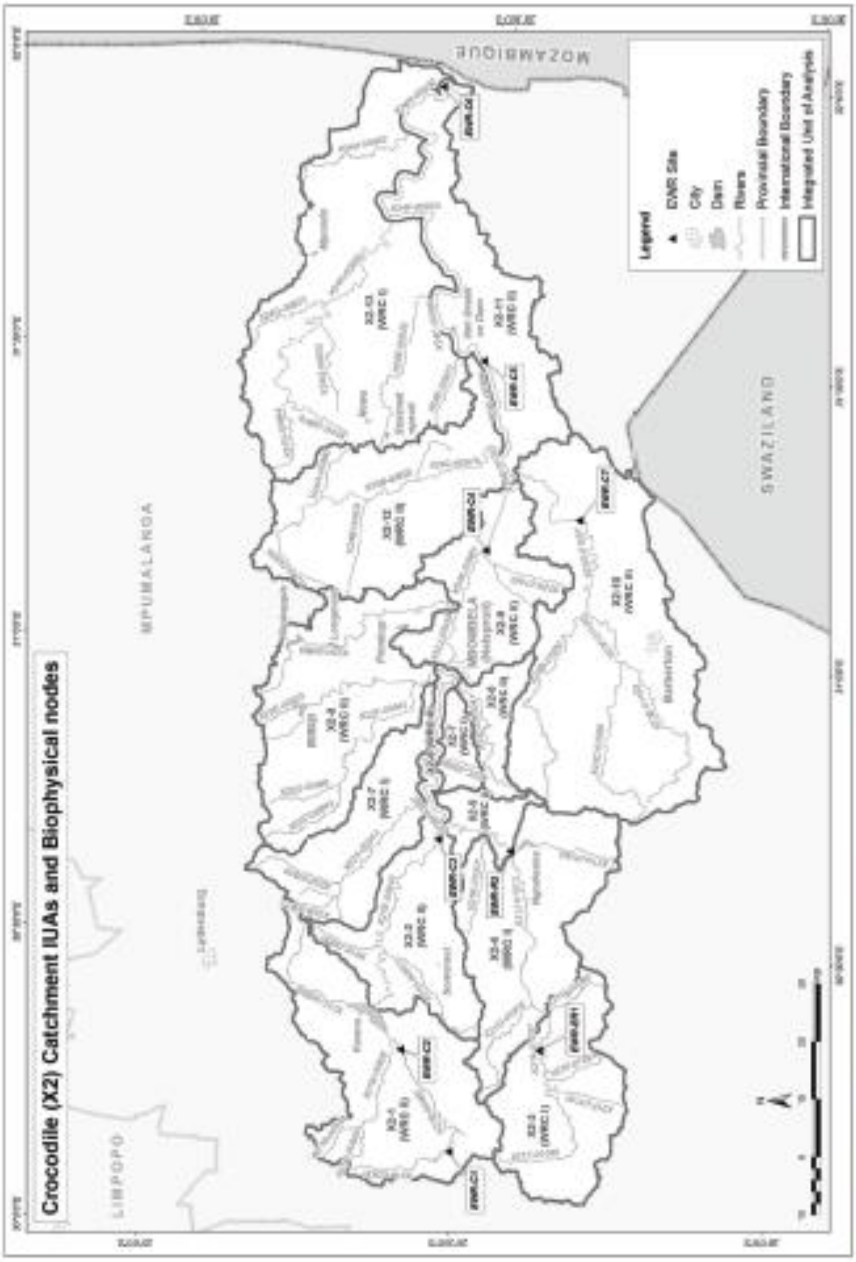

Figure 1.2: Crocodile (X2) Catchment IUAs and Biophysical Nodes

Table 13: **RQOs for RIVERS for water quality (ecological and user) in priority Resource Units of the CROCODILE RIVER System (X2)**

IUA	RU	Target EC	Sub-Component	Narrative RQO	Numerical RQO
IUA X2-1	MRU CROC A (EWR C1) (Crocodile River)	A	Nutrients (phosphate)	Acceptable	50th percentile of the data must be less than 0.015 mg/L PO_4-P (aquatic ecosystems: driver).
			Electrical Conductivity (salts)	Ideal	95th percentile of the data must be less than or equal to 30 mS/m (aquatic ecosystems: driver).
			Faecal coliforms and *E.coli*	Recreation (full contact)	Meet the TWQR of 0-120 counts per 100 ml (DWAF, 1996b).
IUA X2-1	MRU CROC A (EWR C2) (Crocodile River)	C	Nutrients (phosphate)	Acceptable	50th percentile of the data must be less than 0.025 mg/L PO_4-P (aquatic ecosystems: driver).
			Electrical Conductivity (salts)	Ideal	95th percentile of the data must be less than or equal to 30 mS/m (aquatic ecosystems: driver).
			Faecal coliforms and *E.coli*	Recreation (full contact)	Meet the TWQR of 0-130 counts per 100 ml (DWAF, 1996b).
IUA X2-2	MRU CROC B (EWR C3) (Crocodile River)	C	Nutrients (phosphate)	Acceptable	50th percentile of the data must be less than 0.015 mg/L PO_4-P (aquatic ecosystems: driver).
			Electrical Conductivity (salts)	Ideal	95th percentile of the data must be less than or equal to 30 mS/m (aquatic ecosystems: driver).
			Toxics	Ideal	95th percentile of the data must be within the TWQR for toxics (1996a) or the upper limit of the A category in DWAF (2008).
IUA X2-3	MRU CROC D (EWR C4) (Crocodile River)	C	Nutrients (phosphate)	Tolerable	50th percentile of the data must be less than 0.125 mg/L PO_4-P (aquatic ecosystems: driver).
			Electrical Conductivity (salts)	Acceptable	95th percentile of the data must be less than or equal to 70 mS/m (aquatic ecosystems: driver).
			Faecal coliforms and *E.coli*	Recreation (full contact)	Meet the TWQR of 0-130 counts per 100 ml (DWAF, 1996b).
			Toxics	Ideal	95th percentile of the data must be within the TWQR for toxics (1996a) or the upper limit of the A category in DWAF (2008).
IUA X2-11	MRU CROC E (EWR C5) (Crocodile River)	C	Nutrients (phosphate)	Tolerable	50th percentile of the data must be less than 0.075 mg/L PO_4-P (aquatic ecosystems: driver).
			Electrical Conductivity (salts)	Acceptable	95th percentile of the data must be less than or equal to 70 mS/m (aquatic ecosystems: driver).
			Faecal coliforms and *E.coli*	Recreation (full contact)	Meet the TWQR of 0-130 counts per 100 ml (DWAF, 1996b).

			Temperature	Acceptable	A moderate change to instream temperatures should occur infrequently, i.e. vary by no more than 2◦C (aquatic ecosystems: driver).
			Turbidity	Acceptable	Not available (aquatic ecosystems: driver).
			Toxics	Acceptable	95th percentile of the data must be within the CEV for toxics (DWAF, 1996a) or the upper limit of the B category in DWAF (2008).
IUA X2-11	MRU CROC E (EWR C6) (Crocodile River)	C	Nutrients (phosphate)	Tolerable	Phosphate: 50th percentile of the data must be less than 125 mg/L PO_4-P (aquatic ecosystems: driver).
			Electrical Conductivity (salts)	Acceptable	95th percentile of the data must be less than or equal to 70 mS/m (aquatic ecosystems: driver).
			Faecal coliforms and *E.coli*	Recreation (full contact)	Meet the TWQR of 0-130 counts per 100 ml (DWAF, 1996b).
			Temperature	Acceptable	A moderate change to instream temperatures should occur infrequently, i.e. vary by no more than 2◦C (aquatic ecosystems: driver).
			Turbidity	Acceptable	Not available (aquatic ecosystems: driver).
			Toxics	Acceptable	95th percentile of the data must be within the CEV for toxics (DWAF, 1996a) or the B category in DWAF (2008).
IUA X2-10	MRU KAAP A (EWR C7) (Kaap River)	B	Nutrients (phosphate and Total Inorganic Nitrogen)	Tolerable	50th percentile of the data must be less than 0.125 mg/L PO_4-P (aquatic ecosystems: driver). 50th percentile of the data must be < 4.0 mg/L TIN-N (aquatic ecosystems: driver)
			Electrical Conductivity (salts)	Acceptable	95th percentile of the data must be less than or equal to 200 mS/m (Aquatic ecosystems: driver).
			Toxics	Ideal	95th percentile of the data must be within the TWQR for toxics (1996a) or the upper limit of the A category in DWAF (2008).
				Ideal	As levels: 95th percentile of the data must be less than 0.020 mg/L As (aquatic ecosystems: driver).
				Ideal	Cn (free) levels: 95th percentile of the data must be less than 0.004 mg/L Cn (aquatic ecosystems: driver).

Not available: no numerical guideline.
TWQR = Target Water Quality Range (DWAF, 1996a).
CEV = Chronic Effects Value (DWAF, 1996a).
DWAF (1996a): South African Water Quality Guidelines: Volume 7: Aquatic Ecosystems.
DWAF (1996b): South African water quality guidelines. Volume 2: Recreational Use.

Appendix 2 : Research permission letter

Suite 801, 8th Floor
The [illegible] Building
[illegible] Street
Mbombela

Private Bag X11214
Mbombela
1200

Tel 013 753 9000
Fax 013 753 2786

INKOMATI-USUTHU

Enquiries: Dr TK Gyedu-Ababio
Reference: 14/9/4/1
E-mail: [illegible]

Date : 24 February 2020

Mr Takalani Phungela

APPROVAL TO USE THE IUCMA WATER QUALITY DATA FOR ACADEMIC PURPOSES

The above-mentioned subject has reference,

The IUCMA hereby acknowledges receipt of your correspondence dated 10 February 2020 in which you requested permission to use the IUCMA's water quality data for academic purposes.

The IUCMA would like to grant you permission to utilise the data as requested under the following provisions:

- That the data will be used for the purposes for which it has been requested, and nothing else;
- That the IUCMA will also gain access to the results of the study once completed, which could add value to the data and improve the way the IUCMA currently uses the data for decision making in the management of water resources.
- No payment will be required for you to access the IUCMA data as requested.

Wishing you good luck in your studies and looking forward to your studies adding value to the IUCMA processes.

Yours faithfully

Dr TK Gyedu-Ababio
CHIEF EXECUTIVE OFFICER