The impact of discharged effluent on surface water in the Buffalo River Catchment

A Mnyaka

orcid.org/0000-0001-9385-8513

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Supervisor: Dr CW Malherbe

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ABSTRACT

The major threat to the surface water quality in the Buffalo River is caused by the discharged effluents from wastewater treatment works (WWTWs). This is due to the inadequate functioning of the WWTWs and industries that are discharging into the Buffalo River. This study on the impact of discharged effluent on the surface in the Buffalo River catchment was initiated to identify the major impacts caused by the discharged effluent from both industries and WWTWs in the Buffalo River Catchment. The water quality data for the study was received from the Department of Water and Sanitation (DWS) system called the Water Management System (WMS). Water quality data from 2012 to 2019 was obtained from the system. The following parameters were analysed in eleven DWS monitoring points in the Buffalo River Catchment: pH, phosphate (PO_4), chemical oxygen demand (COD), electrical conductivity (EC), Feacal Coliform (f. *coli)*, nitrate& nitrites (NO_2&NO_3), and ammonia (NH_4). All these parameters were dissolved in the surface waters of the Buffalo River Catchment.

The mean range for pH (6.5-7.9), NH_4 (0.12-6.07), NO_2&NO_3 (0.66-6.58), EC (2.2-438.7) COD (9.5-395.4) PO_4 (0.08-9.07) and FC (13.2-16597.9). The results indicated that the discharge effluent deteriorates the water quality in the Buffalo River Catchment. The measured faecal coliform and COD show high elevation compared to the Existing South African standards. Electrical conductivity also exceeded the limits in some of the monitoring points. The aim of the study was to be achieved. Buffalo River catchment water has poor water quality due to discharged effluent from the wastewater treatment works and runoffs from the industry (Da gamma textile industry) The discharged effluent has an impact on the surface water of Buffalo River Catchment as it is polluted with faecal coliform. Water Quality at Buffalo River is deteriorating.

Keywords: Surface Water, Wastewater Effluent, Industrial Effluent, Water Quality, Buffalo River, Pollution, Wastewater Treatment Works.

ABBREVIATIONS AND ACRONYMS

COD	: Chemical Oxygen Demand
DEA	: Department of Environmental Affairs
DO	: Dissolved Oxygen
DWAF	: Department of Water Affairs and Forestry
DWS	: Department of Water and Sanitation
E. coli	*: Escherichia coli*
EC	: Electrical Conductivity
ECA	: Environment Conservation Act
EPA	: Environment Protection Agency
et al.	*:* and others
FC	: Faecal Coliform
GDP	: Green Drop Program
H_2O	: Water
Mg/L	: Milligram per Litre
NEMA	: National Environmental Management Act
NH_4	: Ammonia
NO_2	: Nitrite
NO_{3^-}	: Nitrate
NWA	: National Water Act
NWU	: North-West University
PCA	: Principal Component Analysis
pH	: Potential Hydrogen
PO_4 -	: Phosphate
RQOs	: Resource Quality Objectives
SS	: Suspended Solids
TDS	: Total Dissolved Oxygen
WDCS	: Waste Discharge charge system.

WSA	: Water Services Act
WMS	: Water Management System
WHO	: World Health Organisation
WWTWs	: Wastewater Treatment Works

KEY DEFINITIONS

Surface Water: is defined as rainwater that is collected in water bodies such as dams, lakes, rivers, or streams.

Wastewater: is defined as a mixture of liquid waste that is removed from the industries and residential areas as well as runoff from the stormwater pipes.

Electrical conductivity (EC): is a measure of the ability of water to conduct an electric current.

Suspended solids are the number of tiny solids particles that remain suspended in water and act as a colloid.

pH: is a measure of how acidic or basic water is. The range goes from 0 to 14, with seven being neutral.

Catchment: is an area of land where water collects when it rains, often bounded by hills.

River: is a natural flowing watercourse, usually freshwater, flowing towards an ocean, sea, lake, or another river.

Water Pollution: is the contamination of water bodies usually, because of human activities that it negatively affects their uses.

Eutrophication: is the process in which a water body becomes overly enriched with nutrients, leading to the plentiful growth of simple plant life.

Effluent: is an outflowing of water or gas to a natural body of water, from a structure such as a sewage treatment plant, sewer pipe, industrial wastewater treatment plant or industrial outfall.

Wastewater Treatment Works/Plant: this is the process used to remove contaminants from wastewater to convert it into an effluent that can be returned to the water cycle.

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CHAPTER 1 INTRODUCTION

Water is an essential natural resource which plays a vital role in human life (Iloms, 2018). Water can also play an essential role in our economy, to produce food, health, and the environment (Halder & Islam, 2015). The importance of water resources is well known worldwide as it was recognized by the United Nations (UN) through integrating it into the Millennium Development Goals (MDGs) as the international decade for Action' Water for Life' (Water, 2018). It was also incorporated into the new Sustainable Development Goals (SDGs), which are Global Goals that are set to transform the world and form a part of the 2030 agenda for sustainable development. Water is a dynamic system, a dynamic system that contains both biotic as well as abiotic components. Water contains organic and inorganic matter, Furthermore and insoluble substances contained in water act as life support systems in living organisms (Ahmed *et al*., 2011). When the water quality changes, it may affect the balance of the aquatic environment, rendering it unsuitable for its intended use. Also, these changes result in a shortage of surface water in the world (Iloms, 2018). South Africa is a typical developing country that is in an arid or semi-arid area (Ashton *et al.,* 2008). South Africa as an arid or semi-arid country, South Africa has a seasonal rainfall that is an unevenly distributed water resource (Fatoki *et al.,* 2001). The Mean Annual Rainfall (MAR) is approximately 500 mm^3 per annum, and this is below the world annual average of 860 mm^3 (Otieno & Ochieng, 2004). Approximately 65% of the country receives less than 500 mm^3 of rain annually, which is usually regarded as a minimum rain in dry areas (Annandale & Nealer, 2011) and approximately 20% of other areas in the country receive less than 200 mm^3 per annum (DWA, 1986). Due to this statement, all South African water resources are in global discussions (RSA, 2002).

South Africa is characterized as a water-scarce country with an annual freshwater availability of fewer than 1700 m^3 per capita (Otieno & Ochieng, 2004). A water-scarce country with polluted water resources. Water pollution is defined as the direct alteration of the physical, thermal, and biological properties of water in such a way as to create a hazard or potential hazard to the health, safety, and welfare of any living species (Dragicevic *et al.,* 2010). The different contamination sources may cause pollution, especially in the urban areas of developing countries like South Africa (Ilomns, 2018), where the human population and industries are increasing every year without increasing wastewater facilities. Furthermore, the existing facilities are poorly maintained; as a result, they discharge untreated or poorly treated effluent into the water resource. The untreated effluent or poorly treated effluent caused pollution in water resources (Odjadjare & Okoh, 2010).

1.1 Buffalo River Catchment

The Buffalo River is in the Eastern Cape Province of South Africa (Chigor, *et., al* 2013). The Buffalo River Catchment is one of the longest rivers and it discharges into the Indian ocean. Water in the Buffalo River catchment is used for domestic purposes, agriculture, industrial, recreation, and aquatic life. The major land-use activities in the Buffalo River Catchment area are agricultural activities that includes livestock farming as well as crop farming Van Ginkel *et al.,* 1996). As a result, water from the river is commonly used for livestock (Van Ginkel *et al.,* 1996). The Buffalo River provides water and a source for the discharge of effluents in one of the most populated regions on the South African East Coast. According to Van Ginkel *et al.* (1996), the rapid urbanization in the Buffalo River Catchment as well as the increased population growth has resulted in increased consumption of energy and raw materials. The Buffalo River Catchment is surrounded by more than five Wastewater Treatment Works (WWTWs), that are discharging wastewater into the water resource. Industries in the area discharge their effluent in the Buffalo catchment tributaries (Van Ginkel *et al.,* 1996).

1.2 Problem Statement

The gradual increase in population and industrial growth in South Africa is one of a few major concerns. Several cases of direct discharge of effluent into the water resources leading to pollution and metal contamination have been observed in South Africa (Iloms, 2018). It has been found that the major source of water contamination in rivers is inadequately treated wastewater from WWTWs. The WWTWs are not well equipped to remove large quantities of biodegradable waste as well as intractable metals (Iloms, 2018). The human population is increasing and the infrastructure such as wastewater facilities capacity is not upgraded.

The Buffalo River Catchment is one of the important catchments in the Eastern Cape because it supports many towns in former Ciskei in the Eastern Cape which include Stutterheim, Cathcart, Keiskammahoek, King Williams Town, Bisho and East London. Eastern Cape has a limited number of wastewater treatment facilities, and it has been reported that most wastewater treatment facilities are poorly maintained (Mema, 2010).

These WWTWs are discharging their final effluent into the surface water resources. Previous studies have indicated that the Buffalo River Catchment is stressed due to the rapidly growing population in the area (Van Ginkel *et al*.,1996). Therefore, it is crucial to determine the impact caused by the discharged effluent at the Buffalo River Catchment because there is no new construction of new WWTWs and those that are upgraded exceed the targeted time due to lack of funds. Moreover, there are still people who are using water from water resources such as rivers for drinking (Mema, 2010).

1.3 Research Aim

This study's aim was to analyse the impact of discharged effluent on the surface water of the Buffalo River Catchment.

1.4. Research Questions

(a) What impact is caused by the discharged effluent on the water quality in the Buffalo River Catchment?

(b) Does the Buffalo River Catchment deteriorate with time due to the discharged effluent from wastewater?

1.5. Research Hypothesis

a) The discharged effluent will cause an impact on surface water quality at Buffalo River.

b). The surface water quality deteriorates with time in Buffalo River Catchment.

1.6. Layout of the study

Chapter 1: This chapter provides the introduction, research problem statement, aim, research hypothesis, research question of the study, the Buffalo River catchment generally and the structure and outline of the thesis.

Chapter 2: This chapter presents a literature review on the impact of discharged effluent on surface water, Wastewater treatment works, industrial and domestic effluent on the Environment, impact on Human Health, Impact on discharged metals and Legislation and management of water resources in South Africa.

Chapter 3: This chapter provides a detailed methodology used for the study, introduces the study area, data collection, description of data, the research design, data analysis and methodological limitations.

Chapter 4: This chapter provides the results and findings of the study based on data from the Buffalo River Catchment. Various data analysis methods were used to visualise data and present the temporal and spatial variability in the data from 2012 to 2019.

Chapter 5: This chapter is a discussion of the results and the contribution to the current literature. Conclusion and recommendations are included in this chapter.

CHAPTER 2 LITERATURE REVIEW

2.1. Surface Water

Surface water is a significant source for domestic, agricultural, recreational, or other purposes. Moreover, surface water sources are more vulnerable to various types of contamination and pollution (Chigor *et al.,* 2013). A variety of discharges can impact these sources into the water resource (Edokpayi *et al.,* 2015). Furthermore, the most critical discharges typically change the status of water quality. Water quality is defined by the chemical, physical and biological qualities of water that determine its suitability for a variety of purposes as well as the conservation of aquatic ecosystem health and integrity (Edokpayi *et al.,* 2017). Water quality may be affected by pollution from various sources in water resources. The sources include effluent discharges from municipal wastewater and industrial wastewater (Momba *et al*., 2006).

Surface water is primarily used for domestic, recreational, and agricultural uses in rural areas in South Africa, as it is in most other developing countries across the world. Surface water quality in many parts of the country is also threatened by excessive nutrient inflow, mainly from domestic effluent (untreated wastewater) and industrial and sewage effluent (treated wastewater from sewage treatment works), run-off from agricultural lands and uncontrolled disposal of wastewater from informal settlements (Nyenje *et al*., 2010). Natural processes and manmade activities both have a negative impact on water quality (Edokpayi *et al*., 2017). Natural water quality varies from place to location, depending on seasonal and climatic variations, as well as the types of soils, rocks, and surfaces it passes through. Agricultural activities, urban and industrial development, mining, and recreation all have a substantial impact on natural water quality and water use potential (Edokpayi *et al.,* 2017).

2.2. Wastewater Treatment

The process of removing contaminants from the wastewater is known as sewage treatment (Naidoo, 2013a). The contaminants are removed from both the runoff and domestic wastewater. Domestic water is normally composed of black water with faecal matter from human and animal wastes and grey water from household activities. The contamination removal includes physical, chemical, and biological processes (Tchobanoglous *et al*., 2004). Moreover, the sewage can be treated close to where it is created, for example in the septic tanks, or it can be collected and transported through sewer pipes and pump stations to municipal treatment works. (DWAF, 2001). There has been a significant reduction in the amount of chemicals discharged into the streams since the enforcement of the National Water Act (NWA): 36 of 1998; National Environmental Management Act (NEMA): 107 of 1998; Environment Conservation Act (ECA): 107 of 1989; and other environmental legislation. Furthermore, the deterioration of water quality about microbial contamination occurs (DWAF, 2001).

Sanitation systems can have an impact on water quantitatively through increased water use and a qualitative way through the passage of organisms and chemicals from the human body to the natural environment (Water, 2018).

The increase in population has led to an increase in human impact on the environment (Bilgrami & Kumar, 1997). Approximately 90% of the WWTWs in South Africa do not comply with the conditions of their Water Use Licence (WUL). The most significant source of organic matter with an anthropogenic origin in the surface water is human waste and waste from domestic activities as well as other public use effluents that are usually combined in the municipal sewage works for treatment before being discharged into surface water resources (DWAF, 2001). Eutrophication is the process by which an entire body of water, or parts of it, becomes progressively enriched with minerals and nutrients, particularly nitrogen and phosphorus (DWAF, 2001). This may result in an algal bloom, a rapid increase in the population of algae, floating algal and macrophyte mats, benthic algal and submerged macrophyte agglomerations (Meybeck & Helmer 1992). Furthermore, algae members are unsustainable, they will eventually die and can be decomposed by bacteria. This process reduces the oxygen in the water and encourages some algae species to produce toxins which may pollute the river system (Meybeck & Helmer, 1992). The sewage treatment plants' effluent has an impact on surface water resources when the untreated sludge is applied to agricultural land in the form of irrigation (DWAF, 2001).

The discharged effluent from the WWTWs is known as the most significant cause of water pollution globally (Vander Post & Schutte, 2003). The accumulation of chemicals from the WWTWs into surface water destroys the nature of the water resource. The raw and partially treated discharged effluent damages the environment and cause harm to human health. The primary purpose of treatment works is to eliminate nutrients through the addition of chemicals (Morrison *et al*., 2001). Moreover, the addition of specific chemicals in the wastewater treatment works is known reduce sludge volume. Currently the process of dewatering during, biological treatment has been recommended to reduce pH levels. Vander Post & Schutte (2003), explained that the massive amounts of waste products that pass through WWTWs daily, have a nutrient removal strategy which is critical for the preservation of our lakes, streams, rivers, and other receiving water bodies. WWTWs effluent that has not been appropriately treated affects the water quality of the receiving water bodies. This has been linked to high electrical conductivity, suspended solids, salts, nitrogen, phosphorus, and low dissolved oxygen levels in rivers (Fatoki *et al*., 2003).

A study which was conducted by Morrison *et al*. (2001) on the physicochemical properties of receiving water bodies in relation to the final waste of treated wastewater in rural areas, revealed that the Keiskammahoek WWTW in the Eastern Cape has poor sanitation services. It was also revealed that biological oxygen demand (BOD) and dissolved oxygen (DO) levels exceeded the

European standards for the protection of aquatic ecosystems. This has resulted in poor water quality for the Keiskamma River in the Eastern Cape. Igbinosa and Okoh (2009) investigated WWTWs in a rural community in the Eastern Cape and observed that the final effluent after treatment does not meet the required standards in terms of organic waste. The results indicated that DO, COD, or PO_4, NO_3&NO_2 are essential for the supply of clean and safe water.

According to the study conducted by Dungeni & Momba (2010), it was indicated that the WWTWs are ineffectively removing contaminants and show numerous impacts on the environment. Furthermore, the study also indicated that the trace organic chemicals are released into the environment through the discharged effluent from the municipal WWTWs, industrial manufacturing process, leaking sewer pipeline and the overflow of the sewer utility holes (Dungeni & Momba, 2010).

2.3 Water Quality Parameters That Impact on The Surface Water Resource

2.3.1 Suspended Solids (SS)

According to DEAT (2006), suspended solids are defined as particles which can enter surface water bodies from land-use practices, human-induced activities, erosion, and disturbance of riparian vegetation and industrial and domestic discharges carrying suspended sediment loads. The impact of pollution through wastewater treatment works may destroy the aquatic species' habitat, and this can change species diversity in water resources. When the suspended solids are high, the feeding capacity of fish is affected and the respiration become impaired (Kazunga *et al*., 2002). Suspended Solids are the particles found suspended in the wastewater and are removed through sedimentation and filtration during the treatment process.

2.3.2. Electrical Conductivity (EC)

The EC measures the total amount of material dissolved in a sample of water and is thus frequently used in general water quality characterization (Dube, 2020). The EC value is proportional to the total dissolved solutes (TDS) in the water. The TDS concentration changes can be toxic because the density of the water determines the flow of water into and out of the cells of the organ. The concentrations of EC accumulate naturally in the natural environment as well, because of anthropogenic activities such as domestic and industrial wastewater discharges and surface runoff (Du Preez *et al.,* 2000). Elevated EC levels in isolated water bodies can also be an indication of excessive evaporation, particularly during drought seasons, and can even give water a brackish taste, affecting aquatic life in that receiving water environment (Morrison *et al.,* 2001).

Alternatively, high salt content can be the result of bad crops, particularly when there is chlorine and sulphate (Walsh & Wepener, 2009).

2.3.3. pH

The pH of less than 7 indicates acidity, while a pH of greater than 7 indicates a base (Dube, 2020). The range of pH disturbs the solubility state and the mobility of metals, which in turn can be absorbed by the aquatic ecosystem. To ensure support for aquatic life, healthy water has an almost neutral pH. By altering other aspects of water chemistry, a shift in stream water pH may also impact aquatic life indirectly. High pH 14 values are toxic to plant and animal organisms (Dallas & Day, 2004). Some fish cannot survive at low pH, low and high pH influence both plant and animal life, and acid pH increases the gill permeability of fish (Wright & Welbourn, 2002). Low pH levels, for instance, will increase the solubility of some heavy metals. The pH is manipulated during the chemical treatment of waste in treatment plants to isolate waste by coagulation; ammonia removal; disinfection and prevention of some biochemical-based reactions (Naidoo, 2013b). Due to the artificial addition of alkaline waste, the high pH of freshwater is often harmful and corrosive, and often this could be due to the production of ammonia from nutrient ions and reduction of conditions (Dube, 2020).

2.3.4. Ammonia

Ammonia is an excellent indicator of water quality, especially in areas where agricultural activities predominate. Plants and soil microbes fix nitrogen in soil and water, which can end up in aquatic systems (Rounsevell & Reay, 2009). Household detergents and industrial chemicals may contain ammonia. The high levels of ammonia and nitrates are commonly linked together. Ammonia and nitrates are said to be positively correlated to wastewater treatment works. Ammonia is oxidized to form nitrite, which is then oxidized to form nitrate, and on the other hand, in areas with high COD levels, nitrates are reduced to form nitrites, which are then oxidized to form ammonia (Sanchez *et al*., 2007). Phosphorus, ammonia, pH, and COD are relativity closed and they can be influenced from season to season.

2.3.5. Nitrate

Nitrate is strongly linked to the presence of nitrites and ammonia in water bodies because these are either oxidized or reduced and change from one form to the other. Nitrate is a nutrient that is required for plant growth. Many farmers use nitrogen-rich fertilizers to stimulate crop growth (Schröder.*et al*., 2004). Nitrogen can also be produced naturally because of atmospheric deposition during lightning storms. Increased nutrient loading in water resources causes eutrophication, which leads to a decline in water quality. Nitrates are frequently found in agricultural runoff as well as sewage and effluent (Walakira & Okot-Okumu, 2011). The presence of nitrate in WWTWs may be harmful.

2.3.6. Phosphates

The presence of phosphate indicates the presence of a variety of factors that influence water quality. Phosphate levels that are elevated indicate urban land use as they are associated with household detergents, industrial and domestic wastewater (DWAF, 2001). It could also indicate the use of agricultural land use impacts (fertilizers and nutrients) on water resources. Phosphorus is an important nutrient required for plant growth (Schröder *et al.,* 2004). Phosphorus also promotes the growth of unwanted aquatic flora, which can potentially cause oxygen deprivation and thus affect the species. Phosphate has a negative impact on water quality because it causes eutrophication because of agricultural runoff and loading (Teklehaimanot *et al*., 2015).

2.3.7. Chemical Oxygen Demand (COD)

Chemical oxygen demand (COD) is a metric for the oxidation of reduced compounds in water (Dallas & Day, 2004). The larger the presence of oxidizable pollutants in the water, the higher the COD discovered in it (Naidoo, 2013b). It is a typical way to assess the number of organic compounds in water without measuring them, and it's a good indicator of organic contamination in surface waters. Excessive use of urban land for agricultural to wastewater can result in a nutrient load in the aquatic environment, affecting dissolved oxygen (Bere & Tundisi, 2010). The amount of nutrients in WWTWs and urban wastewater increases because of their nutrient load.

2.4 The Impact Caused by the Discharged Effluent from Industrial and Domestic Waste

2.4.1. Impact on the Environment.

Water forms part of the environment, where most life forms survive (Iloms, 2018). Water as a unique substance can be renewed naturally and cleans itself by breaking down or diluting or settling contaminants to reduce toxic levels (Iloms, 2018). However, the process of nature takes a prolonged time. The release of energy, elements, or compounds into the environment at levels that can adversely impact biological functioning or pose unacceptable levels of danger to other organisms in the environment (Fernandez-Luqueño *et al.,* 2013). When the compounds, elements and energy enter our water through home and industrial activities, they lead to water pollution. Water pollution is defined as the addition of contaminants to the surface water bodies such as lakes, rivers, and oceans and groundwater to a certain degree that it cannot be used for specific needs such as drinking, bathing or cooking (Owa ,2014).Furthermore, Water pollution is defined by the United States Environmental Protection Agency (1997) as any human-caused contamination that reduces the quality of water available to humans and other naturally existing organisms. Despite its enormous importance, water is vulnerable to human impacts such as contamination from run-off and dumping of waste from human industrial activities, which has devastating consequences for the economy and human and livestock health, as well as damaging aquatic habitat and destroying marine life (Masere *et al.*, 2012). The bioaccumulation of non-biodegradable compounds and heavy metals in fish and shellfish, which is considered lethal to humans when consumed in large quantities (Owa, 2014; Dan'azumi and Bichi, (2010).

The excessive nutrients discharged into the water bodies can result in eutrophication and a reduction in the available oxygen that ultimately alters the biotic community structure and function. Wakelin *et al*., (2008) also reported that excess discharge of turbid effluents could cause sand and grit deposition into the aquatic system, disruption of sediment characteristics and impediment the flow of natural water. The total physico-chemical and hydrological environment are always influenced by the introduction of poorly treated effluents affecting numerous micro and macro-fauna present in the water bodies. The presence of the vulnerable micro and macro-fauna can lead to death and the survival of the tolerant one. The situation can lead to discrepancy among the cluster of organisms present and the total alterations to the surroundings in the form of light and oxygen contents, food sources in addition to loss of habitat, and nutrient modification (Wakelin *et al*., 2008).

Hydrocarbons, detergents, pesticides, nitrogen, phosphorus, and heavy metals are the primary chemical contaminants from wastewater. Larsdotter (2006) reported that nitrogen and phosphorus are known to be nutrient limiting and the occurrence of nitrogen in the discharged wastewater can be unpleasant due to its ecological and public health impact. Nitrogen occurs mainly in organic form, and its occurrence is linked to municipal sewage disposals and the application of fertilizer to crops (Hurse & Connor, 1999). The excess nitrogen in water bodies because of municipal sewage disposal and fertilization application can result in the formation of ammonia, which is poisonous to fish and exerts an oxygen demand on receiving water bodies by nitrifying (Jenkins *et al.,* 2003). The presence of nitrogen and other chemical contaminants tends to cause algal blooms. Algal blooms disrupt the natural composition and diversity of organisms in aquatic communities, making large-scale fishing difficult and posing a problem for water treatment (Mamabolo, 2012).

2.4.2. Impact on Health

The discharged effluent containing human and animal faeces provides most waterborne microorganisms that cause human disease (Akpor, 2011), These microorganisms contain a wide range of viruses, bacteria, and protozoa that could end up in drinking water supplies or receiving bodies of water (Lahnsteiner & Lempert, 2007). Microbial infections are thought to be important contributors to many waterborne epidemics. The most frequent health risks connected with untreated drinking and recreational waters are diseases caused by bacteria, viruses, and protozoa. Cholera, typhoid fever, shigellosis, salmonellosis, campylobacteriosis, giardiasis, cryptosporidiosis, and Hepatitis A virus are all transmitted from contaminated water (WHO, 2008). Untreated or inadequately treated heavy metal contaminated wastewater effluents cause a variety of health and environmental impacts when released into receiving water bodies. Heavy metals harm the growth of aquatic organisms and can cause serious upsets in biological wastewater treatment plants. Some reports have linked skeletal damage (osteoporosis) in humans to heavy metals. Long-term exposure to cadmium in humans may lead to renal dysfunction. Exposure to contaminated water with copper may result in liver damage and anemia. When zinc is taken up in high concentrations, it may cause system dysfunctions in humans (Akpor &Muchie, 2011).

2.4.3. Impact Caused by Discharged Metals

Metals are widely distributed, and they occur naturally on the surface water. According to Dallas & Day (2004), the metals that occur naturally are non-toxic to aquatic life. The contamination of aquatic species with metals at elevated concentrations poses a threat. These metals accumulate in the tissues of various aquatic species, including fish, influencing species richness, diversity, and distribution (Milenkovic *et al.,* 2005). For consumption, some people always use raw water that is taken from the natural environment without being purified (Cho, & Yun, 2011). Metals are a significant class of environmentally dangerous compounds among all the pollutants present in the aquatic system (Chimuriwo, 2016). Gagnon *et al.,* (2006) indicated that the presence of metals is influenced by the physical and chemical conditions of the receiving environment. The physical and chemical conditions of the effluent and the receiving environment affect the number of metals in wastewater (Gagnon *et al.,* 2006). Metal accumulation in an aquatic ecosystem is harmful to both humans and the ecosystem. Most of the metals are removed from liquid wastes throughout the treatment process and eventually wind up in the solids that emerge from it. Population increase has an impact on metal removal in wastewater treatment since the plant will be compelled to process higher volumes of influents than it was built for (Manugufala *et al.,* 2011).

2.5. Legislation and Management of Water Resources in South Africa

In South Africa, the environmental impact that is caused by the effluent discharge from the wastewater treatment works is controlled and managed by various legislation. Like other countries, South Africa has developed guidelines, standards, and policies to make sure that all water resources in the country are protected and for sustainable use. South African Department of Water and Sanitation is the custodian of the country's water resources (Mothetha, 2016).

2.5.1. National Environmental Management (NEMA) Act No.107 of 1998

The primary purpose of national environmental management is to ensure the environment and its nature is protected and managed in such a way that all the resources are conserved for future benefit. National Environmental Management Act also applies to the disposal of wastewater into the water resources, which can result in deteriorating the water quality in the water resource and may cause mortality in different species due to accumulation of contaminants in the water resources (NEMA, 1998). The act highlights that industrial and domestic waste discharges must be monitored to adhere to effluent standards before they discharged into the water resource (NEMA, 1998).

2.5.2. National Water Act (NWA) Act No. 36 of 1998

The management, protection, use, development, conservation, and control of the water resources provides a good legal framework for the National Water Act. One of the NWA requirements is the implementation of its regulation for the disposal of waste effluent and other activities that are aimed at the protection and managing the water resources (NWA, 1998). The act states that water abstracted for industrial purposes shall be returned into the water source from which it was abstracted, in accordance with the standards set by DWA, based on section 151 (2) of the NWA, which indicates that anyone who commits an offence under this act is liable to a fine or imprisonment for five years and can be liable for the remediation costs (NWA, 1998).

2.5.3 Water Services Act (WSA) Act No 108 of 1997)

The discharge of industrial effluents and wastewater shall be carried out in accordance with the requirements of the NWA and the WSA of South Africa (WSA, 1997). The local authorities have the mandate to treat wastewater prior to disposal in accordance with the requirements of the Act and other environmental legislation (WSA, 1007). Each user or discharger is required and expected to ensure that the effluent discharged into the resource complies with the provisions laid down and the legislation (WSA, 1997).

2.5.4. Green Drop Certification

Green Drop Certification (GDC) is an incentive-based regulation programme implemented by the Department of Water and Forestry which is currently known as Department of Water and Sanitation to ensure that municipalities comply with the set national norms and standards. According to Muller (2013), the first Green Drop certificate was launched in 2008. The Green Drop Certification assist the municipalities to generate effluent data on the system called Green Drop System (GDS) currently known as Integrated Regulatory Information System (IRIS). The generation of the effluent data on the IRIS assist the municipalities to easily identify non-compliance against the Green Drop criterion besides license conditions of the WWTWs (Muller,2013). The municipalities that achieve the required compliance with all the Green Drop criterion are awarded with a Green Drop Certificate. The score must range from 90% - 100% (Muller, 2013).

CHAPTER 3 METHODOLOGY

3.1 Description of Study Area

The Buffalo River Catchment (R20) is in the Eastern Cape province of South Africa. The Buffalo River is a warm, turbid, polluted, alkaline system containing four human-made impoundments along the river (O'Keeffe, 1989). Buffalo River Catchment originates from the afforested area in the Pirie Mountains in a high rainfall area. It is situated between two towns Stutterheim and Keiskammahoek, the altitude of the area is approximately 1300 m (Palmer *et al.,* 2004). The Buffalo River Catchment flows in a south-eastern direction, passing through Zwelitsha in King William's Town and Mdantsane. After almost 125 km, it discharges into the sea in East London. The catchment covers an area of 1276 km^2. The upper reaches of the Buffalo River Catchment are characterized by a steep slope and high altitude, which decreases along its length. The upper reaches of the Buffalo River Catchment altitude are between 900 m and 250m *(*Van Ginkel *et al.,* 1996). Buffalo River Catchment has some tributaries that include Izele, Cwecwe, Yellowwoods and Green rivers (Yahaya *et al*., 2018). Moreover, most tributaries are situated in the upper reaches, and the middle reaches of the catchment. The catchment has deeply incised valleys towards the coast below the level of the coastal plain (Yahaya *et al.,* 2018). The lower coastal belt is situated between the coast and about 250m above sea level and is approximately 10 km wide. The catchment becomes very narrow close to the sea and the river flows in a gorge, the tributaries are low and have steep gradients *(*Van Ginkel *et al.,* 1996).

Figure 1: Map that shows the overview of the Buffalo River (Ravele, 2021)

3.2. Monitoring Site Selection

The surface water monitoring points used for the study covered the whole Buffalo River Catchment. Eleven monitoring sites were selected because of their role in terms of the industrial and wastewater vicinity and the proximity to the Buffalo River. Moreover, these monitoring points are also Department of Water and Sanitation Monitoring point from the Upper, Middle and Lower Reaches of the Buffalo River Catchment. The monitoring sites that were selected for the study covered the whole Catchment, the area where there were no activities taking place, the area discharging point of the wastewater treatment works and the sampling site that are passing through the residential area, to detect impact on the discharged effluent on the surface water. The map (Figure 2) below shows the surface water monitoring points selected for the study at Buffalo River Catchment.

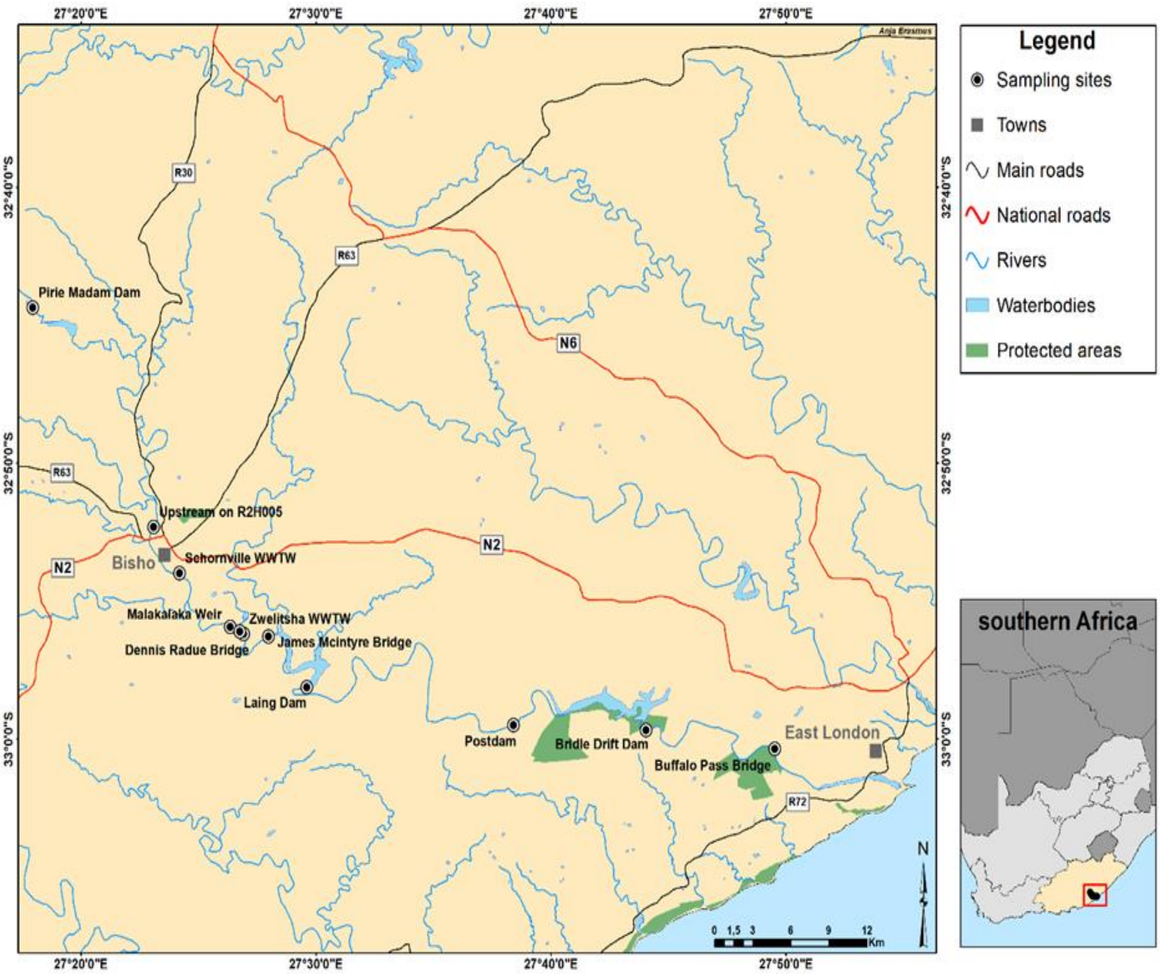

Figure 2: Map that shows all the monitoring points of the study from 2012-2019

The list of selected surface water monitoring sites and their co-ordinates at the Buffalo River catchment for the study are presented in the table 1 below.

Table 1: The DWS monitoring points for Buffalo River Catchment.

Monitoring Sites	Co-ordinates E	Co-ordinates S
Bridle Drift Dam on Buffalo River	-32.99472222	27.7338889
Buffalo Pass Bridge	-33.006111	27.825333
Buffalo River @ Dennis Radue Bridge	-32.93227778	27.4391944
Laing Dam	-32.9687	27.4935
Pirie Madam Dam	-32.73963889	27.29908333
Zwelitsha WWTW	-32.936611	27.448778
Upstream on R2H005	-32.871861	27.38475
Schornville WWTW	-32.56.188	27.24.240´

Postdam	-32.99163889	27.6400278
Malakalaka Weir	-32.93511111	27.44588889
James Mcintyre Bridge of R2h010 On Buffalo River	-32.93813889	27.46630556

3.3. Climate and Rainfall

The Buffalo River Catchment is a typical catchment with mixed evaporation rates (high and low). Rainfall of the catchment ranges from a mean annual of 930-2000 mm in the upper reaches to an average of 450-640 mm in the middle reaches (King Williams Town) and 762-900 mm in the lower reaches (Van Ginkel *et al.,* 1996). However, the catchment receives maximum rainfall from spring to autumn and rainfall usually occurs in the form of small storms. Furthermore, the catchment has semi-arid or temperate transition zones with approximately 1300 km^2 of summer rainfall (Van Ginkel *et al*., 1996). Buffalo River is also characterised by warm and temperate weather with temperature ranging from 8 and 39 degrees Celsius (^0C) with an annual mean of 21^oC and the annual temperature for inland areas is 18^oC (Van Ginkel *et al.,* 1992).

3.4. Geology

Buffalo River Catchment is not rich in terms of mineral wealth. According to Van Ginkel *et al*. (1996), the geology of the area consists predominantly of sedimentary rocks of the Lower Beaufort Series of the Karoo System with a few dolerite outcrops. In some places, the slopes are almost vertical forming bare rock cliffs up to 120 m in height. Below the cliffs, the surface is strewn with large dolerite and sandstone boulders. A feature of the middle plateau is the occurrence of hills formed partly of marine deposits and indicating relatively recent geological submergence beneath the sea (RHP, 2004).

3.5. Flow Characteristics

The Buffalo River contains several DWAF flow gauging weirs accustomed to monitoring flow along the river. There are three gauges in the Buffalo River. Limited flow information is available between the Laing and the Bridle Drift Dam (O'Keeffe *et al.,*1992). The Buffalo River has a perennial flow in the upper reaches until the river reaches King William's Town, where water can be temporary during dry seasons (O'Keeffe *et al.,*1992). However, return flows from King William's Town and Zwelitsha W (WWTW) maintain flow into the Buffalo River. Water is released from the Laing Dam to the Bridle drift Dam, where some water abstraction for East London takes place (O'Keeffe *et al*.,1992; Van Ginkel *et al.,*1996).

3.6. Catchment Land Use

The Buffalo River Catchment consist of native forests that cover approximately 7% of the catchment area. The pine and *Eucalyptus* orchards, cover 4% of the Buffalo River Catchment (RHP, 2004). The Perie Forest, located in the upper reaches, is mostly made up of local forests that are not restricted to public use, so many tree species are used to make traditional medicine, lumber, and construction wood (O'Keefe *et al.,* 1992). The Buffalo River has been converted to degraded forest and grassland for 17% of its length (RHP, 2004). Urbanization and industrialization account for 12% of the total land area occupied. Bridle Drift Dam is in the Imtiaz Coastal Nature Reserve, which encompasses 5.6 square kilometres of natural forest (CES, 2004). There is an industrial area with the Da Gamma textile industry based in the Buffalo River (O'Keefe *et al.,*1992). There are also agricultural activities that are taking place along the Buffalo River Catchment between Mdantsane WWTW and Zwelitsha WWTW and as well as Schornville WWTW that were believed to contribute to wastewater entering the Buffalo River (O'Keefe *et al*., 1992).

3.7. Research Design

For this study, a quantitative research method was selected (Sibanda *et a*l., 2009). Quantitative is a method that deals explicitly with numerical data. In this method, the data is summarized into figures that were analysed using statistical methods. Frequently, quantitative research is used to support or expand a theory that already exists. The quantitative research method uses statistical information, and it can also predict using the collected data, compares groups, and identifies relationships between variables (Leedy and Ormrod, 2013). The collection of water quality data in the Buffalo River Catchment and analysis and interpretation of data required a statistical method which would be able to achieve the aims of the study.

3.8 Data Collection

Water quality data was obtained from the South African DWS from Water Management System (WMS). The water quality data have been collected across South Africa since the early 1970s. A substantial amount of analytical data are available for the Buffalo River in the Eastern Cape dating back to the early 1970s, due to regular assessments of monitoring stations and the completion of a water quality study on the system. For this study eight-years-old data was obtained from DWS- WMS, the data was from 2012- 2019. The DWS as the custodian of South African water resource. The department is collecting surface water quality in all South African catchments including Buffalo River Catchment. The samples are collected and analysed, and the data is captured in WMS. The DWS monitoring points are selected based on the activities around the catchment and the monitoring parameters are based on the activities. The samples were taken in the water resource normal during the morning and they were sent to the different laboratories for analysis. The in-situ for physical parameters were done on site. The results are captured on department water management system. After the analysis were done the results were captured in the DWS-WMS for interpretation.

2.9 Data Analysis

To achieve the aim of the research study, the statistical method geometric mean for each parameter was calculated to determine the impact of the discharged effluent at each monitoring point in the Buffalo River Catchment. The mean for each parameter was plotted in a graph to determine the trend for each monitoring point and parameter. The comparison between the discharged effluent in each monitoring point will also be represented in column graphs to determine the impact on the surface water of the Buffalo River, the data will be compared to South African water quality guidelines for domestic, irrigation and agriculture (DWAF,1996a) The South African water quality discharged limits will be used to compare the compliance within the discharged limits hence Buffalo River is not classified and there are no Resource Quality Objectives of the Buffalo River to be compared with.

Table 2: The DWA wastewater discharge standards applicable to discharge wastewater into the water resource and guidelines for aquatic ecosystem (DWA aquatic ecosystem guidelines, volume 7).

Determinants/Parameter	Existing SA general standards	Existing SA future standards	Aquatic ecosystem standards	Domestic Use (DWAF, 1996b)	Agricultural /Irrigation DWAF, 1996d)
Faecal Coliforms (per 100 mL)	1000	1000	N/A	-	-
Chemical Oxygen Demand (mg/L)	75	30	0.1-0.17	-	-
pH	5. 5-9.5	5.5-7.5	6-9	-	6.5-8.4
Ammonia (ionised and un-ionised) as Nitrogen (mg/L)	3	1	0.007	0-1	-
Nitrate/Nitrate as Nitrogen (mg/L)	15	15	0-6	0-6	0.5
Chlorine as free Chlorine (mg/L)	0.25	0.014	0.0002	-	-

Suspended Solids (mg/L)	25	18	¤ N/A	-	-
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.	N/A	N/A	N/A
Orthophosphate as phosphorous (mg/L)	10	1 (median) and 2.5 (maximum)	N/A	N/A	N/A
Fluoride (mg/l)	1	1	N/A	N/A	N/A
Soap, oil, or grease (mg/L)	2.5	0	N/A	N/A	N/A
Dissolved Arsenic (mg/L)	0.02	0,01	N/A	N/A	N/A
Dissolved Cadmium (VI) (mg/L)	0.005	0,001	N/A	N/A	N/A
Dissolved Copper (mg/L)	0.01	0,002	N/A	N/A	N/A
Dissolved Cyanide (mg/L)	0.02	0,01	N/A	N/A	N/A
Dissolved Iron (mg/L)	0.3	0,3	N/A		N/A
Dissolved Lead (mg/L)	0.01	0,006	N/A	N/A	N/A
Dissolved Manganese (mg/L)	0.1	0,1	N/A	N/A	N/A
Dissolved selenium (mg/L)	0.02	0,04	N/A	N/A	N/A
Dissolved Zinc (mg/L)	0.1	0,04	N/A	N/A	N/A
Boron (mg/L)	1	0,5	N/A	N/A	N/A

3.10. Statistical Analysis

The multivariate analysis sought to identify possible sources that influence water quality (Gvozdić *et al.,* 2012). The results were analysed using multivariate statistics in the form of principal component analyses (PCAs) to determine whether any spatial differences existed due to variations in the concentration of parameters at each site, regardless of the time of sampling. Furthermore, a PCA was conducted to determine if there were any spatial or temporal trends within the water quality variables between sites as well as between different sampling surveys (van den Brink *et al*., 2003). PCA was performed using monitoring site and monitoring year as covariates. All the data were log transformed prior to analyses. The multivariate Principal Component Analysis (PCA) was performed using Canoco version 5.

3.11. Ethical Considerations

The study aimed to focus on the historical data as was available from the Department of Water and Sanitation Water Management System for the water quality of Buffalo River Catchment. The study was classified as a low risk. Ethical number is NWU-01299 - 20-A9 (ANNEXURE A).

Chapter 4 RESULTS AND DISCUSSION

4.1. The mean results of the discharged parameters in Surface Water in Buffalo River Catchment.

4.1.1 pH

The pH results (Figure 3) at the Buffalo River catchment during the study period ranged from 6.5 – 8.3 in Figure 3. The pH complies with the limit per wastewater discharge limits. Although there are two- wastewater treatment works that are discharging directly into the Buffalo River Catchment, they did not have an impact in the Buffalo River Catchment pH. The value of pH was within the acceptable limit during the study period.

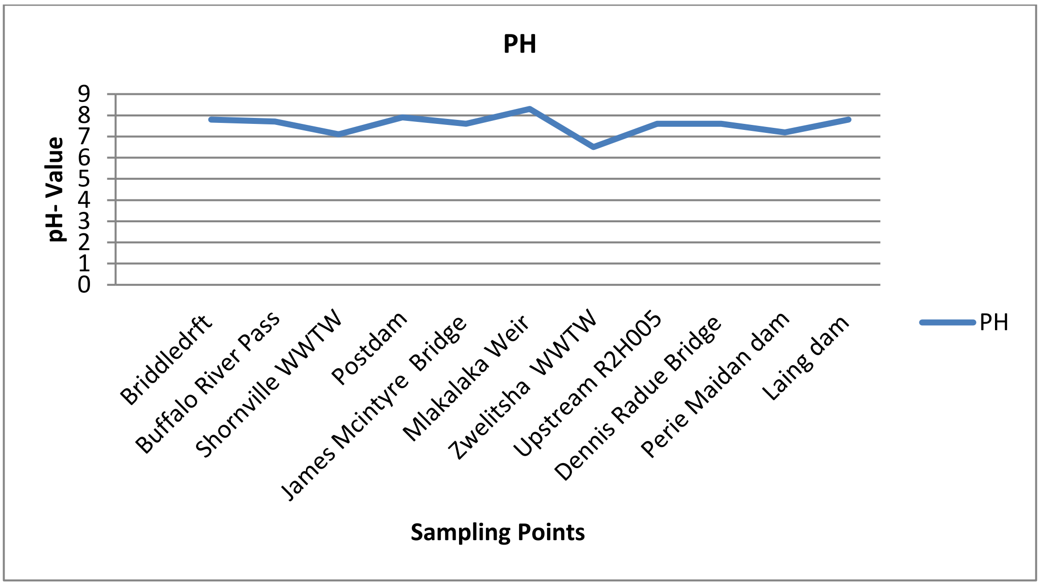

Figure 3: The mean pH at the selected sites within the Buffalo River from 2012-2019

4.1.2. Ammonia

The mean value in the Buffalo River ranged from 0.12 mg/L to 6.07 mg/L (Figure 4). Other monitoring sites were within the limits and Zwelitsha WWTWs exceeded the limit with 6.07 mg/L. The poor performance of the works may be responsible for this. In the study conducted by (Agyemang *at el.,* 2013), it was also discovered that ammonia increased in the effluent discharged by WWTWs. The main reason for the high concentration may be attributed by WWTWs failure to treat ammonia in the discharged point.

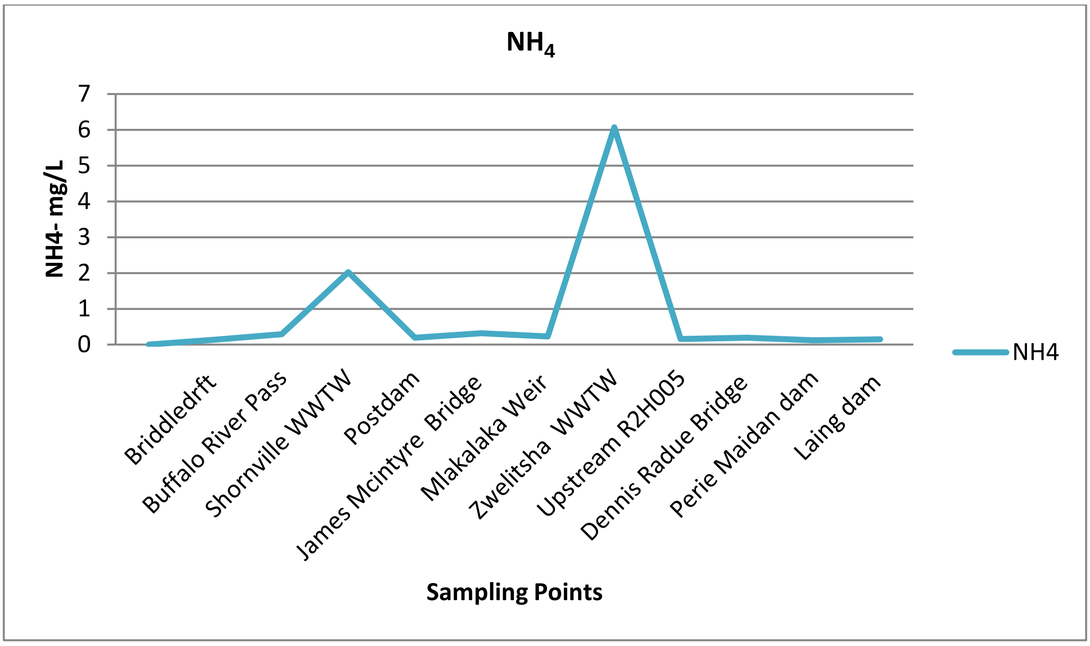

Figure 4: The mean Ammonia at the selected sites within the Buffalo River from 2012-2019

4.1.3. Nitrate And Nitrite

Figure 5 below indicates the nitrate and nitrite concentration in the Buffalo River and the standards as per South African wastewater discharge limits ranging from 1.5 mg/L – 15 mg/L. The nitrate and nitrite that are discharged into the Buffalo River catchment comply with South African discharged limits. The mean values for nitrate in the Buffalo River ranged from 0.66 mg/L- 6.56 mg/L during the assessment period.

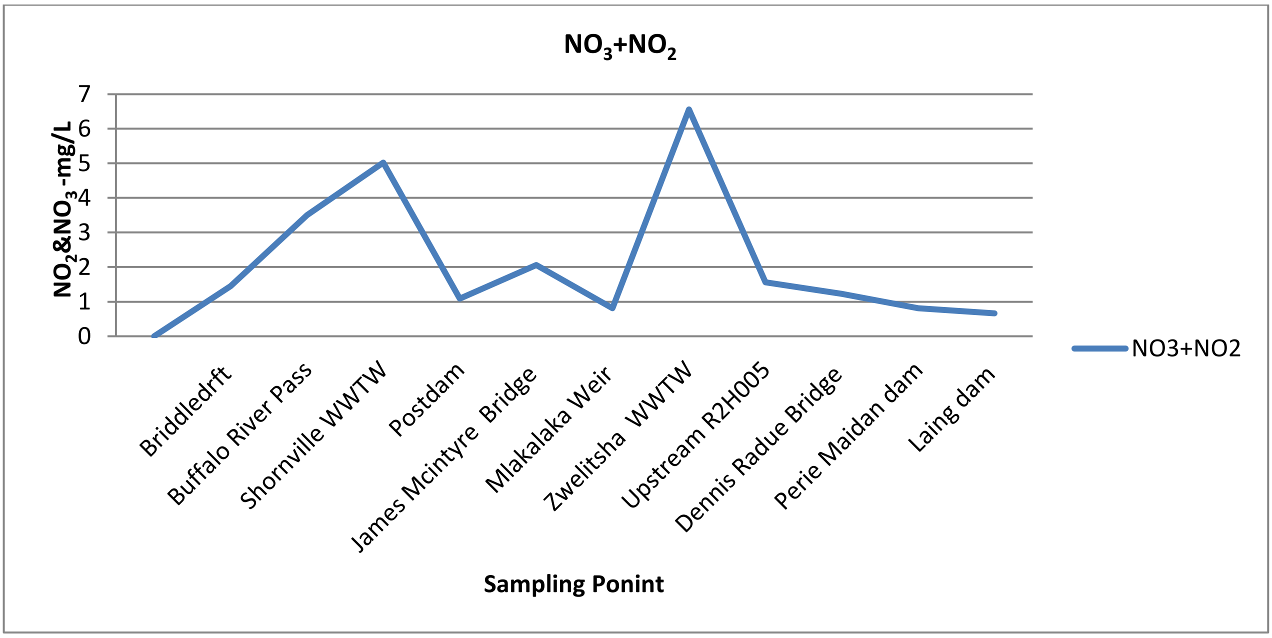

Figure 5: The mean Nitrate & Nitrite at the selected sites within the Buffalo River from 2012-2019

4.1.4 Electrical Conductivity

The measured electrical conductivity in the Buffalo River Catchment is shown in (Figure 6) for the 2012 to 2019 period. According to the DWS discharge limits, the limits are 70 mS/m above intake to a maximum of 150 mS/m general limits and 50 mS/m for above background receiving water, to a maximum of 100 mS/m for special limits. The measured EC during the study period ranged from 2.2- 438.7 S/m. The monitoring point James McIntyre Bridge complied with the minimum standard for electrical conductivity while the monitoring point in Mlakalaka weir had the highest value for electrical conductivity. The highest concentration of electrical conductivity could be caused by the high dissolved ions upstream of the river (Walakira & Okot-Okumu, 2011). However, the high concentration of water colorants, dissolved salts, organic wastes, insecticides, pesticides, chemical wastes, alkali, sodium, and detergents are some of the constituents of textile effluent (Kurek *et al., 2019*). The high concentration of salt may cause harm to the aquatic ecosystem.

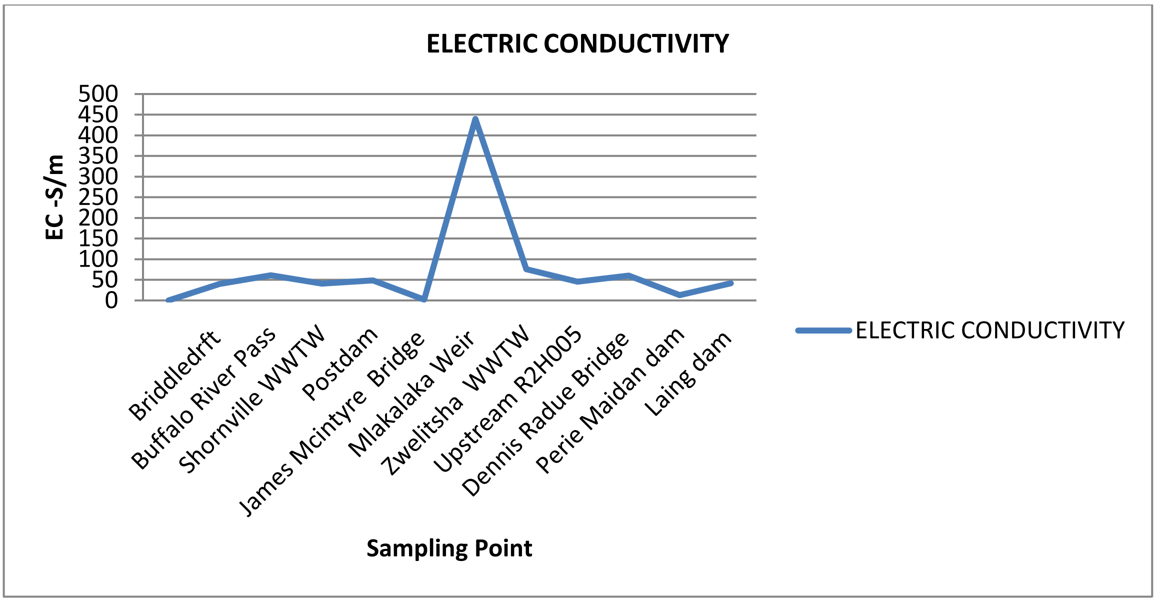

Figure 6: The mean electrical conductivity at the selected sites within the Buffalo River from 2012-2019

4.1.5 Chemical Oxygen Demand

In Figure 7 the results of the measured chemical oxygen demand (COD) for the Buffalo River are presented from 2012 to 2019. The discharged COD at Buffalo River Catchment was within the South African water quality guidelines for domestic, agricultural-irrigation and aquatic ecosystem and DWS wastewater discharged limits. The COD that was discharged during the study period in all monitoring points in the surface water at Buffalo River was 50 mg/L. Mlakalaka Weir exceeded the limits as it was measured at 395,4 mg/L. The COD is used as the routine measurement of effluents and a measure of the amount of oxygen required for the degradation of organic waste (Dallas & Day, 2004). The standard limit for COD ranged from 50 mg/L to 75 mg/L.

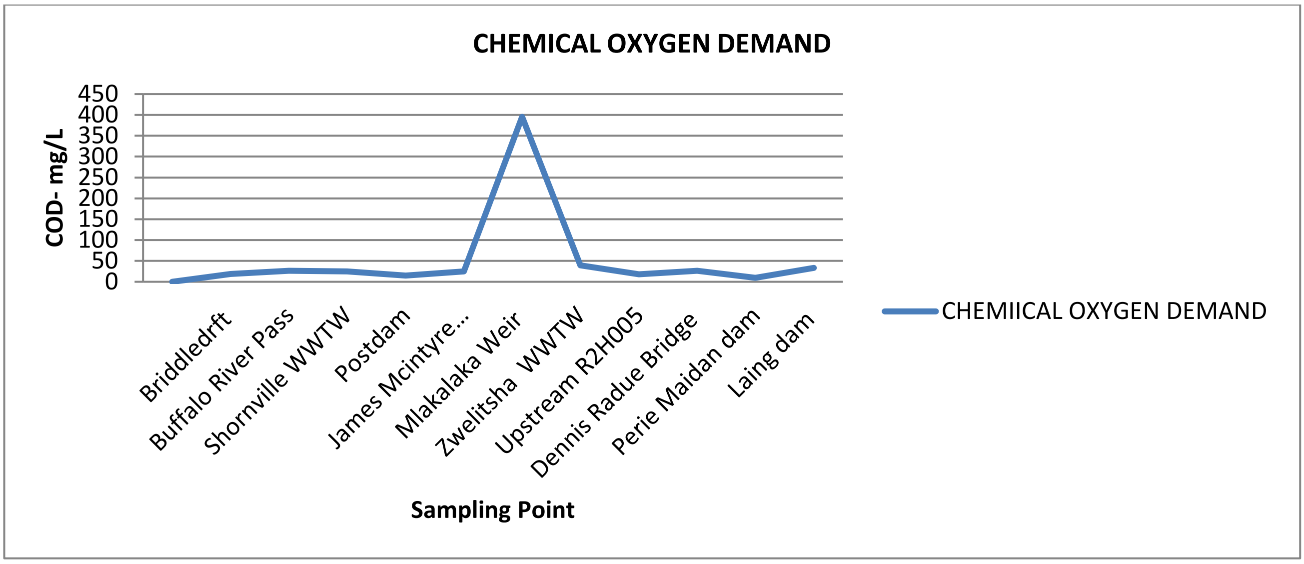

Figure 7: The mean COD at the selected sites within the Buffalo River from 2012-2019

4.1.6 Faecal Coliform

The mean concentration of faecal coliforms ranged from 13.20 - 11212.5cfu/100mL indicated in (Figure 8). According to South African water quality guidelines, the discharged limit of faecal coliform ranges from 0 -1000Cfu/100ml (DWAF, 1996b). The effluent that was discharged at Buffalo River Catchment exceeded the limits as per South African water quality guidelines for domestic, agriculture – irrigation, aquatic ecosystem, and DWS wastewater discharged limits. The previous study by Osode & Okoh (2009) indicated that the Buffalo River is contaminated with faecal coliforms due to malfunctioning of the WWTWs in the Buffalo City Municipality.

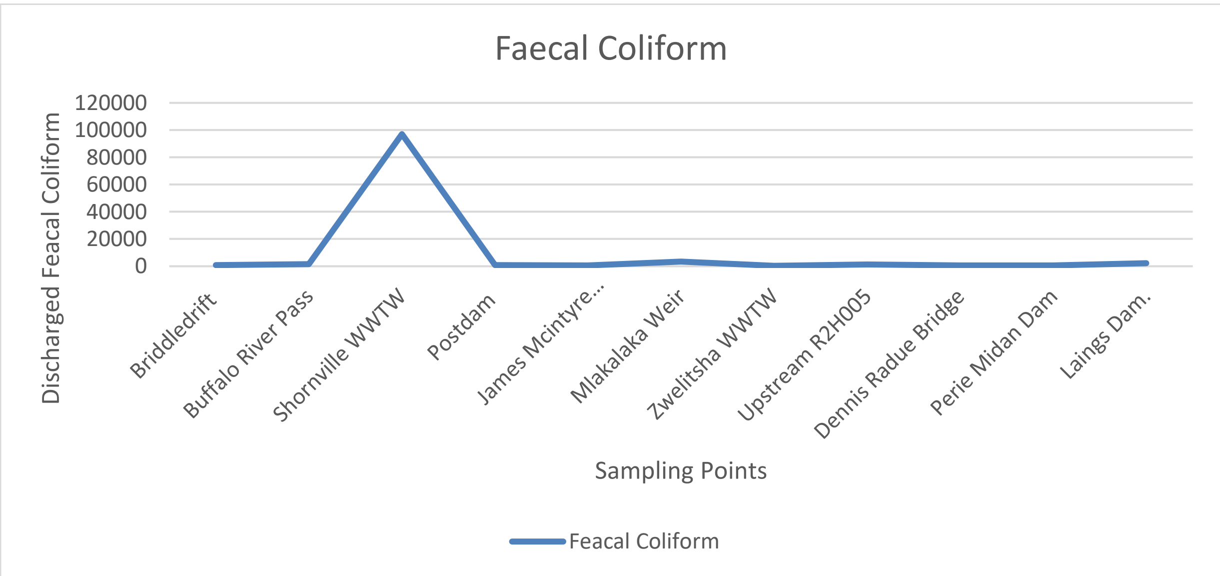

Figure 8: The mean Faecal Coliforms at the selected sites within the Buffalo River from 2012-2019.

4.1.7 Phosphate

During the assessment period, the concentration of phosphate was recorded, and it ranged between 0.08 - 9.07 mg/L (Figure 9) for the discharged effluent at Buffalo River from all monitoring points as shown in Figure 9. According to South African water quality guidelines for domestic, agricultural – irrigation, and aquatic ecosystems, the value for Mlakalaka Weir has exceeded the limits. The Phosphate value from the results has exceeded the limits which is 1 (DWAF, 1996b). However, the phosphate is within general limits as per DWS discharge limits. The presence of phosphate is an indication of many factors that affect water quality. phosphate levels indicate urban land use as they are associated with domestic detergents Elevated and industrial and domestic wastewater. The high levels of PO_4 indicate that the Buffalo River is influenced by the discharge of industrial effluent. This confirmed that the practise of wastewater effluent irrigation is a source of pollutants to shallow groundwater and nearby surface water (Turner *et al.,* 2019).

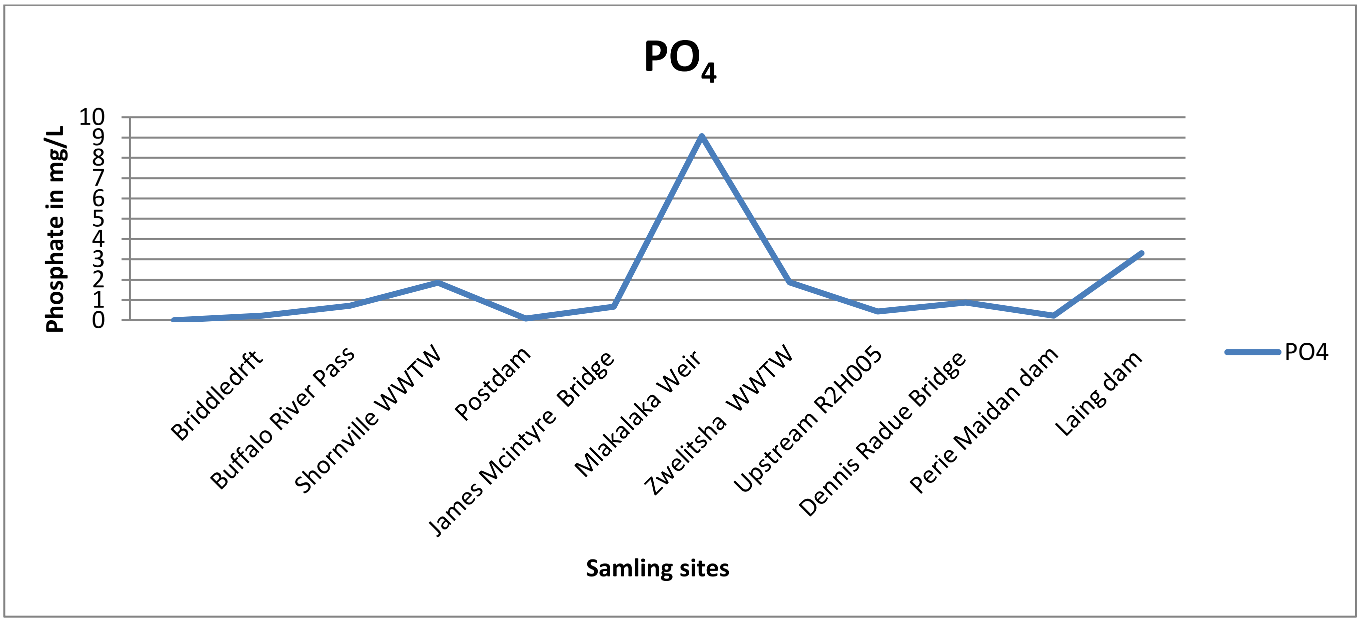

Figure 9: The mean Phosphate at the selected sites within the Buffalo River from 2012-2019.

4.2. The Discharged Effluent in Buffalo River Comparison From 2012 to 2019

4.2.1. Bridle drift dam

Figure 10 and Figure 11 indicate the yearly mean of the discharged water quality parameters in the Bridle drift dam. The COD, EC, pH, PO_4, NO_3+NO_2, and NH_3 discharged during the study period comply with the limits as per South African Water Quality Guidelines for domestic, agricultural-irrigation, aquatic ecosystem, and as well as DWS wastewater discharged limits. The limits are COD (30- 75mg/L),EC (50-70S/m) pH (6.5-9) PO_4(1-10), NO_2&NO_3 (1-15mg/L) and fc (0-100cf per 100ml). The discharged water quality containing Faecal Coliform at Bridle drift dam is indicated in

Figure 10. The Faecal Coliform exceeded all the limits as per South African Water Quality guidelines (DWAF, 1996b). A high concentration of Faecal Coliforms in the surface water may cause a high risk to human well-being as it causes some diseases.

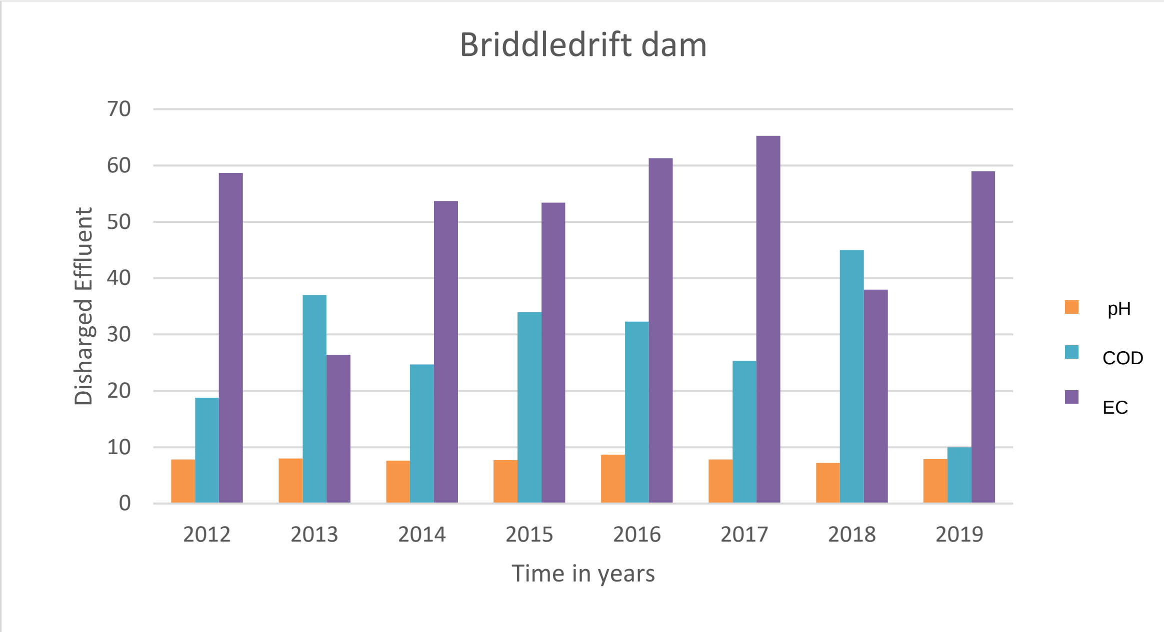

Figure 10: The yearly mean results for pH, COD and EC at Bridle drift dam from 2012- 2019

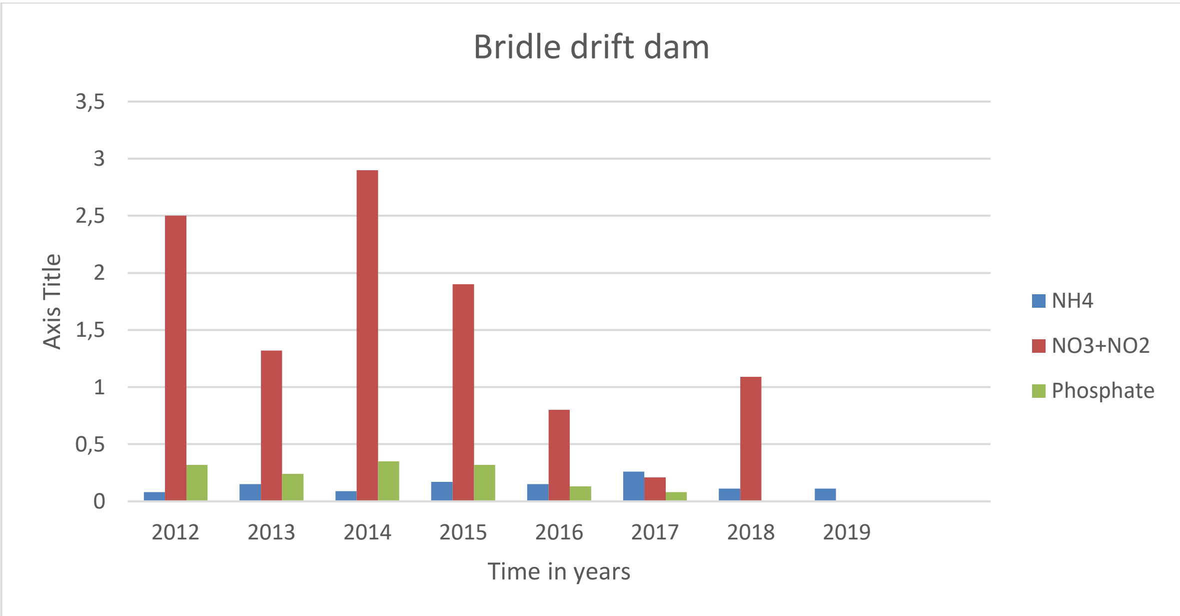

Figure11: The yearly mean results for NH_4, NO_2&NO_3 and PO_4 at Bridle drift dam from 2012- 2019

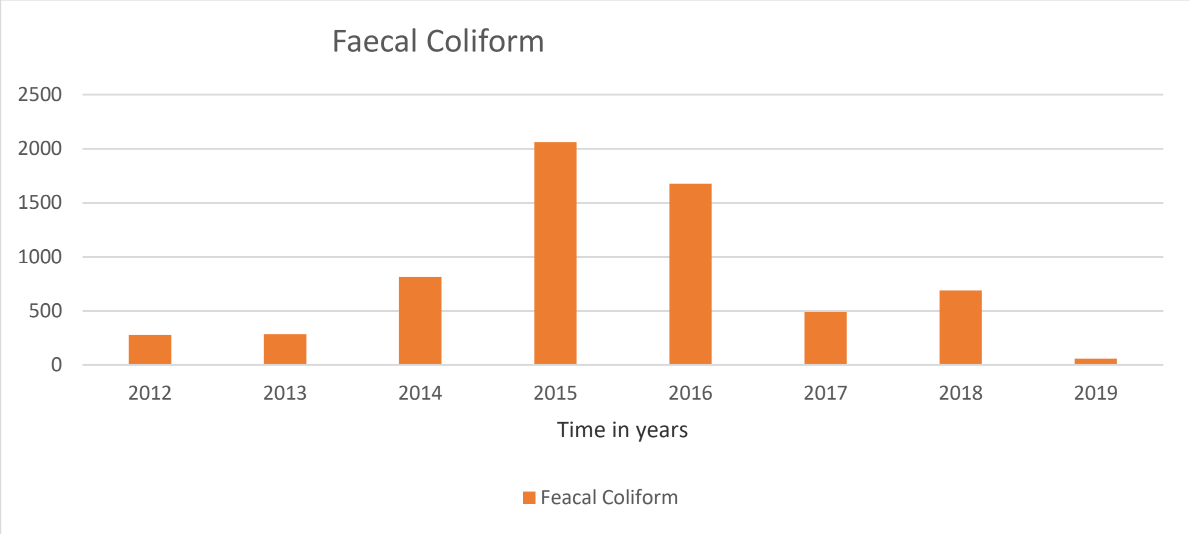

Figure 12: The yearly mean results for Faecal Coliform results at Bridle drift dam from 2012- 2019

4.2.2. Buffalo River Pass

Figure 13, Figure 14, and Figure 15 indicate the yearly mean of the discharged water quality parameters at the Buffalo River pass. pH, COD, EC, NO_2&NO_3, NH_4, and PO_4 were within the limits as per South African Water Quality Guidelines for Domestic, Agricultural–Irrigation and for DWS wastewater discharged limits. (DWAF, 1996b) The discharged limits are pH (6.5-9) COD (30-75) NO_2&NO_3 (0.5-15), NH_4 (0-3) and PO_4 (10) However, for the aquatic ecosystem all the parameters exceeded the limits. Faecal Coliform is represented in Figure 15 and the Faecal Coliform results exceeded all the limits at Buffalo River during the study period except for 2013 and 2019.

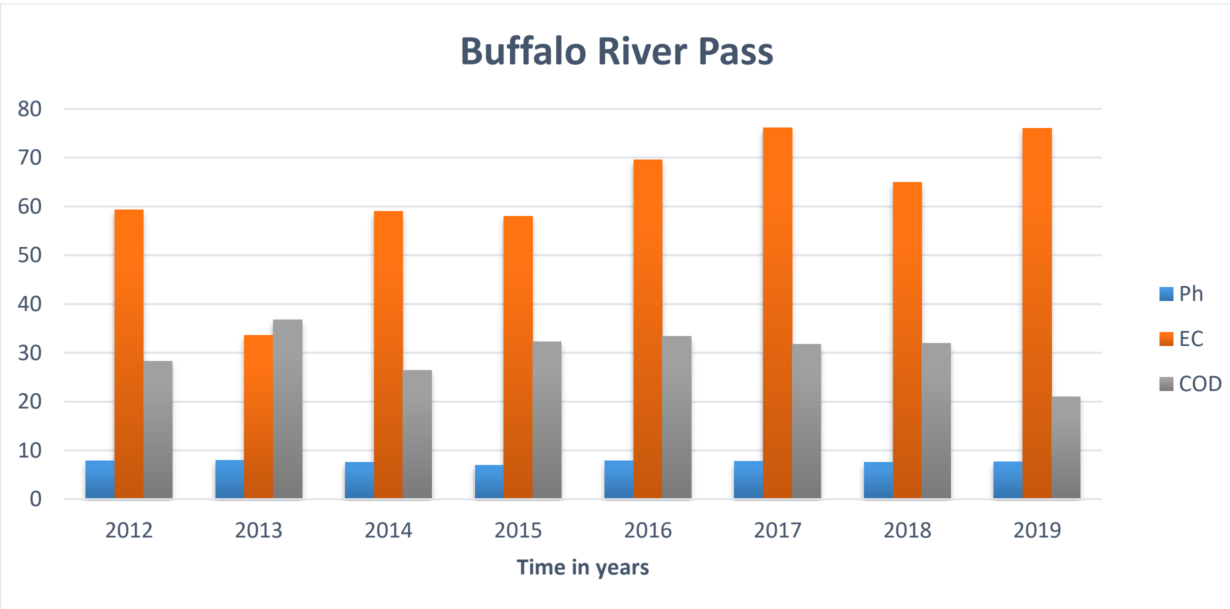

Figure 13: The yearly mean results for pH, COD and EC at Buffalo River Pass from 2012-2019

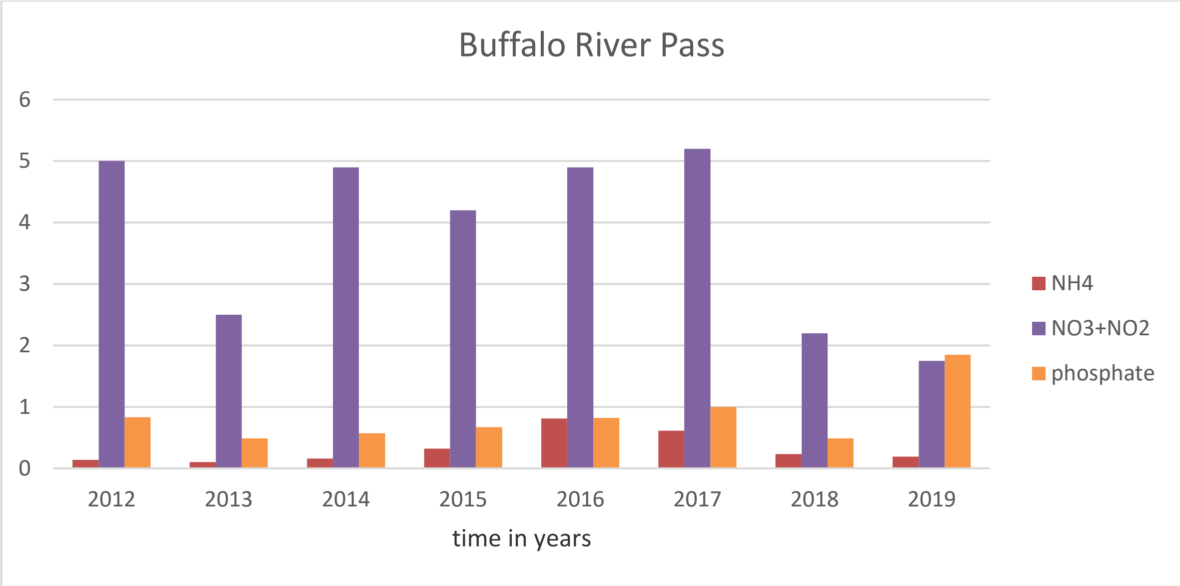

Figure 14: The yearly mean results for NH_3, NO_3 +NO_2 and Phosphate at Buffalo River Pass 2012-2019

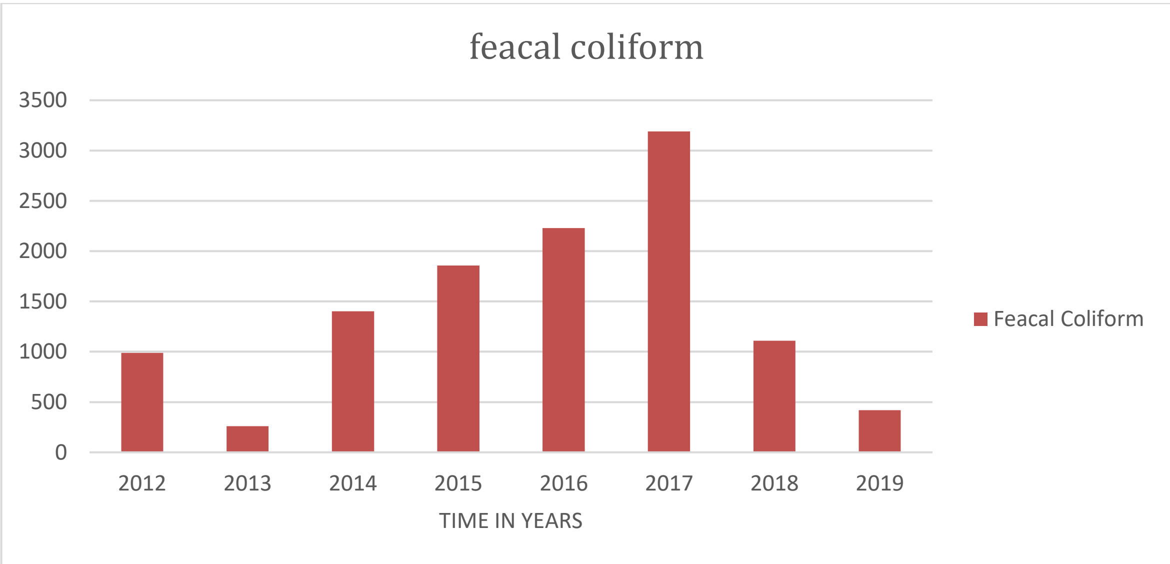

Figure 15: The yearly mean results for Faecal Coliforms at Buffalo River Pass WWTW from 2012-2019

4.2.3. Schornville WWTWs

Figure 16 below indicates the yearly mean of discharged water quality parameters in Schornville WWTW. Figure 16 indicates the discharged parameter of pH, COD, and EC, and Figure 17 indicates the discharged NO_2&NO_3, NH_4, and PO_4 while Figure 18 indicates the yearly mean of the discharged faecal coliform at Schornville WWTWs during the study period. The results show that the following water quality parameters (COD, EC, pH, PO_4-, NO_2+NO_3, and NH_4) were within the acceptable limits for South African Water Quality Guidelines for domestic, Agriculture- irrigation, aquatic ecosystem, and as well as DWS wastewater discharged limits. Figure 18 represents the water quality containing faecal coliform during the study period. The Faecal Coliform indicated in Figure 18 exceeded all the limits.

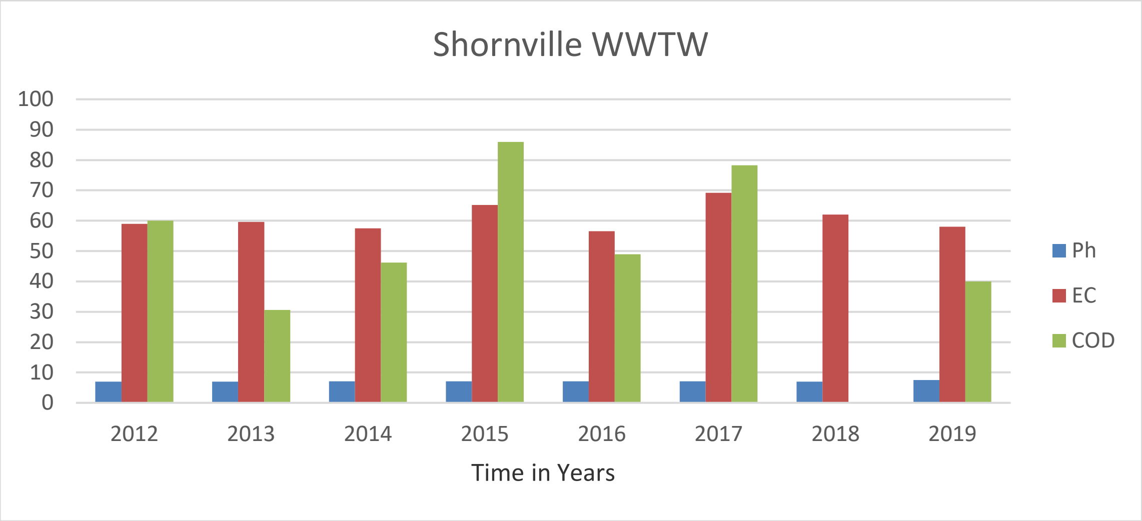

Figure 16: The yearly mean results for pH, COD and EC Schornville WWTW from 2012-2019

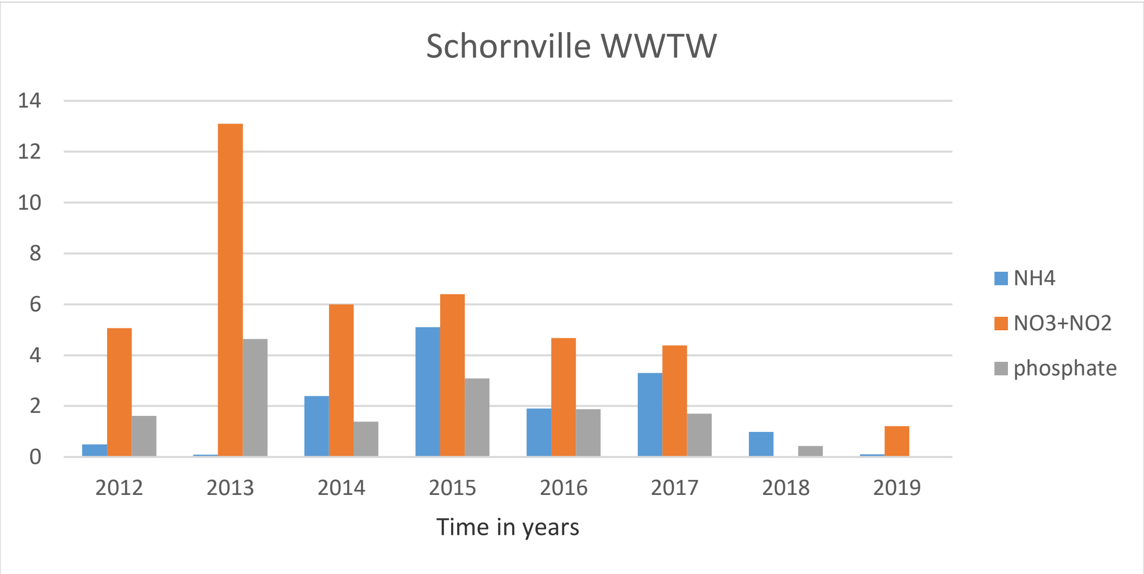

Figure 17: The yearly mean results for NH_4, NO_2&NO_3 and PO_4 at Schornville WWTW from 2012-2019

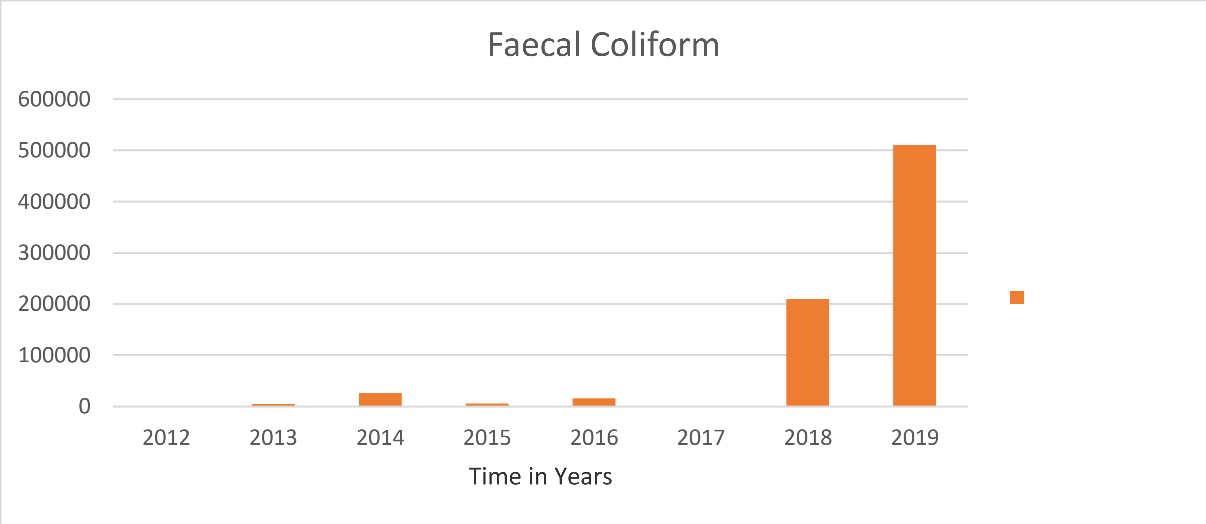

Figure 18: The yearly mean results for Faecal Coliform at Schornville WWTW from 2012-2019

4.2.4. Postdam

Figure 19 and Figure 20 indicate the yearly mean of the discharged water quality parameters into the Postdam. The COD, EC, pH, PO_4^-, NO_2&NO_3, and NH_4 discharged during the study period. All the parameters complied with the limits as per South African Water Quality guidelines for domestic, agricultural- irrigation, aquatic ecosystem and as well as DWS wastewater discharged limits. The discharged water quality containing Faecal Coliform at Postdam is indicated in Figure 21. The faecal coliform was extremely high in 2018. There was no data for faecal coliform for Postdam from 2014 to 2016. The results indicates that the Faecal Coliform for Postdam during the study period exceeded the limits as per South African Water Quality guidelines for domestic, Agriculture – irrigation, aquatic ecosystem and DWS wastewater discharged system.

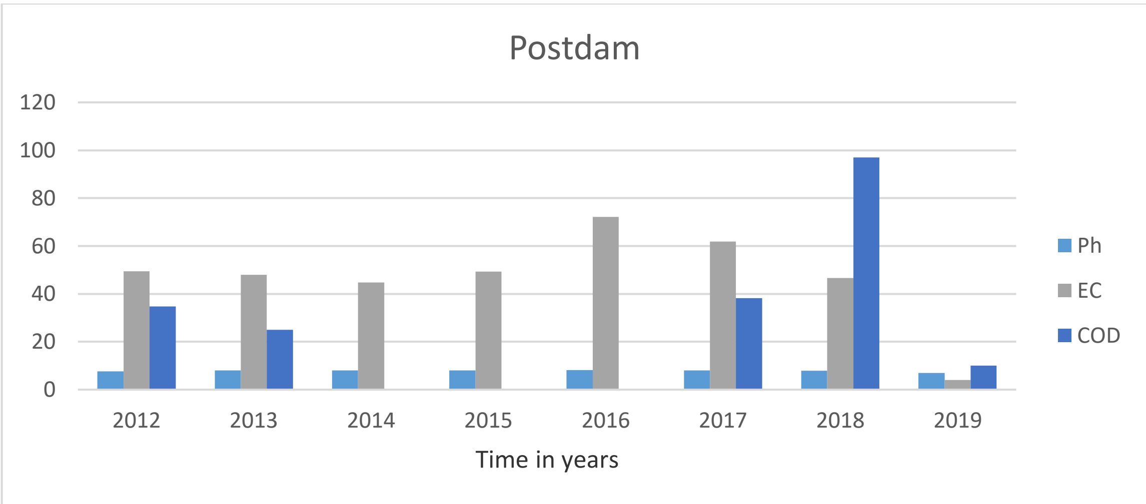

Figure 19: The yearly mean results for pH, COD and EC at Postdam from 2012-2019

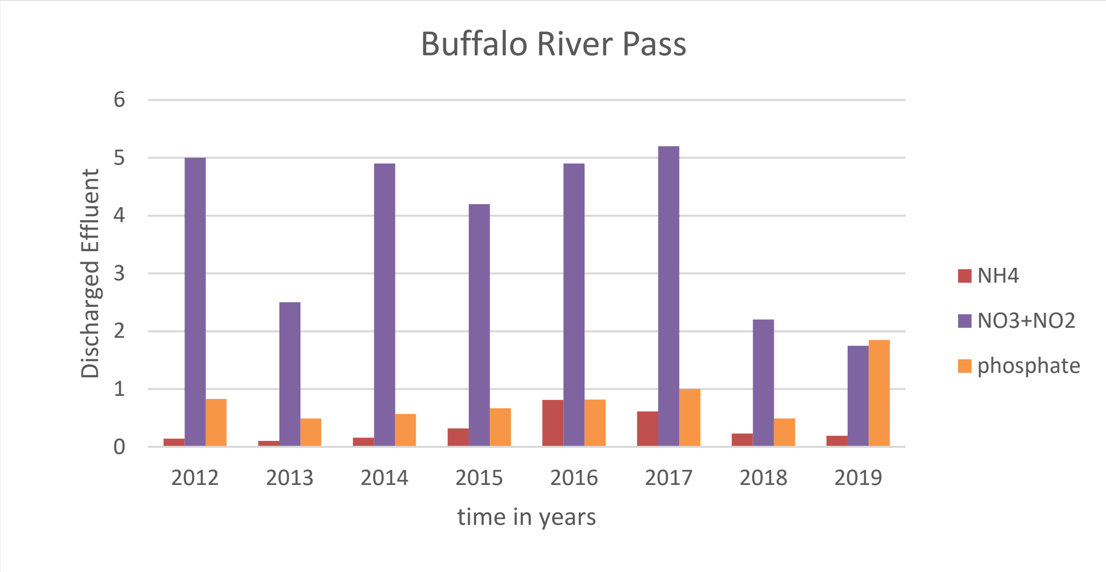

Figure 20: The yearly mean results for NH_4, NO_2&NO_3 and PO_4 Postdam from 2012-2019

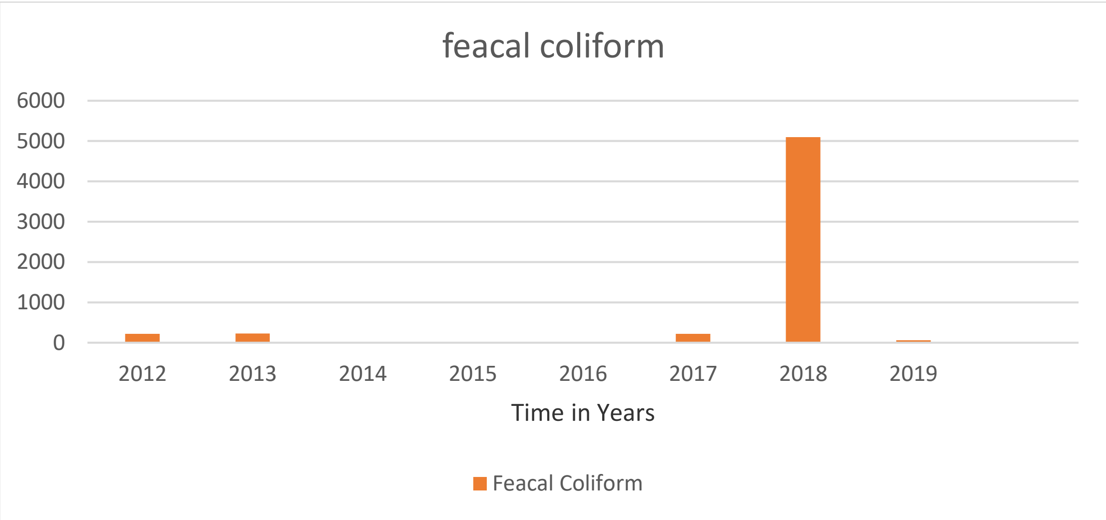

Figure 21: The yearly mean results for Faecal Coliform at Postdam from 2012-2019

4.2.5 Mlakalaka Weir

Figure 22 and Figure 23 indicate the yearly mean of the discharged water quality parameters of the Mlakalaka Weir. The COD, EC, pH, PO_4, NO_2&NO_3, and NH_4 were discharged during the study period. All the parameters complied with the limits as per South African Water Quality Guidelines for domestic, agricultural- irrigation, aquatic ecosystem, and as well as DWS wastewater discharged limits. The discharged water quality containing Faecal Coliform at Mlakalaka Weir is indicated in Figure 24. The faecal coliform was extremely high in 2018. There was no data for faecal coliform for Mlakalaka Weir from 2014 to 2016. The results indicate that the Faecal Coliform for Mlakalaka Weir during the study period exceeded the limits as per South African Water Quality Guidelines for domestic, Agriculture – irrigation, and aquatic ecosystems (DWAF, 1996b). and DWS wastewater discharged system.

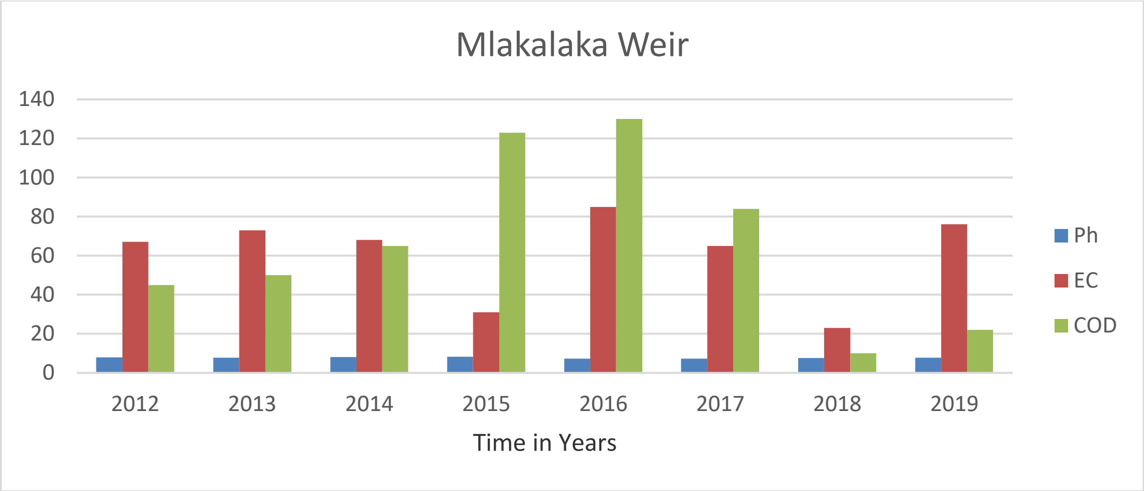

Figure 22: The yearly results for pH, COD and EC at Mlakalaka Weir from 2012-2019

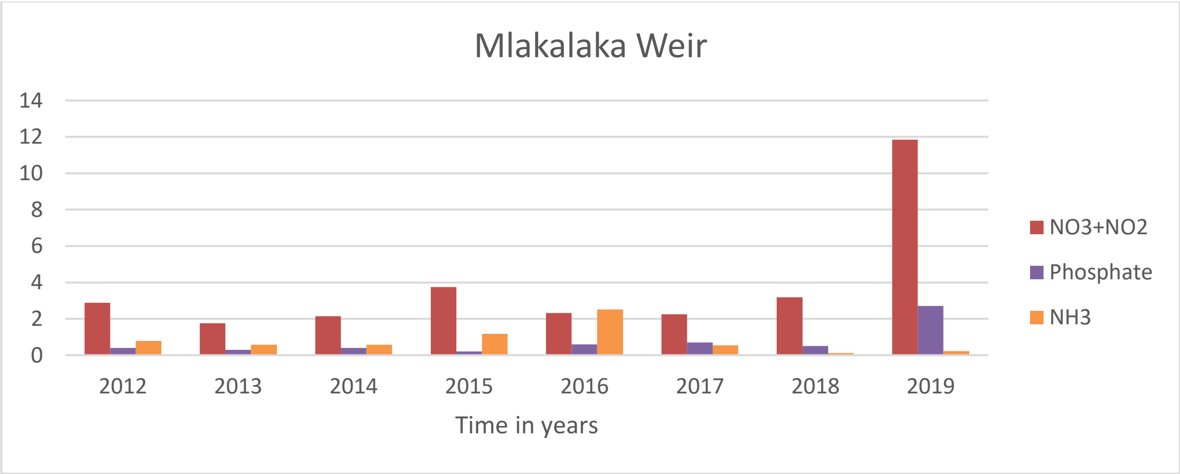

Figure 23: The yearly mean results for NH_3, NO_3& NO_2 and PO_4 at Mlakalaka Weir from 2012-2019

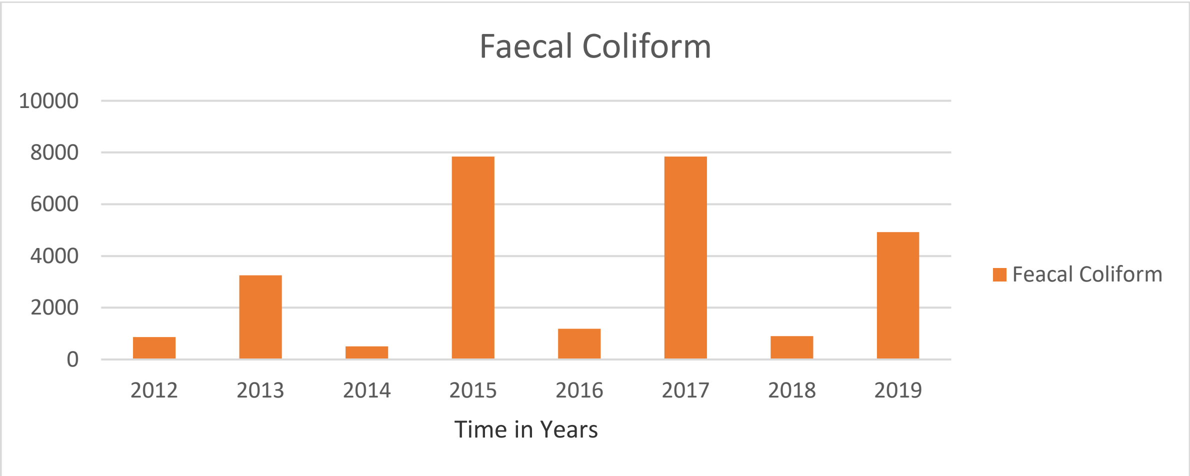

Figure 24: The yearly mean results for Faecal Coliform at Mlakalaka Weir from 2012-2019

4.2.6. James McIntyre Bridge

Figure 25, Figure 26, and Figure 27 indicate the yearly mean of the discharged effluent at James McIntyre Bridge. In Figure 25 the discharged pH, COD and EC are within the acceptable standards as per the South African Water Quality Standard for domestic, agriculture, and aquatic ecosystem and as well as Figure 26 indicate the discharged NH_4, NO_2&NO_3, and PO_4 and Figure 27 Faecal Coliform is within the acceptable standard as except for 2015 and 2018 where the limits were very high.

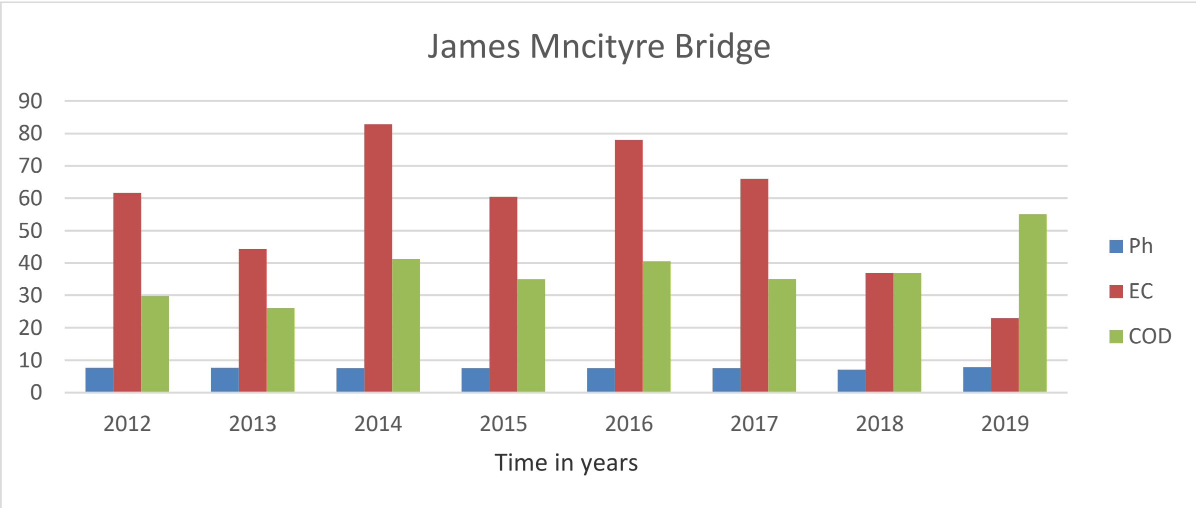

Figure 25: The yearly mean results for discharged pH, COD and EC at James McIntyre Bridge from 2012-2019

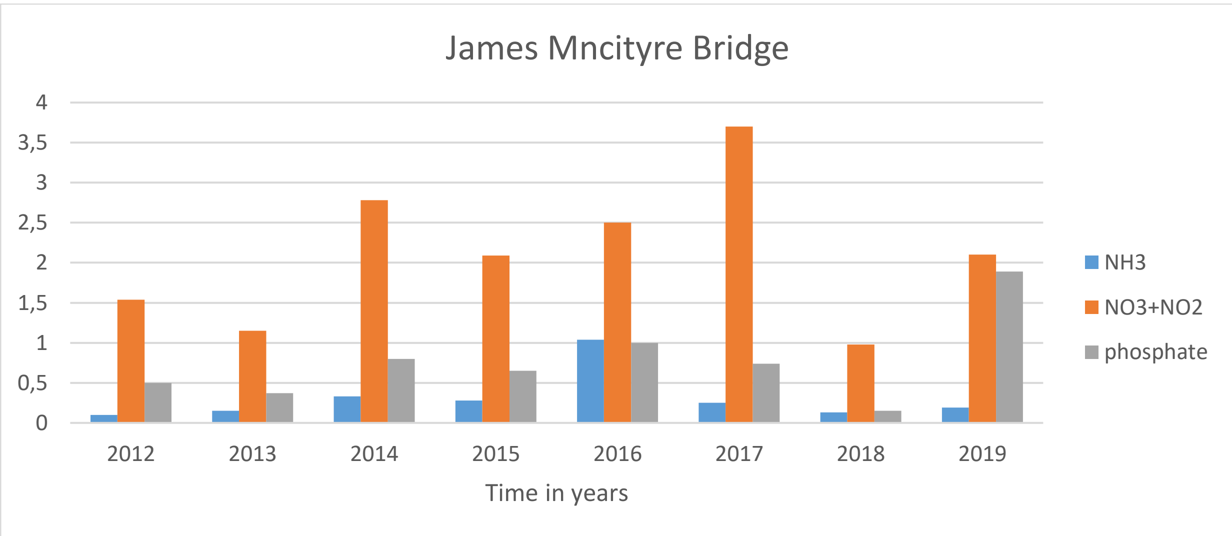

Figure 26: The yearly mean results for NH_4, NO_2&NO_3 and PO_4 at James McIntyre Bridge from 2012-2019

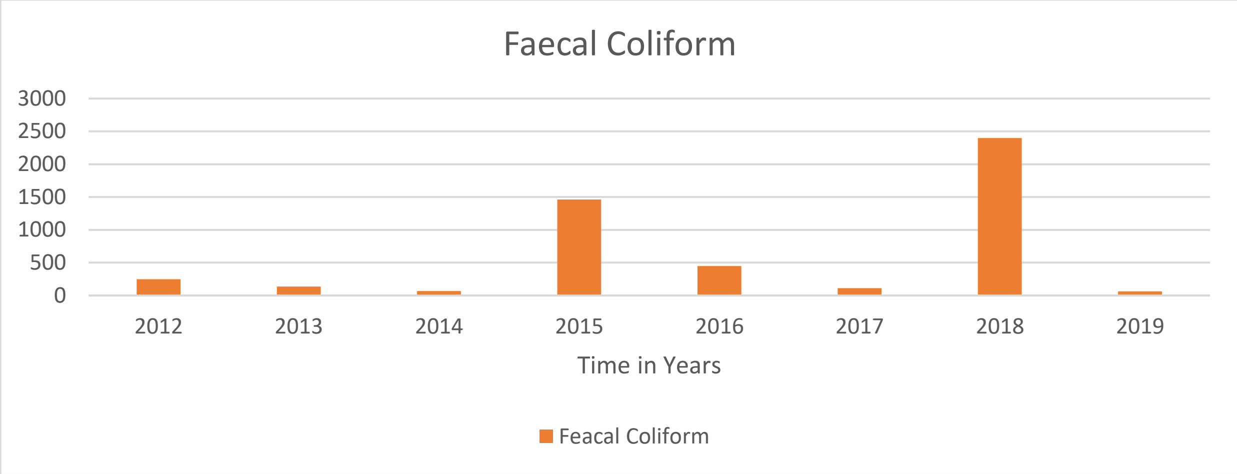

Figure 27: The yearly mean results for faecal coliform at James McIntyre Bridge for the period 2012 – 2019

4.2.7. Upstream Of R2H005

Figure 28 shows the discharged pH, EC, and COD, while Figure 29 shows the discharged $NO_{2\&}$ NO_3, NH_4, and PO_4 and Figure 30 indicates the discharged Faecal Coliform at Upstream R2H005. pH, EC, and COD. As well NO_2 & NO_3, NH_4, and PO_4^3 in Figure 28 were within the standard limits during the study period. As per South African Water quality guidelines for domestic, Agriculture-Irrigation, aquatic ecosystem, and DWS wastewater discharged limits. The discharge of faecal coliform is indicated in figure 30, Faecal Coliform has exceeded the South African guides limits for domestics, agricultural – irrigation, aquatic ecosystem, and DWS wastewater discharges limits. However, in 2015 and 2018 was extremely high.

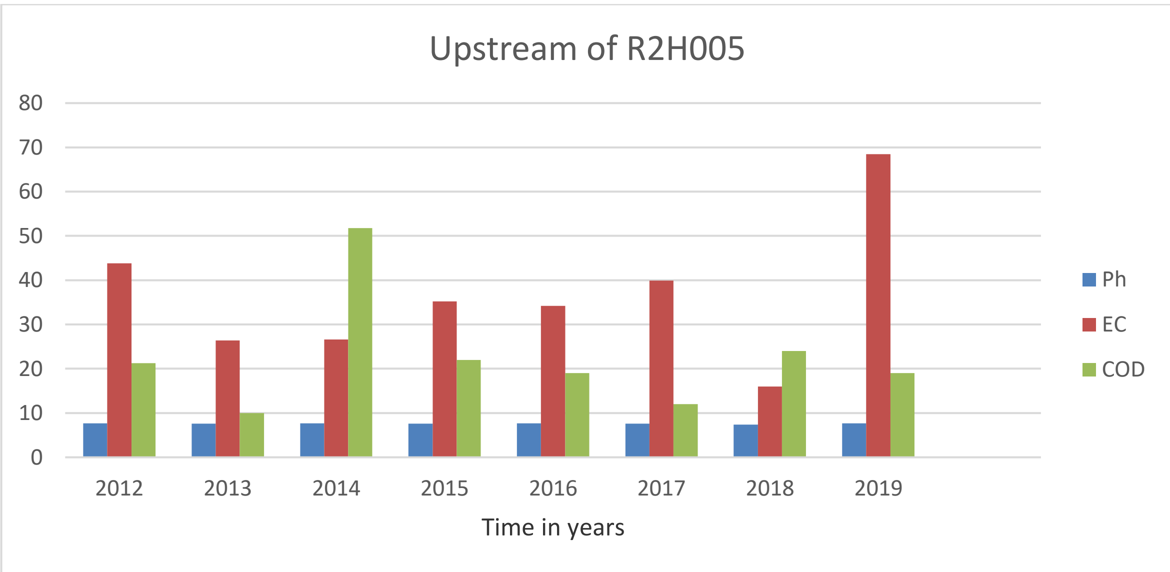

Figure 28: The yearly mean results for pH, COD and EC at Upstream R2H005 from 2012-2019

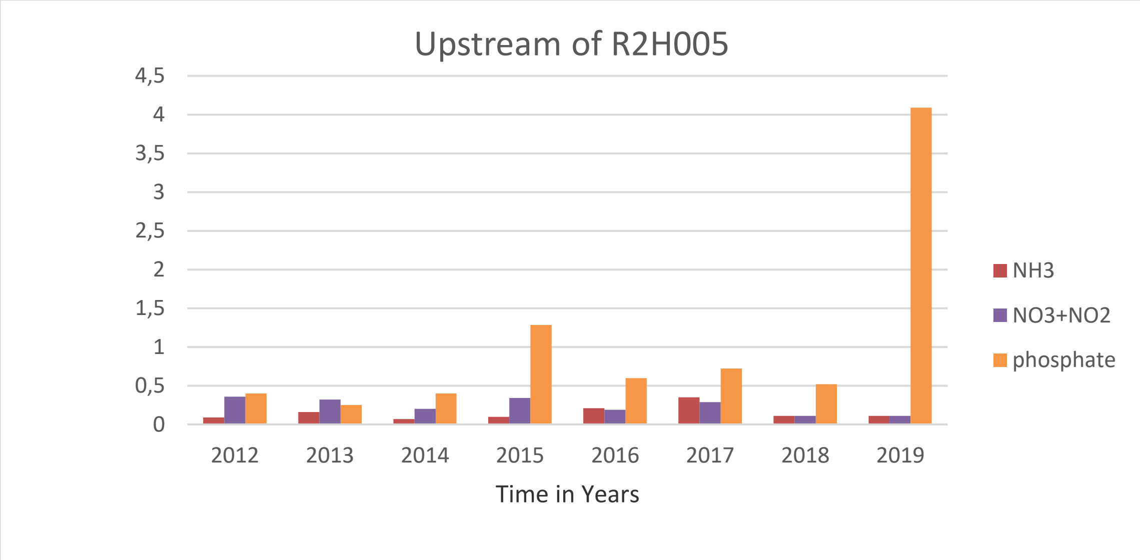

Figure 29: The yearly mean results for NH_3, NO_3 &NO_2 and PO_4 at Upstream of R2H005 from 2012-2019

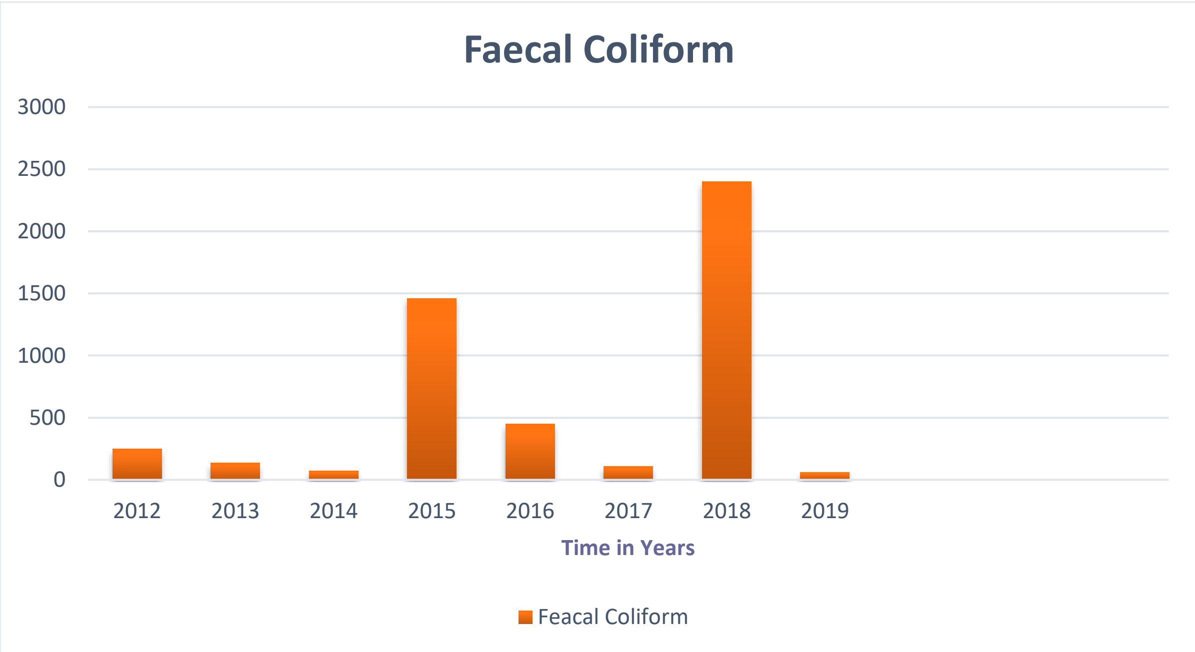

Figure 30: The yearly mean results for Faecal Coliform at Upstream R2H005 from 2012-2019.

4.2.8. Zwelitsha WWTW

Figure 31 indicates the yearly mean of the discharged water quality parameters pH, EC, and COD, while Figure 32 indicates the discharged NO_2 & NO_3, NH_4, and PO_4 and Figure 33 indicates the discharged Faecal Coliform during the study period at Zwelitsha WWTW. pH, EC, and COD. As well as NO_2 & NO_3, NH_4, and PO_4 in Figure 30. The NO_2 & NO_3, and PO_4 concentrations were within the standard limits as per South African Water quality guidelines for domestic, agriculture- irrigation, aquatic ecosystem, and as well as DWS wastewater discharged limits. However, NH_4 exceeded all the limits in 2016. According to the South African Water Quality Standard, the limits for NH_3 are (2 gm/L- 6 mg/L) and NH_4 is 16 mg/L. The high ammonia is normally caused by the failure of the WWTWs to treat ammonia effectively. Faecal Coliform during the study period is indicated in Figure 33. The results it was extreme in 2016 as a result it exceeded South African Water Quality guidelines limits for domestic agriculture- irrigation, aquatic ecosystem, and the DWS wastewater discharge limits.

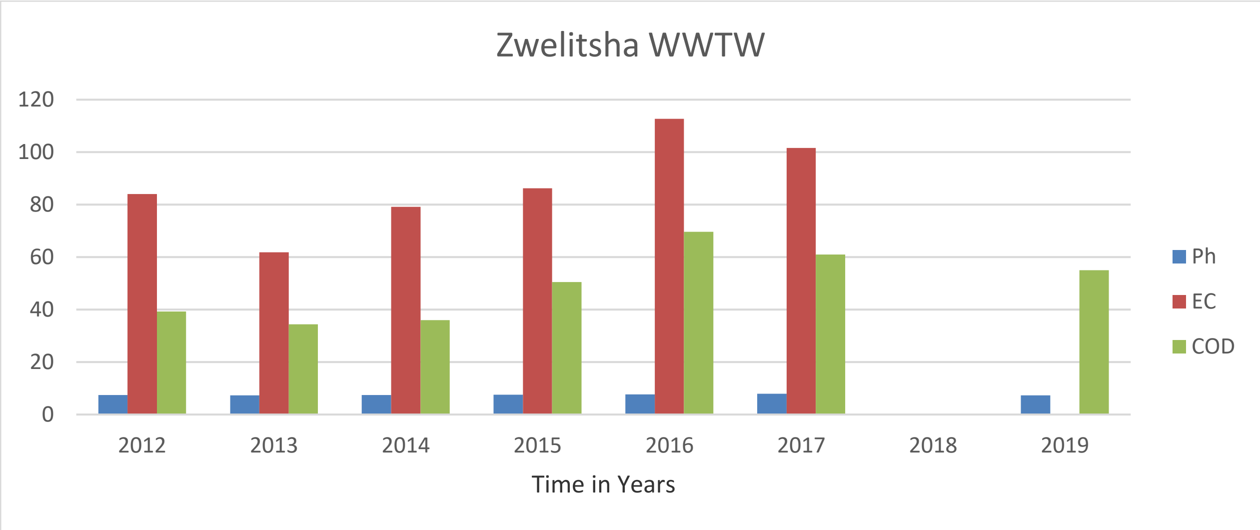

Figure 31: The mean yearly results for pH, COD and EC at Zwelitsha WWTW from 2012-2019

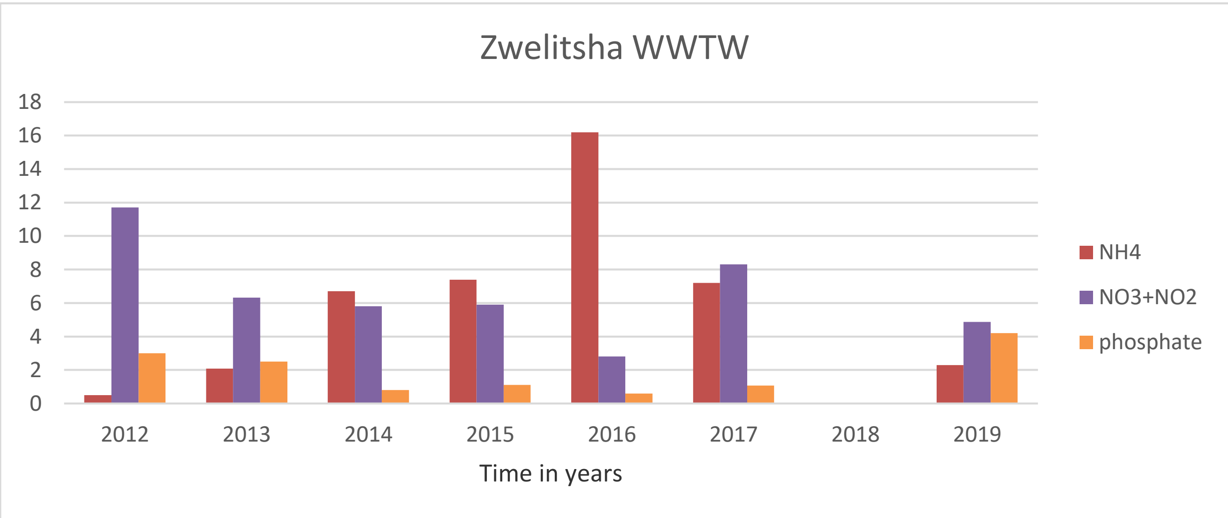

Figure 32: The yearly mean results for NH_4, NO_2 &NO_3 and Phosphate at Zwelitsha WWTW from 2012-2019

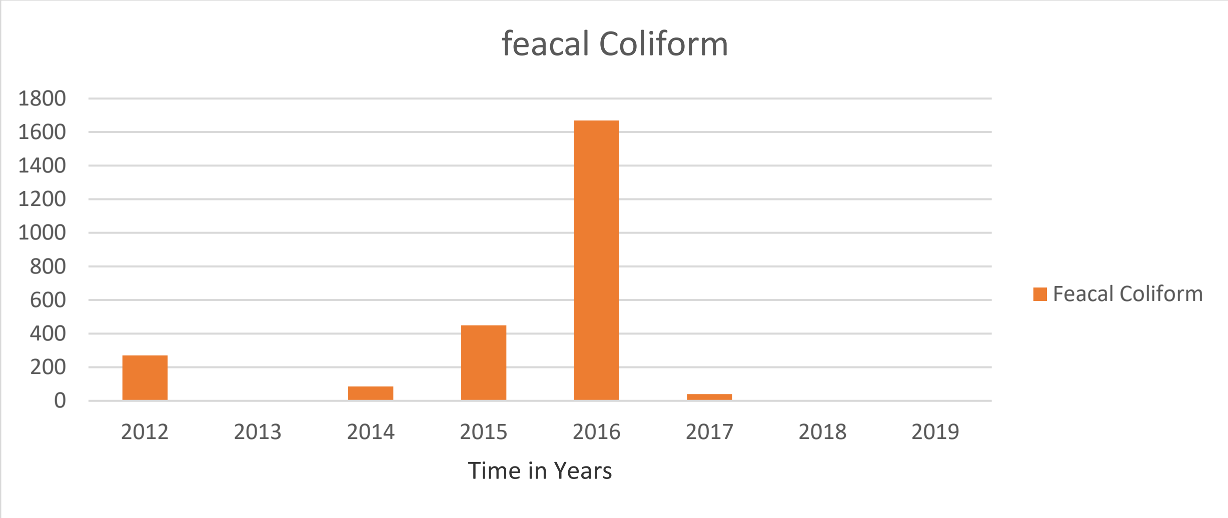

Figure 33: The yearly mean results for Faecal Coliform discharged at Zwelitsha WWTW from 2012-2019

4.2.9. Dennis Radue Bridge

Figure 34 indicates the yearly mean of the discharged Water quality parameters pH, COD and EC during the study period. Figure 35 indicates the discharged NH_3, NO_3 +NO_2, and PO_4 at Dennis Radue Bridge. All the below parameters are within the acceptable standard as per South African Water Quality Guidelines for domestic, agriculture -irrigation, Aquatic ecosystem as well as DWS wastewater discharged limits. Furthermore, in figure 36 discharges of Faecal Coliform exceeded the standard limits in 2015, 2016, and 2019. As per South African Water Quality Guidelines, Faecal coliform standard limits are from 0 – 1000 mL per discharge.

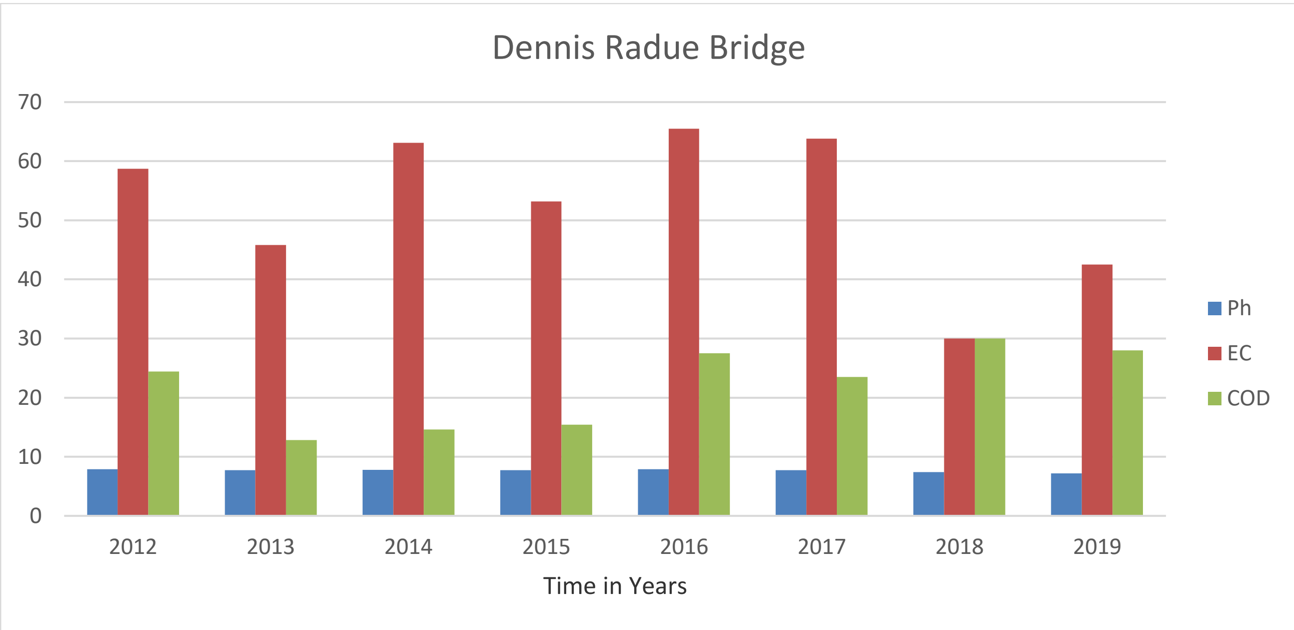

Figure 34: The yearly mean results pH, COD and EC at Dennis Radue Bridge from 2012-2019

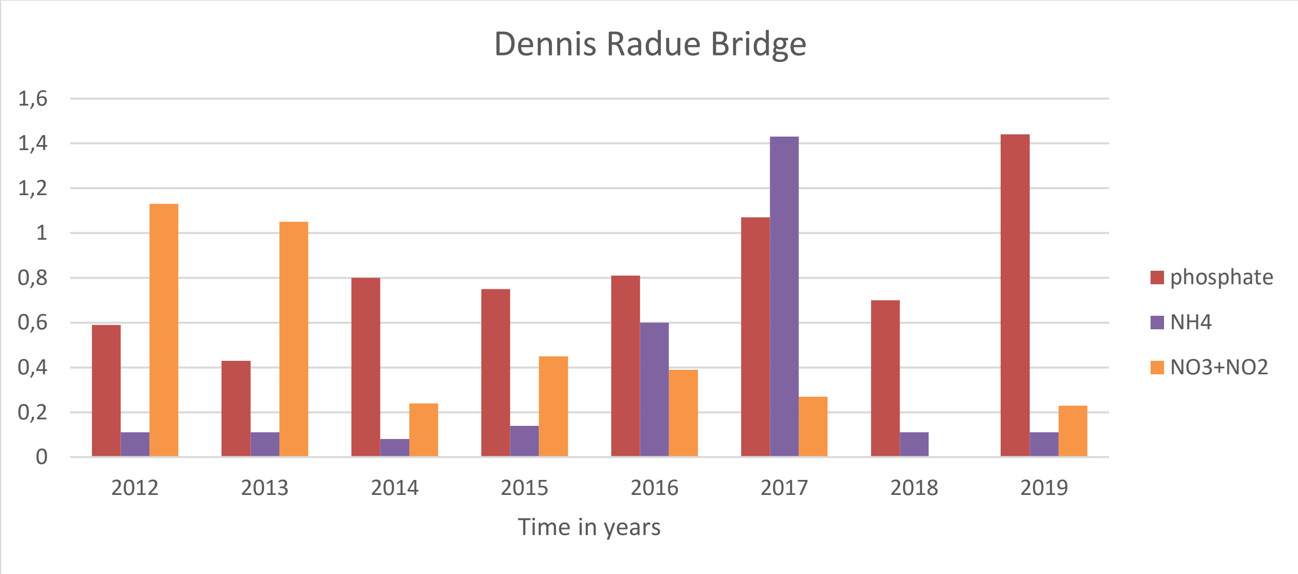

Figure 35: The mean yearly results for NH_4, NO_3 &NO_2 and PO_4 at Dennis Radue Bridge from 2012-2019

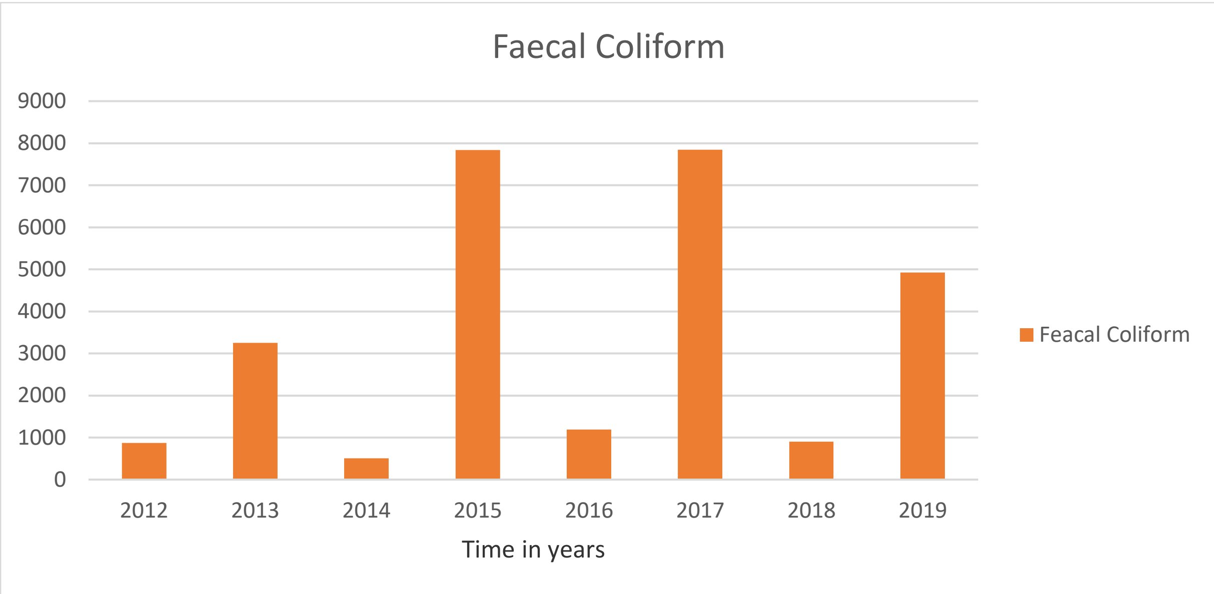

Figure 36: The yearly mean results for Faecal Coliform at Dennis Radue from 2012-2019

4.2.10. Perie Maidan Dam

Figure 37 and Figure 38 indicate the yearly mean of the discharged water quality parameters in the Perie Maidan dam. COD, EC, pH, PO_4-, NO_2&NO_3, and NH_3 discharged during the study period comply with the limits as per South African Water Quality Guidelines for domestic, agricultural-irrigation, aquatic ecosystem, and as well as DWS wastewater discharged limits. The discharged water quality containing faecal coliform at Perrie Maidan dam is indicated in figure 39. The Faecal Coliform exceeded all the limits as per South African Water Quality Guidelines in 2016.

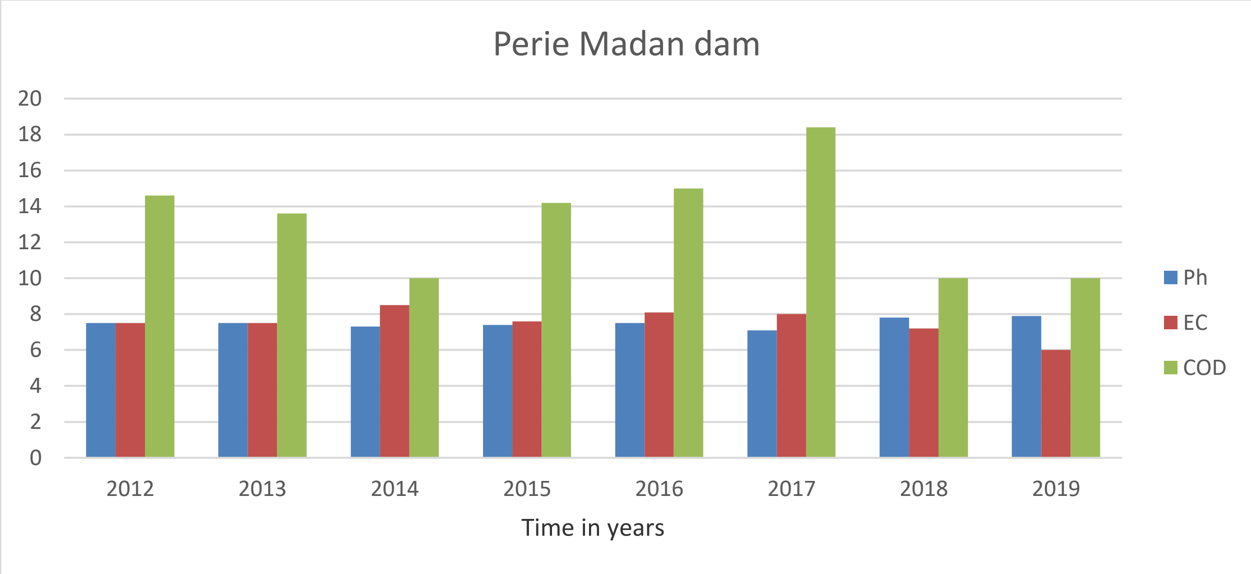

Figure 37: The yearly mean results for pH, COD and EC at Perie Madam dam from 2012-2019

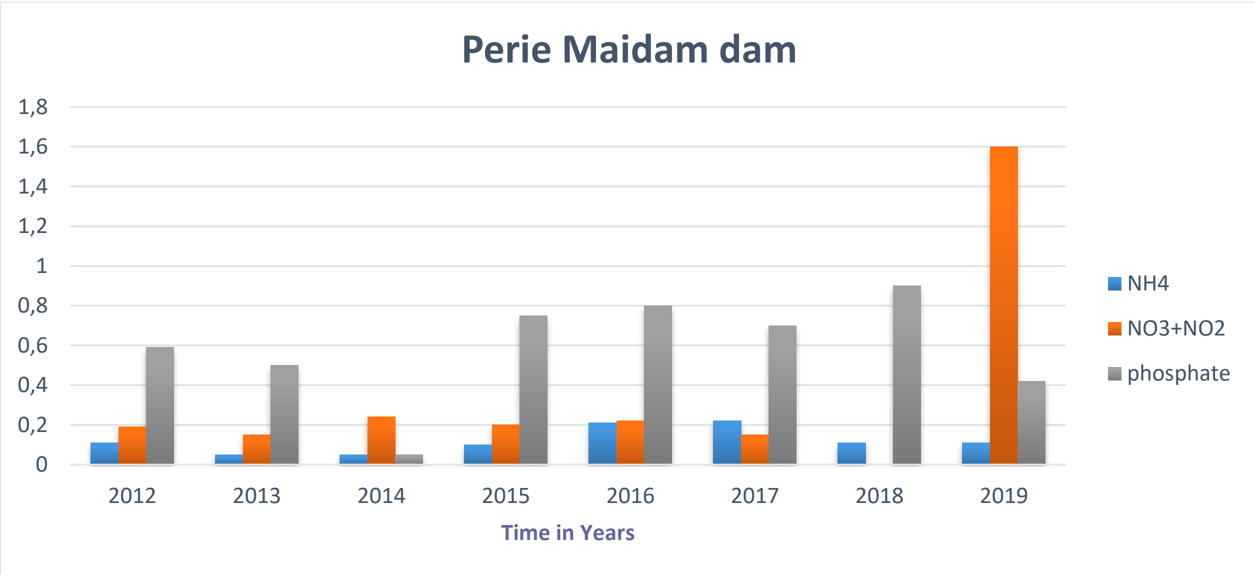

Figure 38: The mean yearly results for NH_4, NO_2&NO_3 and PO_4 at Perie Maiden dam 2012- 2019

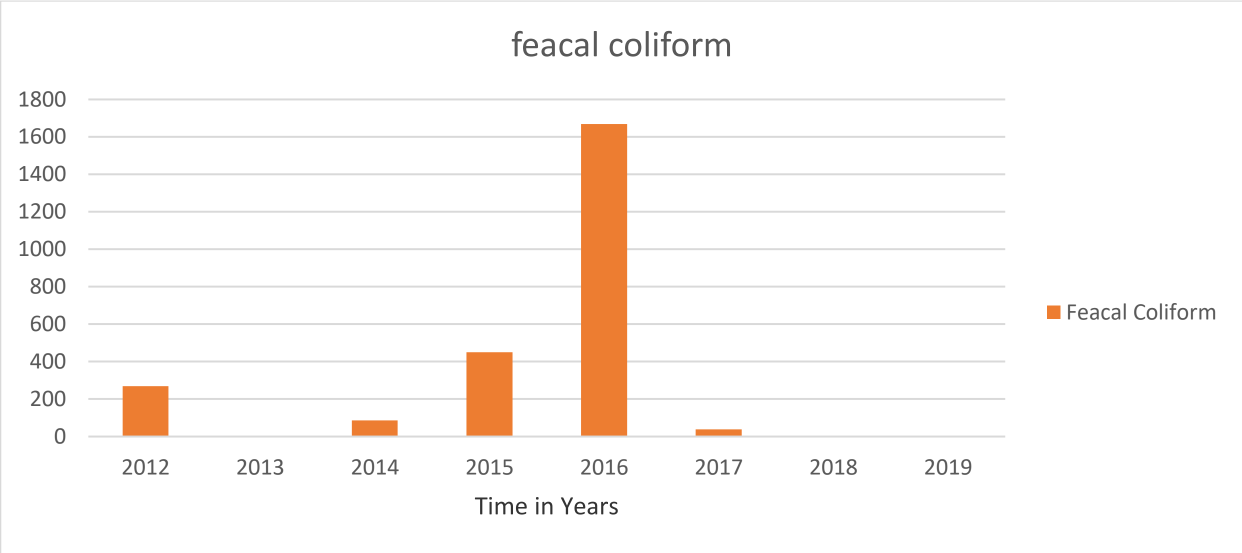

Figure 39: The yearly mean results for Faecal Coliform at Perie Maiden dam from 2012-2019

4.2.11. Laing Dam

Figure 40 and Figure 41 indicate the discharged water quality parameters of the Laing Maidan dam. COD, EC, pH, PO_4^{3-}, NO_3+NO_2, and NH_3 discharged during the study period comply with the limits as per South African Water Quality Guidelines for domestic, agricultural- irrigation, aquatic ecosystem, and as well as DWS wastewater discharged limits. However, COD and NH_4 exceeded the discharged limits as per water quality guidelines for domestic, agriculture – irrigation, aquatic ecosystem, and DWS wastewater discharged limits. The limit for COD is (30 mg/L- 75 mg/L) and the limits for NH_3 (2 mg/L-6 mg/L). The discharged Faecal Coliform at the Laing dam is represented in Figure 42. The Faecal Coliform exceeded all the limits as per South African Water Quality Guidelines in 2015 and 2018.

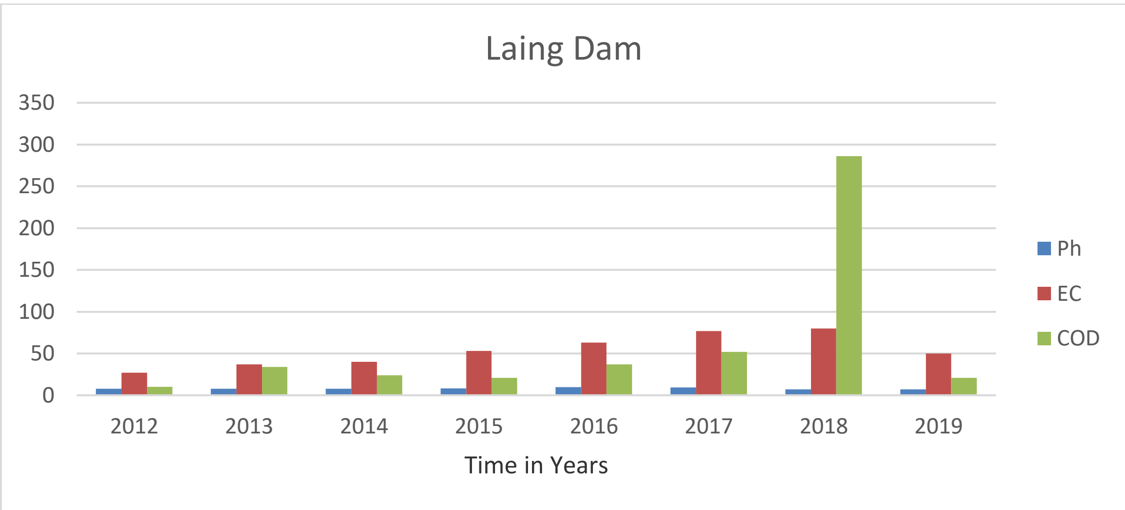

Figure 40: Graph that indicate the discharged pH, COD and EC at Laing dam from 2012-2019

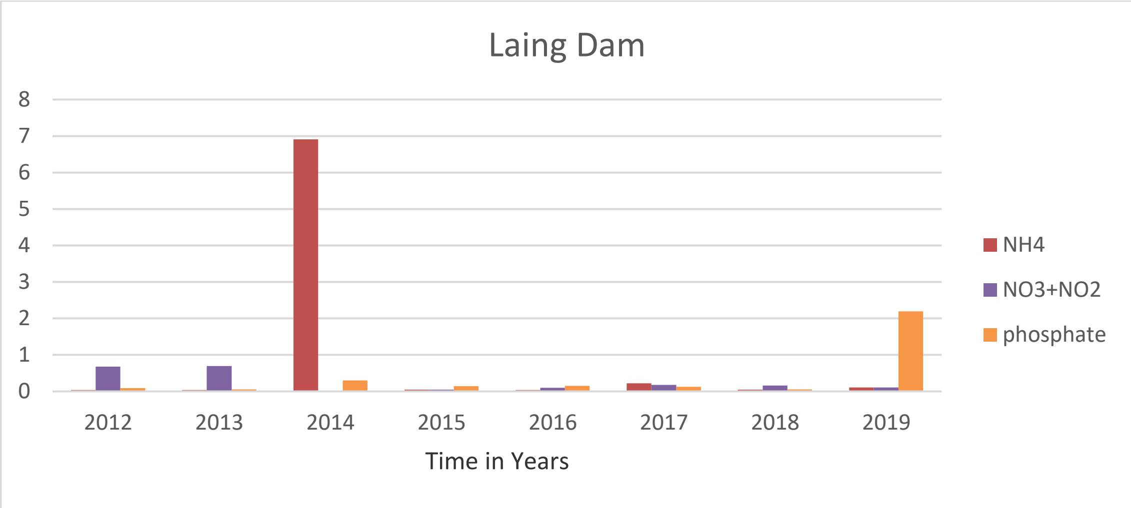

Figure 41: Graph that indicate the discharged NH_4, NO_2+NO_3 and PO_4 at Laing dam from 2012-2019

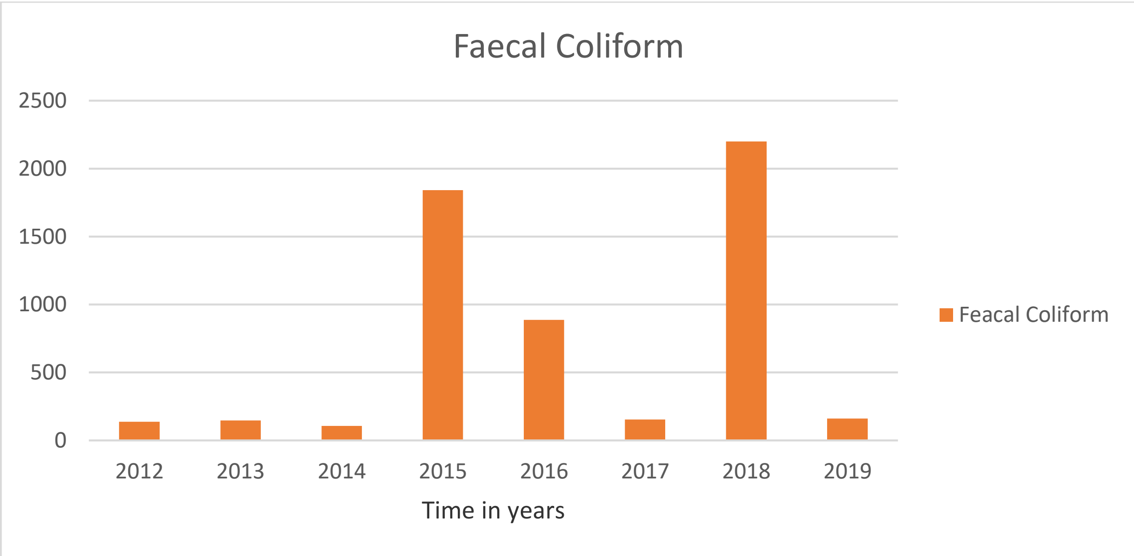

Figure 42: The yearly mean results for feacal coliform at Laing dam from 2012- 2019

4.3. Spatial and temporal variation in water quality.

The discharged effluent in surface water of Buffalo River Catchment is represented in the form of a PCA biplot in Figure 43. The NO_3&NO_2 variables were dominant in the Buffalo Pass, Schornville WWTW and Bridle drift Dam points in terms of spatial variation. The concentration of pH, PO_4^3 and EC were the highest at the Mlakalaka Weir. High NO_3&NO_2 concentration can be associated with high decomposition of organic matter through anaerobic bacteria (Kumar, 2002). NH_4-N and phosphate increased in Mlakalaka Weir due to the agricultural activities that are taking place around the Mlakalaka area (Sibanda *et al*.,2015). According to Nebel and Wright (1998), ammonia and phosphate concentration is higher in areas where there is sewage contamination. Therefore, it could indicate that Mlakalaka also received some effluent pollution. The PCA biplot described was 62% of the variation in data on the first axis and a further 21% on the second axis. The Monitoring sites Mlakalaka Weir (MK), Pirie Dam (Pirie) and Dennis Radue (DR) were grouped in the lower half of the PCA in Figure 43. Variation in the Shornville (SV), Buffalo Pass, Bridle drift and James McIntyre (JMB) was driven by temporal variation in the nitrate and nitrite concentrations during the study period.

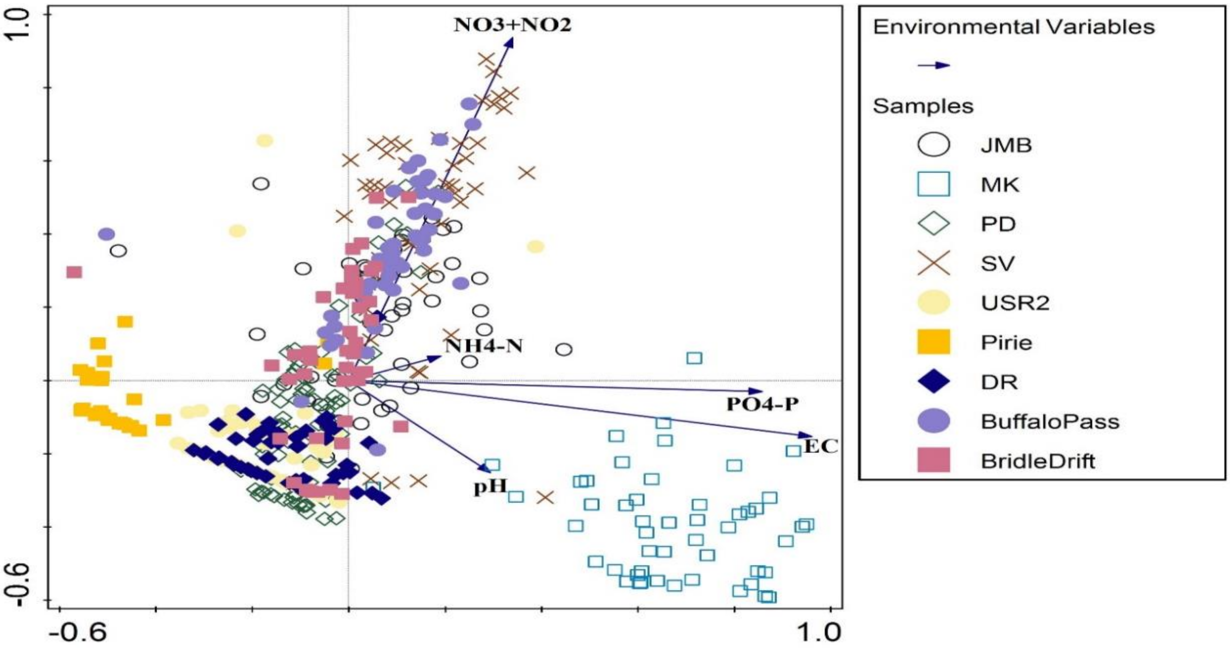

Figure 43: Principal component analysis of discharged effluent at the surface water (Buffalo River from 2012-2019)

In figure 44 below indicates that results from PCA for the discharged effluent. The study shows that there were no trends of the discharged parameter during the study period. When describing the temporal variation (after classification of data based on sampling year), Figure 44 below, is the evidence of how variable data was in terms of sampling years has not consistent patterns were found linking specific water quality variables with the sampling year.

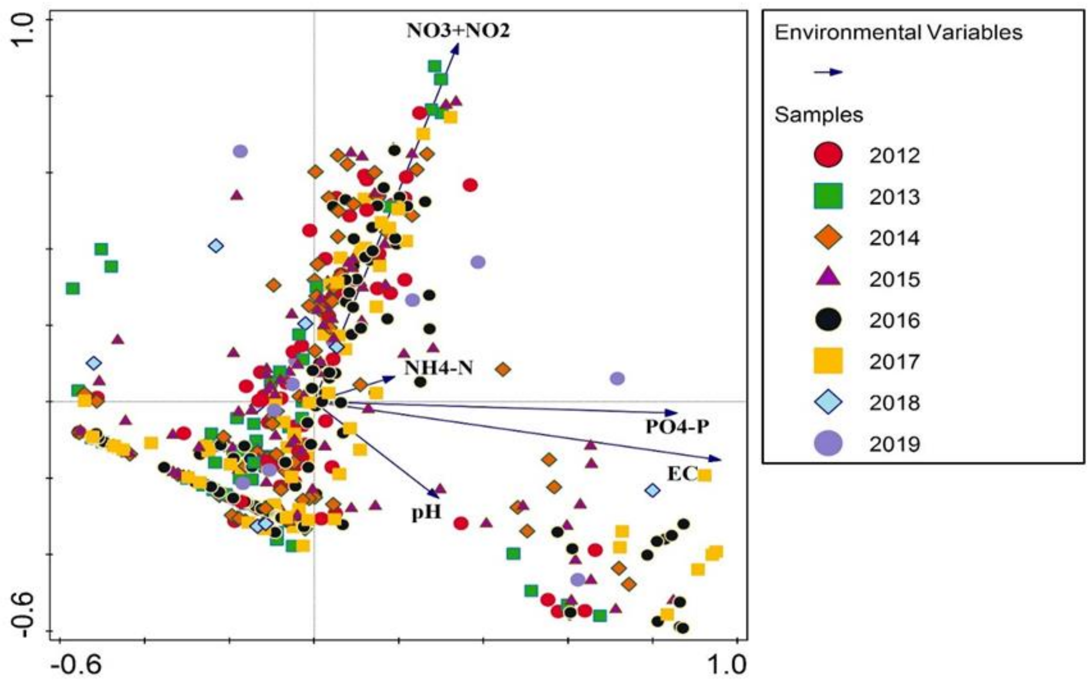

Figure 44: The principal component analysis (PCA) with classification for sampling years (2012-2019)

Table: 3 The Eigenvalues and cumulated variance percentage of obtained components.

Statistic	AXIS 1	AXIS 2	AXIS 3	AXIS 4
Eigenvalues	0.6215	0.2096	0.0933	0.0720
Explained variation (cumulative)	62.15	83.11	92.44	99.64

The results of the study show that the discharged effluent parameters in the Buffalo River Catchment have a negative impact on the surface water. The results of the geometric mean that was determined for the discharged effluent parameters were pH (6.5-7.9), NH_4(0.12-6.07), NO_2&NO_3 (0.66-6.58), EC (2.2-438.7) COD (9.5-395.4) PO_4(0.08-9.07) and FC (13.2-16597.9. The NH_4 was within the Water Quality guidelines limits for some monitoring points except for Zwelitsha WWTWs which exceeded the limits of all South African water quality guidelines for domestic and agriculture as well as guidelines for aquatic ecosystems. The NO_3&NO_2 concentrations were within the limits for the South African wastewater discharged limits, Except for the Zwelitsha WWTWs which exceeded the limit. This could be cause malfunctioning of the WWTWs. It was noted that during the study period the WWTW was under upgrade and not all the processes were operational. The electrical conductivity during the study period has exceeded the limits during for all the South African water quality guidelines i.e., domestic, recreational, and aquatic ecosystem, The EC also exceeded the South African discharge limits. The COD exceeded the limits in some monitoring points. Throughout the study period the phosphate results were within the limits as per South African guidelines and discharge limits. The Faecal Coliform discharged during the study period has exceeded the South African discharge limits. The Faecal Coliform is a threat to both human well-being, animal and as well as the aquatic ecosystem (Dallas & Day, 2004). The Faecal Coliform and Electrical Conductivity did not comply with all the South African Water Quality guidelines for domestic and agricultural purposes as well as guidelines for aquatic ecosystems. According to the discharge limit and water quality guidelines, the two parameters were not applicable as no guidelines were present. This means that they were not supposed to be detected. All the discharge parameters in the Buffalo River catchment for aquatic ecosystems exceeded the standard limits. Moreover, the aquatic ecosystems are threatened in the Buffalo River (Dallas &Day, 2004).

There are several factors that may contribute of high levels of Faecal Coliform into the surface water in the Buffalo River Catchment, the population increase (Momba *et al*.,2006). The factors include increased population in the Buffalo River Catchment communities, the WWTWs were designed to serve the population available at that time of the construction of WWTWs. Therefore, the WWTWs may be over capacitated due to the increased population. When the WWTWs are over-capacitated, it means that the WWTWs will be operating above the limit of the design capacity and it will discharge partially treated effluent that will cause a significant impact on the surface water (Momba *et al*.,2006). The poorly maintained infrastructure, due to the unavailable source of funds, it become a challenge for municipality to keep the good standard of operation of WWTWs (Fatoki *et al*.,2001).The WWTWs that are discharging in the Buffalo River are not maintained and others are still using outdated processes which are unrepairable, other WWTWs do not have generators to keep the works running when there is no electricity (Morrison *et al*., 2001). Morrison *et al*., (2001) study indicated that the lack of funding in the municipality make it difficult for the works to procure chemicals for disinfecting the final effluent before it is discharged into a water resource. This causes the works to discharge poor or untreated effluent into surface water which cause pollution in the water resource. The discharge at Buffalo River effluent varied from year to year in terms of quality due to climate change.

The comparison of the discharged effluent through graphs was also done to check which year has higher concentrations and which parameter was continuously exceeding the various limits during the study period. The results revealed that faecal coliform continuously exceeded the standard limit of South African guidelines for domestic, recreational, and aquatic ecosystem as well as the South African discharge limits. The faecal coliform that was discharged in the Buffalo River was extremely high between 2015 and 2018. This could have been caused by the drought in the Eastern Cape between these years. There were areas where there were low rainfall and others no rainfall at all. Buffalo River was also affected by the low rainfall during these years. Furthermore, when there is a low rainfall there was no dilution occurred in the surface water hence the faecal coliform concentration was very high, and this means that it was not treated to meet the acceptable standard. The example in the Zwelitsha WWTW, Buffalo River Pass, Bridle drift Dam is in the upper reaches of the catchment, the parameters are high because the areas that are surrounding the dam is heavily impacted by agricultural activities and urban populations (Chigor & Okoh, 2012). Dennis Radue bridge and Mlakalaka weir monitoring points also have high Faecal Coliform. Other monitoring points in surface water are also affected by surface run-off from agriculture farms that are using fertilizers. Raw fertilizers/ Manure might increase the faecal coliform in the water resource.

Several related studies on the effects of discharged effluent from WWTW on water quality were conducted in various parts of South Africa (Kwazulu Natal, Limpopo, as well as the Eastern Cape), and it was found that some guidelines and limits for water and wastewater had been exceeded, which is consistent with the findings of this study. Gitari *et al.,* (2017) investigation on the physico-chemical evaluation of the Mvudi River, an effluent receiving stream, produced the following results:

• At the downstream site, the discharged pH ranged from 7 to 7.95.

• The EC concentration was found to range from 39.4 to 316 mS/m.

• The river water's COD downstream ranged from 83 to 195 mg/L, while upstream points fluctuated between 16 and 30 mg/L.

• The upstream point's nitrate profile ranged from 0.63 to 16.27 mg/L, while the downstream point's ranged from 0.8 to 23.4 mg/L.

A similar study was conducted by Naidoo (2013a) on the impact of wastewater discharges on river water quality in the eThekwini Municipality (Durban) and discovered the following: The results revealed a difference in river water quality between upstream and downstream points, with elevated pH levels at the downstream point associated with wastewater discharge. The same was true for EC, nitrate, *E. coli*, and faecal coliforms, which were found in higher concentrations downstream than upstream.

A study completed by (Morrison *et al.,* 2001) at the Keiskammahoek WWTW. The study was to check the impact of point source pollution. The findings of this study were the following:

- The pH results in the study were within the South African water quality guidelines limits.
- The results of the discharge sites have multiple increases in the electrical conductivity in the river compared to the values at the reference site.
- In most cases at the discharge point, the orthophosphate levels exceeded the limits.
- The concentration of ammonium was lower at the upstream site compared to the downstream site. The concentration exceeds the old South Africa guideline for wastewater discharge for ammonia in effluent 1.5 mg/L at pH>8.5 (Government Gazzette, 1984) and the TWQR for domestic use with a limit of 1.
- Nitrate values varied in the different samples but 87% of the sampling period the guidelines were met.
- The inability of WWTWs to remove chemical oxygen demanding substances in the incoming effluent. This caused high COD values.

The impact of discharged effluent on surface water in Buffalo River indicated that the discharged effluent has a negative impact on the Buffalo River surface water. The situational analysis study conducted by Van Ginkel *et al., (*1996) in the Buffalo River showed that the river is polluted by effluent discharges from the surrounding community. Whereas the study conducted by Morrison *et al.,* (2001), revealed that there was an adverse impact on the physico-chemical characteristics of the receiving watershed because of the discharge of inadequately treated effluents from the wastewater treatment facility. This clearly indicate that water quality in the Buffalo River catchment have become worse and will become more impacted if the discharged effluent problems are not fixed and enforced by Department of Water and Sanitation.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusion

The study was undertaken to determine the impact of discharged effluent on surface water of Buffalo River Catchment. The main aim of the study was to analyse the impact of discharged effluent on surface water of the Buffalo River Catchment. The aim of the study was achieved, and it can be concluded that the discharged effluent has an impact on surface water of the Buffalo River Catchment. Moreover, the surface water quality status of the Buffalo River Catchment is deteriorating with time from the effluent discharged from wastewater treatment work. After all the discharged parameters were analysed and compared with the South African water quality guidelines for domestic use, recreational and irrigation as well as with the South African discharge limits. The pH, phosphate, nitrate, and nitrites were found within the limits as per the South African water quality guidelines. However, electrical conductivity at James Mncityre Bridge and the COD at Postdam exceeded the limits of the water quality guidelines and discharge limits. The faecal coliform measured during the study period in most monitoring points exceeded all the limits as per South African Water Quality guidelines. Many factors that might be contributing to high faecal coliform counts such as effluent from WWTWs and surface run-offs from the agricultural activities. During the study period, it was discovered that Zwelitsha WWTW and Schornville WWTW that discharged directly into Buffalo River Catchment were not operating during the study period. Zwelitsha WWTW was in the process of being upgraded from 2012- 2019. Most of the processes such as screens, grit channels, aerators and clarifier were not operating. The raw sewage was running through the WWTW into the water resource without being treated properly. The state of WWTW in South Africa is a major concern, and even when WWTWs were upgraded, the would be no follow up maintenance to keep the WWTWs to good operational standard. The high faecal coliform counts were also observed at Schornville WWTW, this might be due to an over capacity of the works. The WWTW was designed to serve 12 608 populations (DWS-IRIS) with a capacity of 4800 kL/day. The works operational capacity is 6800kL/day which is more than the design capacity.

5.2. Recommendations

The following recommendations are made based on the results of the study:

According to data used in the study, monitoring of water quality in the Buffalo River catchment was inconsistent. Therefore, DWS should design a proper monitoring programme so that non-compliance and failures from effluence dischargers in the catchment can be easily identified. This can also assist in the improvement of water quality in the catchment area.

The invertebrates and fish are particularly vulnerable to contaminated water, it is advised that a further study on invertebrates in the Buffalo River Catchment should be conducted to determine the availability of aquatic ecosystems in the water resource. The study will also

According to the results received from the study, there is a clear indication of non-compliance from the WWTWs. Therefore, it is recommended that DWS should enforce stringent penalties on all the non-complying municipalities that are discharging in the Buffalo River catchment. This can be done through the development of waste discharged charge system (WDCS). It forms part of the Pricing Strategy, which is being established under the National Water Act (Act 36 of 1998). The WDCS is based on the polluter-pays principle and aims to promote the sustainable development and efficient use of water resources. It also promotes the internalisation of environmental costs by impactors and create financial incentives for dischargers to reduce waste and use water resources in a more optimal way (Pegram *et al.,*2014).

6. BIBLIOGRAPHY

Adeniji, A.O., Okoh, O.O. and Okoh, A.I., 2017. Petroleum hydrocarbon fingerprints of water and sediment samples of Buffalo River Estuary in the Eastern Cape Province, South Africa. *Journal of Analytical Methods in Chemistry*, *2017*.

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

Agyemang, E.O., Awuah, E., Darkwah, L., Arthur, R. and Osei, G., 2013. Water quality assessment of a wastewater treatment plant in a Ghanaian Beverage Industry. *International Journal of Water Resources and Environmental Engineering*, *5*(5), pp.272-279.

Ahmed, M.K., Das, M., Islam, M.M., Akter, M.S., Islam, S. and Al-Mansur, M.A., 2011. Physico-chemical properties of tannery and textile effluents and surface water of River Buriganga and Karnatoli, Bangladesh. *World Applied Sciences Journal*, *12*(2), pp.152-159.

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

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

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

Ashton, P.J., Hardwick, D., and Breen, C.M., 2008. Changes in water availability and demand within South Africa's shared river basins as determinants of regional social-ecological resilience. *Burns, MJ & Weaver, AvB*, pp.279-310.

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

Bilgrami, K.S. and Kumar, S., 1997. Effects of copper, lead and zinc on phytoplankton growth. *Biologia plantarum*, *39*(2), pp.315-317.

Cho, Y. and Yun, R., 2011. A raw water source heat pump air-conditioning system. *Energy and Buildings*, *43*(11), pp.3068-3073.

Chigor, V.N. and Okoh, A.I., 2012. Quantitative detection and characterization of human adenoviruses in the Buffalo River in the Eastern Cape Province of South Africa. *Food and environmental virology*, *4*(4), pp.198-208.

Chigor, V.N., Sibanda, T. and Okoh, A.I., 2013. Studies on the bacteriological qualities of the Buffalo River and three source water dams along its course in the Eastern Cape Province of South Africa. Environmental Science and Pollution Research, 20(6), pp.4125-4136.

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

Coastal Environmental Services (CES), 2004. State of Environmental Report: Amatole District.

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

Dallas H. F.and Day, H., 2011. Understanding the basics of water quality. *Water resources planning and management*, pp.68-89.

Dan'azumi, S. and Bichi, M.H., 2010. Industrial pollution and implication on source of water supply in Kano, Nigeria. *International Journal of Engineering & Technology*, *10*(1), pp.101-109.

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

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

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

Department of Water Affairs and Forestry (DWAF). (1996a). South African Water Quality Guidelines (2nd edition). Volume 5: Agriculture Use: Livestock Watering. Pretoria: DWAF.

Department of Water Affairs and Forestry (DWAF). 2001. Water Quality Management Orientation Course: Introduction to sustainability, environmental management, and water quality. The Republic of South Africa.

Department of Water Affairs (DWA).1986. Management of the Water Resources of the Republic of South Africa. Department of Water Affairs, Pretoria. 93

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

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

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

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

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

Du Preez, J.H., 2000. Parameters for the determination and evaluation of heat stress in dairy cattle in South Africa.

Dube, X.N.M, 2020. Assessment of water quality and associated impacts of the sewage discharges into the Mooi River Catchment (Doctoral dissertation, North-West University (South Africa).

Dungeni, M.O.M.B. and Momba, M.N.B., 2010. The abundance of Cryptosporidium and Giardia spp. in treated effluents produced by four wastewater treatment plants in the Gauteng Province of South Africa. *Water SA*, *36*(4).

Edokpayi, J.N., Odiyo, J.O. and Durowoju, O.S., 2017. Impact of wastewater on surface water quality in developing countries: a case study of South Africa. *Water quality*, pp.401-416 –

Edokpayi, J.N., Odiyo, J.O., Msagati, T.A. and Popoola, E.O., 2015. The removal efficiency of faecal indicator organisms, nutrients, and heavy metals from a Peri-Urban wastewater treatment plant in Thohoyandou, Limpopo Province, South Africa. International journal of environmental research and public health, 12(7), pp.7300-7320.

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

Fatoki, O.S.P. Gogwana, and Ogunfowokan, A.O. 2003. Pollution assessment in the Keiskamma River and in the impoundment downstream, Water SA, Vol. 29(2), pp. 183–187

Fernández-Luqueño F, López-Valdez F, Gamero-Melo P, Luna-Suárez S, Aguilera-González EN, Martínez AI, García-Guillermo MDS, Hernández-Martínez G, Herrera-Mendoza R, Álvarez-Garza MA, Pérez-Velázquez IR (2013). Heavy metal pollution in drinking water-a global risk for human health: A review. African Journal of Environmental Science and Technology 7(7): 567 - 584.

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

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

Gitari, W.M., Tshikovhi, F.P. and Akinyemi, S.A., 2017. Physicochemical Appraisal of Effluents Receiving Stream: A Case Study of Mvudi River, South Africa. *Journal of Environmental Science and Allied Research*, *2017*, pp.25-31.

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

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

Hurse, T.J. and Connor, M.A., 1999. Nitrogen removal from wastewater treatment lagoons. *Water science and technology*, *39*(6), pp.191-198.

Igbinosa, E.O. and Okoh, A.I., 2009. Impact of discharge wastewater effluents on the Physico-chemical qualities of a receiving watershed in a typical rural community. International Journal of Environmental Science & Technology, 6(2), pp.175-182.

Iloms, E.C., 2018. *Investigating industrial effluent impacts on municipal wastewater treatment plant* (Doctoral dissertation).

Jenkins D, Richard M, and Daigger G 2003. Manual on the Causes and Control of Activated Sludge Bulking and Foaming. 2nd edition. Lewis's publishers, Boca.

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

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

Kurek, K., Bugajski, P., Młyński, D. and Nowobilska-Majewska, E., 2019. The impact of treated sewage on water quality in Mordarka stream. Journal of Ecological Engineering, 20(1).

Lahnsteiner J, and Lempert G.,2007. Water management in windhoek, namibia. Water Science and Technology 55(1 - 2): 441 - 448.

Larsdotter, K., 2006. *Microalgae for phosphorus removal from wastewater in a Nordic climate* (Doctoral dissertation, KTH).

Leedy, P.D. and Ormrod, J.E., 2013. The nature and tools of research. *Practical research: Planning and design*, *1*, pp.1-26.

pp.2743-2759.

Mamabolo MF (2012). Effects of cooperative governance in the sewage treatment works in the upper Vaal River (Doctoral dissertation, North-West University).

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

Masere, T.P., Munodawafa, A. and Chitata, T. 2012. Assessment of human impact on water quality along Manyame River. International Journal of Development and Sustainability. Vol. 1

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

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

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

Momba, M.N.B., Osode, A.N. and Sibewu, M., 2006. The impact of inadequate wastewater treatment on the receiving water bodies–Case study: Buffalo City and Nkokobe Municipalities of the Eastern Cape Province. Water Sa, 32(5).

Morrison, G., Fatoki, O.S., Persson, L. and Ekberg, A. 2001. Assessment of the impact of point source pollution from the Keiskammahoek Sewage Treatment Plant on the Keiskamma River-pH, electrical conductivity, oxygen-demanding substance (COD) and nutrients. *Water SA 27*(4), pp.475-480. 102

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

Muller, M.J., 2013. *Linking institutional and ecological provisions for wastewater treatment discharge in a rural municipality, Eastern Cape, South Africa* (Doctoral dissertation, Rhodes University).

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

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

Nebel, B.J. and Wright, R.T., 1998. *Environmental science: the way the world works*. Pearson Educación

Nyenje, P.M., Foppen, J.W., Uhlenbrook, S., Kulabako, R. and Muwanga, A., 2010. Eutrophication and nutrient release in urban areas of sub-Saharan Africa—a review. *Science of the total environment*, *408*(3), pp.447-455.

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

O'Keeffe, J.H. 1989. Conserving rivers in southern Africa. Biological Conservation, 49(4), pp. 255-274.

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

Osode, A.N. and Okoh, A.I., 2009. Impact of discharged wastewater final effluent on the physicochemical qualities of a receiving watershed in a suburban community of the Eastern Cape Province. CLEAN–Soil, Air, Water, 37(12), pp.938-944.

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

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

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

Pegram, G.C., Weston, D. and Reddy, S.T., 2014. Implementation of the waste discharge charge system. *Water Practice and Technology*, *9*(2), pp.125-134.

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

Ravele, K., 2021. The impacts of irrigation by industrial effluent on the groundwater resource in Zwelitsha-King Williamstown, Eastern Cape (Doctoral dissertation, North-West University (South Africa).

Republic of South Africa (2002) Proposed First Edition National Water Resource Strategy (RSA, 2002)
River Health Programme (RHP), 2004 State of South African river. River Heath Programme, East London Report prepared by Amathole District Municipality, East London.

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

Sanchez, E., Colmenarejo, M. F., Vincente, J., Rubio, A., Garcia, M. G., Travieso, L., et al. (2007). Use of the Water Quality Index and Dissolved Oxygen Deficit as Simple Indicators of Watersheds Pollution. *Ecological Indicators, 7*, 315-328. 106.

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

Sibanda, T., Nonner, J.C. and Uhlenbrook, S., 2009. Comparison of groundwater recharge estimation methods for the semi-arid Nyamandhlovu area, Zimbabwe. *Hydrogeology Journal*, *17*(6), pp.1427-144

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

Statistics South Africa. 2012. Census for 2011. Available online [http://www.statssa.gov.za/?page_id=993&id=tlokwe-city-council-municipality]. Accessed 28 October 2018.

Tchobanoglous, G. Burton, F.L. and Stensel, H. D. 2004. Wastewater Engineering

Teklehaimanot, G.Z., Kamika, I., Coetzee, M.A.A. and Momba, M.N.B., 2015. Seasonal variation of nutrient loads in treated wastewater effluents and receiving water bodies in Sedibeng and Soshanguve, South Africa. *Environmental monitoring and assessment*, *187*(9), pp.1-15.

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

Turner, R.D., Warne, M.S.J., Dawes, L.A., Thompson, K. and Will, G.D. 2019. Greywater irrigation as a source of organic micro-pollutants to shallow groundwater and nearby surface water. Science of the Total Environment, 669, pp. 570-578.

United State. Environmental Protection Agency (1997). Inductively Coupled Plasma-Atomic Emission Spectrophotometry, Method 6010B, Revision 2.0, SW-846 Manual, 3rd edition, Office of Solid Waste and Emergency Response

Van den Brink, P.J., Van den Brink, N.W. and Ter Braak, C.J. 2003. Multivariate analysis of ecotoxicological data using ordination: demonstrations of utility based on various examples. *Australasian Journal of Ecotoxicology*, *9*(2), pp.141-156. 108

Van Ginkel, C.E., O'Keeffe, J.H., Hughes, D.A., Herald, J.R. and Ashton, P.J., 1996. A situation analysis of water quality in the catchment of the Buffalo River, Eastern Cape with special emphasis on the impacts of low cost, high-density urban development on water quality. Water research commission report, (405/2), p.96.

Vander Post, D.C and Schutte, C.F. (2003). A proposed chemical mechanism for biological phosphate removal in activated sludge treatment of wastewater. *Water SA*, 29(2), 125-129.

Water, U.N., 2018. Sustainable Development Goal 6 Synthesis Report on Water and Sanitation 2018. *United Nations New York: New York, NY, USA*, p.10017.

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

Walakira, P. and Okot-Okumu, J., 2011. Impact of industrial effluents on water quality of streams in Nakawa-Ntinda, Uganda. *Journal of Applied Sciences and Environmental Management*, *15*(2).

Wallach, R., Ben-Arie, O. and Graber, E.R., 2005. Soil water repellency induced by long-term irrigation with treated sewage effluent. *Journal of Environmental Quality*, *34*(5), pp.1910-1920.

Walsh, G.W. and Wepener, V., 2009. The influence of land use on water quality and diatom community structures in urban and agriculturally stressed rivers. *Water Sa*,

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

World Health Organization (WHO). 2008. Guidelines for Drinking-water Quality [electronic resource]: incorporating 1st and 2nd addenda, Vol. 1. Recommendations.
Wright, D.A. and Welbourn, P. 2002. Environmental Toxicology. Cambridge University Press. 110

Yahaya, A., Adeniji, O.A., Okoh, O.O., Songca, S.P. and Okoh, A.I., 2018. Distribution of polychlorinated biphenyl along the course of the Buffalo River, Eastern Cape Province, South Africa, and possible health risks. *Water SA*, *44*(4), pp.601-611.

Annexure A: Ethical Approval

NWU®
NORTH-WEST UNIVERSITY
NOORDWES-UNIVERSITEIT
YUNIBESITI YA BOKONE-BOPHIRIMA

Private Bag X1290, Potchefstroom
South Africa 2520

Tel: 018 299-1111/2222
Fax: 018 299-4910
Web: http://www.nwu.ac.za

Senate Committee for Research Ethics
Tel: 018 299-4849
Email: nkosinathi.machine@nwu.ac.za

ETHICS APPROVAL LETTER OF STUDY

Based on the review by the **Faculty of Natural and Agricultural Sciences Ethics Committee (FNASREC)**, the Committee hereby clears your study as no ethical risk. This implies that the FNASREC grants permission that, provided the general conditions specified below are met, the study may be initiated, using the ethics number below.

Study title: The impact of discharged effluent on surface water quality in the Buffalo River Catchment
Study Leader/Supervisor: Dr CW Malherbe
Student: A Mnyaka

Ethics number:	N	W	U	-	0	1	2	9	9	-	2	0	-	A	9
	Institution				Study Number						Year			Status	

Status: S = Submission; R = Re-Submission; P = Provisional Authorisation; A = Authorisation

Application type: Single **Risk Category:** **No Risk**

Commencement date: 01/02/2020
Expiry date: 30/09/2023

General conditions:

The following general terms and conditions apply:

- *The commencement date indicates the date when the study may be started.*
- *In the interest of ethical responsibility, the NWU-SCRE and FNASREC reserves the right to:*
  - *request access to any information or data at any time during the course or after completion of the study;*
  - *to ask further questions, seek additional information, require further modification or monitor the conduct of your research or the informed consent process;*
  - *withdraw or postpone approval if:*
    - *any unethical principles or practices of the study are revealed or suspected;*
    - *it becomes apparent that any relevant information was withheld from the FNASREC or that information has been false or misrepresented;*
    - *submission of the annual (or otherwise stipulated) monitoring report, the required amendments, or reporting of adverse events or incidents was not done in a timely manner and accurately; and / or*
    - *new institutional rules, national legislation or international conventions deem it necessary.*
- *FNASREC can be contacted for further information or any report templates via Roelof.Burger@nwu.ac.za 018 299 4269*

The FNASREC would like to remain at your service as scientist and researcher, and wishes you well with your study. Please do not hesitate to contact the FNASREC or the NWU-SCRE for any further enquiries or requests for assistance.

Yours sincerely,

Prof Roelof Burger
Chairperson Faculty of Natural and Agricultural Sciences Ethics Committee (FNASREC)

File reference: 9.1.5.4.2

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