Environmental implications of Sewage Water Overflow: A Case Study of Cosmo City, Johannesburg, South Africa.

By

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Submitted in accordance with the requirements for the degree

of

Master of Science

In the subject

Life Sciences

at the

University of South Africa

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DECLARATION

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I declare that the study titled: The environmental implications of Sewage Water Overflow: A Case Study of Cosmo City, Johannesburg, South Africa is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references. This research has been submitted for review under the Journal of Water, Sanitation and Hygiene for Development.

SIGNATURE DATE DATE
(Mr T.C. MAVHUNGU)

ACKNOWLEDGEMENTS

To my Supervisor Dr LT Mankga, thank you for your support, guidance, and advice. Without your support, advice, and guidance this work would not have been accomplished.

While not forgetting Mr Mokgoshi J. Mamashila for his assistance and guidance on analyzing survey data using IBM SPSS statistics. Thendo Mugwena for her assistance in drawing the map of the study area. May the Lord God bless you and continue to give you more knowledge and power for all your endeavours.

I am very thankful to the residents of Cosmo City, the Councillor Mpula Mosito, and Cosmo City leadership who participated in the data collection.

Aquatico Laboratories (Pty) Ltd for their assistance in water sample collection and analysis, Johannesburg Health District and Johannesburg Water for granting me permission to do my study within Cosmo City Municipality area.

To the team that helped during the house visits and data collection, Netshiungani Ntshengedzeni and Shangolashu Kitty. To Letlakana Sebata the manager of Innovation and Technology at Johannesburg Water for his patience, guidance, and willingness to assist throughout the permission application to conduct the research within the Cosmo City area.

ABSTRACT

Cosmo City, situated in Johannesburg, Gauteng, has been experiencing SWO in previous years which poses a significant threat to the environment and water bodies such as wetlands, rivers, and streams. This raises concerns about the water quality of Zandspruit river as well as human health risks potentially posed by the level of pollution to the surrounding water bodies. The study aimed to investigate the impacts of sewage water overflows into the Zandspruit river, and the perceptions of the community towards SWO. Water samples were collected from Prestine Spruit stream a tributary of Zandspruit river for 12 months from 3 sampling sites of the stream for analysis. Water quality parameters such as pH, temperature, electrical conductivity, and total dissolved solids were measured in the field using a water quality multimeter, while other parameters such as turbidity, metals, nitrates, phosphate, COD, and *E. coli* were analysed at SANAS accredited laboratories. The results were compared to the South African water quality guidelines and other set standards. Most of the water quality parameters were found to be within the permissible standard limits with COD, *E. coli* and turbidity being the only parameters found to be above the permissible set standards. The detection of COD, *E. coli* and turbidity above set standards, is an indication that the river water is highly polluted. Perceptions of the community towards SWO was studied using a survey, through the distribution of questionnaires to community members. The purpose of the questionnaire was to assess community's perceptions towards SWO. The survey was carried for a period of 3 months. On the survey results, the community perceived that the main causes of sewage water overflows were population growth, blockage, and broken sewers. The community also perceived that sewage water overflows are negatively impacting the environment, human health, river water quality, and the economy. The survey results are in conformity with experimental results. The overall results of this study revealed that sewage water overflows surrounding Cosmo City are negatively impacting the river water quality and poses health risk concerns. Therefore, there is a need to monitor and manage sewage water overflows in Cosmo City to mitigate any negative impacts that arise because of sewage water overflows.

Keywords: Cosmo city, sewage water overflow, physico-chemical parameters, *E coli*, water quality, water pollution

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ACRONYMS AND ABBREVIATIONS

EU	European Union
USEPA	United States Environmental Protection Agency
SALII	Southern African Legal Information Institute
UP	University of Pretoria
EPAI	Environmental Protection Agency of Ireland
DWA	Department of Water Affairs
NRMMC	Natural Resource Management Ministerial Council
APHA	American Public Health Association
SAEPA	South Australia Environmental Protection Authority
DWAF	Department of Water Affairs and Forestry
OUTA	Organization Undoing Tax Abuse
SWO	Sewage Water Overflow
SA.EPA	South Australia Environmental Protection Authority
WWTW	Wastewater Treatment Works
SAHRC	South African Human Rights Commission
CBD	Central Business District
EXT	Extension
HPLC	High Performance Liquid Chromatography
AAS	Atomic Absorption Spectrometry
IC	Ion Chromatography
NTU	Nephelometric Turbidity Units
MFT	Multiple Fermentation Tube
MPN	Most Portable Number

MF	Membrane Filter
NSW.EPA	New South Wales Environmental Protection Authority
EDTA	Ethylenediaminetetraacetic acid
WHO	World Health Organization
E. COLI	*Escherichia Coli*
Zn	Zinc
Cu	Copper
Pb	Lead
Cd	Cadmium
COD	Chemical Oxygen Demand
BOD	Biological Oxygen Demand
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
DS	Dissolved Solids
MPWT	Ministry of Public Works and Transport
GGGI	Global Green Growth Institute
GDPW	General Directorate of Public Works
SMCD	Sewerage Management and Construction Department
DWS	Department of Water and Sanitation
SA	South Africa
CSUS	Office of Water Programs California State University Sacramento
DES	Department of Environmental Science

CHAPTER 1: INTRODUCTION

1. 1 Background

Sewage Water Overflows (SWOs) is the overflowing of sewage from designed sewer systems (OWPCSUS,2008). According to Giakoumis and Voulvoulis (2023), sewer systems are disigned to collect and carry sewage from domestic, commercial, and industrial activities as well as stormwater runnoff. When sewage exceeds the capacity of sewer system under certain circumstances, it then overflows as raw or partially treated sewage into the environment (USEPA,2001).The frequent discharge of sewage water overflows (SWOs) arising from current poor strategic wastewater management is a long-standing problem within the water industry globally, and the water pollution caused by the frequent use of SWOs has been attracting increased media and political coverage globally (Giakoumis and Voulvoulis,2023). SOWs are a complex problem because they pose human health risks and degrade the environment (Weigner *et al.,* 2021). Sewage water overflows are generally because of improper disposal household waste both liquid and solid together with other sources such as agricultural runoff, management of wastewater treatment infrastructure, industrial activities, as well as the general decline in operation which contributes to water quality deterioration of water resources (Gqomfa *et al.*, 2022). Sewage is an overflowing wastewater from a community that is composed of organic and inorganic materials that pollute water environment (Salakinkop *et al.,* 2014). It contains pathogenic organisms and chemical features that can deteriorates the quality of water sources (Motheta, 2016), and the most common chemical features of sewage water are the concentrations of Chemical oxygen demand (COD), Biochemical Oxygen Demand (BOD), nitrogen (N), nitrate, (NO^{-3}) phosphorus (P), and Electrical Conductivity (EC) because of dissolved solids and large ranges of pH (Sabeen *et al.,* 2018).

Human and animal wastes have always been the main contributors of microbial pathogens in sewage water (Akpor *et al.,* 2014). Microbial pathogens enter the water sources through the release of partial treated sewage or leakages of sewage from poorly maintained septic tanks (Motheta, 2016). Additionally, microbial pathogens serve as water quality indicators, by detecting and isolating pathogens that have always been difficult, expensive and time consuming to identify (Akpor and Muchie, 2011). Recent contamination of water bodies by sewage or animal waste, and viruses, protozoa and disease-causing bacteria is indicated by the presence of *E. coli* (Munyao, 2018*)*. *E. coli* and fecal coliforms belong to a microbial group of total coliform and *E. coli* that has been the only exclusive microbe found in both human and animals feces (British Columbia, 2012). In this instance, *E. coli* was considered as the species of coliform bacteria and regarded as the best indicator of human fecal pollution and possible presence of pathogens (Wadzanai, 2010).

During extreme weather events to heavy rainfall events, sewerage systems, pump stations that cannot manage extra flow become overloaded releasing untreated sewage onto streets, storm water drains, streams, and rivers (Erskine *et al.,* 2011). The major causes of sewage overflow are oldness of the infrastructure, lack of maintenance, poor operation procedures, pipe breaks and an inadequate flow capacity (Mema, 2010). South Africa like any other country in the world is facing water quality problems and most of its freshwater environments have been negatively affected by human activities and sewage water overflows (Naidoo, 2013). The eThekwini Metropolitan area located in KwaZulu-Natal province for instance, is currently experiencing water quality problems because of sewage water overflows (Naidoo, 2013). Similarly, there was an ongoing sewage water overflows in Vaal River (In Vaal triangle, Gauteng Province) which has been resolved based on community engagements and investigations done by South African Human Rights Commission (SAHRC) to ascertain the risk of human rights violation caused by sewage water overflow contamination (OUTA, 2018). Zandspruit River in (Johannesburg, Gauteng Province) has been experiencing the sewage waterflows with various concerns of health risks over the previous years. SWO discharging into Zandspruit river from the Cosmo city community could been the main cause of water pollution and this river flows into Watercombe dam that joins Jukskei River which is interlinked with Crocodile River then flows into Hartbeespoort dam to join Limpopo River (Olumuyiwa 2016; Van der Hoven *et al.,* 2017). Raw sewage has been overflowing from Zandspruit pump station into Zandspruit river for long periods with little or no evidence of improvements to the situation (Figure 1.1).

This study aimed to investigate impacts of sewage water overflow into Pristine stream a tributary of Zandspruit river. We also elucidated the perceptions of Cosmo City communities towards SWO. Furthermore, we compared the concentrations of the physico-chemical parameters to the South African Water Quality guidelines for aquatic ecosystem and other set standards. Also, this study provided a seasonal comparison of the investigated parameters to discern seasonal variations of water quality.

Figure 1.1: Sewage oveflowing from Zandspruit pumpstation (Bega,2023).

1.2 Research Problem: Case study of Cosmo city

Cosmo City has been regarded as the city currently experiencing a raw sewage water overflowing into the local water systems affecting downstream ecosystem and degrading the environment (Figure 1.2). Raw sewage in Cosmo City overflow into the rivers and streams (Luvhengo, 2015). The sewage water overflow (SWO) in Cosmo City is also exacerbated by the illegal dumping of solid wastes that block the drainage sewage pipes (Mphaka, 2015). This SWO contribute to the physical environmental damage thus posing a serious health issue to the community (Anna, 2012). Furthermore, public, and private property, and state economy are highly negatively impacted because of SWO (USEPA, 2004). It produces a bad smell which is a nuisance to the residents and tourists (Anna, 2012). The sewage water overflowing from Cosmo City extend to the Zandspruit River and flows into Watercombe Dam in Farmall at Kya Sand (Figure 1.3). Consequently, Watercombe dam has developed hyacinth weed, which is stimulated by this raw sewage (Figure1. 4). The sewage water overflows further from Watercombe dam down Zandspruit river (Figure1.5).

Figure 1.2: Photos taken during site visits showing raw sewage overflowing into Pristine stream (Taken by Mavhungu TC).

Figure 1.3: Raw sewage pours into the Zandspruit River and further to the Watercombe Dam in Farmall at Kya Sand. (Source: Luvhengo, 2015).

Figure 1.4: Picture showing Hyacinth plants overgrown at the Watercombe Dam

Figure 1.5: Water contaminated of sewage flowing down from Watercombe Dam along Zandspruit River (Taken by Mavhungu TC).

1.3 Relevance of the research

Environmental water pollution has attracted a lot of attention in the past and is a global concern, as the economy expands and the population increases, sewage treatment plants has operated under duress stress (Motheta, 2016). Sewage water contains many different chemical components such as Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), nitrogen, Nitrate (NO_3^-), Phosphate (PO_4^{3-}), Electrical conductivity (EC) because of dissolved solids (DS) and large ranges of pH (Sabeen *et al*., 2018, Table 1.1).

Sewage water pollutes clean water resources which are required by all forms of lives, such as micro-organisms and human beings (Saad *et al.*, 2017). Therefore, sewage water pollution negatively affects all living organisms. Sewage water pollution is more common in high industrialized and urbanized areas (Munyasya, *et al.*, 2015). High industrialization and urbanization produce more wastewater into the public sewage systems leading to Sewage Water Overflows (SWO) into water bodies such as rivers, lakes, sea etc. (Munyasya, *et al.*, 2015). SWO cause environmental health concerns, and public issues, damages water collections systems which are the municipal and nation's valuable infrastructure (USEPA, 2004).

Sewage water overflows can be alleviated by the provision of better sewage infrastructure and clean water supply (Mohammed, 2017). Better sewage infrastructure and clean water supply is a universal need and basic human right, nevertheless many rivers in most African countries are polluted due to sewage water overflows (Mohammed, 2017). Similarly, many rivers of South Africa in most of its provinces including Gauteng province are being polluted by SWO resulting from leaking sewage systems (Anna, 2012). Population increase is also a major catalyst of SWO in Gauteng province (Mphaka, 2015). In Cosmo City for instance, population is increasing day by day due to migrations of people from different parts of South Africa, and other countries around the world (Mphaka, 2015).

Table 1.1: Showing the standard limits of various water quality parameters.

Parameter	General standard limit	Special standard limit
E. coli	1000/100 ml **(e) (b) (g)**	130/100 ml **(a)** ≤300/100 ml **(b)**
COD (mg/l)	75 mg/l **(a) (g),** 60 mg/l **(f)** 5 mg/l **(b)** 250 mg/l **(c)**	≤30 mg/l **(a) (g),** 100 mg/l **(f)** - -
pH	5.5 - 9.5 **(a) (d) (e) (g)** 7.8 - 8.3 **(c)** 6 - 9 **(d) (f)**	5.5 – 7.5 **(a) (g)** - -
NO_3^-	≤15 mg/l **(a) (g)** 50 mg/l **(b)** 10 mg/l **(c)**	1.5 mg/l **(a) (g)**
PO_4^{3-}	10 mg/l **(a)** 0.02 mg/l – 0.07mg/l **(b)**	1 - 2.5 mg/l **(a) (g)** -
EC (mS/m)	70 – 150 mS/m **(a) (f) (g)**	50 -100 mS/m **(a) (g)**
Temperature (˚C)	37 ˚C **(d)** 25 ˚C **(b)** 30 ˚C **(c)**	
Turbidity (NTU)	10 NTU **(c)**	-
TDS (mg/l)	1500 mg/l (**e),** 500 mg/l **(f)**	1000 mg/l **(f)**
Cd (mg/l)	0.005 mg/l **(a)** 0.01 mg/l **(d)**	0.001mg/l **(a)** -
Cu (mg/l)	0.01 mg/l**(a)** 0.10 – 1.0 mg/l **(b)** 0.25 mg/l **(d)**	0.002 mg/l **(a)** - -
Pb (mg/l)	0.01 mg/l **(a)** 0.05 mg/l **(b)** 0.10 mg/l **(d)**	0.006 mg/l **(a)** - -
Zn (mg/l)	0.1 mg/l **(a)** 1.0 mg/l **(d)** 0.30 mg/l **(b)**	0.04 mg/l **(a)**

(a) SA (source: DWA,1999), **(b)** EU (EPAI, 2001), **(c)** India (Source: Gadhia *et al*., 2012), **(d)** WHO (Source: Levi and CO, 2007), **(e)** SA (Source: UP and SALII,2013)
(f) SA (Van Schoor, 2005), **(g)** (DWS, 2017).

1.4 The purpose of the study

This study reveals the impact of SWO on the communities in Cosmo City. It significantly highlighting the negative impacts caused by SWO to the public, and environment. The study increases knowledge to the society as to what extent can SWO impact the environment, and what to do when such issues arise. Furthermore, the research benefits the public on what measures could be taken to minimize the impacts of SWO. The findings will lay a foundation for future research in the field of SWO and their implications.

1.5 Aims and objectives of the study.

The purpose of the study is to investigate the main physico-chemical parameters of sewage water, and their impacts. Also, to investigate the perceptions of Cosmo City communities towards Sewage Water Overflows.

Specific objectives

To determine the levels of Chemical Oxygen Demand (COD), pH, Electrical Conductivity (EC), Total dissolved solids (TDS), turbidity and temperature.

To determine the concentration of *Escherichia coli (E. coli).*

To determine the levels of nutrients such as nitrate (NO_3^-), and phosphate (PO_4^{3-})

To determine toxic level of metals such as zinc (Zn), copper (Cu), cadmium (Cd) & lead (Pb) found in sewage water.

To compare the concentrations of the abovementioned parameters to the South African and other set standards for water quality.

To establish the perceptions of Cosmo City communities towards the causes, impacts, and management of SWO.

Hypothesis

SWO is negatively impacting the river water quality, public health, and environment.

Physico-chemical characteristics of the river water are above South African and International set standards for water quality.

1.6 Research Questions

To what extent is the SWO from Cosmo City affecting the river water quality, public health, and environment?

What mitigation measures can be proposed to minimize the impact caused by SWO to river water quality, public health, and environment?

What are the views, perceptions, and attitudes of Cosmo City's community towards SWO?

1.7 Research Limitations

This study focuses on characterizing sewage water to make the necessary recommendations about their impacts to the environment and living organisms because of SWO. The study encompasses the analysis of *Escherichia coli* (*E. coli*) and neither Total coliform nor both because of cost limitation. Recent contamination of water bodies by sewage or animal waste is indicated by the presence of *E. coli*. The presence of viruses, protozoa and disease-causing bacteria is also indicated by the presence *E. coli* and in this instance, it is also considered that *E. coli* is the best species of coliform bacteria and being the best indicator of human fecal pollutions and presence of pathogens (Wadzanai, 2010). For this reason, a measure of *E. coli* alone for microbiological quality is deemed enough for the purposes of this study.

Due to financial constraints, only four heavy metals (Cu, Cd, Zn and Pb) were analyzed in this study. The four metals were chosen because they are the most common toxic metals found in wastewater (Akpor and Muchie, 2011). Since measurement of EC is quick and simple, it is suggested that the standard measurement of EC with the application of a conversion factor to a TDS measurement be adopted (DWAF, 1996). All dissolved solids have a strong correlation with TDS and EC of effluent (Muigai *et al.*, 2010). This study encompasses the analysis of COD and neither BOD, due to time nor cost limitations. The BOD values are always lower than COD values in wastewater because COD test measures both chemically and biologically oxidized substances while BOD test only measures the biodegradable substances and requires a relatively long time to obtain the results (Akpor and Muchie, 2011). Furthermore, COD test is relatively easy, precise and is unaffected by interferences as in the BOD test (APHA, 2005). Therefore, for the purposes of this study, measuring COD alone is deemed sufficient.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter represents the views of other researchers. The definitions or meanings of terms are discussed or reviewed based on other researchers' work. Sewage water and its characteristics, Sewage water overflows, and their causes, impacts and their management will clearly be discussed.

2.2 Sewage water and its characteristics.

Sewage is the wastewater from domestic, commercial, agricultural, industrial activities and human waste (David, 2010) that overflows into the aquatic environment (USEPA, 2004). Sewage is a complex mixture of substances in water, as colloidal suspension, or as coarse suspended matter (David, 2010). It is carried through sewers as liquid and solid waste (Blaettler,2018) and as a result, this wastewater flows into the community streets or drainages (Ibiam and Igewnyi, 2012). The principal characteristics of sewage are microbial pathogens, oxygen depleting substances, total suspended solids (TSS), toxins and floatable and trash (USEPA, 2000). Sewage water introduces a wide range of chemical and microbial pollutants to the natural water bodies (Akpor and Muchie, 2011) and it contains pathogenic organisms that can deteriorate the quality of water sources (Motheta, 2016). The most common chemical features of sewage water are the concentrations of COD, BOD, nitrogen, nitrate, phosphorus, and Electrical Conductivity (EC) because of dissolved solids and large ranges of pH (Sabeen *et al.*, 2018). Characteristics of sewage water were studied as pH, turbidity, TDS, BOD, COD, (TSS), and heavy metals such as Cu, Zn, Pb and Cd (Velusamy and Kannan, 2016).

2.3. Microbial pathogens within the sewage water

2.3.1 *E coli*

Human and animal wastes are the main contributors of microbial pathogens in sewage water (Akpor *et al.*, 2014). Microbial pathogens enter the water sources through the release of partial treated sewage or leakages of sewage from poorly maintained septic tanks (Motheta, 2016). Microbial pathogens serve as water quality indicators that detect water pathogens that have always been difficult, expensive and time consuming (Akpor and Muchie, 2011). Recent contamination of water bodies by sewage or animal waste, and viruses, protozoa and disease-causing bacteria is indicated by the presence of *E. coli* (Munyao, 2018,*)* *E. coli* and fecal coliforms belong to a microbial group called total coliform, but *E. coli* has been the only exclusive microbe found in human and animals feces (British Columbia, 2012). In this instance, *E. coli* is considered as a species of coliform bacteria that indicate human fecal pollutions (Wadzanai, 2010). As such, many pathogens found in raw sewage are linked to many serious illnesses, for examples: diarrhea, hepatitis, pneumonia etc. (Table 2.1).

Table 2.1: Microbial pathogens associated with raw sewage and their health effects (Source: USEPA, 2004).

Pathogen	**Health Effects**
Viruses	▪ Diarrhea ▪ Gastroenteritis ▪ Hepatitis ▪ Meningitis ▪ Pneumonia ▪ Paralysis ▪ Respiratory infections
Protozoa	▪ Abdominal cramps ▪ Intestinal parasites ▪ Severe diarrhea ▪ Ulcers
Bacteria	▪ Abdominal pain ▪ Cholera ▪ Food poisoning ▪ Severe diarrhea ▪ Typhoid fever
Helminths (Worms)	▪ Anemia ▪ Chest pain ▪ Digestive problems ▪ Fever ▪ Insomnia ▪ Muscle aches ▪ Vomiting

2.3.2 Turbidity

Turbidity has been considered as an important factor in water quality. It is the light scattering ability of water and causes light to be absorbed through the water (Falguni and Niladri, 2012). The causes of turbidity in water are suspended organic and colloidal matter i.e., inorganic matter, pathogens and other small or microscopic organisms (British Columbia, 2012). Similarly, turbidity results as the cloudiness of water that represent fine suspended particles of clay or silt, waste effluents, as well as micro-organisms (Munyao, 2018). This turbidity is attached to microorganisms such as viruses and bacteria that are a threat to human health because it is mainly caused by ingress of dirty water from outside the system such as storm water resulted from drains during heavy rainfall (Mohammed, 2017). Turbidity is measured in turbidity units (NTU) (Munyao, 2018). According to Mohammed (2017), turbidity of less than 5 NTU is usually acceptable to consumers, but the recommended median turbidity for drinking water purposes should be below 0.1 NTU.

2.3.3 Temperature

Temperature is also an important component of water quality because of its great impact on aquatic life (Osman and Kloas, 2010). It influences the amount of oxygen dissolved in water that is available to aquatic organisms and plants (Osman and Kloas, 2010). The growth, health, distribution, and survival of aquatic animals are affected by temperature (Osman and Kloas, 2010). Most biological and chemical process that occurs in water depends on temperature (Saad *et al.*, 2017). As a result, temperature has been identified as the most critical factor in aquatic environments (Saad *et al*., 2017). It is a good measure for assessing the effects of temperatures on living organisms and it is also measured in degrees Celsius (˚C) (Munyao, 2018). However, higher levels of temperature speed up the growth of microbial activity and algae in the water (Mohammed, 2017).

2.3.4 Electrical Conductivity (EC)

Electrical conductivity is an indirect measure of ion concentration and the ability to conduct an electric current within the water (Osman and Kloas, 2010). Electrical conductivity is a physical property of water which depends on the level of salts in the water (Munyao, 2018). It gives a good estimate of the total dissolved salts content of a water within the river (Munyao, 2018). Also, it serves as the ability to carry an electric current such as the concentrations of ions, mobility of the ion, oxidation state and temperature of water (Opperman, 2008). Electrical conductivity measurement is sometimes applied for the determination of water quality applications such as total dissolved solids (Opperman, 2008) and the more the electric current can be conducted by water, the more ions are present in water (Osman and Kloas, 2010). Electrical conductivity is dependent on the nature and numbers as well as the migration of the ionic species in a solution and it increases with an increase in the amount of mobility ions (Mohammed, 2017).

2.3.5 Total dissolved solids (TDS)

Total dissolved solids are related to electrical conductivity and water turbidity which indicates the present of materials suspended or dissolved in water (Mohammed, 2017). The quantity of all compounds dissolved in water is measured as the concentration of total dissolved solids. Most dissolved substances in water carry an electric charge that as a results links total dissolved solids with electrical conductivity (Opperman, 2008). Total dissolved solids indicate the number of salts within the water resources that impact water usage such as domestic consumption, agricultural as well as industrial activities (Opperman, 2008). Total dissolved solids information can be used to determine the overall ion effect in a water resource (Opperman, 2008). The main contributors of total dissolved solids within the water environment are sewage water, urban water runoff, industrial wastewater, and natural sources (Mohammed, 2017).

2.3.6 pH

The pH indicates the acidity or alkalinity of the water by measuring the amount of hydrogen ions present in a water sample (Osman and Kloas, 2010, Munyao,2018). Usually, pH in the water affects the solubility and availability of nutrients in terms of how it can be utilized by aquatic animals and other organisms within the water. Therefore, this signifies the importance of pH when assessing the quality of water (Osman and Kloas, 2010). Additionally, it is dependent on the interactions of various dissolved substances in water, such as aquatic plants photosynthetic process, respiration of aquatic living organisms, dissolution of CO_2 components and oxidation reactions and precipitation as well as decomposition of organic matter (Saad *et al.,* 2017).

It is measured on a scale ranging from 0 to 14 in this way: 1) pH of 7 indicating a neutral water, 2) pH less than 7 indicating the acidity of water and finally, pH above 7 indicates that the water is alkaline (Munyao, 2018). However, the pH within the water decreases with an increasing hydrogen ion (Opperman, 2008). The World Health Organization set standard limits for pH that ranges from 6.5 to 8.5 for drinking water purposes. Therefore, high levels of pH within the water increases the corrosion of water pipes resulting in contamination, bad smell that affect taste and appearance of drinking water (Mohammed, 2017).

2.3.7 Nutrients (Nitrate and Phosphate)

The nutrient status of a water resource is represented by high levels of nitrate and phosphate (Opperman, 2008). High levels of nitrate within the water systems are influenced by urban and agricultural activities, and nitrate is usually contained in sewage discharges (Opperman, 2008). Generally, nitrates occur naturally in water and soil, but its excessive level in water is mainly due to human activities such as agricultural activities such as human waste and industrial pollution (Mothetha, 2016; Mohammed, 2017).

Similarly, the abundance of phosphate in water resources emanates from urban wastewater as well as detergents from domestic wastewater (Opperman, 2008). Mothetha (2016), stated that sewage or wastewater effluents are the main carriers of phosphate into water bodies where effluents are discharged. The excessive release of untreated or partial treated sewage water (wastewater) to the environment influences the high levels of nutrients such as phosphate and nitrate into water resources, causing a process called eutrophication. Eutrophication encourages the overgrowth of weeds and algae into water resources (Muisa *et al.*, 2015). Phosphate interferes with water treatment process such as coagulation at levels above 1.0 mg/l, harboring microorganisms due to organic particles that were not removed before water was distributed to users (Mohammed, 2017).

2.3.8 Biological Oxygen Demand (BOD)

BOD is the amount of dissolved oxygen in water required by micro-organisms to breakdown organic matter for food (Mothetha, 2016). It is usually used as a gauge of effectiveness of wastewater treatment plants by measuring the concentrations of organic compounds in water. The organic contaminants in aquatic systems are indicated by the presents of BOD, which negatively impact the water quality and biodiversity of the river system (Mothetha, 2016). BOD represents the amount of oxygen required by microorganisms to degrade organic materials into oxidizable inorganic material (Singare and Jagtap, 2018). Also, the high concentration of BOD is generally influenced by high temperature and nutrients from domestic wastewater due to urban settlements (Vijayakumar *et al.,* 2014). In contrast, low values of BOD are related to increased surface runoffs, soil erosion and effluents discharge into receiving water bodies (Vijayakumar *et al*., 2014).

2.3.9 Chemical Oxygen Demand (COD)

COD represents the amount of oxygen required to break down organic matter with the aid of a strong chemical oxidant (GGGI *et al*., 2018). It is determined by a test in which the amount oxygen is consumed to chemically oxidize organic water contaminants into inorganic end products (GGGI *et al*., 2018). The COD test determines the chemical decomposition of substances dissolved or held in suspension of water (Naidoo, 2013). When measuring the strength of streams and polluted water, COD is the most critical parameter to consider because of its test which could be easily utilized (GGGI *et al*., 2018). Generally, the high concentration of COD in water indicates the presents of contaminants at an alarming rate, and it represents the increased amount of dissolved oxygen consumed in the water (Naidoo, 2013). It is useful in evaluating the performance of wastewater treatment plants and monitoring water bodies that are relatively polluted (GGGI *et al*., 2018).

2.3.10 Metals

Metals are environmental pollutants originating from human activities such as disposal of sewage water from domestic residential dwellings and discharges from industrials, as well as natural activities such as groundwater infiltrations (Akpor, 2014). They are very toxic and carcinogenic even at very low concentrations, representing serious threats to human health and aquatic living organisms (Akpor, 2014). According to Akpor and Muchie (2011), the most persistent heavy metals in sewage water that are important for wastewater treatment are Arsenic, Cadmium, Calcium, Chromium, Cobalt, Copper, Iron, Lead, Magnesium, Manganese, Mercury, Molybdenum, Nickel, Potassium, Selenium, Sodium, Vanadium and Zinc. Once these heavy metals are accumulated in sewage water, they cannot be degraded like organic pollutants, but accumulates throughout the food chain resulting in potential human health risks and ecological disturbances (Akpor, 2014). Metals accumulated in sewage water depends on the type of local factors such as industries in the region, lifestyles of the residential dwellings and environmental impact caused by careless disposal of hazardous wastes (Kaushal and Singh, 2017).

2.4 Sewage water overflow channels

Sewage water overflows are described as sanitary sewer overflows (SSO) or combined sewer overflows (CSO) that are the discharges of raw or partially treated sewage from sewerage systems to the environment (USEPA, 2001). SSO are discharges of untreated sewage due to broken pipes, pipe blockages, infiltration and inflow from leaky pipes, insufficient system capacity and equipment failures from municipal sanitary sewer systems (USEPA, 2001). Sanitary sewer are systems designed to collect and transport sewage as well as other wastewater to a wastewater treatment plant for proper treatment and disposal (USEPA, 2000) CSO is the combination of untreated sewage and storm water discharged from municipal sewer systems or treatment plants and it occurs mostly when system's capacity is overloaded during periods of heavy rainfalls or snow melt (USEPA, 2001). It is also designed to carry sanitary sewage and storm water to a sewage treatment plant during dry weather periods. As a result, they occasionally overflow during periods of rainfall since the wastewater volume in the combined sewer system can exceed the capacity of the sewer system or treatment plant (USEPA, 2000). Sewage Overflow can occur during dry weather or wet weather, this also includes overflows from manholes onto streets and sidewalks (NSWEPA, 2003). Sewage overflows can occur at any location and any time in a collection system (USEPA, 2004).

2.5 Causes of sewage water overflow

Sewage water overflows are occurring due to extensive industrialization, urbanization, and increased population density (Akpor *et al.*, 2014) within a specific place or location. High industrialization, urbanization, and population density result in the production of more wastewaters into the public sewage systems leading to Sewage Water Overflows (SWO) into water bodies such as rivers, lakes, sea etc. (Munyasya, *et al*., 2015). During moderate to heavy rainfall events, sewerage systems become overloaded releasing untreated sewage onto streets, storm water drains, streams, and rivers (Erskine *et al*., 2011). Sewage water overflows results in additional wastewater into sewer manholes which subsequently overflow pump stations that cannot manage the extra flow water and that is also overburdening the Wastewater Treatment Works (WWTW) (Erskine *et al.*, 2011).

The major causes of sewage overflow are oldness of the infrastructure, lack of maintenance, poor operation procedures, pipe breaks and inadequate flow capacity (Mema, 2010). Globally, lack of storm water drainage infrastructure, blocked and poorly maintained drains are the main causes of SWO (Akpor, 2011). Most cities and towns around the world initially built their sewer collection systems over 100 years ago (USEPA, 2001). Most of these systems were not upgraded, maintained, or repaired frequently resulting in occasional blockages, mechanical and electrical failure that produces SWO occurrence (USEPA, 2001). Over the past centuries, sewer infrastructures were represented as huge public asset that accounts for billions of money to local state and federal investment (USEPA, 2004). If the sewer infrastructure is not properly managed for a longer period it faces an increased risk of deterioration, posing an unacceptable risk to human health and environment thus impacting the state and local economies (USEPA, 2004).

In South Africa, the declining state of municipal sewage water treatment infrastructure is considered as the largest contributor of SWO (Momba *et al*., 2006). Industrial wastewaters discharged directly or indirectly into the environment through public sewerage systems which contribute to SWO, causing water quality problems into water bodies (Ijeoma and Achi, 2011). Sewage overflows occur in large volumes when the system is not operated or maintained properly (NSWEPA, 2003). The frequent sewage overflows are caused by rainfall infiltrating through the ground into leaky sewers, failure of pumps, blocked or broken pipes, sewers and sewage pumping stations that are too small to carry sewage as well as failure of the power supply at sewage pumping stations or other equipment (USEPA, 2000). Design weaknesses, overloaded system capacity, faulty equipment and machinery of municipal sewage treatment plants are some of the examples that cause SWO (Momba *et al.,* 2006).

2.6 Impacts of sewage water overflow

Sewage water overflows (SWO) are polluting most aquatic ecosystems around the world (Muisa *et al*., 2015). These lead to pollution problems which pose a great risk in terms of wastewater management i.e., increasing water treatment cost, introducing microbial contaminants and chemical pollutants into water environment (Akpor et al., 2014; Muisa *et al*., 2015). SWO can have significant negative impacts on the economy e.g., untreated sewage pollutes water bodies, which will stimulate high restrictions on industrial wastewater discharges (USEPA, 2000). Sewage water contains large quantities of nutrients such as nitrate and phosphate (Muisa *et al*., 2015). which can cause algal bloom into the receiving water body if left untreated (Kaushal and Singh, 2017). Also, these nutrients can cause an increase of algae or aquatic weed growth, that in turn can deplete dissolved oxygen, worsen aesthetics, reduce biological diversity, and impair the use of water (NSWEPA, 2003; Akpor and Muchie, 2011). SWO causes an increased amounts of mosquito breeding, resulting in public pest and potential disease problems (NRMMC, 2004).

SWO causes environmental impacts such as degradation of ecosystems, decreasing the significant of aquatic plants that help in preserving waterways condition and biodiversity loss. These include loss of fish and crustaceans that are the critical diet for both animal and human (Mothetha, 2016). SWO creates significant public health and water quality concerns, contributing pathogens, solids, debris, and toxic pollutants to receiving waters (Kaushal and Singh, 2017). Sewage water contains a range of pollutants which have potential impacts to the environmental (Table 2.2).

Table 2.2: Showing sewage water pollutants together with their potential impacts to the environment (Source: NRMMC, 2004).

Pollutant	**Potential Impact**
Suspended Solids	▪ Deposited sediment affects aquatic insect habitats.
Turbidity	▪ Reduces water clarity, resulting in impact on fish and aquatic plants.
Phosphorus/Nitrogen	▪ Stimulates growth of algae and undesirable aquatic plants, micro- organisms, and invertebrates (e.g., mosquitos).
Ammonia, metals, and pesticides	▪ Toxic to fish and aquatic insects at high levels.
Organic matter/Biochemical oxygen demand	▪ Reduces dissolved oxygen levels, affecting fish, insects, and micro-organisms productivity.
Gross pollutants/Litter	▪ Visually unattractive.

2.7 Management of Sewage Water Overflow

The world is facing problems related to management of sewage water overflows (Akpor *et al*., 2014). Sewage water overflow management problem in developing countries is mainly because of poor or lack of sanitation (Wenchuan *et al*., 2015). Management of Sewage overflow can be met through condition assessment and system observation of the sewer infrastructure to gather data or information to determine structural, operational and performance of the infrastructure assets (Tafuri and Field, 2010). Infrastructural failures are determined through condition assessment which includes system failure analysis so that ways to prevent future breakdowns are identified as a result this will maximize ways to make sound and technical judgements on asset management (Tafuri and Field, 2010). The main objective of sewage water management is to remove sewage away from people to prevent unhealthy conditions and storm water to avoid damage from flooding (Wenchuan et al., 2015).

Sewage water can be managed through treatment of wastewater, and this is achieved through two processes, which are chemical and biological treatment processes for the removal of impurities (Kaushal and Singh, 2017). According to USEPA, (2001) municipal wastewater treatment plants are required to treat and disinfect the sewage water which meets the required water quality standards of the state before discharges into waterways. In South Africa, it is mandatory through the South African Water Act (Act 54 of 1996) for sewage water to be treated in an acceptable standard before reaches water sources (Mema, 2010).

Assessment of water to determine whether the regulatory standards are met is an important component of management (Swanepoel et al., 2009). Public water is increasingly protected from pollution at a treatment plant by enforcing the treatment of wastewater and legislative controls in many developed countries (Swanepoel *et al*., 2009). Protection of water supply from contamination is the priority defense against diseases (Mohammed, 2017). Although sewage water management is a worldwide problem, there are several ways to treat sewage water before discharged to the aquatic environment (Figure 2.1).

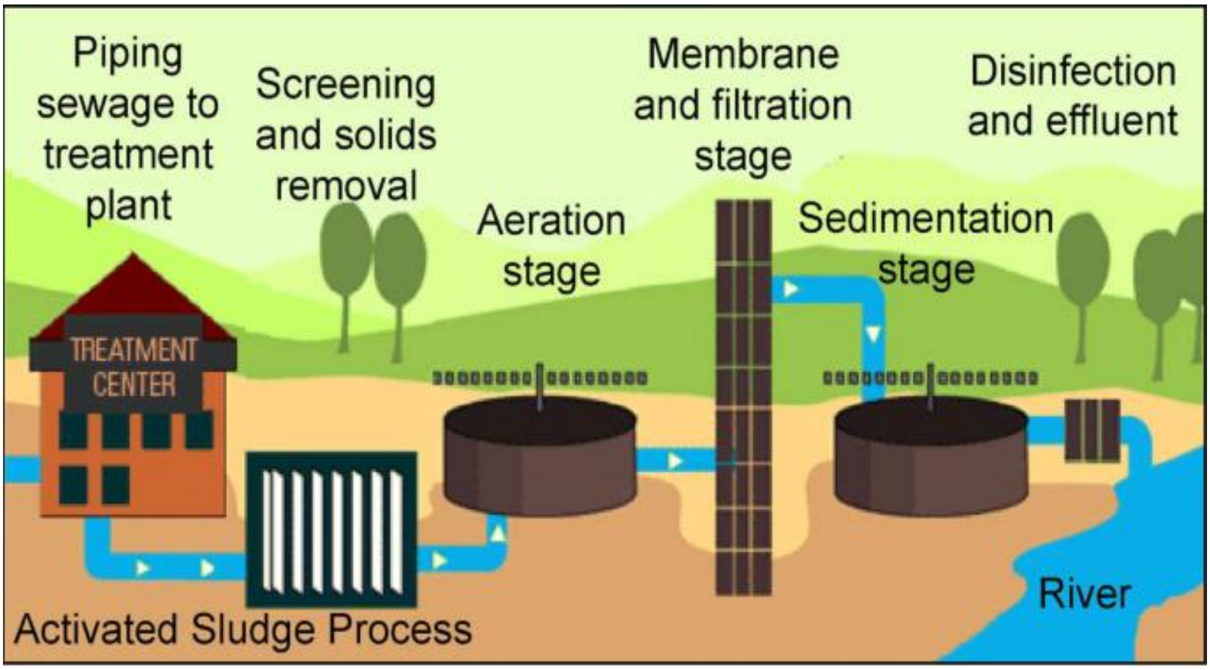

Figure 2.1: Showing treatment stages of raw sewage within a wastewater treatment plant (Source: Baharvand and Mansouri Daneshvar, 2019).

2.7.1 Sustainable management of sewage water overflows

Sustainability of sewage water overflows is mainly based on three pillars, which are environment, society, and economy (Ali and Anisur, 2019). In the context of sewage water overflow management, sustainability requires the minimization of sewage overflows to allow future generation accessibility of water bodies (Shamusi, 2012). Sustainable management of sewage water can be achieved through complying with the requirements of wastewater discharge standards, planning adequate and suitable treatment, and regular monitoring of wastewater (Akpor and Muchie, 2011). Additionally, the sustainable management of sewage water requires proper selection of treatment methods along with innovative technologies to protect public health and environment (Kaushal and Singh, 2017).

Traditionally, sewage water overflows are managed by conveying sewage to the treatment facilities as well as surface waters (Berland *et al*., 2017). The sewage water collection systems are specifically designed for sewage treatment that are a combined sewer systems and separate sewer systems (Berland *et al*., 2017). The combined sewer systems carry stormwater and other wastewater from various sources such as residential, commercial, and industrial sources in the same system, and it flows during storm events discharging a mixture of untreated sewage and stormwater into the water bodies. On the hand, separate sewers transport stormwater and sanitary sewage in separate sewer systems, the untreated stormwater is discharged to streams, resulting into excessive soil moisture, and rising shallow groundwater which could in turn stimulate the post-storm into sewers causing overflows (Berland *et al*., 2017).

The success of a sewage water overflow management strategy is achieved through a sustainable sewer infrastructure, by focusing on the three pillars of sustainability:1) the environment 2) society, and 3) economy. The environmental pillar encourages the use of appropriate materials that reduce the impact on the environment during the life cycle of an infrastructure, and the economic pillar focuses on achieving the right balance of long-term service, maintenance, and life cycle costs, while the social pillar focuses on the improvement of lives of those affected by the projects from different areas (Ali and Anisur, 2019). The sustainable management of sewage water overflow can be achieved through assessment of the sewer infrastructure (Figure 2.2).

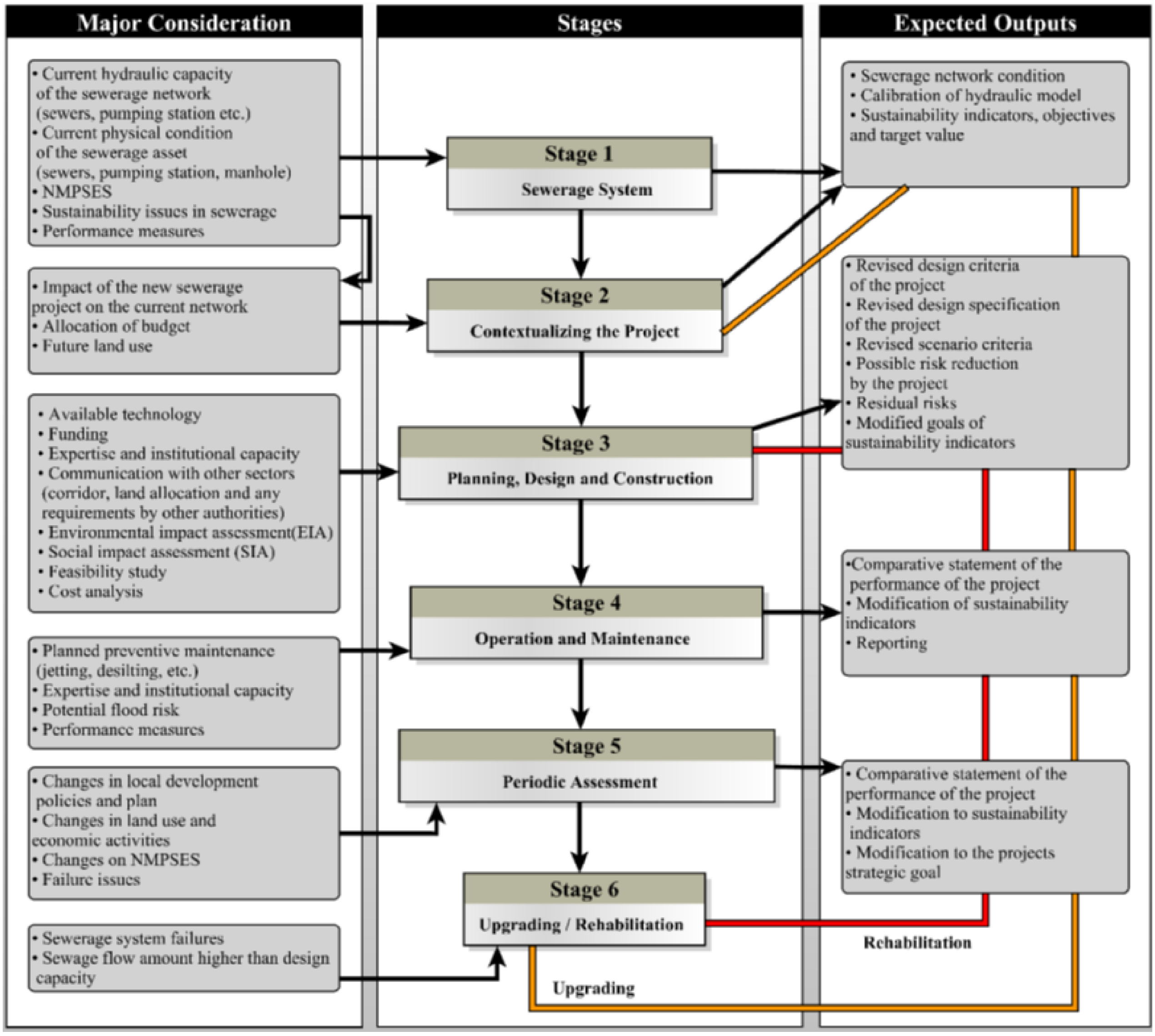

Figure 2.2: Showing the sustainability assessment of a sewer infrastructure (Source: Ali and Anisur,2019).

Recently, green infrastructure was largely focused on stormwater infiltration management technologies that today it is seen as the most promising technology to provide solutions in the field of sewage water overflow management (Berland et al., 2017). According to Berland *et al.*, (2017) green infrastructure management approaches are used to reduce the amount of untreated sewage runoff discharging to surface water sources and keep rainwater out of the sewer system to minimize sewer overflows. Also, it enhances natural hydrologic cycle process of infiltration, evapotranspiration, and reusage (USEPA, 2008). Green infrastructure technology approach uses the natural landscape to capture and treat rainwater and eliminates a portion of stormwater entering waterways, thereby lowering the pressure of the sewer system, and raising its capacity (Claudia, 2014).

To develop effective sewage water overflow management and build cost effective management solutions with physical and operational resilience, hard urban surfaces should be replaced by vegetated or permeable surfaces and natural shorelines such as wetlands, to mitigate the effects of sewage water overflows (Xin *et al.*, 2015). Green infrastructure is the best approach since it provides multiple environmental benefits and support sustainable communities (Christopher, 2014). Furthermore, green infrastructure technologies and practices are more beneficial to use in combination with sewer systems to manage sewage water overflows (Claudia, 2014).

CHAPTER 3: RESEARCH DESIGNS AND METHODOLOGY

3.1 Introduction

This chapter illustrates the methods and materials used for the purposes of this study. Experimental and survey design methods were employed as the two major strategies to enquire data for the current study. In an experimental method, water samples were collected from a river, during sewage water overfalls and transferred to the laboratory for analysis of physico-chemical parameters to determine their levels and compare them to water quality set standards. During the survey method, a total of 250 households were chosen based on the availability to represent the sample population of Cosmo City community. Data was collected through the distribution of questionnaires to members of the community. The purpose of the questionnaire was to assess the community's perceptions, attitudes, and knowledge towards SWO and its impacts. Access to the community was through the assistance of the ward councilor.

3.2 Study area

3.2.1 Location

Cosmo city is situated 25 km North-West of the Johannesburg Central Business District (CBD) directly adjacent to Malibongwe Drive between Randburg and Lanseria airport (Olumuyiwa, 2016). It is found at -26.021818 latitude South and 27.930758 longitude East (Figure 3.1). It was established as a pilot project to integrate the low, middle, and high-income communities to live together sharing the same water resources (Mphaka, 2015). Cosmo City is a mixed-income housing development made up of three different classes of housing: fully subsidized houses, finance/credit-linked and bonded housing (Olumuyiwa, 2016). It is a formal area involving the establishment of township and relocation of households from informal settlements.

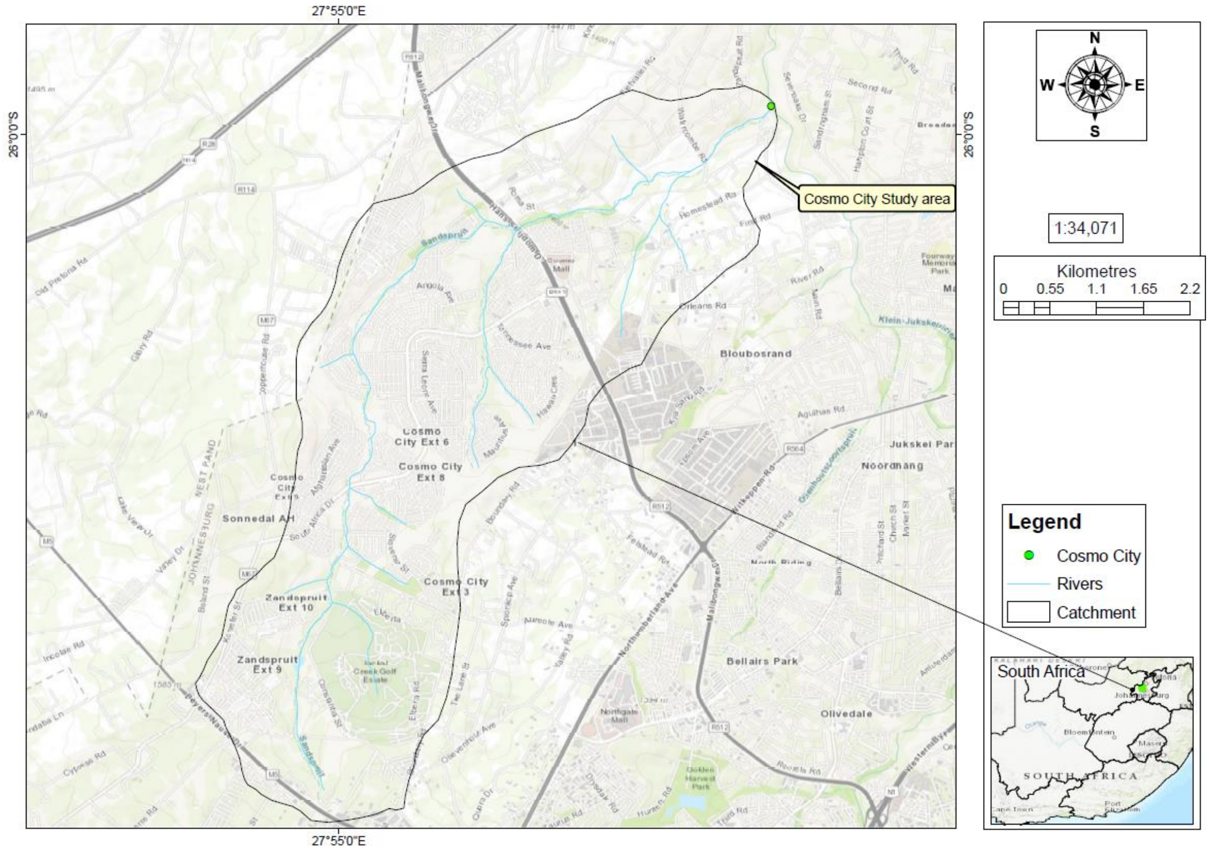

Figure 3.1: Map showing location of the study area in the context of Gauteng Province in South Africa

3.1.2 Hydrology

The hydrological sensitive areas within Cosmo City include Wetlands and two perennial streams that run through the area. The two perennial streams are Sandspruit and Prestine Spruit (Mphaka, 2015). Zandspruit River is the combination of the two streams (Sandspruit and Prestine Spruit). Sandspruit has got its origin from Honeydew and via Zandspruit informal settlements while Prestine Spruit originates from EXT 6 in Cosmo city. Sandspruit and Prestine Spruit join each other between EXT 2 and EXT 0 in Cosmo city to form the Zandspruit River (Olumuyiwa, 2016). Zandspruit River flows to Watercombe Dam before it joins Klein Jukskei River a tributary of Jukskei River that links up with the Crocodile River which flows into Hartbeespoort Dam to join Limpopo River (Figure 3.2).

Figure 3.2: Map showing hydrological features in Cosmo city and its extensions (Source:Olumuyiwa, 2016).

3.2. Data collection and sampling methods

3.2.1 Water samples data collection

Approximately, 48 water samples were collected from three different locations of the stream (Table 3.1 and Figure 3.3). Samples were collected on a seasonal basis (Autumn, Winter, Spring and Summer) at each specific sampling location within a period of 12 months and the sampling locations were chosen based on accessibility and safety. One point was upstream away from the sewage, the second point was midstream where sewage was flowing into the river, and the third point was downstream where there was no sewage water overflow. The samples were collected at 8 O'clock in the morning and transferred to the Aquatico

Laboratories while stored in iced coolers at 4˚C to prevent change in volume due to evaporation prior to analysis and to prevent contamination, sample bottles were rinsed with EDTA prior to collection. The samples were analyzed in triplicate at Aquatico Laboratories which are accredited by the South African National Accreditation System (SANAS).

Table 3.1: Coordinates of the selected sampling points and the respective locations

Site	Location	Coordinates: X	Y
Site 1	Pristine Spruit: Upstream	27.932002	-26.022047
Site 2	Pristine Spruit: Midstream	27.931715	-26.021421
Site 3	Pristine Spruit: Downstream	27.931906	-26.016514

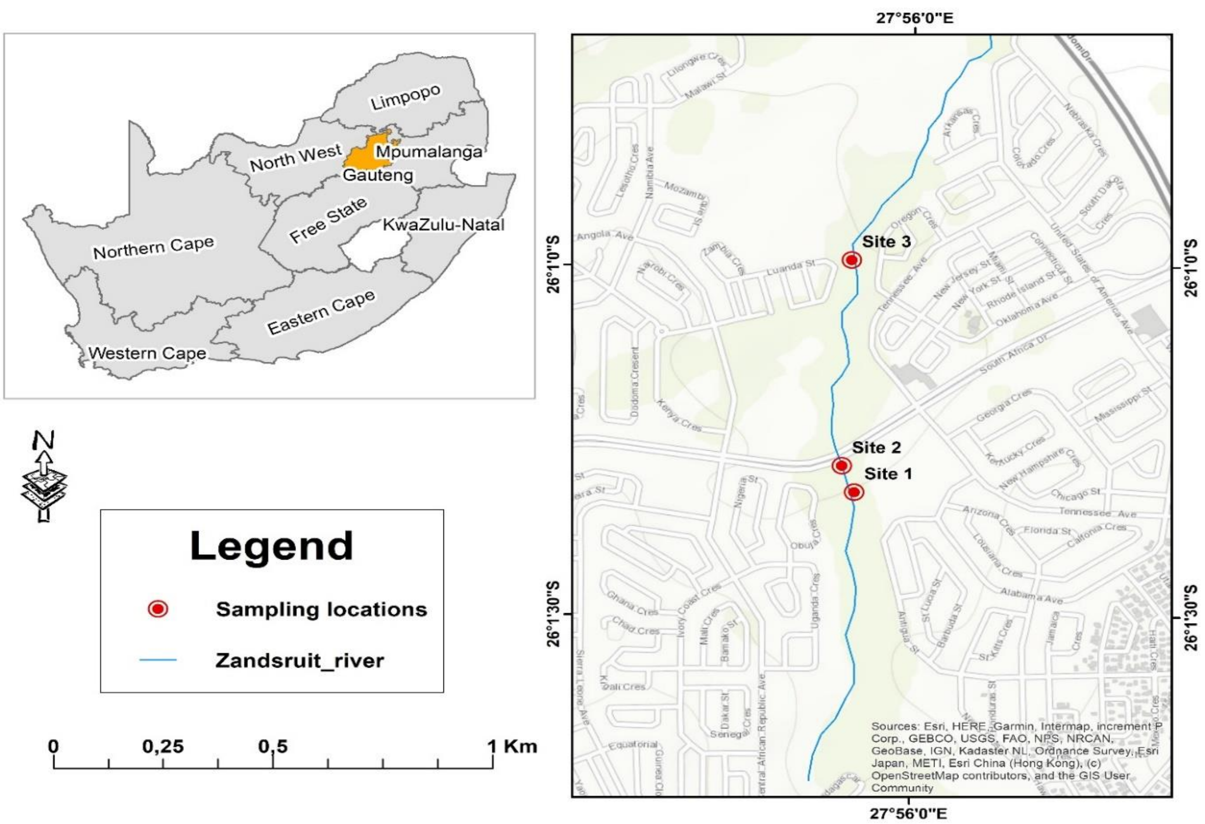

Figure 3.3: Map showing selected sampling points and location of the study area in the context of Gauteng Province in South Africa.

3.3 Water samples data analysis

The necessity of environmental protection had stimulated development of all kinds of methods allowing determination of different pollutants elements of the natural environment, including methods of determining inorganic ions and cations in water. Other methods such as High-Performance Liquid Chromatography (HPLC), atomic absorption spectrometry (AAS) and Ion Chromatography (IC) were used depending on what is being measured based on Michalski (2006). The pH, temperature, electrical conductivity (EC), and total dissolved solids (TDS) were measured in the field using a multimeter reader HANNA-HI 9829.The water was also tested for Turbidity, *E.coli*, chemical oxygen demand, metal ions (copper, cadmium, zinc, and lead), and non-metal ions (nitrates and phosphates) in an accredited lab.

3.3.1 Analysis procedure for chemical oxygen demand (COD)

Chemical Oxygen Demand is the amount of oxygen consumed when oxidizing oxygen -demanding substances in water with chemical oxidants (Song *et al.*, 2021). Chemical oxygen demand (COD) was analyzed by Reflux Technique Standard Method (APHA, 2005). This method uses dichromate as an oxidant, which is the most superior oxidant and applicable to a wide variety of samples and ease of manipulation (APHA, 2005). The samples measured were oxidized under reflux with a known amount of potassium dichromate in strong sulphuric acid with silver sulphate as a catalyst. Organic matter reduced part of the dichromate and the remainder was determined by titration with iron (II) ammonium sulphate or iron (II) sulphate using ferroin as indicator. Interferences from chloride were suppressed by the addition of mercuric sulphate to the reaction mixture. The chemical oxygen demand (COD) was expressed as milligrams of oxygen absorbed from standard dichromate per liter of sample.

3.3.2 Analysis procedure for metal ions

Metals are environmental pollutants originating from human activities such as disposal of sewage water from domestic residential dwellings and discharges from industrials, as well as natural activities such as groundwater infiltrations (Akpor, 2014). They are very toxic and carcinogenic even at very low concentrations, representing serious threats to human health and aquatic living organisms (Akpor, 2014). Metal ions form when a metal element loses its electrons during chemical reactions to form positive ions (Sarmistha *et al.,* 2021). The toxicity of metal ions (e.g., copper, cadmium, zinc, and lead) commonly found in sewage water were determined by Atomic Absorption Spectrometry (AAS) following the method by

Sharma and Tyagi (2013) (Figure 3.4 and Figure 3.5). AAS is a technique for determining the concentration of elements within water samples. The method provides both sensitivity and selectivity because other elements in the sample do not generally absorb light at the chosen wavelength compared to other methods (APHA, 2015).

Figure 3.4: Schematic flow diagram of Atomic Absorption Spectrometry (AAS) used to analyze toxicity of ion within metals (Researcher, 2019).

Figure 3.5: Schematics of AAS (Sharma and Tyagi, 2013).

The sample was aspirated into flame and atomized. The light beam was directed through the flame. Atoms in their ground state absorbed monochromatic radiation from the source. The intensity of the transmitted light was measured by a photoelectric detector. A liquid sample was aspirated and mixed as an aerosol with combustible gases. During combustion, atoms of the element of interest in the sample were reduced to their atomic state. Free, unexcited ground state atoms of the element absorbed light at characteristic wavelengths; the reduction of the light energy at the analytical wavelength measured the amount of the element in the sample. Light of specific wavelength was passed through the atomic vapor of an element of interest and measurement was made from attenuation of the intensity because of absorption.

3.3.3 Analysis procedure for non- metal ions

Non-metals are those elements that can form negative ions by gaining electrons during chemical reactions (Petrucci *et al.*,2011). Non-metals were determined by High Performance Liquid Chromatography (HPLC) method (Figure 3.6). The non-metals that were analyzed were phosphate (PO_4^{3-}) and nitrate (NO_3^-) and the samples were passed into a constant moving mobile phase that moved the sample into the Reversed phase chromatography by an injector. The separation was effectively carried out in the stationary phase packed in a column. The separated sample characteristics eluting the HPLC column were visible at the detector, and the mobile phase left the detector was collected by waste system. The detector was connected to a data collection system that stores the produced results (overflow). The data collection system then projected the chromatogram results on the screen. Finally, the end results appeared as chromatogram peaks of various heights depending on the concentration of the sample constituents.

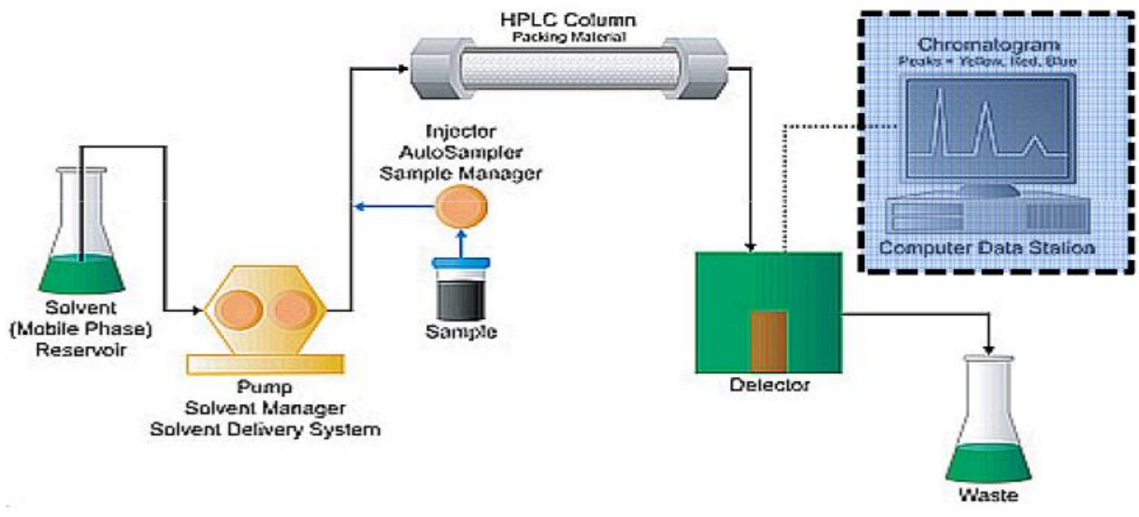

Figure 3.6: The example of operation of HPLC system (Gilala, 2010).

3.3.4 Analysis procedure for pH, Temperature, EC, TDS, and Turbidity

According to DES (2018), pH, temperature, electrical conductivity (EC) and total dissolved solids (TDS) are in situ water quality parameters that require measurement at the time of sampling since they can rapidly change. The pH indicates the acidity or alkalinity of the water by measuring the amount of hydrogen ions present in a water sample (Osman and Kloas, 2010, Munyao,2018). Temperature is a measure of kinetic energy of water, it varies according to season, depth, and time of the day in some cases (Robert *et al.*, 2014). Temperature is also an important component of water quality because of its great impact on aquatic life (Osman and Kloas, 2010). EC is a measure of the of water to conduct electric current due to the presents of dissolved salts (DES, 2018). Total dissolved solids indicate the number of salts within the water resources that impacts water usage such as domestic consumption, agricultural as well as industrial activities (Opperman, 2008). Turbidity is a measure of the presence of soluble, suspended, and colloidal particles that hinder the transmission of light through water in a water body (DES,2018). The pH, temperature, electrical conductivity (EC) and total dissolved solids (TDS) were measured in the field using a multimeter reader HANNA-HI 9829, while turbidity was measured in the laboratory using a turbidity meter. The procedures were adopted as recommended by DWAF (1996) and following the methods by APHA (1999). Equipment and materials that were used were multimeter, probe, buffer solutions for calibrating the instrument, distilled water, and data sheet. The meter was turned on and calibrated according to protocols found in the manufacturer's instructions.

Turbidity is the light scattering ability of water and causes light to be absorbed through water (Falguni and Niladri, 2012). It is attached to microorganisms such as viruses and bacteria that are a threat to human health because it is mainly caused by ingress of dirty water from outside the system such as storm water resulted from drains during heavy rainfall (Mohammed, 2017). Measurement of turbidity is important because it does not only measure the cloudiness of water, but also provide attachment places for other water pollutants such as metals and bacteria (DES,2018). Turbidity was measured using a turbidity meter (Orion Aquafast II). Equipment and materials that were used are turbidity meter kit, sterile tissues, distilled water, and data sheet. The turbidity meter was also calibrated as per the manufacturer's instructions.

The water sample bottle was turned upside down 2-3 times to ensure that the sample were well mixed. The sterile was rinsed with distilled water, and then the turbidity tube was emptied with some of the sampled water. The turbidity tube was then filled to the neck with some of the sampled water. Tubes were capped with a marked cap and wiped with a lint-free tissue. A clean tube was then placed into the chamber of the turbidity meter, and the cap of the tube was aligned with the mark on the chamber. An appropriate range was selected on the selection knob and the readings were recorded as nephelometric turbidity units (NTU) on the data sheet as soon as the reading stabilizes. The tube was then removed from the chamber, emptied, rinsed with distilled water, and dried up before putting it back into the turbidity kit.

3.3.5 Analysis procedure for *E. coli*

According to Bartram and Ballance (1999) there are two techniques commonly used to detect the presence of microorganisms in water. These techniques are Multiple Fermentation Tube (MFT) or Most Portable Number (MPN) technique and the Membrane Filter (MF) technique. MF technique can be used to test relatively large number of samples and yields results faster than MFT technique (Bartram and Balance,1999). The MF technique is more sensitive, faster, and less laborious than other published methods (APHA,1999). Membrane Filtration analysis technique was selected to analyze the presents of *E. coli* in this study. This procedure was adopted as described in APHA (1999). MF method was chosen to analyze *E.coli* because it gives more reliable and precise data better than MPN method, which is time consuming, labour intensive and less precise (Prince, 2016).

For the analysis of *E. coli,* the Membrane filters with a known uniform porosity of predetermined size of 0.45 µm which was sufficiently small to trap microorganisms was used. The sample passed through the membrane using a filter funnel and vacuum system. Organisms in the sample were concentrated on the surface of the membrane. The membrane, with its trapped bacteria, was then placed in a special plate containing a pad saturated with the appropriate medium. On the upper surface of the membrane the growth of organisms in the form of colonies was facilitated by the passage of nutrients through the filter during incubation. Discrete colonies formed on the surface of the membrane and were transferred into a coliform media. Colonies were counted after full incubation and the results were expressed as number of colonies per 100 ml of sample. The following formula was used to calculate the results:

Number of colonies per 100 ml = [(No. of colonies)/ (volume filtered)] × 100

3.4. Survey sample data collection of questionnaires and analysis

In a survey, the goal of sampling strategy is to obtain a sample that is a representative of the population of interest (Ponto, 2015). Cosmo City community was selected as the area of interest because it has been experiencing sewage water overflows in the past. According to (Ponto, 2015), it is not feasible to collect data from an entire population of interest, only a subset of the sample or population was used to estimate the population responses. The Cosmo city households were the only target for sampling in this study since it was not possible to collect data from the whole community and the surrounding areas. As per the ward councilor, the community of Cosmo City consists of 12 000 households with a population of ± 70 000. To this study, we only surveyed 250 households amongst 12 000 households to estimate the population responses since it was not possible to collect data from the whole community, this was adopted from Ponto (2015). Cosmo City area is made up of 10 extensions, as such we managed to collect data from only 25 households due to intense number of extensions to accommodate the whole community. As such, 25 households were surveyed from each extension (25 multiply by 10) to make up a total of 250 households as a representative sample of the population.

The households were selected using random sampling method. A random sampling method was used to select participants within the community of Cosmo City based on household stand numbers. Random sampling gives each target member an equal chance to be selected (Mnisi, 2011). It also increases the likelihood that the entire population will be reflected accurately by the responses from the sample of interest (Ponto, 2015). In each extension, the households were numbered 0 to 47, and the first number was numbered house number 1 then followed by number 3, then 5, 7, 9,11, 13, 15, 17, 19, 21, 23, 25, 27, 29, 31, 33, 35, 37, 39, 40, 41, 43, 45, 47. This method was adopted from Mnisi (2011). Data was collected through the distribution of questionnaires to members of Cosmo city community. The purpose of the questionnaire was to assess the community's perceptions, attitudes, and knowledge towards SWO and its impacts. Access to the community was through the assistance of the ward councilor. The questionnaires were distributed personally by the researcher to each household of the community. The questionnaire was designed with a set of questions that were presented in English to each respondent, and luckily the researcher was able to speak and understand all languages of South Africa, he was able assist those who could not understand English better.

Questionnaires were composed of closed-ended questions. Closed ended questions are easy to analyze, they are made up of numbers than opinions (Mnisi, 2011). The main questions of the study in the questionnaire include, causes of sewage water overflows, impacts of sewage water overflows and management of sewage water overflows. The survey was conducted for a period of 3 months and the random numbers were generated using Excel 2016. Data collected through questionnaire was analyzed using IBM SPSS statistics 28.0.1.0. Once the entire survey questionnaires were collected, every response item on each questionnaire was carefully entered as a number code under the question's header in the SPSS. Mnisi (2011), indicated the importance of referring to the original aims of the study and the hypothesis that you wish to achieve to keep the analysis focused when analyzing questionnaire. Therefore, we referred to each questionnaire after recording data on SPSS for data accuracy.

3.4.1 Reliability and Validity

The questionnaire was designed guided by the research objectives and questions. The questionnaire was tested after completion before it was used on a large population sample, to see if it would obtain the required results. This was done by asking the Supervisors to read it through and see if there were any ambiguities which the researcher did not notice. The supervisors advised on what was required for corrections, this includes the length, structure, questions, and wording of the questionnaire.

CHAPTER 4. RESULTS PRESENTATION

4.1 Introduction

This chapter focuses on the presentation of laboratory, and questionnaire survey results. The results from laboratory analysis contain both physical and chemical characteristics of the sewage water samples collected from Prestine Spruit stream a tributary of Zandspruit River while the results from the questionnaire survey revealed different perceptions of Cosmo City community over sewage water overflow.

4.2 Physico-chemical characteristics of sewage water obtained during laboratory analysis.

The data for physical and chemical characteristics of sewage water was collected from Prestine Spruit stream. The data analysed was presented on a seasonal basis (Autumn, Winter, Spring and Summer) for each specific sampling location. The results were presented as means and average mean values of sewage water characteristics (Figures 4.1 and 4.2). The mean and average mean values listed are the values obtained from three different sampling points from the upstream, midstream, and downstream of Prestine Spruit stream (Tables 4.1, 4.2, 4.3 and 4.4). Physical characteristics of sewage water such as pH, turbidity, temperature, and TDS were analysed in the field during collection of samples whereas chemical parameters such as Nitrate (NO_3^-), Phosphate (PO_4^{3-}) Copper (Cu), zinc (Zn) cadmium (Cd), Chemical Oxygen Demand (COD) and *E. coli* were all analyzed in the laboratory.

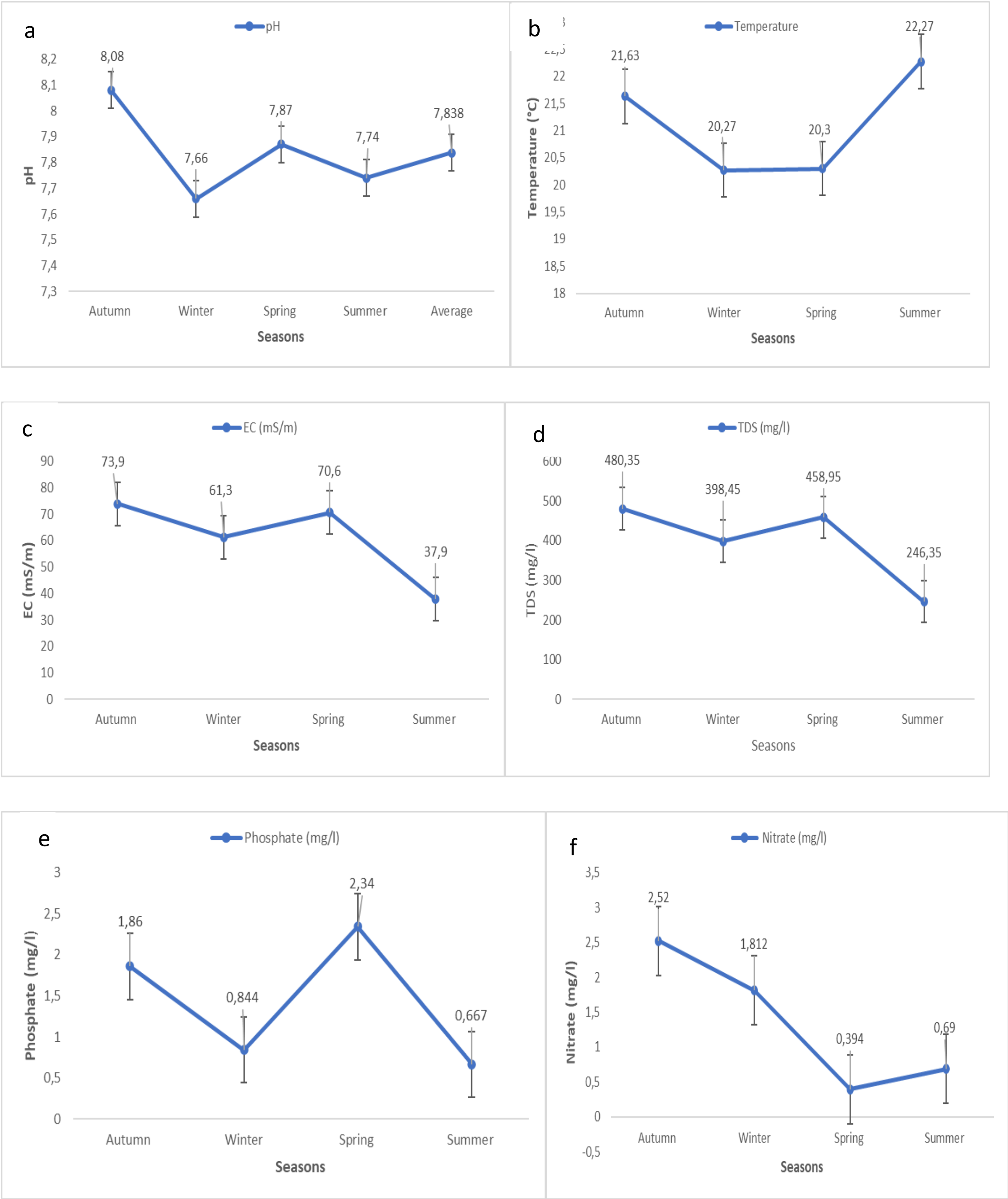

Figure 4.1: Seasonal average mean values of pH, temperature, EC, TDS, phosphate, and nitrate as investigated for four seasons along Pristine Spruit stream, a tributary of Zandspruit River.

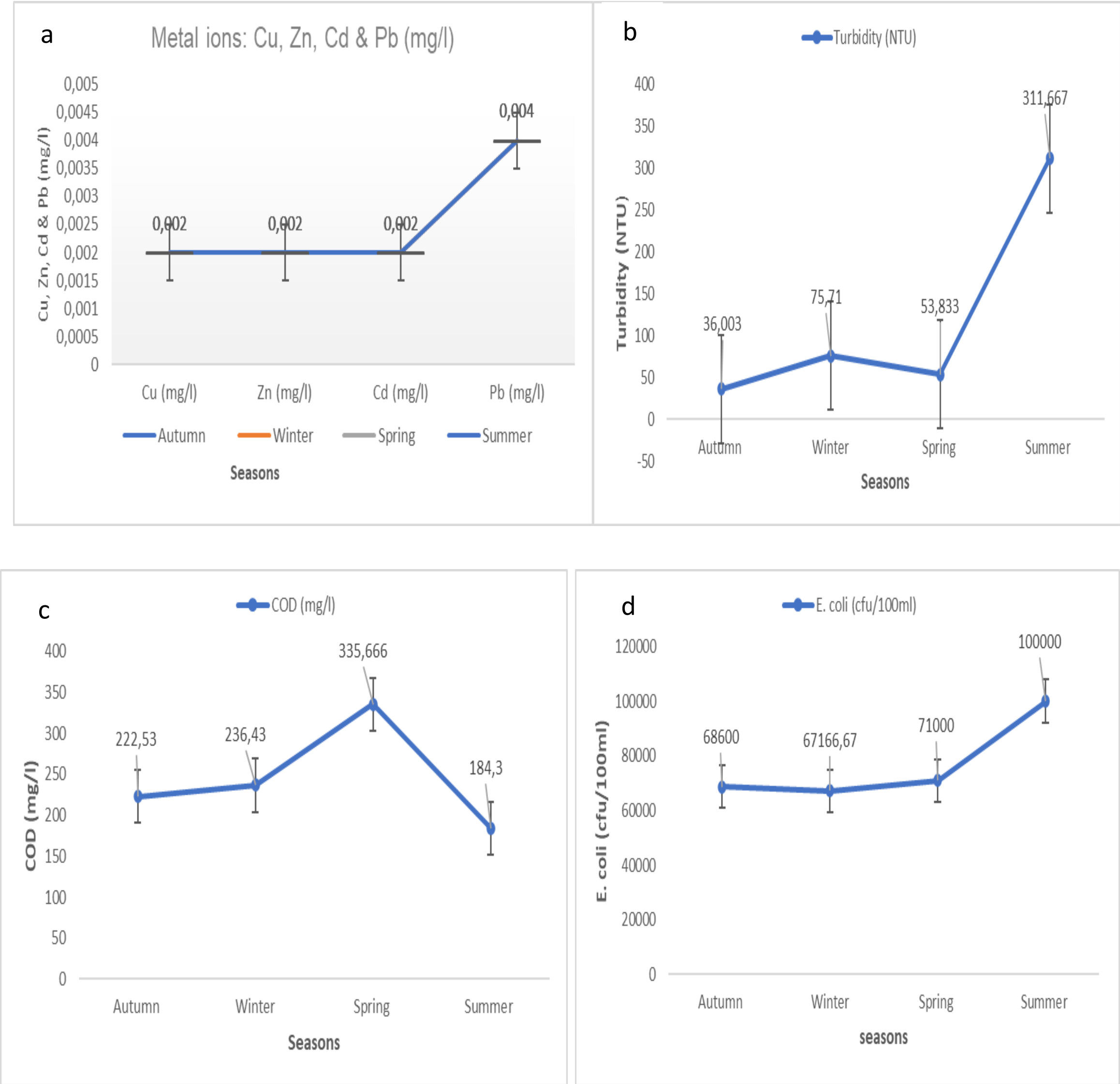

Figure 4.2: Seasonal average mean values of metal ions (Cu, Zn, Cd & Pb), turbidity COD and E.coli investigated for four seasons along Pristine Spruit stream, a tributary of Zandspruit River.

4.2.1 Autumn season

In autumn season (Table 4.1), pH values ranged from 8,04 – 8,12, with the highest value of 8,12 detected at midstream section and the lowest value of 8,04 was detected downstream. The value of pH in the upstream section was detected as 8.10. The average value for pH was detected as 8,08. Temperature values ranged from 21,1 - 22,3 ℃ and the highest value 22,3 ℃ was detected upstream, while lowest value 21,1℃ was measured in the downstream section. Midstream value for temperature was detected as 21,5 ℃. The average value for temperature was found to be 21,63 ℃. EC value ranges were found to be 64,1 - 91,1 mS/m with the highest value 91,1 mS/m detected in the midstream section, and the lowest EC value 64,1 mS/m was detected in the upstream section. The EC value 66.5 mS/m was detected in the downstream section. The EC values of the three sections have an average value of 73,9 mS/m (Table 4.1).

TDS highest value 462,15 mg/l and lowest value 416.65 mg/l were observed on the midstream and upstream sections, respectively. TDS value 432,25 mg/l was observed in the downstream section. The average TDS value was found to be 437,02 mg/l. PO_4^{3-} values ranged from 0,39 – 4,48 mg/l. The highest value 4,48 and lowest value 0,39 mg/l were observed in the midstream and upstream, respectively. The PO_4^{3-} value 0,697 mg/l was observed on the downstream section, while the average value for PO_4^{3-} was found to be 1,86 mg/l. NO_3^- value ranges were found to be 0,991 - 6,19 mg/l in the downstream and upstream, respectively. The lowest value 0,382 mg/l was detected in the midstream section. The average nitrate value was found to be 2,52 mg/l (Table 4.1).

The Cu, Zn, and Cd value concentrations were recorded as 0,002 mg/l in upstream, midstream, and downstream sections, respectively. As such, their average value was recorded as 0,002 mg/l. Pb value concentration was recorded as 0,004 in all three sections, the upstream, midstream, and downstream. Hence, the average value for lead was observed as 0,004 mg/l. *E. coli* values ranges were recorded as 5800 – 100000 cfu/100 ml, with the highest value 100000 cfu/100 ml and lowest value 5800 cfu/100 ml being recorded in midstream and upstream, respectively. The *E. coli* downstream value 100000 cfu/100 ml was observed like that of the midstream section. The *E. coli* average value was found the be 68600 cfu/100 ml (Table 4.1).

Turbidity values were observed ranging from 2,19 – 102 NTU, the highest value 102 and lowest value 2,19 NTU were recorded in the midstream and downstream sections respectively. The upstream section turbidity value was observed as 3,82 NTU, and the average turbidity value for all sections was recorded as 36,003 NTU. The values of COD were observed as 37,4 – 561 mg/I. The COD's lowest value of 37,4 and highest of value 561 mg/l were recorded in the upstream and midstream sections, respectively. The COD concentration in the downstream section was recorded as 69,2 mg/l. The COD concentration was found to be 222,53 mg/l (Table 4.1).

Table 4.1: Mean values of physico- chemical parameters investigated along Pristine Spruit stream tributary of Zandspruit River in autumn season.

Date	Parameter	Upstream	Midstream	Downstream	Average
30/04/2019	pH	8,10	8,12	8,04	8,08
30/04/2019	Temperature (℃)	22,3	21,5	21,1	21,63
30/04/2019	EC (mS/m)	64,1	91,1	66,5	73,9
30/04/2019	TDS (mg/l)	416,65	462,15	432,25	437,02
30/04/2019	PO_4^{3-} (mg/l)	0,39	4,48	0,697	1,86
30/04/2019	NO_3^- (mg/l)	6,19	0,382	0,991	2,52
30/04/2019	Cu (mg/l)	0,002	0,002	0,002	0,002
30/04/2019	Zn (mg/l)	0,002	0,002	0,002	0,002
30/04/2019	Cd (mg/l)	0,002	0,002	0,002	0,002
30/04/2019	Pb (mg/l)	0,004	0,004	0,004	0,004
30/04/2019	*E. coli (*cfu/100 ml)	5800	100000	100000	68600
30/04/2019	Turbidity (NTU)	3,82	102	2,19	36,003
30/04/2019	COD (mg/l)	37,4	561	69,2	222,53

4.2.2 Winter season

In winter season (Table 4.2), pH values ranged from 7,38 – 8,12, with the highest value of 8,12 detected at upstream section and the lowest value of 7,38 was detected in the midstream section. The value of pH in the downstream section was recorded as 7,49. The average value for pH was found to be 7,66. Temperature values ranged from 20,2 - 20,4 ℃ , and the highest value 20,4 ℃ was detected upstream, while the lowest value 20,2℃ was measured in the downstream section. Midstream value for temperature was detected as 20,2 ℃, which is similar to downstream section. The average value for temperature was found to be 20,27 ℃. EC value ranges were found to be 58,3 – 62,8,1 mS/m with the highest value 62,8 mS/m detected in the midstream section, and the lowest EC value 58,3 mS/m was detected in the upstream section. The EC value 62.8 mS/m was detected in the downstream section. The EC values of the three sections have an average value of 61,3 mS/m (Table 4.2).

TDS highest value 408.2 mg/l and lowest value 378,95 mg/l were observed on the midstream and upstream sections, respectively. TDS value 408,2 mg/l was observed in the downstream section. The average for TDS values was found to be 398,45 mg/l. PO_4^{3-} values ranged from 0,408 – 1,37 mg/l. The highest value 1,37 and lowest value 0,408 mg/l were observed in the downstream and upstream, respectively. The PO_4^{3-} value 0,754 mg/l was observed in the midstream section, while the average value for PO_4^{3-} was found to be 0.844 mg/l. NO_3^- value ranges were found to be 0,194 – 5 mg/l in the downstream and upstream, respectively. The lowest value 0,194 mg/l was detected in the downstream section. The nitrate value in midstream section was observed as 0,241 mg/l. The average nitrate value was found to be 2,52 mg/l (Table 4.2).

Cu and Cd value ranges were recorded as 0,002 mg/l in upstream, midstream, and downstream sections, respectively. As such, their average value was recorded as 0.002 mg/l. Pb value ranges were recorded as 0,004 in all three sections, the upstream, midstream, and downstream. Hence, the average value for lead was observed as 0,004 mg/l. Zn values ranged from 0,002 -0,005 mg/l respectively. The Zn lowest value 0,002 mg/l was detected in the upstream section, while the highest value 0,005 mg/l was observed in the midstream section and 0,003 mg/l was recorded in the downstream section. *E. coli* values ranges were recorded as 1500 – 100000 cfu/100 ml, with the highest value 100000 cfu/100 ml and lowest value 1500 cfu/100 ml being recorded in midstream and upstream, respectively. The *E. coli* downstream value 100000 cfu/100 ml was observed like that of the midstream section. The *E. coli* average value was found to be 67166,67 cfu/100 ml (Table 4.2).

Turbidity values were observed ranging from 2,82 – 127 NTU, the highest value 127 and lowest value 2,82 NTU were recorded in the midstream and upstream sections respectively. The downstream section turbidity value was observed as 97,3 NTU, and the average turbidity value for all sections was recorded as 75,71 NTU. The value ranges for chemical oxygen demand (COD) were observed as 35,3 – 424 mg/I. The COD lowest value 35,3 and highest value 424 mg/l were recorded in the upstream and midstream sections, respectively. The COD value in the downstream section was recorded as 250 mg/l. The COD average value was found to be 236,43 mg/l (Table 4.2).

Table 4.2: Mean values of physico-chemical parameters investigated along Prestine Spruit stream tributary of Zandspruit in winter season.

Date	Parameter	Upstream	Midstream	Downstream	Average
28/06/2019	pH	8.12	7.38	7.49	7.66
28/06/2019	Temperature (℃)	20.4	20.2	20.2	20.27
28/06/2019	EC (mS/m)	58.3	62.8	62.8	61.3
28/06/2019	TDS (mg/l)	378.95	408.2	408.2	398.45
28/06/2019	PO_4^{3-} (mg/l)	0.408	0.754	1.37	0.844
28/06/2019	NO_3^- (mg/l))	5.00	0.241	0.194	1.812
28/06/2019	Cu (mg/l)	0.002	0.002	0.002	0.002
28/06/2019	Zn (mg/l)	0.002	0.005	0.003	0.003
28/06/2019	Cd (mg/l)	0.002	0.002	0.002	0.002
28/06/2019	Pb (mg/l)	0.004	0.004	0.004	0.004
28/06/2019	*E. coli* (cfu/100ml)	1500	100000	100000	67166.67
28/06/2019	Turbidity (NTU)	2.82	127	97.3	75.71
28/06/2019	COD (mg/l)	35.3	424	250	236.43

4.2.3 Spring season

In spring season (Table 4.3), pH values ranged from 7,59 – 8,26, with the highest value 8,26 detected at midstream section and the lowest value 7,59 was detected in the upstream section. The value of pH in the downstream section was recorded as 7,77. The average value for pH was found to be as 7,87. Temperature values ranged from 18,7 - 20,3 ℃ , and the highest value 20,3 ℃ was detected in the midstream and downstream sections respectively, while the lowest value 18,7℃ was measured in the upstream section. Midstream value 20,3 ℃ for temperature is like that of the downstream section. The average value for temperature was found to be 20,3 ℃. EC value ranges were found to be 52,9 – 83,4 mS/m with the highest value 83,4 mS/m detected in the midstream section, and the lowest EC value 52,9 mS/m was detected in the upstream section. The EC value 75.5 mS/m was detected in the downstream section. The EC values of the three sections have an average value of 70,6 mS/m (Table 4.3).

TDS highest value 542.1 mg/l and lowest value 338 mg/l were observed on the midstream and upstream sections, respectively. TDS value 490,75 mg/l was observed in the downstream section. The average for TDS values was found to be 456,95 mg/l. PO_4^{3-} values ranged from 0,371 – 3,49 mg/l. The highest value 3,49 and lowest value 0,371 mg/l were observed in the midstream and upstream, respectively. The PO_4^{3-} value 3,16 mg/l was observed in the downstream section, while the average value for phosphate was found to be 2,340 mg/l. NO_3^- value ranges were found to be 0,194 – 0,794 mg/l in the downstream and upstream, respectively. The lowest value 0,194 mg/l was detected in the midstream and downstream sections. The average nitrate value was found to be 0,394 mg/l (Table 4.3).

Cu, Zn and Cd value ranges were recorded as 0,002 mg/l in upstream, midstream, and downstream sections, respectively. As such, their average value was recorded as 0.002 mg/l. Pb value ranges were recorded as 0,004 in all three sections, the upstream, midstream, and downstream. Hence, the average value for lead was observed as 0,004 mg/l. *E. coli* values ranges were recorded as 13000 – 100000 cfu/100 ml, with the highest value 100000 cfu/100 ml and lowest value 13000 cfu/100 ml being recorded in midstream and upstream, respectively. The *E. coli* downstream value 100000 cfu/100 ml was observed similar to that of the midstream section. The *E. coli* average value was found to be 71000 cfu/100 ml (Table 4.3).

Turbidity values were observed ranging from 4,70 – 134 NTU, the highest value 134 and lowest value 4,70 NTU were recorded in the midstream and upstream sections respectively. The downstream section turbidity value was observed as 22,8 NTU, and the average turbidity value for all sections was recorded as 53,83 NTU. The value ranges for COD were observed as 64,0 – 599 mg/I. The COD lowest value 64,0 and highest value 599 mg/l were recorded in the upstream and midstream sections, respectively. The COD value in the downstream section was recorded as 344 mg/l. The COD average value was found to be 335,67 mg/l (Table 4.3).

Table 4.3: Mean values of physico-chemical parameters investigated along Prestine Spruit stream tributary of Zandspruit River in spring season.

Date	Parameter	Upstream	Midstream	Downstream	Average
27/09/2019	pH	7.59	8.26	7.77	7,87333
27/09/2019	Temperature (℃)	18.7	20.3	20.3	20,3
27/09/2019	EC (mS/m)	52.9	83.4	75.5	70,6
27/09/2019	TDS (mg/l)	338	542.1	490.75	456,95
27/09/2019	PO_4^{3-} (mg/l)	0.371	3.49	3.16	2,340
27/09/2019	NO_3^- (mg/l)	0.794	0.194	0.194	0,394
27/09/2019	Cu (mg/l)	0.002	0.002	0.002	0,002
27/09/2019	Zn (mg/l)	0.002	0.002	0.002	0,002
27/09/2019	Cd (mg/l)	0.002	0.002	0.002	0,002
27/09/2019	Pb (mg/l)	0.004	0.004	0.004	0,004
27/09/2019	*E. coli* (cfu/100ml)	13000	100000	100000	71000
27/09/2019	Turbidity (NTU)	4.70	134	22.8	53,833
27/09/2019	COD (mg/l)	64.0	599	344	335,666

4.2.4 Summer season

In summer season (Table 4.4), pH values ranged from 7,58 – 7.88, with the highest value 7,88 detected at midstream section and the lowest value 7,58 was detected in the downstream section as illustrated in table 4.4. The value of pH in the upstream section was recorded as 7,75. The average value for pH was found to be 7,737. Temperature values ranged from 22,2 - 22,3 ℃ , and the highest value 22,3 ℃ was detected in the midstream and downstream sections respectively, while the lowest value 22,2℃ was measured in the upstream section. Midstream value 22,3 ℃ for temperature is like that of the downstream section. The average value for temperature was found to be 22,27 ℃. EC value ranges were found to be 29,7 – 52,3 mS/m with the highest value 52,3 mS/m detected in the midstream section, and the lowest EC value 29,7 mS/m was detected in the downstream section. The EC value 331,7 mS/m was detected in the upstream section. The EC values of the three sections have an average value of 37,9 mS/m (Table 4.4).

The average for TDS values was found to be 246,35 mg/l. TDS highest value 339,95 mg/l and lowest value 193,05 mg/l were observed on the midstream and downstream sections, respectively. TDS value 206,05 mg/l was observed in the upstream section. PO_4^{3-} values ranged from 0,139 – 1,34 mg/l. The highest value, 1.34 mg/l, and lowest value 0,139 mg/l were observed in the upstream and midstream, respectively. The PO_4^{3-} value 0,523 mg/l was observed in the downstream section, while the average value was found to be 0,667 mg/l. NO_3^- value ranges were found to be 0,194 – 1,68 mg/l in the downstream and upstream, respectively. The value 0,197 mg/l was detected in the midstream section. The average nitrate value was found to be 0.690 mg/l. Cu, Zn and Cd value ranges were recorded as 0,002 mg/l in upstream, midstream, and downstream sections, respectively. As such, their average value was recorded as 0.002 mg/l. Pb value ranges were recorded as 0,004 in all three sections, the upstream, midstream, and downstream. Hence, the average value for lead was observed as 0,004 mg/l (Table 4.4).

E. coli values ranges were recorded as 100000 cfu/100 ml in all three sections, the upstream, midstream, and downstream, respectively. The *E. coli* average value was found to be 100000 cfu/100 ml. Turbidity values were observed ranging from 48,0 – 722 NTU, the highest value 722 and lowest value 48,0 NTU were recorded in the downstream and midstream sections respectively. The upstream section turbidity value was observed as 165 NTU, and the average turbidity value for all three sections was recorded as 311.667 NTU. The value ranges for COD were observed as 64,9 – 291 mg/I. The COD lowest value 64,9 and highest value 291 mg/l were recorded in the upstream and midstream sections, respectively. The COD value in the downstream section was recorded as 197 mg/l. The COD average value was found to be 184.3 mg/l (Table 4.4).

Table 4.4: Mean values of physico-chemical parameters investigated along Prestine Spruit stream tributary of Zandspruit River in summer season.

Date	Parameter	Upstream	Midstream	Downstream	Average
20/01/2020	pH	7.75	7.88	7.58	7.737
20/01/2020	Temperature(℃)	22.2	22.3	22.3	22.267
20/01/2020	EC (mS/m)	31.7	52.3	29.7	37.9
20/01/2020	TDS (mg/l)	206.05	339.95	193.05	246.35
20/01/2020	PO_4^{3-} (mg/l)	0.139	1.34	0.523	0.667
20/01/2020	NO_3^- (mg/l)	1.68	0.197	0.194	0.690
20/01/2020	Cu (mg/l)	0.002	0.002	0.002	0.002
20/01/2020	Zn (mg/l)	0.002	0.002	0.002	0.002
20/01/2020	Cd (mg/l)	0.002	0.002	0.002	0.002
20/01/2020	Pb (mg/l)	0.004	0.004	0.004	0.004
20/01/2020	*E. coli* (cfu/100m)	100000	100000	100000	100000
20/01/2020	Turbidity (NTU)	165	48.0	722	311.667
20/01/2020	COD (mg/l)	64.9	291	197	184.3

4.3 Questionnaire survey results revealing different perceptions of Cosmo City community respondents towards sewage water overflows.

An overview of the questionnaire survey results about the perceptions towards sewage water overflows that was conducted in the community of Cosmo City are presented on Appendix 2. The findings are presented on Figures 4.3 and 4.4, to illustrate the perceptions of the community towards the causes, sources, impacts and management of sewage water overflows. We had a total of 250 participants who responded to the questionnaire survey.

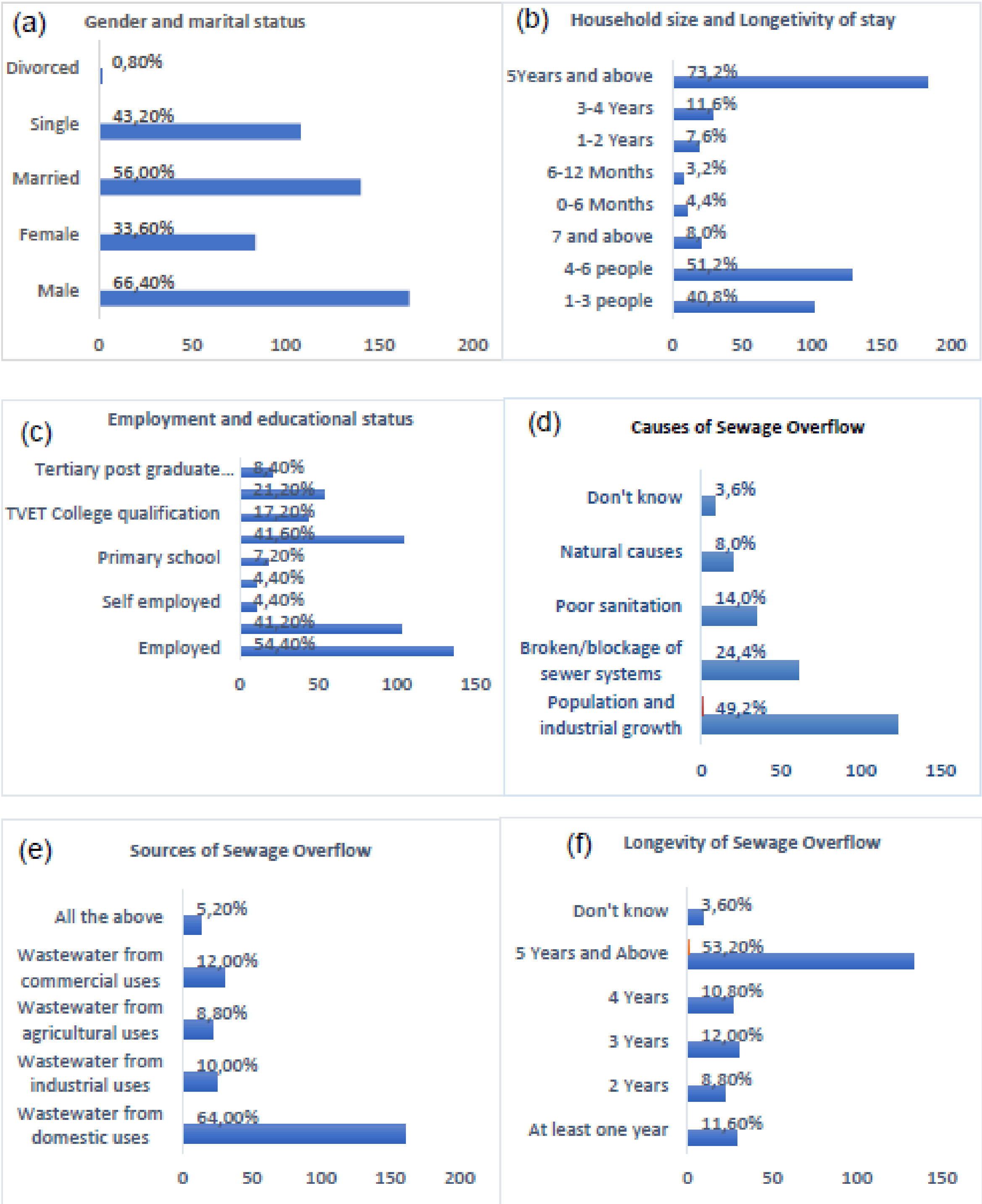

Figure 4.3: Gender, marital, household size, longevity of stay, employment, and educational status, causes and sources of sewage overflow as well as longevity of sewage overflow results as obtained during the questionnaire survey.

Figure 4.4: Impacts, action towards management of sewage overflow, minimization and management of sewage overflow results as obtained during the questionnaire survey.

4.3.1 Biographic information.

4.3.1.1 Gender and marital status

The results showed that many respondents who participated in this survey are males 66.4%, while female respondents have a total of 33.6%. This is because during the survey, we have observed that most females did not want to participate without the authority from their husbands. Most females referred their husbands to answer all the questions in the questionnaire and referring to their men to respond. More than half 56% of the respondents are married, 43.2% are single, while 0.8% are divorced as illustrated on Figure 4.3**a.**

4.3.1.2 Household size and longevity of satay

The number of members in a family is bound to affect water usage, and families are made of different number of members. Some families are large with many family members, while others are small with few family members. In an entire sample of 250 respondents, 51,2% were staying in a family of 4 -6 people per household, 40,8% were staying in a family of 3 people per household, while 8% were staying in a family of 7 people or more. These results indicate that most people stayed in a family of between 3 and 6 people per household (Figure 4.3 **b**). It was also important for this research to determine the household size to understand how much impact a family can put on their sewer systems.

The results (Figure 4.3 **b**). revealed that 73,2% respondents stayed in Cosmo City for 5 years and longer,11,6% stayed for a period of between 3 - 4 years, 7,6% had been staying in the area for a period of between 1 - 2 years, while 3.2% had been staying for a period of 1 year or less. It was important to understand how long a respondent stayed in the study area so that the information acquired could be used to understand and corelate the length of occurrence of sewage water overflows within the study area. Many people stayed in Cosmo City for a long period of time, while experiencing the issue of sewage water overflows.

4.3.1.3 Employment and educational status

The findings (Figure 4.3 **c**). indicated that 54,4% respondents were formally employed from different institutions while 41,2% are self-employed, and 4,4% are not employed. The results also indicated that only 4,4% did not go to school, 41,6% completed secondary school, 21,2% had degrees from university, 17,2% went to TVET Colleges, 8,4% have acquired postgraduate qualifications, while 7,2% had manged to complete primary school.

4.3.2 Perceptions of the community towards causes of sewage water overflows.

The results (Figure 4.3 **d**) indicate that 49,2% of the respondents suggested population growth as the major cause of sewage water overflow, 24,4% suggested blockage, and broken sewers, 14% suggested poor sanitation, while 8,0% respondents indicated that sewage water overflows are because of natural causes, and 0.8% don't know the causes of sewage water overflows These results show that most people are aware of the causes of sewage water overflows within their area.

4.3.3 Perceptions of the community towards sources of sewage water overflows.

All-inclusive 250 participants responded to this question, 64% respondents indicated that sewage water overflow results from domestic uses, 10% suggested industrial uses, 8.8% suggested agricultural uses, while 12% believes commercial uses are the main sources of sewage water overflows. Surprisingly 5,2% of the overall respondents believe that sewage water overflow around their area is coming from all sources of sewage water as indicated on Figure 4.3 **e**.

4.3.4 Perceptions of the community towards longevity of sewage water overflows.

Entirely 250 participants responded to this question, 11,6% respondents indicated that sewage water overflow had been occurring for a period of 1 year, 8,8% indicated 2 years, 12,6% - 10.8% indicated that sewage water overflow had been existing for the past 3-4 years respectively, while 53,2% indicated that sewage water overflows materialized for more than 5 years. Only 3,6% showed that they cannot remember how long sewage water overflow has been developing in their area (Figure 4.3 **f**).

4.3.5 Perceptions of the community towards impacts of sewage water overflows.

This question includes the impacts sewage wage water overflow on the environment, river water quality, human health, and the economy. A total of 250 participants responded to this question.

The results (Figure 4.4 **a**) revealed the impacts of sewage water overflow towards the environment in such a way that 25,2% of the participants indicated that water bodies are degraded, 22,8% revealed that surface and ground water are polluted, 22% indicated that air is polluted, 9.6% indicated soil pollution and 13,2% revealed that soil is eroded. Whereas only 7,2% indicated that they don't that impacts of sewage water overflow towards environment. On water quality, 13,6% indicated that sewage water overflows cause eutrophication in the river water, 28,4% revealed that the physical state of the river water changes, 9,2% indicated that sewage water overflows increase nutrients into the river water, 27,6% revealed that more waste is brought in the river water due to sewage water overflows, 14,4% indicated that aquatic organisms die as a result of sewage flowing into the river, while 6,8% don't know if sewage water overflow has any impact into the river water quality (Figure 4.4 **b**).

Furthermore, 65,6% showed that sewage water overflows impact human health in such a way that it creates bad smell, 24,8% and 8,4% indicated that sewage water overflows cause illnesses and deaths respectively, whereas 1,2% does not know if it has any impact towards human health (Figure 4.4 **c**). On economic impacts (Figure 4.4 **d)**, 32,4% participants indicated that sewage water overflows increase wastewater treatment cost, 26,4% indicated decreased value of properties, 6,4% indicated decreased value of properties, 28,4% revealed damaged of properties, 4,8% indicated the loss of jobs to people, whereas only 1,6% revealed that they don't know what impacts sewage overflows bring to the economy.

4.3.6 Perceptions of the community on action taken towards management of sewage water overflows

Entirely 250 participants responded to this question, 15.2% and 64.0% indicated that they can contact a licensed plumber, and local municipality respectively, when they see sewage water overflowing around their area of residents, 4,8% indicated that they can call their neighbour to assist, 2,8% revealed that they can investigate the matter and fix it themselves, whereas 13,2% indicated that they don't take any action when they see sewage water overflowing around their area (Figure 4.4 **e**).

4.3.7. Community's perceptions towards minimization and management of sewage water overflows

Comprehensively, 250 participants responded to this question, 61,6% of the respondents have indicated increasing the sewer capacity, 14,4% indicated the upgrading of deteriorating sewer infrastructure, 61.6% suggested introduction of education campaigns, and 12,4% indicated routine inspections of the sewer infrastructure are the best ways to minimize sewage water overflows, whereas 3,2% indicated that sewage water should be allowed to flow directly into streams to minimize sewage water overflows around their area (Figure 4.4 **f** and **g**).

CHAPTER 5. DISCUSSIONS

5.1. Introduction

The study aimed to investigate the impacts of sewage water overflows into the Zandspruit river, and the perceptions of the community towards SWO. Firstly, we determined the levels of chemical oxygen demand, pH, electrical conductivity, Total dissolved solids, Turbidity, and temperature. Then, we determined the concentration of *Escherichia coli* (*E. coli)* and the levels of nutrients such as nitrate and phosphate within the water. We also determined the toxic level of metals such as Zinc (Zn), Copper (Cu), Cadmium (Cd), and Lead (Pb) within the sewage water (Appendix 1), and we compared the concentration of the parameters to the South African water quality standards. Lastly, we established, the perceptions of Cosmo City communities towards the cause, impacts and the management of sewage water overflow (Appendix 2).

5.2. Physico-chemical parameters

The pH is dependent on the interactions of dissolved substances in water, such as aquatic plants photosynthetic process, respiration of aquatic living organisms, precipitation as well as decomposition of organic matter (Saad *et al.,* 2017). In this study, we detected the highest pH value of 8,08 in the Autumn season (Figure 4.1**a**) and the lowest pH 7.74 value in summer season (Figure 4.1**a**). Usually, the dilution of river water due to sewage and precipitation increases the pH value in water (Yee Ling *et al.,* 2016). The average mean pH value detected was 7.838 (Appendix 1), which falls within the standard limits of 5.5 – 9.5 as set by DWAF (1999); Domestic Water Sanitation (DWS) (2017); Levi and CO (2007) for the discharge of wastewater to the environment. Similarly, USEPA (2004) has a set standard of 6-9 for wastewater reuse. As a result, the pH of the sewage water does not cause any danger to the environment and river water quality.

Factors such as seasonal variations, exposure to solar radiation, flow rate, humidity and cloud cover in the area usually influence the changes in temperature (Otieno *et al.,* 2017). In addition, surface water temperature is influenced by the intensity of solar radiation, flow rate humidity and the cloud cover. In the present study, the highest temperature value of 22,27 °C was observed during summer season and the lowest value of 20.27 °C was recorded during winter season (Figure 4.1**b**). High temperature value recorded in the summer may be due to heat rising temperature of surface water, while low temperature value was due to the decrease of temperature of the surface water in winter. The temperature values of the present study are in conformity with the recommended water quality standards of 25-35, 30 and 37 set by DWAF (1999), EU (EPAI, 2001), Levi and CO (2007), and India (Gadhia *et al.*, 2012). Thus, the temperature of the river water is not affected by sewage water overflows where it can pose threat to the environment and river water quality.

EC is dependent on the nature and numbers as well as the migration of the ionic species in a solution and it increases with the amount of ions mobility within the water (Mohammed, 2017). In the other hand, the conductivity of surface water decreases because rainfall increase river water volume increases that dilutes the water (Gadhia *et al.*, 2012). Electrical conductivity values of the present study ranged from 37.9 to 73.9 mS/m, with the highest value 73.9 mS/m being detected during autumn season, and low value of 37.9 mS/m during summer season (Figure 4.1**c**). Typically, low EC value in summer season might be due to the dilution of river water since rain and sewage water overflows increase the volume of water. During winter season, the EC value in surface water increase because of low mixing of freshwater input (Gadhia, *et al.*, 2012), so as in the present study, low value of 73.9 mS/m was recorded during autumn season, a season that separate summer and winter that attributed to low rain fall and low volume of water within the river. The EC value in this study falls within the permissible limits of 70 – 150 mS/m according to DWAF (1999) and DWS (2017).

Like EC, TDS values in surface water were higher during winter season and lower in the summer season as described in Gadhia *et al*., (2012). In our study, the highest of TDS value 480.35 mg/l was recorded during autumn and low value of 246,35 mg/l during summer season (Figure 4.1**d**). The high value of TDS was detected during winter because of high volumes of suspended or dissolved materials in surface water since there was no fresh water from rainfall to dilute the river system. In summer season, low value of 246,35 was recorded, this might from rain and the high mixing of more fresh water from sewage water overflow or storm water flowing into the river system. The TDS values in our study was lower compared to the South African standard limits of 500 – 1500 mg/l for wastewater (UP and SALII, 2013; and Van Schoor, 2005), thus the parameter does not pose any threat to the water environment and river water quality.

In this study, phosphate value ranged from 0.667 to 1.86 mg/l, with the highest value of 1.86 mg/l detected in autumn season, while lowest value of 0.667 mg/l detected in summer season (Figure 4.1**e**). The high phosphate value in autumn season might be because of the usage of phosphate additions in the detergent formulations that are disposed in domestical wastewater.

The lower value of phosphate in summer season could be attributed to dilution of sewage water due to rain since summer is a rainy season in South Africa. Kamusoko and Musasa (2012), obtained the highest phosphate level of 2.74 mg/l which is higher than that of our study. The standard limits set by DWAF (1999), and DSW (2017) for the discharge of wastewater is 12.5 mg/l which is higher than the phosphate levels obtained in our study. Similarly, EPAI (2001) have set standard limits of 0.02 – 0.07 mg/l, which correlates with our study. The phosphate levels of our study are comparable to those of EPAI (2001) and are in conformity to the set standard limits. As a result, the phosphate levels within the water pose no danger to the environment, river water quality and aquatic lives.

Nitrates concentration is usually attributed to the increasing of fertilization processes from agricultural practices and sewage (Georgieva *et al.,* 2018). In our study, nitrates values ranged from 0.394 - 2.52 mg/l, with the highest value (2.52 mg/l) detected in autumn season, while lowest value (0.394 mg/l) detected in spring season (Figure 4.1**f**). The high value of nitrates in autumn season might be due to agricultural practices from nearby areas producing wastewater containing a lot of fertilizers, and other activities such as industrial wastes together with human wastes that are disposed in domestically wastewater. Mothetha (2016) revealed excessive levels of nitrates in water that are attributed to human activities such as agricultural activities, human waste, and industrial pollution that is similar to our study. However, the lower value of nitrates in spring season could be attributed to the dilution of sewage water due to rain, since spring is a season approaching summer during rainy season in South Africa. The average value of all 4 seasons was obtained as 1.354 mg/l (appendix 1). These values were below the South African standards (15 mg/l) set by DWAF (1999) and DWS (2017) for the discharge of wastewater to the environment. The values of nitrate in our study were lower than standard limits set of 50 mg/l and 10 mg/l as described by EPAI (2001) and Gadhia *et al.*, 2012 for nitrates in wastewater. Again, this parameter is not a potential threat to the water environment and society.

In this study, we obtained identical values of 0.002 mg/l for Cu, Zn and Cd in all four seasons. However, Pb value was obtained at 0.004 mg/l in all four seasons (Figure 4.2**a**). The values of Cu were lower than the standard limit of 0.01mg/l set by DWA (1999) for the discharge of wastewater. The standard limits of 0.1 – 1 mg/l and 0.25 mg/l as labelled by EPAI (2001), Levi and CO (2007) respectively were higher than the values obtained in this study. The values of Zn were lower than the standard limit of 0.1 mg/l as set by DWAF (1999). Similarly, the values in our study for Zn were lower than the standard limits of 0.30

and 1.0 mg/l as described by EPAI (2001), Levi and CO (2007). However, the values of Cd were lower than the standard limits of 0.005 and 0.01 mg/l as set by DWA (1999), Levi and CO (2007), as compared to our study for the discharge of wastewater. Also, the values of Pb in our study were lower than the standard limit of 0.01 mg/l as set by DWA (1999). Similarly, the Pb values of the present study are lower than the standard limits of 0.05 and 0.10 mg/l as described by EPAI (2001), Levi and CO (2007) for the discharge of wastewater to the environment. Thus, the parameters Cu, Zn, Cd and Pb values correspond to standard limits of DWAF (1999), Levi and CO (2007).

Overall, the detection of metal ions in constant value might imply that there are not too many metals that are brought into the river water because of sewage water overflow, other than the natural ions found in the river water. Furthermore, even though metal ions are brought into the river water as result of sewage water overflow, they quickly settle down into the sediments, which makes it difficult for them to be detected in the river water. Although, the values of heavy metals in this study were detected in lower limits, they pose a threat to living organisms. Heavy metals are toxic even at very low concentrations and cause a serious threat to human health and aquatic living organisms (Akpor *et al.,* 2014). Furthermore, once heavy metals accumulate in sewage water, they degrade like any other pollutants and accumulate in the food chain, which results in ecological disturbances and results in human health risks (Kaushal and Singh, 2017). Therefore, the detection of metal ions in the river water samples could mean that human health is in danger if they are to catch and eat fish from Zandspruit. Similarly, metals ions could be transferred through by using the water from Zandspruit for irrigation of vegetables, where humans end up eating them. Then, metals are then transferred through the food chain.

In the present study, we found that the turbidity mean ranged from 36.003 - 311.667 NTU, with the lowest value (36.003 NTU) detected in Autumn season and the highest value (311.667 NTU) detected in summer season (Figure 4.2**b**). The average mean value for turbidity was 119.303 NTU in all four seasons (Appendix 1) and this value is above the standards limits of 10 NTU as described by Gadhia *et al.,* (2012). Therefore, this parameter is posing a threat to aquatic living organisms. The Pristine Spruit river flow rate was low during sample collections and the lowest value of turbidity in autumn season could be because of no rain that caused flooding and the re-suspension of deposited of sediments. While the high turbidity value during summer season could be due to high flow rate in the river, resulting to re-suspension of deposited sediments. Storm water from rain and particles carried by wind might also play a huge role in the increasement of turbidity during summer season. Seng *et al.,* (2018) and his colleagues recorded a high value of turbidity in their research. The values detected from polluted river water ranged from 11 – 60 NTU. Similarly, Edokpayi *et al*., (2018), reported high values of turbidity ranging from 1.12 - 739.9 NTU. The turbidity values in our study concur with Seng *et al.,* (2018) and Edokpayi *et al.,* (2018), however, the high value turbidity usually poses a threat to aquatic organisms.

Like turbidity, COD values of the present study were above set standards. COD values ranging from 184.3 – 335.67 mg/l with the highest value of 335.67mg/l were detected in spring season. While the lowest value of 184.3 mg/l was observed in summer season (Figure 4.2**c**). The average value of COD was observed as 244.73 mg/l in all four seasons (appendix 1) which is found to be higher than the permissible limits for the discharge of wastewater to the environment as described by DWS (2017), EPAI (2001), DWAF (1999). High turbidity and COD can be because of organic matter from sewage discharges into the river through runoffs, water treatment outfalls which are in proximity and industrial effluents. Furthermore, death of bacteria cells can also cause an increase of turbidity and COD, as the cells decompose, organic carbon is released which in turn increases the amount of turbidity and COD (Gqomfa *et al.,* 2022). Similarly, the high concentration of turbidity and COD in the present study is because of organic matter and decomposition of bacteria cells from sewage water overflowing into the river. Therefore, the COD and turbidity concentrations detected in our study pose a threat within the aquatic environment.

The concentration of *E. coli* for the study ranged from 68600 - 100000 cfu/100 ml. The *E. coli* of (68600 cfu/100ml) was detected in autumn season, while the highest value (100000 cfu/100 ml) was detected in summer season, and the average mean concentration observed was 244.732 cfu/ml (Figure 4.2**d**). These values were found to be higher than South African and European, standard limits of 1000 cfu/100ml for the discharged of wastewater into the environment as described by DWS, (2017) and EPAI (2001). Naidoo and Olaniran (2014) demonstrated that the concentration of *E. coli* should be zero cfu/100ml at any point. These results concur with Van der Hoven *et al.,* 2017 in Zandspruit river where *E.coli* was found to be above set standards. Overall, the presents of *E. coli* in high concentration are an indication that water is highly polluted by sewage water. Thus, the concentration of *E. coli* as detected in the present study, poses a danger to the environment, river water quality and human healthy if they physically contact these waters polluted by sewage. Woldetsadik *et al.,* (2017) indicated that wastewater originating from households are the key sources of *E. coli* contamination. This is similar to our findings that was found within the community of Cosmo city where *E. coli* was detected in water of the Pristine Spruit stream water.

5.3 Questionnaire survey discussions

The results of the survey are discussed to reveal the overall perceptions of Cosmo City community towards the implications of sewage water overflows. This includes the perceptions towards causes, sources, longevity of sewage water overflow, impacts, management, and minimization of sewage water overflows (Appendix 2).

5.3.1 Biographic information

A total of 250 participants responded to the questionnaire survey. Many respondents who participated in the survey were males than female respondents. More than half (140) of the respondents were married, while 108 were single (Appendix 2). It was found that most respondents were formally employed, and running their own business (self-employed), while few respondents were not employed. We also discovered that most respondents were educated and only fewer were uneducated. It was important to determine the household size number to understand the pressure placed on their sewage system. Also, it was discovered that the household number ranged from 3 – 6 members. Somehow, the number of members in a family will bound to affect water usage and sewage system, which will ultimately result in high volume of disposable waste such as newspapers, cans, and plastic containers etc, that can block sewer drains and cause sewage water overflows (Mphaka, 2015).

5.3.2 Perceptions of the community towards causes of sewage overflow.

The findings in our study regarding the causes of sewage overflow revealed that most respondents have a perception that population growth is the major cause of sewage water overflows around the area of Cosmo City, (Appendix 2). Some respondents indicated that blockage and broken sewers, poor sanitation and natural causes contribute to sewage water overflows. Only few of the respondents have no idea of what the causes of sewage water overflow are. The findings in this study correspond with what was stated as the main causes of sewage water overflows by NRMMC (2004) in Australia.

5.3.3 Perceptions of the community towards sources of sewage water

Our results pertaining the perceptions of the community towards sources of sewage water, reveal that sewage water overflow is from domestic use, industrial use, agricultural use, and commercial use are the main sources of sewage water overflows in Cosmo City, (Figure 4.3

e). However, domestic use was found to be the highest contributor of sewage overflows in Cosmo City than all other sources. Interestingly, few respondents don't know the sources of sewage water overflow. Similarly, Borisova *et al.,* (2013) identified industrial, agricultural uses and runoff from homes are the great contributor of sewage water overflows that pollute streams, rivers, and lakes in urban areas.

5.3.4 Perceptions of the community towards longevity of sewage water overflow

We also found that sewage water overflow has been existing for more than 5 years in Cosmo City. Surprisingly, few respondents don't know the longevity of sewage overflow occurring in their area (Figure 4.3 **f**). NRMMC (2004) portrayed that sewage water overflows should be reduced to an exceptional frequency that is acceptable to the community. In that context, sewage water overflows should have a temporal existence within the community.

5.4.5 Perceptions of the community towards impacts of sewage water overflow.

The results have shown that sewage water overflows were negatively impacting the environment, the quality of water in rivers, human health, and the economy. Most respondents indicated that sewage water overflows impacted the environment in such a way that water bodies were polluted and degraded. Respondents also indicated that sewage overflows create bad smell and caused illnesses in their environment (Figures 4.4 **a,b,c,** and **d**). The community of Cosmo city had the perception that sewage water overflowing around their area is negatively affecting their lives and environment. Mbonambi (2016) in KwaZulu-Natal, revealed that sewage water overflow negatively affects the environment and impacts the health of the residents. Also, Gqomfa *et al.* (2022) indicated that water bodies that are extremely polluted by sewage water overflows are associated with diseases that are a threat to human's health.

5.3.6 Perceptions of the community on action taken towards management and minimization of sewage water overflows.

There are various management techniques that people could take when they see sewage water overflowing around their area of residents (Tafuri and Field, 2010). Management actions can be taken to minimize sewage water overflows, and respondents had different perceptions towards sewage water overflows. Most respondents indicated that the good way to manage sewage overflows within their community was to contact the local municipality or a licensed plumber. While some respondents responded that they ask their neighbours to investigate the issue. Interestingly, few respondents don't know what to do when encounter sewage overflows on their community (Figure 4.4 **e, f,** and **g**). Overall, the results showed that people in Cosmo City request the municipality for assistant to eradicate sewage water overflows in their area.

In this study, the respondents had perceptions that sewer capacity is too small to carry all the sewage produced in their area and must be increased. They mentioned that the sewage system is deteriorating, should be upgraded, and must have routine inspections. Many of the respondents responded that the education campaign introduction to the community and the routine inspections of the sewer infrastructure, will be the best ways to manage sewage overflows within the community. Amongst all solutions of managing and minimization of sewage water overflows, the community of Cosmo City suggested education campaigns and the increasing of sewer system capacity is the best way to manage the sewage overflows. Few respondents have shown that sewage water overflows should be allowed to flow directly into streams without any form of treatment (Figure 4.4 **g**). Education campaigns have been recommended as the best strategies used to provide knowledge and information about water quality issues within a particular community in the past (Christopher *et al.,* 2019).

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

Most of the water quality parameters were found to be within the permissible standard limits with COD, *E. coli* and turbidity being the only parameters found to be above the permissible set standards. The detection of COD, *E. coli* and turbidity above set standards is an indication that the river water is highly polluted. Overall, the detection of metal ions in constant value might imply that there are not too many metals that are brought into the river water because of sewage water overflow, other than the natural ions found in the river water. Furthermore, even though metal ions could be brought into the river water as result of sewage water overflow, they quickly settle down into the sediments, which makes it difficult for them to be detected in the river water. Therefore, future studies should include the measurements of metal ions in the sediments of Zandspruit river. Although the levels of Physico-chemical parameters were mostly found to be in compliant with the permissible standard limits, there is a need to monitor the impacts of sewage water overflows in accordance with the set standards to ensure any abnormalities. Measures should be put in place to reduce the levels of water contamination from sewage overflows. These measures may include design containment methods which confine sewage water overflows as well as exploring new methods in environmental engineering. The introduction of education campaigns or awareness should be implemented to the community to indicate how sewage water overflows can be minimized. Further studies should include the monitoring and assessment of sewage water overflows in Cosmo City to identify possible ways or measures to deal with any negative impacts that arise because of sewage water overflows. The data gathered in this study will assist the Johannesburg water and Department of water and sanitation to manage and take appropriate actions over a prolonged sewage water overflows in Cosmo city.

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APPENDICES:

APPENDIX 1. Seasonal and Yearly average mean values of physico-chemical parameters investigated for four seasons from Prestine Spruit stream a tributary of Zandspruit River.

Parameter	**Autumn**	**Winter**	**Spring**	**Summer**	**Average**	**Standard Dev**
pH	8,08	7,66	7,87	7,74	7,838	0,183
Temperature(℃)	21,63	20,27	20,3	22,27	21,118	0,996
EC (mS/m)	73,9	61,3	70,6	37,9	60,925	16,251
TDS (mg/l)	480,35	398,45	458,95	246,35	396,013	105,639
PO_4^{3-} (mg/l)	1,86	0,844	2,34	0,667	1,428	0,804
NO_3^- (mg/l)	2,52	1,812	0,394	0,69	1,354	0,989
Cu (mg/l)	0,002	0,002	0,002	0,002	0,002	0
Zn (mg/l)	0,002	0,002	0,002	0,002	0,002	0
Cd (mg/l)	0,002	0,002	0,002	0,002	0,002	0
Pb (mg/l)	0,004	0,004	0,004	0,004	0,004	0
E. coli (cfu/100ml)	68600	67166.67	71000	100000	76691,67	17477,223
Turbidity (NTU)	36,003	75,71	53,833	311,667	119,303	129,266
COD (mg/l)	222,53	236,43	335,666	184,3	244,732	64,505

APPENDIX 2. Frequency Table showing participants Survey results in Cosmo City.

Gender	**N**	**%**
Male	166	66.4%
Female	84	33.6%
Marital Status	**N**	**%**
Married	140	56.0%
Single	108	43.2%
Divorced	2	0.8%
Employment Status	**N**	**%**
Employed	136	54.4%
Unemployed	103	41.2%
Self employed	11	4.4%
Educational Status	**N**	**%**
No schooling	11	4.4%
Primary school	18	7.2%
Secondary school	104	41.6%
TVET College qualification	43	17.2%
University/Technicon degree	53	21.2%
Tertiary post graduate qualification	21	8.4%
Household Size	**N**	**%**
1-3	102	40.8%
4-6	128	51.2%
7 and above	20	8.0%
Longevity of Stay	**N**	**%**
0-6 Months	11	4.4%
6-12 Months	8	3.2%
1-2 Years	19	7.6%
3-4 Years	29	11.6%
5Years and above	183	73.2%
Causes of Sewage Overflow	**N**	**%**
Population and industrial growth	123	49.2%
Broken/blockage of sewer systems	61	24.4%
Poor sanitation	35	14.0%
Natural causes	20	8.0%
Don't know	9	3.6%
Missing	2	0.8%
Sources of Sewage Overflow	**N**	**%**
Wastewater from domestic uses	160	64.0%
Wastewater from industrial uses	25	10.0%
Wastewater from agricultural uses	22	8.8%

Wastewater from commercial uses	30	12.0%
All the above	13	5.2%
Wastewater from domestic uses	160	64.0%
Longevity of Sewage Overflow	**N**	**%**
At least one year	29	11.6%
2 Years	22	8.8%
3 Years	30	12.0%
4 Years	27	10.8%
5 Years and Above	133	53.2%
Don't know	9	3.6%
Environmental Impacts of Sewage Overflow	**N**	**%**
Degradation of water bodies	63	25.2%
Surface and ground water pollution	57	22.8%
Air pollution	55	22.0%
Soil pollution	24	9.6%
Soil erosion	33	13.2%
Don't know	18	7.2%
River Water Quality Impacts of Sewage Overflow	**N**	**%**
Eutrophication	34	13.6%
Physical change to the state of water	71	28.4%
Increased nutrients into the water bodies	23	9.2%
Brings more waste into the river water	69	27.6%
Death to aquatic organisms	36	14.4%
Don't know	17	6.8%
Human health impacts of Sewage Overflow	**N**	**%**
Bad smell	164	65.6%
Illnesses	62	24.8%
Deaths	21	8.4%
Don't know	3	1.2%
Economic impacts of Sewage Overflow	**N**	**%**
Increased wastewater treatment cost	81	32.4%
Decreased value of properties	66	26.4%
Lower industry production	16	6.4%
Damage properties	71	28.4%
Loss of Jobs	12	4.8%
Don't know	4	1.6%
Action taken towards management of Sewage Overflow	**N**	**%**
Contact a licensed plumber to investigate the situation	38	15.2%
Contact local municipality service centre to investigate the situation	160	64.0%
Investigate the matter yourself and fix it	7	2.8%
Call my neighbour to assist in fixing the problem	12	4.8%
Do nothing	33	13.2%

Management of Sewage Overflow	**N**	**%**
By increasing the sewer system capacity	154	61.6%
By upgrading the deteriorating sewer infrastructure	36	14.4%
By allowing sewage to overflow on the surface into streams	8	3.2%
By introducing education campaigns to residents about sewage water overflows	154	61.6%
Don't know	21	8.4%
Minimization of Sewage Overflow	**N**	**%**
By introducing education campaigns to residents about sewage water overflows	154	61.6%
Government/Municipality should upgrade the drainage systems	36	14.4%
Repairing and replacing the damaged sewer equipment	8	3.2%
Routine inspections and proactive operation of the sewer system	31	12.4%
Don't know	21	8.4%

APPENDIX A: Permission letter to conduct research in Cosmo City for Johannesburg Health District

GAUTENG PROVINCE
HEALTH
REPUBLIC OF SOUTH AFRICA

Joburg
a world class African city

JOHANNESBURG HEALTH DISTRICT

Enquiries: Dr EM Ohaju
Tel: 011 694 3888 Cell: 076 8831659
Email: Elizabeth.Ohaju@gauteng.gov.za

Hillbrow CHC: Administration Building
Cr Smith Str. & Klein Street
Private Bag X21, Johannesburg
South Africa, 2017

UNISA
University of South Africa
Johannesburg, South Africa
tc.mavhungu@gmail.com

DRC Ref: 2019-03-001

NHRD Ref no: GP_201903_001

Dear: Mr Tendani Charles Mavhungu

TITLE*: The environmental implications of Sewage Water Overflow: A Case Study of Cosmo City, Johannesburg, South Africa.*

Your application for research approval refers.

The District Research Committee has reviewed your application. This letter serves as an in-principle approval to access the Districts Health facilities (mentioned below) for the above project subject to following conditions:

- The facility to be visited: CITY OF JOHANNESBURG METROPOLITAN MUNICIPALITY OFFICES
- This facility will be visited from **01/07/2019 to 01/07/2020**
- The research can only commence after you submit an ethics clearance certificate from a recognized institution.
- You will report to the Facility Manager before initiating the study.

Region	Regional Health Manager	Contact No.	Cell phone
L A	Peter Manganye	011 407 6545	082 461 8273

The following conditions must be observed:

- Participants' rights and confidentiality will be maintained all the time.
- No resources (Financial, material and human resources) from the above facilities will be used for the study. Neither the District nor the facility will incur any additional cost for this study.
- The study will comply with **Publicly Financed Research and Development Act, 2008 (Act 51 of 2008) and its related Regulations**.

- You will submit a copy (electronic and hard copy) of your final report. In addition, you will submit a six-monthly progress report to the District Research Committee.
- Your supervisor and University of South Africa will ensure that these reports are being submitted timeously to the District Research Committee.
- The District must be acknowledged in all the reports/publications generated from the research and a copy of these reports/publications must be submitted to the District Research Committee.

We reserve our right to withdraw our approval, if you breach any of the conditions mentioned above.

Please feel free to contact us, if you have any further queries. On behalf of the District Research Committee, we would like to thank you for choosing our District to conduct such an important study.

Regards,

Dr E.M Ohaju
Chairperson: District Research Committee
Johannesburg Health District
Date 1/07/2019

Mrs M.L Morewane
Chief Director
Johannesburg Health District
Date: 01/07/2019

Dr R Bismilla
Executive Director
Johannesburg Health District
Date: 9/7/19.

APPENDIX B: Ethics Approval by UNISA to conduct research project.

UNISA university of south africa

CAES HEALTH RESEARCH ETHICS COMMITTEE

Date: 18/02/2019

Dear Mr Mavhungu

Decision: Ethics Approval from 14/02/2019 to 28/02/2020

NHREC Registration # : REC-170616-051
REC Reference # : 2019/CAES/019
Name : Mr TC Mavhungu
Student #: 64064271

Researcher(s): Mr TC Mavhungu
64064271@mylife.unisa.ac.za

Supervisor (s): Ms LT Mankga
mankglt@unisa.ac.za; 011-471-3604

Dr K Yessoufou
kowiyouy@uj.ac.za; 011-559-2434

Working title of research:

The environmental implications of sewage water overflow: A case study of Cosmo City, Johannesburg, South Africa

Qualification: MSc Life Science

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

Due date for progress report: 28 February 2020

Please note the points below for further action:

1. The committee notes the researcher's undertaking to obtain permission from Cosmo City and Johannesburg Water. This must be obtained and submitted to the committee before data gathering may commence.
2. The researcher indicates that samples will be collected in triplicate – what is meant by this? Does it mean that three samples will be collected at the same place and time?

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How many sample points will there be in total? The researcher indicates that samples will be taken over a period of twelve months. How regularly will samples be taken at each sampling point? Will seasonal fluctuation be taken into account?

3. Will the researcher identify areas where sewage overflow is entering the river? Will samples be taken in any such areas? For instance, the community may be able to point out areas where overflow historically occur on a regular basis. The researcher should consider a pilot study to identify such areas of concern and to ensure these are included in the sampling points.
4. The description of the statistical analysis that will be applied is vague and more detail is required. The researcher should provide detail on the variables and the type of matrix that will be used. Furthermore, what is the motivation for the use of ANOVA? Which version of ANOVA will be used? Furthermore, there is no indication in the analysis section how the comparison with the standards will be done.

*The **minimal risk application** was **reviewed** by the CAES Health Research Ethics Committee on 14 February 2019 in compliance with the Unisa Policy on Research Ethics and the Standard Operating Procedure on Research Ethics Risk Assessment.*

The proposed research may now commence with the provisions that:

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

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research. Secondary use of identifiable human research data require additional ethics clearance.

7. No field work activities may continue after the expiry date. Submission of a completed research ethics progress report will constitute an application for renewal of Ethics Research Committee approval.

Note:

The reference number ***2019/CAES/019*** *should be clearly indicated on all forms of communication with the intended research participants, as well as with the Committee.*

Yours sincerely,

Prof EL Kempen
Chair of CAES Health REC
E-mail: kempeel@unisa.ac.za
Tel: (011) 471-2241

Prof MJ Linington
Executive Dean : CAES
E-mail: lininmj@unisa.ac.za
Tel: (011) 471-3806

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APPENDIX C: Consent form to participate in the study.

CONSENT FORM

Ethics clearance reference number: *2019/CAES/019*

DATE: 29/01/2019

Title of Research Project: The environmental implications of Sewage Water Overflow: A Case Study of Cosmo City, Johannesburg, South Africa.

Dear Prospective Participant

My name is Tendani Charles Mavhungu and I am doing research with Dr. LT Mankga, senior lecturer at the Department of Life and Consumer Sciences. I have registerd a Masters of Life Sciences degree at the University of South Africa.

THE PURPOSE OF THE STUDY

The aim of this research is to investigate the of sewage water overflow into Zandspruit River water quality. Through publication, the study will reveal to the public the impact of sewage water overflow, highlighting the awareness to the public about the negative impacts arising because of sewage water overflow. The study will increase knowledge to the society as to what extent can sewage water overflow impact the environment, and what to do when such issues arise. Furthermore, the research will benefit to the public on what measures could be taken to minimize the impacts of sewage water overflow. The findings will lay a foundation for future research in the field of sewage water overflow and their implications.

WHY BEING AM I INVITED TO PARTICIPATE?

The study involves collection of water samples from Zandspruit River and Watercombe Dam of which all falls within Cosmo City primes as well as establishing the perceptions of the Cosmo City community towards sewage water overflows. The aim of the study is to investigate the characteristics and impacts of sewage water into Zandspruit River as well as the causes of sewage water overflows in Cosmo City. Thus, Cosmo City community are invited to participate since the study will be carried out within their area of residence/management.

WHAT IS THE NATURE OF MY PARTICIPATION IN THIS STUDY?

The researcher requests a consent from Cosmo City ward councilor and selected community members to give the views and attitudes towards the sewage water overflows i.e. causes and, impacts of sewage water overflow and how sewage water overflows can be managed. Participation of the community will be through answering questions provided by the researcher on a questionnaire survey format. The researcher will also require assistance from the ward councilor and community when identifying areas where sewage overflows are more occurring around Cosmo City. This will aid the researcher to collect water samples from a good representative sampling sites around Cosmo City area. The researcher will also be assisted by Aquatico Laboratories (Pty). Ltd. technician and supervisor during sample collection. The samples will be collected for the period of 12 months, potential stating from February 2019 to January 2020. You are encouraged to ask question or raise concerns at any time about the nature of the study or the methods I am using.

CAN I WITHDRAW FROM THIS STUDY EVEN AFTER HAVING AGREED TO PARTICIPATE?

The researcher will proceed with study immediately after receiving a consent from Como City ward councilor and selected community members. Any information that might be provided by the municipality ward councilor and selected community members will be treated with strict confidentiality. The data will only be used for the intended study. The information supplied will be only available to my supervisor and Unisa Ethics committee. Once the study is completed, the dissertation may be read by future students. The study may be published in a journal. You can withdraw from the research project at your own discretion and signing this document does not put you in any contract or whatsoever with the researcher or UNISA and this is not a legal document. This research project will be guided by the UNISA Research Ethical Procedures.

WHAT ARE THE POTENTIAL BENEFITS OF TAKING PART IN THIS STUDY?

Through publication, the study will reveal to the public the impact of sewage water overflow, highlighting the awareness to the public about the negative impacts arising because of sewage water overflow. The study will increase knowledge to the society as to what extent can sewage water overflow impact the environment, and what to do when such issues arise. Furthermore, the research will benefit to the public on what measures could be taken to minimize the impacts of sewage water overflow. The findings will lay a foundation for future research in the field of sewage water overflow and their implications.

WILL THE INFORMATION THAT I CONVEY TO THE RESEARCHER AND MY IDENTITY BE KEPT CONFIDENTIAL?

The researcher guarantees the participants that the information they will provide in this study will be for research purposes and possible publication in scientific journals. Issues with regards to confidentiality and privacy to participants and data will always be observed during the study and publication process. Furthermore, neither the researcher nor the University will be responsible for a participant who provides information that harms the reputation of their company/themselves.

HOW WILL THE RESEARCHER(S) PROTECT THE SECURITY OF DATA?

Any information provided in hard copies by the participant will be stored by the researcher or supervisor in a looked cupboard while electronic information will be stored on a password protected computer. Future use of the stored data will be subject to further Research Ethics Review and approval if applicable. Hard copies will be shredded, and/or electronic copies will be permanently deleted from the hard drive of the computer using a relevant software programme once it's used for this study.

WILL I RECEIVE PAYMENT OR ANY INCENTIVES FOR PARTICIPATING IN THIS STUDY?

There will be no payment or reward incurred by the participant during the period of this study.

HAS THE STUDY RECEIVED ETHICS APPROVAL?

This study has received approval from the Unisa Research Ethics Review Committee. A copy of the approval letter can be obtained from the researcher/ supervisor if you so wish.

HOW WILL I BE INFORMED OF THE FINDINGS/RESULTS OF THE RESEARCH?

Should you have concerns about the study, you may contact Dr LT Mankga, at the Department of Life and Consumer Sciences, Florida Campus, UNISA. Tel: +27 11 471 3604|Fax: +27 11 471 2796, email: mankglt@unisa.ac.za

Thank you for taking time to read this information sheet and for participating in this study.

Thank you.

signature: __________

Tendani Charles Mavhungu

LETTER OF CONSET TO PARTICIPATE IN THE RESEARCH PROJECT

Dear Sir/Madam

I, Tendani Charles am doing research with Dr LT Mankga, a lecturer in the Department of Life and Consumer Sciences towards a Master degree of Life Sciences at the University of South Africa. We are inviting you to participate in a study entitled: **The environmental implications of Sewage Water Overflow: A Case Study of Cosmo City, Johannesburg, South Africa**.

Your participation in this research will be highly appreciated, the information you provide shall be kept confidential and no participant shall be held responsible for any information provided. You can withdraw from the research project at your own discretion and signing this document does not put you in any contract or whatsoever with the researcher or UNISA and this is not a legal document. This research project will be guided by the UNISA Research Ethical Procedures.

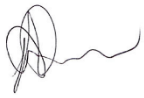
You give your consent by signing this document, for the researcher to use the information you provided, only for academic purposes related to this Thesis with the title: **The environmental implications of Sewage Water Overflow: A Case Study of Cosmo City, Johannesburg, South Africa**. Any misinterpretation or any damages for this information by the researcher is not your responsibility or liability.

The aim of the study is to investigate the impacts of sewage water overflow into Zandspruit River water quality and to investigate the main physico-chemical parameters of sewage water from Zandspruit River, as well as establishing the perceptions of Cosmo City Community towards sewage water overflows. You have been selected because the study will take place within your area of residence/management.

Participant signature: ……………………………………………….

Date: ……………………………………………...

Yours sincerely

signature: 

Tendani Charles Mavhungu
Student at UNISA

CONSENT TO PARTICIPATE IN THIS STUDY

I, __________________, confirm that the person asking my consent to take part in this research has told me about the nature, procedure, potential benefits and anticipated inconvenience of participation.

I have read (or had explained to me) and understood the study as explained in the information sheet.

I have had enough opportunity to ask questions and am prepared to participate in the study.

I understand that my participation is voluntary and that I am free to withdraw at any time without penalty (if applicable).

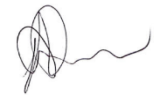
I am aware that the findings of this study will be processed into a research report, journal publications and/or conference proceedings, but that my participation will be kept confidential unless otherwise specified.

I have received a signed copy of the informed consent agreement.

Participant Name & Surname…………………………………………

Participant Signature……………………………………………Date…………………

Researcher's Name & Surname: Tendani Charles Mavhungu

Researcher's signature: …………………… Date: ………………………

APPENDIX D: Survey Questionnaire

Questionnaire to the community of Cosmo City

The environmental implications of Sewage Water Overflow: A Case Study of Cosmo City, Johannesburg, South Africa.

Student Name: Tendani Charles Mavhungu

Dear Valued Respondent,

This questionnaire survey is for educational purposes only and all responses will remain anonymous. May you please take few minutes of your valuable time and answer the questions below to the best of your knowledge. Sign the consent form attached to this questionnaire as proof that you are voluntarily taking part in this study. Indicate your possible responses provided by ticking on the boxes and or writing in the spaces provided where appropriate. NB: You may choose more than one on the answers provided on each specific question.

A. Demographic information

1) Where do you stay in Cosmo City? (tick the correct option)

Ext 0	**Ext 2**	**Ext 3**	**Ext 4**	**Ext 5**
Ext 6	**Ext 7**	**Ext 8**	**Ext 9**	**Ext 10**

Gender:

a) Male
b) Female

Marital Status:

a) Married
b) Single
c) Divorced

2) Are you the ward councilor? | Yes | No |

B. Employment Status

Kindly state your employment status:

a) Employed
b) Unemployed
c) Self-employment
d) Other:
Specify…………………………………………………………………………….

C. Education Status

a) No schooling ☐
b) Primary school ☐
c) Secondary school ☐
d) TVET College school ☐
e) University/Technicon ☐
f) Tertiary post graduate qualification ☐
g) Other
specify…………………………………………………………………………………

D. Socio-Economic Variables

1) Household size:

a) 1-3 ☐
b) 4-6 ☐
c) 7 and above ☐

2) How long have you been living in this area?

a) 0-6 months ☐
b) 6-12 months ☐
c) 1-2 years ☐
d) 3-4 years ☐
e) 5years and above ☐

E. To document the perceptions of Cosmo City Community towards causes of sewage water overflow.

1) What do you think are the causes of sewage water overflow in your area?

a. Population and Industrial growth ☐
b. Broken/Blockage of the sewer systems. ☐
c. Poor sanitation in neighborhood ☐
d. Natural causes (i.e., flooding during rainy season) ☐
e I don't know. ☐
f. Other specify……………………………………………………………

2) Where do you think sewage water overflows are coming from around your area?

a. Sewage wastewater from domestic uses ☐
b. Sewage is wastewater from industrial uses. ☐
c. Sewage is wastewater from agricultural uses. ☐
d. Sewage is wastewater from commercial uses. ☐
e. All the above ☐
f. I don't know. ☐
g. Other specify………………………………………………………….

3) For how long have sewage water overflows been occurring in your area?

a. At least one year
b. 2 years
c. 3 years
d. 4 years
e. 5 years and above
f. I can’t remember.

F. <u>To verify the perceptions of Cosmo City Community towards the impacts of sewage water overflow.</u>

1) What do you think are the impacts brought by sewage water overflow on the?

a) Environment

a) Degradation of water bodies

b) Surface and ground water pollution
c) Air pollution
d) Soil pollution
e) Soil erosion
f) I don’t know.
g) Other specify…………………………………………………………………………

b) River water quality

a) Eutrophication
b) Physical change to the state of water
c) Increased nutrients into the water
d) Brings more waste into the river water.
e) Death to aquatic organisms
f) I don’t know.
g) Other specify…………………………………………………………………………

c) Human Health

a) Bad smell
b) Illnesses
c) Deaths
d) I don’t know.
e) Other specify………………………………………………………………………

d) Economy

a) Increased wastewater treatment cost
b) Decreased value of properties
c) Lower industry production
d) Damage properties i.e., roads and pipes due to corrosion
e) Loss of jobs
f) I don't know.
g) Other
specify………………………………………………………….................................

G. <u>To verify the perceptions of Cosmo City Community towards the management of sewage water overflow.</u>

1) What action do you take when you see sewage water overflowing in your area?

a) Contact a licensed plumber to investigate the situation.
b) Contact local municipality Service Centre to investigate the situation.
c) Investigate the matter yourself and fix it.
d) Call my neighbour to assist in fixing the problem caused by sewage overflow.
e) Nothing
f) Other:
Specify……………………………...

2) In your opinion, how do you think sewage water overflow can be managed?

a. By increasing the sewer system capacity
b. By upgrading the deteriorating sewer infrastructure
c. By allowing sewage to overflow on the surface into streams
d. By introducing education campaigns to residents about sewage water overflows
e. I don't know.
f. Other
Specify………………………………………………………………….................

3) How do you think sewage water overflow can be prevented or minimized in your area?

a. By introducing education campaigns to residents about sewage water overflows
b. Government /Municipality should upgrade the drainage systems.
c. Repairing and replacing the damaged sewer equipment
d. Routine inspections and proactive operation of the sewer
e. I don't know.
f. Other
specify……………………………………………………………………………