THE IMPACT OF INFORMAL SETTLEMENT ON WATER QUALITY OF DIEP RIVER IN DUNOON

by

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DECLARATION

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

Signed **Date**

ABSTRACT

More than 80% of the world's largely untreated wastewater is dumped into the environment and water bodies such as rivers and lakes. Unfortunately, many governments have been struggling to meet the increasing water demands due to rapid population growth in urban areas. One major problem has been poor sanitation and poor waste disposal practices in informal settlements, which led to the contamination of water resources. This research aimed to investigate the impact of the Dunoon informal settlement on the water quality of the Diep River in South Africa. It also demonstrates the health and environmental risks associated with poor sanitation and the use and consumption of contaminated water in the Dunoon informal settlement and seeks ways to mitigate such risks. The research used both qualitative and quantitative methods.

The Diep River is used daily, mainly for farming and recreational activities. For this research, monthly water samples were collected from four strategic points of the river and sent to a laboratory to determine the concentration levels of water quality-related parameters inclusive of nitrate, phosphates, chemical oxygen demand, total suspended solids, dissolved oxygen, ammonia, and *E. coli*. On some occasions, the pH, dissolved oxygen, electrical conductivity, turbidity, salinity, and temperature were measured on the field using a multi-parameter reader. The results were compared with the South African water quality guidelines for aquatic ecosystems, recreation, and agriculture, and South African National Standards. Raw data of samples collected by Outa (Organization Undoing Tax Abuse) was also analysed using SPSS, and compared to the researcher's findings.

The average concentrations of *E. coli*, DO, electrical conductivity, salinity, ammonia, turbidity, and chemical oxygen demand exceeded the recommended limits in both the wet and dry seasons. The recommended limit for *E. coli* is 0 cfu/100 mL for irrigation and 0-130 cfu/100 mL for recreation purposes, but the average highest *E.coli* count was 1436.3 cfu/100 mL in the wet season and 11737.5 cfu/100 mL in the dry season, which was way above the recommended limits. The average COD in the wet season was 250.5 mg/L and 186.8 mg/L in the dry season, higher than the recommended limit of ≤ 75 mg/L. The EC averages in the wet season (2453.3 µS/cm) and the dry season (32208 µS/cm) were both higher than the recommended limit of 0 – 40 mS/m, equivalent to 0 - 400 µS/cm, while the turbidity averages in the wet season (60.18 FNU) and the dry season (257.04 FNU) were also greater than the acceptable limits of 3 NTU for recreational purposes and 0-1 NTU for domestic purposes (where NTU is equivalent to FNU). The average ammonia in the wet season was 9.2 mg/L and 6.1 mg/L in the dry season. The averages in both the wet and dry seasons were higher than the recommended limit of ≤1.5 mg/L. The findings also revealed that the Dunoon informal settlement has contributed to the decline of water quality in the Diep River because of inadequate waste collection sanitation and other activities.

Questionnaires and observations were also used to collect data from the residents of Dunoon informal settlement and the data was also analysed using SPSS. The findings revealed that the community perceived Diep River water as polluted, and this has compromised the health of the Dunoon informal settlement residents and degraded the environment as per their responses. Given these findings, some of the recommendations are to frequently monitor and manage waste products discharged into the neighbouring aquatic environments. The lack of knowledge about legislation and water resources management amongst communities needs to be addressed through educational programs and various media platforms. Microbial, parasitic, and virus-related diseases have been spreading because of contaminated water and poor processes in the Dunoon informal settlement. Most of the community members in the Dunoon informal settlement have indicated that they suffer from skin-related diseases, diarrhoea, cholera, and other diseases due to poor sanitation and inadequate waste collection.

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DEDICATION

I would also like to dedicate this dissertation to my late mother Lulama Patience Beja and my late father Mafu Mabandla for the different roles they have played in teaching me to work hard, be disciplined, and persevere in life till I reach my goals.

GLOSSARY

Contamination is the presence of a constituent, impurity, or some other undesirable element that corrupts, infects, makes unfit, or makes inferior a material, physical body, natural environment, workplace, etc.

Eutrophication is the process by which a body of water becomes enriched in dissolved nutrients (such as phosphates) that stimulate the growth of aquatic plant life, usually resulting in the depletion of dissolved oxygen.

Industrialization - the large-scale development of industries in a region or country.

Informal settlements refer to residential shacks built on planned or unplanned areas with no formal planning approval. They lack suitable infrastructure and services.

Nutrients – Chemicals that are important foods for plants, and largely for planktonic algae when dissolved in water. Some of the examples are nitrates, ammonium, and phosphates.

Sedimentation is when particles of soil are eroded and deposited as layers of solids in river sand.

Sewage is waste material such as faeces or dirty water from homes and factories.

Urbanization refers to the population transfer from rural areas to urban areas, the steady increase in the percentage of people living in urban areas, and how each society adapts to this change.

Wastewater is used water that comes from any combination of domestic, industrial, commercial, or agricultural activities, surface runoff or stormwater, and any sewer inflow or sewer infiltration.

Water Pollution is defined as the physical, biological, or chemical change in water quality that negatively affects living organisms or makes water unfitting for the desired use.

LIST OF ACRONYMS

BNR- Biological Nutrient Removal

BOD5- Biochemical Oxygen Demand

COD- Chemical Oxygen Demand

DEAT- Department of Environmental Affairs and Tourism

DO- Dissolved Oxygen

DWA- Department of Water Affairs

DWAF- Department of Water Affairs and Forestry

EC- Electrical conductivity

ECA- Environmental Conservation Act

E. coli- Escherichia coli

IUA- Integrated Units of Analysis

TSS- Total suspended solids

WWAP- World Water Assessment Programme

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CHAPTER ONE: INTRODUCTION

1.1. Background to the study

One of society's biggest challenges is the scarcity of water. The uneven distribution of water across the globe makes it even harder to manage water as some areas have ample water supply, while other areas may range from arid to semi-arid. Environmental factors such as floods and droughts also make it hard to deal with the management of water.

Water pollution has to do with the contamination of water bodies and is normally a consequence of several factors including human activities. Examples of water bodies include lakes, rivers, oceans, aquifers, and groundwater. When contaminants are introduced into the natural environment, it can result in water pollution. For instance, when inefficiently treated wastewater is allowed to flow into natural water bodies, the result may be the degradation of aquatic ecosystems. Consequently, the people who live nearby that water source may experience health problems as they would tend to use the same contaminated water for irrigation, drinking, or bathing.

Contamination of water may originate from point sources or non-point sources. Point source pollution is when contamination stems from a single source. An example of this is operational waste from industries, wastewater treatment plants, and so on. Non-point source pollution, on the other hand, is contamination that arises from various sources which may include agricultural sources, stormwater runoff, and debris blown into the water away from land (Jamwal et al., 2011). Sewage water, agricultural practices, oil spills, and radioactive substances are the most common types of water contamination (World Water Assessment Programme, 2017). The scarcity of water and the need for ecological sustainability has triggered the introduction of the treatment of wastewater as an additional water resource in the national resource management plan of Mediterranean countries. There has been an introduction of practices for the treatment of wastewater and reuse (Barcelo & Petrovic, 2011). Sewage, garbage, and liquid waste coming from households, agricultural lands, and factories are often discharged into lakes and rivers either directly or indirectly. This makes sewage and household wastewater the main causes of water pollution. These wastes have toxins and dangerous chemicals that poison the water, harming aquatic animals and plants. South Africa's freshwater supply is under increasing pressure due to rapid population growth and economic development. There are also concerns that water stress will worsen because of the current climate change projections. These projections tend to show uncertain after-effects for aquifer systems and the related groundwater goods and services (Knuppe, 2011).

South Africa is a semi-arid country with high water stress because of low rainfall volumes and high evaporation (Adewumi et al., 2010). The country has felt the financial, human, and ecological impacts due to climate changes experienced both locally and globally, predominantly where water resources are under severe strain (Schulze, 2005). During the apartheid period in South Africa, the Department of Water Affairs and Forestry (DWAF) was responsible to ensure that the water needs of those chosen by the government, such as white farmers, were met. The democratic dispensation in South Africa brought change as the DWAF is now ensuring that all its citizens have access to safe water and basic water sanitation (Seward, 2010). Despite this, a study has shown that South African households, in general, still lack adequate sanitation facilities (Petterson, 2019). A report by Stats SA shows that 45,6% of households do not have toilets inside their dwellings, and 12,2% use pit latrines (Petterson, 2019).

According to reports, the Vaal River in South Africa is highly polluted, and the major contributors have been indicated as a high level of saline acid mine drainage effluent that is pumped into the river. Raw or partially treated sewage from local wastewater treatment plants is a major pollutant that creates serious health risks. The presence of *E. Coli* is also an indication of faecal existence in the water. *E. Coli* counts of 200 – 400 per 100ml of water signify a major risk of gastrointestinal disorders (Bega, 2017). Due to high pollution levels, the Vaal river has turned green and a lot of fish have been found dead in the riverbanks. The community of Parys, located in the banks of the river, had suffered immensely due to such pollution. Tap water had smelt of dead fish and had changed the colour to green (Bega, 2018).

1.2. Location of study

Dunoon is a township situated in Milnerton, a suburb in Cape Town. It is located around relatively affluent areas such as Parklands, Table View, Killarney Gardens, and Richwood.
Many of the residents of Dunoon work in these areas as low-skilled workers, domestic workers, and waitresses in restaurants. Some of the problems in Dunoon are lack of proper housing, inadequate water supply and sanitation, poor service delivery, unemployment, and other social problems. Although water supply is a problem in other informal settlements, the natural resource (Diep River) that runs through Dunoon is highly polluted mainly due to poor sanitation, inadequate waste collection, and other factors. In 2011, the population of Dunoon was 31,133 with 11,496 households, and the population in this area is growing at a fast rate (Statistics SA, 2011). These figures have increased over the years as an informal settlement has been developed in Dunoon after 2011. The majority of residents in Dunoon are not owners but rent the homes they live in. The study area will cover backyard dwellers and the sections of Dunoon informal settlement, namely Bekela, Ethembeni, Kwa 5, New rest, and Zwezwe.

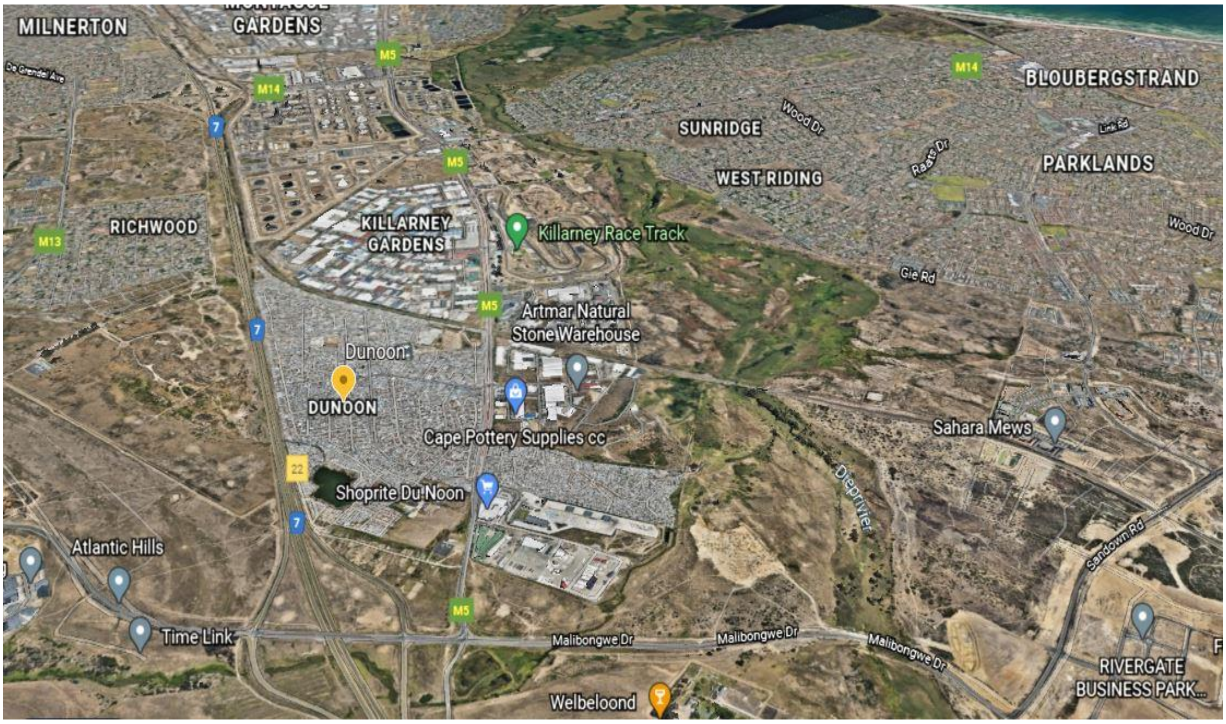

Figure 1.1: Dunoon Map (Google Earth, 2020)

1.3. Problem Statement

When the quality and visual value of water have been adversely affected by anthropogenic influences, it results in wastewater (Akpor et al., 2015). Studies have shown that wastewater disposal to water bodies is a major problem in developing countries (Van Der Merwe-Botha & Manus, 2011:1). This has resulted in an increasing problem of water pollution that is negatively affecting human health, causing deaths each year. The challenges may escalate in the future if there are no proper intervention measures in place (World Water Assessment Programme, 2017).

Water pollution remains a problem globally; a UNESCO report shows that over 80% of sewage in developing countries is discharged untreated, and this results in the pollution of rivers, coastal areas, and lakes (World Water Assessment Programme, 2017). The pollution of urban areas is also increasing due to the influx of people from rural areas to urban areas in search of better opportunities. Most of them live in informal settlements and this increases the demand for water resources. The informal settlement population is perceived as a great polluter of the environment due to a lack of amenities. According to the United Nations (2017), 844 million individuals lack basic services such as drinking water. Two billion people utilize drinking water contaminated by faeces, and 423 million take water from unprotected rivers, boreholes, and springs (Scofield, 2018).

The Department of Water Affairs (DWA) has expressed fears about poor water quality, noting that it is a risk to the growth of the South African economy. Not only does it have negative impacts on the health of humans and the environment; it may also be a catalyst for social unrest and may even cause deaths. According to the DWA, malfunctioning wastewater treatment works is one of the main causes of deteriorating water quality in South Africa (Mitchell et al., 2014). As part of the Western Cape River Health Programme sponsored by the Department of Water Affairs and Forestry, CapeNature compiled a river report which revealed that, generally, just a small number of the upper reaches of Cape Town's rivers are still in a good condition (Gosling, 2007). This clearly shows that the quality of water in the rivers had been deteriorating due to several reasons.

1.4. Research question

The overall question to be answered by this study is: What are the impacts of the informal settlement on the water quality of the Diep River in Dunoon?

The specific research questions are:

- What current legislation is in place and what is the state of compliance?
- What are the causes of pollution?
- What are the environmental and health impacts posed by poor water quality?
- What are the possible recommendations on how the impact of water contamination and challenges could be minimized?

The research question above will be answered to investigate the impact of the informal settlement on the water quality of Diep River in Dunoon.

1.5. Aim and objectives

The main aim of this study was to investigate the impact of the informal settlement on the water quality of Diep River in Dunoon. The study pursued the objectives below to achieve the main aim:

- To assess the knowledge, attitudes, and practices of the community of Dunoon
- To investigate the water quality of the Diep River using the following parameters: pH, conductivity, total suspended solids, and nitrates, to name a few.
- To investigate the environmental and health risks posed by human behaviours on water resources using questionnaires, checklist, observations, and results from water tests for *E. Coli*.

1.6. Validity and reliability

To ensure that errors are reduced, and the data collected is reliable, valid, and of high quality, special attention will be dedicated to the following:

- Various relevant resources were used for the study.

- Both the questionnaire and checklist were tested in a different area that would be excluded from the final study.
- There were briefings and training for all supporting staff. This was conducted by the study leader before the use of any instruments to ensure that they are well versed.
- There were also tests conducted in accredited labs
- The researcher also analysed data but made use of a statistics expert for accuracy

1.7. Ethics (Ref: 208224963/04/2020)

It is crucial to give attention to ethical consideration when conducting research. The protection of research participants' identities is one of the important aspects (Maree, 2016).

- Ethical approval was required from the Faculty of Ethics Committee of CPUT.
- Consent forms and confidentiality forms from CPUT were used for the survey. These forms were available in English.
- Questionnaires and checklists were used to obtain information from the Dunoon community.
- Only questionnaires were used to obtain information from the Potsdam plant
- Research participants were 18 years and older

1.8. Delineation of study

The research will be done in the informal settlement located in the area of Dunoon. Dunoon is a township under Milnerton. The study will investigate the impact of the informal settlement on Diep River's water quality. It will also seek to find out about the behaviours and attitudes of the Dunoon residents. The study will also look into matters of legislation enforcement and compliance.

1.9. Rationale and significance of the study

Water is relatively scarce in South Africa with an average of 497mm annual rainfalls. Rainfall is unevenly distributed and highly seasonal. Several factors influence the supply of water in South Africa, and these include rapid urbanization, population growth, economic development, demand for high levels of services, and so on (Meyer, 2007). The challenges for sustainable water management practices are massive (Swatuk, 2017).

There is a direct method that can be used to address the challenges related to water quality, and it is to reduce the amount of pollution emitted from point and non-point sources. When assessed against the costly and extensive wastewater treatment improvements, the advantage of pollution reduction is that it exemplifies a more direct and low-cost method intended to improve the quality of water. There have been a variety of responses around the world that are geared towards improving water quality. These include the reduction through policy and market improvement, water treatment options such as distillations and reverse osmoses, and small-scale treatments which include sodium dichloroisocyanurate (NaDCC), boiling water, solar disinfection, and chlorine (Bouman et al., 2010).

The study will create awareness of what the source of pollution is in Diep River, Dunoon. The study will also benefit:

- The community of Dunoon and surroundings areas. The research will engage Dunoon residents and make them aware of the state of water quality and how they may contribute to minimize or manage waste and promote good health amongst the community.
- The City of Cape Town municipality. As Dunoon falls under the City of Cape Town, the study could inform many other similar studies that the city will have to do.
- Environmental legislation makers and enforcers. It will assist them in finding out why there is a lack of law enforcement and why societies and organizations do not adhere to legislation, and so suggest what needs to be done as a way forward.

1.10. Expected outcomes

- Highlight the issues that might assist the City of Cape Town in initiating programs that would promote awareness and educate the Dunoon community on water quality and the efficient use of water
- Highlight health risks associated with poor sanitation and consumption of contaminated water, and seek ways to mitigate such risks
- Improved knowledge and practices on water resources to prevent or eliminate pollution.
- Gain knowledge of whether the informal settlement contributes to the reduction of water quality

1.11. Summary

The South African government has been struggling to meet the increasing demands due to rapid growth in urban areas. Poor sanitation and poor waste disposal practices in communities have led to the contamination of water resources. Research shows that more than 80% of the world's largely untreated wastewater is dumped into the environment and water bodies such as rivers and lakes. Many informal settlements are located close to water resources such as rivers and wetlands. There is a great concern expressed due to water degradation. The perception is that, to a certain extent, informal settlements contribute to water pollution, leading to an adverse impact on the environment and health.

Legislation has been utilised as an essential instrument for managing society and protecting citizens and the environment. However, legislation has not been properly enforced in South Africa (Paterson & Kotze, 2009). According to an estimate by the World Health Organization, waterborne diseases result in two million deaths yearly, manifesting in the form of diarrhoea and infections (World Health Organization, 2019).

This research will investigate the impact of the informal settlement on the water quality of the Diep River in Dunoon. Both qualitative and quantitative approaches will be used. The research will use random sampling techniques to select the population under investigation. The sample size is 395 people residing in the Dunoon informal settlement. All collected data will be loaded and analysed using SPSS with Excel. Tests on some contaminants will also be done**.** The study will raise awareness concerning the attitudes and practices of residents of Dunoon informal settlement about their role in ensuring that the quality of water in the Diep River is acceptable. It will also highlight the health and environmental risks associated with poor sanitation and consumption of contaminated water and seek ways to mitigate such risks.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

Water is a scarce resource in South Africa, but the demand for this resource continues to rise due to climate change, pollution, rapid population growth, informal settlements lacking basic services, and other factors. The study aims to assess the impact of Dunoon informal settlement on the quality of water in Diep River and to review the environmental and health risks posed by human behaviours on water resources. It also seeks to review the principle of sustainable development and water in South Africa. These will be guided by the literature review concerning what has been done around the world and locally.

Informal settlements are unplanned settlements that have not been decreed as residential zones for humans, made up mainly of informal residences in the form of shacks (Stats SA, 2011). Informal settlements are identified by the 2009 National Housing Code's informal settlement upgrading program based on the following characteristics: inappropriate location, restricted public, private investment, social stress, poverty, and vulnerability. Due to economic challenges, many South Africans in rural areas tend to move to cities in search of better opportunities. When they get to the cities, they stay in overcrowded squatter camps. These squatter camps are mostly characterized by poor health conditions and lack of employment opportunities.

Among all the natural resources, water is the most crucial and is essential for economic development, production of food, and overall survival of all living organisms. It is vital in shaping economic and social development. Many cities across the world are currently experiencing a severe scarcity of water. Almost 40 percent of the food supply worldwide and various industrial processes require water, and water quality is critical given various uses of water in those industrial processes. It also helps in maintaining the integrity of the natural environment. The quality of water is impacted by a variety of human and natural influences and is declining due to the rise of urbanization, population growth, industrial production, climate change, non-compliance of wastewater treatment plants, agricultural waste, and other factors. The subsequent water pollution poses a major threat to the well-being of both the environment and the population.

2.2. Causes of water pollution around the informal settlement

Human beings are often responsible for the main causes of water pollution, mostly due to an increase in human activities, especially in informal settlements where there is a lack of services. One of the central problems faced by residents in informal settlements is the lack of a proper system for waste management. As a result of a lack of established collection points, heaps of waste are spread in and around residential zones which leads to environmental and health problems. A small number of residents choose to burn or bury their waste near their residences (Ameyibor et al., 2003).

Approximately 15 million people in South Africa lack adequate sanitation. Every citizen has a right to access basic services and municipalities are responsible to provide such services. However, the provision of basic services is a challenge and is aggravated by growing unemployment and the spread of unplanned informal settlements (Cousins, 2004). According to a Statistics SA (2016) media release, 45.6% of households in South Africa have no toilet inside their homes, and less than 50% of households have a toilet outside of their residence.

Of the remaining 75.5% of people with access to sanitation, 12.2% have pit latrines, and 60.6% are connected to a sewerage system. In some informal settlements, toilets are shared; for example, in Ezindlovini in Khayelitsha, which is a settlement of more than 20000 people sharing 380 communal toilets, some of the residents do not have toilet facilities at all. Residents have been protesting and demanding help from the local government to address this problem (Anon, 2016:12). Informal settlements lack centralized sewerage systems. This leads to liquid waste such as water from bathing, laundry, kitchen, and other domestic uses to be randomly discharged anywhere within the settlement. This dumping practice contaminates the surface water, groundwater, and environment and is a major cause of waterborne diseases (Ameyibor et al., 2003). Table 2.1 below shows the major pollutants and the associated health and environmental impacts.

Table 2.1: Major water pollutants, examples, and source

Major water pollutants, examples, and source			
Health impact	**Examples**	**Source**	**References**
Infectious Agents	parasites, bacteria, viruses	Sewage, Human and Animal excretes	(Olaolu et al., 2014)
Organic chemicals	Pesticides, detergents, oil, plastics	Domestic, agricultural, industries waste	(Gupta & Chandra, 2013), (Arnone & Walling, 2007)
Inorganic chemicals	Acids, salt, metals, caustics	Industrial and Domestic affluent	(Arnone & Walling, 2007)
Radioactive material	Uranium, radon, thorium	Power plants, mining, natural sources	(Villa et al., 2011)
Environmental Impact	**Examples**	**Source**	**References**
Plants nutrients	Phosphate, Nitrates	Chemical fertilizer, manure, sewage	(Arnone & Walling, 2007)

Sediments	Silt, soil	Soil erosion	(Strydom & King, 2015)
Oxygen demanding	Manure, Agricultural waste	Agricultural runoffs, sewage	(Sun et al., 2012)
Thermal	Heat	Power plants and industries	(Nordell, 2003)

2.3. Urbanization and Population growth

As stated by Worldometer, South Africa's population in rural areas exceeded the population of urban areas by 10% in the year 1955. However, this is not the case anymore. In 2019, the South African population in urban areas was at 66.3%, and it was estimated to rise to 66.7% by 2020 (Worldometer, 2020).

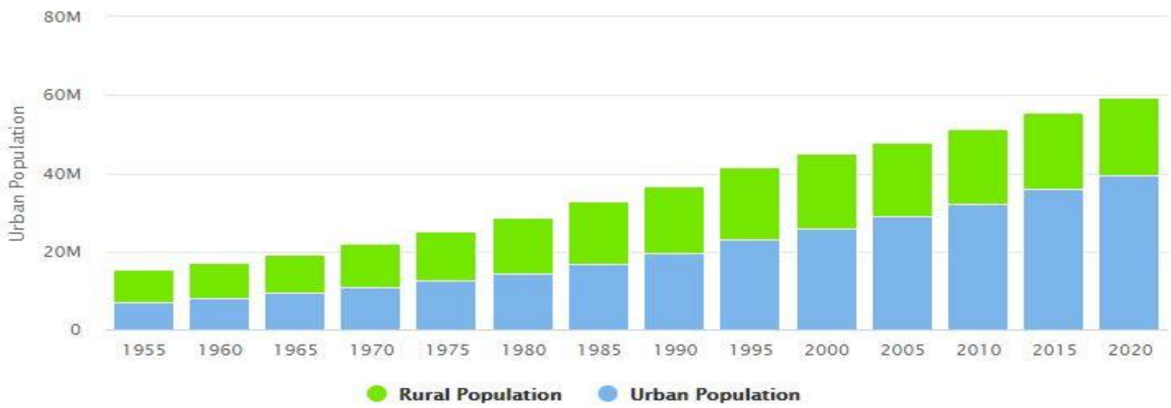

Figure 2.1: South African Urban vs Rural Population from 1955 to 2020 (Worldometer, 2020).

Urbanization is a major cause of the rapid spread of informal settlements. Many people moving from rural areas cannot afford houses, and so build shacks in the most vulnerable areas such as wetlands and riverbanks. Informal settlements are sometimes located in the most unfavourable conditions such as those that are close to water bodies (Barrow, 2006).
The Nairobi River in Kenya, for example, is largely used by populations of low-income especially those living in informal settlements, as a source of water for washing, cleaning, and watering crops. Furthermore, it is used to dump domestic and human waste as several homes lack toilet facilities. Industrial waste is also regularly discarded into the river and, as a result, the river is infected by harmful bacteria (Mbui, 2019). A study was conducted, revealing high levels of Escherichia coli (*E. Coli*) up to one million units in 100ml of water. The existence of *E. Coli* in drinking water indicates the presence of faecal contamination, which could result in periodic epidemic diseases such as cholera, typhoid, and dysentery (Mbui, 2019).

According to Barnes (2003), a study conducted in Cape Town showed that much of the pollution is derived from human waste in informal settlements where the municipality has not put appropriate sewerage systems or does not have adequate maintenance in place. In some parts of the settlements, sewage leaks into a stormwater drain and flows into the water bodies. Barnes's work included the analysis of water samples for six years from the Plankenbrug River in Stellenbosch, which flows into the Eerste River (Barnes, 2003).

In the study of Barnes (2003), samples were collected from the Plankenbrug River and interviews conducted at Kayamnandi, the informal settlement close to the river. The results revealed that the river was highly contaminated with dangerously high levels of faeces, which could adversely affect the health of all citizens that may come into contact with the water. The tests also revealed the presence of 13 million *E. Coli* per 100 ml of water. However, not all the faecal contamination originated from Kayamnandi. Large amounts of faecal contamination occasionally entered the river at various points below Kayamnandi (Barnes, 2003).

The physical disturbance of the land due to the construction of informal settlements alters the use of land, and this may lead to disasters. The alteration of land use due to urbanization and agriculture causes precipitation to run off quickly, resulting in severe erosion, flash flooding, reduced groundwater, recharge, and wildly fluctuating streamflow. This poor use of land leads to nutrient over-enrichment and sediment-contaminated water, which harms fish, plankton, and aquatic plants and may slit up channels, lakes, and reservoirs (Barrow, 2006). One of the major challenges that emanate from informal settlements which exist along riverbanks is that people tend to do laundry in the river, as is the case with one of the Alexandra informal settlements called Stjwetla, closest to the Jukskei River. Furthermore, as a result of the large population, there are sewage problems time and again which find their way into the river (Mawela, 2008). The settlements are also critically impacted by pollution, erosion, and sedimentation generated by the construction of these informal settlements, which use up the dissolved oxygen content in the environment and decrease the total biodiversity of the area (Owusu-Asante & Ndiritu, 2009).

An informal settlement of Site C in Khayelitsha is situated at the edge of the river. The river is regularly blocked with litter, smells of toxin, and is a dwelling place for rats. A lot of the litter is dumped by the residents of Site C into the river (Green, 2018). See below pictures of polluted rivers that are close to the informal settlement in Khayelitsha.

Figure 2.2a: Illegal dumping in Khayelitsha (Green, 2019)

Figure 2.2b: Illegal dumping in Langa, into Black River

2.3.1. Agriculture as a source of water pollution

Seventy percent of water extractions globally are for agriculture, and agriculture is also a source of non-point pollution. Non-point source pollution is contamination that arises from various sources which may include agricultural sources, stormwater run-off, and debris blown into the water away from land (Barcelo & Petrovic, 2011). Large amounts of agrochemicals, organic matter, drug residues, sediments, and saline drainage are discharged by farms into water bodies (United Nations Environment Programme, 2016). Agriculture is a non-point source of pollution because its contaminants are not from a single source but from various sources such as toxins from farm equipment, run-off from barnyards, fertilizers, pesticides, livestock waste, oil, soil ammonia, sediments, feedlots, and croplands, which carry away manure, etc. (Barrow, 2006; Strydom & King, 2015).

Agricultural non-point source pollution is one of the leading sources of water quality impacts in rivers and lakes and other water bodies. The improvement of agricultural non-point source pollution is becoming one of the central subjects for sustainable agricultural and social development in agriculture globally. Varieties and consumption of pesticides globally have been increasing rapidly as a result of increased human population and drive for an increase in crop production. Pesticide misapplications have become a serious concern, and this has caused the water bodies (through run-offs) and the environment to be heavily polluted, posing a risk to human health (Sun et al., 2012). Contaminants like fertilizers and pesticides can be very toxic to humans and may destroy the environment. Nitrates from agriculture pollute drinking water, posing a risk of blue-baby syndrome in infants and stomach cancer in adults. Agriculture produces ammonia, nitrous oxide, and methane, which contribute to acid rain, global warming, and Ozone layer depletion (Conway & Pretty, 2009).

The rapid growth of urban centres has been attracting greater numbers of rural immigrants, including small-scale farmers, in search of better opportunities because of the rise of large-scale farming, climate change, and loss of land. As a result, there has been a rise in the number of informal settlements constructed as municipalities cannot keep up with the planning and infrastructure development for new influxes (Bisanga et al., 2019). Informal settlements may have crop or livestock farming, and in some cases, there might be farms that are near the rivers. River pollution may be due to commercial or subsistence farming, or small-scale or large-scale farming; e.g., the Umgeni River which is situated close to farmland.

The Umgeni River supplies drinking water for over five million individuals and is the main source of water for Durban city and Pietermaritzburg (Bosworth, 2013). In 2011, the Department of Water Affairs informed the Parliamentary Monitoring Group about the health status of South African rivers. One of the rivers mentioned was the middle Umgeni River in KwaZulu-Natal, which suffered high levels of phosphate because of waste from beef cattle feedlots, poultry farms, and informal settlements without sanitation amenities (South Africa. Department of Water Affairs, 2011). The NEPAD Water Centres of Excellence projected that the sewage pollution that enters the Umgeni River, combined with nutrients from run-off from dairy, pig, and poultry farms could affect the neighbouring water bodies like the Albert Falls Dam through pollutants such as nitrogen and phosphorous that promote algal growth, and this could lead to eutrophics (Bosworth, 2013).

2.4. Impact of pollution on Water quality

Due to the pollution of rivers by dumping, littering, and raw sewage run-offs, the quality of water is affected. Therefore, the pH and conductivity of the water are altered. The term “water quality” is used in this review to express the suitability of water to sustain a variety of uses or processes. Any specific use will possess some requirements for the physical, chemical, or biological characteristics of water; for instance, limits on the concentrations of toxic substances for the use of drinking water, or temperature and pH range restrictions for water that supports invertebrate communities (Bartman & Balance, 1996). Water quality also describes how suitable the water is for maintaining recreational, domestic, agricultural, and industrial or aquatic ecosystem processes (Western Cape (South Africa). Department of Environmental Affairs and Development Planning, 2011).

Generally, the quality of natural water differs from one place to another, subject to seasonal changes, soil and rock type, and the surface through which it flows. The quality of water is considerably changed by various human activities like mining and recreation, urban and industrial development, and agriculture (Kretzmann, 2019). The quality is also altered extensively within the spatial catchment area. The standards for water quality have generally been set up for various traditional water quality variables like total suspended solids (TSS), chemical oxygen demand (COD), faecal coliform, ammonium nitrate, dissolved oxygen, total phosphate, conductivity, and pH (Western Cape (South Africa). Department of Environmental Affairs and Development Planning, 2011). Water pollution is a massive problem in South Africa for surface water and groundwater because of untreated sewage that is discarded into river bodies, acid mine drainage from deserted mines, pollution from agriculture, and poor sanitation in an informal settlement. Because of their poor condition, many wastewater treatment plants are not operating properly. This results in extensive waste spillage that places the environment and people’s health in danger (Kahinda & Boroto, 2009). Van Der Merwe-Botha & Manus (2011) state that wastewater is the major barrier in a multi-barrier system of making sure that drinking water is of high quality and is safe for consumption.

In addition to the stormwater drain pollution such as the Strand, the major pollutant outlets are found at Hout Bay, Camps Bay, Kuils River, and Mouille Point (Plastic Pollution 2018). Examples of persistent pollutants include household products like detergents, soaps, perfumes, disinfectants, skin and hair products, dental care products, and surfactants. These pollutants also include pharmaceutical and personal healthcare products like prescription and over-the-counter drugs (Petrik et al., 2017). Human and environmental well-being could be adversely impacted by some contaminants. For instance, in some regions like Asia, the populations of vulture species have dropped significantly. This decline has been attributed to the veterinary use of diclofenac, which is a human pharmaceutical used to treat antiinflammations (Petrik et al., 2017). It has also been associated with one of the active ingredients in the contraceptive pill associated with endocrine disruption and feminization in fish, called the ethynylestradiol (Petrik et al., 2017).

As part of the Western Cape River Health Programme sponsored by the Department of Water Affairs and Forestry, whose objective is to investigate the quality, quantity, and ecosystem health in the Western Cape, CapeNature compiled a report which revealed that, generally, just a small number of the upper reaches of Cape Town's rivers are still in a good condition (Gosling, 2007). This shows that the quality of water in the rivers had been deteriorating due to several reasons. The report also found that the current water demand is greater than the available water yield in Cape Town, and this has been made worse by recent dry winters. Spills into the Kuils, Black, and Vygekraal rivers, as a result of sewage effluent from blocked sewage works, were creating serious environmental and health problems (Gosling, 2007).

Figure 2.3: Raw sewage nearby and into Black River in the Langa informal settlement

The quality of water in South Africa has deteriorated. This has brought about challenges such as microbiological contamination and eutrophication; just to name but a few (Strydom & King, 2015). Microbiological pollutants from sewage often lead to contagious diseases that infect drinking water, affecting life on land and in water. Water supplies that have been inadequately treated will have noticeable levels of total coliform bacteria and faecal coliforms due to the presence of Escherichia coli (*E. Coli*). *E. Coli* is an indication of faecal pollution coming from humans and warm-blooded animals (Strydom & King, 2015).

According to the City of Cape Town water quality report conducted in different points of Diep River in Milnerton areas, from January to June 2020, the highest *E. Coli* count was recorded in March with 30 000 000 units per 100ml of water at Theo Marais Canal just before the junction with the Diep River (Haskins, 2020). The results are a clear indication of pollution. Human contact with water containing 400 counts of *E. Coli* per 100ml is regarded as harmful to human health, and those affected may show signs of gastric disturbances and skin irritations.

Eutrophication is excessive nutrient enrichment, increased growth of microscopic floating plants, algae, and the formation of floating plants in water bodies (Smith & Schindler, 2009). It also tends to cause the suffocation of fish and water organisms. Eutrophication is characterized by too much plant and algal growth as a result of the increased availability of one or more limiting growth factors needed for photosynthesis, such as sunlight, carbon dioxide, and nutrient fertilizers (Schindler, 2006). The pH of water can also change to acidic due to sulphate particles from acid rain. This can cause damage to aquatic life, resulting in a high number of deaths within an environment (Khan & Ansari, 2005). The growth of photosynthetic plants and micro-organisms can also be disrupted because of suspended particles that tend to reduce the amount of sunlight penetrating the water (Strydom & King, 2015). As the water quality has deteriorated, causing eutrophication, therefore the eutrophication will cause alteration in the species composition within the aquatic ecosystem.

2.4.1. Impacts of pollution on the environment

When the environment deteriorates as a result of the depletion of resources such as air, water, and soil, it leads to environmental degradation (Choudhary et al., 2015). The process of environmental degradation compromises the natural environment, which in turn reduces biological diversity and negatively impacts the general health of the environment (Mbonambi, 2016). The environment may also deteriorate as a result of problems related to urban growth in developing and developed countries; for example, pollution of water and air, refuse disposal, and loss of farmlands and natural areas (Barrow, 2006). There are various kinds of water pollution, and all of them tend to harm the environment.

Informal settlements are susceptible to ruin by the natural elements and easy to destroy by fires. Fires may cause air pollution and, in turn, the particles from air pollution may pollute the water bodies. Inadequate planning regarding drainage or sewage systems exposes the informal settlement to flooding and diseases as a result of still water and waste that is not collected. This, in turn, degrades the ecosystems and their inhabitants (Socio-Economic Rights Institute, 2018). A City report on the state of informal settlements in Cape Town pointed out that some settlements namely Joe Slovo, Nonqubela, Sweet Home, and other informal settlements in Cape Town have very poor drainage (Kahinda & Boroto, 2009).

Figure 2.4: Flooding in Kosovo informal settlement, Philippi, Cape Town (SABC News, 2020)

The Disaster Mitigation for Sustainable Livelihoods Programme (DiMP) at the University of Cape Town revealed that, of the 47 informal settlements they studied, 20% of the residences in those settlements were built in areas of high flooding. When these factors are linked with high degrees of poverty, overpopulation, and the absence of emergency services, it may cause the households in the informal settlement to be especially susceptible to incidents that can destabilize their health and livelihoods and have disastrous consequences (Socio-Economic Rights Institute, 2018).

Vaal River supplies about 50 percent of Gauteng's water. Because of waste that gets dumped into the river stream, this river has been a target of water pollution. According to a News24 article written by Phakgadi (2019), vanadium and potassium carbonate were the chemicals found in the Vaal River (Phakgadi, 2019). This affects the aquatic ecosystem and harms the environment.

Water contaminants that have recently been found include chemicals like pesticides, pharmaceuticals and veterinary medicines, flame retardants, nanomaterials, and endocrine-disrupting compounds. In recent times, there has been growing concern around these chemicals because either they were not identified in tests before or their concentrations were very low. These chemicals are washed out into water supplies from various sources (Walters, 2017). There is also a risk posed by heavy metals that come from industrial processes. These can build up in nearby lakes and rivers, causing harm to fish and shellfish, and thus negatively impacting the rest of the food chain (Masindi & Muedi, 2018).

2.4.2. Health Impacts as a result of water pollution

The United Nations General Assembly declared safe and clean drinking water and sanitation as a human right. Masses of people will benefit from clean and safe household water, and this will ensure that they are not infected (Misati, 2016). In 2010, it was estimated that 1.8 billion people worldwide drank unsafe water (Onda et al., 2012). This kind of situation happens most frequently in developing countries, and the problem becomes worse in rural areas. Pathogens and chemicals in water cause diseases. Pathogens are disease-causing micro-organisms, which are a serious problem in water resources (Arnone & Walling, 2007).

Humans need to consume clean and safe drinking water for health reasons. This will minimize their susceptibility to common illnesses such as diarrhoea, particularly in young children. Diarrheal diseases are a leading cause of child deaths in developing countries. In 2011, it was reported that diarrheal diseases accounted for deaths of more than 700000 children below age 5 (Edokpayi et al., 2018). According to the World Health Organization (2017), water diseases are illnesses brought about by pathogenic micro-organisms that are transmitted in water bodies and that may spread while washing, drinking water, or by consumption of food exposed to polluted water.

When polluted water is used in food preparation, it can be the basis of foodborne disease through the consumption of similar bacteria. Water-washed diseases result from a lack of personal hygiene when the skin or eye comes into contact with contaminated water. The term "waterborne diseases" is generally used to indicate infections that are a result of infected water. Vector-borne diseases are transmitted by insects like mosquitos that have aquatic immature stages. Water-based diseases spread due to organisms that grow in water (Kretzmann, 2019). Table 2.2 below depicts some of the water-related diseases.

Table 2.2: Water-related diseases (Gleick, 2002)

Some of the water-related diseases			
Water-Borne	**Water-Washed**	**Water-Based**	**Water-Vector**
Dysentery	Trachoma	Schistosomiasis	Malaria
Cholera	Scabies	Taeniasis	Yellow fever
Typhoid fever	Yaws	Enterobiasis	Filariasis (parasitic worms)
Hepatitis A	Shigella	Echinococcosis	Japanese encephalitis

A study was conducted by Kimani-Murage & Ngindu (2007) in the Langas informal settlement in Kenya. In response to interviews, the majority of the people (89%) indicated that they used shallow wells as their main source of domestic water, while 2% indicated that they used water from deep wells, and 9% indicated that they used tap water from the municipality (Kimani-Murage & Ngindu, 2007). The wells were located close to the pit latrines; between 15 meters and 30 meters from the pit latrines. In many cases, the distance between the wells and the pit latrines was likely less than 15 meters, and a majority of the wells (about 59%) were projected to be at a distance 15 and 30 meters from the pit latrines.

This condition poses severe health threats to the inhabitants of the informal settlement as they are susceptible to risks of waterborne infections. All 31 samples that were taken from the shallow wells tested positive for total coliforms. The greatest probability of total coliforms for the majority of the samples (71%) was 1100+ per 100 ml. Three out of the four samples taken from the deep well were found positive for total coliforms. The maximum number of total coliforms was found to be 240. The maximum number of thermotolerant coliforms was 23 and two samples were negative. The tap water test showed negative coliforms. The finding also indicated that most of the domestic water sources in the Langas slums were polluted with faeces and did not comply with the WHO guidelines for drinking water quality (Kimani-Murage & Ngindu, 2007).

A similar study about the detection of human enteric viruses at the Umgeni River in KwaZulu-Natal in South Africa, focusing on five points of the river, was conducted by Lin & Singh (2015). The sampling sites included five large parts of the river, which are Umgeni River mouth (estuarine/brackish water), Reservoir Hills (informal settlement/domestic waste), New Germany Wastewater Works (treated water after chlorination that enters the adjoining Umgeni River water), Krantzkloof Nature Reserve (vegetation and conservation area) and Inanda Dam (restricted water containment).

From each of the five different sites of Umgeni River, water samples (25L each) were collected in April, July, October 2011, and January 2012. Nested integrated cell culture polymerase chain reaction (ICC-PCR) confirmed that 90% of water samples which contained infectious viral particles had viral infectivity. The molecular representation of these viruses proved that the majority of viral isolates originated from humans. Quantification of viral groups using quantitative PCR indicated fairly high genome copies of enteroviruses. The study results revealed that the water in the river, which is possibly used for domestic and recreational activities, contained infectious viruses. The presence of adenoviruses and enteroviruses in the study water samples could indicate that there is faecal contamination (Lin & Singh, 2015).

Another study conducted by Van Abel et al. (2017) used a quantitative microbial risk assessment (QMRA) methodology to evaluate the risks associated with the presence of noroviruses in surface water used for recreational, drinking, and domestic purposes in South Africa (Van Abel et al., 2017). According to this study, water samples (10L) were collected at various sampling points situated on the Klip, Suikerbosrant, and Rietspruit rivers in the Gauteng province. These rivers all flow into the Vaal River (Van Abel et al., 2017). The results of this assessment show that selected surface waters in South Africa are contaminated with norovirus, which can lead to high risks of infection due to exposure utilizing drinking surface water that has not been treated, as well as domestic and recreational use. Moreover, this study presented quantitative data on the concentration of norovirus GI and GII in surface waters, which is important for QMRA.

Noroviruses contain seven genogroups (GI–VII) with GI, GII, and GIV causing infections in humans. Following a mean incubation time of 24 hours, norovirus illness, characterized by diarrhoea, vomiting, fever, headache, and muscle aches, is self-limiting with symptoms usually lasting between 24 and 48 hours (Van Abel et al., 2017). The sample results of the QMRA revealed that a lower risk was observed for GI as compared to GII, and the daily probability of infection risk was lower for domestic use of water compared to drinking water exposures. They also showed that the probability of illness each year from recreation exposures was lowest for playing by the river compared to boating and swimming. At the same time, there was a higher risk burden for individuals of lower socioeconomic status populations who may utilize surface water that has not been treated for several household and recreational purposes (Van Abel et al., 2017).

Diarrhoea is one of the leading causes of mortality among young children in South Africa. For children infected by the Human Immunodeficiency Virus (HIV), this problem is even worse (Edokpayi et al., 2018). A survey made in Limpopo communities indicated that, apart from the municipal taps, water sources in the study area were highly contaminated with *E. Coli* in both the dry and wet seasons (Edokpayi et al., 2018). In Cape Town, the people staying in Zeekoevlei were left shocked after piles of fish washed up on the lakeshores on Fisherman's Walk due to a water-related disease. It was later confirmed by the City of Cape Town that the water was contaminated by a virus called Herpes Koi. This is a famous fishing spot for the inhabitants of Pelican Park, and children use it as a play area. Yet, it has been ruined by pollution and refuses (Cornelissen, 2016).

Figure 2.5: Water Disease kills fish in Pelican Park, Cape Town (Cornelissen, 2016)

2.5. Legislation adherence in South Africa

Paterson & Kotze (2009) define international law as referring to a body of rules which tie actions and mutual relations of nation-states to specific shared principles, standards, and procedures. The responsibility of international environmental law is to attempt to control pollution and natural resource depletion within a sustainable framework. It is a branch of law made by states to govern issues arising between states (Guruswamy & Leach, 2017).

International law uses sanctions for enforcing compliance with its rules. The sanctions can be economic, membership suspension, trade sanctions, and so on. The management of legislation enforcement and compliance in international law has been questioned by many for lack of credibility (Yang, 2006).

However, other countries have been able to adhere to legislation to some extent. For example, Switzerland is one of the countries with high-quality tap water. The Swiss citizens and government have taken measures in the last three decades to protect the country's water resources. One such measure is a ban on phosphate in laundry detergents. Another important step involved switching to sustainable agricultural practices that minimize the application of fertilizers and pesticides (Kohler, 2006). The United Kingdom also has strict water regulations. It uses a decentralized system with independent inspections for each of the countries within the United Kingdom. They each produce a report every year. For example, 3,853,350 water quality tests were carried out in 2014, out of which only 32,000 samples failed to comply with one of the quality standards (DWI, 2015).

Since Zimbabwe obtained independence, development in the country's water sector was driven by the Water Act of 1976, revised from the 1927 Act, which legally excluded the bulk of the black population from gaining access to agricultural water (Manzungu, 2002). However, the Water Act of 1976 had its core weaknesses such as the centralization of water rights at the Water Court in Harare, which involved the issuing of water rights permanently on a first-come-first-served basis. This implied that when water resources were fully apportioned, there could be no further issuing of water rights despite the need. The process of reallocating water rights was extremely lengthy and complicated in cases of water shortage. This is because water rights would not be changed, even if the right holders were not using their water rights. The only time water rights could be changed was when the rights holder offered to do so. Right owners were not required to pay for the ownership of the water right or to provide general water service. The act did not mention anything about water quality and environmental factors, and there was hardly any attention given to groundwater supplies (Makurira & Mugumo, 2005).

The Water Act (1976) was revised several times to conform to global modern trends. This led to the revamp of the Water Act (1976), which was substituted with the Water Act (1998), meeting the requirements of global trends and tackling pressing national problems. The Act also encouraged stakeholder participation in water governance. According to Manzungu (2004), most of the vulnerable and disadvantaged groups were excluded from water management decisions. Manzungu indicated that the main problem to participation was the absence of effort by Sub-Catchment Councils (SCCs) in Zimbabwe to communicate with the stakeholders about the amended or new legislation and the reasons why they existed (Manzungu, 2004). The meaningful participation of the relevant stakeholders in the governance of water resources in their respective areas has been hampered by the lack of knowledge regarding the Water Act, SCCs, and additional matters relating to water management transformation (Manzungu, 2004).

A lot of international principles such as the polluter pays principle, sustainable development, precautionary principle, and prevention principle have been adopted by South Africa. The Polluter Pays Principle ensures that those who cause pollution are made liable for the costs of managing it so that it does not cause damage to human health and the environment. The regulation of pollution affecting the land, air, and water is mostly based on this principle (Ingwani et al., 2010).

According to Paterson & Kotze (2009), South African authorities have constitutional expertise over a variety of pollution and waste management issues. By-laws and service delivery policies are the primary methods of governance used by municipalities to deliver specific outcomes effectively. These by-laws provide the legal bases for the enforcement of policies relating to a wide range of commercial, private, and industrial activities (Paterson & Kotze, 2009). For example, the City of Cape Town developed some by-laws to help regulate water resources within the metro. Some of these are the Water By-law 2010, the Treated Effluent Amended

By-law 2015, and the Wastewater and Industrial Effluent By-law 2013. By-laws carry penalties, including financial charges, in cases of non-compliance (City of Cape Town, 2011).

Existing legislation is not adequate to address major challenges such as changes in climate or growth in population. It is when companies resolve to move forward and go beyond environmental legislation that the greatest capacity for improving tends to be seen (Rabadan & Saez-Martinez, 2017). The government should introduce programmes to educate the people who stay next to the rivers about the importance of keeping the water clean. Water and waste management is thought to be a joint responsibility of government authorities and businesses (Rabadan & Saez-Martinez, 2017). See legislation in Table 2.3 below.

Table 2.3: Relevant International and South African Legislation

Relevant International and South African Legislation	
Relevant Legislation	**Description and Relevance**
Convention on the Law of the Non-Navigational Uses of International Watercourses	The Convention encompasses the uses and preservation of all waters that cross over international borders, involving both surface and groundwater (General Assembly of the United Nations, 1997).
Convention on the Protection and Use of Transboundary Watercourses and International Lakes Helsinki	Convention aims to prevent, control, and reduce the transboundary impact concerning transboundary watercourses and international lakes (Mccaffrey, 1998).
The four IWRM Dublin principles	Freshwater is a limited and vulnerable resource, crucial to sustaining life, development, and the environment. Water development and management should be built upon a participatory approach, involving all stakeholders (GWP-TAC, 2000).
Constitution of the Republic of South Africa (No. 108 of 1996)	Chapter 2 – Bill of Rights. Section 24- Environmental Rights (Paterson & Kotze, 2009; Strydom & King, 2015)
National Environmental Management Act (NEMA) (No. 107 of 1998)	Provides the framework for enforcing Section 24- Environmental Authorisation (control of activities that may have a detrimental effect on the environment). Section 28- Duty of care and remediation of environmental damage. (Paterson & Kotze, 2009; Strydom & King, 2015)

National Water Act (Act No.36 of 1998)	It contains rules about how water resources such as rivers, dams, streams are protected, used, managed, and controlled in an integrated way. Equity, efficiency, and sustainability are the principles of the National Water Act which guide the protection, development, use, control, and management of resources. (Paterson & Kotze, 2009; Strydom & King, 2015)
Water Service Act 108 of 1997	Rules about how municipalities should provide for the rights of access to basic water supply and basic sanitation to local communities. Sufficient water and an environment not harmful to health or well-being are necessary (Paterson & Kotze, 2009; Strydom & King, 2015)

2.5.1. Sustainable development and water

The Brundtland Commission made sustainable development popular and placed it in context, defining it as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Barnaby, 1987). The focus of the commission was on economic, socio-political, and ecological/environmental conditions. The concept of sustainable development advocates setting up strong measures to stimulate economic and social development, especially for people in developing countries, as well as making sure that the integrity of the environment is sustained for upcoming generations. Principles of International Environmental Law and Policymaking (e.g., Stockholm and Rio Declarations, and Agenda 21) have been adopted by South Africa (Fuggle & Rabie, 2015). South Africa has hosted important international conferences such as the 2002 World Summit on Sustainable Development. The most important priorities for urban water sustainability include access to safe drinking water, management of wastewater for improved public health, and protection against flooding (Larsen et al., 2016).

The real achievements of sustainable urban development are still inadequate because of challenges, even though it has drawn interest for many years (Rathnayaka et al., 2016). Changes that have been implemented to create greener water and improve wastewater management have drawn attention and proposals. This is because the growth of the integrated urban water system is understood to play a key role in urban water sustainability (Capodaglio et al., 2016). Sustainable development requires that outputs such as waste and pollution, as well as inputs, be handled effectively whether in urban or rural environments. Some of the urban challenges that take priority are water supply, refuse, sewage disposal, energy, informal settlement, and transport (Barrow, 2006).

In the transition towards sustainable development, it is important to include the public in decisions regarding water management. This helps to encourage practitioners in developing a more viable management practice (Rabadan & Saez-Martinez, 2017). The responsibility for water and waste management should be shared between government authorities and businesses. Even so, there is difficulty in determining where public responsibility ends and corporate responsibilities begin (Rabadan & Saez-Martinez, 2017).

To attain the goal of sustainable development, precautionary and proactive measures need to be taken because humans seem to be more exposed (Barrow, 2006). These measures are intended to monitor the handling and disposal of hazardous substances that could negatively and irreversibly destroy the environment. Certain substances pose major risks to the environment due to their toxicity, persistence, and capacity to bioaccumulate. In cases where the behaviour of a particular substance is barely known, that substance is presumed to be a threat. A system that could be used to identify this type of pollutant has not yet been established in South Africa, particularly relative to discharge into water resources (Strydom & King, 2015).

Reflecting briefly from the above, the urban population is growing rapidly in South Africa and this has resulted in most of the poor and vulnerable people living in shacks. These shacks lack basic services, and they are located in the most unsuitable places. This results in many problems like floods, diseases, and degradation of the environment. The City of Cape Town has seen a drastic increase in population growth which put pressure on the government to house these large numbers. As a result, there has been an increase in the mushrooming of informal settlements. Some of these settlements are found along the riverbanks. One of the reasons for building next to riverbanks is to have easy access to water since literature has shown that the government often struggles to provide basic services to the informal settlement. The City of Cape Town has tried to upgrade some informal settlements, but it cannot keep up with the growing urban population.

2.5. Conclusion

The water demand continues to rise, and this calls for more improved management of supplies. Rivers are sensitive and important ecosystems that have been extensively damaged globally and locally. This chapter briefly reviewed the impact of informal settlements on the quality of water in South African rivers. The quality of water is affected mostly by human activities and is declining due to the rise of urbanization, population growth, industrial production, climate change, non-compliance of wastewater treatment plants, agricultural waste, and other factors.

Attempts to provide general coverage for water and sanitation continue to face challenges in South Africa and the most vulnerable and poor communities are largely affected by this failure. The overcrowded informal settlements with inadequate sanitation are a major problem, coupled with the lack of other services like waste collection. Due to a lack of such services, the health of human beings is being negatively impacted by water-related diseases as the water bodies are extensively polluted. The use of polluted water from rivers for washing, swimming, drinking, and cooking has resulted in the spread of water-related diseases. This poses a major threat to the well-being of both the environment and the population. Even though South Africa has powerful laws, there is a challenge with enforcement and compliance. To promote sustainable development, it is vital to incorporate the populace in decisions about water management. This may assist to encourage experts in developing feasible management practices. Water and waste management is understood to be a mutual responsibility of government authorities, businesses, and all stakeholders.

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CHAPTER 3: METHODOLOGY

3.1. Introduction

This chapter describes the research design and methodology selected for the study in Dunoon. It further shows every step, in detail, that was taken in collecting the data. The chapter presents the methods adopted in this research, research procedures and data collection techniques utilized, and the type of research practices used to answer the study's research objectives. It also outlines sample times, sampling procedure and parameters, sample points, and the plan for data analysis. Raw data from Outa sampling reports were also used to analyse the Diep River water quality.

3.2. Research design and methodology

Qualitative and quantitative methodologies were used for this study. The qualitative approach was chosen because it reinforces the understanding and interpretation of meaning as well as the motives and attitudes of humans, while the quantitative approach was chosen because it is more measurable and can be tested, and results are more precise and accurate. A researcher's ontological and epistemological perspective, coupled with their research skills and practices, may influence their choice of research design. The use of both approaches also allowed the researcher to gain more understanding and to collaborate while compensating for the weakness in using each approach alone. It has also allowed that the study is approached from different points of view using different techniques, thus allowing the recognition of the aspects of the phenomenon in a more accurate way.

3.2.1. Sampling Technique

The research has used simple random sampling techniques to select a representation of the population under investigation. A simple random sample is meant to be an unbiased representation of the group and every member of a larger population has an equal chance of being selected (Goddard & Melville, 2001).

According to Census 2011, Dunoon had a population of 29268 (Statistics SA, 2011). The sample size was calculated using Slovin's formula, where (n) is the sample size, (N) is the given Dunoon population size, and (e) is the margin of error (Statistics How To, 2019). The margin of error is defined as the "range of values below and above the sample statistic in a confidence interval". The confidence interval reveals the amount of uncertainty concerning a sample and was calculated based on the statistics of the observed data.

The sample size was computed with 95% of the confidence interval, hence the margin of error was 0.05 (Statistics How To, 2019). It was calculated as n = N / (1+Ne2):

where: n (number of samples) = 395

N (total population) = 29,268

e (error margin / margin of error) = 0.05

Therefore, the sample size was 395.

3.3 Data collection

The data was collected from Dunoon informal settlement and from the Potsdam Wastewater Treatment Plant, which services Dunoon and other areas and is located in Milnerton. Data relating to water contaminant tests made from the Diep River catchment area was requested for different seasons from the City of Cape Town. The reason for the two different seasons was that water quality changes as seasons change. The different seasons may either have a negative or positive impact on water quality. Permission to use the Outa sampling results report for the Diep River area was also requested.

Samples of water from the Diep River were collected to test the quality of water. The pH, dissolved oxygen, water conductivity, and temperature of the stream were measured on-site using a portable HANNA - HI 9829 multi-parameter reader. The water was also tested for *E. Coli* bacteria, total suspended solids, phosphates, and nitrates in an accredited lab.

3.3.1 Primary data

Primary data was collected by the researcher from first-hand sources using surveys, observations through a checklist, and lab tests. There was a questionnaire for the Potsdam Treatment Plant and a questionnaire for the Dunoon community. The tests focused on some of the contaminants from the Diep River water. These tests were done over four months (two tests in winter, and two in summer) at different points of the river. One point was close to the informal settlement, the second point was close to the farm just opposite the informal settlement, the third point was the part of Diep River close to where the treatment plant discharges its treated water, and the fourth point was where there are no settlements, industries or farms. Data collected by Outa from two independent labs (Vinlab and Makoya Amanzi Water) was used. The Outa data was collected from January to May 2020 from seven points namely,

M14 (Diep river at M14 Bridge): located in the Diep River at Blaauwberg Road in the M14 Road-33°50'00.7"S 18°31'17.4"E

PDA (Potsdam pond outflow): Pond located at the Potsdam Waterworks where the treatment plant discharges its treated water into the river. 33°50'31.5"S 18°31'08.9"E

PDB (After Potsdam water treatment works):- 33°50'36.2"S 18°31'05.9"E

TMS (Theo Marais stormwater drain): Theo Marais Canal close to the Koeberg pump station- 33°50'52.7"S 18°31'11.8"E

MCC (Milnerton Canoe club (Woodbridge, parking area island): Milnerton lagoon at Woodbridge Island-33°52'53.2"S 18°29'23.0"E

PDD (After Potsdam sewage works): After Potsdam sewage works close to Theo Marais. - 33°50'46.8"S 18°30'57.7"E

PDC (Potsdam treatment works): Potsdam water treatment plant temporary discharge into the river. 33°50'45.3"S 18°31'03.9"E (Greggor, 2020).

3.3.2 Secondary Data

The data was gathered from readily available resources that included the census, journals, books, working papers, reports, and general news as reported in newspapers to have more current information.

Secondary data was also acquired from the City of Cape Town's Department of Water and Sanitation as they are responsible for managing water catchment areas, water storage, treatment of wastewater, and ensuring that it is disposed of safely back to the environment. The data contained the parameters which are key to this study.

3.4 Data collection methods

Various methods were used to collect data. These methods included observations, a questionnaire for the Dunoon informal settlement, a questionnaire for a City of Cape Town official, documents, and City of Cape Town report(s) from the Department of Water and Sanitation.

3.4.1 Observations

This study also used qualitative observation for several days. Notes and pictures of observed behaviours and activities in the Dunoon informal settlement and Diep River were taken. The following questions were part of the checklist that was used for the study area:

· What are the main sources of water pollution in your area?

· How is the household waste disposed of?

· What type of sanitation is used?

· Are there any forms of pollution in the river?

The purpose of using observations was to gather more reliable data not based on human perceptions but based on the actions and behaviours of participants. Observations are also important in creating data for validating the information that is provided in questionnaires or face-to-face interviews (Hancock et al., 2009). This method gives important information about the environment where a research venture is taken.

3.4.2 Questionnaire to Dunoon informal settlement communities

The target group for the sample was 18 years and older, both males and females residing in the Dunoon informal settlement. Some of the questionnaires were administered by the teachers, who handed them to students to take home to their parents and were collected by the researcher at the school. Some of the questionnaires were given to a community member, who assisted in distributing them among other members of the community. The questionnaire consisted of multiple-choice and open-ended questions, making up a total of 31 questions. It was categorised according to demographic data, socioeconomic data, water pollution and water management, and health impacts. The first part of the questionnaire requested responses regarding gender, age, and education levels. The second part focused on questions about employment status and household income. The third part focused on water use and diseases resulting from such use. The last part of the questionnaire was about pollution and water management practices. The purpose of the questionnaire was to assess the Dunoon community's level of awareness and to assess their knowledge, attitudes, and practices towards river water pollution, waste management, as well as what they thought needed to be done to prevent these problems arising from pollution.

3.4.3 Questionnaire to a City official on Potsdam treatment plant

Data was also collected through an online questionnaire given to a City of Cape Town official for the Potsdam Treatment Plant. The questionnaire aimed to gain more information about plant history, operations, and whether it contributes to the causes of pollution in the Diep River. Some of the questions were:

· What is the quantity of solid waste that the plant recovers from wastewater annually?
· Does the plant have a wastewater risk abetment plan?
· How much of the recovered water is disposed of into Diep River weekly?
· What measures are in place to ensure that water disposed of into the river does not contain contaminants?
· How does the plant manage their sludge?

3.4.4 Documents

According to Creswell (2004), it is vital to widely explore the literature on the research topic before designing a research proposal. The process of collecting data from various documents began at the beginning of the research proposal. This phase of data collection was valuable in establishing the study within a wide-ranging theoretical discussion. Various forms of secondary sources were utilized in the research, and these included reports, journal articles, press articles, working papers, web-based sources, and textbooks dealing with water quality. The secondary sources were used to construct a broad understanding of the topic from an international perspective to the South African context. The process of identifying and appraising all published reviews allowed the researcher to describe the quality of this evidence base, summarise, and compare the reviews' conclusions and discuss the strength of these conclusions. It also assisted in supporting the argument to answer the research question.

3.5 Water sampling in Diep River

Reports have shown that the Diep River is an important freshwater ecosystem utilised for irrigation and recreational activities; however, it has been contaminated by various activities. The Diep River stems from the Riebeek Kasteel Mountains north-east of Malmesbury and flowing for approximately 65 kilometres south-west towards Cape Town before it goes into the sea at Milnerton. The size of the Diep River catchment area is 1,495 km2. The Diep River has been famous for activities such as fishing, swimming, and boating (City of Cape Town, 2016). Over decades, there has been a decline in the water quality of the Diep River because of reasons such as the poor development of informal settlements near the river stream, farming practices, treatment plants, and so on. In the upper catchment, the land is mostly used for agriculture, whereas in the lower catchment it is predominantly used for formal and informal residential settlements and industrial developments.

The Potsdam Wastewater Treatment plant stormwater from primarily residential areas goes into the estuary through several drains which include the Bayside Canal (entering at the north-western corner of Rietvlei) and many others near the eastern and northern boundaries. Those which drain low-cost areas and informal settlement, below and above the Blaauwberg Bridge, are of great concern. Around the Diep River, there are also industrial developments such as the Montague Gardens industrial area, the Caltex Oil Refinery (now Chevron), and a fertilizer factory (City of Cape Town, 2016). The samples were collected at four points of the Diep River over four months, in June and July of 2020 in winter and November and December of 2020 in summer.

3.5.1. Sampling site locations and description

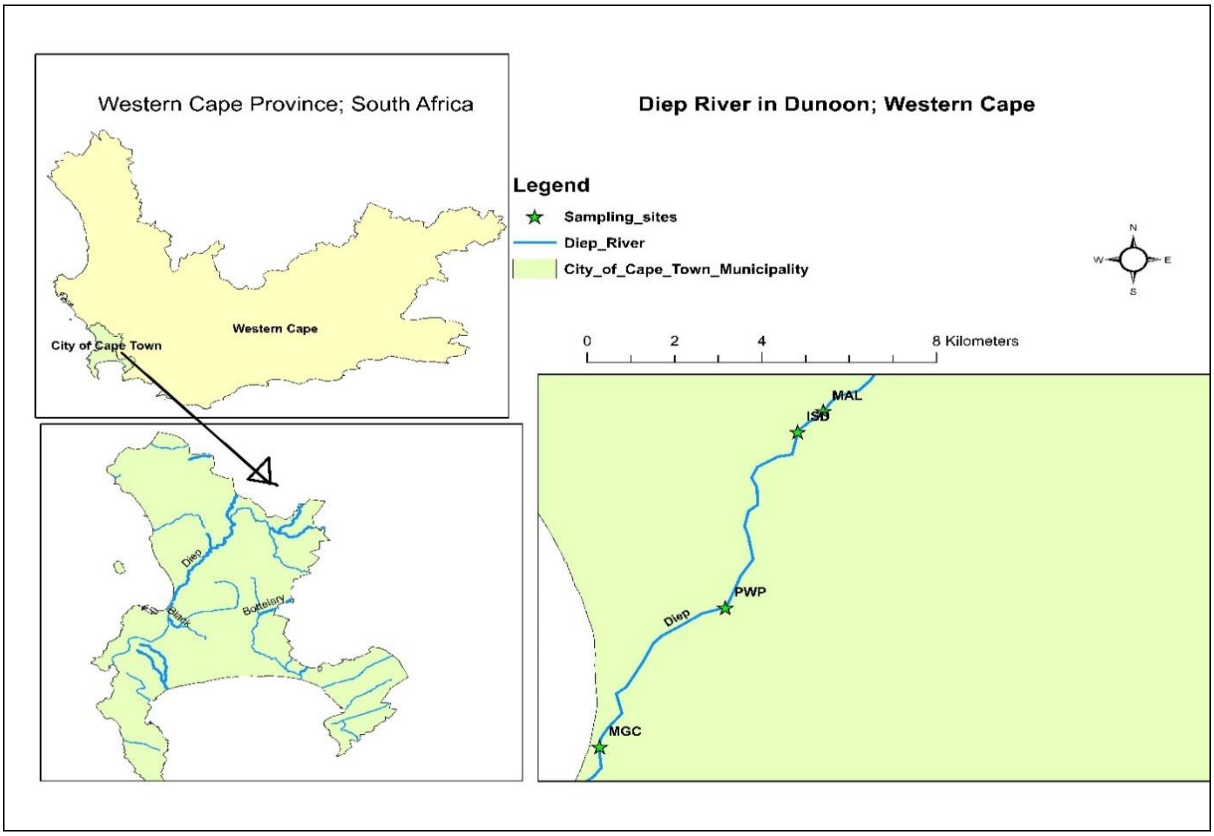

Figure 3.1: Sampling sites

ISD: The closest point of the river to Dunoon's informal settlement (Zwezwe). It is two meters downstream of the bridge at Malibongwe Drive and about 30m to the informal settlement.

MAL: It is located between the Dunoon informal settlement and the farm, and close to the Malibongwe Drive bridge. It is 390m from the Diep River to the farm, about 120m from the Diep River to the farm grazing land, and about 160m from the Dunoon informal settlement (Zwezwe).

PWP: It is situated close to the Potsdam Wastewater Treatment plant, about 482 meters from the closest edge of the plant upstream.

MGC: The point is situated near the Milnerton Golf Club opposite R27, where there is no informal residential area around Diep River. It is about 1m from the Golf Club upstream.

3.5.2. Water sampling procedure

Clean, white plastic 500ml bottles were used for the chemical analysis, and sterile 100ml bottles were used for the *E. Coli*. After rinsing, the plastic bottle was plunged into the stream and filled up with water. The bottle was closed tightly to keep the air from getting into it. In instances where it was not possible to reach the river surface and plunge the plastic bottle into the water to collect a sample, a scoop was used to collect the sample and fill the plastic bottle. The bottles of all samples were each marked with a unique description and date and time when the sample was taken. Samples were kept in a cooler box with ice bricks and stored at a temperature below 4°C. The samples were thereafter taken to the laboratory (Vinlab) where they were analysed for dissolved oxygen, total suspended solids and COD, phosphates, and nitrates. Four sets of samples were collected over four months and, during each set of collections, new and clean bottles were used.

A total of four sampling points was chosen along the river. These sampling points were chosen based on the ease of accessibility of that specific river point. Three of the points were also chosen based on their location near a particular land-use activity carried out along the river. The first sampling point was located within the residential areas, the second point was between the residential area and agricultural area, the third point was close to the Potsdam treatment plant, and the last point was in a non-residential area. It was important to sample at the different land-use areas as they impact water use and water quality in different ways. Below are the sample points identified:

3.5.3 Geographical coordinates for sampling points

Table 3.1: Coordinates for sampling points

Sample Point	Longitude	Latitude
ISD	33°48'23.2"S	18°31'50.5"E
MAL	33°48'02.8"S	18°32'10.1"E
PWP	33°50'46.8"S	18°30'57.7"E
MGC	33°52'53.2"S	18°29'23.0"E

3.6. Water quality parameter analysis

3.6.1. Water quality field parameter analysis

Field sampling was conducted monthly. The pH, dissolved oxygen, water conductivity, turbidity, and temperature of the stream were measured in situ using a portable HANNA - HI 9829 multi-parameter reader over four months (in June and July 2020 which is the wet season, and November and December 2020 which is the dry season). The Hanna HI9828-0 Calibration solution was used for the quick calibration of pH, conductivity, and dissolved oxygen. The Hanna HI9829-18 turbidity calibration solution was used to calibrate turbidity.

Table 3.2: Fieldwork Timetable

Sampling Month	Parameter	Instrument used
June	COD, TSS, NH_4-N, PO_4 and Nitrate, *E. Coli*. Collection of Samples for lab analyses	See below (3.7.2.1- 3.7.2.4)
July	pH, dissolved oxygen, water conductivity, and temperature. Collection of Samples for lab analyses	portable multi-parameter reader (HANNA - HI 9829)
November	pH, dissolved oxygen, water conductivity, and temperature. Collection of Samples for lab analyses.	portable multi-parameter reader (HANNA - HI 9829)
December	pH, dissolved oxygen, water conductivity, and temperature	portable multi-parameter reader (HANNA - HI 9829)

3.6.2 Laboratory analysis and instruments

The testing of some parameters was conducted in Vinlab H_2O. Vinlab is an ISO17025 accredited laboratory as determined by SANAS. It is an independent analysis laboratory located in Stellenbosch and is focused on delivering accurate, timely, and user-friendly results. Parameters analysed in the laboratory were chemical oxygen demand (COD), phosphates, nitrates, ammonia, total suspended solids, and microbial tests.

3.6.2.1. Chemical oxygen demand

The Chemical Oxygen Demand (COD) was analysed using potassium dichromate as an oxidizing agent. The dichromate oxidises COD material in the sample through the digestion method, using reagents such as sulphuric acid, potassium dichromate, potassium hydrogen phthalate. The spectrophotometer was used to analyse the sample at wavelength 610 nm.

3.6.2.2. Total suspended solids

The sample was analysed for total suspended solids using the Hach gravimetric method 8158. A glass fiber filter disc was used as a filter in a filtering flask. Deionized water was pulled through the filter with a vacuum. Thereafter, the fiber filter disc was dried to a constant weight in an oven at 102-105 °C (217–221 °F) to establish the weight of the empty disc. The same fiber filter disc was used to also dry up a well-mixed filtered sample into a constant weight in an oven at 102-105 °C (217–221 °F). The difference in weight between the empty disc and the disc with the remaining materials revealed the total suspended solids.

3.6.2.3. Chemical analyses (NH_4-N, PO_4 and Nitrate)

Nitrate in the water samples was determined using a colourimetric method on the gallery. The colourimetric method is based on the direct correlation between the intensity of the colour of a solution and the concentration of the coloured component (the analyte sample) which it contains.

Ammonia (NH_4-N) was also determined using a colourimetric method on the gallery method. The ammonia analyser colourimeter was set to gauge the intensity of light at a wavelength inside the range of 645–655 nm. Reagents were added to the sample to produce the colour, and the intensity of the colour is proportional to the free ammonia concentration in the sample. Phosphate (PO_4) in the water samples was also analysed using the colourimetric method on the gallery.

3.6.2.4. Microbial test

E. Coli was tested using the Hach USEPA membrane filtration method 8367, m-TEC Agar. This method detects *E. Coli* in recreational freshwater samples and is a two-step process. The first step involves the incubation of membrane filters on m-TEC Agar for 2 hours at 35°C to resuscitate injured organisms. Thermotolerant organisms are then selected by fermentation of lactose at a higher temperature of 44.5°C. The second step involves distinguishing urease-negative *E. Coli* from other thermotolerant coliforms that hydrolyse urea by using a substrate medium containing urea. If the urease-negative colonies are yellow or yellow-brown, it indicates the presence of *E. Coli*.

3.7 Data analysis

The research analysed negative human activities or practices that degrade Diep River water, human attitudes towards water sustainability, and satisfaction with present environmental circumstances. Through observations, the researcher captured data on the ongoing actions and behaviours of community members. To analyse the observations, the researcher reviewed what was observed. Some samples of water from the Diep River were also collected to test the quality of water and were analysed at Vinlab. The oxygen levels in the water, pH, and conductivity of the water were analysed. The water was also tested for *E. Coli* bacteria, total suspended solids, and nitrates. The raw data consisted of sample results that were conducted by Vinlab and Makoya Amanzi water and energy from January to May 2020. Some of the collected data was loaded and analysed using the Statistical Package for Social Sciences (SPSS) software version 26. The statistical technique that was used is regression analysis to distinguish and understand the relationships among some of the independent variables and the dependent variables. Raw data collected by Outa was also used to analyse by the researcher. The Outa data was also analysed using SPSS software version 25 and MS Excel.

3.8. Limitations of the study

Although the research methodology has more strengths, there are few limitations to the research methods embraced by the study. One of the limitations was the lack of constantly monitoring surface water quality in the Diep River. Therefore, the results do not indicate the variability between sample intervals through which interesting patterns may have surfaced. Another shortcoming was the lack of direct analyses of surface runoff in the informal settlement before it got into the river, thus allowing for the impacts of the informal settlement on hydrology to be isolated. Few parameters were used to analyse the quality of water; with more parameters and more sample points, even greater accuracy could have been achieved. Nevertheless, reports from the City of Cape Town helped to bridge the gap.

During observations, the researcher took photos and notes, and some community members were suspicious that the information might be used against them. The Potsdam Wastewater Treatment Plant was closed to the public due to Covid-19 incidents and modification of the plant. This meant that one of the initially proposed points, where Potsdam releases its water to the river, was not accessible. Due to this limitation, the point had to be changed to the nearest accessible area close to the Potsdam plant, which meant that the water would be a little bit diluted. For both the city official and the Dunoon community, there were no face-to-face interviews due to Covid-19. There was also a deviation in the number of questionnaires that were administered to Dunoon residents due to Covid-19 and protests. Instead of administering 395 questionnaires, a total of 260 questionnaires were administered to the community in the Dunoon informal settlement namely Bekela, Ethembeni, Kwa 5, New rest, and Zwezwe. Of the 260 questionnaires, 11 were spoilt, leaving 249 to be used for analysis.

3.9. Ethics consideration

It is crucial to give attention to ethical consideration when conducting research. The protection of research participants' identities is one of the important aspects (Maree, 2016). The City of Cape Town was consulted and informed in detail about the research, how long the study would take and how the findings of the study would be disseminated and used. Permission to conduct sample tests, to get the City of Cape Town reports on Diep River water quality, to interview a City official, and to do the research in the study area was granted by the City of Cape Town. The proposal for the study was also submitted to the CPUT Higher Degrees Committee (HDC) for ethical approval and was approved. Consent forms and confidentiality forms from CPUT were also used. The researcher ensured that the research participants were anonymous, and the information provided was confidential and was only to be used for academic purposes.

CHAPTER 4: Results and Discussions

4.1. Introduction

This chapter presents the results of data collected from all the research participants, including the Dunoon community members and an official from the City of Cape Town. It presents and discusses the results obtained during the fieldwork and observations made in Dunoon and Diep River. It also presents findings on the causes of pollution, the quality of water in the Diep River, and the environmental and health impacts. The results and discussion sections are divided into four parts and all the parts have subheadings. The first part deals with observed activities in Dunoon and Diep River that resulted in the degradation of the environment and poor water quality. The second part presents analysed data on the water quality of some parts of the Diep River catchment area over four months (June, July, November, and December). The third part deals with findings drawn from raw data taken from Outa. The fourth part contains results from the community questionnaires. The results are also analysed and summarised.

4.2. Observations in Dunoon informal Settlement

Informal settlements are areas with insufficient access to potable water, inadequate sanitation, poor drainage systems, a high population density, and unsafe land tenure (UN-Habitat, 2003). According to Borges et al. (2015), a combination of these issues often has outcomes of serious and widespread contamination of surface water. Dunoon informal settlement is also affected by the same problems of population overcrowding, lack of adequate sanitation, unsecured building structures, lack of access to potable water, pollution, and so on.

Figure 4.1: City Truck Delivering water for Dunoon, Zwezwe area

4.2.1. Waste Disposal Practices

Uchegbu (2002) states that the waste produced should be stored correctly for easy collection and disposal by the relevant authority. On-site storage is of main importance due to public health concerns and aesthetic considerations. In the Dunoon informal settlement, the day-to-day waste generated through human activities is left to accumulate in dump-sites near the residential areas. The environment of Dunoon is highly polluted as the community lacks basic services and waste management services. Waste removal is a big problem in the Dunoon informal settlement and this, in turn, degrades the environment.

A majority of the people dispose of waste (illegally) all around the place; in drains, wetlands, empty lands, Diep River, and around Diep River. A few of the people burn their waste in their yards. The burning of waste at dumpsites or individual dwellings causes air pollution. Various emissions from open burning are poisonous. Air pollutants can be a source of harmful health effects (Wiedinmyer et al., 2014). Burning trash can also result in particles finding their way into the river. Some of the problems in the Dunoon informal settlement are sewage overspills and pollution due to solid waste that enters the stormwater drainage system. Several waste elements get carried away with the stormwater and also gather into the Diep River. Though a portion of the waste is carried away with the stormwater, part of the waste blocks and clogs the stormwater drainage system. This can be dangerous because of the risk of flooding and destruction of housing structures and lives, and may also pose health risks.

Figure 4.2: Pollution in Dunoon informal settlement close to Diep River

Figure 4.3: Rubble Pollution in Dunoon informal settlement

Figure 4.4: Illegal Dumping Site close to Dwellings

4.2.2. Disposal of greywater

Greywater is defined as wastewater that is generated from household activities such as bathing, and washing of laundry and dishes (Carden et al., 2007). The most common method to manage greywater in Dunoon informal settlement is to dispose of it onto the ground. A large amount of greywater is either discarded into the stormwater system, causing the pollution of downstream water bodies, or is disposed of onto the ground in the settlement.

According to Carden et al. (2007), the greywater produced in high-density informal mushrooming settlements across the major cities in South Africa is harmful from a pathogenic and salinity perspective and has to be handled as a sanitation problem and not as a drainage issue. An example of this is the Langrug informal settlement in Franschhoek, where residents largely collect water from the toilet blocks using buckets. The water is generally used for bathing, laundry, and household cleaning and this results in the production of 'greywater', which is disposed of outside their residences. The greywater forms streams in drainage channels and flows into the Stiebeuels River, Franschhoek River, and ultimately the Berg River. Pollution levels in the Berg River have been rising every year, and this can substantially have an impact on the quality of fruit grown using the river water for irrigation (Roberts, 2018). This is a similar case to the congested Dunoon informal settlement, where residents also dispose of greywater on open spaces close to the river. The disposed of greywater enters the river through runoffs, causing pollution. Carden et al. (2007) state that it is important to ensure that residents in informal settlements are educated and empowered about managing greywater.

Figure 4.5: Pollution in drains

4.2.3. Sanitation

Environmental hygiene plays an important part in preventing diseases. It also has a bearing on the natural environment and the protection of natural resources such as water. Adequate sanitation is fundamental in improving the environment (South Africa. Department of Water Affairs and Forestry, 2004). Dunoon informal settlement has a challenge of poor sanitation as the community uses shared communal toilets that are generally blocked and unhygienic. People prefer to help themselves in open land. This is evident in that one finds human waste in the paths of Dunoon informal settlement. Most of the shared toilets are unclean and full to the point that they leak to the outside and have no taps close by for people to wash their hands. Literature shows that this is common in most informal settlements within the African continent.

Over 65% of the informal settlement residents lack access to adequate sanitation (UN-Habitat, 2014), and this has been acknowledged as one of the major social issues of the post-apartheid period in South Africa (Masindi & Dunker, 2016). McFarlane (2008) observed that in India, women chose to excrete human waste in open spaces rather than to use messy restrooms. Poor sanitation forces informal settlement dwellers to use nearby open spaces or unhygienic pit latrines (Buttenheim, 2008). This was also observed in the Jarimeri informal settlement in Mumbai. The state of communal toilets in Jarimeri is bad, unclean, and lacks maintenance. Several individuals have made alternative in-house toilets. Those who cannot afford in-house toilets use public toilets or defecate in the banks of the Mithi River (Biswas, 2020). Similarly, some of the residents in the Dunoon informal settlement use open space and the riverbank as defecation zones due to dirty and blocked communal toilets. According to WHO (2019), this lack of adequate sanitation in informal settlements is likely to cause diarrhoeal fatalities.

4.3. Land use in Dunoon informal settlement

In the Dunoon informal settlement, apart from using the land to build their homes, people use the land for subsistence farming. Crops are grown along the Malibongwe Drive and in certain plots inside the informal settlement. There is also pig and goat farming. Piglets and small goats are kept within people’s yards in the informal settlement and moved to the kraals when they grow. During the observation, there was a very bad odour in the farm area of the Dunoon informal settlement. Cows were also observed entering the Table View nature reserve close to the river for grazing. The livestock was also observed grazing and using the river for drinking purposes, especially close to ISD and MAL. There are a lot of holes in the area as the community of Dunoon also practice sand mining to make floors for their houses.

Numerous studies have indicated a relationship between land use and water quality indicators (Buck et al., 2004; Li et al., 2008). Land-use changes in urbanization and agricultural practices harm water quality (Camara, 2019). The different land uses in Dunoon and around the Diep River may result in poor water quality.

Figure 4.6: Livestock grazing close to ISD

Figure 4.7: Livestock watering close to ISD

Figure 4.8: Crop farming Dunoon informal settlement close to Malibongwe Drive

Figure 4.9: Pig and goat farming

4.4. Diep River, Litter

Around and into the Diep River there was a noticeable dumped waste that could be harmful to the environment. The Diep River is polluted with litter such as plastics, paper, cans, bottles, and used nappies just to name a few, especially upstream Dunoon. Waste such as papers, bottles, cigarette butts, construction waste, and plastic bags was observed at the Malibongwe bridge point, between Dunoon informal settlement and the farm. The rest of the waste comes from waste disposed of on land and washed off by rain into the river.

Littering and dumping into and around rivers is a common activity in informal settlements built at the edges of the river. In the same way as Dunoon, the residents of the Alexandra informal settlement litter and dump waste into the Jukskei River due to the lack of urban drainage infrastructure and inadequate waste removal. This has an impact on water quality and the environment. In wet seasons, contaminants are also regularly washed into the Jukskei River (Fitchet, 2017). Rivers are known as the main route for litter flow, especially plastic debris, into the ocean. Research has attempted to estimate the litter discharged by the rivers into the ocean. According to Jambeck's calculations, the scale of the annual land-based plastic released into the marine is between 4.8 and 12.7 million metric tons (Jambeck, 2015). This may compromise the marine ecosystem and the surrounding environment.

Figure 4.10: Pollution in Diep River under Malibongwe Bridge

4.5. Observed Invasive Plants

The Diep River has tall water reeds, especially in the area of Dunoon. The reeds in the Dunoon area were dryer than the reads in Milnerton. There were also floating plants such as the water hyacinth, especially in the area downstream Potsdam wastewater treatment plant. The water hyacinth is an aquatic invasive weed that harms aquatic ecosystems.

These invasive alien plants directly threaten water security, indigenous biological diversity, ecological functioning of natural systems, and productive land use. Approximately 10 million hectares of land in South Africa have been invaded by invasive plants with a projection of 3,303 million m3 per annum water use (Le Maitre et al., 2000).

During the observation, there was also evidence that the City had hired contractors to clear the invasive plants. There were also few birds noticed in the river downstream. The literature has shown that water quality can be altered because of the presence of hyacinth (Tobias et al., 2019). Nitrates and phosphates from sewage, untreated wastewater, and fertilizers that enter the river may worsen the growth of hyacinth (Honlah et al., 2019). In areas with high coverage of hyacinth, the dissolved oxygen decreases, threatening the ecosystem. The invasive plants are also a breeding ground for diseases (Waithaka, 2013). As shown in Figure 4.11, the PWP site had high coverage of hyacinth and this may pose a threat to the ecosystem.

Figure 4.11: Water hyacinth close to Potsdam Wastewater Works

Figure 4.12: Invasive plant clearing

4.6. Flooding in Dunoon informal settlement

During winter rainfalls, the Dunoon informal settlement experiences flooding due to the overflow of water from the Diep River. The informal settlement also lacks stormwater drainage channels, and the few existing ones are filled with household waste, thereby contributing to flooding. These floods often cause damage to homes and furniture.

Most of the poor people in urban areas often live in dangerous and unhealthy environments. They construct their houses and grow their food on riverbanks so that they can have access to water. The people of the Dunoon informal settlement, for example, have been building very close to the river with inadequate building material, seemingly disregarding the danger associated with flooding. This was also observed in Nairobi, Kenya where the Maili Saba slum, part of Dandora, next to the river, experienced flooding regularly during rainy seasons (Douglas et al., 2008). Nairobi informal settlement structures are also built with weak, inadequate building materials just like in Dunoon. The riverine flood damages can be avoided by building away from water bodies and keeping the few drainage channels clean. Figure 4.13 below shows floods experienced by the Dunoon informal settlement in July 2020, and Figure 4.14 shows a blocked drainage channel.

Figure 4.13: Flooding in Dunoon Informal settlement, Zwezwe

Figure 4.14: Closest drain to the river near Malibongwe Drive bridge

4.7. Potsdam wastewater Plant

The main purpose of water treatment is to remove waste products from water and make it suitable for human consumption (Akpor et al., 2015). On the contrary, wastewater treatment plants have been one of the main sources of pollution on water bodies, due to the ageing treatment infrastructure for wastewater and sewage. The government has renewed emphasis on increasing infrastructure investments as part of a bigger policy effort to lay the groundwork for quicker and pro-poor economic growth, and more rapid economic and social integration of the society (Bogetic & Fedderke, 2006). The Potsdam treatment plant, which services Dunoon and other areas, is under modification since 2019. On observation, there was a leakage of pipes from the Potsdam treatment plant into the river (see Figure 4.15). Raw sewage found its way to the Diep River. However, a few days later the leakage was fixed.

Figure 4.15: Raw sewage entering Diep river due to pipe burst

4.8. Water Quality of Diep River

Water quality challenges are mainly induced by human activity. However, it is also imperative to take note that natural causes can affect the quality of water. The hydrodynamics of the Diep River has been altered over the years, and this has resulted in water quality seriously deteriorating. The area is invaded by several alien and indigenous species. These problems are highlighted by a fish kill in December 2006, which led to the Diep Estuary being included in the C.A.P.E. Estuaries Programme mandated to develop the Estuaries Management plan (Jackson et al., 2011). Other factors that contribute to deteriorating water quality in Diep River are the landfills, litter, Potsdam wastewater treatment plant effluent quality, stormwater drainage, poor solid waste management, and poor sanitation in neighbouring areas such as Dunoon and Joe Slovo.

The concentrations of the following parameters from different points will be presented and discussed: pH, dissolved oxygen, water conductivity, *E. Coli* bacteria, total suspended solids, nitrates, phosphates, temperature, and COD. Please see the water sampling results below.

4.8.1. Water sampling results over four months

Water samples collected over four months were tested in the field and laboratory for specific parameters. Table 4.1 and 4.2 below show the results from those tests.

Table 4.1: Field-tested parameters, Diep River

Date	Points	Temperature (°C)	pH	EC (µS /cm)	Turbidity (FNU)	Salinity (PSU)
08/07/2020	MGC	12.46	7.25	3183	4.0	1.68
	PWP	14.28	6.93	2188	180	1.13
	ISD	10.47	7.29	2407	17.5	1.25
	MAL	11.33	7.43	2035	39.2	1.05
04/11/2020	MGC	21.07	8.86	23.99	16.0	14.59
	PWP	21.28	7.33	3067	23.7	1.60
	ISD	19.05	7.60	10.11	122	5.73
	MAL	20.96	7.76	7348	234	4.06
02/12/2020	MGC	21.18	9.07	18.86	19.5	11.23
	PWP	23.02	9.71	2412	19.8	1.24
	ISD	17.85	7.42	3053	19.3	1.60
	MAL	16.70	7.89	4590	1602	2.47

Table 4.2: Laboratory tested parameters, Diep River

	Parameters Tested at the Laboratory							
25/06/2020	**Point**	**TSS**	**COD**	**DO**	**Nitrates**	**Ammonia**	**Phosphates**	***E. Coli***
	MGC	3.00	611		<0.50	13.56	3.89	1400
	PWP	376.00	486		<0.50	22.20	4.33	9000
	ISD	5.00	159		1.70	2.56	1.47	ND
	MAL	12.00	67.2		1.22	4.11	1.06	50
8/07/2020	MGC	7.00	138	3.91	<0.50	9.20	3.08	90
	PWP	130.00	255	3.44	<0.50	9.43	2.84	900

	ISD	18.00	147	3.98	2.63	3.38	1.87	ND
	MAL	26.00	141	4.13	1.45	9.31	1.99	50
04/11/2020	MGC	51.00	281	9.23	0.97	1.91	1.09	800
	PWP	49.00	101	2.296	<0.50	9.91	2.48	76000
	ISD	50.00	174	0.035	<0.50	<0.15	6.07	1100
	MAL	163.00	153	5.072	<0.50	0.43	2.60	300
02/12/2020	MGC	62.00	363	8.977	0.53	1.18	1.44	200
	PWP	38.00	76.6	5.27	<0.50	2.62	1.08	700
	ISD	125.00	205	0.246	<0.50	32.39	5.85	8000
	MAL	97.00	141	4.602	<0.50	<0.15	2.75	500

4.1.1.1. *E. Coli* concentration in all four sampling sites

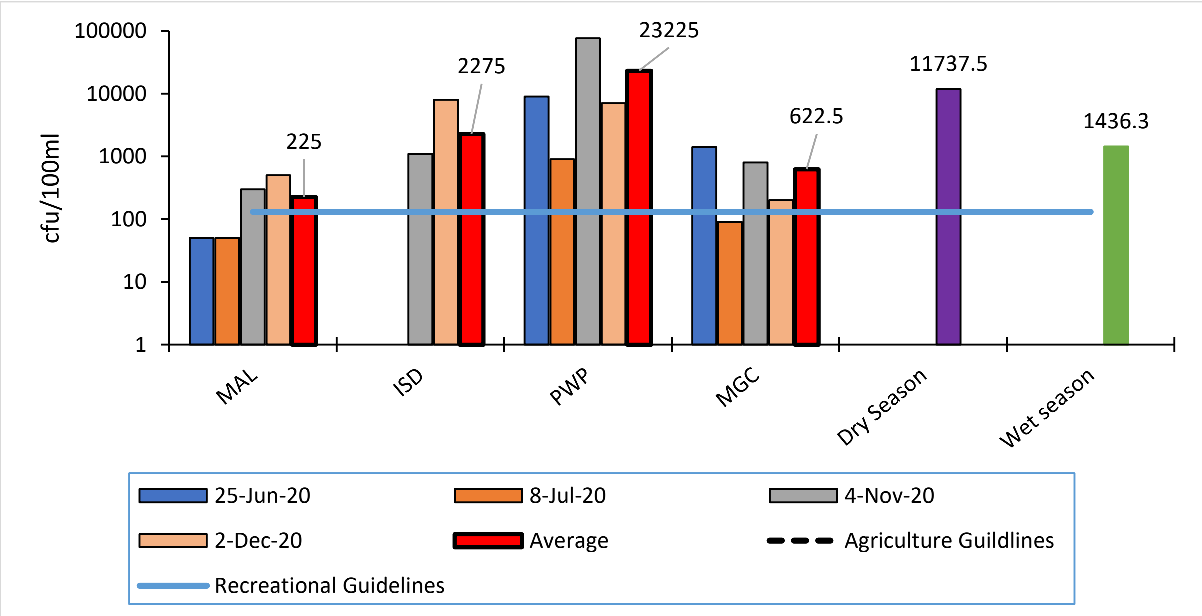

Figure 4.16: *E. Coli* results

Figure 4.16 shows the *E. Coli* results from four different points of the Diep River. The results show that PWP recorded the highest levels of *E. Coli*. The water standard of South Africa states that the *E. Coli* levels should not exceed 0 cfu/100 mL for irrigation and 0-130 cfu/100 mL for recreation purposes. All of the average measurements exceeded these limits. MAL had the lowest average of *E. Coli* with a value of 225 cfu/100 mL. PWP had the highest average with 23225 cfu/100 mL, which is way above the prescribed limits. This high *E. Coli* count could be attributed to the proximity of PWP to the Potsdam Wastewater Treatment Plant as the plant discharges its wastewater into the Diep River. The *E. Coli* levels are higher during the dry season than the wet season.

All the points of the Diep River were contaminated by *E. Coli* in summer, whereas only ISD had *E. Coli* levels undetected during the winter months. This could be because the *E. Coli* levels were diluted by the rain and there were fewer shacks around the river. In most African countries, surface water is threatened by pollution caused by coliform bacteria and the situation poses risks to humans and the environment. Several cases of waterborne diseases have been attributed to *E. Coli* as a contributing agent (Müller et al., 2001; Islam & Islam, 2020).

Figure 4.16 shows that during both the wet and dry seasons, the average levels of *E. Coli* exceeded the limits. This is in line with a study that was conducted in 2009 by Paulse et al. (2009) which also showed that the Diep River was highly contaminated with *E. Coli*, exceeding the maximum limit for the river water throughout the study (Department of Water Affairs and Forestry, 1996a-c). The results in Paulse's study showed that the Theo Marais Sports Club site, which is surrounded by industrial, waste plant, and residential areas, was the most contaminated because of the waste effluent from these areas. According to Hamelin et al. (2006) and Kümmerer (2009), the presence of *E. Coli* in water used for recreational purposes, for irrigation, or drinking purposes creates a possible risk for infections in animals and humans.

4.8.2 Ammonia concentration in all four sampling sites

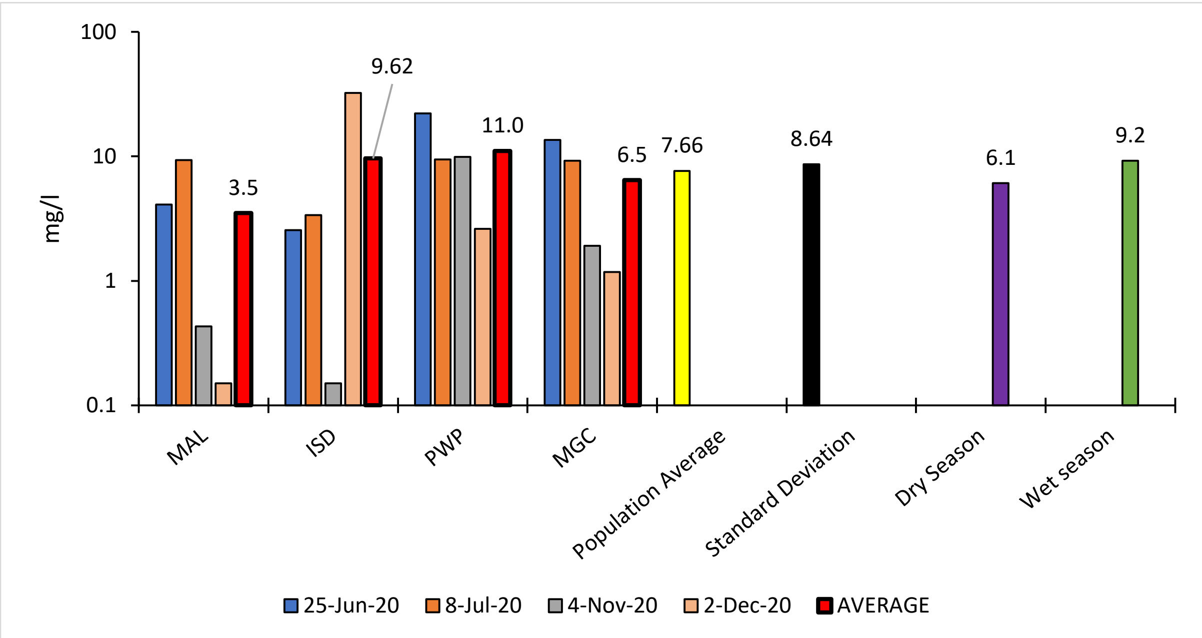

Figure 4.17: Ammonia results

Figure 4.17 shows the results for ammonia in all four sampled sites. The highest level of ammonia recorded in a single day was recorded at ISD, while the lowest was recorded at MAL. The highest average was recorded at PWP with 11.04 mg/L and the lowest was MAL which had 3.5 mg/L. The average ammonia for PWP was 3 times higher than the lowest average recorded. The level of ammonia fluctuates greatly along the river. On average, the wet season had the highest levels of ammonia.

According to the South African National Standards for drinking water, the ammonia content should be ≤1.5 mg/L (South African National Standards 241, 2015). During both the dry and wet seasons, the average levels of ammonia exceeded the recommended limit. The increase during wet seasons may be attributed to waste from farming activities and sewage entering the river through runoffs. Extreme levels of ammonia can change the aquatic ecosystem, causing extensive eutrophication. This may trigger other environmental problems, such as nitrous oxide emission and depleted oxygen in the water bodies (Canfield et al., 2010). Literature has shown that excessive ammonia leads to eutrophication; for example, eutrophic conditions were observed in the Loloan River estuary in Bali, where high concentrations of ammonia were recorded (Suteja & Dirgayusa, 2018)

4.8.3. Phosphate concentration in all four sampling sites

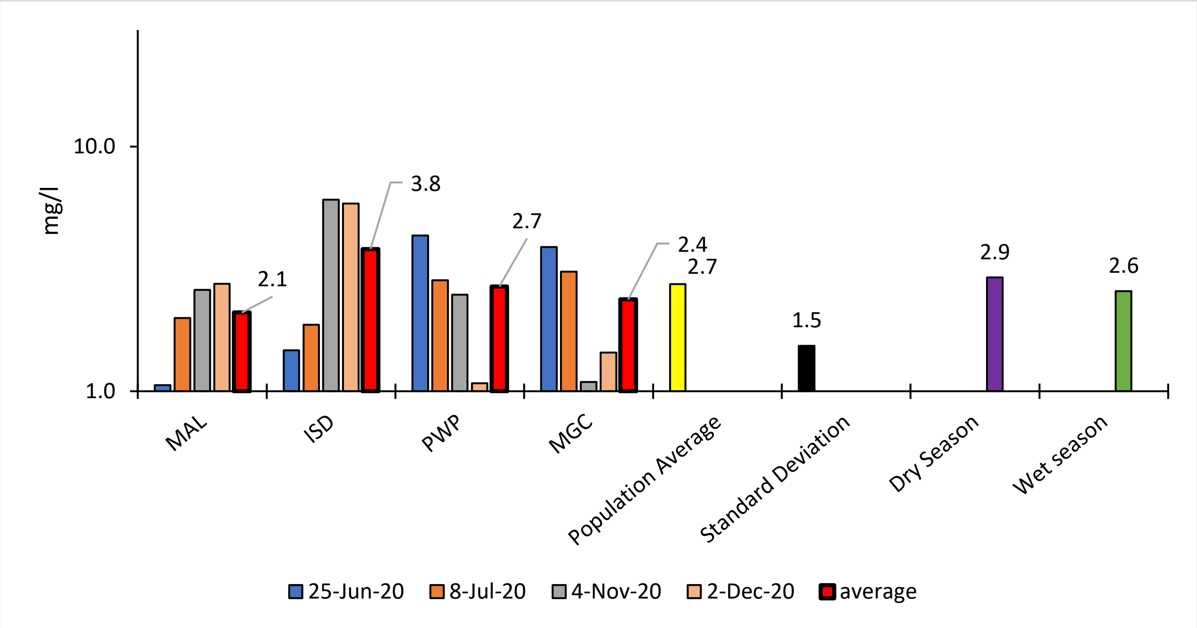

Figure 4.18: Phosphate results

The results of phosphate are shown in Figure 4.18 above. MAL had the lowest average mean phosphate level of 2.1 mg/L, while ISD had the highest average mean (3.8 mg/L). The average level of phosphate recorded for the four locations over four months of recording was 2.75 mg/L. This indicates that most of the results were centred around the mean. There was not much fluctuation of phosphate levels in the river. There were very few differences in the levels of phosphate recorded in all four locations. The dry season had a slightly higher average of 2.9 mg/L compared to 2.6 mg/L in the wet season.

Phosphate originates from animal wastes, sewage, detergents, fertilizers, disturbed land, and road salts used in the winter (Gautam et al., 2014). It is an essential nutrient for the development of organisms, and it is not categorised as a harmful or toxic element for mankind at low concentrations. The results obtained in the phosphate study were not expected as similar studies show higher phosphate, especially during wet seasons. For example, the middle Umgeni River in KwaZulu-Natal experienced high levels of phosphate because of informal settlements lacking sanitation facilities, effluent from cattle feedlots, and poultry farms (South Africa. Department of Water Affairs, 2011).

Despite all the activities in and around the Diep River, phosphate levels were within the limit of South African guidelines for aquatic ecosystems. This was in line with Griffin's results that indicated a steady rise in phosphate levels in South African freshwater over a while, but have decreased sharply in recent times; a trend which cannot simply be ascribed to a single phosphate source (Griffin, 2017). This trend is supported by the Pairwise Comparison which confirmed that the levels of phosphate increased from 1985 to 2008 ($p<0.001$), then decreased until 2013 ($p<0.001$) at sites across the country (Griffin, 2017). Large amounts of phosphorus stimulate the growth of alga (eutrophication phenomenon), thereby limiting the penetration of sunlight and the circulation of carbon dioxide, leading to depleted dissolved oxygen levels in the aquatic ecosystem (Khan et al., 2010). As an example, the eutrophication phenomenon was also experienced in one of the sites by the Umtata catchment area in South Africa where there were high levels of phosphates (Fatoki et al., 2001). A similar incident had occurred in the Diep River in 2006, which led to the death of tons of fish (Jackson et al., 2011).

4.8.4. Nitrate concentration in all four sampling sites

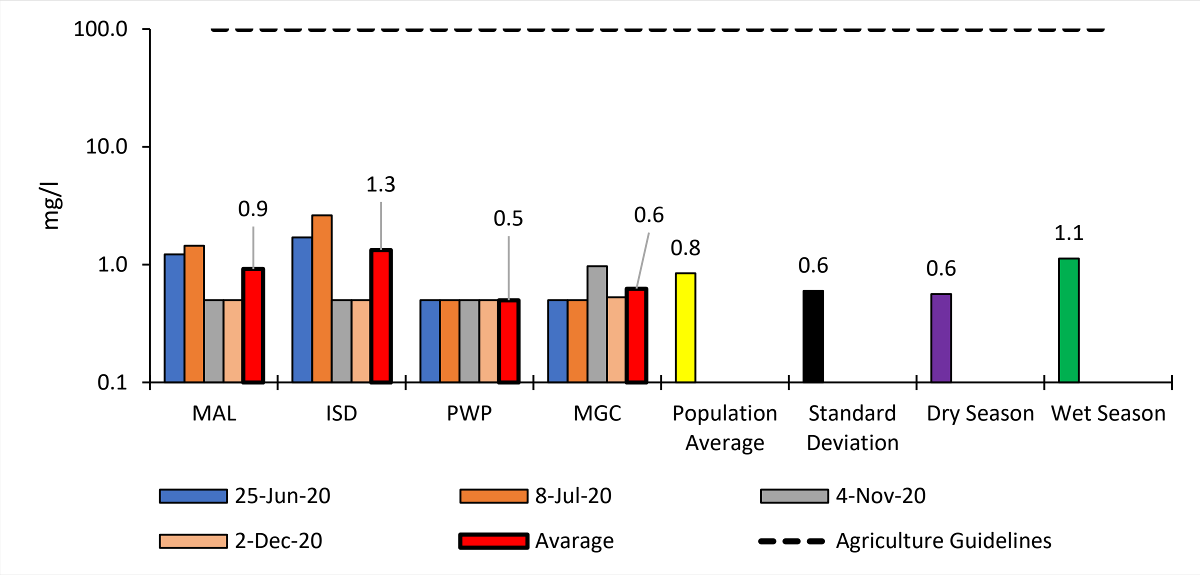

Figure 4.19: Nitrate results

Figure 4.19 shows the analysis of nitrate results from the four different locations where measurements were taken. ISD had the highest average nitrate levels of 1.3 mg/L, while PWP had the lowest with 0.5 mg/L. The South African water guidelines state that the amount of nitrate should be in the range of 0-100 mg/L for agricultural purposes (Department of Water Affairs and Forestry, 1996c). Extreme levels of nitrate are normally due to improper disposal of human and animal waste or the extensive use of chemical fertilizers (Garzon-Vidueira et al., 2020). The lack of sanitation facilities, effluent from cattle feedlots, and domestic waste may be the cause of high levels of nitrate in ISD. In the Dunoon informal settlement, there is also goat and pig farming, and animal waste may end up in the Diep River through runoffs. This is in line with the findings from a study conducted by Garzon-Vidueira et al. (2020).

Nitrates enter streams from natural sources such as decomposing plants, animal waste, and human causes like sewage or fertilizers. Concentrations of over 10 mg/L will affect the freshwater aquatic environment. The nitrate concentration in the river was within the South African water guidelines limit of 0-100 mg/L for agricultural use in both the dry and wet seasons, and also within the South African National Standards limit of 12 mg/L. However, the wet season had higher concentrations than the dry season. The study results showed consistency with Nyamangara et al. (2013) findings which indicated lower concentrations in the dry season and higher concentrations in the wet season. The study was also in line with another study of the Jukskei River in Alexandra, which showed a rise in nitrate concentration in the rainy season (Matowanyika, 2010).

4.8.5. Total Suspended Solids (TSS) concentration in all four sampling sites

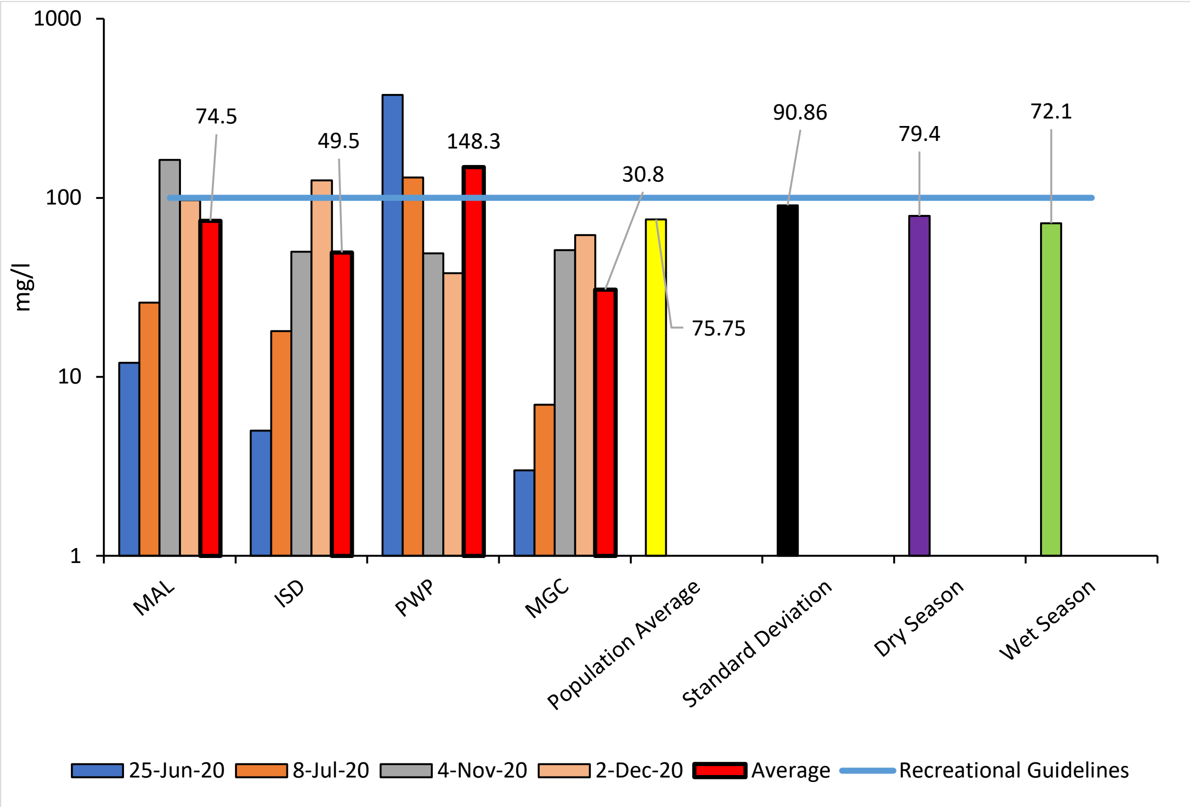

Figure 4.20: Results for Total Suspended Solids (TSS)

Figure 4.20 shows the analysis of TSS results from the four collection points. The results show that PWP had the highest average with 148.3 mg/L, while MGC had the lowest with 30.8 mg/L. According to the South African water guidelines, the TSS levels for aquatic ecosystems should not exceed the limit of 100 mg/L. The analysis shows that only PWP had an average that exceeded the limit. The other three sites had TSS levels below the threshold but there was a major fluctuation in terms of the levels.

The suspended material contains silt, clay, fine particles of organic and inorganic matter, soluble organic compounds, plankton, and other microscopic organisms. The existence of suspended solids is normally related to a reduction in the clarity of water; for example, light penetration or visibility (South Africa. Department of Environmental Affairs, 2018). Total suspended solids (TSS) carried by rain runoff water are recognised as one of the main sources of polluted sediments from urban settlements (Rossi et al., 2005). Torres & Bertrand-Krajewski (2008) also agree that several pollutants in urban rainy-weather discharges are connected to particles carried in suspension.

The seasonal averages in this study were below the 100 mg/L limit. TSS levels were high during the dry season, which had 79.4 mg/L, compared to 72.1 mg/L in the wet season. These results contradicted those obtained in the study conducted in the Jukskei River, Alexandra by

Matowanyika (2010), where the total suspended solids increased during the wet season and were low during the dry season. However, the results were similar to those obtained from the Chobe River in Botswana in a study by Fox & Alexander (2015), which showed higher TSS levels during the dry season and lower TSS during the wet season. This may be due to the different climatic regions, but it remains to be investigated by future studies.

4.8.6. Chemical Oxygen Demand (COD) concentration in all four sampling sites

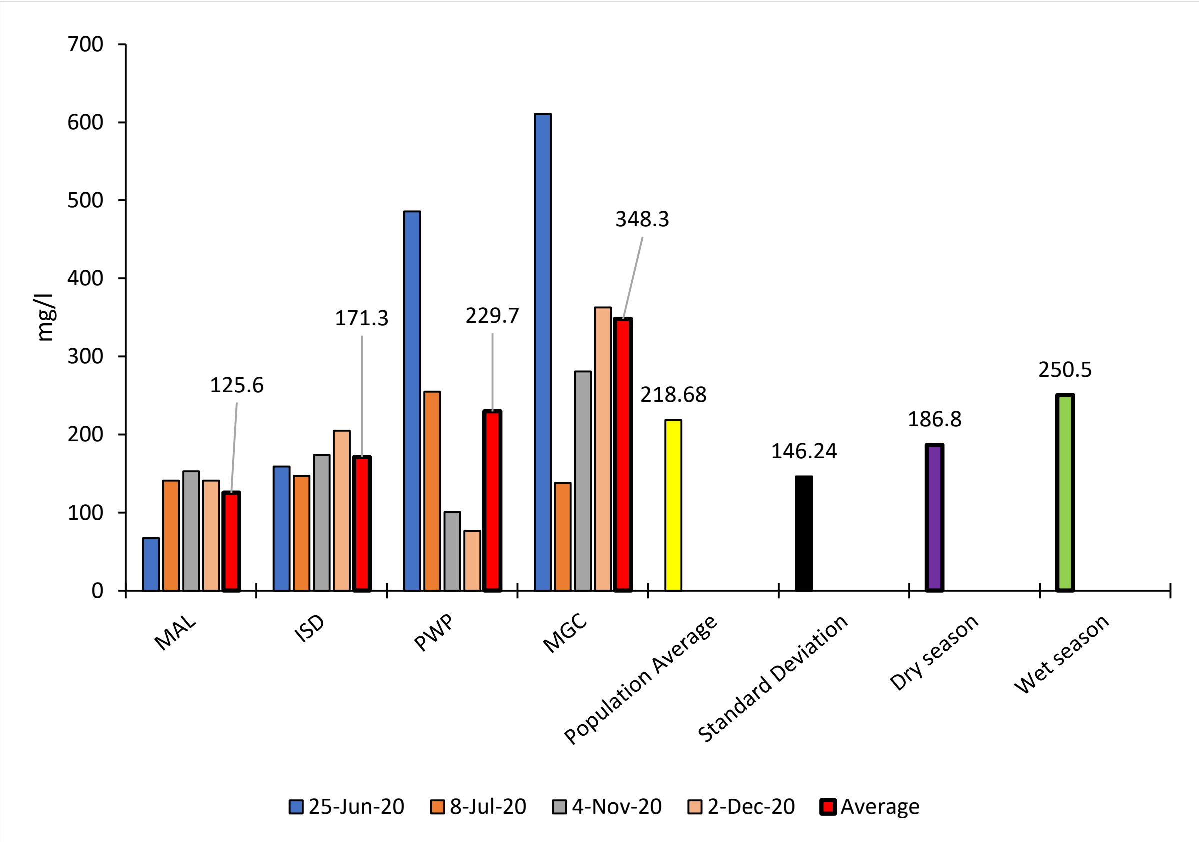

Figure 4.21: Chemical Oxygen Demand (COD) results

Figure 4.21 shows the results of COD for samples that were collected in four different sites. MGC had the highest levels of COD with an average of 348.3 mg/L. The lowest recorded levels were at MAL with an average of 125.6 mg/L. This shows that the COD recorded at MGC was 2.5 times higher than that of MAL. The average level of COD recorded for the four locations over four months was 218.7 mg/L. The results show that the levels of COD are not centred around the mean, indicating some fluctuations. The dry season had a lower average than the wet season.

High levels of COD indicate the existence of all kinds of biodegradable and nonbiodegradable organic matter, causing high levels of pollution (Islam, 2019; American Public Health Association, 2005). COD may also increase as a result of the death of bacteria cells. As the cells decompose they release dissolved organic carbon, thus increasing COD. Low levels of

COD in river systems indicate good water quality, while high levels indicate pollution and may cause harm to aquatic life, especially fish (Edokpayi et al., 2017). Surface water should have low COD to sustain human beings and fish. The South African water guidelines for wastewater recommend that COD levels should not exceed 75 mg/L (South Africa, 2013). The average COD results at all individual sites exceeded this limit, indicating that the river was highly polluted. The high concentration of COD in this study may be attributed to sewage and fertilizer that enters the river through runoffs, industrial effluents, and the Potsdam wastewater plant outfalls.

4.8.7. Dissolved Oxygen (DO) concentration in all four sampling sites

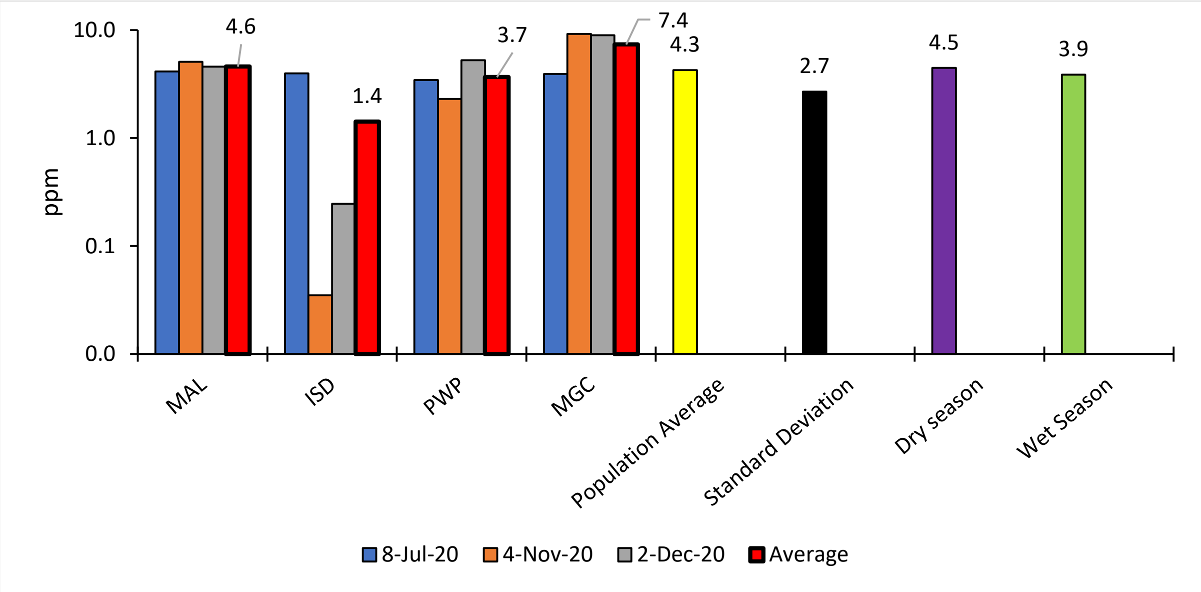

Figure 4.22: Dissolved Oxygen (DO) Results

Figure 4.22 shows the results of DO for the four collection points. MGC had the highest DO average at 7.4 ppm while ISD had the lowest at 1.4 ppm. The difference between the MGC and ISD DO levels is very high, with the MGC average being 5 times higher than that at ISD. There is not much difference between the wet and dry season DO levels. The dry season average is slightly high with 4.5 ppm, compared to 3.9 ppm during the wet season. Dissolved Oxygen measures the amount of oxygen that is dissolved in water (USGS, 2009). Some of the human issues that have an impact on dissolved oxygen in streams involve the addition of oxygen-consuming organic wastes; for example, sewage, changing the river flow, increasing the water temperature, and the adding of chemicals.

The low dissolved oxygen in ISD can be attributed to the slow-moving water at the point because of many reeds. Other contributing factors may be pollution through solid waste, sewage, and fertilizer that enter the river through runoffs. The PWP levels of dissolved oxygen may be attributed to the wastewater plant and other diffused sources. MAL is the closest point to ISD, but there is a huge variation in the levels of dissolved oxygen. The level of dissolved oxygen is mostly attributed to fertilizer, plastics, and solid waste entering the river. Of the four points, MGC had the highest dissolved oxygen levels. This may be attributed to the rapid movement of water at that point.

Dissolved oxygen is one of the major elements that influence biochemical activities in water bodies. DO levels can be impacted by industrial, municipal, and agricultural waste discharges and sewer overflows into the river (Haider et al., 2013; Haider, 2010). The low amount of dissolved oxygen may threaten the ecosystem. Plastic and solid waste in the river may also affect the levels of dissolved oxygen, thereby affecting the ecosystem (Kulkarni, 2016). Slow-moving water tends to have low dissolved oxygen than rapid-moving water. Bacteria from sewage and fertilizers can affect oxygen levels in rivers as the organic matter decomposes (Oram, 2020). According to Edokpayi et al. (2017), DO levels less than 5 mg/L could harm the aquatic ecosystem. In all sites except MGC, the levels were less than 5 mg/L, meaning that the aquatic life is compromised at the three sites. The average DO values during the wet and dry seasons were less than the 5 mg/L.

4.8.8. Water temperature in all four sampling sites

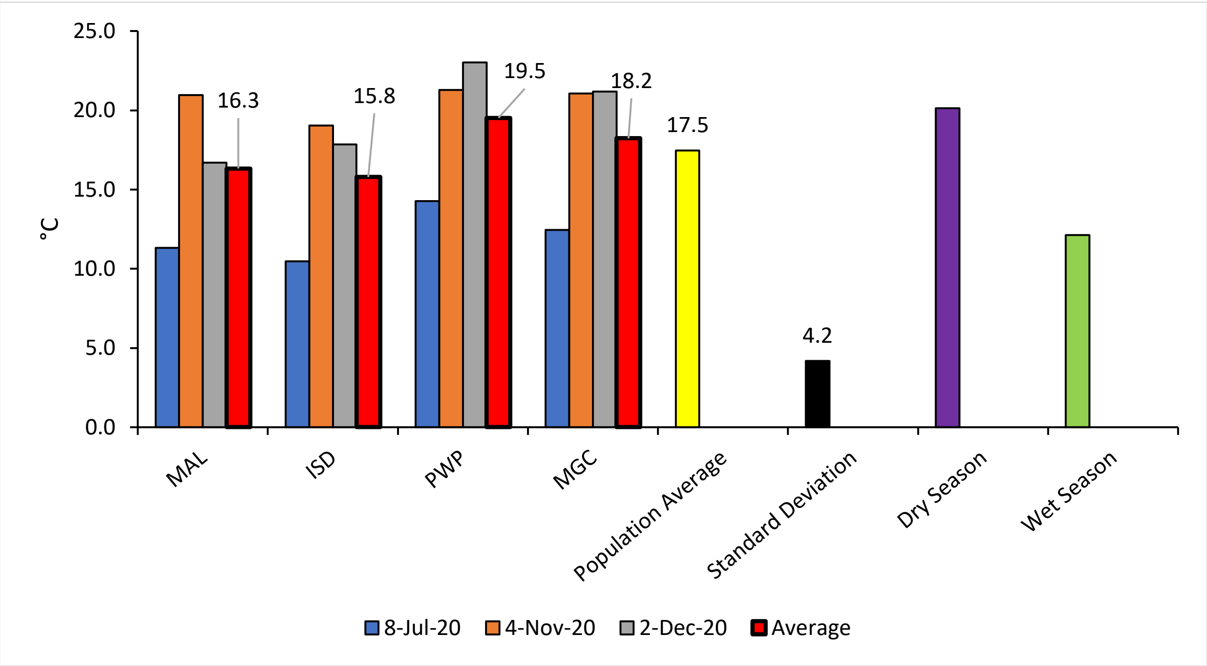

Figure 4.23: Water temperature results

Figure 4.23 shows the results of water temperature at the four collection points. PWP had the highest average water temperature of 19.5°C, while ISD had the lowest average water temperature of 15.8 °C. The results show that the average water temperatures of the different sites were around the same mean. The average temperature reading for all the sites during the wet season was 12.1°C. This is because the wet season was in winter, while the dry season was in summer. The temperature results were slightly different from those in a previous study of the Diep River conducted by Awe et al. (2020) in which, for the four seasons, the average temperature range was 14.0°C and 24.2°C, while the range in this study was between 15.8°C and 19.5°C. The slight temperature difference could be attributed to the fact that the samples were taken on different days and times. Both studies indicated that temperatures were generally lowest in winter and highest in summer (Department of Water Affairs and Forestry, 1996a, 1996).

Various factors affect water temperature, and these include air temperature, groundwater inflows, stormwater runoffs, turbidity, and sunlight exposure. It is essential to consider both maximum and optimum temperatures when it comes to the health of organisms. The tastiness, viscosity, solubility, smell, and chemical reactions are affected by temperature (American Public Health Association, 2005). The variation in river water temperature generally depends on the season, physical location, time of sampling, and temperature of effluents entering the stream (Ahipathy & Puttaiah, 2006).

Sometimes the temperature variations may be the reason for an increase of alien species and a decrease in the diversity of native species (Wolf et al., 2014). High temperatures may increase the toxicity of the water for domestic use. The observed water temperature was also below the 25°C acceptable limits for no risk, recommended by the World Health Organization (World Health Organization, 2004).

4.8.9. The pH results in all four sampling sites

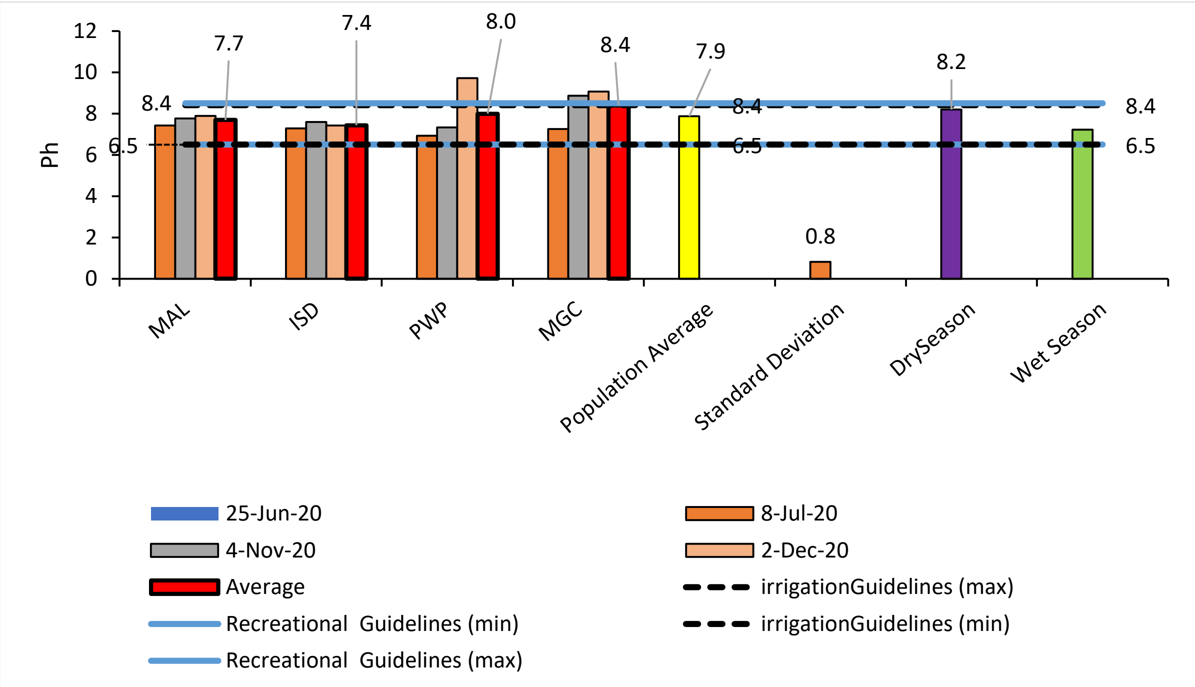

Figure 4.24: pH results

The above graph (Figure 4.24) shows the analysis of pH results from the four sampled sites of this study. MGC had the highest pH average of 8.4, while the lowest was at ISD with a pH of 7.4. The pH of all the sites was clustered around the mean of 7.9. The South African water guidelines indicate that water should have a pH range of 6.5 to 8.4 for irrigation purposes and 6.5 to 8.5 for recreational use (Department of Water Affairs and Forestry, 1996a). The average pH of all the sites fell within these ranges. Only PWP and MGC recorded pH levels of greater than 9. The average pH during the dry season was 8.2, compared to 7.2 during the wet season.

The pH measures the concentration of hydrogen ion and it indicates the relative acidity or alkalinity of water. For drinking water, the ideal pH range is 6.5 to 8.5, as defined within the WHO standards (World Health Organization, 2006). When the values of pH are high, it signifies that there is a high level of chloride, bicarbonate, or carbonate, to name a few. That means the water is alkaline (Uddin et al., 2014). For domestic water use, the permissible pH range in South Africa is 6 to 9 and, based on the results, the average of all sites fell within this range (Department of Water Affairs and Forestry, 1996).

The pH results in this study were slightly higher than those obtained by Awe et al. (2020) in a previous study conducted in Diep River, even though they were both within the recommended limits for domestic, recreational, and agricultural water use (Department of Water Affairs and Forestry, 1996, 1996a). The average water pH range recorded in Awe's study was 7.16 to 7.98, whereas the pH range in this study was 7.4 to 8.4.

4.8.10. Electrical Conductivity (EC) in all four sampling sites

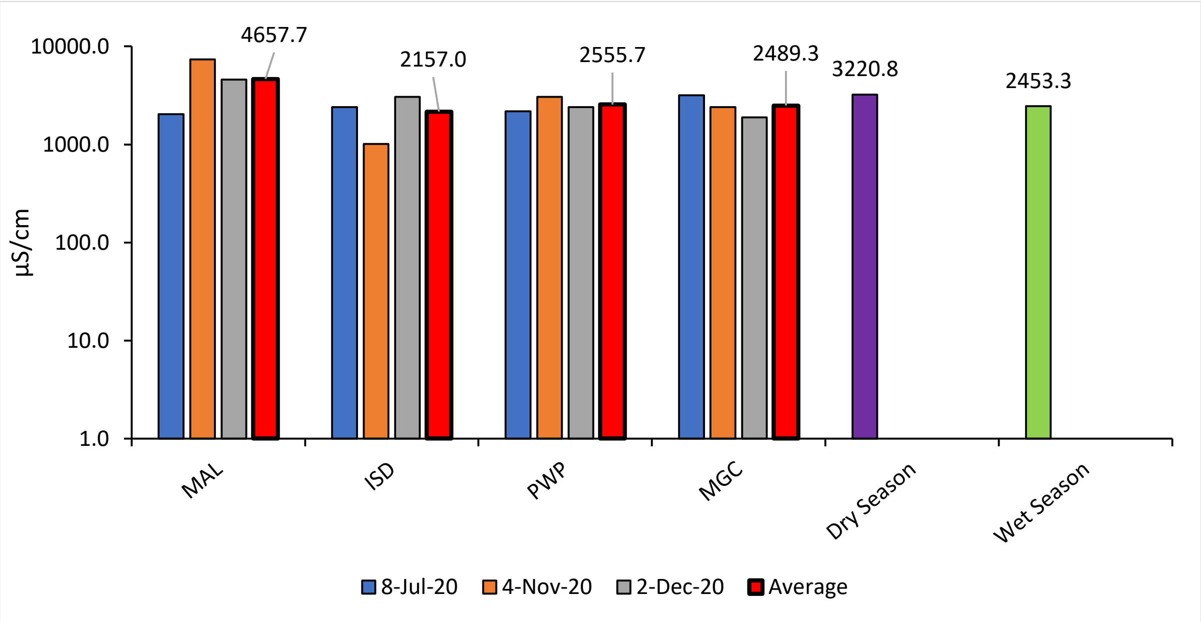

Figure 4.25: Electrical Conductivity (EC) results

Figure 4.25 shows the EC results for the four sampling sites. MAL had the highest EC levels at 4657.7 µS/cm, while ISD had the lowest, recording 2157 µS/cm. The MAL EC levels were twice as high as that of ISD. MAL was an outlier with high levels of EC, whereas the rest of the sites were clustered around the same mean. The EC levels during the dry season were over 1000 µS/cm higher than those of the wet season. According to South African National Standards, the conductivity at 25°C should be ≤170 mS/m, whereas the South African water guidelines limits for irrigation are 0 – 40 mS/m (equivalent to 0 - 400 µS/cm). Both these limits were exceeded at all the points, especially MAL.

Electrical Conductivity refers to the measure of a solution's capability, such as water in a stream, to pass an electric current. It indicates the concentration of dissolved electrolyte ions in the water. An indication of an increase in conductivity may signify that polluting discharges have entered the water. In the ideal world, freshwater streams should have a conductivity between 150 to 500 µS/cm to support diverse aquatic life (Tchobanoglous et al., 2003). Since Dunoon is located in a farming area, the high EC in ISD and MAL may be attributed to runoffs from the higher input of salts from agricultural and domestic waste. This view is supported by Korkanç et al. (2017), who has indicated that an increase in conductivity can be attributed to anthropogenic discharges and runoff of wastewater into water bodies, thereby making the water unsuitable for domestic use and irrigation purposes.

MGC is far from agricultural activities and very close to Lagoon beach. The high EC at this point may be attributed to seawater intrusion, as Kumar et al. (2015) and Sylus & Ramesh (2015) have indicated that the intrusion of seawater into rivers in delta regions and coastal lines may also alter the EC, pH, and TDS. In a study that was conducted in the Benue River in Nigeria, the results indicated lower conductivity during the dry season. This trend may be attributed to an increase in the concentration of organic and inorganic materials and salts because of runoff from domestic and other human activities into the river during the wet season, discharges by the feeder streams, and industrial effluents (Anhwange et al., 2012).

A similar study by Awe et al. (2020) showed that electrical conductivity values at the Milnerton Woodbridge (DC) site were higher than the acceptable range of 0 to 1500 µS/cm set by the Department of Water and Sanitation of South Africa (1996b), whereas the Table Bay Nature Reserve (DA) and Theo Marais (DB) sites were below 1500 µS/cm in all seasons except spring. The possible contributing factors to the high EC values were wastewater runoff into the rivers, river flows, and tidal waves.

4.8.11. Salinity concentration on all four sampling sites

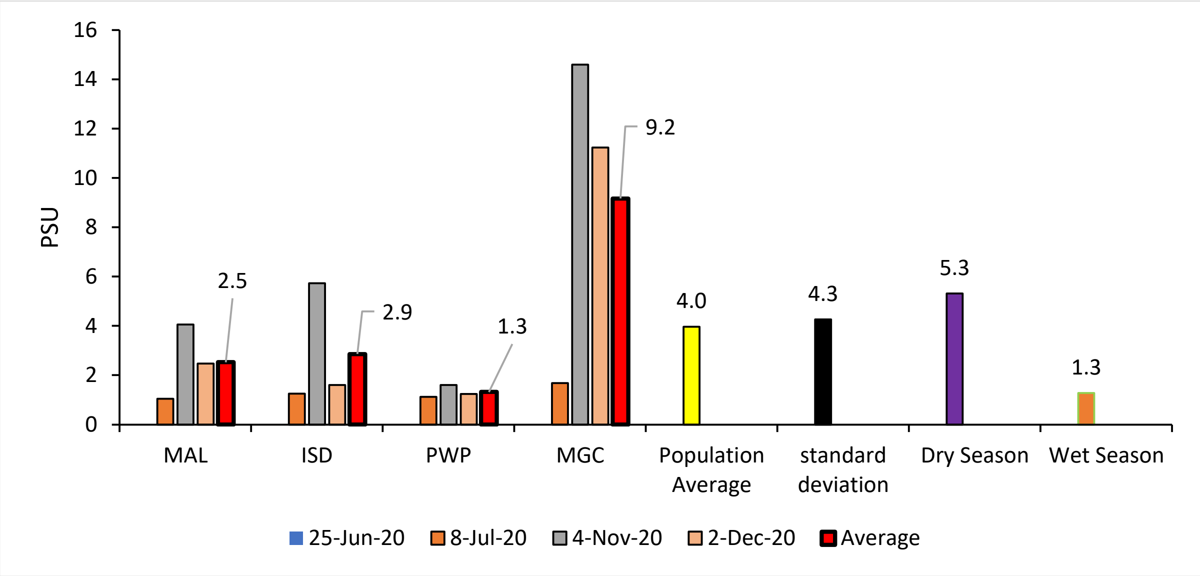

Figure 4.26: Salinity Results

The above graph (Figure 4.26) shows the analysis of salinity results for the four sites. MGC had the highest level of salinity with an average of 9.2 psu. PWP had the lowest level at 1.3 psu. There was a huge difference between the highest and the lowest levels of salinity recorded. MGC was an outlier and the other three sites were centred around the same mean. MGC in this analysis recorded the highest level of salinity on all the different days on which the measurements were taken. The level of salinity in the dry season was 4.1 times higher than that of the wet season.

Salinity is used to describe the total concentration of dissolved salts in water (Hussain et al., 2017). Naturally, the river or lake water with a salinity of about 70 mg/L will have a specific conductivity of between 80 and 130 μS/cm at 25 °C. The real ratio depends on the existing ions (Van Niekerk et al., 2014). An increase in the volume or concentration of salinity in streams destroys town water supplies, affects agriculture and horticulture, and adversely impacts on river ecosystems. Salinity can cause a decline in plant growth and water quality, resulting in lower crop yields and degradation of water supplies. Excessive salt has an impact on total soil health, decreasing productivity. It destroys plants, leaving bare soil that is susceptible to erosion (Minhas et al., 2020). MGC is close to the lagoon beach and has more levels of salinity and this may be because of seawater intrusion.

In a study conducted by Awe et al. (2020), the seasonal salinity values recorded at the different Diep River study sites ranged from 915 to 5231 mg/L, while the seasonal range in this study was from 1.3 psu to 9.2 psu (equivalent to 1300 to 5300 mg/L). In Awe's study, most of the seasonal salinity values recorded at the studied Diep River sites were higher than the recommended acceptable value of less than 1000 mg/L for the protection of freshwater life

(Kaushal et al., 2005). In this study, the Diep River exceeded the acceptable limit at all sites, with the dry season showing a higher average than the wet season. Awe's study recorded the highest salinity levels during spring.

4.8.12. Turbidity in all four sampling sites

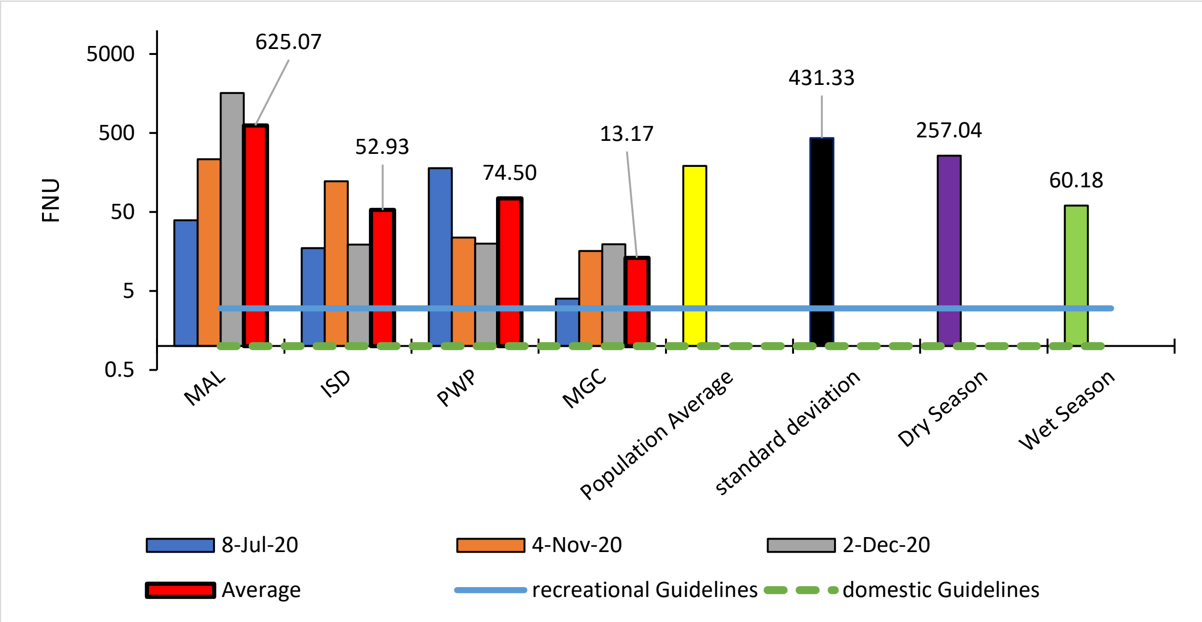

Figure 4.27: Turbidity Results

Figure 4.27 shows the results of turbidity in the river for the four different sites. The MAL had the highest average levels of turbidity at 625.07 FNU, while the lowest was 13.17 FNU at MGC. This means that the average turbidity level of MAL was 47 times higher than that of MGC. For recreational purposes, the turbidity levels should not exceed 3 NTU, whereas for domestic purposes the accepted range is 0-1 NTU. (The NTU unit is equivalent to FNU). The turbidity levels at all four sampling sites exceeded this limit. The level of turbidity in the dry season was 4 times higher than that of the wet season. The average population for turbidity was 191.42 FNU.

Most studies show that during and after rainfalls, turbidity increases greatly because of sediments that are washed off into the stream. For example, in a study conducted by Eliku & Leta (2018) in the Awash River in Ethiopia, the highest recorded mean turbidity value was 139.61 NTU during the wet season due to surface runoff from nearby agricultural land, while the lowest recorded average turbidity value was 36.4 NTU during the dry season. Similarly, in the Mvudi River in South Africa, the turbidity values recorded in winter during the dry season were 1.3–14.7 NTU, indicating a decrease as expected, while those recorded in the wet season were high, ranging between 13.3 NTU and 473 NTU. The high values can be due to high frequencies of rainfall, leading to erosion and surface runoff transporting suspended materials into the water bodies (Edokpayi et al., 2015).

However, the study results showed higher turbidity in dry seasons, and this may be attributed to the disturbance of land activities in and around the Diep River, such as the expansion of the Dunoon informal settlement close to the river and the cleaning of the river (removing silt) during summer.

4.8.13. Correlation between turbidity and TSS

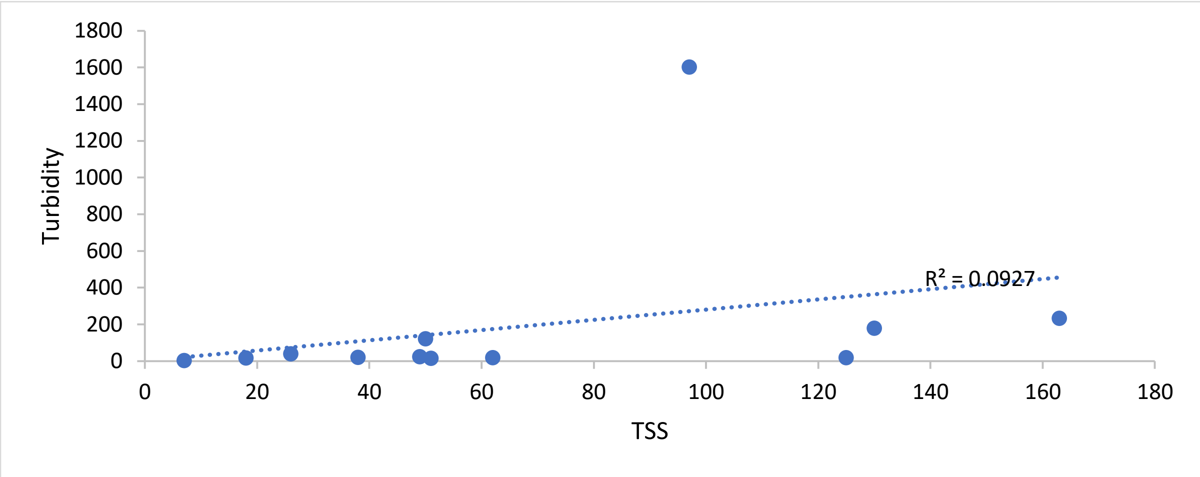

Figure 4.28: Correlation between turbidity and TSS

Figure 4.28 shows the linear regression analysis of TSS and turbidity. The results show that the square of the correlation (R^2) is 9%, which means that the variation in TSS is not explained by turbidity. The correlation value is 0.30, indicating that there is no correlation between TSS and turbidity.

An increase in turbidity can signify a rise in the erosion of stream banks, which may have a lasting effect on water bodies (Langland & Cronin, 2003)**.** The construction activities of the informal settlement in Dunoon may result in an increase in river water pollution, especially sediment concentration, in the Diep River. Turbidity and TSS have similarities in the measurement of some particles, but they are different, which makes it very difficult to establish any kind of correlation between the two.

4.8.14. Correlation between *E. Coli* and Temperature

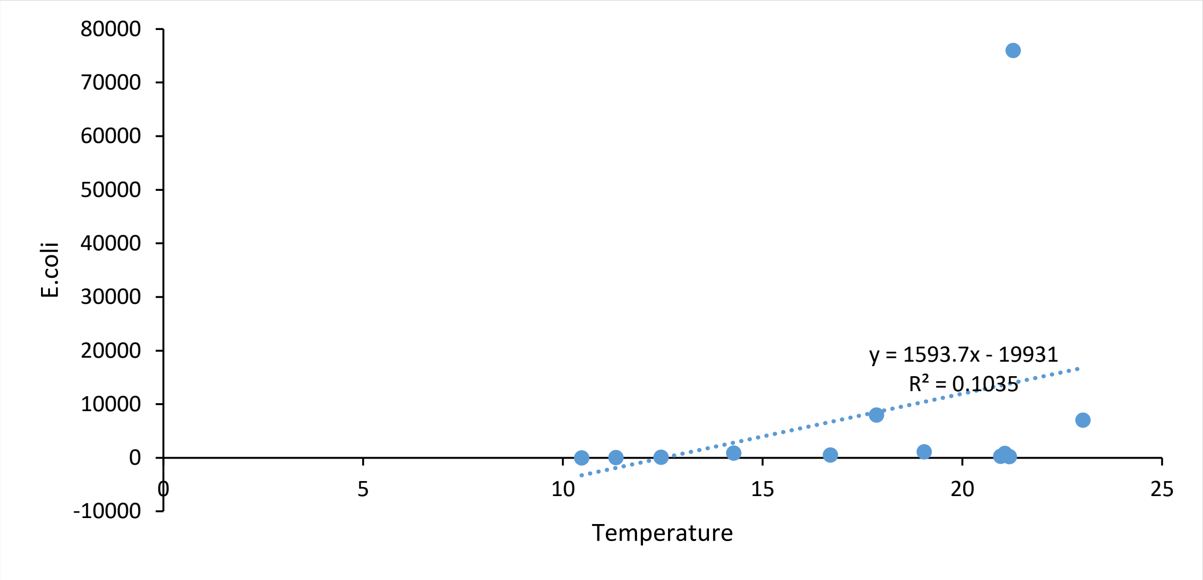

Figure 4.29: Correlation between *E. Coli* and Temperature

Figure 4.29 shows the linear regression analysis of *E. Coli* and temperature. The results show R^2 of 10%. This shows that the variation in *E. Coli* is not explained by temperature. The correlation value is 0.32, which indicates that there is no correlation between *E. Coli* and temperature.

According to Kumar & Libchaber (2013), *E. Coli* can multiply with pressure between 1 and 400atm and temperature between 23°C and 40°C. The *E. Coli* cells also increase with an increase in temperature and their rate of survival depends on temperature (Blaustein, 2013). On the contrary, some studies have shown that an increase in temperature may kill pathogens, thus reducing their concentrations (Walters et al., 2011; Vermeulen & Hofstra, 2013). Despite this, few studies have shown a positive correlation between bacterial concentrations and water temperature because of the coincidence of summer temperature and intervals of heavy rainfalls, and high levels of discharge (Schilling et al., 2009). This study indicated that there was no correlation between *E. Coli* and temperature, and this could be because the highest average temperature in the research study was 19.5°C and the lowest 15.8°C. The temperatures were much lower than the temperature required to grow and divide the *E. Coli* cells.

4.8.15. Correlation between temperature and pH

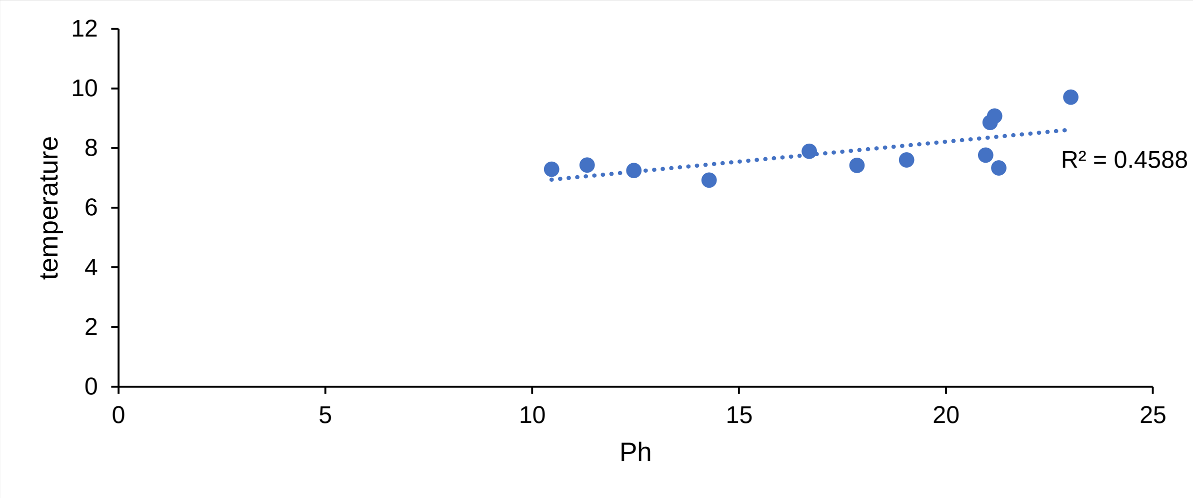

Figure 4.30: Correlation between temperature and pH

Figure 4.30 shows the linear regression results between temperature and pH. The results show R^2 of 45%, which indicates that pH is not explained by temperature. The correlation value of 0.68 is close to 1 and this shows a positive correlation between temperature and water. This means that as temperature increases pH also increases. All samples have a unique relationship between temperature and pH, expressed with a temperature co-efficient. Nevertheless, this is different for each sample, so it is not easy to compensate for it. As temperature increases, the degree of photosynthesis increases, which may increase pH value and the alkalinity of water. Hence the results may show a positive correlation.

In the Betwa River in India, the pH recorded a positive correlation of 0.9356 with temperature and this may be because of the existence of numerous macrophytes (Zaidi & Pal, 2015). Similarly, this study also shows a positive correlation of pH with temperature.

4.9. Usage of standards

The South African water guideline standards were used to analyse the research findings, but it is important to also consider the Diep River catchment objectives when doing analyses as the objectives have specific limits for different points in the catchment area according to how the river water is used. According to a South African Government Gazette promulgated on the 6th of November 2020, Diep River is one of the sub-catchments under the Berg Catchment area. The Integrated Units of Analysis (IUAs) are classified according to three management classes, namely Class I, Class II, and Class III, where Class I indicates high environmental protection and minimal utilization, the second class indicates moderate environmental protection and moderate usage, and the third class indicates sustainable minimal environmental protection and high utilization. The Diep River catchment area falls under Class

III. The Diep River parameter limits may differ in different places e.g., *E. Coli* limits according to objectives may be ≥2500 in the farming areas and ≤500 in Rietvlei/Diep River (South Africa, 2020). This also explains why the Diep River water is highly polluted.

4.10. Analysis of water quality results from Outa sampling

Figure 4.31 below shows the different sites where samples were taken along the lower Diep River catchment. Water quality tests were done on the various locations and the results were displayed graphically. The water quality tests included *E. Coli*, pH, electrical conductivity, total suspended solids, nitrate, orthophosphates, COD, faecal coliforms, ammonia (NH3), Ammonium (NH4), and Phosphorous.

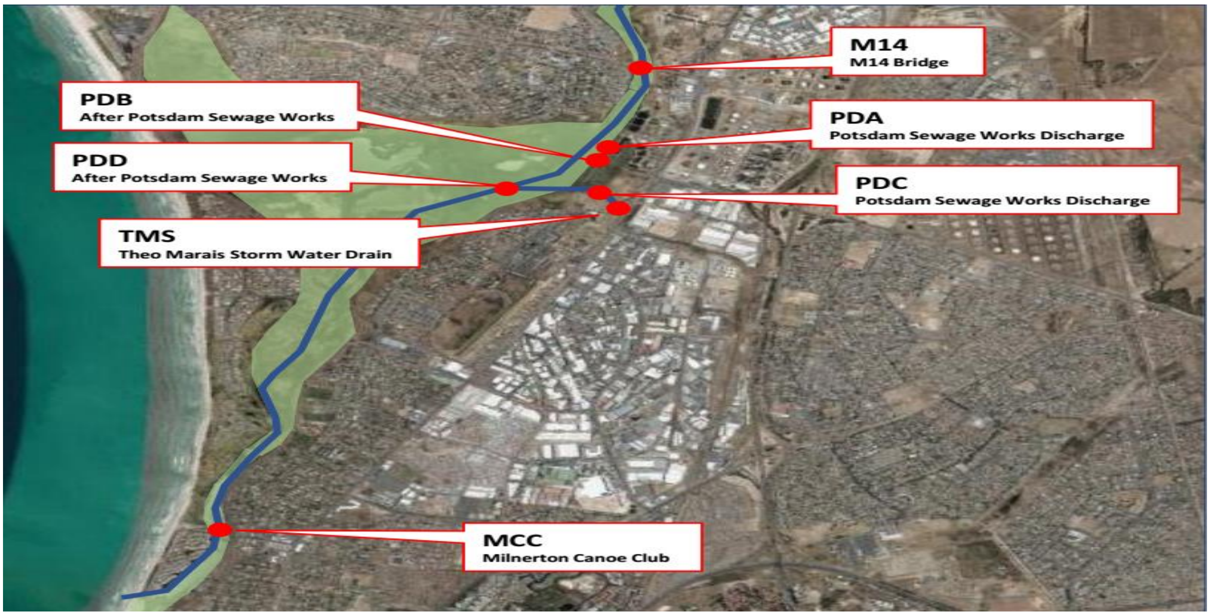

Figure 4.31: Sampling Locations (Greggor, 2020)

4.10.1. *E. Coli* results

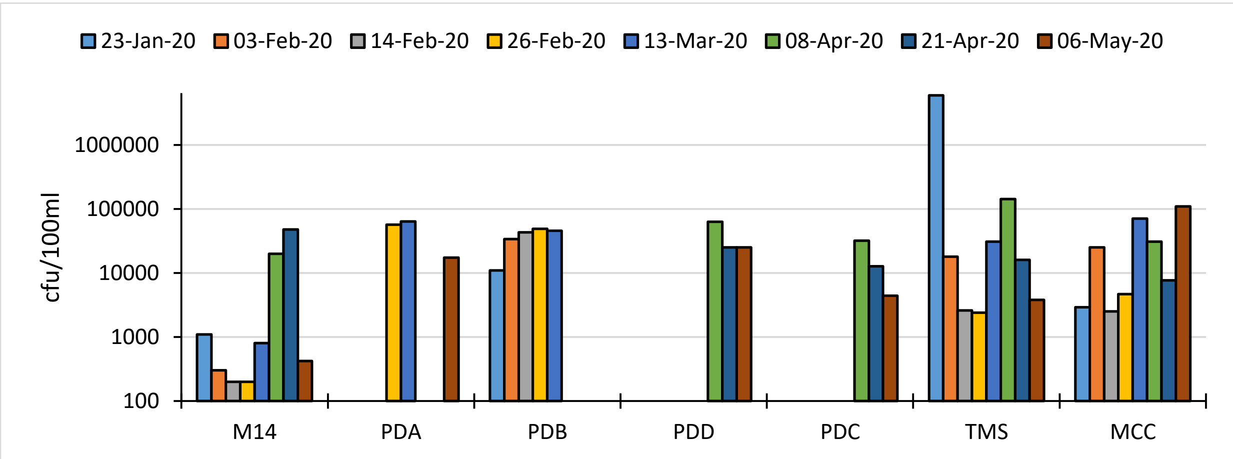

Figure 4.32: *E. Coli* at different points of Diep River

Figure 4.32 shows Outa's results indicating the level of *E. Coli* measured in cfu/100 mL from seven points of the Diep River starting from M14 (M14 Bridge) to MCC (Milnerton Canoe Club). The results from tests indicate that most of the sites had *E. Coli* levels above 1000 cfu/100 mL. This is way above the prescribed level as per the City of Cape Town guidelines. Theo Marais Stormwater Drain (TMS) recorded the highest level with 6000000 cfu/100 mL, and the lowest recorded was at M14 which had 200 cfu/100 mL. Of all the sites, Theo Marais Storm Water Drain had the highest average *E. Coli* levels of 777100 cfu/100 mL, while the lowest average was at Milnerton Canoe Club (MCC) with 31850 cfu/100 mL. TMS average had the highest average as it had two of the highest readings of *E. Coli*. Most of the results were around the average of 31850 cfu/100 mL. The *E. Coli* count of most of the sites also exceeded the South African guideline limit of 1000 cfu/100 mL for irrigation, except for M14, which was sometimes within the required limit.

In comparison, the highest *E. Coli* count in this study was 76000 cfu/100 mL. PWP had the highest average with 23225 cfu/100 mL, which is way above the prescribed level (see Figure 4.16). Even though there was a huge difference between the results from the City of Cape Town, Outa, and this study, they all showed that the *E. Coli* levels exceeded the required threshold. The difference may be because all samples were collected at different times, seasons, and points.

4.10.2. Comparison of *E. Coli* results from the City of Cape Town and OUTA

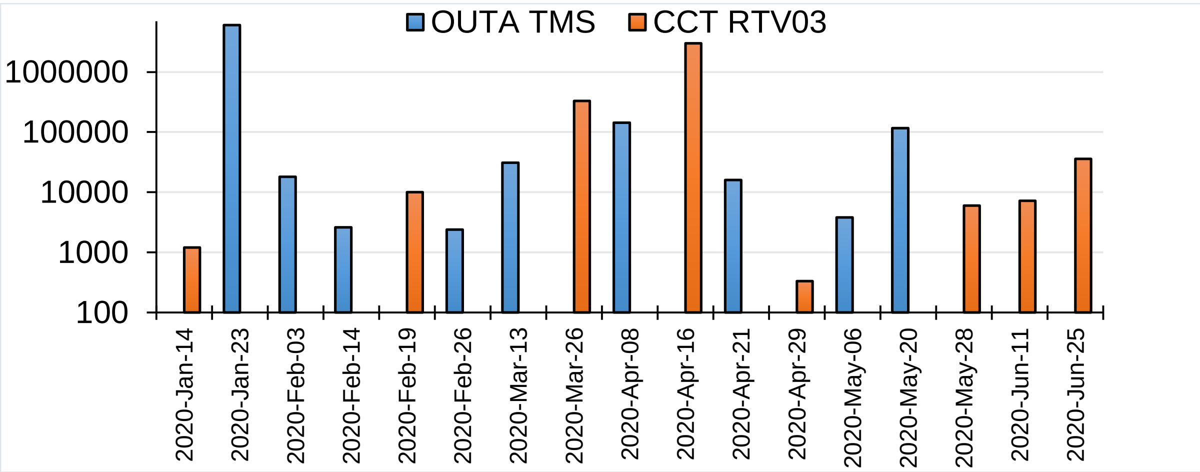

Figure 4.33: *E. Coli* Comparison between OUTA Theo Marais Storm Water Drain and City of Cape Town RVTO3

A comparison was made between the *E. Coli* results obtained from the City of Cape Town and OUTA, as shown in Figure 4.33. There is a huge difference between the results of the test conducted by the City of Cape Town and those conducted by OUTA. This may be attributed to the fact that the samples and tests were never taken on the same day to have a definite comparison. The first test was carried out on the 14th of January by the City of Cape Town and it recorded *E. Coli* levels of 1200 cfu/100 mL. Eight days later, OUTA tested the water at the same site and the *E. Coli* levels were 6000000 cfu/100 mL. Two weeks later some tests were carried out by OUTA and the *E. Coli* levels were at 18000 cfu/100 mL, which shows major fluctuations.

The most comparable results were taken 5 days apart and showed 2600 cfu/100 mL for OUTA compared to 10000 cfu/100 mL for the City of Cape Town 5 days later. This clearly shows that there is a huge fluctuation when it comes to *E. Coli* levels. The highest level of *E. Coli* recorded by the City of Cape Town was 3000000 cfu/100 mL while OUTA recorded 6000000 cfu/100 mL. The average level was 703756 cfu/100 mL and 423842 cfu/100 mL for OUTA and the City of Cape Town, respectively, which again is a huge difference. Both the Outa and City results in most of the sites exceeded the South African guideline limit of 0-100 cfu/100 mL for irrigation and 0-130 cfu/100 mL for recreational use.

The most comparable results were in the City of Cape Town's RTV03 (Theo Marais) and this study's PWP, recorded in June. PWP is the closest point to RTV03. The City of Cape Town recorded higher values at 36000, while the value at PWP was 9000. The difference may be because RTV03 is closest to industries, oil refinery, and Potsdam Wastewater Plant, while PWP is downstream and there was already dilution at the point.

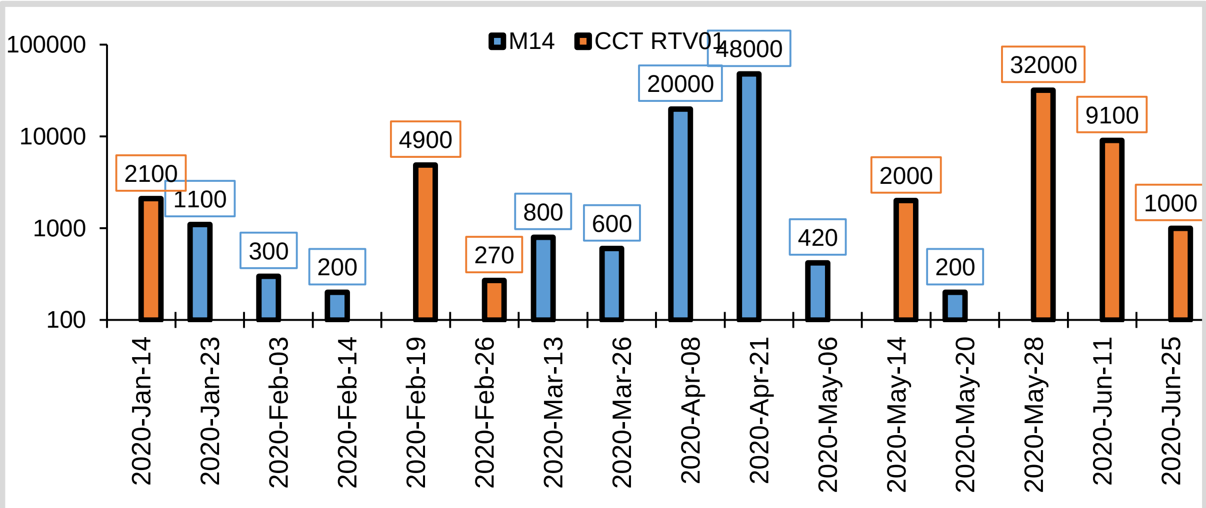

Figure 4.34: *E. Coli* comparison between OUTA M14 and City of Cape TownRTV01

Figure 4.34 shows another comparison of OUTA results and City of Cape Town results. Again, the most comparable results are from samples taken 5 days apart. The results from these tests indicate that on the 14th of February 2020 OUTA tested the water and it had *E. Coli* levels of 200 cfu/100 mL. On the 19th of February 2020, the *E. Coli* levels recorded by the City of Cape Town were 4900 cfu/100 mL. The highest *E. Coli* level for OUTA was 48000 cfu/100 mL and the average was 7958 cfu/100 mL. For the City of Cape Town, the highest was 32000 cfu/100 mL and the average was 7339 cfu/100 mL.

The most comparable sites in June were Outa's M14, just before Potsdam Wastewater Plant, and PWP from this study, downstream Potsdam Wastewater Plant. PWP had 9000 cfu/100 mL of *E. Coli*, while M14 had 9100 cfu/100 mL.

4.10.3. pH results

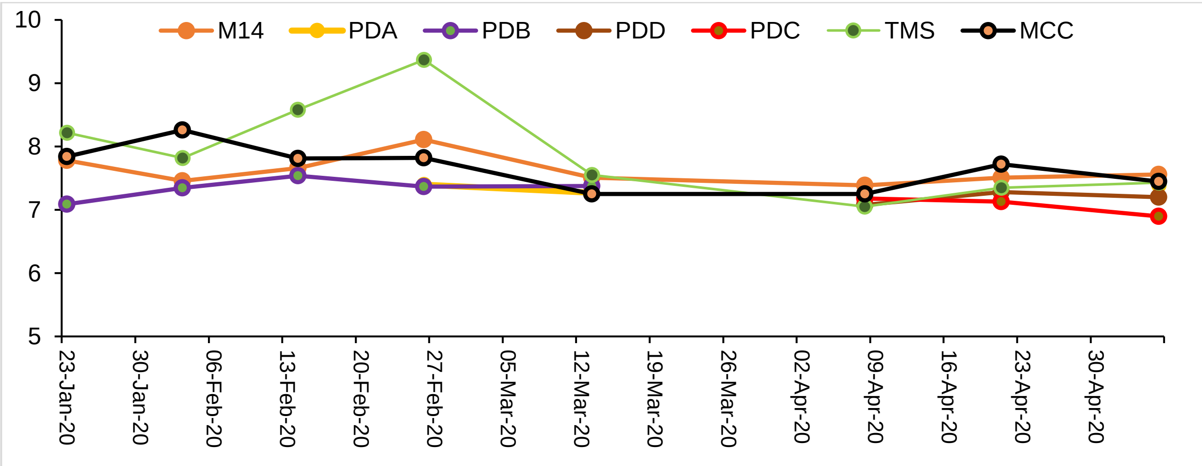

Figure 4.35: pH at different points of Diep River

Figure 4.35 shows Outa's pH results for the different locations along the Diep River catchment. Most of the results from the pH test were centred around the mean of 7,45. The water pH is mainly neutral except for TMS which had the highest pH level of 9,37, while PDC had the lowest pH level of 6,9. There was not much difference in the pH levels between Outa's findings and those of this study. The pH findings of this study were slightly higher than those of Outa, with the highest pH being 9.7 in PWP (compared to TMS pH level of 9.37), and the lowest pH being 6.93 in PWP (compared to TMS pH level of 6.9).

4.10.4. Electrical conductivity results

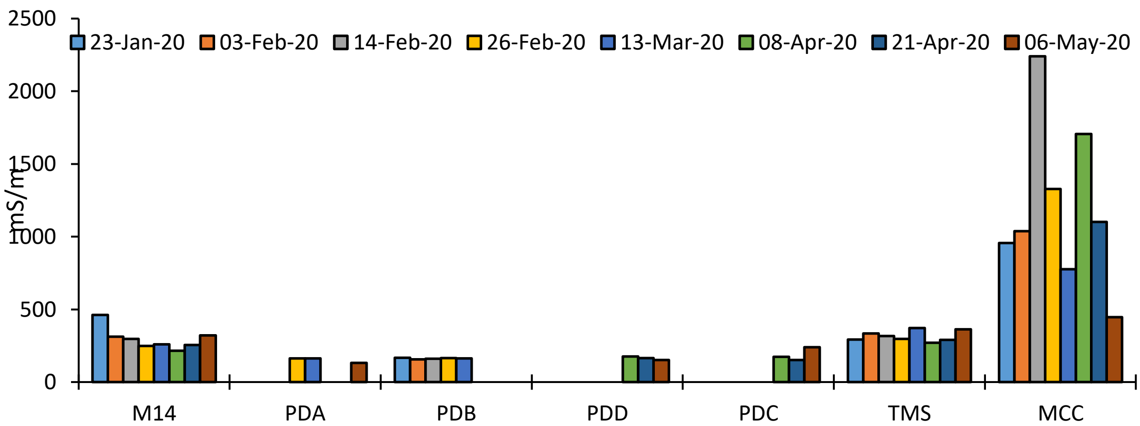

Figure 4.36: Electrical conductivity at different points of the Diep River

Figure 4.36 shows the analysis of Outa's electrical conductivity results at the different sites along the Diep River catchment. Electrical conductivity was high at MCC, which recorded the highest levels of 2240 mS/m and had an average of 1199,3 mS/m. The lowest recorded was 132 mS/m at PDA. The lowest average was at PDA and this may be attributed to fewer tests conducted at the site. The rest of the sites had an average electrical conductivity of less than 300 mS/m. All sites exceeded the South African guideline limit of 0.0 – 40.00 mS/m for irrigation, and also exceeded the South African eutrophication threshold of 50 mS/m.

There is also a huge difference between Outa's water electrical conductivity results and those of the researcher in this study. MCC recorded the highest levels of EC at 2240 mS/m, compared to the researcher's Malibongwe bridge point with the highest EC levels of 4657.7 µS/cm (equivalent to 465.77 mS/m). PDA had the lowest levels of 132 mS/m, compared to the researcher's Dunoon informal settlement point which had the lowest levels at 2157 µS/cm (equivalent to 215.7 mS/m).

4.10.5. Suspended solids results

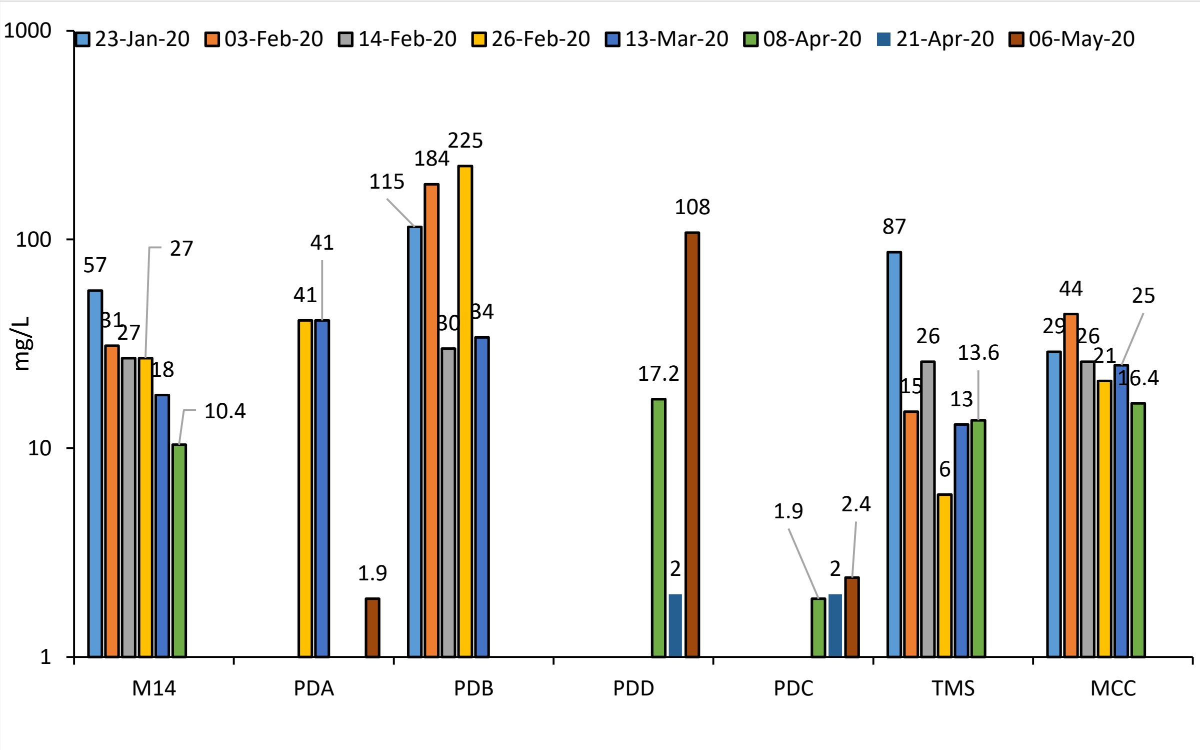

Figure 4.37: Suspended solids at different points of Diep River

The level of total suspended solids was measured by Outa and figure 4.37 shows the results of the analysis. Total suspended solids were high at PDB, which recorded 225 mg/L and an average of 118 mg/L. The lowest amount of suspended solids was 1,9 mg/L, recorded at PDA and PDC. The average for all the sites was less than 30 mg/L except for After Potsdam

Sewage Works (PDD). Most of the sites were within the South African eutrophication threshold of 100 mg/L from January to May, except for PDB.

The levels of total suspended solids recorded by the researcher in this study were higher than those recorded by Outa. Outa's PBD recorded the highest levels at 225 mg/L and the highest average of 118 mg/L, compared to PWP's highest levels of 376 mg/L and the highest average of 148.25 mg/L. Outa's PDA recorded the lowest levels at 1.9 mg/L, compared to MGC at 3 mg/L in this study.

4.10.6. Nitrate solids results

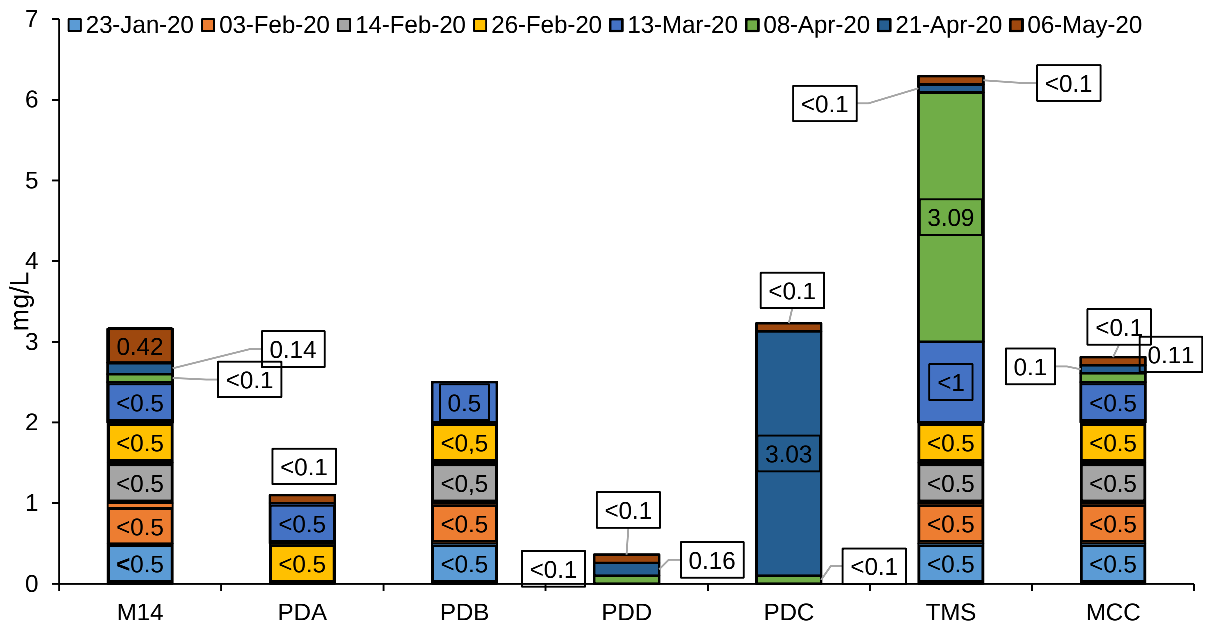

Figure 4.38: Nitrate at different points of Diep River

Figure 4.38 shows the level of nitrate along the Diep River catchment. Most sites recorded nitrate of less than 0,5 mg/L. The only outlier was Theo Marais Storm Water Drain, which recorded 3,09 mg/L on the 8th of April. The lowest recorded was less than 0,1 mg/L. The average nitrate for the majority of the sites was less than 0,5 mg/L except for Theo Marais Storm Water Drain, which had 1,08 mg/L. The South African guideline limit of 0 – 100 mg/L for agriculture was met at all the sites.

In comparison, ISD had the highest average of 1.3 mg/L, with PWP recording the lowest average at 0.5 mg/L. This indicates a slight difference between Outa's nitrate results and those of the researcher, although, in general, they follow the same trend. However, this study included the wet season, whereas Outa's study was during dry seasons.

4.10.7. Orthophosphates solids results

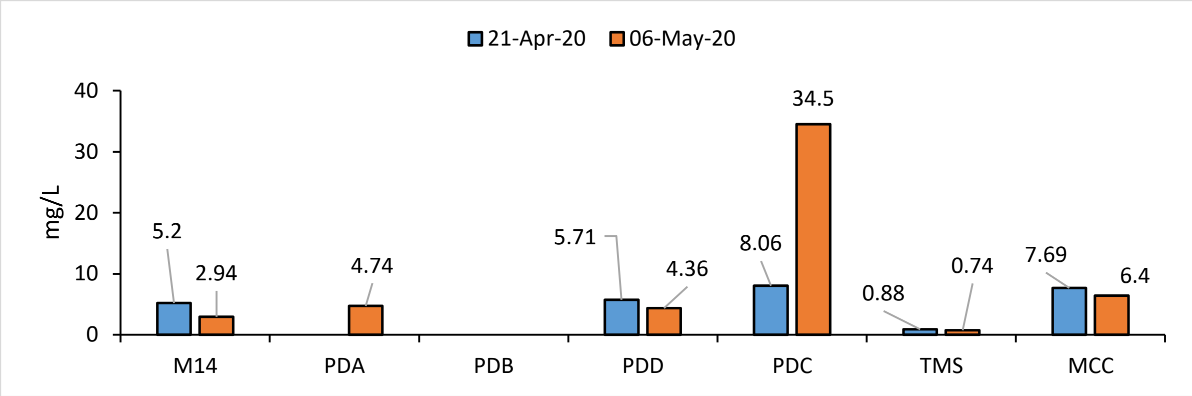

Figure 4.39: Orthophosphates at different points of Diep River

Figure 4.39 shows Outa's orthophosphate test results. Few tests were carried out on orthophosphates along the Diep River catchment. Potsdam Sewage Works Discharge had the highest number of orthophosphates with 34,5 mg/L. While the lowest was recorded at TMS and had 0,74 mg/L. The highest average was 21,8 mg/L at Potsdam Sewage Works Discharge. Most of the points were within the South African guideline limit of less than 5 mg/L for the aquatic ecosystem, except PDC in both months, and MCC in April.

A comparison between the Outa and the researcher's phosphate results indicates a huge difference. Malibongwe bridge (MAL) had the lowest phosphate levels of 1.06 mg/L (compared to Outa's TMS with 0.74 mg/L) and ISD had the highest number 6.07 mg/L (compared to Outa's Potsdam Sewage Works Discharge point with 34,5 mg/L. While the lowest was recorded at Theo Marais Storm Water Drain and had 0,74 mg/L. The highest average was 21,8 mg/L at Potsdam Sewage Works Discharge (compared to the researcher's highest average of 3.82 mg/L at ISD.

4.10.8. Chemical oxygen demand (COD) results

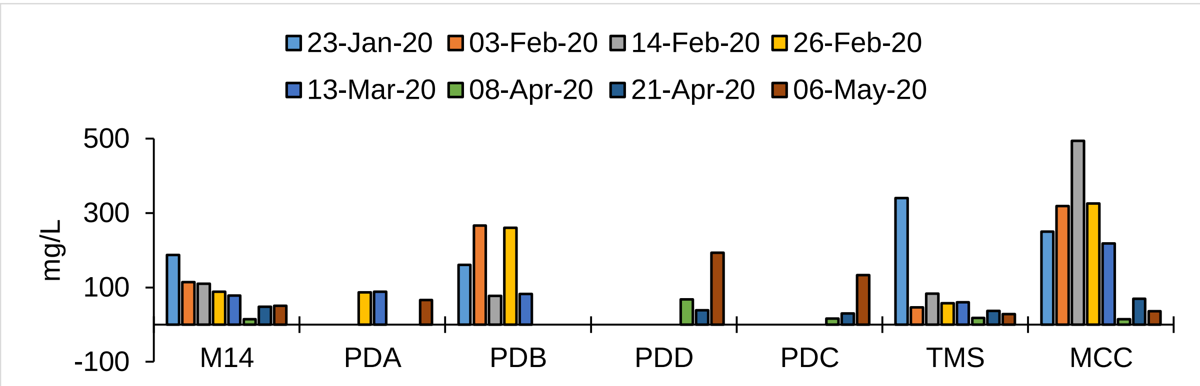

Figure 4.40: COD at different points of Diep River

Figure 4.40 shows the analysis of COD results. MCC had the highest number of COD, with the highest being 494 mg/L. The lowest number of COD recorded was 14,6 mg/L at M14 and MCC. MCC had the lowest COD and also the highest number of COD. The highest average for all sites was 216 mg/L and the lowest was 60 mg/L. The results from the tests for most of the sites were oscillating around the average of 60 mg/L.

In comparison, the researcher's findings show that the MGC had the highest levels of COD at 611 mg/L. The lowest recorded levels were at the MAL at 62.7 mg/L. The highest average was 348.25 mg/L at MGC, and the lowest average was 123.55 mg/L at MAL. This indicates a huge difference between Outa results and the researcher's findings.

4.10.9. Faecal coliforms results

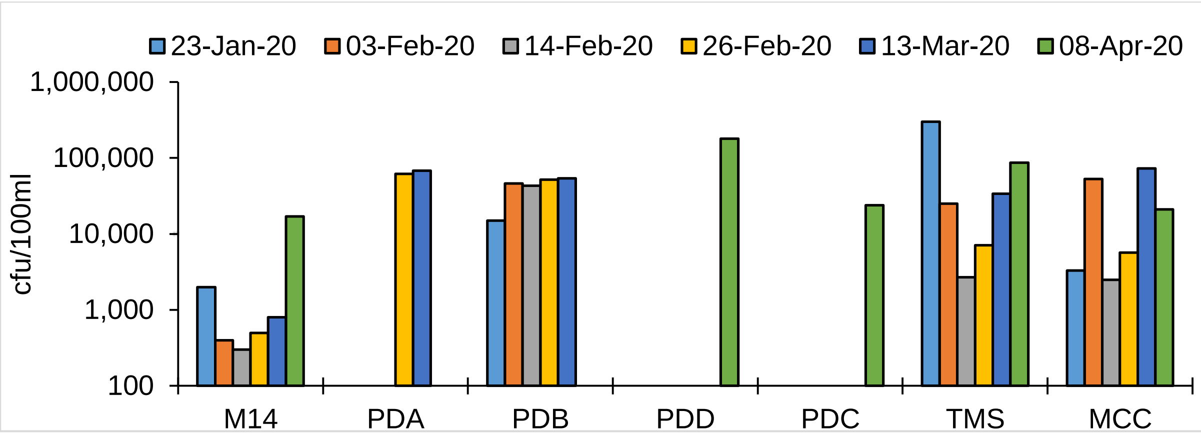

Figure 4.41: Faecal coliforms at different points of Diep River

Figure 4.41 shows Outa's faecal coliform results. M14 recorded the lowest levels of faecal coliform with an average of 3500 cfu/100 mL. TMS had the highest level with 300000 cfu/100 mL, and the site had an average of 75967 cfu/100 mL. All the sites did not show any major fluctuations in terms of the test results, with most results being around the average of 75967 cfu/100 mL.

Both the lowest average faecal coliform count (3500 cfu/100 mL) recorded in M14 and the highest average (75967 cfu/100 mL) recorded in Theo Marais exceeded the 0–150 cfu/100 mL range set for full contact recreation uses (DWAF, 1996c). The average level of faecal coliform recorded in all sites also exceeded the South African limit of 200 cfu/100 mL for water used for livestock watering. Therefore, the river water is not suitable for drinking and recreational purposes because it may cause disease and illness (DWAF, 1996b, 1996c).

4.10.10. Ammonia NH_4 results

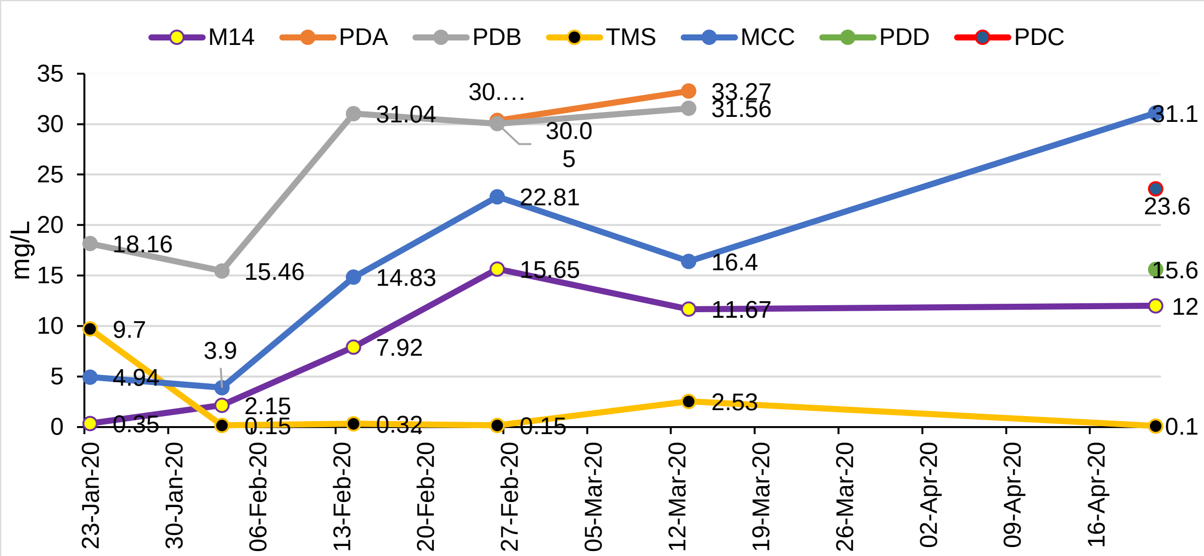

Figure 4.42: Ammonia NH_4 at different points of Diep River

Figure 4.42 shows the results of the analysis of Ammonia NH_4 from the Diep River catchment. PDD recorded the highest levels of ammonia NH_4 with an average of 25 mg/L. Theo Marais Storm Water Drain recorded the lowest levels of ammonia with an average of 2,2 mg/L, which is a huge difference from PDD. There was a 22,8 mg/L difference between the highest average and the lowest average. There were major fluctuations between the results of all sites. Most of the sites in the graph have exceeded the South African National Standards limit of ≤ 1.5 mg/L (South African National Standards, 2015).

4.10.11. Ammonia NH_3 results

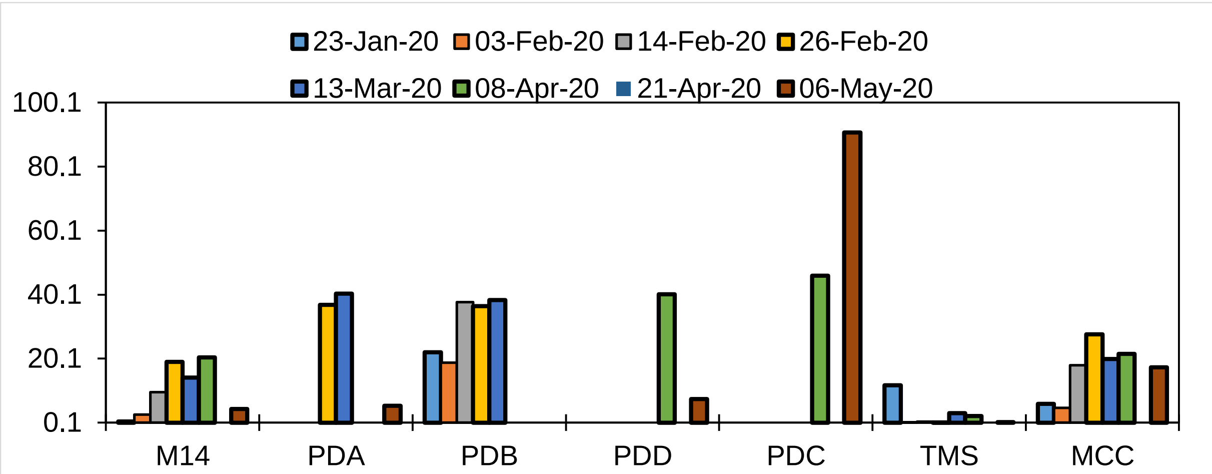

Figure 4.43: Ammonia NH_3 at different points of Diep River

Ammonia NH_3 was analysed in the Diep River catchment and Figure 4.43 shows the results of the analysis. The lowest average of ammonia NH_3 was recorded at Theo Marais Storm Water Drain with an average of 2,57 mg/L, while PDD had the highest average of 30,71 mg/L. The highest level on one day was recorded at Potsdam Sewage Works Discharge with 90,8 mg/L. Most points exceeded the South African guideline limit 0.0-1.0 mg/L for domestic use. The limit for agriculture (aquaculture/cold-water species) is 0-0.025 mg/L, while the limit for warm water species is 2.0-0.3 mg/L. There were fluctuations for each site, but average values at all the sites exceeded both limits for warm and cold species.

4.11. Comparison of water quality results from 3 Outa points

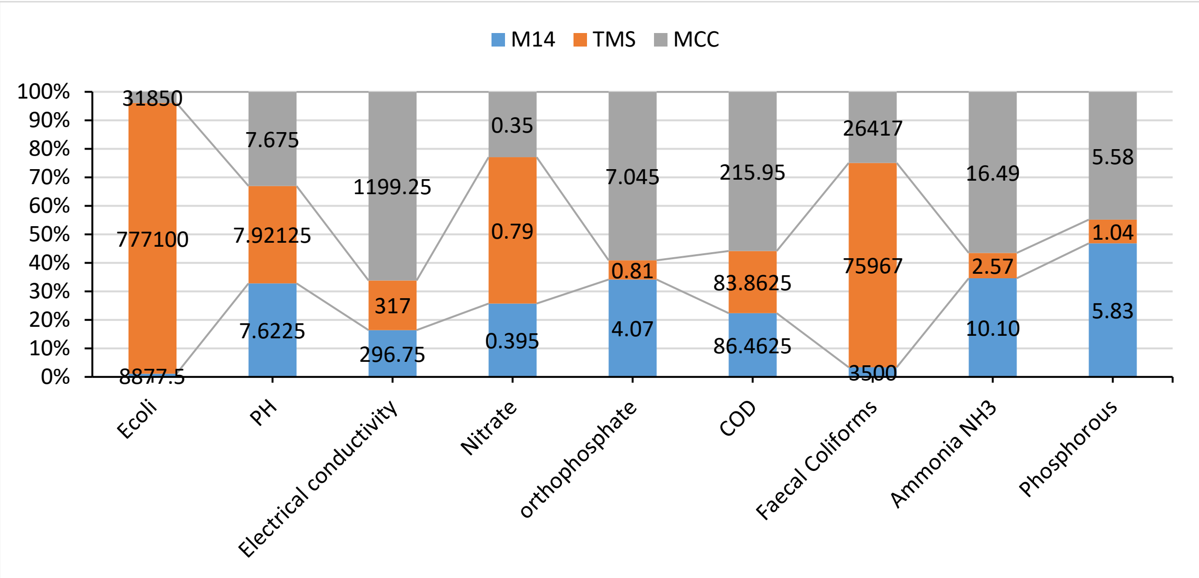

Figure 4:44: Comparison of M14, TMS, and MCC on all attributes

Figure 4.44 shows a comparison between 3 Outa sites that had tests taken on most of the test days. The results show that there was no correlation between variables. A large value of a particular variable did not influence the value of other variables under test. The only variables that seemed to be correlated were *E. Coli* and faecal coliforms, where each site that had the highest levels of *E. Coli* also had the highest faecal coliform levels.

4.12. Demographic Data

Two hundred and sixty (260) dwellers living in the Dunoon informal settlement with sections namely Bekela, Ethembeni, Kwa 5, New Rest, and Zwezwe were surveyed through questionnaires. About 11 of the questionnaires were spoilt, leaving 249 to be used for analysis. Table 4.3 shows that the proportion of males was slightly lower than expected - 39% or 97 males compared to 61% or 152 females. Most of the population residing in the informal settlement consists of blacks (see Table 4.4). The largest age group surveyed was between 28 and 39 years old at (43%), followed by 18-29 (34.5%), then 39-50 (19.7%), with the lowest being over 50 years old at (2.8%). The surveyed population in Dunoon was predominantly young adults.

In comparison with the above survey results, the South African Census of 2011 indicated that the number of males in Dunoon was slightly greater at 15.208 (52%), compared to the number of females at 14.060, (48%) (Census, 2011). However, the number of female questionnaire respondents was higher than that of males. The reason for this could be that this research covered only a portion of Dunoon, focusing on the informal settlement rather than the whole area of Dunoon, and there might also be an increase in the number of slums headed by females.

The highest age group in the 2011 census was between 25-29 at 18.58%, while the lowest age group was over the age of 85 at 0.06%. The age grouping for the research and the census were very different and this makes it difficult to compare. However, both age group distributions from the census and research findings reveal that the Dunoon informal settlement population is predominantly young adults.

Table 4.3: Surveyed gender distribution in Dunoon informal settlement

Gender					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Male	97	39.0	39.0	39.0
	Female	152	61.0	61.0	100.0
	Total	249	100.0	100.0	

Table 4.4: Surveyed race distribution in Dunoon informal settlement

Race					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Black	247	99.2	99.2	99.2
	Coloured	2	.8	.8	100.0
	Total	249	100.0	100.0	

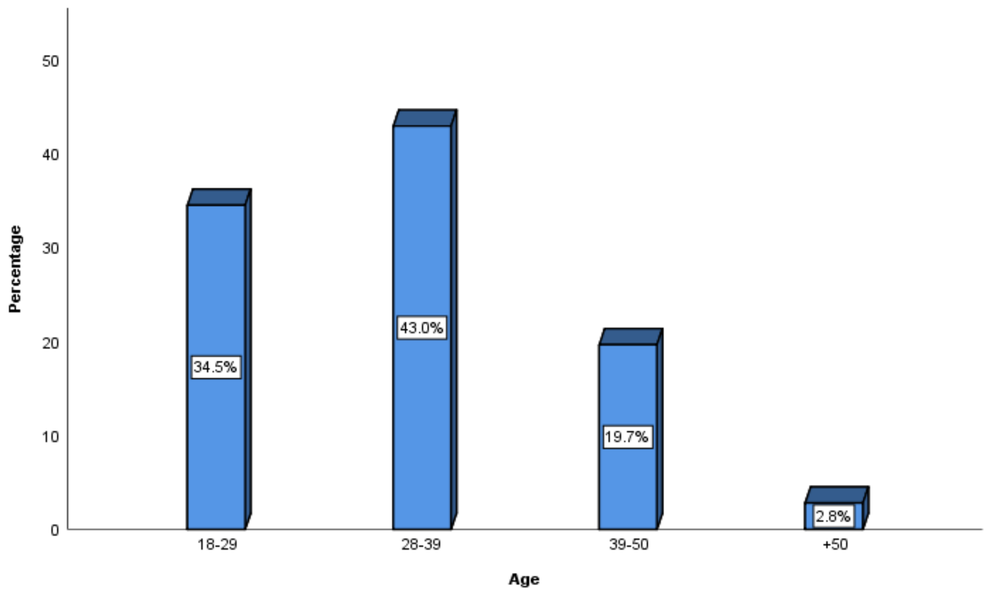

Figure 4.45: Surveyed Age Distribution in Dunoon Informal Settlement

More than half of the surveyed population had a secondary level of education, followed by 24,90% with tertiary level, and 10,84% with a primary level of education. Similarly, the 2011 census recorded that the highest group (52%) were at the secondary education level. About 63.1% of the population were not employed, leaving only 36.9% of the total surveyed population as employed (see Table 4.5). According to the 2011 census, the labour force was 17904. Of the 17904, the number of employed people was 11328, much more than those who were unemployed at 6576. This contradicts with the research findings, and the reason could be that the study focused on the more vulnerable and poorer group in the area of Dunoon. The survey results in this study revealed that most of the working class in the Dunoon informal settlement earned less than R2000. In comparison, the 2011 census revealed that the largest employed group in Dunoon, representing 27% of the working households, earned between R1601 & R3200, followed by 23% earning between R1000 to R16000.

Table 4.5: Surveyed employment distribution in Dunoon informal settlement

Employed					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	92	36.9	36.9	36.9
	No	157	63.1	63.1	100.0
	Total	249	100.0	100.0	

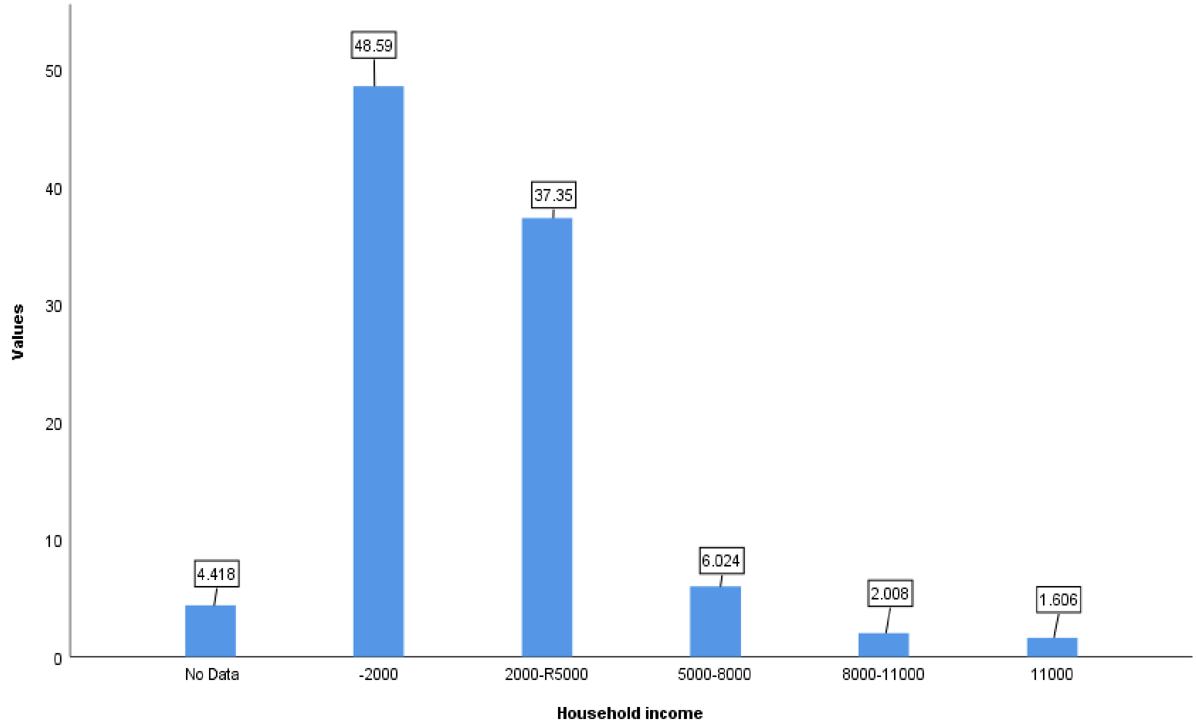

Figure 4.46: Household income in Dunoon informal settlement

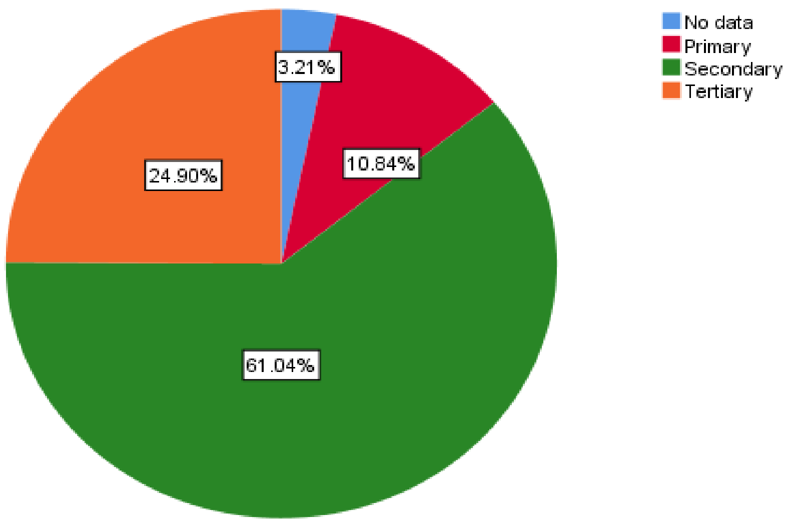

Figure 4.47: Education Levels in Dunoon informal Settlement

4.2. Dunoon Water Sources and uses in Dunoon Informal settlement

The main sources of water for the Dunoon informal settlement are municipal shared taps for the older sections of the informal settlement. Zwezwe and New Rest - the newer sections of the informal settlement, developed between the years 2018 and 2020 - receive water from a truck provided by the City of Cape Town (see Table 4.6). The water is used by the community for cooking, cleaning, bathing, laundry, and other purposes. Out of the 249 respondents, only 41 indicated that they use river water mostly for irrigation. A few of the 41 said that they use the river water for washing, laundry, dishwashing, and cooking as shown in Table 4.7. Most of the surveyed population (89.05%) have also indicated that river water was not important for them. The main reason was that the river destroys their houses when there is flooding. They also indicated that the river water was contaminated.

Table 4.6: Water sources in Dunoon informal settlement

Water sources					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Municipal shared Taps	144	57.8	57.8	57.8
	Truck municipality water	105	42.2	42.2	100.0
	Total	249	100.0	100.0	

Table 4.7: Household water uses in Dunoon informal settlement

Household Water Uses				
		Responses		Percent of Cases
		N	Percent	
Household water-uses	Cooking Drinking	246	32.1%	99.2%
	Flushing Toilet	24	3.1%	9.7%
	Dishwashing	210	27.4%	84.7%
	Bathing & Laundry	238	31.1%	96.0%
	Others	48	6.3%	19.4%
Total		766	100.0%	308.9%

4.13. Diep River water uses

The majority of people indicated that they did not use the river water. Out of the 249 questionnaire responses, only 41 indicated that they used river water mostly for irrigation of gardens. Only 5 people indicated that they used the river water for cooking and drinking. A few questionnaires had contradictions as people said that the river water was not valuable for them, yet they also indicated that they used the river water for different purposes as depicted in Table 4.8 below. As per observations, the river was highly polluted and people who did not have tap water receive water from the City’s water truck. The water was not sufficient to meet their daily needs. It was also observed that the river was used for recreational purposes such as boating and fishing downstream Dunoon in Milnerton, even though signs were indicating that the river was polluted and should not be used for activities like boating, swimming, and so on (see Appendix H).

Table 4.8: Diep River water uses in Dunoon informal settlement

Diep River Water uses in Dunoon informal Settlement				
		Responses		Percent of Cases
		N	Percent	
River water uses	Cooking drinking	5	12.2%	19.2%
	Irrigation	19	46.3%	73.1%
	Dishwashing	6	14.6%	23.1%
	Laundry	7	17.1%	26.9%
	Bath	4	9.8%	15.4%
Total		41	100.0%	157.7%

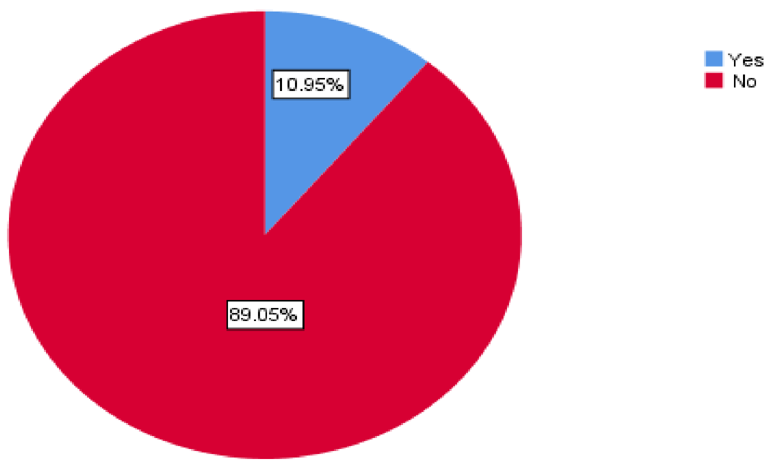

Figure 4.48: Is the river a valuable resource for you?

4.14. Environmental impact and contamination

The main causes of pollution in the Dunoon informal settlement were domestic sewage, agricultural waste, industrial waste, and solid waste. One of the major problems in Dunoon was solid waste management, although some sections of the informal settlement of Dunoon used bins to dispose of waste. Apart from bins, they also used drains, toilets, open space, and pits to dispose of waste. Some of the communities indicated that they burned their waste, causing air pollution. Many households admitted to disposing of human waste in harmful ways, which contributed to environmental degradation and contaminated river water. Most of the Dunoon informal settlement dwellers used an exterior non-flush toilet, a few used the exterior flush, and the backyard dwellers used interior flush toilets from the houses.

Literature shows that migrants in several targeted cities worldwide are compelled to cluster in areas characterized by unsafe tenure, inadequate access to basic services and labour markets, and exposure to environmental dangers such as flooding (Tacoli et al., 2015). Some studies have also indicated that there are vast environmental problems associated with informal settlements and low-income houses related to the location, drainage, and waste disposal. These studies argue that several low-income houses, including informal settlements, are located in unplanned land (French et al., 2021). For example, infrastructure such as water supply pipelines and electricity poles are not placed in a controlled way and hence they can trigger environmental problems. The people of the Dunoon informal settlement live in unsafe residences with inadequate basic services. In the wet season, the houses are destroyed by floods as some parts of the settlement are located close to the river and other parts beneath the power lines. This may result in fires and air pollution since the building material is highly flammable.

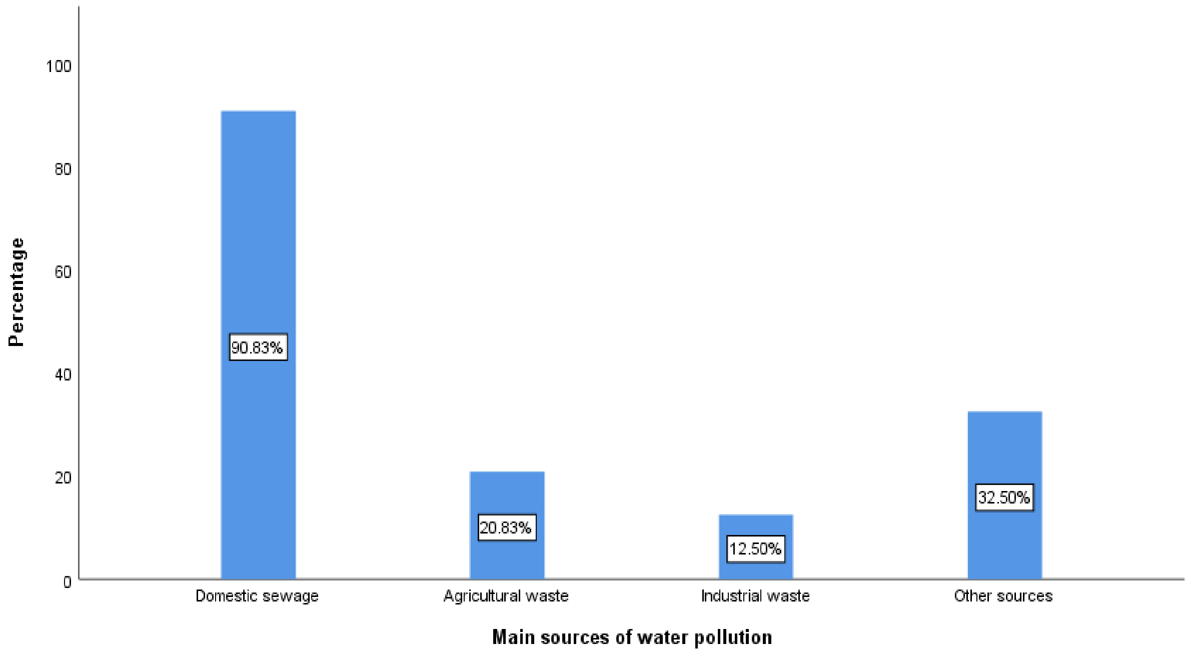

Figure 4.49: Main sources of water pollution in Dunoon

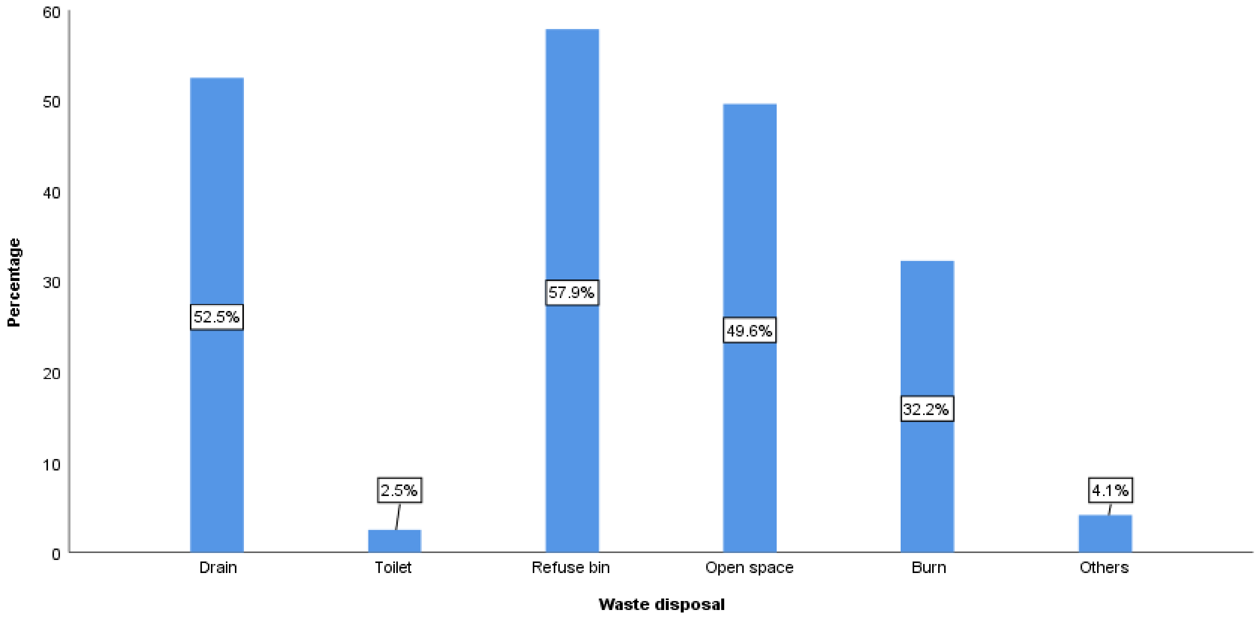

Figure 4.50: How do you dispose of household waste?

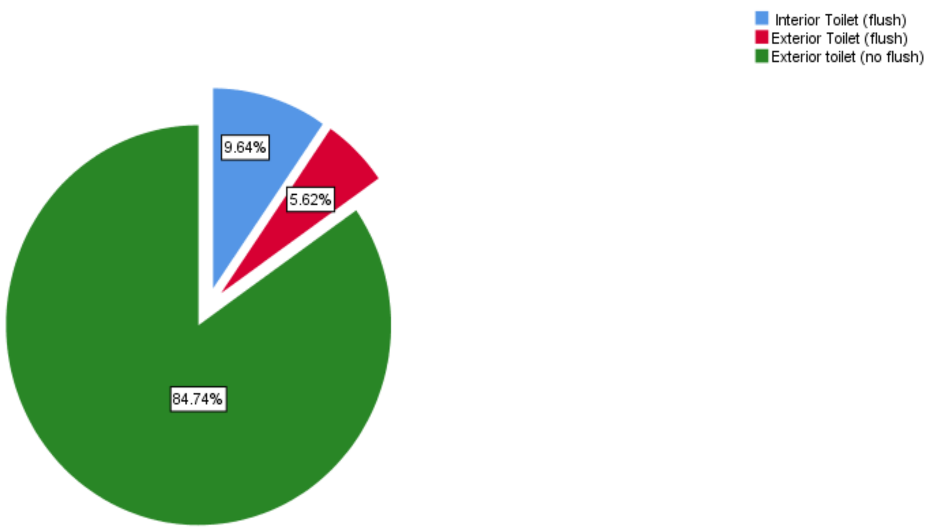

Figure 4.51: Toilets used in Dunoon informal settlement

4.15. Health impact in Dunoon informal settlement

Due to the use or consumption of contaminated water, some of the respondents have suffered diseases like malaria, typhoid, cholera, asthma, diarrhoea, and skin disease. Skin diseases account for 57.3% of all the diseases suffered by the respondents as a result of using or consuming contaminated water, followed by diarrhoea with 33.6%. Although some respondents indicated that they did not use river water, during flooding they are exposed to contaminated water. The contaminated water contains pathogens and chemicals that are a danger to human health and may result in skin diseases. Hence the majority of respondents in the questionnaire indicated that they suffered from skin problems. Some of the problems related to diarrhoea may be due to poor water storage, poor sanitation, and poor waste disposal.

Poor sanitation can result in exposure to faecal contamination through various environmental pathways, leading to undesirable health consequences. Exposure to faecal-polluted surface water has been confirmed to display an increased risk of helminth infections (Fuhrimann et al. 2017; Mather et al. 2020). The factors contributing to the urban sanitation crisis include insufficient water supply, poor drainage infrastructure, open defecation, poor faecal sludge management, and badly constructed or maintained sanitation facilities. They are worsened by inadequate solid waste management, high population density, and climate change, which consequently can raise the exposure to faecal pathogens (Bian et al., 2015 & Hawkins et al., 2013). Similar to the above-mentioned studies, Dunoon is highly populated, lacks adequate sanitation, people defecate on open spaces, and dispose of waste on open land and drains. This poses high health risks amongst Dunoon informal settlement dwellers as shown in Table 4.9 below.

Table 4.9: Diseases as a result of water usage in Dunoon

Diseases as a result of water usage in Dunoon				
		Responses		
		N	Percent	Percent of Cases
Diseases resulting from the use of water	Malaria	1	0.4%	0.5%
	Typhoid	2	0.8%	1.1%
	Other Diseases	2	0.8%	1.1%
	Cholera	8	3.2%	4.4%
	Asthma	10	4.0%	5.5%
	Diarrhoea	85	33.6%	46.7%
	Skin disease	145	57.3%	79.7%
Total		253	100.0%	139.0%

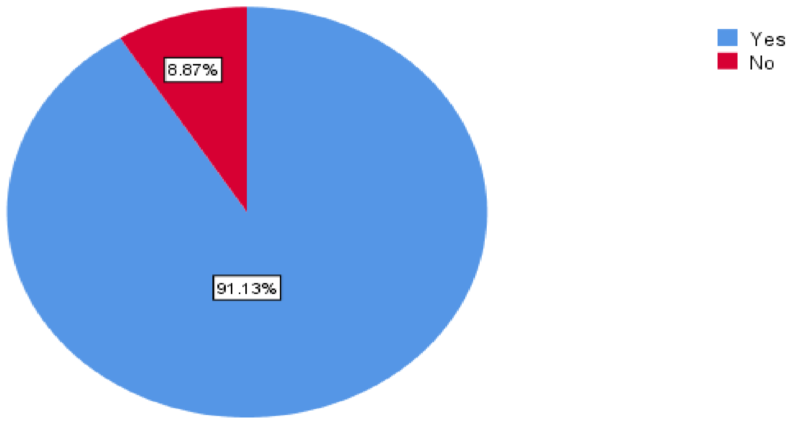

Figure 4.52: Can anything be done to reduce water pollution?

Ninety-one percent (91%) of the respondents indicated that something can be done to reduce pollution in the Dunoon informal settlement, while 8.87% indicated that nothing can be done. Few respondents indicated that it was not only their responsibility but also the municipality's responsibility to change the situation in Dunoon informal settlement. The majority of the community blamed the municipality for not providing houses and adequate basic services such as sanitation and waste management. In the survey, about 63.9% of respondents indicated that they were not satisfied with municipality service delivery regarding waste, and 36.1% indicated that they were satisfied. See figure below.

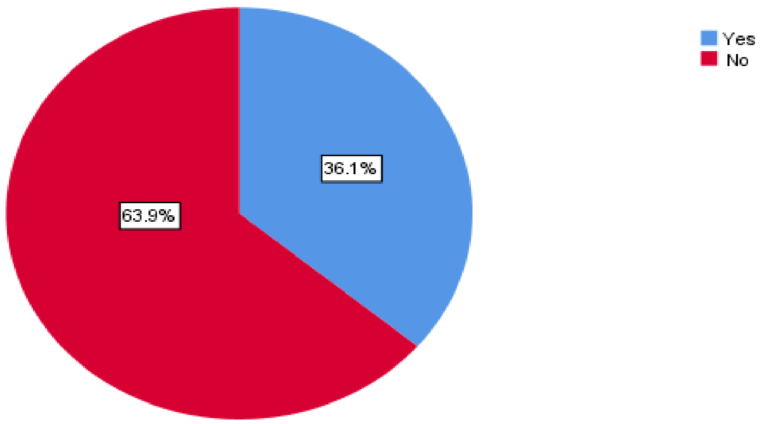

Figure 4.53: Are you satisfied with the municipal service delivery regarding waste management?

4.16. Conclusion

The Diep River is mainly used for agricultural and recreational purposes. The South African water quality guidelines for aquatic ecosystems, recreation, and agriculture were used for analysis. Recreational and agricultural guidelines are interchangeable. The reason for using different guidelines is that the Diep River water uses differ at different points of the Diep River. From Malmesbury to Dunoon, farming practices are more prevalent, and towards Milnerton downstream Dunoon, the water is mostly used for recreational purposes. Most of the tested parameters exceeded the permissible levels except for pH, temperature, phosphates, and TSS. The observations and the questionnaires highlighted some of the activities by the Dunoon informal settlement dwellers, which cause pollution in the river water and the environment. This was evidence that there is a lack of awareness on how to protect the river. Although the results from Outa were different from the research findings, all the results combined proved that the water in the Diep River is highly polluted.

CHAPTER 5: CONCLUSION & RECOMMENDATIONS

5.1. Introduction

This chapter provides the conclusion and recommendations from the research study. The purpose of this research study was to investigate the impact of the informal settlement on the water quality of the Diep River in Dunoon. To achieve the main aim, the study used the four objectives below.

The objectives of this research were to:

- Assess the knowledge, attitudes, and practices of the community of Dunoon
- Investigate water quality of the Diep River using the following parameters: pH, conductivity, total suspended solids, phosphates, COD, nitrates, ammonia, *E. Coli,* and other parameters.
- Investigate the environmental and health risks posed by human behaviours on water resources using questionnaires, checklist, observations, and results from water tests for *E. Coli*

5.2. Key findings

- The Diep River is polluted due to diffused sources, e.g., drainage, runoffs, seepages, different land use, industrial waste, and agricultural waste.
- The residents of the Dunoon informal settlement have also contributed to the pollution of the river due to the lack of adequate sanitation and inadequate management of solid waste. Apart from this, the dwellers in the Dunoon informal settlement practice farming, and the cattle grazing in the river contaminates the water resource.
- The Potsdam wastewater treatment plant also contributes to polluting Diep River, as the highest contents of *E. Coli* were close to the plant.
- The Diep River water at the points that were tested is not suitable for drinking, recreation, or the aquatic ecosystem, as the *E. Coli* levels were above the accepted levels for these scenarios.
- Most of the residents in the informal settlement indicated that the river is not a valuable resource for them.
- Due to inadequate sanitation and exposure to contaminated water, especially during floods, the residents of the Dunoon informal settlement indicated that they suffer various diseases, mostly skin-related.

5.3. Conclusion

This study aimed to investigate the impact of the informal settlement on the water quality of the Diep River in Dunoon. The literature revealed that there is a continual decline in the water quality in the Diep River.

Human beings are often responsible for the main causes of water pollution, mostly due to an increase in human activities in the informal settlement. Other factors contributing to the decline in the quality of water are the rise of urbanization, population growth, industrial production, climate change, non-compliance of wastewater treatment plants, and agricultural waste. The overcrowded informal settlements with inadequate sanitation are a major problem, coupled with the lack of other services such as waste collection. Due to a lack of such services, the health of human beings is being negatively impacted by water-related diseases as the water bodies are extensively polluted.

Legislation has been introduced to enforce compliance with the law and also to standardize the exploitation of this natural, namely water. Some of the examples of legislation are the National Water Act (1998) as well as the Department of Water Affairs and Forestry (1996) guidelines for water quality. These are assessment tools for water protection and conservation, but there is still a lack of enforcement and monitoring.

The research results indicated that a few people in Dunoon use the river water for irrigation and livestock watering. In areas downstream, the Diep River is used by some of the members of the community for boating. The results also indicated that, on average, the parameters that exceeded the South African water guideline limits were *E. Coli*, nitrates, chemical oxygen demand, dissolved oxygen, electrical conductivity, turbidity, and salinity in both the dry and wet seasons, and ammonia during the wet season. The *E. Coli* results for both the City of Cape Town and Outa were also very high, exceeding the limit. Some of the Outa-tested parameters that exceeded the limit were faecal coliforms in all sites and ammonia in most of the sites. The results also recognised that there is a connection between the Dunoon informal settlement and the poor quality of the Diep River water resource.
Based on the results of this study, the water quality of Diep River, particularly close to ISD, has declined. This was evidenced by the low average dissolved oxygen levels and the average summer *E. Coli* levels that were higher than the acceptable limit. In a single day's recording in December, ISD had the highest ammonia levels. The average ammonia was also high. Even though the phosphate levels were within the acceptable limit, ISD recorded the highest average levels. The highest average nitrate levels were recorded at ISD. This can be attributed to the overcrowded Dunoon informal settlement with inadequate sanitation and a lack of waste

collection services. It is, therefore, necessary to improve the management of waste and sewage issues in the Dunoon informal settlement.

5.4. Recommendations

The degradation of urban rivers is a major problem in South Africa and, for this reason, the combination of water quality monitoring with water resource protection is crucial. The rapid growth in informal settlements is also a major concern in urban areas. Based on the findings of this research, the following measures and practices can be implemented to reduce and monitor the level of water pollution in the Diep River, associated with Dunoon informal settlement:

- Constantly inspect and monitor water quality and runoff nearer to the cause of contamination within the informal settlement
- The government should introduce programmes to educate the people about river resources and about the importance of keeping the water clean.
- There is also a need to educate stakeholders so that they can contribute efficiently during the decision-making processes. Poor people and women should be a part of decision-making.
- The local, provincial and national governments and the different departments (such as the Departments of Human Settlement, Agriculture, Minerals, Water and Sanitation, and so on) need to work in harmony regarding water policies and governance as one activity in one department can affect the water resources.
- The water laws and policies on protecting and conserving water bodies need to be more stringent
- Continuously enforce and monitor legislation adherence by industries, water waste plants, farms, and all involved parties to prevent pollution.
- The growth of emerging river contaminants that are not commonly monitored requires proactive further research on the application of new techniques for better monitoring of water in water bodies.
- Basic services such as sanitation and waste collection need to be done regularly in the Dunoon informal settlement to prevent river pollution.
- The Potsdam Wastewater Treatment Plant needs to improve its wastewater treatment techniques and methods to minimize the number of pollutants discharged into the Diep River. Potsdam treatment plant is currently undergoing modification. This may improve the operations and performance of the plant in the future. However, there is a need for alternative emergency measures to improve the water plant's operations.

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Appendix A1: Dunoon Informal settlements questionnaire

QUESTIONNAIRE – Dunoon Informal settlements

As part of my Master's research at the Cape Peninsula University of Technology, I am conducting a survey that investigates ***the impact of informal settlements on water quality of Diep River in Dunoon***. I would appreciate it if you can participate in the survey. Your response will be kept anonymous

DEMOGRAPHIC DATA

1. **What is your age?**

   ☐ 18-29 years ☐ 28-39 years ☐ 39-50 years ☐ over 50 years

2. **What is your Gender?**

   ☐ Female ☐ Male

3. **What is your race?**

   ☐ Black ☐ Colored ☐ White ☐ other please specify) ……………

4. **What is your level of education?**

   ☐ Primary ☐ Secondary ☐ Tertiary others (please specify) ....

SOCIO-ECONOMIC DATA

5. **Are you currently employed?**

   ☐ Yes ☐ No

6. **What is the average monthly income of your household?**

   ☐ Less than R2000 ☐ R2000-R5000 ☐ R5000-R8000 ☐ R8000-R11000

   ☐ More than R11000

7. **What is your residential area?**

☐ Informal settlement ☐ Back yard shack ☐ Other (please specify) ....

8. What is the water source in your house?

☐ Municipal shared Taps ☐ Municipality Truck delivery ☐ River

☐ Other (Please specify): ....

9. If you receive water from truck delivery, is the water enough for your needs?

………………………………………………………………………………………

10. What are the main uses of water in your household? Select all that apply

☐ Cooking & Drinking ☐ Flushing Toilet ☐ Dishwashing

☐ Bathing ☐ others (please specify) ....

11. What do you use the river water for? Select all that apply

☐ Cooking & Drinking ☐ Irrigation ☐ Dishwashing ☐ Laundry

☐ Do not use river water ☐ Bathing

☐ others (please specify) ....

12. Is the river a valuable resource for you? If yes, how?

…………………………………………………………………………………………

…………………………………………………………………………………………

13. Does the outside toilet cistern leak or is it blocked?

☐ Yes ☐ No

14. Do your outside taps Leak?

☐ Yes ☐ No ☐ Don't have taps

15. If yes, how long has it been happening?

☐ One week ☐ One month ☐ More than one month ☐ One year

16. Do you use tap water for gardening or washing cars?

☐ Yes ☐ No

17. Do you purify your household water before use?

☐ Yes ☐ No

18. If yes, which purification methods do you use?

☐ Boil ☐ filter ☐ Bleach ☐ Others please specify……………….

19. What types of sanitation do you have at home?

☐ Interior Toilet (flush) ☐ Exterior Toilet (flush) ☐ Exterior toilet (no flush)

☐ Other (Please Specify)……………………………………………………….

20. Do you ever experience flooding in your area?

☐ Yes ☐ No

HEALTH DATA

21. As a result of using/drinking water, have any household members suffered from the following diseases? Select all that apply

☐ Diarrhea ☐ Cholera ☐ Skin disease ☐Typhoid ☐ Malaria ☐ Asthma

☐ Other (Please Specify) ....

22. How do you store your water?

....

POLLUTION & WATER MANAGEMENT PRACTICE

23. How important is water management to you and your household?

……………………………………………………………………………………………..

……………………………………………………………………………………………..

24. How concerned are you about water pollution?

☐ Extremely concerned ☐ Concerned ☐ Not Concerned

25. Do you think that there is anything that can be done to reduce/eliminate water pollution?

………………………………………………………………………………………….

…………………………………………………………………………………………...

26. What are the main sources of water pollution in your area?

☐ Domestic sewage ☐ Agricultural Waste ☐ Industrial Waste

☐ Other…………………………………………………………

27. Do your outside taps sometimes have brown water running out?

☐ Most of the time ☐ Sometimes ☐ Not at all ☐ Not taps

28. How do you dispose of household waste?

☐ Down the drain ☐ Flush Toilet ☐ Refuse bins ☐ Open space ☐ Burn

☐ Other (Please specify) ....

29. How often does the municipality collect domestic waste?

……………………………………………………………………………………………….

30. Are you satisfied with the municipal service delivery in terms of waste management?

……………………………………………………………………………………………………
……………………………………………………………………………………………………
…………………………………………………………………………………………………

Thank you for your cooperation

Appendix A2: Consent form

CONSENT FORM FOR PARTICIPATION IN RESEARCH

(for Participant)

The impact of informal settlements on water quality of Diep River in Dunoon

I ……………………………………………………………………………………………………

being 18 years old and above, hereby consent to participate as requested in the research project as stated above.

1. I have read and understood the provided information.
2. Specifics on procedures and any threats have been clarified to my satisfaction.
3. I agree to audio/video recording of the information I provide during my involvement.
4. I have been made aware that I should maintain a duplicate of the Information Sheet and Consent Form for future reference.
5. I understand that:
    - I will not directly benefit from partaking in this research study.
    - I am at liberty to withdraw from the project at any stage and can decline to answer certain questions.
    - As explained even though the information gained in this research will be published, I will remain anonymous, and each participant's information will remain private.
    - I am free to participate or not, or withdraw after participating, I will not be affected negatively by the choice I make.
    - I may ask that the recording/observation be stopped at any period, and that I may withdraw at any stage from the study without disadvantage.
6. I agree/do not agree to the tape/transcript being made accessible to other researchers, who are judged by the researcher and team to be doing related research, on the condition that my identity is not exposed.
7. I, the participant whose signature appears below, have read a transcript of my involvement, and approve its use by the researcher as explained. I also approve of its publication.

Participant's signature……………………………………Date…………………...

8. I certify that I have explained the study to the volunteer and consider that she/he understands what is involved and freely consents to participation.

Researcher's name……………………………………………………………..................

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

Appendix B: Dunoon Area Checklist

Checklist for the Dunoon Area

Environmental	Direct Observation	Comments
Is the environment polluted?		
Is there dumping or littering in the river?		
Is the river water polluted?		
Besides the river is there any other water resources in the area and what is the condition		
Is sewage around the river and land?		
Are there any existing other sources of pollution?		
Are there animals in and around the area?		
Do the animals drink the water?		
What do households do when the toilet is full or blocked?		
Drainage	**Direct Observation**	**Comments**
What kind of drainage system is installed (Sewer, earth, concrete, open, covered, earth)?		
What is the present status of the drainage facilities?		
How often are floods occurring in the area?		
Is wastewater channelled into rainwater drainage?		
Are household satisfied with the drainage system?		
Health & Hygiene	**Direct Observation**	**Comments**
What is the most important health issue in the area?		
Are there any health facilities in your area offering programmers on sanitation and hygiene?		
Do they normally visit the community for such talks?		
How close are the handwashing facilities to your toilet/latrine?		

Appendix C1: Request for permission to conduct research

Cape Peninsula University of Technology

20 January 2020
Department of Water and Sanitation
City of Cape Town

RE: Permission to Conduct Research Study

To Whom It May Concern:

I am writing to request permission to conduct a research study within the community of Dunoon. I am currently enrolled in the Master of Environmental Management programme at Cape Peninsula University of Technology (CPUT) in Cape Town and am in the process of writing my Master's dissertation. The study is entitled "*The impact of informal settlements on water quality of Diep River in Dunoon*". It is a requirement for ethical clearance to receive permission from the concerned authorities for the study area.

I hope that the City of Cape Town will allow me to recruit 395 individuals from the Dunoon informal settlement, who are above the age of 18 years, to anonymously complete a 3-page questionnaire (copy enclosed). Due to the nature of the study, I also request permission to obtain reports from the City of Cape Town for the Diep River catchment area (specifically Milnerton areas) for use in my research study. I would appreciate it if you can allow me to conduct an interview with a City official from the Potsdam Wastewater Treatment Plant, which services Dunoon.

The survey results will be pooled for the dissertation project and individual results of this study will remain absolutely confidential and anonymous. Should this study be published, only pooled results will be documented. No costs will be incurred by either your institution or the individual participants.

Your approval to conduct this study will be greatly appreciated. I will follow up with a telephone call next week and would be happy to answer any questions or concerns that you may have at that time. You may contact me at my email address: bgqomfa@gmail.com and/or my supervisors at shalek@cput.ac.za> and maphangaT@cput.ac.za.

If you agree, kindly submit a signed letter of permission on your institution's letterhead acknowledging your consent and permission for me to conduct this survey/study at the aforementioned area.

Sincerely,

Babalwa Gqomfa

Appendix C2: Permission to conduct Research Granted

CITY OF CAPE TOWN
ISIXEKO SASEKAPA
STAD KAAPSTAD

Date	: 25 March 2019
To	: Director: Policy & Strategy
Reference	: PSRR - 0258

Research Approval Request

In terms of the City of Cape Town System of Delegations (May 2019) - Part 29, No 1 Subsection 4, 5 and 6 "Research:

(4) To consider any request for the commissioning of an organizational wide research report in the City and to approve or refuse such a request.

(5) To grant authority to external parties that wish to conduct research within the City of Cape Town and/or publish the results thereof.

(6) To after consultation with the relevant Executive Director: grant permission to employees of the City of Cape Town to conduct research, surveys etc. related to their studies, within the relevant directorate

The Director: Policy & Strategy is hereby requested to consider, in terms of sub-section 5, the request received from

Name	: B. Gqomfa
Designation	: Masters Student
Affiliation	: Cape Peninsula University
Research Title	: The impact of informal settlements on water quality of Diep River in Dunoon

Taking into account the recommendations below (see Annexure for detailed review):

Recommendations

That the Director: Policy & Strategy grants permission to Mrs B. Gqomfa, in her capacity as Masters student within the Department of Environmental and Occupational Studies, in the Applied Sciences Faculty at the Cape Peninsula University of Technology (CPUT), to conduct research in the City of Cape Town subject to the following conditions:

- One CCT official working at the Potsdam Wastewater Treatment Plan to be interviewed, to be advised by the Dir: Water & Sanitation.
- Relevant CCT reports on water contaminants test to be made available, in line with operational requirements.
- No face to face interviews to be undertaken with City officials and can only be undertaken telephonically or via Skype, until further notice.
- Willingness and/or availability of individual CCT staff members to participate in the provision of requested data, on voluntary basis;
- Clear acknowledgment in the report that the views of participating officials do not constitute official policy.
- Clear acknowledgment in the report that any analysis derived by the researcher from City data does not constitute official CCT policy
- City officials and inputs to be anonymized
- The City branding and logo not being used in the research report;
- Submission of the completed research report to the Director: Water & Sanitation, the Director: Policy & Strategy, the Manager: Valuations and the Manager: Research Branch, Policy & Strategy, within 3 months of completion of the research report.

Delegated authority:	Acceptance by Applicant:
Approved ☑ Comment: Access to City facilities, staff, data will be impacted by Covid-19 disaster response. Research subject to disaster directives.	I, BABALWA GQOMFA, confirm that I agree to abide by the conditions as stipulated above.
Not Approved ☐ Comment:	
Hugh Cole: [signature] Director: Organisational Policy & Strategy	Applicant: [signature]
Date: 25/3/2020	Date: 26/03/2020

CIVIC CENTRE ISIKO LEENKONZO ZOLUNTU BURGERSENTRUM
12 HERTZOG BOULEVARD CAPE TOWN 8001 PRIVATE BAG X9181 CAPE TOWN 8000
www.capetown.gov.za

Making progress possible. Together.

Appendix D1: Potsdam Treatment plant questionnaire

Cape Peninsula University of Technology

AN INVESTIGATION OF THE IMPACT OF INFORMAL SETTLEMENTS ON WATER QUALITY OF DIEP RIVER IN DUNOON.

Contact Information	
Facility Name	Contact Name
Facility Address	Contact Number
Email Address	Facility Type

Type of treated wastewater (indicate by X)

Domestic ☐

Industrial ☐

Municipal ☐

How many stages of treatments do you have?

Primary ☐

Secondary ☐

Tertiary ☐

Others ☐ (please specify) ....

What is the design capacity of the plant?

Class A ☐

Class B ☐

Class C ☐

Class D ☐

What type of treatment technology is the plant using?

Tracking ☐

Activated Sludge ☐

BNR with only nitrification and denitrification ☐

How many process controllers are employed at your plant Class A?

☐ None ☐ One ☐ Two ☐Three ☐ Four ☐ Five

What class is your supervisor? ....treat

Does the plant have a wastewater risk abetment plan? Yes ☐ No ☐

Does the plant have a maintenance team, (electrical, civil, mechanic) Yes ☐ No ☐

How does the plant manage their sludge?

....

……………………………………………………………………………………………………...

Where does the treated wastewater go after it leaves the plant?

☐ Rivers or Stream ☐Ocean ☐ Lakes ☐Others (Reuse) ....

How do you ensure that treated water is clean and free of contaminants before it is released from your treatment plant?

………
…..

………
…...

What year was the plant built?

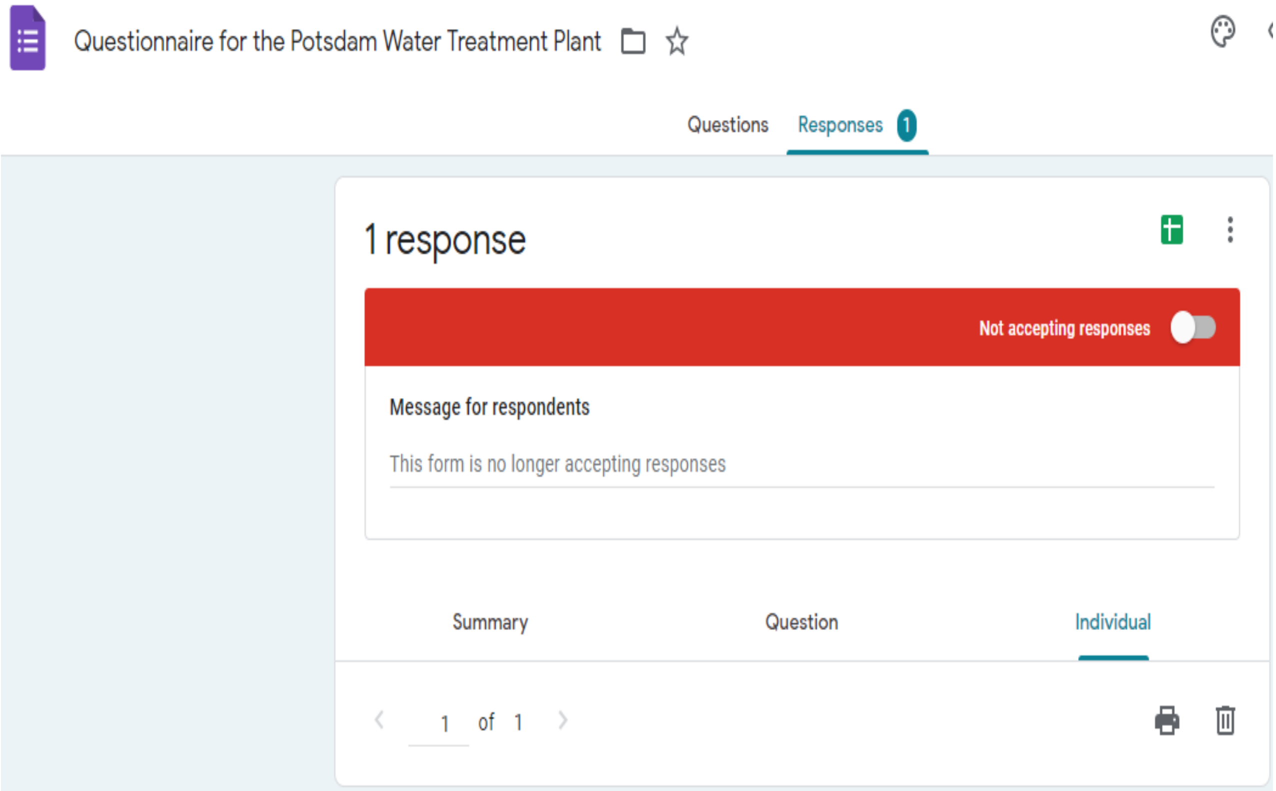
....

Was it ever modified in recent years?

....

Are there plans in place to modify the plant? Yes ☐ No ☐

Appendix D2: Online Response from Potsdam Treatment Plant



Appendix E: Permission to use Diep river sampling results report (Outa)

Gmail — Babalwa Gqomfa <bgqomfa@gmail.com>

Permission to use Diep River Sampling Report
3 messages

Babalwa Gqomfa <bgqomfa@gmail.com> — Thu, Aug 20, 2020 at 9:36 AM
To: samantha.vannispen@outa.co.za

Good day Samantha

I trust that you are well. I am a Master of Environmental Management student at the Cape Peninsula University of Technology, Cape Town. Yesterday I called and spoke to Fikile, who provided me with your email address.

The purpose of this email is to request permission to use the Diep River Sampling Report, published on the Outa Website, as part of my literature review (Thesis). I will make sure that proper acknowledgement is included in the thesis.

I would really appreciate your consent.

Thank you

Regards
Babalwa

Samantha Van Nispen <samantha.vannispen@outa.co.za> — Thu, Aug 20, 2020 at 9:38 AM
To: Babalwa Gqomfa <bgqomfa@gmail.com>

Good Morning Babalwa

You are welcome to use the report in your thesis. Please share a copy of it with me when you are done?

Best of luck!!

Samantha

[Quoted text hidden]

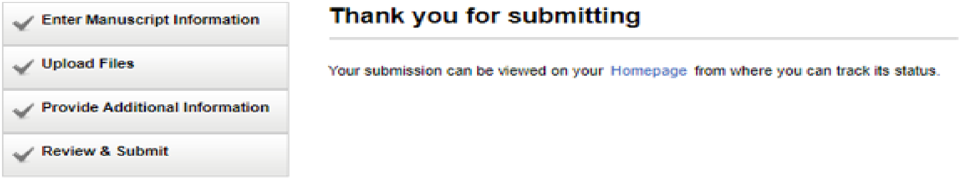
Babalwa Gqomfa <bgqomfa@gmail.com> — Thu, Aug 20, 2020 at 10:39 AM
To: Samantha Van Nispen <samantha.vannispen@outa.co.za>

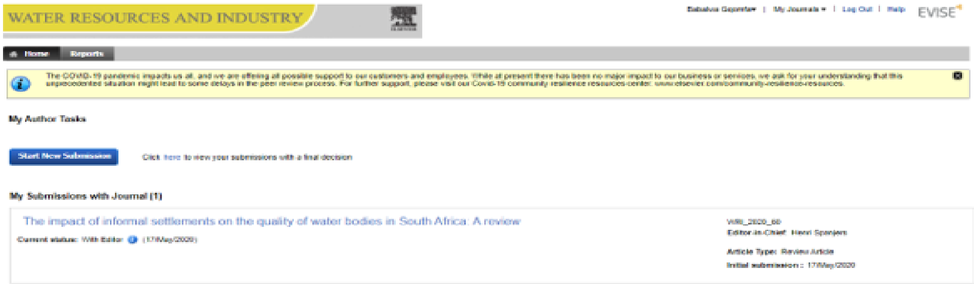
Thank you very much Samantha. Much appreciated.
I will certainly share a copy of my Thesis when I'm all done.

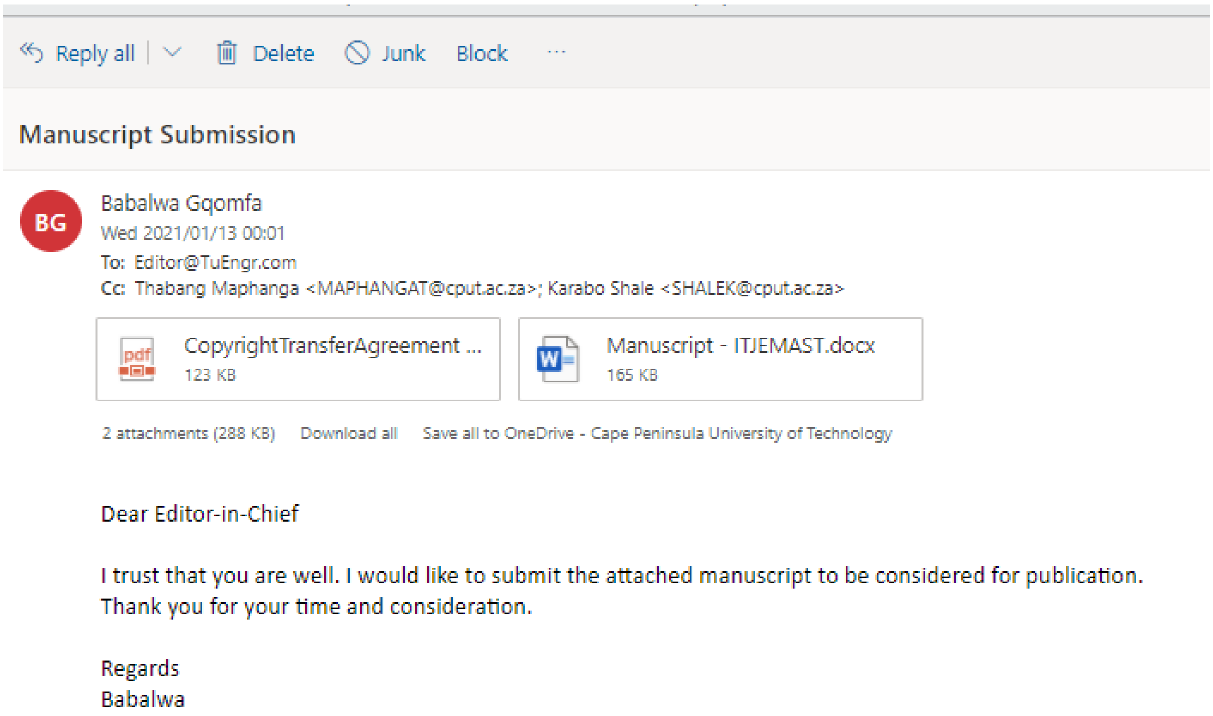
Have a great day further

Regards
Babalwa
[Quoted text hidden]

Appendix F: Proof of manuscript submission







Appendix G: Boating activities at Diep River close to MGC

Appendix H: CPUT Ethics approval letter

Cape Peninsula
University of Technology

P.O. Box 1906 · Bellville 7535 South Africa ·Tel: +27 21 953 8677 (Bellville), +27 21 460 4213 (Cape Town)

Ethics Approval Letter **Reference no:** 208224963/04/2020

Office of the Chairperson **Research Ethics Committee**	**Faculty of Applied Sciences**

On 27 April 2020, the Faculty Research Ethics Committee of the Faculty of Applied Sciences granted ethics approval to Gqomfa, B. for research activities related to a project to be undertaken for a degree (Master of Environmental Management) at the Cape Peninsula University of Technology.

Title of project:	Impact of informal settlements on the water quality of the Diep River, Dunoon, Cape Town

Comments (Add any further comments deemed necessary, e.g. permission required)

1. Human subjects are included in the proposed study.
2. This permission is granted for the duration of the study.
3. Research activities are restricted to those detailed in the research proposal.
4. The research team must comply with conditions outlined in AppSci/ASFREC/2015/1.1 v1, CODE OF ETHICS, ETHICAL VALUES AND GUIDELINES FOR RESEARCHERS.

Signed: Chairperson: Research Ethics Committee	**27/04/2020** **Date**