An assessment of the impact wastewater pollution has on the quality of surface water bodies in the vicinity of Zastron and Matlakeng Township, Free State Province

by

Malcolm de Jager

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Declaration

I, Malcolm de Jager, identity number and student number do declare that this research project submitted to the Central University of Technology, Free State for the Degree Masters in Health Sciences: Environmental Health, is my own independent work; and complies with the code of Academic Integrity, as well as other relevant policies, procedures, rules and regulations of the Central University of Technology, Free State; and has not been submitted before to any institution by myself or any other person in fulfilment (or partial fulfilment) of the requirements for the attainment of any qualification.

The work was conducted under the guidance of Professor Annabel Fossey and Dr. Leana Esterhuizen.

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Malcolm de Jager

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I certify that the above statement is correct

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Dr Leana Esterhuizen

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Abbreviations

AEV	Acute Effect Value
ANOVA	Analysis of Variance
ASPT	Average Score per Taxa
AWQUS	Aquatic Water Quality Limits for Urban Streams
BBI	Beck's Biotic Index
CCME WQI	Canadian Council of Ministers of the Environment Water Quality Index
CEV	Chronic Effect Value
DO	Dissolved Oxygen
E. coli	*Escherichia coli*
EC	Electrical conductivity
GPS	Global Positioning System
GSM	Gravel, Sand and Mud
IDP	Integrated Development Plan
MDGR	Millennium Development Goals
MPN	Most Probable Number
NFSWQI	National Sanitation Foundation Water Quality Index
NH_3	Ammonia
NO_3	Nitrate
NTU	Nephelometric turbidity units
pH	Potential Hydrogen
PO_4	Phosphate
RHP	River Health Programme
SAICE	South African Institute of Civil Engineering
SANDF	South African National Defence Force
SANS	South African National Standards

SASS	South African Scoring System
SASS5	South African Scoring System Version 5
SIC	Stone in Current
SOOC	Stone out of Current
TBI	Trent Biotic Index
TDS	Total dissolved solids
TWQR	Targeted Water Quality Range
WAQWQI	Weight Arithmetic Water Quality Index
WQG	Water Quality Guidelines
WQI	Water Quality Index
WWQI	Weighted Water Quality Index

Abstract

Introduction: A breakdown in wastewater infrastructural systems have, in recent times, resulted in extensive pollution of rivers, dams and streams in the vicinity of Zastron and Matlakeng Township. The consequence of extensive pollution of these surface water bodies has resulted in the degradation of the water quality and the health of the ecosystem. Polluted water may become a source for transmitting waterborne diseases, which is a cause for concern, especially when the water is used to irrigate agricultural produce. An assessment of the surface water quality of water bodies in the Zastron and Matlakeng Township provided information about the extent of the deterioration and degradation of the water quality of the surface water bodies.

Methodology: In this study, an assessment of the municipal complaints registers of the Mohokare Local Municipality was conducted to identify suitable sampling sites in the rivers, dams and streams that were directly impacted by untreated sewerage flowing from blocked manholes or sewerage leakages from pipe bursts overflowing in the Matlakeng Township. From this analysis, ten surface water bodies were identified to most likely be affected by wastewater pollution as a result of the infrastructural breakdown in the vicinity. To assess the water quality of the 10 sampling sites, the physical, chemical and microbiological water quality properties of the sampling sites were measured over three sampling rounds. To determine the ecological health status of the macroinvertebrate sampling site habitats, an ecological assessment for the 10 sampling sites was also conducted. A number of indexes were used to determine the water quality status for each of the sampling sites. These included the calculation of a Water Quality Index (WQI), the South African Scoring System (SASS), and the Average Score per Taxa (ASPT).

Results and discussion: The study found that on assessment of community infrastructure related complaints lodged with the municipality were mostly as a result of and poor workmanship

with the construction of sewer networks. This resulted in blocked manholes and sewerage leakages that which caused sewerage overflowing from manholes and burst pipes. The infrastructural breakdowns had resulted in the discharge of untreated wastewater into surface water bodies located within close proximity to where most challenges were identified from community complaints. The assessment of the physical, chemical and microbiological water quality had revealed non-compliant Turbidity, Ammonia and Phosphates parameters, while the microbiological water quality had declined extensively after the first sampling round. Turbidity and elevated concentrations of Ammonia and Phosphates, as well as the high counts of faecal coliforms could be attributed to wastewater pollution.

The calculation of the CCME WQI classified all the sampling sites as poor. Sampling site H and site D were the only two sampling sites classified as marginal. The two sites are located furthest from wastewater pollution and thus, the classification. The ecological assessment revealed that all the surface water bodies were classified as critically impaired. Sampling sites classified as critically impaired are sites where only a few pollution tolerant macroinvertebrates survive. Most of the sensitive aquatic organisms have died because of the wastewater pollution from the breakdown in wastewater infrastructural systems.

Conclusion: It can be concluded that the surface water bodies in the vicinity of the Zastron and Matlakeng Township was polluted by wastewater that had flown into it from either blocked or overflowing manholes and malfunctioning pump stations. It is recommended that infrastructural needs in the areas identified, as those mostly affected by infrastructural challenges should receive attention by the responsible local authority in order to prevent any further wastewater pollution of the surface water bodies. Such an intervention can result in the improvement and the restoration of the surface water body quality over time.

Chapter 1

Introduction

1.1 Background

Water is a natural resource necessary for humans, animals, plants and aquatic organisms to survive. In general, water is used for agricultural, industrial and domestic purposes, as well as for recreational activities. In South Africa, the quality of fresh water is deteriorating, mostly because of ever growing human activities (Ashton, 2010; Oberholster et al., 2010). It is a major concern for government that, in the near future, the country will no longer be able to meet the demands for different water uses (Oberholster & Ashton, 2008).

The mandate of the Department of Water and Sanitation (DWS) is to ensure that municipalities render acceptable, safe, and efficient water and sanitation services. Municipalities, on the other hand, are mandated to provide safe water and sanitation services to all residents in South Africa. This mandate is presented in terms of Part B of Schedule 4 of the Constitution of the Republic of South Africa (The Constitution of the Republic of South Africa, 1996). To ensure that municipalities are held accountable, the Department of Water and Sanitation has internal mechanisms in place to regulate the provision of water services. These mechanisms include legislation to ensure water service provision, pollution prevention and the monitoring of water and wastewater quality (Pocket Guide to South Africa 2014/15, 2016). The application of regulatory requirements holds municipalities accountable to protect, manage, develop, conserve, and control water resources (Pocket Guide to South Africa 2014/15, 2016).

In 2010, the DWS undertook the first green drop assessment of 156 South African municipalities. These municipalities are responsible for an infrastructural network that is comprised of 821 wastewater collector and treatment systems (DWA, 2011). In a provincial comparative analysis presented in 2011, the Green Drop Report found that the three lowest performing provinces were Free State, Limpopo and the Northern Cape. These provinces achieved an overall Green Drop score of 31.5%, 24% and 23% respectively (DWA, 2011). For the Free State, it was mentioned in the report that many of the municipalities did not meet the requirements of the regulation programme. The report also mentioned that wastewater management services were in disarray and did not meet legislative compliance (DWA, 2011).

Mohokare Local Municipality is located in the southern part of the Xhariep District of the Free State Province. Municipal services are provided to the towns of Zastron, Rouxville and Smithfield. Zastron serves as the administrative capital of the Mohokare Local Municipality (Mohokare LocaL Municipality, 2017). This municipality was one of the 156 municipalities studied by DWA in 2011 and one of the many that did not meet the Green Drop requirements (DWA, 2011).

Poor municipal services are characterized by not delivering on what was promised, not making an effort to improve the provision of services, such as water, and not dealing with problems and queries (Stone, 2011). The poor municipal service delivery by the Mohokare Local Municipality has resulted in numerous complaints about overflowing sewerage in the town of Zastron being disregarded. As a result, the community has reported this poor performance of the Mohokare Local Municipality to the Premier of the Free State Province and the South African Human Rights Commission (The Citizen, 2018). The infrastructural challenges related to wastewater management faced by the Mohokare Local Municipality and the notable complaints lodged by residents in the town of Zastron and Matlakeng Township, promoted the need for this study.

1.2 Research aims and objectives

The aim of this study was to assess wastewater pollution on the physical, chemical, microbiological and ecological quality of surface water bodies in the vicinity of Zastron and Matlakeng Township.

To achieve these aims, the following objectives were devised:

- To assess the municipal infrastructure complaints registers of the Mohokare Local Municipality to obtain an understanding of the types of infrastructural challenges faced by the communities;
- The data from the infrastructure assessment will be used to identify the surface water bodies in the vicinity of Zastron and Matlakeng Township which were most likely affected by the wastewater pollution;
- To analyse the water quality in terms of physical, chemical and microbiological, and ecological properties of the surface water bodies;
- To calculate a water quality index to classify the water quality condition of the sampling sites
- To an index to describe the ecological health status of the sampling sites; and
- To reach conclusions about the potential impact of the wastewater pollution on receiving surface water bodies in the vicinity of the Zastron and Matlakeng Township.

1.3 Layout of the dissertation

This dissertation is comprised of seven chapters.

Chapter 1: Introduction

In Chapter 1, the research project, together with the rationale, are introduced. The aim and objectives are also presented.

Chapter 2: Literature Review

In Chapter 2, an overview of the literature pertaining to water, water use, water pollution, water quality properties, infrastructure, wastewater infrastructure, wastewater infrastructure challenges and legislation to protect water resources, is presented.

Chapter 3: Materials and Methods

In Chapter 3, the study area is defined and the various techniques used in the study are described.

Chapter 4: Municipal Services Complaints

In Chapter 4, the results obtained from the assessment of the municipal complaints registers, integrated development plans and the service delivery and budget implementation plans of the Mohokare Local Municipality are presented and discussed.

Chapter 5: Water Quality Properties

In Chapter 5, the results of the physical, chemical and microbiological water quality assessments are presented and discussed.

Chapter 6: Ecological Quality of Surface Water in the Zastron Area

In Chapter 6, the results of the ecological assessment of the surface water bodies studied are presented and discussed.

Chapter 7: Discussion and Concluding Remarks

In Chapter 7, the concluding chapter, the key findings from the study are presented and integrated into the existing body of knowledge. In this chapter, the implications of poor wastewater infrastructure on both water quality and the ecological condition of the surface water bodies studied, are discussed.

References

The references in this dissertation have been prepared using the reference manager, Mendeley.

Chapter 2

Literature Review

2.1 Introduction

All living organisms, including humans, require water for their survival. Water is required for growth and the maintenance of various biological activities (Kayembe et al., 2018). In 2010, the United Nations General Assembly formally recognised the right to safe and clean drinking water and sanitation as a human right that is essential for the full enjoyment of life (Resolution A/RES/64/292). This right encompasses access to sufficient, continuous, clean, physically accessible, and affordable water for personal and domestic use (WHO, 2018).

About 70% of the earth's surface is covered by water, of which approximately 2.5% is fresh water, or about 34.5 million cubic kilometres. A large quantity of this fresh water is inaccessible as it is trapped in the ice caps. Thus, the total amount of usable fresh water on Earth is estimated to be approximately 200 000 cubic kilometres (WFA nd).

Water sources include wells, lakes, springs or rivers. Many rural communities in developing countries often rely exclusively on groundwater for domestic use (Agudosi et al., 2018). However, one of the major challenges of the 21st century is to give to all humans access to safe drinking water (WWAP, 2009). Approximately 2.1 billion people lack access to safe drinking water (Guilfoos et al, 2019). The majority of the populations that are deprived of safe drinking water reside in Sub-Saharan Africa and Asia (Lewis et al., 2018). Access to safe drinking water has thus become an important public health issue from local to national level in many countries, including South Africa (Edokpayi et al., 2018).

The World Health Organization defined 'drinking water' as water that "does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages" (WHO, 2011). It is therefore imperative to ensure a safe and adequate water supply for the well-being of all humans, as water plays an essential role in their health, economy, food production and the environment (Singh and Saharan, 2010). Water scarcity already affects every continent to some extent and hinders the sustainability of natural resources, as well as economic and social development. The Millennium Development Goals Report of 2015 recorded that water scarcity affects more than 40% of people around the world and is expected to increase (MDGR, 2015).

Worldwide, the proportion of urban communities that have access to safe drinking water is much greater than rural communities. Currently, 96% of urban communities have access to safe drinking water, compared with 84% of rural populations and since 1990, the proportion of the global rural populations without access to safe drinking water, has declined by more than half, from 38% to 16% in 2015 (MDGR, 2015).

2.2 Water resources in South Africa

Overall, South Africa is a water scarce country. South Africa is ranked as the 30th driest country in the world (GreenCape, 2017). Water availability in South Africa varies greatly in space and time. While the West is dry with rainfall as low as 100 mm and only during the summer, the East and Southeast receive rainfall throughout the year with an average of up to 1,000 mm. The total annual surface runoff is estimated at 43 to 48 km^3, depending on the source (Aquastat, 2016).

In South Africa, there are two main types of rivers, mountain rivers and lowland rivers. The water in mountain rivers flows rapidly along narrow valleys, while in lowland rivers, the water flows slower in wider channels, often with terraced valleys (Khan et al., 2013). The main rivers in South Africa are the Orange River, which drains to the Atlantic Ocean, while the Limpopo River, Incomati River, Maputo River, Tugela River, Olifants River (Limpopo), and Breede River all drain to the Indian Ocean.

Surface waters include all inland waters that occur permanently or intermittently on earth. Surface water is found in lakes, rivers, and reservoirs (Amouei et al., 2012; Sardar et al., 2013). Lakes form through the natural flow of water moving under the force of gravity along channels and then accumulating in depressions in the earth (Khan et al., 2017). Lakes are fed by surface water run-off and rivers (Viljoen, 2006). When the water is not trapped in a depression, the lake is only temporary. This may occur when the water flow is fast thus allowing the water to flow into a river, or seep into the ground or evaporate (Davison et al., 2002). Several factors determine the size of a lake. These factors include the origin of the depression where the water accumulates, the water regime, river channel stability, water exchange characters, water balance structure, temperature and dissolved load (Lazarova et al., 2011). In contrast to a naturally formed lake, a human-made inland lake is referred to as a reservoir.

Groundwater resources are limited because of geology. Groundwater is fresh water found in the subsurface pore space of soil and fissures in rocks. The spaces in the rocks that store and transmit groundwater are referred to as aquifers. Large porous aquifers occur only in a few areas in South Africa (Ponsadailakshmi et al., 2018). However, groundwater is, often the primary water source in the rural and more arid areas of the country (DWA, 2013). It is expected that groundwater used for human consumption will increase further, especially in the western part of the country, where perennial rivers do not occur (GreenCape, 2017).

2.3 Water use

Water is used extensively in society for various purposes. Water is used for domestic, commercial, industrial, agricultural, mining, recreational, and environmental activities. Each community, household and individual uses water for various domestic purposes. Domestic use includes water that is used in the home every day for household purposes, such as drinking, food preparation, bathing and washing clothes and dishes (Cohen et al., 2012).

Water is essential to most industries. Steel, chemical, food, paper, chemical and petroleum refining industries are major users of water (Daud *et al.*, 2017). Industrial water is used for a variety of purposes, such as processing, cleaning, transportation, dilution, and cooling in manufacturing and other industries (Dev and Bali, 2018). Depending on the distribution of industries, the amount of industrial water used varies from area to area, but is usually low in rural areas. Most of the water used by industry is not consumed and can be returned to the water supply. This wastewater though can contain hazardous material such as heavy metals or acids. However, industrial returned wastewater is usually regulated by environmental legislation, which provides guidelines for its treatment so it can be safely re-used by the population (Government Gazette Notice Number 665, 2013).

Water is used extensively in the South African mining sector. Mining water is used for the extraction of minerals such as coal, iron, sand and gravel. Water is also used for mineral processing, dust suppression and slurry transport. In quarrying operations, water is used in crushing, screening washing and flotation of mined materials (Khan et al., 2017).

Water is also used extensively in agriculture. Globally, agriculture accounts for 70% of all water withdrawals (Bester and Vermeulen, 2010). Agricultural water is used to grow fresh produce and sustain livestock, which are central dietary requirements. Farming activities such as orchards, pasture, horticultural crops, stock animals, feedlots and fish farms require vast amounts of water. One of the most important uses of agriculture water is for irrigation (Kourgialas et al., 2017). Approximately two-thirds of South Africa's water is used for agricultural irrigation (GreenCape, 2017).

2.4 Water and wastewater services

To protect the environment and human health, countries should have effective water and wastewater treatment systems in place. Wastewater is described as a complex mixture of organic and inorganic materials (Odlare, 2014). It originates from domestic, commercial and industrial sources (Naidoo, 2013). A wastewater infrastructural system is comprised of waste collectors, pump stations and treatment plants (USEPA, 1998). Its function is to collect wastewater from homes, businesses and industries and deliver it to municipal wastewater treatment plants. A wastewater treatment plant treats the water to acceptable standards prior to it discharging the treated wastewater effluent into receiving water bodies (USEPA, 1998).

The need for good water and wastewater services is critical for the health of urban and rural areas. In South Africa, a large service delivery gap exists between rural and urban areas, especially in the provinces of Limpopo, Eastern Cape, North West and KwaZulu-Natal (Managa, 2012). An example of such a service delivery gap is in the rural village of KwaNyuswa in KwaZulu-Natal. In this settlement, 42% of the households have access to water, 2% walk more than 200 m to access water and only 3% have access to flush toilets (Mzimela, 2013). Another example is the assessment conducted to rate water and sanitation services provided by the Bushbuckridge Local Municipality, Mpumalanga province (Mnisi, 2001). In this assessment it was found that 100% of the residents of New Forest location experienced water problems because of poor service delivery (Mnisi, 2001). In comparison, the municipalities in urban provinces deliver better services, than many rural areas. An example is Western Cape Province, where 77% of all households have access to water inside a dwelling and 86% have access to a flush toilets connected to a sewerage system (Jacobs, 2013).

South Africa is faced with many challenges that relate to operation and maintenance of water and wastewater infrastructural systems. A significant number of wastewater treatment systems are failing as a result of inadequate operational and maintenance capacity, as well as a shortage of skilled personnel in several South African municipalities (Fourie, 2008). The South African Institute of Civil Engineering (SAICE) emphasised that the status of public infrastructure, particularly wastewater treatment systems, is inappropriately designed and unsustainable in some municipalities (SAICE, 2011). As a result of urbanisation, the wastewater treatment systems in urban areas are experiencing challenges because of increased pressures associated with the expansion of the population (Mema, 2010). Many rural areas experience similar infrastructural challenges with the upkeep of wastewater treatment systems. According to the Department of Water and Sanitation, 66% of the municipal wastewater treatment systems are in a poor condition, with 35% requiring a capacity upgrade, and 56% in need of additional skilled personnel to deal with operational and maintenance matters (Gool and Saaligha, 2013).

Wastewater treatment plants are becoming a major source of surface water pollution. In South Africa, many surface water bodies are polluted by malfunctioning municipal wastewater infrastructural systems and some of these wastewater treatment systems are poorly designed and, in most parts of the country, contribute to water pollution (Mema, 2010). The pollution in some of the country's surface water bodies negatively affects the ability to provide clean water for domestic, agricultural and industrial use and, in turn, impacts negatively on the economy of a country (Water Research Commission, 2014).

Clean water is pivotal to the economic well-being of a country. The Groblersdal irrigation scheme is an example of how polluted water can threaten the economy of a country. The scheme exports agricultural produce to the value of R 50 – 100 million annually and creates 30 000 job opportunities (Water Research Commission, 2014). The scheme, unknowingly, used surface water contaminated by poorly treated wastewater to irrigate agricultural produce. Water quality tests that were performed on the produce by the European Regulator, revealed that quality of the water was poor. This prompted a stern warning from the European Regulator in which the scheme was instructed to attend to the poor water quality, or it would be at risk of losing its rights to the export market (Water Research Commission, 2014). Another example of how sewerage pollution affected surface water quality was the pollution of the Vaal River. Poorly maintained wastewater infrastructure systems of the Emfuleni Local Municipality, which are located close to the Vaal River, resulted in untreated sewerage flowing from malfunctioning pump stations into the river. The South African National Defence Force (SANDF) was deployed to salvage the situation, because of the environmental and health risks that the polluted rivers posed (News24, 2018). An assessment of the infrastructure by the SANDF found that the major contributors to the pollution of the river were wastewater treatment plants, pump stations and burst pipes in the vicinity of the Vaal River (News24, 2018).

2.5 Water pollution

Water pollution occurs when harmful substances, such as chemicals or microorganisms, contaminate water bodies making them toxic to humans or the environment. Olaniran (2014) defined water pollution as the presence of excessive amounts of a hazard (pollutant) in water in such a way that the water is no longer suitable for drinking, bathing, cooking or other uses (Owa, 2014).

Quality water supplies continue to dwindle because of resource depletion and pollution. If the water is polluted it is still there but, can not be used. This is particularly severe in the more arid countries, such as South Africa, where water scarcity and associated increasing water pollution limit social and economic development, which is linked closely to the prevalence of poverty, hunger and disease (Ochieng et al., 2010). Water bodies become polluted through natural processes, or through mechanisms of displacement and dispersal related to human activities, although water degradation is mostly as the result of human activities (Daud et al., 2017).

Pollutants enter the environment's water sources from two main types of sources. These sources include point sources and non-point sources (Varol and Şen, 2009). A point source is a single, identifiable source of pollution, such as a pipe or a drain. Contaminants from point sources discharge either into surface water or groundwater through an area that is small, relative to the area or volume of the receiving water body (Daud et al., 2017). For example, industrial wastes are commonly discharged into rivers and the sea in this way. In contrast, non-point sources, which are often termed 'diffuse' pollution, refer to pollution that occurs over a wide area and is not easily attributed to a single source (Khan et al., 2004). Non-point sources are often associated with particular land uses, as well as deposition from the atmosphere, either by precipitation (wet deposition) or by dry fallout (dry deposition). Fertilisers and pesticides from agricultural fields also release contaminates into water bodies (Jerome and Pius, 2010).

2.5.1 Water pollution through natural processes

Natural pollution of water bodies occurs mainly through geological influences and rainfall. The geology of a surrounding river drainage basin has been considered as one of the leading natural factors that affect the quality of water in streams. Rocks present in the bed of water channels are slowly dissolved by carbonic and sulphuric acids that have been absorbed by moisture (rain) in the atmosphere (DWAF, 2004). The dissolved rocks increase the sediment load and alter the acidity of the water in streams (DWAF, 2004). Heavy metals from the geological surroundings, such as lead, mercury, zinc, cadmium and arsenic, are dangerous pollutants that are often deposited with natural sediment in the bottom of stream channels (Khattak, et al., 2012).

Mercury contamination of aquatic ecosystems has been known for decades. Mercury may enter water-ways through erosion of natural mercury deposits. One of the best known examples of mercury toxicity was recorded in the coastal town of Minamata on Kyushu Island, Japan, in the middle of the twentieth century. People became seriously ill because of high toxic levels of mercury in the water (Khattak, et al., 2012).

Rainfall contributes to the pollution of water bodies through the depositing of contents conveyed in runoff. Rainfall carries waste, such as plastics, papers, faeces and sewage, along channels into water bodies in the vicinity (Chigor et al., 2012). In addition, runoff may also carry plant debris and sand, silt and clay into rivers and streams resulting in muddy, turbid water. Severe rainfall events can lead to excessive erosion and landslides, which may dramatically increase the content of the suspended material in affected rivers and lakes (Palmer et al., 2004).

2.5.2 Water pollution through anthropogenic activities

A wide range of anthropogenic activities pollute water bodies. Anthropogenic activities are widespread and vary in the degree in which they disrupt ecosystems and restrict water use (Lajçi et al., 2017). Some of these activities include indiscriminate waste disposal, farming and mining (Varol and Şen, 2009; Gyamfia et al., 2019).

Factories, manufacturing industries and mining are major contributors to water pollution. These industries are often responsible for point source pollution by pouring chemicals and industrial waste into streams, rivers or the sea. Chemical production by metal processing and smelting has been proven to be the primary source of heavy metal pollution (Yang et al., 2018). Tie and dye industries produce chemicals, such as zinc sulphate and copper salts, which have devastating effects on aquatic environments when they are discharged into rivers (Owa, 2014).

Agriculture is another major contributor to the pollution of water bodies (Zhang et al., 2011). The application of pesticides, fertilisers and also inadequate sewage disposal enter water bodies, mainly through runoff (Ambani and Annegarn, 2015). The nutrient enrichment through runoff, mainly nitrogen and phosphorus, can result in excessive algae growth in a water body, which is referred to as eutrophication (Owa, 2014). Excessive amounts of nutrients can lead to low levels of dissolved oxygen in the water. This, together with algal growth that blocks the light penetration needed for aquatic plant growth, leads to the death of plants, fish and other aquatic animals (Yang et al., 2018).

Despite its social and economic importance, mining degrades water quality in various ways. The impact of mining pollution depends on the type of minerals, the chemicals used in the metal extraction processes, climate, life stage of the mine, and environmental management practices in place (Musvoto and de Lange, 2019). In mining, only a small proportion of the large quantities of excavated mining ore contain the desired substance. Large quantities of water are used to process these ores, which in turn generates excessive amounts of chemicals, heavy metals, soil and other waste rock materials. Metals, such as arsenic, cadmium and lead, leach from mining sites into the surroundings and contaminate the environment and water bodies in the vicinity of the mines (Minolfi et al., 2018).

The waste disposal from various industrial, household and agricultural activities is a major contributor to the contamination of water (Sharma and Kumari, 2019). With the world population ever increasing, disposing of sewage and wastewater has become a substantial problem. The treatment capabilities for sewage and wastewater are lacking in many areas of the world, especially in the poorer and developing countries (Minolfi et al., 2018). As a result, large amounts of sewage-polluted, untreated water are discharged into water bodies every day, contaminating the water intended for drinking and other uses (Zamxaka et al., 2004; Bodrud-Doza et al., 2016). Furthermore, in the poorer areas, many townships and municipalities do not have the means to dispose of household waste, and thus dispose it in water bodies in their vicinity (Chigor et al., 2012).

2.6 Effects of polluted surface water

Today, water pollution has become a major problem, and is among the leading causes of disease and death in the world (Daud et al., 2017). The health effects that poor quality water may have on a consumer can be divided into two categories; those health effects that are acute or those that are chronic in nature. Acute health effects appear soon after consumption of the poor quality water, while the chronic health effects show only after the poor quality water has been used for a long time (DWAF, 1998). Chronic health effects could be serious and long-lasting, or they may be insignificant and only temporary.

Most chemicals arising in drinking water are a health concern only after an extended exposure of years, rather than months. The major exception is nitrate (WHO, 2017). Typically, changes in chemical water quality occur progressively, except for those substances that are discharged or leached intermittently into flowing surface waters or groundwater from, for example, wastewater treatment plants or contaminated landfill sites. Several chemicals, when they occur at unacceptable levels in drinking water, may be of concern to human health (Table 2.3).

Table 2.1 Water chemicals that are of concern to human health

Chemical	Health effects
Arsenic	Populations ingesting arsenic-contaminated drinking-water show signs of chronic arsenicism, including dermal lesions such as hyperpigmentation and hypopigmentation, peripheral neuropathy, skin cancer, bladder and lung cancers, and peripheral vascular disease. Dermal lesions were the most commonly observed symptom, occurring after minimum exposure periods of approximately 5 years. Effects on the cardiovascular system were observed in children

	consuming arsenic−contaminated water (mean concentration 0.6 mg/l) for an average of 7 years (WHO, 2011).
Fluoride	Fluoride is beneficial to human health in trace amounts but can be toxic when ingested in excessive amounts (Varol and Dauraz, 2016). At high concentrations, fluoride is a dominant calcium absorbing element and can interfere with the calcified structure of bones and teeth in the human body to cause dental or skeletal fluorosis (Mhlongo et al., 2018).
Nitrate/Nitrite	Bottle-fed infants less than 6 months old are at risk of contracting methaemoglobinaemia (blue-baby syndrome) through nitrite exposure after consumption of formula reconstituted with drinking-water containing nitrite (WHO, 2017). Nitrates in the drinking water form compounds in the body that change haemoglobin to methaemoglobin, thereby decreasing the ability of blood to carry oxygen (Varol and Dauraz, 2016).
Sulphate	This is particularly common in mining areas. It causes diarrhoea, predominantly in users not accustomed to drinking water with high sulphate concentrations (DWAF, 2001; Daud et al., 2017).

Regardless of the source, water is susceptible to contamination with microorganisms and organic matter among other pollutants. Water acts as a passive carrier for numerous organisms that can cause human illness. Infectious diseases caused by pathogenic bacteria, viruses and parasites, for example protozoa and helminths, are the most common and widespread health risks associated with drinking-water (WHO, 2017; Daly et al., 2018). Microbial contaminants such as coliforms, *E. coli*, *Cryptosporidium parvum*, and *Giardia lamblia* compromise the safety of the water. The presence of *E. coli*, *Klebsiella*, and *Enterobacter* species in water are likely indicators of the presence of pathogenic organisms such as *Clostridium pafringens*, *Salmonella*, and Protozoa. These pathogens cause diarrhoea, giardiasis, dysentery and gastroenteritis, which are common among the rural dwellers of developing nations (Onyango et al., 2018). Among the water-borne protozoan pathogens, *Giardia* and *Cryptosporidium* are the most common causes of major diarrhoeal outbreaks globally (Moreno et al., 2018).

In 1993, an epidemic of cryptosporidiosis struck Miluwaukee, Wisconsin. Hundreds of thousands of people became ill and 50 died (Davis et al., 2009). In May 2000, 4800 people in the rural town of Walkerton in Ontario, Canada, experienced an outbreak of a water-borne disease caused by *E. coli* O157:H7 and *Campylobacter* in the drinking water system. Seven people died and many people became seriously ill. The contamination was ultimately traced to a source that had been identified as a potential threat to the drinking water system 22 years earlier, but no remedial action was taken to manage the public health risk (Hrudey and Hrudey, 2009). These events demonstrate that even 'modern' water treatment and distribution facilities are vulnerable to contamination by infectious pathogens.

The microbial contamination of drinking water is a serious problem in developing counties where the situation of fresh water availability is impacted by the lack of proper management and financial constraints. In Africa, on the 6th September 2018, a cholera outbreak in Harare, Zimbabwe, was declared by the Ministry of Health and Child Care. Twenty-five patients were admitted to a hospital in Harare with acute watery diarrhoea and vomiting caused by *Vibrio cholerae* serotype O1 Ogawa. One woman died. By the 15th September, a further 3621 cumulative suspected cases were reported (WHO, 2018). Contaminated water from boreholes and wells in Harare was suspected to be the source of the outbreak.

2.7 Surface water quality assessments

2.7.1 Introduction

One of the unique characteristics of water is its excellent dissolving capability. During the hydrological cycle of water, it comes into contact with a wide range of substances, which may be dissolved by the water to a greater or lesser extent (DWAF, 2001). The type of substances, as well as the amount of the substances determines the properties (quality) of the water. Oxygen and carbon dioxide are important gasses that dissolve in water. Inorganic compounds that dissolve in water include sodium chloride and calcium sulphate, while organic substances include humic acids and carbohydrates (DWAF, 2001). Besides the dissolved substances found in water, substances that do not dissolve, but remain in suspension as very small suspended or colloidal particles, are also found in water. Such suspended substances, in particular microorganisms, also affect the quality of water. Thus, to evaluate the quality of water, the concentration of dissolved substances is determined together with the physical and microbiological properties of the water (DWAF, 2001).

A wide range of different substances is found in water. However, in water quality assessment only a few of the commonly occurring substances exists at concentrations that are of concern for domestic water users (Kasperczyk et al., 2017). These substances can be sorted into four groups (DWAF, 2001); substances that give an indication of general water quality; substances that are normally present in most waters at concentrations, which may affect the health of consumers; substances which do not occur frequently at concentrations of concern to health, but are typically present in soft corrosive waters that cause them to be leached from pipes and appliances; and substances that could be commonly found in water at concentrations, which may affect aesthetics, for example the staining of clothes, or may have economic effects, such as corrosion (Table 2.1).

Table 2.2 Commonly occurring substances used in water quality assessment (Modified from DWAF, 2001)

Substance	Type of indicator
Substances that give an indication of general water quality (Indicates potential problems and should be frequently tested at all points in the water supply system).	
Electrical conductivity (total dissolved salts)	Indicator of total dissolved salts (TDS), and also establishes if the water is drinkable and capable of slaking thirst.
Faecal coliforms	Indicator of the possible presence of disease-causing organisms. It establishes if water is polluted with faecal matter.

pH value	Has a marked effect on the taste of the water and also indicates possible corrosion problems resulting from dissolution of metals such as copper, zinc and cadmium that can be toxic.
Turbidity	Affects the appearance and thus the aesthetic acceptability of the water.
Substances that are normally present in most waters at concentrations, which may affect the health of consumers	
Nitrate & nitrite	Common in groundwater (borehole) samples, particularly in areas of intensive agricultural activity or where pit latrines are used. Severe toxic effects are possible in infants.
Total coliforms	Provides an additional indicator of disease-causing organisms, and the effectiveness of disinfection.

2.7.2 Physical properties of water

The physical properties of water include properties such as turbidity, potential hydrogen (pH), electrical conductivity (EC), colour, odour and taste. The physical properties of water largely determine the aesthetic properties of water that include appearance, taste and general drinkability of the water (DWAF, 2001). Physical characteristics of water are mostly determined by the senses of touch, sight, smell and taste (Jotwani et al., 2014). Turbidity is a measure of the clarity of water. Suspended and colloidal material in the water determines the light-transmitting properties of the water and ultimately influences the clarity of the water (Mohsin et al., 2013). The passage of light through water decreases as the presence of suspended and colloidal material in water increases. Thus, water that contains relatively high levels of suspended and colloidal material will be regarded as being turbid. Turbidity also influences the temperature of water. As turbidity increases, so does the temperature because suspended particles tend to absorb more heat (WHO, 2004). Warmer water, as a result of higher turbidity levels, causes the concentration of dissolved oxygen (DO) to decline. Thus, warm water holds less DO than cold water. Also, because of the reduced light penetration in turbid water, photosynthesis and the production of DO is reduced, which in turn affects the growth rate of aquatic algae and other aquatic plants (Mohsin et al., 2013).

The pH of water is a measure of the relative amount of free hydrogen and hydroxyl ions in water. The pH of water determines the solubility and biological availability of chemical constituents, such as nutrients in the water, and these are important to sustain aquatic life in nature or may render the water harmful for human consumption. Chemical constituents include phosphorus, nitrogen and carbon as well as heavy metals, such as lead, copper and cadmium (Bester and Vermeulen, 2010).

EC is a measure of the capacity of water to conduct electrical current. EC is also directly related to the concentration of salts dissolved in water, and therefore to the total dissolved solids (TDS). Thus, salts and inorganic materials, such as alkalis, chlorides, sulfides and carbon compounds, dissolve in water to produce positively charged ions and negatively charged ions that conduct electricity (Kasperczyk et al., 2017). When the concentration of charged ions in water is increased, the EC of the water will also increase. Thus, EC of distilled or deionised water is low because of the absence of charged ions, while the EC of seawater is high because of a much higher concentration of charged ions present in the seawater (Mohsin et al., 2013).

2.7.3 Chemical properties of water

The chemical properties of water are determined by four main groups of dissolved substances. The group of metallic substances includes arsenic, cadmium, calcium, copper, iron, magnesium, manganese, potassium, sodium and zinc, while examples of inorganic non-metallic substances are chloride, fluoride, nitrate and sulphate (DWAF, 2001). The final two groups are the aggregate group of organic substances and the aggregate group of inorganic substances.

Several metallic substances occur in trace amounts in water. A trace element or substance occurs in water at very low concentrations. Cyanide, although not a metallic substance, is often listed amongst the trace elements because it also occurs in trace amounts in water. Table 2.2 provides a list of a few important trace substances that are found in water together with some facts and effects.

Table 2.3 Trace substances that occur in natural water

Trace element/substance	Facts and effects
Aluminium (Al)	Al is one of the trace metals present in drinking water. Al salts are used extensively as coagulants in drinking water treatment to enhance the removal of particulate, colloidal and dissolved substances (Wang et al., 2018).
Arsenic (As)	As is odourless and tasteless and enters drinking water supplies from natural deposits in the earth or as a result of agricultural and industrial practices. As may be found in some drinking water supplies, including wells. Exposure to high levels of As can cause serious health effects (Mhlongo, et al., 2018).
Lead (Pb)	The primary sources of Pb in drinking water are due to the corrosion of household plumbing systems and erosion of natural deposits (Boakye-Ansah et al., 2016). Pb can leach into water from pipes, solder, fixtures, faucets (brass) and fittings (Chabukdhara et al., 2017). The amount of Pb in water also depends on the types and amounts of minerals in the water, how long the water stays in the pipes, the amount of wear in the pipes, and the water's acidity and temperature (Gordon et al., 2008).
Mercury (Hg)	Hg is typically released from industrial and agricultural processes; household, commercial and medical products containing mercury; sewage discharge; and sediment (Lajçi et al., 2017). When exposed to high concentrations, Hg vapour may cause damage to the nervous system (Gordon et al., 2008). Inorganic mercury is produced from elemental mercury through the process of oxidation. Hg is the most common form present in drinking water, but is not considered to be very harmful to humans (WHO, 2011).

Water can contain a large number of organic compounds. The main element of organic compounds is carbon. Organic compounds behave differently in a liquid. They usually do not dissolve as ions, but rather go into solution as molecules of the compound. Organic compounds in water include algae and bacterial by-products, carbohydrates and proteins, synthetic organic compounds such as pesticides and herbicides, and products formed during water treatment such as chloroform and other chlorinated products (DWAF, 2001). These compounds are usually present in very low concentrations, but they may be harmful even at low concentrations.

Aggregate inorganic substances are measured by total dissolved solids (TDS) and hardness. TDS is the term used to describe the inorganic salts and small amounts of organic matter present in solution in water. The principal constituents are usually calcium, magnesium, sodium and potassium cations, and carbonate, hydrogen carbonate, chloride, sulfate and nitrate anions. The total solids content of water is defined as the residue remaining after evaporation of the water and then drying the residue to a constant weight at 103°C to 105°C (Arora, 2017). Hardness is a natural characteristic of water that can enhance its palatability and consumer acceptability for drinking purposes (DWAF, 2001). The hardness of water is due to the presence of calcium and magnesium minerals that are naturally present in the water (DWAF, 2001). The common signs of a hard water supply are poor lathering of soaps and scum. The hardness is made up of two parts: temporary (carbonate) and permanent (non-carbonate) hardness. The temporary hardness of water can easily be removed by boiling the water (Arora, 2017).

2.7.4 Microbiological properties of water

Waterborne diseases are usually caused by enteric pathogens. Enteric pathogens are transmitted by the faecal-oral route. These pathogens are generally excreted in faeces by infected people, carried in faecally contaminated food or water and then ingested by other individuals. However, water also plays a role in the transmission of pathogens, which are not faecally excreted, such as opportunistic pathogens that are normal external body flora (Burgess and Pletschke, 2008).

To ensure safe water, there must be no pathogens in the water at the point of use. The microbiological quality of the raw water is directly linked to the quality of the treated water. The assessment of microbial quality of water is usually based on testing indicator microorganisms. An ideal indictor organism should always be present when the pathogen is present and should be absent in uncontaminated water; should be present in numbers greater than the pathogen it indicates; should have a survival in the environment and resistance to the treatment processes that is comparable to that of pathogens; should not be harmful to human health; should be easy to identify and to isolate; and should be suitable for all types of water (Burgess and Pletschke, 2008).

One of the categories of indicator microorganisms is coliform bacteria. Certain coliform groups are members of the normal microbial flora of the human gastrointestinal tract and are relatively easy to detect (Nkwe et al., 2015). Faecal coliforms are comprised of aerobic and/or facultative anaerobic Gram-negative, non-spore forming, rod-shaped bacteria that ferment lactose to gas (Daud et al., 2017). If coliforms are present in treated drinking water, it is an indication that the drinking water has not been adequately disinfected (McOmber, 2017). The absence of coliforms in the distribution system minimises the likelihood for faecal pathogens to be present in drinking water (WHO, 2013).

The indicator organism *Escherichia coli* (*E. coli*) is used to indicate the presence of faeces of humans and other warm-blooded animals in water (Ikonen et al., 2017). *E. coli* is a species within the thermotolerant coliform group, generally regarded as the most specific indicator of faecal contamination, and therefore an essential indicator for public health (Lam et al., 2017). Thus, the presence of *E. coli* in water samples, also indicates the possible presence of pathogenic organisms of human origin (Nkwe et al., 2015).

Besides coliform bacteria and *E. coli*, the presence of several other organisms is also determined when assessing water quality. These organisms are protozoan parasites, heterotrophs and bacteriophages. *Cryptosporidium* and *Giardia* species are typical protozoan parasites (Ikonen et al., 2017). Although *Cryptosporidium* species are commonly transmitted by water; other sources of infection include food-borne and person-to-person transmissions (Ikonen et al., 2017). *Giardia* is a genus of anaerobic flagellated protozoan parasites of the phylum Sarcomastigophora that colonises and reproduces in the small intestines of several vertebrates and causes giardiasis (Zhang et al., 2017). Heterotrophs are broadly defined as microorganisms that require organic carbon to grow and include bacteria, yeasts and moulds. A variety of simple culture-based tests that are intended to recover a wide range of microorganisms from water are collectively referred to as heterotrophic plate count test procedures (WHO, 2013).

2.7.5 Water quality index

A water quality index (WQI) is a method of providing an overall description of water quality. A WQI is a composite indicator of water quality that pools together complex water quality data into an aggregate value. A WQI thus reduces a large amount of information about water quality into a single value (Shiji et al., 2016; Singh and Hussian, 2016; Galal Uddin et al., 2017).

Water quality, expressed in the form of a WQI, was first reported in 1965. This first attempt to develop a WQI was undertaken by Horton (1965). Later, a WQI similar to Horton's index was developed by Brown et al. in 1970 (Brown et al., 1970). Thereafter, countries such as the United States of America and Canada developed indices that were designed to be more suited to water conditions in their countries (Bereskie et al., 1970). Subsequently, indices were formulated by several national and international organisations. These WQIs were developed to be more flexible, so that they are able to incorporate a variable composition of water quality measurements that are more location-specific, and take into account changing water conditions (Bereskie et al., 1970; Brown, et al., 1972; Yousefi et al., 2018). These WQIs include the National Sanitation Foundation Water Quality Index (NFSWQI) (Brown et al., 1970); Weight Arithmetic Water Quality Index (WAWQI) (Brown, et al., 1972), Weighted Water Quality Index (W-WQI) (Tiwar and Mishra, 1985); British Columbia Water Quality Index (CCME, 1999) and Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) (CCME, 2001).

In recent times, the utilisation of a WQI has gained popularity because of its description of water quality as a single value. A WQI is often used to classify water quality data into simple terms, such as excellent, good, poor, very poor and unsuitable for use (Sorlini et al., 2012; Shiji et al., 2016; Yousefi et al., 2018). These classifications provide important information about the general water quality status, which facilitates choices of water-treatments (Yousefi et al., 2018). The use of a WQI, on a continuous basis, provides long-term data that is helpful in decision-making and when communicating information about water quality (Akter et al., 2016; Galal Uddin et al., 2017). These data can then be used to predict potentially harmful conditions of water such as for aquatic habitats and aquatic life, quality of irrigation water for agriculture and livestock, recreation and aesthetics, and drinking water supplies (Scheili et al., 2015). Using a WQI to describe the overall quality of water is also a convenient method of communicating the overall potential impact of water when planning water quality interventions (Singh and Hussian, 2016).

2.8 Ecological water quality assessments

2.8.1 Introduction

Anthropogenic activities may deteriorate the ecosystem functions of surface water bodies. Examples of some pollutants that may kill aquatic organisms are poisons, pesticides, phenols and heavy metals (Belle, 2015). The presence of these pollutants in water has resulted in the loss of aquatic organisms, as well as ecosystem functionality of many surface water bodies around the world (Cox, Oeding and Taffs, 2019). The health of surface water bodies is also influenced by many factors such as flow regime, habitat structure, biotic interactions as well as energy sources (Ollis, 2005). Other factors that influence the ecological health of surface water bodies includes the physical, chemical and microbiological properties of water (Ollis, 2005).

To determine what impact anthropogenic factors, as well as natural factors has on the ecological health status of surface water bodies, rapid and simplified techniques should be available to measure water quality. Therefore, many countries have developed techniques that are used to assess the ecological health status of surface water bodies (Wang et al., 2009). Examples of countries where these techniques have been developed and used are the USA, Europe, Australia, Canada and South Africa (Wang et al., 2009).

A bioassessment is an example of a rapid and simplified technique available to determine ecological water quality. The bioassessment technique measures the response, condition and community integrity of aquatic organisms in order to assess the ecological water quality of a surface waterbody (Ollis, 2005). An example of aquatic organisms that are used to determine ecological health of surface water bodies are macroinvertebrates. Macroinvertebrates are described as organisms that are large enough to be visible to the naked eye and do not have a backbone (Schumaker Chadde and Water, 2019). These macroinvertebrates provide nutrients and are vital for the decomposition of materials in surface water bodies (Wallace, 1996). Macroinvertebrate populations and habitats can be used to indicate changes in water quality to determine the extent to which a water body may be polluted (Liefferink, 2014).

2.8.2 South African Scoring System

Currently in South Africa, the South African Scoring System (SASS) is the most popular biotic index used to determine ecological health of surface water bodies. Several modifications have been made to the SASS over time. The last modification was made to the SASS version 4 as a result of certain limitations identified from previous bioassessments. These modifications included the inclusion of macroinvertebrate species that had previously been omitted, some sensitivity scores as well as changes to the sampling protocol (Dickens and Graham, 2002). The application of the SASS version 5 is ideal because it can used to determine the degree of pollution of surface water bodies by assessing the presence or the absence of different macroinvertebrate species in water (Dickens and Graham, 2002). The macroinvertebrate species are given sensitivity scores between 1 and 15, where the high scores are indicative of high sensitivity to pollution (Bere and Nyamupingidza, 2014).

SASS5 has therefore become an integral component of the River Health Programmes implemented by the Department of Water and Sanitation (Ollis, 2005).

2.8.3 Classification of the ecological condition

Dallas (2007) developed a standard reporting format for the for biomonitoring data. A regional reference condition approach is used to classify the quality of an ecological system (Dallas, 2007). The approach requires the identification of a regional reference condition at a site, which provides a means of comparing the observed conditions with expected conditions so that the degree of impairment or deviation from natural conditions can be determined (Ollis, 2005). The classification of a site using the regional approach requires the initial classification of the site to be based on the geographic and physical attributes (Ollis, 2005). Once data is available from the bioassessment method in the form of SASS scores and Average Score per Taxa (ASPT), it is then compared to a specific reference condition. This comparison provides an indication of any form of deterioration or deviation from the surface waterbody's natural condition when compared to the reference condition (Dallas, 2007).

2.9 Legislation to prevent surface water pollution

The Constitution of the Republic of South Africa (1996) stipulates that everyone has the right to an environment that is not harmful to their health and well-being (The Constitution of the Republic of South Africa, 1996). In South Africa, a number of legislation pieces has been put in place to facilitate the monitoring and to protect water bodies from pollution. With this provision, the Constitution paved the way for the enactment of the National Water Act in 1998. The National Water Act contains measures that guide the monitoring and protection of water sources from pollution as well as the management of this important resource (National Water Act, No 36 of 1998).

The Department of Water and Sanitation, who is mandated to manage and protect water resources in South Africa, developed a broad spectrum of Water Quality Guidelines (WQG). These guidelines include the South African Water Quality Guidelines for: Domestic Water Use; Agricultural Water Use; Irrigation Water Use; and Aquatic Ecosystems (DWA, 1996). The WQG for aquatic ecosystems provide a Target Water Quality Range (TWQR), an Acute Effect Value (AEV) and the Chronic Effect Value (CEV). Each of these standards serves a specific purpose (DWA, 1996). In the case of the TWQR, it stipulates the ideal range for a particular water quality property. Whereas the WQG for the domestic, agriculture and irrigational uses provides acceptable standards against which different waters can be used without it having a negative impact on health, environment and agricultural produce (DWA, 1996).

Chapter 3

Materials and Methods

3.1 Introduction

This study was carried out to assess what impact wastewater pollution has on the water quality of rivers, dams and streams in the vicinity of Zastron and Matlakeng Township, Free State Province. To ascertain the impact of wastewater pollution on these surface water bodies; the physical, chemical and microbiological water quality properties were measured over a three sampling rounds. The status of the water bodies was also assessed in terms of the effects that polluted water had on aquatic organisms living in the water. Therefore, the ecological assessment involved the assessment of the macroinvertebrate families present in various macroinvertebrate habitats.

3.2 Study area

The Free State Province is located in the centre of the country, South Africa. The province is characterised by farmlands and widely dispersed towns. The Xhariep District is one of five district municipalities in the Free State Province (See Figure 3.1) (Free State Province Provincial Growth and Development Strategy, 2005). The district is located in the southern part of the province and is described as being semi-arid with a dispersed settlement pattern (Xhariep District Municipality, 2018). The Xhariep District is comprised of 17 rural towns, including the study area, Zastron (Xhariep District Municipality, 2018). Zastron borders Lesotho and the Eastern Cape Province and is located at the foot of the Aasvoëlberg characterised as a mountain with a hole in it, famously known as the *Eye of Zastron* (Zastron | South African History Online, 2019). The Matlakeng Township forms part of the town Zastron, and where various smaller locations are found (See Figure 3.2). These locations include Old Location, Refeng Khotso, Phomolong, Itumeleng and Ezibeleni.

Figure 3.1 South African map indicating the central position of the Free State Province (Map data, 2019)

Figure 3.2 Map of the Xhariep District in the Free State indicating the location of Mohokare Local Municipality and the Town Zastron (Municipalities of South Africa, 2019)

The Integrated Development Plan (IDP) of the Mohokare Local Municipality identifies Zastron as the administrative capital of the municipality. The IDP of the municipality identified a need for an improvement in the quality and status of all rivers and tributaries (Mohokare Local Municipality, 2017). This came as a result of the contamination of rivers and tributaries from current farming practices and urban effluent discharge. Another weakness identified in the IDP of the Municipality was an aging infrastructure, such as roads and equipment (Mohokare Local Municipality, 2017).

3.3 The purpose of this study

To investigate public complaints regarding the water quality and the ecological health status of surface bodies as a result of infrastructural breakdown and the treatment efficacy of the wastewater treatment works on the rivers, dams and streams in the Zastron and Matlakeng area. The investigation was portioned in two phases.

3.4 Study design

In phase one, an assessment of the infrastructural integrity of pipes, manholes, pump stations and wastewater treatment works was carried out. This was achieved by analysing the municipal complaint registers of the Mohokare Local Municipality, to determine suitable sampling sites in areas where most infrastructure related complaints were received from. The sampling sites would most probably be located closest to the areas where the community complaints were received from.

In phase two, an environmental impact of the wastewater pollution on rivers, dams and streams in the identified sampling sites was carried out. The study was conducted over three sampling rounds, to establish if a pattern and extent of physical chemical, microbiological and ecological quality variations could be identified. Considering the importance of variations, it is thus important to establish whether a relationship exists among water quality parameters during each sampling round (Teck-Yee Ling et al., 2017). It is also an important indicator to determine if time-based changes have an effect on chemical and microbiological concentrations at water sampling sites (Boroń et al., 2016). The results in this study, is presented as three sampling rounds. Sampling took place in November 2017, May 2018 and November 2018, which represents a six-month interval between the three sampling rounds. The environmental impact included a water quality as well as an ecological assessment of the identified 10 sampling sites. During each of the three sampling rounds, water and ecological samples were collected from the perennial rivers, dams and streams in the vicinity of Matlakeng Township. Water quality was analysed in terms of the physical, chemical and microbiological water quality properties. The compliance of the physical, chemical and microbiological water quality data was compared to the proposed aquatic water quality limits for urban streams (Nyoh, 2015). To ascertain if seasonal effects existed for the water quality data obtained over the three sampling seasons, an analysis of variance and Scheffe's post hoc test were performed (Kenton, 2019).

A water quality index (WQI) best describes the water quality condition of a surface water body. For the purpose of this study, a water quality index was calculated for each of the 10 sampling sites. The WQI was calculated using the data obtained for the physical and chemical and microbiological water quality properties, over the three sampling rounds.

To determine the ecological quality of surface water bodies for each of the 10 macroinvertebrate sampling site habitats, an ecological assessment was carried out. Macroinvertebrates from different biotopes were collected over the three sampling rounds. The ecological quality data was used to classify each macroinvertebrate sampling site habitat by the use of a modelled reference condition developed by Dallas (2007). In Figure 3.3, the study design is presented.

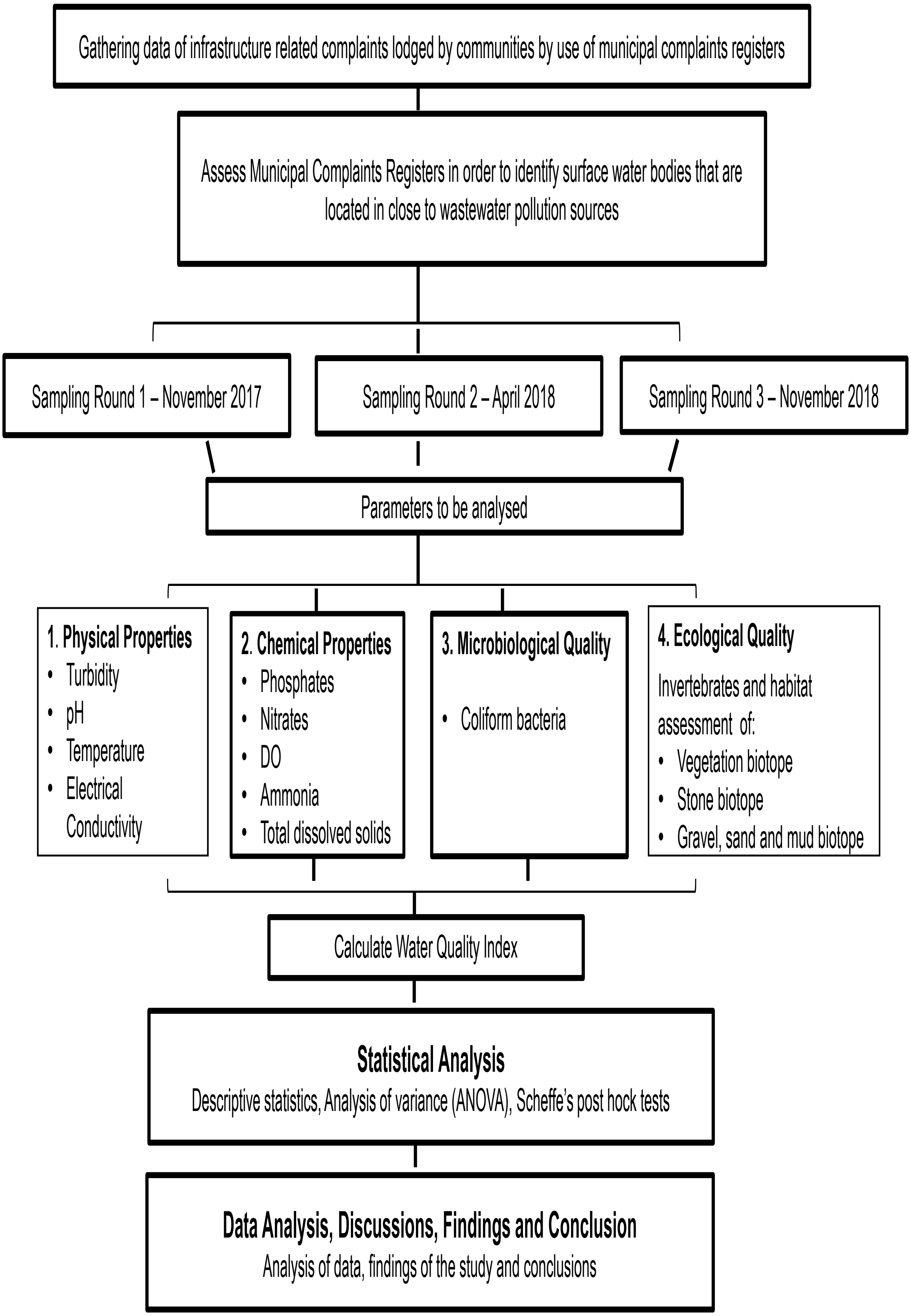


Figure 3.3 Study process

3.5 Analysis of the municipal infrastructure complaints registers of the Mohokare Local Municipality to identify sampling sites

The Mohokare Local Municipality has a complaints management system in place. The complaints management system is designed to ensure that service delivery related complaints are lodged at offices within close proximity to where residents of both Zastron or Matlakeng Township reside. To access the municipal complaints registers for the purposes of this study, approval was requested from the Municipal Manager of the Mohokare Local Municipality. Approval was granted in a formal letter signed by the Municipal Manager. The infrastructure complaint registers for both Zastron and Matlakeng Township was therefore obtained for the purpose of this study (See appendix).

To identify suitable sampling sites, an analysis of the municipal complaint registers was carried out over a period of one year preceding the study. This was achieved by analysing the infrastructure related complaints received from community members of the Mohokare Local Municipality in both Zastron and the Matlakeng Township. The following method was developed and used to identify suitable surface water bodies mostly affected by wastewater pollution:

1. All complaints received by the municipality over a period of one year, preceding the study, were captured in a Microsoft Excel spreadsheet.
2. The relevant complaints information was captured under the following headings:
    a. The date on which the complaint was lodged by a community member;
    b. The address where the infrastructure complaint was located;
    c. The specific location of where the infrastructure complaint was located;
    d. The nature of the infrastructure related complaint (blocked manholes, sewerage spillages, malfunctioning pump stations and burst or broken pipes); and
    e. The technical reasons for the breakdown in infrastructure.

3. After all the data were captured in the spreadsheet, a filter function in Microsoft Excel was applied to each of the headings. This aided to determine the number of complaints received from Zastron and Matlakeng Township.
4. After the application of the respective filters, the following information could be extracted: (a) which infrastructure-related complaints where most prominent and (b) the areas where most complaints were lodged by community members in Zastron or Matlakeng Township.
5. These data, were then calculated as a percentage of all infrastructure related complaints received per area. The data were then plotted on a map of Zastron and Matlakeng Township to depict the locations where most infrastructure-related complaints were received from. These data were then used to create a heat map.
6. The heat map was then used to identify suitable surface water mostly impacted by wastewater pollution.
7. From the heat map, a suitable number of sampling sites were identified for surface water bodies mostly impacted by the wastewater pollution, including the identification of control sampling site located outside the influence of wastewater pollution. The sample site would be used to compare pristine natural conditions of the surface water body, with the water quality of those located within the vicinity of wastewater infrastructural breakdown.

3.6 To determine the physical, chemical and microbiological water quality properties

To conduct on-site sampling of surface water bodies, standard sampling and analytical procedures were followed as prescribed by the National Norms and Standards for Environmental Health in South Africa (National Health Act, 2003). For the microbiological water quality analysis, the instructions provided by IDEXX Laboratories for the Colilert-18 method was followed (IDEXX Laboratories Inc., 2017).

3.6.1 On-site sample collection and measurements

The physical water quality properties (turbidity, electrical conductivity, temperature and pH) were analysed onsite, at each of the 10 sampling sites. To analyse the chemical water quality properties, sterile 500 mL sample bottles were used to collect water, while for the microbiological analysis, 100 mL sterile sample bottles were used. All samples destined for the laboratory were appropriately labelled and placed in an icebox for transportation. To ensure that the integrity of the water samples was preserved, the samples were transported in a cooler box containing icepacks. A mobile thermometer was placed in the cooler box to monitor that the temperature remained between 2 – 10°C. For on-site measurements, a battery operated HACH 2100Q turbidity meter was used to measure the turbidity, while a Hach HQ40d multi instrument was used for the pH, electrical conductivity (EC) and temperature measurements (Figure 3.4).

(a) **(b)**

Figure 3.4 On-site measuring instruments (a) Hach 2100Q Turbidity meter, (b) Hach HQ40d multi instrument used to measure pH, electrical conductivity and temperature

To determine the total dissolved solids (TDS) in mg/L in the water samples, the EC (µS/cm) measurements were used to calculate the TDS. TDS was calculated as follows (The Environmental and Protection Agency, 2001):

$$TDS\ (mg/L) = electrical\ conductivity\ (\mu S/cm) \times 0.67 \quad (1)$$

3.6.2 Calibration and measurement of pH, EC and temperature using the Hach HQ40d multi instrument

The Hach HQ40d multi instrument was calibrated by an accredited service provider prior to use. The calibration of the instrument was carried out prior to each sampling season. The measurements of pH, EC and temperature were conducted using the following procedure:

1. A multi-probe was connected to the Hach HQ40d instrument. The multi-probe was used to collect the water quality data for pH, EC and temperature using a single instrument.
2. To collect the data, the probe was placed midstream at each of the 10 sampling sites.
3. Once the instrument stabilised, a reading for pH, EC and temperature was displayed on the screen. The measurements were captured in a notebook and then transferred into a Microsoft Excel spreadsheet.
4. Distilled water was then used to rinse the probe after measuring pH, EC and temperature at each of the sampling sites. This was done to ensure that the multi-probe provided accurate readings for each of the respective sampling sites.

3.6.3 Laboratory measurements

To analyse all the chemical water quality properties for each of the 10 sampling sites, water samples collected in a 100 mL sample bottle were delivered to the Test It Labs for analysis. The laboratory is a SANAS accredited located in the town of Bloemfontein (Test It, 2018). While the microbiological water quality was analysed in the laboratory of the Central University of Technology, Free State.

3.6.4 Measurements of coliforms using the IDEXX (Colilert18) Quanti-Tray™ method

The IDEXX (Colilert18) Quanti-Tray™ method uses a biotechnological detection approach, which uses the multi-well most probable number (MPN). The method incorporates a defined substrate medium, which contains *θ*-nitrophenyl-*β*-D-galactopyranoside (ONPG) and 4-methylumbelliferyl-*β*-D-glucuronide (MUG). It requires samples to be incubated at 37°C for 18 to 22 hours. A yellow colour indicates the presence of coliform bacteria, which is due to the production of *β*-galactosidase under UV light. The MPN is then calculated by counting the number of positive wells using an MPN table.

The water samples collected to determine the microbiological water quality for each of the 10 sampling sites were removed from the refrigerator in the laboratory of the Central University of Technology at the time of the analysis. To determine the number of feacal coliforms present at each of the sampling sites, the following laboratory procedure was followed:

1. A Colilert medium 18 was added to the 100 mL water samples bottles. The bottles were gently shaken and left to stand for a few minutes for the Colilert medium 18 to dissolve.
2. Each of the 10 water sample bottles containing the medium was then poured into 10 different Quanti-Trays and thereafter sealed. For each of the Quanti-Trays, an identity sample number was allocated to differentiate between the different water samples. The Quanti-Trays were then placed in an incubator at 37°C for 22 hours.
3. After the incubation period, the Quanti-Trays were removed from the incubator for analysis.
4. For each of the Quanti-Trays, the number of positive yellow wells were counted. The MPN tables were used to quantify the number of coliforms present at each of the 10 sampling sites. Figure 3.5 demonstrates the method used to quantify the number of positive wells for feacal coliforms using the MPN table.

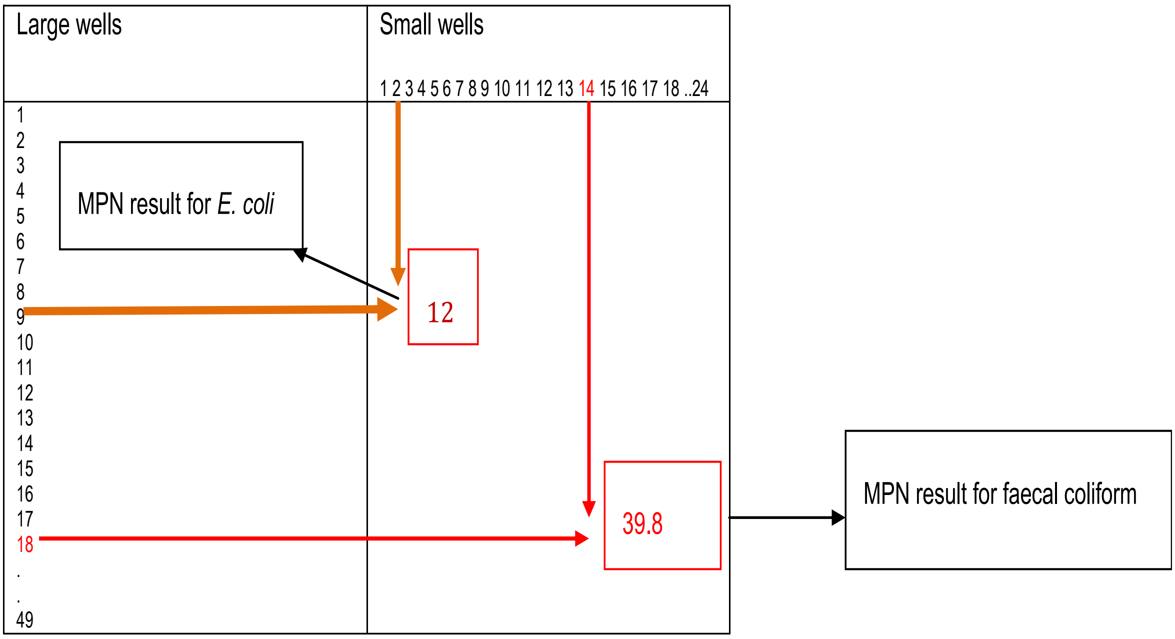


Figure 3.5 Determination of the most probable number (MPN) of faecal coliform bacteria using the MPN table (Nyoh, 2015)

Any quanti-tray displaying positive yellow cells is an indication of the presence of coliform bacteria in the water. Figure 3.6 provides an overview of the laboratory work done using the IDEXX (Colilert18) Quanti-Tray™ method.

(a) (b) (c)

Figure 3.6 97-well Quanti-TrayTM 2000 trays (a) Positive yellow wells identified from the IDEXX (Colilert18) Quanti-Tray™ (b) counting the number of positive yellow cells (c) capturing the data into a Microsoft Excel spreadsheet

3.6.5 Analysis of data

The water quality measurements obtained over the three sampling rounds at each of the 10 sampling sites were captured in a Microsoft Excel spreadsheet for analysis. The physical, chemical and microbiological data were statistically analysed by determining the descriptive statistics and performing inferential tests, which included analysis of variance (ANOVA) and Scheffe's post hoc tests (Kenton, 2019).

3.6.6 Proposed water quality limits

In South Africa, there are no specific standards for certain water quality properties. Therefore, in order to measure compliance for surface water bodies, an intensive literature review was done to find available limits and standards for some of the water quality properties used in this study. Table 3.1 presents the proposed aquatic water quality limits for urban streams that were used in this study, and against which compliance was verified for the water quality properties measured at each of the 10 sampling sites.

Table 3.1 Proposed Aquatic Water Quality Limits for Urban Streams (Belle, 2015)

Water quality property	Original purpose of limit	Proposed limit	Reference
Faecal coliform and *E. coli*	Irrigation	0[1] ≤ 200[2]	United States Environmental Protection Agency (2004)
pH	Aquatic ecosystem	5.5 –9	Environmental Protection Agency Ireland (2001)
Turbidity	Aquatic ecosystem	≤ 5.6 NTU	Australian and New Zealand Environment and Conservation Council (2000)
EC	Aquatic ecosystem	≤ 1000 µS/cm	Environmental Protection Agency Ireland (2001)
TDS	Aquatic ecosystem	≤ 1000 mg/L	Australian and New Zealand Environment and Conservation Council (2000)

Water quality property	Original purpose of limit	Proposed limit	Reference
DO	Aquatic ecosystem	6.5 – 9.5 mg/L	Canadian Council of Ministers of the Environment (2008)
Temperature	Aquatic ecosystem	≥ 5 ≤ 25[3]	Department of Water Affairs (1996); Australian and New Zealand Environment and Conservation Council (2000); Lumb et al. (2006); Le Rous (2013)
Nitrate (NO_3)	Aquatic ecosystem	≤ 2 mg/L	Carmago et al. (2005)
Phosphate (PO_3)	Aquatic ecosystem	≤ 0.7 mg/L	Environmental Protection Agency Ireland (2001)
Ammonia (NH_3)	Aquatic ecosystem	≤ 1.3 mg/L	Lumb et al. (2006)

[1] = crops eaten raw; [2] = commercially processed and fodder crops; [3] = Three references used to determine a temperature range for aquatic water quality limit; EC = electrical conductivity; TDS = total dissolved solids; DO = dissolved oxygen

3.6.7 Statistical analysis

To describe and summarise the physical, chemical and microbiological water quality properties, including the ecological water data, descriptive statics and compliance percentages were calculated. Analysis of variance (ANOVA) tests were performed to ascertain if there were any differences between the three sampling rounds at significance level of 0.05. Scheffe's post hoc test was performed in instances where the ANOVA tests were significant.

3.6.8 Application of the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI)

The Canadian Council of Ministers of the Environment Water Quality Index was developed to provide information about the general health or status of an ecosystem. The index reflects the overall water quality condition of a particular sampling site. The CCME WQI is based on a mathematical framework that focusses on the assessment of the ambient water quality conditions relative to the water quality objectives. The water quality index takes a number of factors into consideration such as the number of water quality variables to be tested, the period of application and the type of water (CCME, 2001).

The CCME WQI was chosen for the purpose of this study based on the following criteria:

1. The WQI takes into consideration different water body types, such as rivers, dams and streams. In this study, the different sampling sites included rivers, dams and streams.
2. For calculation of the CCME WQI values, the minimum amount of data should be collected in a single season within one year. The data collected for this study was collected over three seasons.
3. The CCME WQI does not limit the number of variables to be used in the calculation.

The calculation of the CCME WQI values involved the calculation of three main factors. These factors are the scope (F_1), the frequency (F_2) and the amplitude (F_3) (Canadian Environmental Quality Guidelines Canadian Council of Ministers of the Environment, 2017). The CCMI was calculated in the following manner:

1. **Calculation of F_1**: F_1 denotes the number of properties (expressed as a percentage) that did not meet the proposed limits (failed properties):

$$F_1 = \left(\frac{Number\ of\ failed\ properties}{Total\ number\ of\ properties}\right) \times 100 \quad (2)$$

2. **Calculation of F_2**: F_2 denotes number of measurements (expressed as a percentage) over all three sampling rounds that did not meet the proposed limits (failed properties):

$$F_2 = \left(\frac{Number\ of\ failed\ measurements}{Total\ number\ of\ measurements\ over\ all\ three\ seasons}\right) \times 100 \quad (3)$$

3. **Calculation of F_3:** F_3 is a measure of the extent of the failure of all measurements and is calculated in three steps:

a. **An excursion is calculated for each failed measurement as follows**:

$$Excursion_i = \left(\frac{Failed\ measurement}{Limit\ of\ the\ property}\right) - 1 \quad (4)$$

b. **The normalised sum of all excursions (nse) is calculated as follows**:

$$nse = \frac{\sum_{i=1}^{n} Excursion_i}{\sum_{j=1}^{m} Measurements_j} \quad (5)$$

Where n = number of failed properties and j = total number of measurements over three sampling rounds.

c. **Calculation of F_3:**

$$F_3 = \left(\frac{nse}{0.01nse + 0.01}\right) \quad (6)$$

With the three factors in place, the WQI was then calculated in the following manner:

$$CCME\ WQI = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right) \quad (7)$$

A WQI was calculated for each of the sampling sites using the CCME WQI in a stepwise manner. To demonstrate how this CCME WQI was calculated, Table 3.2 presents an example of water quality data used to calculate the CCME WQI.

Table 3.2 Example of water quality data used to demonstrate the calculation of a WQI for a site

Properties Limits	pH 5.5-9	Temp 25	EC 1000	TDS 1000	Turbidity 4.1-5.6	DO 6.5-9.5	PO_4 0.5-0.7	NO_3 0.5-1	NH_3 1.37
Season 1	7.40	*28.60*	674.00	336.00	*98.80*	*0.14*	*7.63*	*5.10*	*1.60*
Season 2	7.85	11.20	853.00	571.51	*77.00*	*4.48*	*7.00*	*2.60*	0.40

Properties Limits	pH 5.5-9	Temp 25	EC 1000	TDS 1000	Turbidity 4.1-5.6	DO 6.5-9.5	PO_4 0.5-0.7	NO_3 0.5-1	NH_3 1.37
Season 3	7.52	25.40	941.00	630.47	*42.80*	*12.05*	*1.00*	<1.00	1.30

Red and italicized indicates non-compliant measurements

In Table 3.3 the stepwise calculation of the CCME WQI was as follows:

Table 3.3 Step-by-step calculation of WQI using example data

Scope (F_1)	$F_1 = \left(\frac{6}{9}\right) \times 100$ The number of properties that did not meet the limit is 5 (Turbidity, DO, PO_4, NO_3 and NH_3), total number of variables are 9. Therefore: = 55.6
Frequency (F_2)	The number of measurements not meeting the limit is 13, and the total number of measurements for all sampling rounds is 27. Therefore: $F_2 = \left(\frac{13}{27}\right) \times 100$ = 48.15
Excursion	The excursion, is calculated as follows: $Excursion_i = \left(\frac{48.15}{5.6}\right) - 1$ = 7.60 (e.g. for turbidity, where measurement must not exceed the limit) $Excursion_i = \left(\frac{48.15}{25}\right) - 1$ = 18.29 (e.g. for temperature, where measurements must not exceed the limit $Excursion_i = \left(\frac{5.48}{6}\right) - 1$ = - 0.087 (e.g. for DO where measurement must not fall below the limit) Sum of excursion = 7.60+18.2+67.29+23.08+0.087+36.04 = 152.7 Total number of measurements = 27
Normalised sum of excursion (*nse*)	The *nse* is calculated as follows: $nse = \frac{152.71}{27}$ = 5.66
Amplitude (F_3)	F_3 is calculated as follows:

	$F_3 = \left(\frac{5.66}{0.01\ (5.66)+0.01}\right)$ = 84.98
CCME WQI	Finally, the CCME WQI is calculated as follows: $(F_1)^2 + (F_2)^2 + (F_3)^2 = (55.6)^2 + (48.15)^2 + (84.98)^2 = 13985.12$ $100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right) = 100 - \frac{\sqrt{13985.12}}{1.732}$ = CCME WQI = 31.73 = 32

The water condition was classified according to the five condition categories described by the Canadian Environmental Quality Guidelines Canadian Council of Ministers of the Environment (2017). Table 3.4 provides the CCME WQI ranges from 0 to 100.

Table 3.4 Categories used to rank water quality (CCME, 2001)

CCME WQI	Condition	Description
>94 –100	*Excellent condition*	Water quality is protected with absence of threat. Condition is very close to natural levels
>79 – 94	*Good*	Water quality is protected with minor degree of threat. Conditions rarely depart from natural levels
>64 – 79	*Fair*	Water quality is protected but occasionally threatened. Conditions sometimes depart from natural levels
>44 – 64	*Marginal*	Water quality is protected but is threatened frequently. Conditions always depart from natural levels
0 – 44	*Poor*	Water quality is always threatened. Conditions always depart from natural

3.7 Macroinvertebrate sampling

During the collection of water samples and the on-site measurement of physical water quality properties, ecological samples were also sampled at each of the 10 sampling sites. Protective gloves and a wader were worn to protect the sampler against potentially hazardous pollutants in the water. A SASS net was used to collect macroinvertebrates from the stones biotopes, vegetation biotopes, and the gravel, sand and mud biotopes. Seasonal effects were observed and noted on data collection sheets for each of the three sampling rounds. This was to establish the weather, conditions (warm and cold) and if the water sampling sites were lentic or lotic (stagnant or flowing). This information provide valuable insight into the possible reasons for high or low number of macroinvertebrate assemblages available at each macroinvertebrate sampling site habitat.

3.7.1 Stones biotope

For the collection of macroinvertebrates from the stones biotope, the following procedure was followed:

1. For the collection of macroinvertebrates from the stones in current and stones out of current, the SASS net was placed downstream of the stones. A timer was set for two minutes to collect macroinvertebrates at stones in current (SIC) and for one minute for stones out of current (SOOC). The collection of the macroinvertebrates was achieved by kicking and turning to dislodge the stones.
2. For macroinvertebrates to be dislodged from the surfaces of bedrock, the surfaces were rubbed by hand and wader boots, and the dislodged macroinvertebrates were then collected in the SASS net.
3. All macroinvertebrates that were collected from the stones biotope were then massed together to form the stone biotope for macroinvertebrate collection.

3.7.2 Vegetation biotope

For the collection of macroinvertebrates from the marginal and aquatic vegetation, the following procedure was followed:

1. For the collection of macroinvertebrates from the marginal vegetation and along the embankment, the vegetation was pushed and prodded using the SASS net for approximately two metres along the embankment. For the collection of macroinvertebrates from aquatic vegetation, the SASS net was pushed and prod in the aquatic vegetation area of approximately one square metre.
2. While collecting the macroinvertebrates the net was kept below the water surface to ensure that no organisms were collected from above the surface.
3. Macroinvertebrates that were collected from the vegetation biotope were massed together to form the vegetation biotope for macroinvertebrate collection

3.7.3 Gravel, sand and mud biotope

For the collection of macroinvertebrates from the gravel, sand and mud biotope, the following procedure was followed:

1. For the collection of macroinvertebrates from the gravel, sand and mud the gravel, sand and mud was disturbed for one minute using wader boots.
2. Disturbing the gravel, sand and mud the SASS net was swept over the dislodged area to collect the macroinvertebrates.
3. All macroinvertebrates that were collected from the gravel, sand and mud biotope were then massed together to form the gravel, sand and mud biotope for macroinvertebrate collection.

Photos during the collection of macroinvertebrates at different sampling sites was taken at each of the three sampling rounds. In Figure 3.7, the collection of macroinvertebrates from the stones biotope, vegetation biotope and gravel, sand and mud biotope is depicted.

(a) (b) (c)

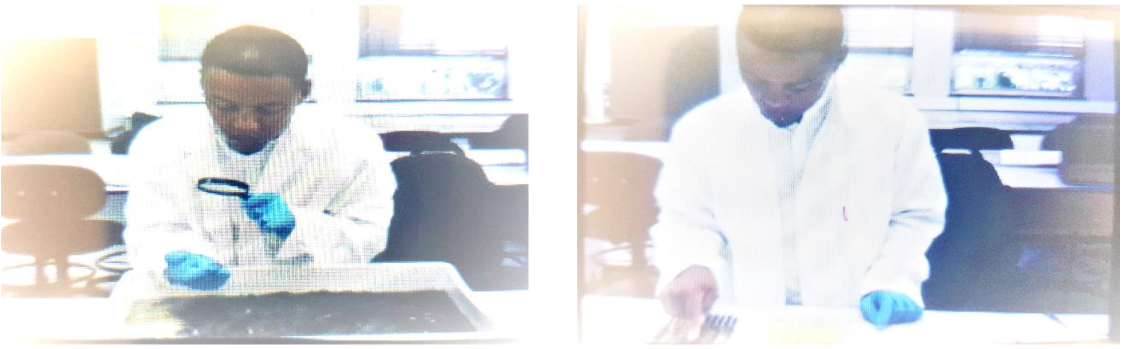
Figure 3.7 Collecting macroinvertebrates from different biotopes (a) Vegetation biotope, (b) stones in current biotope, (c) gravel, sand and mud biotope

3.8 Macroinvertebrate measurements

3.8.1 Enumeration of macroinvertebrates

The ecological samples were enumerated in the laboratory within 72 hours after transportation. The SASS5 method was used to determine the number of different macroinvertebrate families sampled at each of the sampling sites as follows:

1. The macroinvertebrate sample containers containing water were removed from the refrigerator 30 minutes before enumeration and placed in clean water on a tray at room temperature. The room temperature allowed the macroinvertebrates to become active so that they could be identified.
2. To assist with the identification of the macroinvertebrate families, a magnifying glass and the Aquatic Invertebrates of South Africa Illustration Guide (Gerber and Gabriel, 2002) were used (Figure 3.8).



(a) (b)

Figure 3.8 Identification of macroinvertebrates collected during sampling (a) Identifying the macroinvertebrates, (b) Completing SASS5 score sheet

3. A SASS5 score sheet was used to record all the identified macroinvertebrate families.
4. For each of the identified macroinvertebrate families, a sensitivity score was allocated. The sensitivity scores are available on the SASS5 scoring sheet. These sensitivity scores range from one to 15 and indicate the tolerance level of the identified macroinvertebrate families to pollution (Dickens and Graham, 2002). A high sensitivity score indicates that the macroinvertebrates are highly sensitive to pollution, whereas low scores indicate a tolerance to pollution (Table 3.5).

Table 3.5 Example of macroinvertebrates families identified with the sensitivity scores

Order and family	Sensitivity score	Total number of macroinvertebrate families
CRUSTACEA		1
Potamonautidae	3	
HEMIPTERA		1
Corixidae	3	
DIPTERA		3
Simuliidae	5	

Order and family	Sensitivity score	Total number of macroinvertebrate families
Chironomidae	2	
Ephydridae	3	
GASTROPODA		1
Hydrobiidae	3	
Total	19	6

3.9 Macroinvertebrate sampling site habitat classification

To classify a macroinvertebrate habitat-sampling site, three indices are required. These indices are the number of macroinvertebrate families, the SASS5 score and the average score per taxa (ASPT) (Dickens and Graham, 2002). Table 3.6 presents how the three indices were calculated using the data from Table 3.5.

Table 3.6 Calculation of the SASS5 score, number of taxa and ASPT

SASS score	The SASS5 score is calculated by summing the sensitivity scores of the different macroinvertebrate families found at each sampling site. For example, the SASS score = 19
Number of taxa	The number of taxa represents the different macroinvertebrate families found at each sampling site. For example, the number of taxa = 6
ASPT (average score per taxa)	ASPT reflects the overall sensitivity of the macroinvertebrates in a particular site. The ASPT is the SASS score divided by the number of taxa. For example, the ASPT = 19 ÷ 6 = 3.16

Using the different macroinvertebrate families identified at each of the 10 sampling sites, a sensitivity score was allocated to determine the degree of sensitivity of each to pollution (Gerber and Gabriel, 2002). The pollution condition of each of the 10 sampling site was determined by:

1. Calculating the SASS score and the ASPT values.

2. A selection of a reference condition that best reflects the optimum conditions that can be expected in rivers and streams within a specific area, was selected for the study area.
3. The modelled reference condition for the Highveld–Lower Ecoregion was selected as it best reflects the pollution conditions expected in the rivers and streams located in this region.
4. The SASS5 scores and the ASPT values for each sampling sites for the three sampling rounds were plotted on a classification model. To classify the pollution condition of the sampling sites, Figure 3.9 provides an example of such a classification.

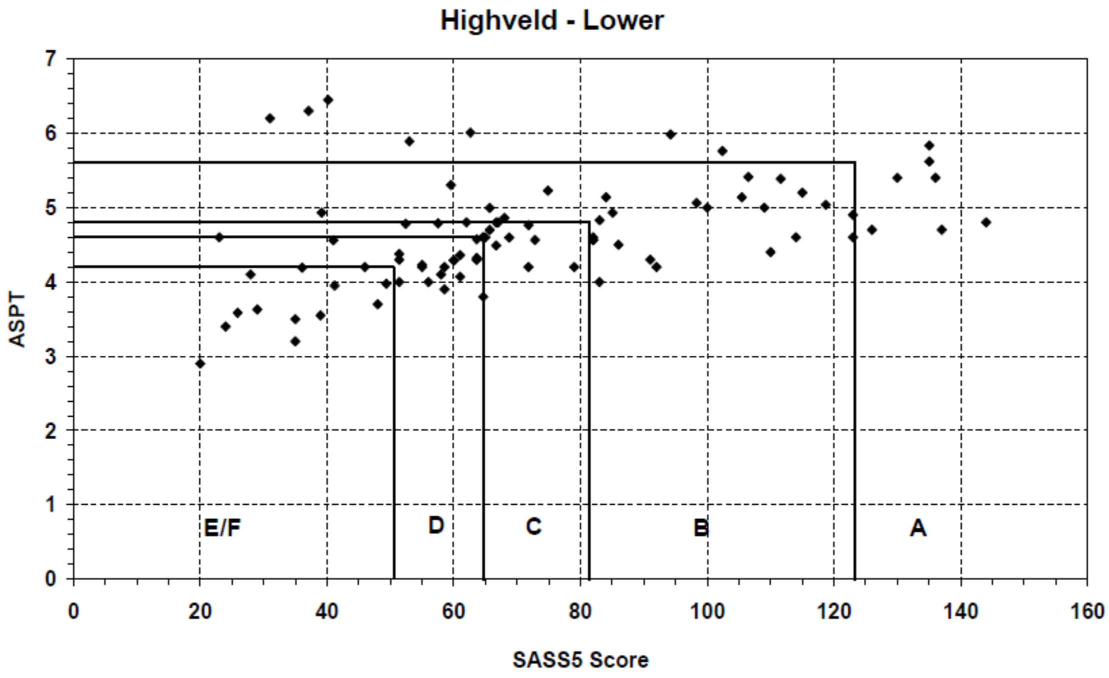


Figure 3.9 Example of the classification of sampling sites using the Highveld–Lower Ecoregion reference (Dallas 2007)

From the plotting of the SASS5 and the ASPT values on the Highveld-Lowe Ecoregion reference, the sampling sites can be classified. Table 3.7 presents the different ecological categories that best describe the condition of a sampling site.

Table 3.7 Categories used to classify a sampling site using SASS and ASPT scores (Dallas, 2007)

SASS5 score	ASPT	Class	Condition	Description
> 124	> 5.6	*A*	Unimpaired	High diversity of taxa with high sensitivity
83 –124	4.8 – 5.6	*B*	Slightly impaired	High diversity of taxa, but with fewer sensitive taxa
60 – 82	4.6 – 4.8	*C*	Moderately impaired	Moderate diversity of taxa
52 – 59	4.2 – 4.6	*D*	Considerably impaired	Mostly tolerant taxa present
30 – 51	< 4.2 (Variable)	*E*	Severely impaired	Only tolerant taxa present
< 30	Variable	*F*	Critically impaired	A few tolerant taxa present

Chapter 4

Municipal Services Complaints

4.1 Introduction

In this study, service delivery complaints, relating to poor infrastructure, were investigated for Zastron and Matlakeng Township of the Mohokare Local Municipality. The complaints registers were assessed for a period of one year. The number of sampling sites was determined by the type of infrastructural breakdown, the magnitude of the pollution and the number of surface water bodies impacted by the wastewater pollution. The most prominent complaints that were identified were recorded was for blocked manholes and sewerage leakages in the areas of Zastron and Matlakeng Township. The data for blocked manholes and sewer leakages were presented as a percentage of all infrastructure related complaints by location. The identification of a suitable number of surface water bodies as sampling sites, then allowed for the assessment of the physical, chemical, microbiological and ecological quality at each of the respective sampling sites.

4.2 Manhole blockages

The complaints lodged by the community of the Mohokare Local Municipality about blocked manholes were analysed to determine if any trends could be identified. Approximately 270 complaints were received about blocked manholes. The majority of these complaints came from Matlakeng Township located near Zastron. Although the number of manhole blockage complaints was spread relatively evenly over the year, the number received during May, July and October was greater than for the other months. Most of the manhole blockage complaints was not supplemented by the cause for the blockage. However, for those complaints that supplied a cause, these included: (1) foreign objects thrown into manholes or flushed from local homes, for example old blankets, shoes, stones, etc., (2) broken pipes, and (3) as a result of the deteriorating infrastructure network.

Table 4.1 shows the number of manhole blockage complaints received per month, as well as the summary statistics for the study year.

Table 4.1 Total number of complaints received about blocked manholes in Zastron and Matlakeng Townships

Month	Number complaints from Zastron (%)	Number complaints from Matlakeng Township (%)	Total
January	2 (11)	16 (89)	18
February	2 (11)	16 (89)	18
March	3 (13)	20 (87)	23
April	0 (0)	12 (100)	12
May	0 (0)	35 (100)	35
June	0 (0)	24 (24)	24
July	4 (12)	29 (88)	33
August	0 (0)	13 (100)	13
September	0 (0)	13 (100)	13
October	0 (0)	39 (100)	39
November	2 (8%)	23 (92)	25
December	0 (0)	16 (100)	16
Total for the year (%)	**13 (5)**	**256 (95)**	**269**
Mean	1.00	21.33	22.41
Max	4.00	39.00	39.00
Min	0.00	12.00	12.00
SD	1.00	9.00	9.15

Most of the spillages caused by the blocked manholes polluted nearby streams and dams. Figure 4.1 shows how blocked manholes resulted in extensive pollution of streams nearby the Matlakeng Township.

(a) (b) (c)

Figure 4.1 Pollution of surface water bodies (a) stream and dam pollution as a result of one blocked manhole spillage, (b) sewerage from the blocked manhole flowing into the adjacent environment and animals drinking the water containing raw sewerage, and (c) raw sewerage from the blocked manhole flowing into a localised river near Matlakeng Township

4.3 Sewerage spillages

Sewerage spillage complaints lodged by the community of the Mohokare Local Municipality were analysed for the study period to determine if any trends could be identified. More than 100 complaints were lodged with the municipality about sewerage spillages. Most of these complaints were received from Matlakeng Township. The highest number of complaints were received during April, June and July. Table 4.2 shows the number of sewerage spillage complaints received per month, as well as the summary statistics for the study year.

Table 4.2 Total number of complaints received about sewerage spillages in Zastron and Matlakeng Townships

Month	Number complaints from Zastron (%)	Number complaints from Matlakeng Township (%)	Total
January	0 (0)	16 (100)	16
February	0 (0)	6 (100)	6
March	1 (12)	7 (88)	8
April	0(0)	11 (100)	11
May	0 (0)	6 (100)	6
June	0 (0)	17 (100)	17
July	4 (24)	13 (76)	17
August	0 (0)	2 (100)	2
September	0 (0)	3 (100)	3
October	0 (0)	3 (100)	3
November	2 (25)	6 (75)	8
December	2 (22)	7 (78)	9
Total for the year (%)	**9 (8)**	**97 (92)**	**106**
Mean	0.75	8.08	8.83
Max	4.00	17.00	17
Min	0.00	2.00	2.00
SD	1.29	5.04	5.41

Most of the raw sewerage spillages in Zastron and Matlakeng Township were as a result of burst pipes, overflowing manholes, malfunctioning pump stations, poor workmanship with the construction and connections of the municipal sewer network. Some of the sewerage spillages occurred in and around the homes and streets of Matlakeng Township. Figure 4.2 portrays the sewerage spillages at a home, in the streets, and also malfunctioning pump stations in and around Matlakeng Township.

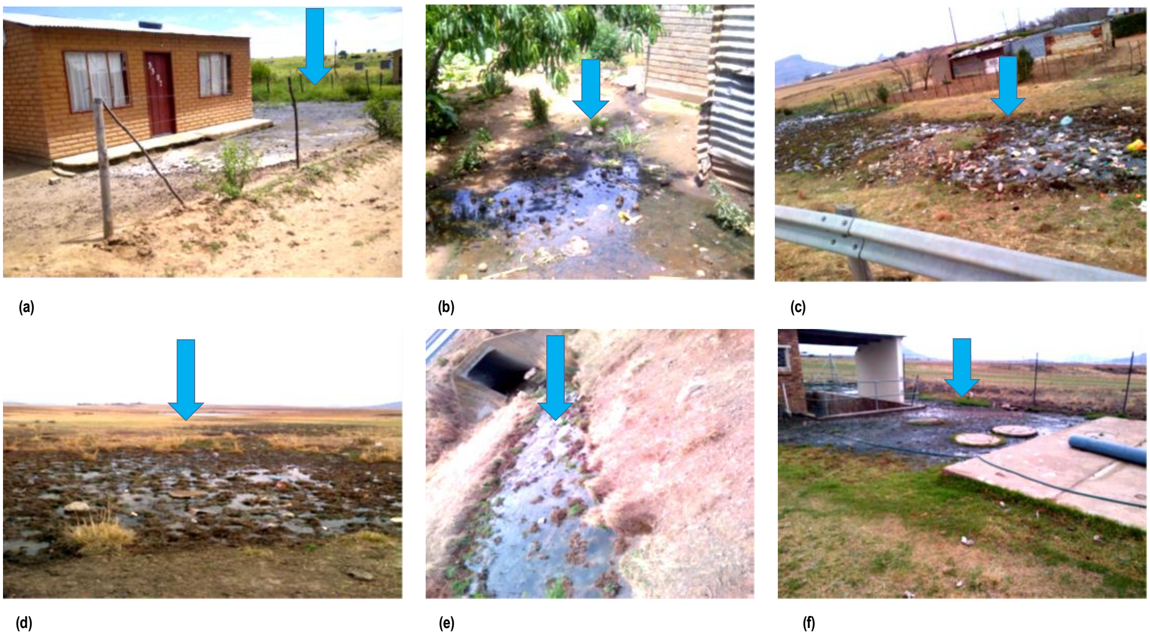


Figure 4.2 Raw sewerage spillages in parts of Matlakeng Township (a) residential yard with a raw sewerage spillage as a result of a poor sewerage network connection, (b) sewerage leakage in the backyard of a house; (c) sewerage spillage from a poor pipe connection, (d) raw sewerage flowing into open land, (e) raw sewerage flowing into streams and, (f) sewerage overflow from a malfunctioning pump station

4.4 Regional distribution of complaints

An analysis of the total number of complaints lodged per location was carried out to identify problem areas where most manhole and sewerage spillage occurred in and around Matlakeng Township. Table 4.3 presents the locations in Matlakeng Township where most manhole blockages and sewerage spillage related complaints were received from. Most complaints were received from Itumeleng location, followed by the Old, Refengkhosto and Ezibeleni.

Table 4.3 Locations in Matlakeng where most sewerage and manhole blockages occurred

Location	Number of complaints	Percentage (%)
Itumeleng	101	27
Old Location	82	22
Refengkhosto	60	16
Ezibeleni	60	16
Kanana	38	10
Phomolong	34	9
Total for the year	**375**	**100**

To generate a heat map, the problem areas that related to the complaints the complaints registers were plotted on a map of Matlakeng Township. The distribution of complaints was relatively similar for areas such as Itumeleng, Old, Ezibeleni and Refengkhotso locations. In Figure 4.3, the data is presented as a percentage of the total number of infrastructure-related complaints lodged by the community per location.

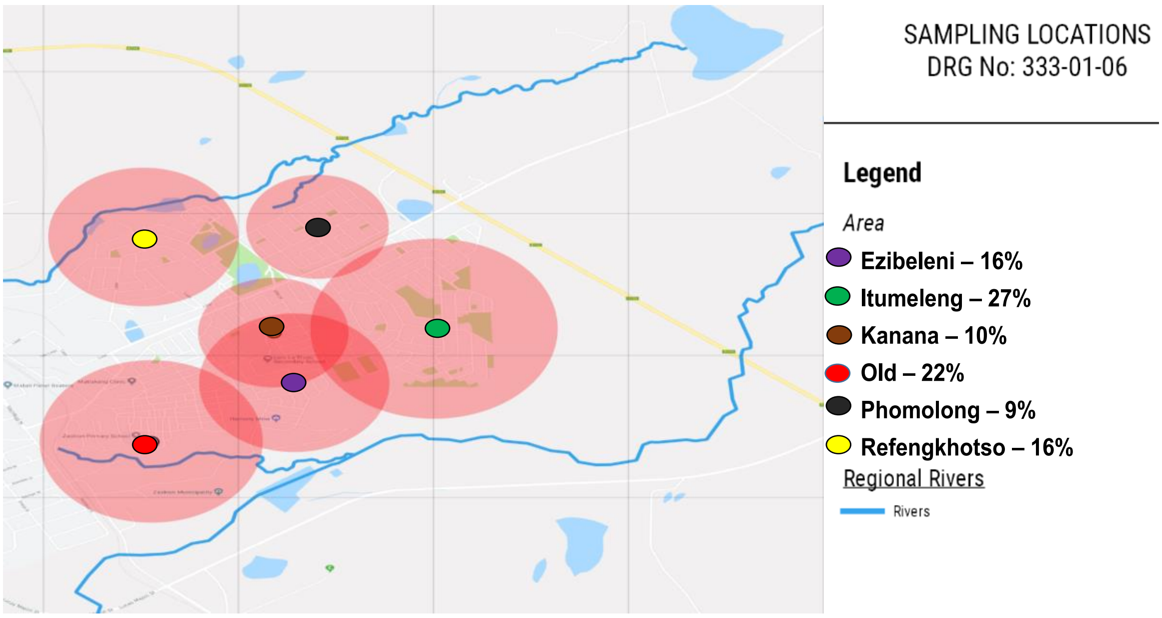


Figure 4.3 Heat map of residential locations in the Matlakeng Township where most complaints of blocked manhole and sewerage spillage were received from communities (Google, 2019)

4.5 Sampling sites

The sampling sites for this study were identified based on the total number of blocked manholes and sewerage spillage complaints per location. Ten sampling sites were identified based on the extent of the wastewater pollution on the receiving surface water body as a result of infrastructural breakdown in the vicinity of the sampling site. Some of the identified infrastructural breakdowns in the vicinity of the sampling sites included blocked manholes, sewerage spillage or malfunctioning pump stations. In Figure 4.4, the yellow dots indicate the 10 sampling sites of the surface water bodies that were mostly affected by wastewater pollution.

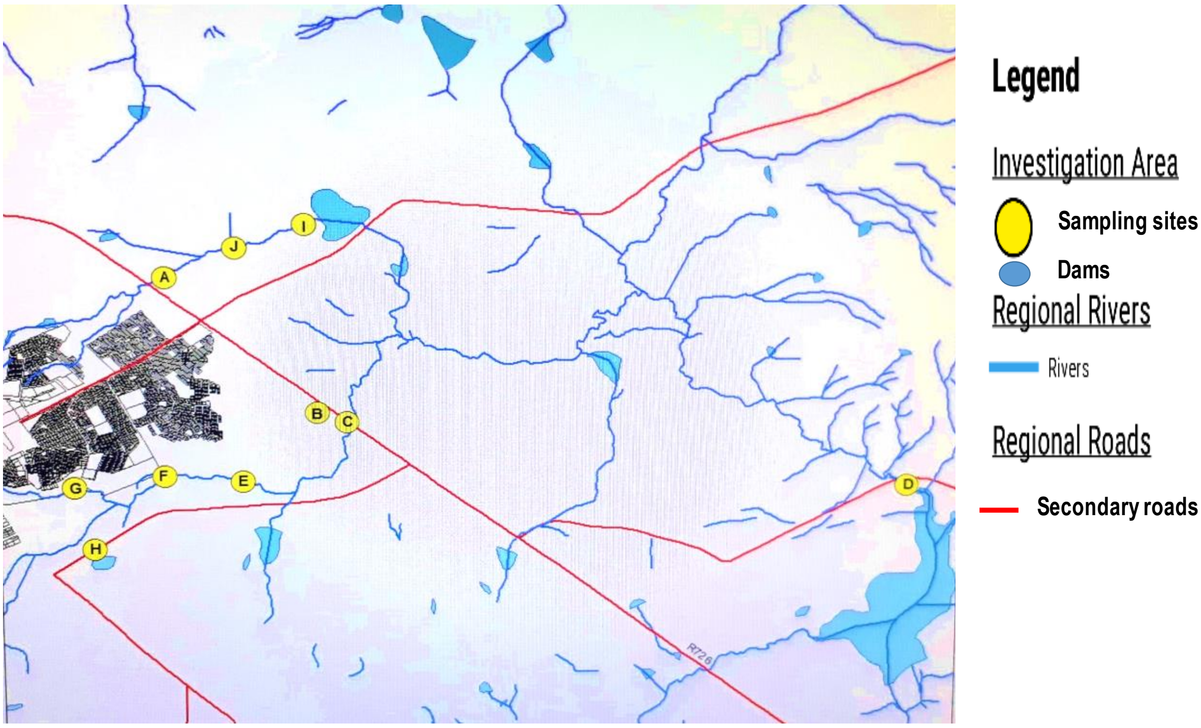


Figure 4.4 Map indicating the detailed positions of the sampling sites as identified by the yellow dots (Rural Development, 2019)

Photos of some of the sampling sites depict the impact of the wastewater pollution as a result of the infrastructural breakdowns in and around the identified sampling sites. Evidence of the sewerage spillages from manholes, broken pipes and the effluent discharged from the Zastron Wastewater

Treatment Works are some of the examples of the extent of the pollution of surface water bodies (Figure 4.5).

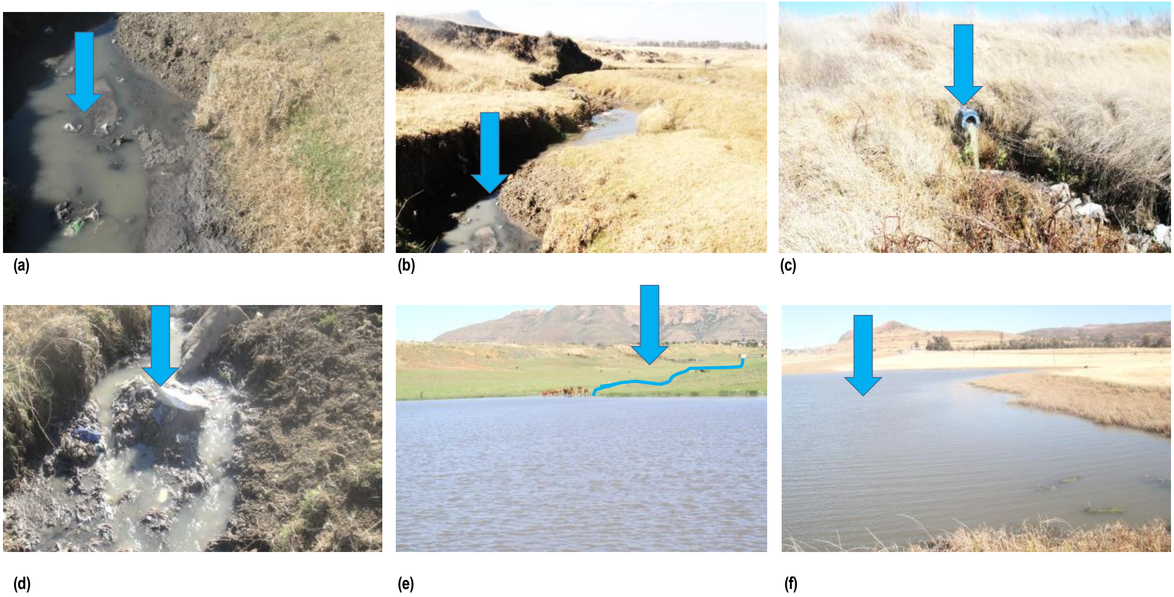


Figure 4.5 Evidence of surface water body pollution (a) raw sewerage build-up on the embankment of a perennial river, (b) sewerage from a malfunctioning pump station flows into a stream, (c) treated wastewater effluent discharged from the Zastron Wastewater Treatment Works, (d) raw sewerage flowing into a perennial river from an overflowing (e) animals grazing at sampling site by raw sewerage flowing from a malfunctioning. The blue line indicates the flow of sewerage from the malfunctioning pump station (f) Sampling site H that is located outside any influence of possible anthropogenic pollutants.

The geographical positioning of the 10 sampling sites was recorded and described in Table 4.4. Table 4.4 presents the coordinates, motivation and description for the selection of the 10 sampling sites.

Table 4.4 Sampling sites, coordinates, description of sampling sites and the motivation for the choice of the site

Sampling site	Coordinates	Description of sampling site	Motivation for the choice of sampling site
A	30°16'48.6"S 27°06'18.0"E	Stream that receives raw sewerage flowing from a malfunctioning pump station.	Malfunctioning pump station.
B	30°17'39.2"S 27°07'19.1"E	Dam that receives raw sewerage flowing from a malfunctioning pump station.	Malfunctioning pump station.
C	30°17'39.2"S 27°07'19.1"E	Perennial river that receives wastewater effluent from the Zastron Wastewater Treatment Works.	Overflowing manholes, malfunctioning pump station and Wastewater Treatment Works.
D	30°18'08.2"S 27°10'29.6"E	All polluted perennial rivers and streams feed into the main water catchment, the Montagu dam.	None.
E	30°18'02.0"S 27°06'40.6"E	Stream that receives wastewater effluent from the Zastron Wastewater Treatment Works.	Wastewater Treatment Works.
F	30°17'56.0"S 27°06'21.2"E	Perennial river that receives raw sewerage from a malfunctioning pump station.	Malfunctioning pump station.
G	30°18'01.8"S 27°05'38.6"E	Perennial river that receives untreated sewerage from an overflowing manhole.	Overflowing manhole.
H	30°18'23.9"S 27°05'58.6"E	A sampling site that does not receive sewage pollutants.	None.
I	30°16'29.9"S 27°07'02.7"E	Stagnant dam that receives raw sewerage pollutants from sampling site A.	Malfunctioning pump station, overflowing manholes, sewerage spillages.
J	30°16'35.7"S 27°06'48.2"E	Perennial river that receives raw sewerage pollutants from sampling site A.	Malfunctioning pump station, manholes, sewerage spillages.

4.6 Discussion

An assessment of the municipal complaints registers of the Mohokare Local Municipality was performed to obtain an understanding of the infrastructural challenges faced by the municipality. The complaint registers revealed that most infrastructure related complaints, lodged by the communities of Zastron and Matlakeng Township, were for blocked manholes and sewerage leakages. The area that experienced most infrastructural challenges was Matlakeng Township. From the complaints registers, some of the reasons supplied by the technical department for the blocked manholes were as a result of (1) foreign objects thrown into manholes or flushed from local homes, for example old blankets, shoes, stones, etc., (2) broken pipes, and (3) as a result of the deteriorating infrastructure network. The complaints about raw sewerage spillages in Matlakeng Township together with the few from Zastron were as a result of overflowing manholes, burst pipes, malfunctioning pump stations, and poor workmanship with the construction and connection of the sewer network.

The percentage of total complaints analysed over the year identified Itumeleng location, followed by the Old, Refeng Khotso and Ezibeleni as the locations where most infrastructural challenges were experienced by community members. From this analysis, ten surface water bodies were identified to most likely be affected by wastewater pollution because of the infrastructural breakdown in the vicinity.

Chapter 5

Water Quality Properties

5.1 Introduction

Water samples were collected at the 10 identified sampling sites in perennial rivers around Matlakeng Township, Zastron. Physical, chemical and microbiological water properties were measured over three sampling rounds (November 2017, M 2018 and November 2018). To ascertain to what extent perennial rivers were polluted as a result of overflowing manholes, sewerage spillages and malfunctioning pump stations. Physical water quality properties were measured on-site. To analyse all the chemical water quality properties for each of the 10 sampling sites, water samples collected in a 100 mL sample bottle were delivered to the Test It Labs for analysis. The laboratory is a SANAS accredited located in the town of Bloemfontein (Test It, 2018). While the microbiological water quality was analysed in the laboratory of the Central University of Technology, Free State. The physical, chemical and microbiological results were used to determine their compliance with water quality standards. Where standards were not available in South Africa, international standards were used to verify compliance.

5.2 Results: Physical water quality properties

In this study, four physical water quality properties were assessed at the 10 sampling sites in the vicinity of Zastron. The four physical water quality properties, pH, turbidity, temperature and electrical conductivity (EC), were assessed over three sampling rounds. The measurements of each of these physical water quality properties were compared to the South African Water Quality Guidelines for Aquatic Ecosystems, the New Zealand Guidelines for Fresh and Marine Water Quality Volume 2, and the EPA standards in order to ascertain their compliance.

5.2.1 pH

The pH of the water at the 10 sampling sites was measured and the compared to the pH standard of 5.5 – 9.0 of the Environmental Protection Agency Standards for Parameters of Water (The Environmental and Protection Agency, 2001). The pH measurements of the three sampling rounds surveyed were compliant when compared to this standard (Table 5.1). The mean pH measurements of the three sampling rounds showed a relatively narrow range of 0.3. Interestingly, only Round 1 and 2 demonstrated pH values greater than 8.

Table 5.1 Summary statistics of the pH measurements over the three sampling rounds

Sample site	pH (standard = 5.5 - 9.0)		
	Round 1	Round 2	Round 3
A	8.45	7.33	7.66
B	7.54	7.70	7.17
C	7.63	7.91	7.53
D	7.32	7.63	7.21
E	8.48	8.82	7.46
F	8.23	8.02	7.86
G	7.70	8.66	7.65
H	7.32	7.77	7.23
I	7.19	7.34	7.66
J	7.40	7.85	7.52
Median	7.60	7.80	7.50
Mean	7.70	7.90	7.50
Max	8.50	8.80	7.90
Min	7.20	7.30	7.20
SD	0.48	0.49	0.23
% Compliance	100	100	100

5.2.2 Turbidity

The measurements of turbidity demonstrated considerable variation over the two sampling rounds. All three sampling rounds demonstrated low compliance values for turbidity when compared to the standard of the Australian and New Zealand Guidelines for Fresh and Marine Water Quality Volume 2: Aquatic Ecosystems-Rationale and Background Information, Australian and New Zealand Environment and Conservation Council and the Agriculture and Resource Management Council of Australia and New Zealand (Australian and New Zeeland Environment and Conservation Council, 2000). Season 1 showed 100% non-compliant values for all the turbidity measurements. The mean turbidity measurements of the different sampling rounds varied prominently from 81.29 in sampling Round 1 to 128.13 in sampling Round 3. The highest turbidity measurement was recorded at sampling site G during round 2 and 3 of sampling (Table 5.2). Sampling site G is described as a sampling site where untreated sewerage was discharged into a river by a blocked and overflowing manhole. The sludge deposits from the untreated sewerage can be attributed to high turbidity levels at the sampling site.

Table 5.2 Summary statistics of the turbidity measurements over the three sampling rounds

Sample site	Turbidity (standard = 5.6 NTU)		
	Round 1	Round 2	Round 3
A	*118.00*	*48.80*	*38.70*
B	*128.00*	*145.00*	*113.00*
C	*164.00*	*34.50*	*115.00*
D	*119.00*	*22.80*	*305.00*
E	*35.70*	*26.50*	*103.00*
F	*27.70*	*116.00*	*49.00*
G	*111.00*	*251.00*	*381.00*
H	*90.00*	*85.20*	*67.90*
I	*35.70*	*24.90*	*65.90*
J	*98.80*	*51.90*	*42.80*
Median	94.40	50.35	85.45

Mean	81.19	80.66	128.13
Max	164.00	251.00	381.00
Min	12.00	22.80	38.70
SD	50.23	72.87	117.99
% Compliance	0	0	0

Red and italicized indicates non-compliant measurements

A visual perspective provides an indication that almost all of the sampling sites showed turbidity measurements greater than the standard. No pattern could be identified across the sites. However, sampling site G stands out, showing relatively high measurements in all sampling rounds. Besides sampling site G, showing the highest measurements, D showed the second highest measurements, including during sampling round 3 (Figure 5.1).

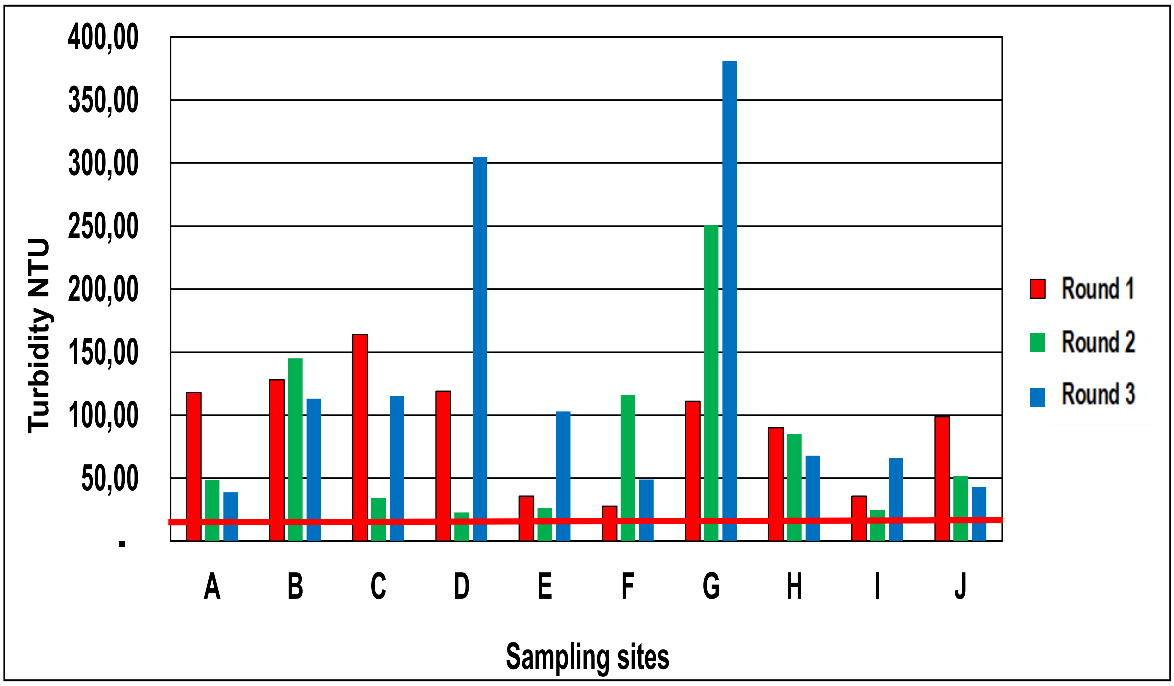


Figure 5.1 Histogram showing the mean turbidity measurements over the three sampling rounds. The red line indicates the standard

5.2.3 Temperature

The temperature measurements were, for the most, compliant when compared to the standard of the South African Water Quality Guidelines for Aquatic Ecosystems (DWA: Water Quality Guidelines for Aquatic Ecosystems, 1996). Only the temperature measurement recorded in Round 1 at sampling site H, exceeded the standard (Table 5.3).

Table 5.3 Summary statistics of the temperature measurement over the three sampling rounds

Sample site	Temperature (standard = 25°C)		
	Round 1	Round 2	Round 3
A	22.00	9.90	22.90
B	24.20	10.50	21.90
C	20.80	9.10	21.70
D	21.50	10.50	*25.50*
E	24.10	11.10	19.60
F	23.80	11.80	*28.50*
G	25.90	14.60	*26.80*
H	*32.60*	11.30	22.00
I	26.40	14.50	22.50
J	28.60	11.20	*25.40*
Median	24.15	11.15	22.70
Mean	24.99	11.45	23.68
Max	32.60	14.60	*28.50*
Min	20.80	9.10	19.60
SD	3.58	1.80	2.74
% Compliance	90	100	50

Red and italicized indicates non-compliant measurements

The Histogram of the temperatures shows that most of the temperatures recorded over the three sampling rounds were within the standard. The five sampling sites D, F, G, H, I and J recorded temperature values greater than the standard in sampling round 3. These high temperatures may be attributed to time of the day when sampling took place. Figure 5.2 shows the sampling sites where the recorded temperature values were greater than the standard in sampling round 3.

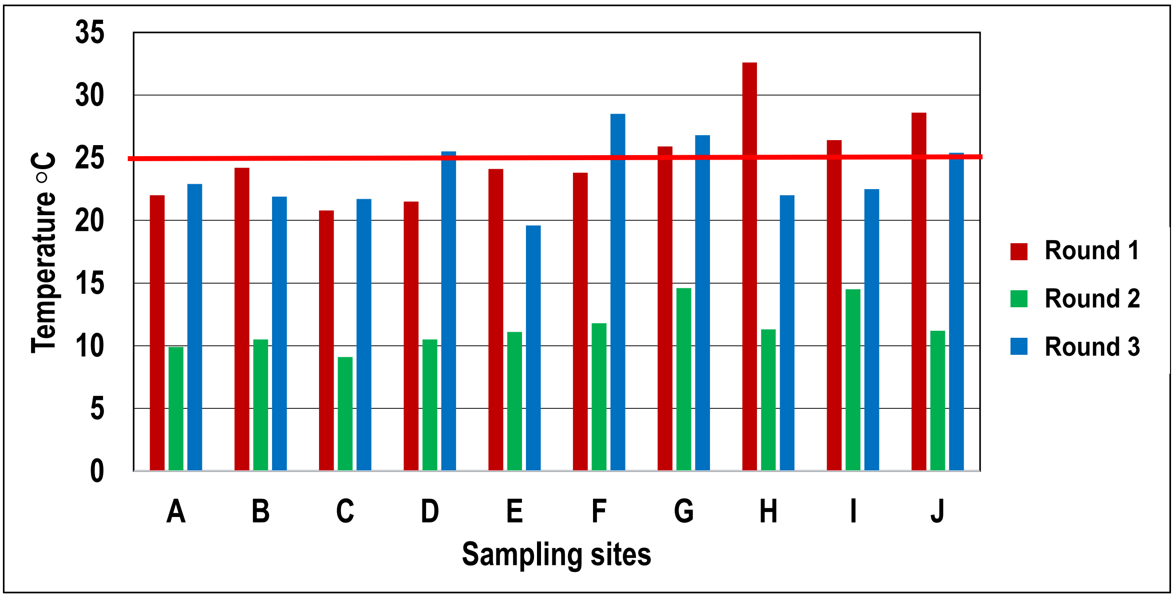


Figure 5.2 Histogram showing the mean temperature measurements over the three sampling rounds. The red line indicates the standard

5.2.4 Electrical conductivity

The EC measurements for all three sampling rounds were, for the most, complaint when compared to the standard of the United States Environmental Protection Agency (The Environmental and Protection Agency, 2001). Only five of the EC measurements were non-compliant, all in sampling round 2 and 3 (Table 5.4). Both sampling sites F and G demonstrated four of the five non-compliant EC measurements. At both sampling sites F and G, untreated wastewater was discharged from a malfunctioning pump station and an overflowing manhole respectively, resulting in the deposit of wastewater sludge into the receiving water bodies. A direct relationship exists between EC and the total dissolved solids (TDS) content of water. The relationship can be described as one where TDS is calculated by the use of EC values. In this instance, the TDS at sampling site G, exceeded the standard and is thus associated with the high EC levels at these sampling sites. The EC measurements for sampling site H were substantially lower in all three sampling rounds, when compared to all the other sampling sites.

Table 5.4 Summary statistics of the electrical conductivity measurement over the three sampling rounds

Sample site	EC (standard = < 1000 mS/cm)		
	Round 1	Round 2	Round 3
A	595.00	891.00	836.00
B	592.00	464.00	868.00
C	820.00	970.00	965.00
D	416.00	694.00	762.00
E	913.00	880.00	989.00
F	891.00	*1020.00*	*1026.00*
G	645.00	*1027.00*	*1800.00*
H	482.00	359.00	543.00
I	771.00	888.00	*1863.00*
J	674.00	853.00	941.00
Median	659.50	884.00	953.00
Mean	679.90	804.60	1059.30
Max	913.00	1027.00	1863.00
Min	416.00	359.00	543.00
SD	167.27	229.12	430.11
% Compliance	100	80	70

Red and italicized indicates non-compliant measurements

5.3 Results: Chemical water quality properties

In this study, five chemical water quality properties were assessed at the 10 sampling sites. The four chemical water quality properties that were assessed were phosphate, nitrate, dissolved oxygen and ammonia. Because no compliance standards exist in South Africa for these chemical properties, the measurements of these chemicals were compared to international standards.

5.3.1 Phosphate

Most of the phosphate concentrations demonstrated measurements that were non-compliant when compared to the standard of < 0.7 mg/L of the Environmental Protection Agency (EPA, 2001). Only three of the phosphate concentrations were compliant (Table 5.5).

Table 5.5 Summary statistics of the phosphate concentration measurements over the three sampling rounds

Sample site	**Phosphate (standard = < 0.7 mg/L)**		
	Round 1	**Round 2**	**Round 3**
A	*9.42*	*20.00*	*6.00*
B	0.38	0.05	*5.00*
C	*13.10*	*22.00*	*29.00*
D	*1.26*	0.05	*1.00*
E	*23.10*	*23.00*	*31.00*
F	*26.00*	*27.00*	*24.00*
G	*12.01*	*40.00*	*65.00*
H	*1.40*	*6.00*	*3.00*
I	*13.16*	*2.00*	*14.00*
J	*7.63*	*7.00*	*1.00*
Median	10.70	13.50	10.00
Mean	10.80	14.70	17.90
Max	26.00	40.00	65.00
Min	0.48	0.05	1.00
SD	8.78	13.61	20.18
% Compliance	10	20	0

Red and italicized indicates non-compliant measurements

5.3.2 Nitrate

Most of the nitrate concentrations demonstrated measurements that were compliant when compared to the recommended standard of < 2 mg/L for ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems (Camargo and Alonso, 2006). However, seven of the nitrate concentration measurements were non-compliant, all in Rounds 1 and 2. All of the nitrate concentration measurements in Season 3 were compliant when compared to the standard (Table 5.6).

Table 5.6 Summary statistics of the nitrate concentration measurements over the three sampling rounds

Sample site	**Nitrate (standard = < 2 mg/L)**		
	Round 1	**Round 2**	**Round 3**
A	*6.30*	1.70	<1.00
B	1.90	0.20	1.70
C	*5.10*	*2.50*	<1.00
D	1.60	1.10	1.90
E	0.90	*5.60*	<1.00
F	0.70	3.90	<1.00
G	0.90	*11.10*	<1.00
H	2.00	0.90	<1.00
I	0.60	1.60	1.60
J	*5.10*	*2.60*	<1.00
Median	1.75	2.10	1.00
Mean	2.50	3.10	1.20
Max	6.30	11.10	1.90
Min	0.60	0.20	1.00
SD	2.14	3.20	0.36
% Compliance	70	60	100

Red and italicized indicates non-compliant measurements

The histogram shows that a few of the sampling sites demonstrated nitrate concentrations that exceeded the standard. For sampling site G, an exceedingly high concentration was recorded for nitrate in Season 2 (Figure 5.6). On the other hand, sampling sites A, C, E, F and J also demonstrated relatively high measurements of nitrate concentrations, although lower than the nitrate concentration recorded for sampling site G.

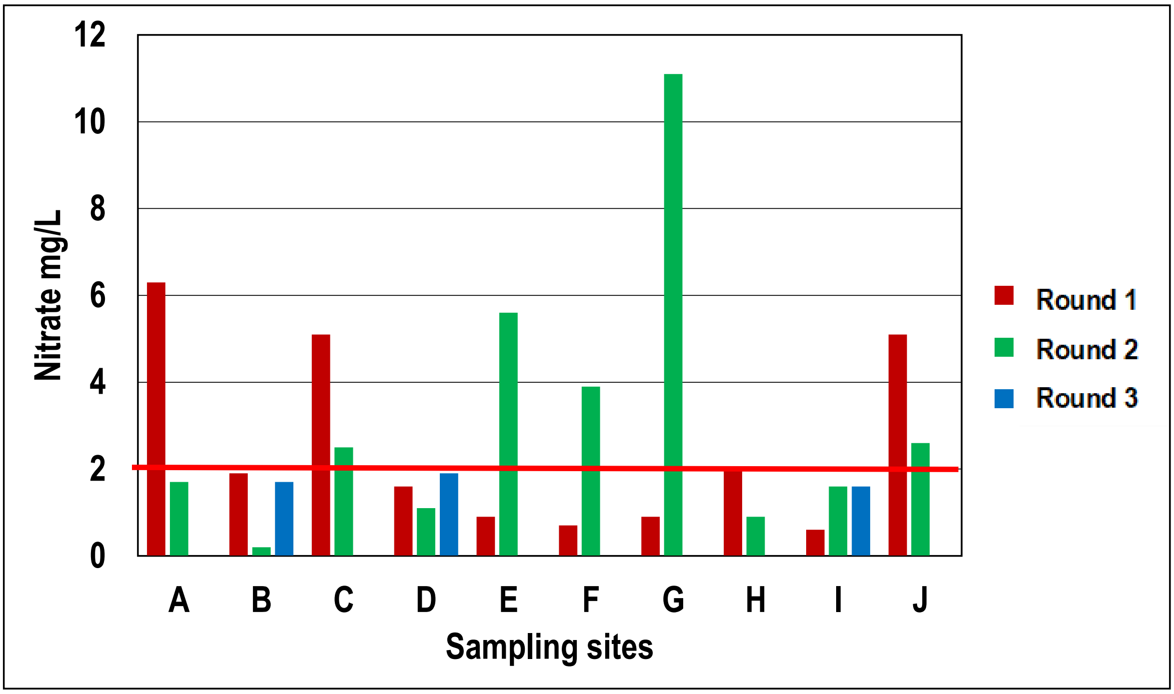


Figure 5.3 Histogram showing the mean nitrate concentration measurements over the three sampling rounds. The red line indicates the standard

5.3.3 Dissolved oxygen

Many of the dissolved oxygen concentrations demonstrated measurements that were compliant when compared to the standard range of 3 – 12 mg/L of the Canadian Water Quality Guidelines (Canadian Water Quality Guidelines Notice to Readers, 1997) (EPA, 2001). The non-compliant dissolved oxygen concentration measurements were all recorded in sampling round 1 and 3. All of the dissolved oxygen concentration measurements during sampling round 2 were compliant when compared to the standard range (Table 5.7).

Table 5.7 Summary statistics of the dissolved oxygen concentration measurements over the three sampling rounds

Sample site	Dissolved oxygen (standard = 3 – 12 mg/L)		
	Round 1	Round 2	Round 3
A	11.70	6.42	*12.60*
B	8.74	8.47	8.12
C	3.85	5.12	3.17
D	*0.66*	9.62	9.00
E	6.89	11.13	4.75
F	9.53	3.30	*13.67*
G	*2.02*	4.95	*1.36*
H	7.55	8.26	6.99
I	*0.13*	4.12	*0.23*
J	*0.14*	4.48	*12.05*
Median	5.13	13.50	10.00
Mean	5.13	6.60	7.20
Max	11.74	11.13	13.67
Min	0.13	3.34	0.23
SD	4.30	2.63	4.76
% Compliance	60	100	50

Red and italicized indicates non-compliant measurements

The histogram shows the non-compliant dissolved oxygen concentration measurements recorded that are outside the range of the standard. Sampling sites A, F and J showed non-compliant dissolved oxygen concentration measurements that were greater than the upper limit of the standard range (Figure 5.7). In contrast, sampling sites G and I showed dissolved oxygen concentration measurements below the standard range in both during sampling round 1 and 3, while sampling sites D and J had a dissolved oxygen concentration measurement below the standard range in one sampling round.

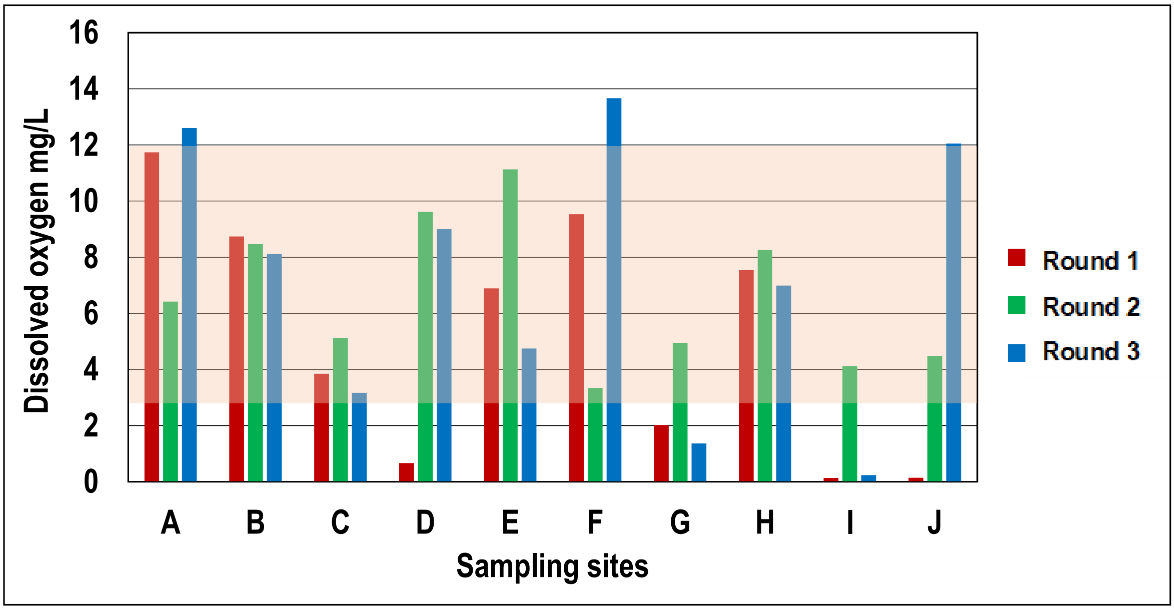


Figure 5.4 Histogram showing the mean dissolved oxygen concentration measurements over the three sampling rounds. The shaded block indicates the range of the standard

5.3.4 Ammonia

Many of the ammonia concentrations demonstrated measurements that were compliant when compared to the standard of 1.5 mg/L of the United States of America Environmental Protection Agency (EPA, 2001). Non-compliant ammonia concentrations measurements were recorded for sampling round 1 and 3, while all the ammonia concentrations measurements recorded for round 2 were compliant when compared to the standard (Table 5.8). Low concentrations of Ammonia at some sampling sites can be attributed to animals that graze in the vicinity. This may be as a result of urine and faeces producing small concentrations of ammonia. This is especially true for areas where there is favourable conditions of good temperature, nitrogen content, a good pH level as well as chemical and microbiological activities in the environment. The results of this study, indicate that certain favourable conditions existed at the sampling site, particularly for temperature, pH and the presence of faecal coliforms.

Table 5.8 Summary statistics of the ammonia concentration measurements over the three sampling rounds

Sample site	Ammonia (standard = < 1.5 mg/L)		
	Round 1	Round 2	Round 3
A	*1.60*	0.23	1.30
B	*2.80*	0.45	*4.70*
C	*22.10*	0.62	*10.00*
D	1.20	0.60	<1.00
E	*18.30*	0.88	*9.60*
F	*30.20*	0.35	*8.50*
G	*23.40*	0.95	*50.00*
H	0.70	0.08	1.00
I	*20.00*	0.53	*2.30*
J	*1.60*	0.40	1.30
Median	12.20	0.51	8.97
Mean	10.60	0.49	3.50
Max	30.20	0.95	50.00
Min	0.70	0.10	1.00
SD	11.60	0.27	14.88
% Compliance	20	100	40

Red and italicized indicates non-compliant measurements

A histogram provides a visual perspective to demonstrate the difference in ammonia concentrations over the three sampling rounds. The histogram shows that most of the sampling sites demonstrated ammonia concentrations that exceeded the standard. All sampling sites showed compliant ammonia concentrations in during sampling round 2 (Figure 5.8). Sampling round 1 and 3, on the other hand, had more than 50% of the sampling sites that were non-compliant when compared to the standard for ammonia.

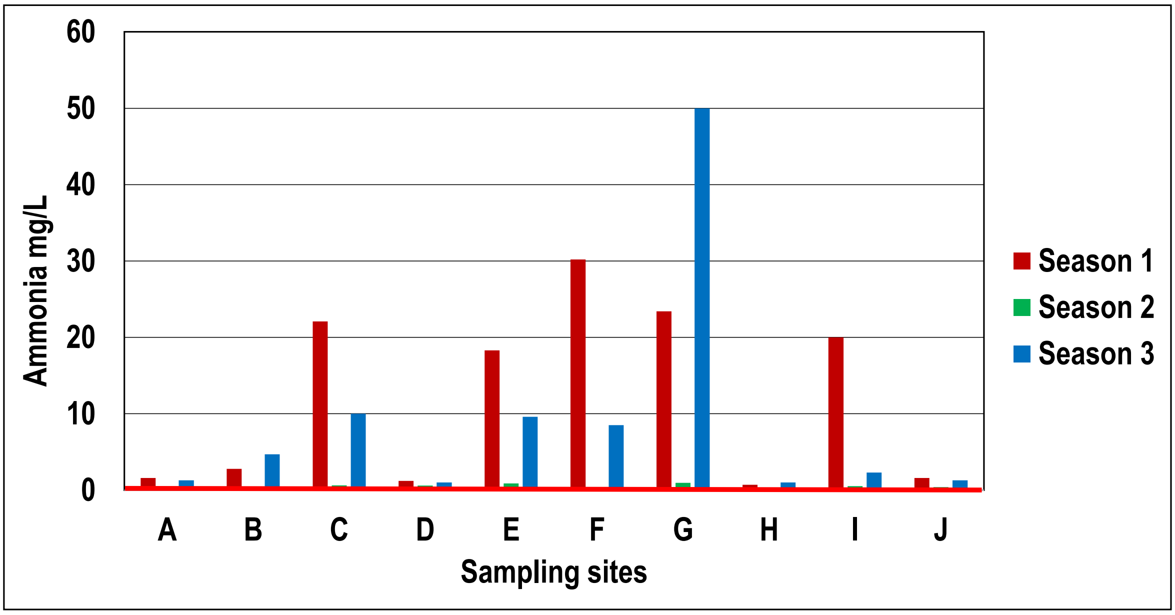


Figure 5.5 Histogram showing the mean ammonia concentration measurements over the three sampling rounds. The red line indicates the standard

5.3.5 Total dissolved solids

Most of the total dissolved solids concentration measurements were compliant when compared to the standard of < 1,000 mg/L of the Australian and New Zealand Guidelines for Fresh and Marine Water Quality Volume 2: Aquatic Ecosystems-Rationale (Australian and New Zeeland Environment and Conservation Council, 2000). The only two non-compliant total dissolved solids measurements were recorded in sampling round 3 (Table 5.9). During final sampling round, a manhole located close to sampling site G was overflowing, discharging untreated sewerage, and can thus be attributed to the high TDS concentrations at this sampling site. Sampling site I, can be described as a swamp, into which raw sewerage flows from other affected dams and streams, and can be associated with high concentrations of sludge from the untreated sewerage that flows into it.

Table 5.9 Summary statistics of the total dissolved solids measurements over the three sampling rounds

Sample site	Total dissolved solids (standard = < 1,000 cfu/ 100ml)		
	Round 1	**Round 2**	**Round 3**
A	230.00	583.57	560.00
B	291.00	310.88	581.56
C	399.00	649.90	646.55
D	212.00	464.98	464.98
E	428.00	589.60	662.63
F	419.00	683.40	687.42
G	328.00	688.09	*1,206.00*
H	238.00	240.53	363.81
I	370.00	594.96	*1,248.21*
J	336.00	571.51	630.47
Median	332.00	586.59	638.50
Mean	325.10	537.74	705.20
Max	428.00	688.09	1,248.20
Min	212.00	240.53	368.80
SD	79.99	153.01	292.01
% Compliance	100	100	80

Red and italicized indicates non-compliant measurements

5.4 Results: Microbiological water quality properties

Most of the feacal coliforms measurements were non-compliant when comparing to the standard of ≤ 1000 cfu/ 100 mL of the South African Water Quality Guidelines for Agricultural Use, Irrigation (DWAF, 1996c). When comparing the results of the feacal coliform measurements obtained in sampling round 1 with that of sampling round 2 and 3, it can be concluded that the microbiological water quality of most of the sampling sites had degenerated (Table 5.10). The sampling site H, was the only sampling point where the feacal coliform measurements was consistently compliant with the standard over all three sampling rounds.

Table 5.10 Microbiological water quality results over three sampling rounds

Sample site	Faecal coliforms (standard ≤ 1000 cfu/100 ml)		
	Round 1	Round 2	Round 3
A	102.20	*>2419.60*	*>2419.60*
B	*1732.90*	*>2419.60*	*>2419.60*
C	*>2419.60*	*>2419.60*	*>2419.60*
D	224.70	*>2419.60*	*>2419.60*
E	101.90	*>2419.60*	*>2419.60*
F	*>2419.60*	*>2419.60*	*>2419.60*
G	*>2419.60*	*>2419.60*	*>2419.60*
H	4.10	387.30	517.20
I	*>2419.60*	*>2419.60*	*>2419.60*
J	178.20	*>2419.60*	11.30
Median	978.80	>2419.60	>2419.60
Mean	1202.24	2216.37	1988.53
Max	>2419.60	>2419.60	>2419.60
Min	4.10	387.30	11.30
SD	1158.07	642.67	916.56
% Compliance	30	0	10

>2419.60 = maximum MPN for coliform bacteria in 100 ml. Red and italicized indicates non-compliant measurements

5.5 Results: Variations for the water quality properties over the three sampling rounds

5.5.1 ANOVA test for physical water quality properties

The potential variation on the measurements of the physical properties was determined by performing analysis of variance tests (ANOVAs) on the data over the three sampling rounds. The ANOVAs revealed significant variations in temperature and EC at $\alpha = 0.05$ (Table 5.11).

Table 5.11 ANOVA tests on the physical properties

Property	Source of Variation	SS	df	MS	F	*P*-value	F crit
pH	Between Groups	0.825	2	0.413	2.307	0.119	3.354
	Within Groups	4.831	27	0.179			
Turbidity	Between Groups	78619.960	2	39309.980	0.826	0.448	3.354
	Within Groups	1284216	27	47563.570			
Temperature	Between Groups	1115.402	2	557.701	70.910	**<0.001**	3.354
	Within Groups	212.350	27	7.865			
EC	Between Groups	747888.500	2	373944.200	4.226	**0.025**	3.354
	Within Groups	2389205	27	88489.090			

Tukey post hoc tests were performed on the temperature and EC data to ascertain which sampling rounds differed significantly from one another. For temperature, the Tukey post hoc test revealed significant differences between sampling Round 1 and 2, as well as between Round 2 and 3, while for EC, significant differences were established between sampling rounds 1 and 3 at α = 0.05 (Table 5.12).

Table 5.12 Tukey post hoc tests for temperature and electrical conductivity

	Temperature			Electrical conductivity		
Sampling round	**Round 1**	**Round 2**	**Round 3**	**Round 1**	**Round 2**	**Round 3**
Round 1						
Round 2	S			NS		
Round 3	NS	S		S	NS	

S = significant and α = 0.05; NS = non-significant and α = 0.05

5.5.2 ANOVA tests for chemical properties

Similar to the physical properties, the potential effect of different sampling rounds was determined for the measurements of the chemical properties over the three sampling rounds by performing ANOVA tests. The ANOVA tests revealed significant variations in total dissolved solids at $\alpha = 0.05$ (Table 5.13).

Table 5.13 ANOVA tests on the chemical properties

Property	Source of Variation	SS	df	MS	F	*P*-value	F crit
Phosphate	Between Groups	256.897	2	128.449	0.575	0.569	3.354
	Within Groups	6028.590	27	223.281			
Nitrate	Between Groups	18.821	2	9.410	1.875	0.173	3.354
	Within Groups	135.481	27	5.018			
Dissolved oxygen	Between Groups	22.645	2	11.322	0.708	0.502	3.354
	Within Groups	431.945	27	15.998			
Ammonia	Between Groups	728.009	2	364.005	3.066	0.063	3.354
	Within Groups	3205.460	27	118.705			
Total dissolved solids	Between Groups	725647.700	2	362823.800	9.458	**0.0008**	3.354
	Within Groups	1035730	27	38360.380			

SS =; df = degrees of freedom; MS =; F P-value =; F crit =

A Tukey post hoc test was performed on the total dissolved solids data to ascertain which sampling rounds differed significantly from one another. The Tukey post hoc test revealed significant differences between sampling round 1 and 3 at $\alpha = 0.05$ (Table 5.14).

Table 5.14 Tukey post hoc test for total dissolved solids

Round	Round 1	Round 2	Round 3
Round 1			
Round 2	NS		
Round 3	S	NS	

S = significant and $\alpha = 0.05$; NS = non-significant and $\alpha = 0.05$

5.6 Results: Water quality index

A water quality index was calculated for each of the 10 sampling sites to describe the overall quality of the water per sampling site. The CCME WQI (CCME, 2001) revealed that most of the water conditions of the respective could be classified as poor. Only sampling site D and sampling site H had water quality conditions that were classified as marginal (Table 5.15). The sources of wastewater pollution from the malfunctioning infrastructure had seriously impacted the remaining water quality of the sampling sites. The water quality sampling sites classified as poor were all located within the direct influence of the failing wastewater infrastructure networks. The marginal water quality condition of the sampling site H, indicates that the water quality departed slightly from the normal compared to all other sampling sites. A few anthropogenic activities, such as swimming, fishing and animal grazing at the sampling site, can be attributes to the marginal water quality condition. The low level of pollution at sampling site D could be attributed to it being the furthest site from the pollution sources. The low level pollution can be related to natural dilution effect that occurs when moving away from the source of pollution. The dilution effect can be attributed to soil and rock filtration as well as wetlands located in the vicinity close to sampling site D.

Table 5.15 Water quality indices and the water quality condition for the different sampling sites

Sampling site	WQI	Condition	Sampling site description
A	40	***Poor***	Stream that received raw sewerage flowing from a malfunctioning pump station.
B	28	***Poor***	Dam that received raw sewerage flowing from a malfunctioning pump station.
C	36	***Poor***	Perennial river that received wastewater effluent from the Zastron Wastewater Treatment Works.
D	52	***Marginal***	All polluted perennial rivers and streams feed into the main water catchment, the Montagu dam.
E	39	***Poor***	Stream that receives wastewater effluent from the Zastron Wastewater Treatment Works.
F	27	***Poor***	Perennial river that received raw sewerage from a malfunctioning pump station.
G	33	***Poor***	Perennial river that received untreated sewerage from an overflowing manhole.
H	58	***Marginal***	Sampling site that did not received sewage pollutants.
I	28	***Poor***	Stagnant dam that received raw sewerage pollutants from sampling site A.
J	32	***Poor***	Perennial river that received raw sewerage pollutants from sampling site A.

5.7 Discussion

Of the 10 water quality properties measured approximately 40% demonstrated non-compliance with the proposed standards for AWQUS. Of the four physical water quality properties, only turbidity was non-compliant, which could be expected for a surface water body polluted by wastewater flowing directly from a manhole or malfunctioning pump stations. The only two chemical water quality properties that were non-compliant with the respective standards were Ammonia and Phosphates. The results of the CCME WQI indicated that only two of the eight surface water bodies had marginal water quality conditions, while the remaining sites had displayed poor water quality conditions. These water bodies included sampling site H and sampling site D. Temperature and electrical conductivity were the only two physical water quality properties that demonstrated strong variances, while TDS was the only chemical water quality property that demonstrated significant differences at $\alpha = 0.05$. The water quality results clearly indicate that the water quality of the surface water bodies in the vicinity of the Zastron and Matlakeng Tow nship is highly degraded and could pose a risk for aquatic organism living in the water, as well as humans and animals who eat food irrigated by these waters or who may use it for domestic purposes.

Chapter 6

Ecological Quality of Surface Water

6.1 Introduction

Because macroinvertebrates families display varying sensitivities to polluted water, their presence and numbers were used to conduct the ecological study on the health status of the macroinvertebrate sampling site habitats. Thus, when water contains mostly pollution tolerant macroinvertebrates, it indicates that the water is heavily polluted. In contrast, when pollution sensitive families are found in the water, the water may be unpolluted or only slightly polluted. Several indices were used to establish the health status of the water macroinvertebrate sampling site habitats (vegetation, stone, gravel, sand and mud), which included calculating the number of macroinvertebrate families, the average score per taxa (ASPT) values and the SASS5 scores. These indices were then used to classify each of the sampling sites into one of six ecological categories, ranging from good to critically modified (Dallas, 2007).

6.2 Results: Macroinvertebrate prevalence

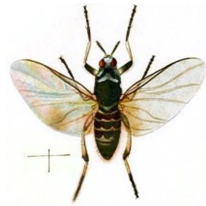
6.2.1 Macroinvertebrate taxa

An assessment of the combined stone in current, vegetation, and gravel, sand and mud biotopes at each of the 10 macroinvertebrate sampling site habitats was carried out for each of the three sampling rounds. Nine orders of macroinvertebrates and 21 macroinvertebrate families were identified. Of the nine orders of macroinvertebrates, the Diptera represented the largest group, comprised of six families. Table 6.1 lists the different macroinvertebrate orders and families of macroinvertebrates.

Table 6.1 Orders and families of macroinvertebrates identified in this study

Order	Family name	Common name	Image
ANNELIDA	Oligochaeta	Brush /egged mayfly	
EMPHEMEROPTERA	Teloganodidae	Spiny crawlers	
ODONTA	Aeshnidae	Dragonflies	
	Chlorocyphidae	Damselflies	
CRUSTACEA	Potamonautidae	Crabs	
HEMIPTERA	Belostomatidae	Giant water bugs	
	Corixidae	Water boatmen	

Order	Family name	Common name	Image
	Pleidae	Pigmy backswimmers	
HYDRACARINA		Water mites	
	Syrphidae	Hoverflies	
	Ceratopogonidae	Biting midges	
DIPTERA	Chironomidae	Midges	
	Psychodidae	Moth flies	
	Ephydridae	Shore flies	

Order	Family name	Common name	Image
	Simuliidae	Black flies	
	Lymnaeidae	Pond snails	
GASTROPODA	Physidae	Pouch snails	
	Hydrophilidae	Water scavenger beetles	
	Helodidae	Marsh beetles	
COLEOPTERA	Hydraenidae	Minute moss beetles	
	Dytiscidae	Predacious diving beetles	

The SASS5 identification guide was used to identify the macroinvertebrate families at the 10-macroinvertebrate sampling site habitats. Relatively few macroinvertebrates were found at the respective macroinvertebrate sampling site habitats; a total of 83 over the three sampling rounds (Table 6.2). The highest numbers of macroinvertebrates were recorded at sampling site habitats B and C. In contrast, the lowest number of macroinvertebrates was recorded at sampling site habitat J. Of the macroinvertebrates counted at the respective macroinvertebrate sampling site habitats, the Corixidae of the Hemiptera, the Syrphidae and Chironomidae of the Diptera were the most abundant. The macroinvertebrate counts revealed that the macroinvertebrate assemblages declined over the three sampling rounds at macroinvertebrate sampling site habitats F, G and I. At macroinvertebrate sampling site habitat G, only Syrphidae macroinvertebrates were present and declined extensively in subsequent sampling.

Table 6.2: Number of macroinvertebrate families identified at each of the 10 macroinvertebrate sampling site habitats for round 1, 2 and 3

Site	**A**			**B**			**C**			**D**			**E**			**F**			**G**			**H**			**I**			**J**		
Round	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Order																														
HYDRACARINA													1									1								
ANNELIDA																														
Oligochaeta								30																						
Hirudinea														4			2						1							
CRUSTACEA																														
Potamonautidae		4		1		1			1																					
ODONATA																														
Chlorocyphidae										1																				
Aeshnidae								1				1											1							
HEMIPTERA																														
Belostomatidae												1											2							
Pleidae					2																									
Corixidae	16			13		16	3		39	6	4	6	18									5	1	4	1	51	3	5		1
DIPTERA																														
Simuliidae													2																	
Syrphidae						3									1	61			108	13		1		3	2		1			
Ceratopogonidae																											3		13	

Site	A			B			C			D			E			F			G			H			I			J		
Chironomidae	2	31	25	5	52	110	5	103	18		13	15	7	77		6	4													
Psychodidae							6						2									27								
Ephydridae	2																													
GASTROPODA																														
Hydrobiidae	5																													
Physidae										1		5															12			
Lymnaeidae	3																											15		
COLEOPTERA																														
Helodidae							2																		1					
Hydraenidae		6																												
Hydrophilidae				1			3			1																				
Dytiscidae							1																							
EPHEMEROPTERA																														
Teloganodidae						2																								
Number of macroinvertebrate families per round per site	5	3	1	4	2	5	6	3	3	4	2	5	5	2	1	2	2	0	1	1	0	4	4	2	3	1	4	2	1	1
Number of macroinvertebrate individuals per round per site	28	41	25	20	54	132	20	134	58	9	17	28	30	81	1	67	6	0	108	13	0	34	5	7	4	51	19	20	13	1
Overall total	94			206			212			54			112			73			121			46			74			34		

The histogram of the number of Corixidae macroinvertebrates, the most prevalent in the study, demonstrates the abundance pattern of Corixidae recorded over the sampling rounds at the respective macroinvertebrate sampling site habitats. The histogram shows that the Corixidae were absent or rare at some macroinvertebrate sampling site habitats, but relatively plentiful at others. At macroinvertebrate sampling site habitats C and I, the highest number of Corixidae macroinvertebrates were counted, and absent at macroinvertebrate sampling site habitats F and G. These two macroinvertebrate sampling site habitats was heavily polluted at each sampling round. The sludge like water discharged into these two sampling sites, because of a blocked and overflowing manhole and a malfunctioning pumpstation respectively, can be associated with the absence of the Corixidae at sampling sites F and G. Figure 6.1 provides a visual perspective of the number of Corixidae at the different macroinvertebrate sampling site habitats per sampling round. In sampling round 2, some of the sampling sites have low numbers of Corixidae, which can be potentially attributed to it having been a dry season (May 2018), with low levels of water and low flow, resulting in a decline.

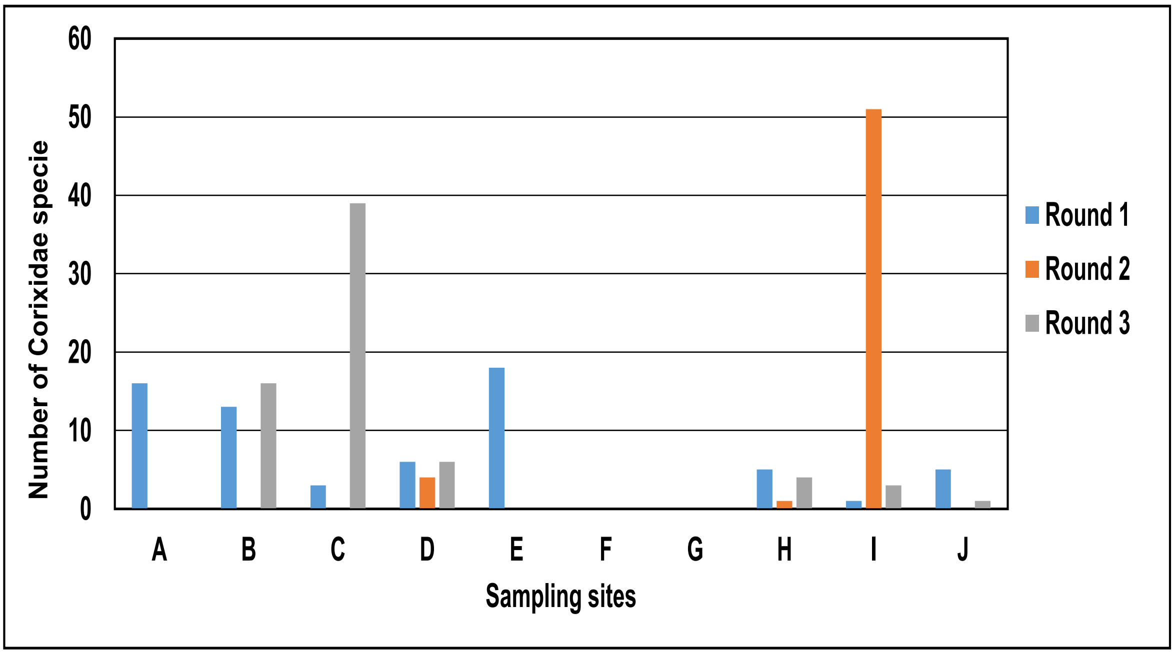


Figure 6.1 A histogram showing the presence of Corixidae species in Round 1, 2 and 3

6.3 Results: Macroinvertebrate sensitivity classification

To establish the extent of the pollution of the sampled water, the macroinvertebrate families were classified in terms of their tolerance to polluted water using the SASS5 rapid bio-assessment method. Each of the 21 identified macroinvertebrate families was allocated sensitivity scores as listed in the SASS5 scoring sheet (Dickens and Graham, 2002). Of the 21-macroinvertebrate families identified, the majority were allocated a sensitivity score of either moderate or tolerant (Table 6.3). More than 70% of the 21 families belonged in the pollution tolerant category.

Table 6.3 Sensitivity scores of observed macroinvertebrate families

Order	Family name	Sensitivity score	Sensitivity class
ANNELIDA	Oligochaeta	1	Pollution tolerant
EMPHEMEROPTERA	Teloganodidae	12	Low pollution tolerant
ODONTA	Aeshnidae	8	Moderately pollutant tolerant
	Chlorocyphidae	10	Moderately pollutant tolerant
CRUSTACEA	Potamonautidae	3	Pollution tolerant
	Belostomatidae	3	Pollution tolerant
HEMIPTERA	Corixidae	3	Pollution tolerant
	Pleidae	4	Pollution tolerant
HYDRACARINA		8	Moderately pollutant tolerant
	Syrphidae	1	Pollution tolerant
	Ceratopogonidae	5	Pollution tolerant
	Chironomidae	2	Pollution tolerant
DIPTERA	Psychodidae	1	Pollution tolerant
	Ephydridae	3	Pollution tolerant
	Simuliidae	5	Pollution tolerant
	Lymnaeidae	3	Pollution tolerant
GASTROPODA	Physidae	3	Pollution tolerant
	Hydrophilidae	5	Pollution tolerant

COLEOPTERA	Helodidae	12	Low pollution tolerant
	Hydraenidae	8	Moderately pollutant tolerant
	Dytiscidae	5	Pollution tolerant
% Pollution tolerant		71	
% Moderately pollution tolerant		19	
% Low pollution tolerant		10	

6.4 Results: Macroinvertebrate sampling site habitat classification

To classify the macroinvertebrate sampling site habitats in terms of the effect of pollution, three indices were calculated. These indices included the number of macroinvertebrate families, the average macroinvertebrates per family (average score per taxa; ASPT) and the SASS5 scores (Table 6.4). From these indices, each of the macroinvertebrate sampling site habitats was classified into one of the following ecological categories; natural, good, fair, poor, seriously modified and critically modified (Dallas, 2007).

Table 6.4 Macroinvertebrate families, SASS score and the ASPT value for Rounds 1, 2 and 3

Index	**Macroinvertebrate family**			**ASPT value**			**SASS5 score**		
Round	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Site									
A	5	3	1	4	1	2	21	2	2
B	4	2	5	3	4	4	13	9	21
C	6	3	3	4	5	3	28	11	8
D	4	2	5	5	2	4	21	5	19
E	5	2	1	3	2	1	19	5	1
F	2	2	0	1	2	0	3	5	0
G	1	1	0	1	0	1	1	0	1

H	4	4	2	3	3	1	13	14	3
I	3	1	4	5	3	1	16	3	7
J	2	1	1	3	5	3	6	5	3
Mean	4	2	2	3	3	2	13	6	6
Median	4	2	1	3	2	2	13	5	3
Min	1	0	0	1	0	0	1	0	0
Max	6	4	5	5	5	4	28	14	21
SD	2	1	2	1	1	1	9	4	7

The Highveld – Lower zone ecoregion was used as a reference condition that best reflects the condition to be expected in rivers and streams of the 10 macroinvertebrate sampling site habitats (Dallas, 2007). The SASS5 score and the ASPT value for each of the three sampling rounds were plotted onto the modelled reference condition (Dallas, 2007) so that each of the macroinvertebrate sampling site habitats could be classified into one of the six ecological categories. Figure 6.2 shows that the classification of all the macroinvertebrate sampling site habitats fell in the lower left quadrant (E/F) of the modelled ecological reference condition.

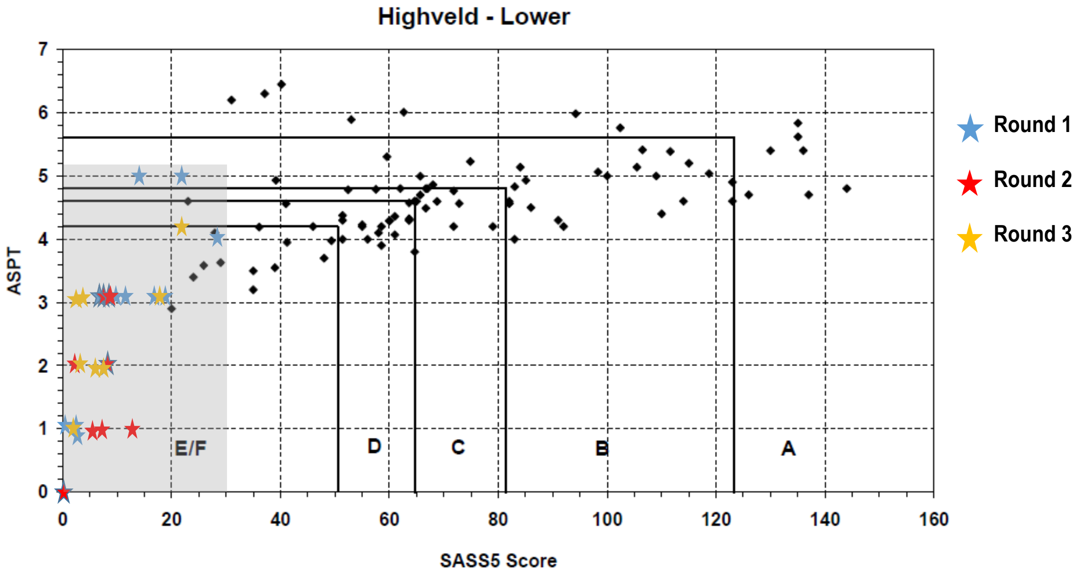


Figure 6.2 Classification of the macroinvertebrate sampling site habitats using the Highveld–Lower zone Ecoregion (Dallas, 2007)

The ASPT values and the SASS5 scores were relatively low for all macroinvertebrate sampling site habitats. All the ASPT values were less than six and the SASS5 scores were lower than 30 (Table 6.5). The macroinvertebrate sampling site habitats are all categorised as critically impaired; and this can be directly associated with the low values. This was reflected by the high values of pollution tolerant macroinvertebrate families present at most of the macroinvertebrate sampling site habitats.

Table 6.5 Ecological category for macroinvertebrate sampling site habitats

	SASS	ASPT	SASS	ASPT	SASS	ASPT	Ecological category	Description	Condition
Round	**1**	**1**	**2**	**2**	**3**	**3**			
Sampling site									
A	21.00	4.20	2.00	0.66	2.00	2.00	**F*	Critically impaired	A few tolerant taxa present
B	13.00	3.25	9.00	4.50	21.00	4.20	*F*	Critically impaired	A few tolerant taxa present
C	28.00	4.67	11.00	3.66	8.00	2.67	*F*	Critically impaired	A few tolerant taxa present
D	21.00	5.25	5.00	2.50	19.00	3.80	*F*	Critically impaired	A few tolerant taxa present
E	19.00	3.80	5.00	2.50	1.00	1.00	*F*	Critically impaired	A few tolerant taxa present
F	3.00	1.50	5.00	2.50	0.00	0.00	*F*	Critically impaired	A few tolerant taxa present
G	1.00	1.00	0.00	0.00	1.00	1.00	*F*	Critically impaired	A few tolerant taxa present
H	13.00	3.25	14.00	3.50	3.00	1.50	*F*	Critically impaired	A few tolerant taxa present
I	16.00	5.33	3.00	3.00	7.00	1.75	*F*	Critically impaired	A few tolerant taxa present
J	6.00	3.00	5.00	5.00	3.00	3.00	*F*	Critically impaired	A few tolerant taxa present
% Critically impaired	100%								

* = according to Dallas (2007); Black = Class F

6.5 Discussion

In this study, nine orders of macroinvertebrates and 21 macroinvertebrate families, which are the most pollution tolerant families, were identified. Of these families, 71% were pollution tolerant with sensitivity scores ranging between one and five. The order of Diptera represented the largest group of macroinvertebrate families. The greatest number of macroinvertebrates that were identified at the 10 macroinvertebrate sampling site habitats were from the Chironomidae, Corixidae, Hemiptera and Syrphidae families. The highest numbers of macroinvertebrates were recorded at macroinvertebrate sampling site habitats B and C. In contrast, the lowest number of macroinvertebrates was recorded at macroinvertebrate sampling site habitat J, which was downstream of several pollution sources. The low numbers of macroinvertebrate families present at this site, support the notion that the site is highly polluted. These counts also revealed that the macroinvertebrate assemblages declined over the three sampling rounds due to persistent blocked manholes resulting in sewerage spillages in the vicinity of the macroinvertebrate sampling site habitats F, G and I. Sampling rounds during different sampling conditions (wet and dry) effects can also be attributed to the variations in the number of macroinvertebrate assemblages. When comparing the two types conditions (wet and dry), a higher number of macroinvertebrates were sampled in the wet season (November 2017 and November 2018), compared with the dry season (June 2018). This reasoning is substantiated by researchers who have established a greater decline in macroinvertebrate assemblages during dry seasons. A dry season, can be associated with the alteration of the community structure, the number of taxa at a given site as well as the community composition of macroinvertebrates at a particular sampling site (Rosset et al., 2017).

Chapter 7

Findings and Conclusions

7.1 Introduction

Surface water quality is declining in many countries around the world and South Africa is no exception (Sibanda et al., 2015). In several studies it was found that the leading cause for the decline in surface water quality was mainly as a result of sewerage flowing from poorly operated wastewater treatment plants. This decline in surface water quality is also exacerbated by poor maintenance of the infrastructure of wastewater treatment plants and their accompanying sewer networks (Mema, 2010). In South Africa, this situation is supported by findings made by the Department of Water and Sanitation (DWA, 2012). This department found that the bulk of wastewater infrastructure systems and sewer networks were deteriorating because of inadequate maintenance and refurbishment, as well as the lack of upgrading non-functional infrastructures (DWA, 2012). Thus, during the monitoring of surface water quality, the deteriorating wastewater treatment plants and their sewer networks resulted in an increase in the number of water samples that do not meet the regulatory standard (Ntombela et al., 2016).

In terms of the Constitution of the Republic of South Africa of 1996, and the Municipal Structures Act of 1998, South African municipalities are legally mandated to provide good quality municipal services and to promote a safe and healthy environment. Blue Drop and Green Drop assessments of municipal services have shown that many South African municipalities were not providing adequate services to the communities that they serve (DWA, 2012). Poorly maintained water and wastewater infrastructural systems have caused blockages resulting in sewerage flowing into streets, thereby creating unbearable living conditions, which have resulted in public protests crying for the municipal services to be improved (Makhari, 2016). These types of service delivery protests are more common in rural municipalities because many of these municipalities do not possess the capacity to operate and maintain water and wastewater infrastructural systems, thus resulting in the collapse of these municipal services (SAICE, 2011; Makhari, 2016). The 2014 Green Drop Report revealed that 30% of South Africa's wastewater treatment infrastructure was in a critical condition because of poor maintenance resulting in millions of litres of untreated wastewater entering surface water bodies each day (SAICE, 2011). An analysis of the challenges faced by many rural municipalities showed that the leading causes for these failures were a lack of forward planning and the reactive basis which municipalities employed to conduct maintenance once a system failure had occurred (Ntombela et al., 2016).

The failure of rural municipalities to provide adequate services to their communities has resulted in extensive pollution of surface water bodies in the vicinities of manhole blockages, sewage overflows and the discharge of poorly treated wastewater effluent. The pollution enrichment of these water bodies has a negative impact on aquatic life in the surface water (Mema, 2010). The raw sewerage affects the available oxygen balance in these surface water bodies by reducing the biological oxygen demand and the dissolved oxygen (Mema, 2010). Reduction in oxygen demand and the dissolved oxygen causes the death of many sensitive aquatic organisms resulting in a reduction of population numbers and the deterioration of the ecosystem functionality (Smith-adao and Poole, 2018).

7.2 Findings

7.2.1 Municipal infrastructure challenges of the Mohokare Local Municipality

There have been numerous public protests by the communities in Zastron and Matlakeng Township of the rural municipality, Mohokare. These protests have mostly been because of breakdowns in the wastewater infrastructure systems and sewer networks. Due to the poor maintenance of the wastewater infrastructure systems and sewer networks, communities are continually experiencing manhole blockages and untreated sewerage flowing into streets. This prompted the need to assess the impact of wastewater pollution on surface water bodies in the vicinity. The study found that on assessment of community infrastructure related complaints lodged with the municipality were mostly for blocked manholes and sewerage leakages that were as a result of overflowing manholes, burst pipes, and poor workmanship with the construction of sewer networks. The distribution of complaints was relatively similar for areas such as Itumeleng, Old, Ezibeleni and Refeng Khotso locations, where communities experienced most of the challenges.

The identified locations, aided in the identification of surface water bodies, located within the vicinity of where most blocked manholes and sewerage leakages were prevalent. Ten surface water bodies were identified; to investigate what impact wastewater pollution may have on the quality of the water and the ecological health status of these surface water bodies. In Table 7.1, each of the 10 sampling sites, are described by the type of infrastructure related breakdown that served as a motivation for the choice of sampling site.

7.2.2 Water quality

In this study, the physical, chemical and microbiological quality of the 10 sampling sites was measured over three sampling rounds. This was to establish the impact that the wastewater pollution had on the surface water bodies, located in the vicinity of the Matlakeng Township. To describe the water quality of each of the surface water bodies, a Water Quality Index was calculated. The calculation of the WQI took into account the sampling results for the three water quality sampling rounds. The study found, that 80% of the water quality conditions of the sampling sites were classified as poor. The only two sampling sites that were not classified as poor, but as marginal, was sampling site H and sampling site D. The reason for the lower pollution levels at sampling site H was due to its remote locality from any potential polluting sources. On the other hand, sampling site D was located furthest from all the sources of anthropogenic pollution, and this the natural dilution effect can be attributed to the low levels of pollution found at the sampling site.

Most of the sampling sites, which were classified as poor, all had high levels of Turbidity, Ammonia, Phosphates, and Total Dissolved Solids particularly sampling sites F and G. The two sampling sites, had at each of the three sampling rounds, experienced high volumes of untreated wastewater pollution flowing from a blocked manhole and a malfunctioning pump station, respectively. In a study of the water quality of the Bloemspruit stream in Manguang, Free State Province, high levels of Turbidity were found at sampling sites located within the proximity of wastewater treatment plants, industries and informal settlements (Nyoh, 2015).

All sampling sites also experienced non-compliant Phosphate concentrations. These high concentrations of Phosphate can be associated with untreated sewerage discharges. To substantiate this finding, sampling sites F, E and G, can be singled out as sampling sites, where the highest average was Phosphate concentration was 25.67 mg/L, 25.70 mg/L and 39.00 mg/L respectively, over the three sampling rounds, remarkably higher than the standard of $\leq$ 0.7 mg/L. Sampling site E, was a surface water body, located downstream of the Zastron Wastewater Treatment Plant. The high Phosphate concentrations at the sampling site, can be associated with inadequate treatment of the wastewater from the Zasttron WWTW. A similar finding was made in a study to establish the faecal water pollution loads as a function of population growth in the Sedibeng and Soshanguve, South Africa found that a relationship exists between the elevated concentrations of phosphate in the wastewater effluent that was discharged from the Meyerton and Sandspruit Wastewater Treatment Plants (Teklehaimanot, 2013).

Elevated concentrations of Ammonia was also identified at sampling sites E, F, G and I, particularly during sampling rounds 1 and 3. The presence of Ammonia in water is closely associated with the presence or outflow of sewerage from wastewater treatment plants (Berenzen et al., 2001). Sampling site E, is located immediately downstream of the Zastron Wastewater Treatment Works, whereas sampling sites F and G were located within close proximity to where untreated sewerage was discharged from overflowing manholes into these receiving surface water bodies. Sampling site I is as a dam, into which the untreated sewerage flowed, particularly from sampling site A and J. The dam produced a prudent odour, which is associated with the presence of Ammonia in the wastewater.

The Dissolved Oxygen (DO) concentration in the water was low at sampling site I and G during sampling Round 1 and 3. Again, both sampling sites, particularly sampling site G, was located directly from where untreated sewerage was discharged into the surface water body. Sewerage is closely associated with the presence of low concentrations of DO as was found in a study of the Effect of a Sewage Effluent on the Distribution of Dissolved Oxygen and Fish in a Stream (Alabaster, 1959).

The microbiological water quality of all the sampling sites, declined substantially after the first sampling round. Sampling site H was the only sampling site that had at each of the three sampling rounds, shown compliant surface water quality when compared to the standard ($\leq$ 1000 cfu/mL). The high counts of faecal coliforms found for most of the surface water bodies studied, is indicative of the impact that untreated sewerage from overflowing manholes, malfunctioning pump stations and the inadequate treatment of wastewater has on the receiving water bodies.

7.2.3 Ecological quality of surface water

To determine the pollution condition as well as the diversity of the macroinvertebrate sampling site habitats, the number of macroinvertebrates identified at each sampling site was calculated using a SASS5 score and an average score per taxon calculation. In this study, of the 21-macroinvertebrate families identified, the majority were allocated a sensitivity score of either moderate or tolerant. More than 70% of the 21 families belonged to the pollution tolerant category. The macroinvertebrate counts revealed that the macroinvertebrate assemblages declined over the three sampling rounds at macroinvertebrate sampling site habitats F, G and I. At macroinvertebrate sampling site habitat G, only Syrphidae macroinvertebrates were present and declined extensively in subsequent sampling. Sampling site F and G are sampling sites that were heavily polluted by untreated sewerage. These sites, had high levels of Turbidity and high concentrations of Phosphates. These two water quality parameters may have adverse effects on the survival of macroinvertebrates. The high levels of Turbidity in many of the sampling sites can be attributed to the decrease or survival of certain macroinvertebrates in the surface water bodies. It can also be suggested, that highly turbid waters may have caused the sensitive macroinvertebrates to migrate to other locations with reduced turbidity, which may have resulted in the reduction of the populations of these sensitive organisms. Phosphates can result in a reduced diversity of macroinvertebrates. This was a finding of a study on the levels of phosphates and nitrates in the rivers in China. The study found that there was a reduced diversity of macroinvertebrates and only pollution tolerant macroinvertebrate families such as Tubificidae, Chironomidae and Physidae were present in the rivers (Duan et al., 2011).

The presence of Ammonia can also be attributed to the low number of sensitive macroinvertebrates present in surface water bodies. A study on the effects of chronic ammonium and nitrite contamination on the macroinvertebrate community in running water microcosms have proven that the presence of Ammonia at elevated concentrations can be extremely toxic to macroinvertebrates (Alabaster, 1980). In this study it was established that in ecological terms, the surface water bodies were critically impaired, inferring that most sensitive aquatic organisms died because of the high levels of pollution, leaving only low numbers of pollution tolerant aquatic organisms present in the surface water bodies. In Table 7.1, the overall description per site is provided, including the ecological classification of each of the 10-macroinvertebrate sampling site habitats.

Table 7.1 Overall summary description of the status of the surface water quality of the sampling sites studied in the Zastron area

Sampling site	WQI	Ecological category	Sampling site description	Reasoning
A	*Poor*	*F*	Stream that receives raw sewerage flowing from a malfunctioning pump station.	Malfunctioning pump station.
B	*Poor*	*F*	Dam that receives raw sewerage flowing from a malfunctioning pump station.	Malfunctioning pump station.
C	*Poor*	*F*	Perennial river that receives wastewater effluent from the Zastron Wastewater Treatment Works.	Overflowing manholes, malfunctioning pump station and Wastewater Treatment Works.
D	*Marginal*	*F*	All polluted perennial rivers and streams feed into the main water catchment, the Montagu dam	None. Located furthest from sources of pollution.
E	*Poor*	*F*	Stream that receives wastewater effluent from the Zastron Wastewater Treatment Works.	Wastewater Treatment Works.
F	*Poor*	*F*	Perennial river that receives raw sewerage from a malfunctioning pump station.	Malfunctioning pump station.
G	*Poor*	*F*	Perennial river that receives untreated sewerage from an overflowing manhole.	Overflowing manhole.
H	*Marginal*	*F*	Site that does not receive direct sewage pollutants.	Located far from sewer networks.
I	*Poor*	*F*	Stagnant dam that receives raw sewerage pollutants from sampling site A.	Malfunctioning pump station, overflowing manholes, sewerage spillages.
J	*Poor*	*F*	Perennial river that receives raw sewerage pollutants from sampling site A.	Malfunctioning pump station, manholes, sewerage spillages.

7.3 Conclusion

It can be concluded that the surface water bodies in the vicinity of the Zastron and Matlakeng Township was polluted by wastewater that had flown into it from either blocked or overflowing manholes and malfunctioning pump stations, and therefore the public complaints in this regard were justified. As a result of the high levels of pollution in the surface water bodies identified in this study, urgent intervention is needed. It is recommended that repairs and maintenance of the wastewater infrastructural systems be done by the responsible local authority in order to prevent any further wastewater pollution of the surface water bodies. Such an intervention can result in the improvement and the restoration of the surface water body quality, over time.

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Appendix
Supplementary information to Chapter 3

Flat No 2

Vechtkop Street

Zastron

9950

22 February 2016

The Municipal Manager

Mohokare Local Municipality

Hoofd Street

Zastron

9950

Dear Sir,

RE: PERMISSION TO CONDUCT DISSERTATIONAL RESEARCH BASED ON MATTERS RELATING TO THE ENVIRONMENT

I, Malcolm de Jager hereby wish to request your permission to conduct dissertational research on matters relating infrastructure and the impact thereof on the Environment.

I have registered for the Master's Degree in Health Sciences: Environmental Health with the Central University of Technology, Free State. For the said programme, it is required of me to conduct research work and therefore I was requested to have granted permission from your institution to conduct research, discuss outcomes of the research methodology and results of the tested parameters.

I hope and trust that my request finds your favourable consideration and approval.

Yours in development,

ML De Jager

051 673 2033

073 681 3438

MOHOKARE LOCAL MUNICIPALITY
MUNICIPAL MANAGER
APPROVED
01 -03- 2016
Signature: ....