A COMBINATION OF CHEMICAL ANALYSIS AND STAKEHOLDER'S PARTICIPATION IN ADDRESSING THE HENNOPS RIVER POLLUTION IN GAUTENG PROVINCE, SOUTH AFRICA

Report to the
Water Research Commission

by

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WRC Report No. 3109/1/23

ISBN 978-0-6392-0567-0

December 2023

WATER RESEARCH COMMISSION

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This is the final report of WRC project no. C2020/2021-00568

EXECUTIVE SUMMARY

This report presents the findings of a large endeavour engaging a multidisciplinary approach to address the highly polluted Hennops River basin. Combining stakeholder engagement and chemistry analyses, this project considered the state of pollution of the Hennops River basin in Gauteng. At the same time a study of possible interventions engaging different stakeholders was conducted to better understand and address the situation on the ground. Root causes and subsequent effects of the pollution were specifically considered including how effective engagement activities and interventions are. Chemical analyses added value and qualified findings from ground-truthing and fieldwork.

A comprehensive state of pollution that included various bacteria like *Escherichia coli*, total bacteria count, physical chemical properties of the water, pharmaceuticals and microplastics were measured. Comprehensive status of the pollution was followed from upstream in Tembisa to downstream Hartbeespoort Dam. All water samples were found to be high with E. coli which decreased as one moves downstream to the Hartbeespoort Dam. The dam was found to be the major sink for pollution that occurs upstream. The data analysis showed that Hennops river water fits mainly in toxicity class I – no acute toxic effect to toxicity class II – slightly acute toxic effect. The water samples collected upstream however demonstrated 80% mortality to *P. reticulata* however since the effect level was below 100% a Hazard Class III (acute hazard) was assigned. The minimum acute hazard could be explained by the dilution effect due to incidence periods of heavy rainfall and flooding that may affect biotic or abiotic conditions throughout life environment. A Hazard Class of V (very high acute hazard) was allocated to the sediment samples collected both upstream and downstream as the samples produced 100% mortality to *Hetereocypris incongruens.* This indicates that most of the pollution sinks on the sediments along the river and this has long term pollution effects. Various amounts of pharmaceuticals were detected in the waters but at low levels (μgL^{-1}) and showed little decrease in concentration downstream. This could suggest varied inputs along the river from various sources. In this both passive sampling and solid phase extraction techniques were used to extract the pharmaceuticals from water at various points along the river followed by HPLC-MS analysis. For microplastics in the water and sediment samples, five polymer types were identified; polyethylene (PE), polypropylene (PP), high density polyethylene, (HDPE), polyester and polystyrene. The predominant polymer type in surface water was PE (48.6%), and that in sediment was PP (52.7%). PE and PP were the most abundant polymer types in both phases, and as these also the leading polymers in plastics production. 80% of the identified microplastics were found to be fibre with most dominant sizes of 1-2 mm for sediments and 0.5-1 mm in water samples. Blue was the most dominant colour of the microplastics in both sediments and water samples. Results obtained at the start of the project and that at the end showed no decrease in various forms of pollution in the river be it microplastics*, E.coli* or pharmaceuticals.

Following the comprehensive chemical analyses throughout the project, stakeholder engagement took place. Through a stakeholder meeting, community workshop and supported clean-up campaigns, awareness was raised relating to the river basin's current chemical and physical state. The level of awareness of communities and stakeholders around the main challenges and opportunities identified was considered. Additional clean-up campaigns, both initiated and supported, were approaches through which the mobilisation of communities and stakeholders was carried out through the project. These events were highly publicised to raise even more awareness and draw the attention of more stakeholders. Local organisations were also empowered through additional support given through the project.

The findings of this study suggests that the root causes of the challenges observed with the Hennops River basin are related to governance and the overall management of the Hennops River basin. A lack of service deliver, poor infrastructure, and lack of the implementation of laws and policies are some of root causes identified. Lack of awareness and lack of political will only exacerbate the overall problem. These root causes contribute to continued illegal dumping, informal settlement, and lack of corporate social responsibility. Communities and stakeholders exhibit a lack of awareness around the issues observed. Furthermore, communities demonstrate a lack of interest in participating in managing the Hennops River basin and its resources as they appropriate river basin management to government alone. Clean-up campaigns, therefore, have had very little effect on long-term addressing of the problem. Thus, targeted interactions with actual communities and with key partners is needed to try and come up with ways on how to change community behaviours upstream.

The results of chemical analysis before and after the start of the clean-up campaigns shows that in most cases clean-up campaigns have minimal long-term impacts. This is mostly due to the small impact intermittent clean-up campaigns have on the environment, given that these take place rarely, on occasions, being seasonal or centred around major events like earth day, Wits 100 celebrations etc. Thus, there is no sustained operations.

Not all key partners are also present during these campaigns like Ekurhuleni municipality representatives and local councillors of the area and other stakeholders with the community itself including churches.

Further, the study found out that the lack of awareness and the lack of resources and support must be addressed should the state of the Hennops River basin be improved through interventions and engagement activities. Further research is needed and is being achieved to span this knowledge gap. It is therefore argued that by addressing these root causes, an eventual change to undesirable effects such as illegal dumping, poor performing wastewater treatment works as well as the lack of service delivery will take place. The addressing of these root causes is imperative before a management framework can be implemented, which would include stakeholder support as well as community participation. Therefore, having engaged in various activities such as clean-up campaigns with little success, it is argued that the root causes identified hinder or limit the success of any further actions.

However, having highlighted these root causes while considering other undesirable effects identified through the methodology of this study, a potential model to be implemented for the management of the Hennops River basin has been presented. While this model can only be implemented after further addressing of root causes, it is an attempt to address a knowledge gap, as well as set the scene for future studies and initiatives.

ACKNOWLEDGEMENTS

The project team wishes to thank the following people for their contributions to the project.

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ACRONYMS & ABBREVIATIONS

CFU	Colony Forming Unit
CBNRM	Community Based Natural Resource Management
DSDME	Directly Suspended Droplet Microextraction
EPA	Environmental Protection Agency
EU	European Union
GC-MS	Gas Chromatography Mass Spectrometry
HDPE	High Density Polyethylene
HF-LPME	Hollow Fibre Liquid Phase Microextraction
HLB	Hydrophilic-Lipophilic Balance
IRBM	Integrated River Basin Management
IWRM	Integrated Water Resource Management
LDPE	Low Density Polyethylene
MPs	Microplastics
NGO	Non-Government Organization
PAHs	Poly Aromatic Hydrocarbons
PAR	Participation Action Research
PE	Polyethylene
PES	Poly Ethylene Sulfone
PET	Polyethylene Terephthalate
POCIS	Polar Organic Chemical Integrative Sampler
POPs	Persistent Organic Pollutants
PP	Polypropylene
PRA	Participatory Rural Appraisal
PTFE	POLYETETRAFLUOROETHLENE

RCA	Root Cause Analysis
RDSE	ROTATING DISK SORPTIVE EXTRACTION
SBSE	STIR BAR SORPTIVE EXTRACTION
SDME	SINGLE DROP MICRO-EXTRACTION
SEM	SCANNING ELECTRON MICROSCOPE
SPE	SOLID PHASE EXTRACTION
SPMD	SEMI PERMEABLE MEMBRANE DEVICE
SPME	SOLID PHASE MICROEXTRACTION
TAC	TOTAL AEROBIC COUNT
TDS	TOTAL DISSOLVED SOLIDS
TWA	TIME-WEIGHTED AVERAGE
UHPLC	Ultra-High Performance Liquid Chromatography
WWTP	Wastewater Treatment Plants
WWTW	WASTEWATER TREATMENT WORKS

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CHAPTER 1: BACKGROUND

1.1 INTRODUCTION

Human life continues to push our planet’s boundaries, having an effect on several key natural resources while also driving human-induced climate change. Even in recent research, it has been highlighted that novel entities, such as plastic pollution has overwhelmed our natural environment surpassing a safe operating space as per planetary boundaries (Persson *et al.*, 2022). Along with this discussion comes considerations of the impending and continued pressures imposed on Earth’s water resources (Bates *et al.*, 2008). It is predicted that global water resources will continue to be threatened by climate change and population growth (Gosling and Arnell, 2016). In the years to come, water-related challenges will only be exacerbated for those regions of the planet which already experience them.

Africa is no stranger to water stress, water scarcity, and water conflict (Falkenmark, 1989; Oyebande, 2001). To make matters worse, it has been predicted that the COVID-19 pandemic of the 2020s will influence socio-economic factors, leading to additional water-related challenges (Boretti, 2020). It has been noted that most of Africa’s population rely on water resources that are unreliable or precarious, and these resources are only to become more unreliable in the future (Vörösmarty *et al.*, 2005). Recent research also suggests that climate change will continue to drive water scarcity across the continent as current adaptation strategies and plans are not effective enough to address the overall issues (Filho *et al.*, 2022). Changes in precipitation, runoff, and evapotranspiration patterns are ultimately affecting Africa’s rivers, including some of the largest and most iconic such as the Congo and Niger Rivers (Gan *et al.*, 2016; Mahe *et al.*, 2013).

Altogether, a negative projection is predicted for Africa’s future water resources and river systems. At the same time, South Africa’s rivers also suffer the same fate with additional factors putting further pressure on them. As a country which is rapidly developing, South Africa’s rivers encounter several issues linked to development and human activity. The first, and most severe of these problems is the ongoing pollution of rivers across the country. To name but a few of these pollution issues, South Africa’s rivers are victims of sewage spills, plastic pollutants, and heavy metal contaminants (Atangana and Oberholster, 2021; Lebepe *et al.*, 2020; Moss *et al.*, 2021; Oberholster *et al.*, 2008; Okonkwo and Mothiba, 2005; Sibanda *et al.*, 2015; Weideman *et al.*, 2020). This goes above and beyond the impact acid mine drainage and eutrophication have had on water resources across the country as a whole (McCarthy, 2011; Naicker *et al.*, 2003; Van Ginkel, 2011). Therefore, South Africa’s rivers and water resources face the impending and constant threat of climate change, but also face challenges related to an alarming amount of pollution being discharged into them.

The Hennops River flows into the larger Crocodile River which ultimately feeds the Hartbeespoort Dam. Within the Hennops River basin, urban settlements, agricultural land as well as industries can be found along the Hennops River and its tributaries. More recently, the state of the Hennops River has become alarming, being reported by the media as heavy polluted and in need of intervention (Bega, 2020; Ngobeni, 2020; Tlhabye, 2018). As suggested in some of these media sources and confirmed by research, the Hennops River, like other rivers across the country are affected by the human activity surrounding it. While the river has been reported as polluted, it must be noted that those living round the Hennops River are also adversely affected. To complicate matters further, communities, industries as well as other facilities and land uses around the river have been attributed to its pollution (Oberholster *et al.*, 2008). Therefore, there is an urgent need to engage with key stakeholders and communities around the polluted Hennops River and its basin.

In view of the above, the current project focuses on combining chemical analyses, stakeholder engagement, and community participation to address the continuous problem of the polluted Hennops River. A variety of water quality parameters, chemical analysis tests and biological tests were implemented as tools to understand the extent and sources of pollution in the river. The status of pollution in the Hennops river was demonstrated using chemical analyses and microbiological tests to determine its water quality. Furthermore, the presence of microplastics was also assessed. In addition to the chemistry component of this project, stakeholder engagement and community participation were harnessed as social science tools to identify root causes behind the current state of the Hennops River. This goes above and beyond identifying point sources of the pollution itself as a social element allowed for key challenges in communities such as Tembisa and Centurion to be identified. Finally, this project engaged different organisations including academic institutions, Non-governmental organisations, businesses, and many other stakeholder and community groups to find solutions to the problem through action and different initiatives.

1.2 PROJECT AIMS

The following were the aims of the project:

1. To carry out a source apportionment of the various pollutants in Hennops river that includes microplastics, phthalates and emerging pollutants using modern techniques based on passive sampling approach at the start and towards the end of the project.
2. To mobilise and involve communities and/or stakeholders to come up with early warning system that timely responses to potential pollutant sources.
3. To mobiles communities and stakeholders to help clean-up the Hennops rivers with potential private sector participation.
4. To come up with future comprehensive strategy that will be used to prevent any future Hennops river pollution.

1.3 SCOPE AND LIMITATIONS

The scope of the work of combining chemical measurements with stakeholders engagement was aimed at finding the comprehensive pollution status while trying to find out the interventions being done to stop the pollution and to participate in these in as much as possible to understand the underlying issues of the root causes and their effects. The chemical measurements were limited to E. coli, total bacteria count, selected pharmaceuticals, and microplastics in water samples along the river upstream (Tembisa) to downstream (Hartbeespoort Dam). Sediment samples were also taken for E.coli, total bacteria count and for microplastics. Sampling for these was done twice at the beginning of the project in the first year and towards the end of study in the second year with interventions among key players happening in between.

Stakeholders engagement was limited to mostly upstream of the river with key partners such as Hennops Rival, Envirocare and Fresh NGO. The team conducted its own clean campaign and was joined by Envirocare as part of Wits 100 celebrations and further joined hands with Hennops Revival and Fresh NGO during their clean up campaigns. Besides, the team had meetings with community members and to assess things for themselves on the root causes.

CHAPTER 2: LITERATURE REVIEW ON CHALLENGES AND SOURCES OF URBAN RIVER POLLUTION

2.1 INTRODUCTION

Rivers play an important role in the water cycle acting as drainage channels for surface water and provide habitat and food for the earth's organisms. Rivers also serve as a source of fresh water, which is essential to sustain humanity and drive economic and national development. A parameter that is used to determine whether water is suitable for consumption or safe for the environment is known as water quality (Khatri and Tyagi, 2015). This is measured by assessing the chemical, physical and biological properties of the water against a defined set of standards (Sultana and Dewan, 2021).

The water quality of rivers is depleting at an alarming rate mainly due to pollution from anthropogenic activities, this hinders the supply of clean adequate water to support life (Khatri and Tyagi, 2015). Rivers that flow around most urban areas are receiving most pollution due to activities associated with urbanization (Oberholster, Botha and Cloete, 2008). Rapid urbanization has led to the emergence of informal settlements in most countries like South Africa and the provision of essential services such as proper sanitation and waste management in such communities remains a challenge for Government authorities (Schutte and Focke, 2007).

Agricultural activities, effluent discharge from wastewater treatment plants (WWTP) and Industries have also been identified to contribute to the discharge of toxic organic compounds into water, among those being emerging contaminants and microplastics (Dalu *et al.*, 2021). The continuous release of these pollutants into the environment may lead to their accumulation which may endanger the lives of human, plants and animals exposed to those water bodies (Yu *et al.*, 2020) (Kay *et al.*, 2018).

The Hennops river valley catchment is located between Johannesburg and Pretoria, its main source originates in Kempton Park in the form of Kaalspruit and ultimately converges with the Crocodile River to feed the Hartbeespoort Dam. The river flows through different functional areas such as residential (formal and informal), industrial, golf estates, recreational and business areas (Petersen, Dabrowski and Forbes, 2017). The river's appeal and aesthetic value attracted a construction of urban infrastructure around it, Centurion central business district has evolved around the centurion lake which Hennops feeds directly into is surrounded by restaurants, hotels, business complexes (Hoffmann, 1994). Some recreational activities in the mid-nineties were swimming, boating and canoeing, however these have stopped due to silting up of the lake and the pollution of Hennops river (Wiechers, Freeman and Howard 2000). A hiking trail was also constructed downstream along the river as a recreational facility. Agricultural activities such as crop production that use the river water for irrigation are also present along the riverbank (Schoeman, 1976).

The Hennops river is facing a decline in water quality due to pollution from upstream activities (Nawn, 2004). This is evident by the death of animal life such as fish, insects and plant life along the river (Petterson 2019). The riverbed is also coated with black sludge along with vast amounts of solid waste being plastics. The upstream land use activities around the river catchment include urban development activities such as industries, formal and informal settlements, wastewater treatment works and agriculture (Hoffmann, 1994).

Tembisa and Ivory Park are densely populated township with housing consisting of squatter shacks that have very poor sanitation that is not properly maintained which result in periodic leakages and are discharged into the Kaalspruit river that forms Hennops (Oberholster, Botha and Cloete, 2008). Other households have improper sanitation in place and have connected toilets directly into the river (Mashazi, Morole and Modley, 2019). This results in faecal matter directly discharged into the river. Provision of sanitation is a challenge and such communities resort to their own means of accessing sanitation such as open defecation, flying toilets or plastic bags, the use of buckets, and improper waste disposal through informal dumpsites which bring rise to pollution into the Hennops river (Muanda, Goldin and Haldenwang, 2020). This introduces pathogenic bacteria and the ingestion of such polluted river water would result in infectious diseases such as cholera, severe diarrhoea and dysentery (Bain *et al.*, 2014). A fact report by (WHO 2019) indicated that pathogen contaminated drinking water is estimated to cause 485 000 diarrhoeal deaths each year.

Illegal littering and dumping introduces plastic pollution and this has been observed in Kaalspruit catchment that drains Tembisa, which has led to the river being polluted with plastics (Bodenstein *et al.*, 2006).

Industrial activities in Clayville include pharmaceuticals manufacturing, food processing factories, beverage production are also associated around the river basin. This types of industries generate large quantities of wastewater that is highly contaminated with both organic and inorganic pollutants (Iloms *et al.*, 2020). The waste discharge from this industrial site is sent for treatment in Olifantsfontein Waste-Water Treatment Works (WWTW) which discharges treated effluent into the Hennops river (Hoffman, 1994).

(Szymonik, Lach and Malińska, 2017) argues that most conventional wastewater treatment plants (WWTP) are inefficient towards the removal of toxic pollutants and during effluent discharges these contaminants are also released into rivers. The Olifantsfontein WWTP releases between 38-60 megalitres/day of effluent return flow into the Hennops river which is a major contributor of flow volume into the river, this may have a potential to release pollutants into the river (Oberholster, Botha and Cloete, 2008). The Sunderland Ridge (WWTP) is located downstream of the river and has also been found to release large quantities of untreated waste into Hennops river (Rimayi *et al.*, 2019).

The Hennops river has now lost its aesthetic appeal and has become a liability instead of the environmental asset with fundamental values to those who are surrounded by it (Singh and Todd 2015). It has become unfit for both living organisms, agricultural and recreational use due to its poor ecological condition (Nawn, 2004) and measures have to be taken for its rehabilitation and placement of pollution preventative measure.

Pollution in the Hennops river comes as a result of different sources, from varying land uses since the river is considered as a common pool resource (Van Oel, Krol and Hoekstra, 2009). Their management is then complex and not easy to implement, however this may be achieved through the development of comprehensive and inclusive intervention measures that involves different stakeholders along the river basin (Mtetwa and Schutte, 2003). Community engagement is one of the proposed methods that can result in sustainable management of the river as a natural resource, this requires different stakeholders come together, participate and share ideas on how a natural resource can be managed. Community Based Natural Resource Management is an approach that works to strengthen locally accountable institutions for natural resource use and management thus enabling local groups of people to make better decisions about the use of resources around them (Roe, D., Nelson, F., and Sandbrook, 2009).

For effective management of the river resource, it is crucial to determine the presence and concentrations of these pollutants in the environmental bodies to raise awareness and develop legislative measures for their control. It is also advisable to monitor the concentrations of these organic pollutants over an extended time frame to achieve a more representative picture of the water quality (Morrone *et al.*, 2021). This can be achieved by the use of automatic sampling systems that can continuously sample the water for defined periods of time. Despite the effectiveness of this approach it is expensive to install the automatic samplers and they require security measures to be put in place where they are deployed which make this approach impractical in some areas (Madrid and Zayas, 2007).

Passive samplers are some of the best fit candidates for the task as they can be deployed in the water bodies for extended periods of time and provide time-weighted average (TWA) concentrations of the contaminants in the water bodies (Tapie *et al.*, 2011). These samplers are relatively cheap to deploy and can manage to sample a wide range of pollutants depending on the design of the samplers. The Chemcatcher® passive samplers will be used in this work as they can be used for sampling for both polar and non-polar organic water pollutants with sufficient enrichment factors and high selectivity. The samplers will be calibrated to provide TWA concentrations of organic pollutants in water bodies.

2.2 ORGANIC POLLUTANTS IN URBAN RIVER SYSTEMS

Emerging contaminants are defined as a broad range of chemicals are not commonly monitored in the environment but have the potential enter into the environment through point and non-point sources and cause known or suspected adverse human health and/or ecological effects (Stuart *et al.*, 2012). The release of these chemicals in the environment may have likely occurred for a long time but not have been recognised until recent developments in the detection methods of the contaminants in the environment (Abtahi *et al.*, 2019). Recent synthesis of the chemicals or changes in use and disposal of existing chemicals can create new sources of contaminants (Mills, 2015).

Water pollution by emerging contaminants has gained research attention over the past decades as these compounds are released into the environment mainly due to anthropogenic sources (Fischer *et al.*, 2012). Emerging contaminant in the aquatic environment can be broadly classified as, pharmaceuticals, personal care products, pesticides, industrial compounds and endocrine disrupting compounds among others (Montes-Grajales, Fennix-Agudelo and Miranda-Castro, 2017).

2.2.1 Pharmaceuticals

Pharmaceuticals are chemical compounds designed for diagnosis, treatment or prevention of diseases and conditions in humans and animals' therapeutic effect on the body, usually active at very low concentrations, can pass through biological membranes and persist in the body long enough to avoid being inactivated before having an effect (Houtman, 2010; Ebele, Abou-Elwafa Abdallah and Harrad, 2017). Pharmaceuticals have found their way into surface water, marine water, ground water and drinking water and the type of pharmaceutical detected is relies on economic, social, cultural and agricultural factors (Zhang *et al.*, 2008).

Since these compounds are intended to treat specific diseases and conditions, their unintended consumption by non-target organisms poses crucial threats to the lives of the organisms (Azuma *et al.*, 2016). Most developed Countries such as Australia and some European countries have developed and put in place legislative measures to prevent possible risks associated with pharmaceuticals in in aquatic systems (Ngqwala and Muchesa, 2020). This still remains an issue in developing countries as no legislative measures have been put in place and their absence has resulted in little or no environmental monitoring of the compounds (Fischer *et al.*, 2012).

Despite the wide usage of pharmaceuticals, very few studies have been conducted from a South African perspective to investigate the behaviour of pharmaceuticals in the aquatic environment. The following are types of pharmaceuticals that have been detected in surface waters in South Africa, antibiotics, antiretrovirals, non-steroidal anti-inflammatory drugs (Farounbi *et al.*, 2020; Madikizela *et al.*, 2017).

Antibiotics are a class of chemical compounds that are administered to provide defence against pathogenic bacteria and fungi. They are used to treat infections in humans and animals such as gonorrhoea, cholera, tuberculosis. Based on their application, these compounds are one of the highly consumed pharmaceuticals globally (Gomes *et al.*, 2020). The physicochemical and biological properties of antibiotics allows them to be persistent in environmental bodies and they are classified as recalcitrant bio-accumulative environmental pollutants as their rate of degradation cannot offset their accumulation (Matongo *et al.*, 2015).

The major concern about the presence of antibiotics in the environment is the proliferation of antimicrobial resistance genes and antimicrobial resistance bacteria. This in turn reduce the therapeutic potential against human and non-human animal bacterial pathogens (Ncibi and Sillanpää, 2015). A surveillance report by (Morrison and Zembower, 2020), demonstrated the occurrence and spread of both antimicrobial resistance genes and antimicrobial resistance bacteria. They demonstrated that globally 3.6% of new Tuberculosis cases and 20.2% of previously treated cases are estimated to have the multidrug resistant TB (MDR-TB) which is the most resistant variant and requires extended treatment duration (up to 20 months) with severe side effects.

South Africa is one of the countries with the highest infections of Human immunodeficiency virus (HIV) in the world and a large proportion of the population is affected by the virus (Shishana, 2012). Antiretroviral (ARV) drugs are medications used for the treatment of infection by retroviruses, primarily HIV by suppressing the HIV viral load, fighting infections and improving the quality of life for those living with HIV. Since a large amount of these drugs are being consumed, they have been detected in surface waters. A study conducted by (Wood, Duvenage and Rohwer, 2015) revealed the presence of ARV drugs in surface water in South Africa. ARV drugs are found to have endocrine disrupting properties and their presence in the environment poses health concerns (Zaid and Greenman, 2019).

2.2.2 Personal Care Products

Personal care products are house-hold products that are mainly used to improve the quality of daily life and this include a large number of synthetic chemicals used in domestic products such as soaps and detergents, tooth paste and other cosmetics (Witorsch and Thomas, 2010). These products contain polycyclic musk or parabens to guard against bacterial infection and the most commonly used antimicrobials are triclosan (2,4,4'-trichloro-2'-hydroxydiphenyl ether) and triclocarban (3,4,4'-trichlorocarbanilide).

The approximate concentration of triclosan and triclocarban in products manufactured in South Africa is about 0.2-0.3% (Lehutso *et al.*, 2017) and considerable amounts of this products containing this compounds are used every resulting in large quantities of chemical substances that could be released into the environment (Witorsch and Thomas, 2010). The widespread use of this products containing this antimicrobial compounds has led to this compounds being detected in human body fluids such as urine and breast milk as it is commonly used in consumer products (Carey and McNamara, 2014) and aquatic environment such as rivers, estuarine water and drinking water mainly due to discharges from wastewater treatment plants (Madikizela *et al.*, 2017).

Comparing to other emerging contaminants, triclosan is not considered as a chemical pollutant with high priority concern and this has led to the widespread use of this compound resulting in increased concentrations of triclosan in the environment (Dhillon *et al.*, 2015). Biodegradation and photolytic degradation limit the availability of triclosan to aquatic organisms, however its by-products such as methyltriclosan and other chlorinated phenols may be highly resistant to degradation and pose higher toxicity that the parent compound (Kola *et al.*, 2015).

Triclosan functions by blocking the active site of enoyl-acyl carrier protein reductase enzyme (ENR) thereby affecting the production of lipids, leading improper production of cell membranes and stopping bacterial proliferation (Levy *et al.*, 1999). The widespread use of triclosan has led to its concern about as natural and engineered processes are driven by microbes, at low concentrations triclosan inhibits the growth of micro-organisms and at higher concentrations it kills them (Dhillon *et al.*, 2015). These anti-microbial compounds are designed to impact microbes in homes and hospitals, their release into the environment can impact complex microbial communities found in engineered and environmental systems. Triclosan has been found to alter microbial community structure or function in wastewater operations such as anaerobic digestion and activated sludge (Carey and McNamara, 2014).

The release of triclosan in aquatic systems kills algae and phytoplankton which are important in carbon fixation and food for other organisms in the water (Kola, Mohd and Yalavarthy, 2015).

The other concern about triclosan is its endocrine disrupting abilities. Triclosan contains two phenol functional groups indicating its potential to act as an endocrine disrupting agent. Triclosan has been found to induce overall depression of the central nervous system of mice, decreased sperm count in male rats and malformations in foetal developments (Farounbi and Ngqwala, 2020). Much research has not been done on its toxicity in humans, its effect on other species and detection in body fluids raises concern.

2.2.3 Personal Care Products

A pesticide may be defined as: a substance or a mixture of substances intended for preventing, destroying, repelling, or mitigating any pest and any substance or mixture of substances intended for use as a plant regulator, defoliant or desiccant (Shifrin and Thomas, 2009). Synthetic pesticides were introduced in the early 20th century and a huge dependency by the agricultural sector has grown as these chemical compounds have brought a lot of benefits including increased crop yields and the reduction of insect-borne illnesses (Olisah, Okoh and Okoh, 2020). The most widely used class of pesticides are Insecticides, fungicides and herbicides (Neumann *et al.*, 2002).

Pesticides are designed to act against target organisms however it is not easy to achieve absolute selectivity and these compounds have a potential to contaminate soil, surface water and ground water. Surface water contamination of pesticides is a threat to the lives of aquatic flora and fauna and also a threat to human health in cases where pesticide polluted water and fish are used for public consumption (Maksymiv, 2015).

The conventional classification of pesticides is based on the target species which yields the following commonly known classes: insecticides, rodenticides, fungicides, herbicides, nematicides (Connell *et al.*, 2010)(Deb, 2018). Pesticides are also classified according to their chemical composition: organochlorine, organophosphate, pyrethroids and carbamates (Connell *et al.*, 2010). Organochlorine pesticides are hydrocarbons that contain chlorine atoms in their structures and are lipophilic. They can be sub-divided into 3 main groups – dichlorodiphenylethanes, chlorinated cyclodienes then lastly chlorinated benzenes and cyclohexanes. They were the most widely used pesticides due to their effectiveness in killing insects however they were banned in many countries due to their persistence in the environment, slow degradation (have half-lives from 60 days-15 years), bioaccumulation in the adipose tissues of humans and animals and biomagnification in the food chain (Burgos-Aceves *et al.*, 2021).

Hexachlorocyclohexane (HCH) is a chlorinated cyclodiene that has 8 isomers that differ by the orientation of the chlorine atoms around the cyclohexane ring and the alpha, gamma, beta and delta isomers are the most commercially significant (Ara *et al.*, 2021). It was an effective insecticide for protection against leaf hoppers and stem borers and control of scabies and lice treatments in humans however the fourth meeting in May, 2009 of the Stockholm conventions added this pesticide to the list of Persistent Organic Pollutants (POPs) (Zhang, Zhang and Yang, 2021).

The acute effects of lindane (gamma isomer) through inhalation exposure in humans are irritation of the nose and throat and chronic exposures have been associated with effects on the liver, blood and immune system. Oral exposure to lindane has been found to have effects on the nervous systems resulting in seizures and convulsions (Betts *et al.*, 2020). The EPA classifies alpha-HCH (lindane) as a probable carcinogen due to effects observed in laboratory animals (Manirakiza *et al.*, 2002).

Atrazine is a herbicide under the class of triazine herbicides that have been widely used as herbicides for the control and elimination of weeds and a wide range of crops (Jiménez-Soto, Cárdenas and Valcárcel, 2012). Physical property of triazines is their solid state at room temperature, low vapor pressure and have a wide solubility range. Because of their high solubility and mobility, triazine residues partition into soil and water due to their chemical properties. This allows for easy distribution in different environmental compartments through surface and underground water (Chen, Haung and Huang, 2014).

Human exposure to atrazine is linked to a number of health effects which include cardiovascular effects and hormonal activity interferences. Since it disrupts hormones, studies have shown that it results in reproductive effects including increased risks of miscarriage, reduced male fertility, low birth weights in off springs (PAN North America). On account to the mentioned toxicity of this compound has received attention and monitoring from agencies including the Environmental Protection Agency of the U.S (EPA) and the European Union (EU) setting out a maximum level of atrazine at 3 µg L^{-1} (Jiménez-Soto, Cárdenas and Valcárcel, 2012).

An investigation conducted by (Hayes *et al.*, 2002) revealed that a low dose of 25 µg/L concentration of atrazine results in 10-fold decrease in testosterone levels in frogs. Further effects of atrazine in male frogs were hermaphrodism was suspected to may have brought a decline in frog populations. Owing to the wide use and acceptability of atrazine, it has been reported in concentrations of 1.2-9.3 µg/L South African surface water (Du Preez *et al.*, 2005).

2.2.4 Phthalate Esters

Phthalates esters (PAE) are synthetic esters of phthalic acid that are widely used in industry as plasticizers to impart flexibility in the production of polyvinyl chloride (PVC), polyvinyl acetate (PVA), polyurethane and cellulosic and non-plasticizers in consumer products such as lubricating oils, automobile parts, paints, glues, insect repellents, photographic films, perfumes, and food packaging (Philips, Jaddoe and Trasande, 2017).

They are classified into two groups: Low molecular weight phthalates (LMW) which are added to consumer products, their examples are di-methyl phthalate (DMP), di-ethyl phthalate (DEP), di-n-butyl phthalate (DBP) and High molecular weight (HMW) phthalates (e.g. di-2-ethylhexylphthalate (DEHP), di-isononylphthalate (DiNP), diisodecylphthalate (DiDP), di-n-octylphthalate (DnOP), butylbenzyl phthalate (BBzP)) are used as plasticizers (A. Lambropoulou, 2010).

The ecological and human health effects of phthalates are mainly related to interference with the endocrine systems of living beings. Since phthalates are lipophilic chemicals, they are readily absorbed to human blood or fluids and quickly transformed into respective primary and secondary metabolites; before excretion, some of these metabolites would wrongly interact with the endocrine molecular signalling system as ligands of transcription factors residing in the nucleus − resulting in untoward health effects (Fromme *et al.*, 2011). Their effects are reduced fertility, feminisation, reproductive organ abnormalities or altered sexual behaviour, have been observed in mammals, fish and benthonic organisms (Domínguez-Morueco, González-Alonso and Valcárcel, 2014).

Human exposure to phthalates occurs through dermal absorption from the daily use of PCPs containing phthalates in their plastic package (Fatoki *et al.*, 2010). Infants are exposed to phthalates by drinking breast milk with their mothers exposed to DEHP and DiNP, and sucking on toys containing phthalates (Wang and Qian, 2021). A research study by (Fromme *et al.*, 2011) in Germany investigated the level of phthalates in breast milk to determine the exposure of infants, the study revealed the average of 3.9 ng/g for DEHP, 0.8 ng/g for DnBP, and 1.2 ng/g for DiBP compounds in breast milk. Fatoki *et al.* (2009) determined the concentration of phthalates in river and dam water to be in the range 0.16 mg/ℓ to 10.17 mg/ℓ using Liquid-liquid extraction, column chromatographic clean-up and capillary gas chromatography detection.

2.3 PLASTICS AND MICROPLASTICS

Microplastics (MP) refer to plastic debris smaller than 5 mm in diameter (Xu *et al.*, 2021). They can be categorized into primary and secondary according to their source. A majority of primary microplastics in the environment are generated from industrial and domestic products that contain particles already in the micro or nano size (Kurniawan *et al.*, 2021). They are plastics released into the environment in the form of small particulates used as raw material in the plastic industry, synthetic textiles, personal care products and electronic equipment. Secondary microplastics result from fragmentation of larger plastics into smaller fragments by photolysis, thermo-oxidation and thermo-degradation (McCormick *et al.*, 2016).

Microplastics can also be described and characterized based on their polymer composition and the basic identified are polyethylene (PE), polypropylene (PP), polyethylene terephthalene, Polyamide and Polyurethane (Duis and Coors, 2016). Microplastics can be found in different morphologies and shapes and can be divided into pellets, granules, sheet, film, fragment, fibre, particles, granules and foam (Duis and Coors, 2016). Plastics are polymers that are intended to be light weight, resistant and durable for domestic and industrial use.

Poor waste and general waste management has led to plastics finding their way into the aquatic environment where they accumulate (Dalu *et al.*, 2021). Microplastics are one of the major water pollutants and have been detected in aquatic environments including oceans, rivers, lakes however studies on microplastic abundances in rivers is limited relatively to marine environment (Xu *et al.*, 2021). They are difficult to detect in the environment and enter the bodies of living organisms through the digestive systems where they tend to accumulate in the their bodies have a potential to cause both acute and chronic toxicity (Kurniawan *et al.*, 2021).

The concern of plastic pollution is not only due to composition and characteristics of plastics, toxic chemical additives whose weight accounts for 4% of the plastics have a possibility to leach out when plastics are disposed (Chen, Ahmad and Gan, 2017). Common additives to microplastics are phthalates, bisphenol A and polybrominated diphenyl ethers (PDBE), these compounds have drastic effects to living organisms and they are commonly classified as endocrine disruptors (Windsor *et al.*, 2019).

The pathway of microplastics into living organisms is through ingestion direct or indirect ingestion, Direct ingestion of microplastics by aquatic organisms occurs either accidentally by unselective behaviour or by active selection where microplastics are identified as food items causes mechanical disturbances such as intestine clogging and penetration into the intestine wall (Yu *et al.*, 2020). MPs polymer cannot be digested by the organism's enzymes, this leads to blockage of the digestive system or sending of false signals to the brain that the stomach is full. This leads to nutritional associated problems such as weight loss, reproductive disruption, growth reduction and energy resource depletion (Eltemsah and Bøhn, 2019).

Properties of microplastics such as large surface-to-volume ratio and chemical composition have allowed microplastics have the capacity to interact with other water contaminants and to accumulate toxic substances on their surfaces and act as a potential concentrated source of pollutant or act as a vector of toxic pollutants in the food web (Eltemsah and Bøhn, 2019). A study was conducted by (Rios, Moore and Jones, 2007) to determine whether MPs have the potential to trap persistent Organic Pollutants, analytical results revealed that PCBs ranged from 27 to 980 ng/g; DDTs from 22 to 7100 ng/g and PAHs from 39 to 1200 ng/g, and aliphatic hydrocarbons from 1.1 to 8600 µg/g.

2.4 SOURCES OF POLLUTANTS IN URBAN RIVER SYSTEMS

Sources of river pollutants can be classified into two main categories, point sources and non-point sources (Zhou *et al.*, 2016). Point Sources of pollution are defined as a discharge directly into a receiving environment from a discrete, identifiable locations and can be measured for example industrial and municipal effluents. Non-point sources are those that enter the environment through diffuse, difficult to identify and quantify sources of pollution as they do not have a single point of entry into the waterbody (Petersen, Dabrowski and Forbes, 2017). The major sources and pathways of organic pollutants in river systems are outlined in **Figure 2.1**.

2.4.1 Wastewater Treatment Plants

When Pharmaceuticals are ingested by the patient or target consumer, they undergo metabolic processes in the consumer bodies – some are converted to metabolites of the drug while others remain as unchanged parent compounds which excreted from the body as faeces and urine (Ncube *et al.*, 2018) which end up in municipal or hospital sewage that is sent off for treatment in Wastewater Treatment Plants (WWTPs). The process flow is outlined in **Figure 2.1**.

The other source of pharmaceuticals in the sewage is the disposal of unconsumed drugs which are disposed by individuals by flushing them down the sink or toilet (Tong, Peake and Braund, 2011). Conventional WWTPs are not specifically designed for removal of pharmaceutical compounds, they purify household wastewater mainly by subsequent application of bacterial degradation of organic matter, and coagulation/flocculation for the removal of suspended solids and phosphates and end up in treated waste (Szymonik, Lach and Malińska, 2017).

Treated waste is in two forms – sewage sludge and aqueous effluent, the aqueous effluent is discharged into receiving water bodies such as rivers and this is how WWTP serve as point sources of river pollution (Talvitie *et al.*, 2015).

WWTPs in developing countries are poorly developed (Dalu *et al.*, 2021), designed to remove large debris items with a mesh screen of 6 mm or larger in the primary treatment. Given the physical properties of some MPs, large quantities of microplastic particles escape the WWTPs and are discharged in great amounts into receiving water bodies such as rivers daily (Mason *et al.*, 2016). A research conducted by (Talvitie *et al.*, 2015) at Viikinmäki WWTP in Helsinki revealed that the number of microfibers in wastewater influent reduced from 180 fibres per litre to between 13.8 and 14.2 fibres per litre after wastewater treatment processed. Although the concentrations of these microplastics are low, the large volumes of water released into the environment from WWTPs per day makes it a concern (Xu *et al.*, 2019). This makes WWTPs one of the major contributors of microplastics in rivers as they receive waste from industries using microplastics and municipal waste-water (Zbyszewski, Corcoran and Hockin, 2014).

Microplastics are used as ingredients in personal care products such as microbeads or scrubs for cosmetics, clothing fibres and toothpaste (Mason *et al.*, 2016). During bathing and washing with these products containing MPs, they are washed down the drain and join municipals sewage which is directed WWTPs (Kurniawan *et al.*, 2021).

2.4.2 Industrial Effluent

The plastic manufacturing and packaging industries serve as direct contributors of MPs into the environment occurring from spills that occur during manufacturing and transport of these products (Verster and Bouwman, 2020). Karlsson *et al.* (2018) investigated the release of MPs plastic pellets in Sweden during production and transport and their findings were that between 3 to 36 million pellets are released annually into the surrounding environments. Effluents from textile industries contain dyes which pollute receiving waters and result in death of aquatic organisms (Semalti, Sharma and Sharma, 2021). Other industries that have been found to release organic pollutants are paint industries which release polymers and plasticizers into water (Lorton, 1988).

2.4.3 Agricultural Activities

Pesticides are commercially sold as liquids, solid or gaseous forms and their application can be through methods such as aerial or canopy spraying, incorporation or injection into the soil and with water (Schulz, 2001). Field applied pesticides may be degraded by microbes or chemical reactions in the soil and atmosphere while those taken up by plants and animals can be converted to degradation products which are sometimes less toxic than the parent compound. Pesticide that are not degraded, immobilized, detoxified or removed with the harvested crop have a potential to cause contamination of river waters, this can be as a result of point sources and non-point sources (Sankhla, 2018).

Non-point sources arise from surface run-off of applied pesticides from fields into rivers in dissolved and particulate forms, leaching to field drains or shallow ground water and spray drift during the application if pesticides (Curchod *et al.*, 2020). Point sources of pesticides into river waters may be from farmyards connected to sewage systems drains by run-off or during the cleaning of application equipment. The treated sewage sludge from WWTP is used as fertilizer in the growing of crops, this sludge contains traces of organic contaminants which are washed off by heavy rains into nearby water bodies (Ademoyegun, Okoh and Okoh, 2020).

2.4.4 Sewage Leakages

Unmanaged sewage mains have become a source of contamination to both ground and surface water through leakages from old, damaged pipes and structural faults. this results in sewage exfiltrating into both ground and river water (Held *et al.*, 2007). Leakage of sewage lines from domestic use may lead to pathogen contamination into water bodies, this may lead to the introduction of nitrates and other nutrients into water that lead to eutrophication (McGrane, 2016). Industrial leakage however poses a greater threat as industrial effluents contain a high content of toxic pollutants (Iloms *et al.*, 2020).

2.4.5 Informal Settlements

Service delivery to informal settlements is a challenge because such areas are occupied illegally and are unplanned, this makes it difficult for relevant authorities to offer services to them. Such areas are characterized by lack of proper infrastructure, overcrowding, poor sanitation and poor waste management. Informal settlements are frequently formed in the vicinity of rivers and streams where they can access water and they end up polluting nearby water bodies (Abbott, 2002). In Gauteng the, Jukskei river is one of the highly contaminated rivers from the township Alexander it flows through (Sibali, Okonkwo and Mccrindle, 2013).

There is often no supply of water to informal settlements and the settler's wash their clothes in rivers that are in close proximity to them which introduces detergents and microplastics in river water (Connell *et al.*, 2010). Waste removal is an issue with urban settler's, and the responsibility lies in the hands of individuals for waste disposal. and waste that is not formally collected is disposed in communal dumps and this can be carried into nearby rivers by wind and water run-off into water bodies where these plastics may be fragment to form MPs (Verster and Bouwman, 2020).

2.4.6 Waste Disposal

Potential pathways of microplastics into river systems is due littering, storm overflows, outflows from wastewater treatment plants (Barboza *et al.*, 2018). Phthalates are not chemically bound to resins or products when used and can easily be easily released into the environment through industrial effluent discharges and leachate from waste dumps (Abtahi *et al.*, 2019). Unused Pharmaceuticals are disposed in landfills which in leach out then contaminate ground water and surface water and the pathway is indicated in **Figure 2.1** (Tong, Peake and Braund, 2011). Following heavy rainfalls, microplastics can be flushed into rivers from poorly managed landfills or illegal waste disposal sites (Ziajahromi, Neale and Leusch, 2016).

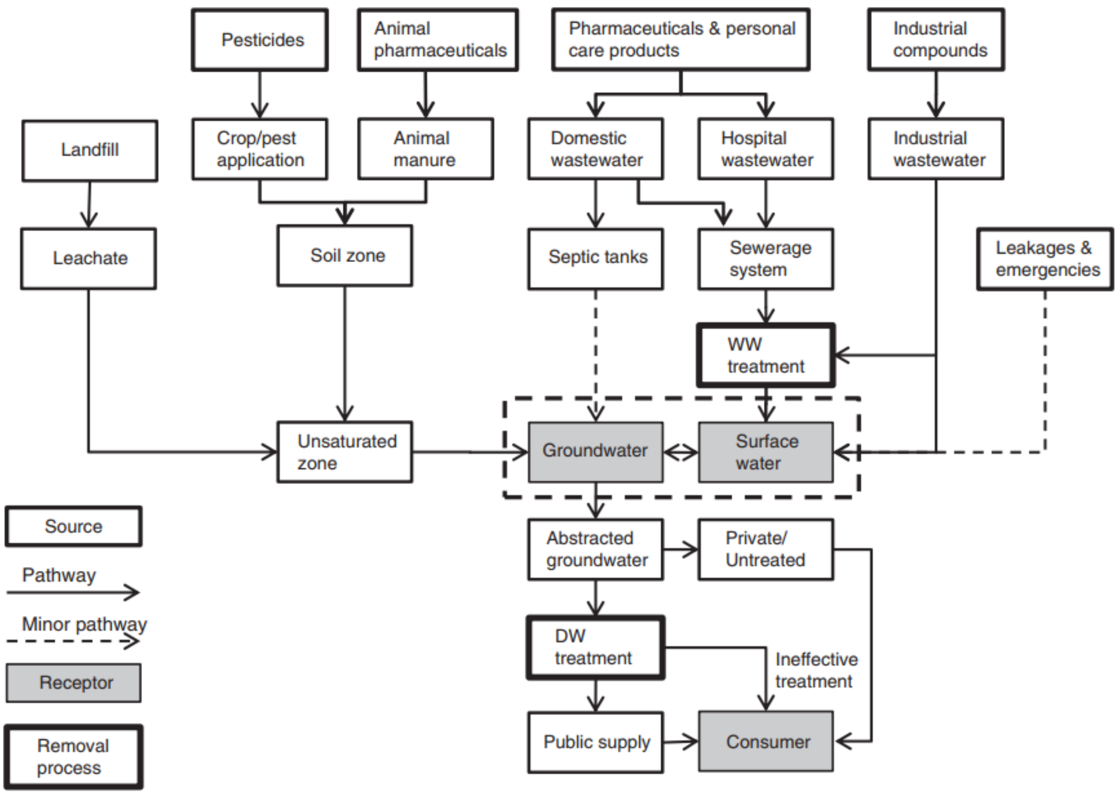


Figure 2.1: Sources and pathways of pollutants in the environment (Stuart *et al.*, 2012)

2.5 MODERN EXTRACTION TECHNIQUES FOR RISK ASSESSMENT OF POLLUTANTS IN WATER BODIES

Owning to the environmental impacts associated with organic pollutants, it is necessary for scientific approaches to be implemented for the analysis of these pollutants. Sample Preparation is an important step in environmental analysis as it allows for sample clean-up and removal of interferences, pre-concentration of analytes to detectable levels and conversion of analytes into a form suitable for the analytical instrument (Olisah, Okoh and Okoh, 2020; Chen, Haung and Huang, 2014).

Two main sample preparation techniques have been traditionally used for extraction of organic pollutants based on the physical state of materials used: Liquid based techniques and solid based techniques (Sibali, Okonkwo and Mccrindle, 2013). Liquid-liquid extraction is a liquid-based extraction technique that was traditionally used for the extraction if organic water pollutants. The principle behind this technique was separation one or more components of a liquid mixture by use of combination of non-polar, water miscible solvents into which the target analytes are partitioned. This technique however suffered a lot of drawbacks such as use of large volumes of expensive and toxic extraction solvents that leaded to pollution, was time consuming and tedious, and lacked automation (Prosen, 2014).

2.5.1 Solid Phase Extraction

As an attempt to solve the concerns arising from liquid-liquid extraction, solid phase extraction (SPE) was widely adopted as a sample preparation technique as it made use of lower volumes of toxic organic solvents (Pichon, 2000). The principle behind this technique was use of the stationary phase which can be in the form of a cartridge, or a packed column filled with adsorbent. Commercially available SPE devices include the syringe barrel columns, cartridges, disk membranes and multiwell plates. The aqueous sample is passed through the stationary phase and the analytes of interest are retained, then an organic solvent is used to elute the analytes off the column which is then collected and sent for analysis (Kataoka, 2017).

The process of SPE consists of four consecutive steps

i. Conditioning of the sorbent for solvation or activation of the functional groups
ii. Sample loading
iii. rinsing to remove undesired components of the matrix
iv. analyte elution by selective desorption with suitable solvent

Sorbents play a major role in this technique and the choice of solvent is based on the type of analytes.

Silica based sorbents and those modified with C_8, C_{18}, or NH_2 were the most commonly used sorbents however due to limitations such as instability at extreme pH values (Fontanals *et al.*, 2019).. The interactions between the analyte and the sorbent phase include hydrogen bonding, π-π interactions, hydrophobic interactions such as van der Waals forces, hydrophilic interactions such as the dipole-dipole,

The preferred sorbent in SPE for the analysis of emerging contaminants such as pesticides, pharmaceuticals and personal care products in water samples is the Oasis® HLB (García-Córcoles *et al.*, 2019). This technique gained popularity due to its benefits such as high reproducibility, low cost, and rapidness. (Madikizela *et al.*, 2014) applied solid phase extraction to investigate the levels of Triclosan and Ketoprofen in Mbokodweni river, South Africa. Maldaner and Jardim, 2012 reported the use of solid-phase extraction and analysis by Liquid-Chromatography mass spectrometry for the analysis of selected pharmaceuticals and pesticides.

SPE has been a promising technique but it also had its shortcomings which were associated with classical sorbents used which did not offer selectivity, the other issue was associated with the clogging of the sorbent bed by particles of sample suspended matter and sample carry over (Rawa-Adkonis *et al.*, 2006).

2.5.2 Solid phase microextraction (SPME)

SPME was introduced by Arthur and Pawliszyn, (1990) as a solvent free solid phase miniaturization technique for the extraction of volatile chlorinated compounds in water. This technique integrates sampling, extraction and preconcentration into a single step and has been used to extract analytes from liquid, gaseous and solid samples (Pawliszyn, 2012). The SPME device consists of the syringe assembly and the polymer fibre as its main components.

This is a non-exhaustive technique that technique relies on the creation of equilibrium between the target analyte and the polymer coated fibre. SPME process consists of two basic steps: the partitioning of analytes between the sample matrix and the subsequent desorption of concentrated analytes into the analytical instrument such as GC and the use of desorption chambers for LC techniques (Kudlejova *et al.*, 2012). This technique is simple and fast however extraction efficiency relies on the partition of analytes of interest between the sample matrix and fibre coating therefore factor such as fibre coating material, extraction time, temperature and sample volume among others need to be optimized (Majedi and Lee, 2017).

SPME configurations can be classified into static mode and dynamic modes. Static modes are typically carried out in stirred samples, and this include fibre SPME, stir bar Sorptive extraction (SBSE), thin film microextraction (TFME), rotating disk Sorptive extraction (RDSE) and dispersive SPME. The dynamic mode includes techniques such as in-tube SPME (IT-SPME), in-needle and in-tip microextraction configurations (Pawliszyn, 2012).

Fibre SPME can be performed using the three main approaches (A. Lambropoulou, 2010):

(1) Headspace SPME (HS-SPME), the stationary phase is suspended in the headspace of the extraction vessel where partitioning of analytes from vapour pressure generated above the sample matrix occurs until equilibrium is obtained.

(2) Direct immersion SPME (DI-SPME), the stationary phase is directly immersed in the sample solution that is constantly stirred or agitated for mixing.

(3) Membrane protected SPME, selective membranes are used to separate coated fibres from sample matrix but allow analytes to permeate through (Kudlejova *et al.*, 2012).

2.5.3 Liquid phase microextraction techniques

To overcome drawbacks associated with this technique, solvent-based miniaturization techniques were developed. Three main classes of liquid-based miniaturization techniques were developed: drop based techniques, membrane supported, and dispersed solvent assisted techniques (Sarafraz-Yazdi and Amiri, 2010).

2.5.3.1 *Single Drop Micro-extraction (SDME)*

This technique utilizes a single drop that is suspended on a tip of a syringe then suspended in an aqueous sample or exposed to a headspace for extraction of target analytes at a pre-determined time (Liu and Dasgupta, 1995). When extraction is completed, the analyte rich micro-drop is retracted into the micro-syringe then transferred into the chromatographic technique for analysis. This method provided several benefits such as use of very low amounts of solvent (1-5 uL). (George, 2016) applied a modified SDME technique and analysis by GC-MS for the extraction of stilbene hormones in water.

Despite the benefits of this method, associated drawbacks such as loss of the drop on the micro-syringe during stirring of the aqueous sample solution, formation of an emulsion and dissolution of the liquid droplet when dealing with dirty samples and volatility of the solvent led to limited use of the method (Sarafraz-Yazdi and Amiri, 2010).

2.5.3.2 *Directly suspended droplet microextraction (DSDME)*

The method involves introduction of a small volume of water immiscible solvent in the vortex of a stirred aqueous sample (Wang *et al.*, 2014). The vortex creates a rotating droplet at or close to the centre of rotation which results in mass transfer of analytes. When extraction is completed, the droplet is withdrawn from the aqueous sample solution then sent to a chromatographic instrument for analysis (Yangcheng *et al.*, 2006). The method offers a wide variety of benefits such as, low cost, rapid equilibration time, increased stirring speeds to enhance the mass transfer process and use of increased solvent volume which can make it applicable for HPLC analysis (Kamal Rajabi and Nikserasht, 2018). (Wang *et al.*, 2014) reported the application of DSDME for the extraction of fungicides – azoxystrobin, dithiofencarb and pyrimethanil from environmental water samples.

Associated drawbacks with this extraction method are difficulty of collection of the microdroplet as part of the aqueous solution may be transferred into the micro-syringe (Kamal Rajabi and Nikserasht, 2018).

2.5.3.3 *Hollow-fibre liquid phase microextraction (HF-LPME)*

This method makes use of a disposable low-cost polypropylene hollow fibre membranes to support the extraction solvent (Wang *et al.*, 2016). This method was developed to overcome the inadequacy in SDME such as the instability of the solvent and limited use of solvent volume (Pedersen-Bjergaard, 1997). The organic solvent is immobilized in the pores of the hollow fibre which offers support and during stirring and loss from vibrations.

A short strip of hollow fibre (3-10 cm) is dipped in an organic solvent to immobilize the solvents in its pores, the lumen of the hollow-fibre is then filled with an extraction solvent by use of a syringe then introduced in an aqueous sample for analysis (Wang *et al.*, 2016). The analytes of interest are transferred from the donor phase (aqueous phase) to the organic layer in the walls of the hollow fibre then into the acceptor phase in the lumen of the hollow fibre. The solvent in the acceptor phase is then retracted into the micro-syringe then sent for analysis.

The solvent choice used in as the acceptor phase and impregnated in the pores of the hollow fibre result in two modes of HF-LPME. In Two-phase HF-LPME, the acceptor solvent in the lumen is the same as that impregnated in the pores of the hollow fibre (de la Guardia and Armenta, 2011). Three phase HLF-LPME, acceptor phase is selected as an alkaline or an acidic aqueous solution. Associated issues with this method include loss of volatile and less non-polar solvents when extraction times are prolonged.

(Sibiya *et al.*, 2013) applied HF-LPME for the determination of five PAHs in Jukskei river South Africa and the concentrations of the compounds were found to be in the range 11-64 ng/L.

2.5.3.4 *Dispersive Liquid-Liquid extraction*

(Rezaee, Assadi and Hosseini, 2006) developed a technique that made use of cloudy state formed when a mixture few microlitre volumes of extraction solvent along with a disperser solvent is introduced into an aqueous sample solution. The dispersed solvent in the aqueous phase creates a large surface area of interaction between both phases leading to a rapid, quasi-instantaneous mass transfer process (A. Lambropoulou, 2010). High density chlorinated organic solvents such as nitrobenzene, chloroform are used as extraction solvents and lower density solvents are used as disperser solvents such as acetonitrile and methanol (Letseka and George, 2016). The technique involves addition of the predetermined solvent mixture to create the cloudy solution followed by centrifuging of the mixture to result in phase separation of the aqueous and the organic layer, the organic layer rich in analytes is carefully drawn and analysed using GC and LC techniques (Sarafraz-Yazdi and Amiri, 2010).

The major drawbacks associated with this technique are that the preconcentration and analysis step are performed separately making it difficult to integrate online and suffers highly of matrix interferences (Prosen, 2014).

2.5.4 Passive Sampler Approach

The commonly used approach for sampling organic water pollutants is active sampling (bottle or grab sampling). In this approach, the samples are collected from specific sampling points in time to be processed and analysed later (Madrid and Zayas, 2007)). This sampling method only reflects the contaminant concentration at the moment of sampling and may fail to detect sporadic changes of contaminants, it is however advisable to monitor the pollutants concentrations of these organic pollutants over an extended time frame to achieve a more representative picture of the water quality. Owing to the low concentrations of organic compounds in water typically in the ngL^{-1} to μgL^{-1} range, it is necessary to use large volumes of water or the use of automatic samplers which are expensive and require security measures to be put in place (Vrana *et al.*, 2005). The limitations to this technique can be achieved by a number of approaches and emerging techniques such as repeated spot sampling, automated sequential sampling, continuous online monitoring systems, biomonitoring and passive samplers (Salim and Górecki, 2019).

Passive samplers may fit the bill as environmental monitoring devices for organic pollutants as they are low cost, non-mechanical, easy to deploy over a range of field locations and periods of time and can be used to derive the time-weighted average (TWA) concentrations of a substance in the sampled medium or the equilibrium concentrations of a substance on the sampler (Madrid and Zayas, 2007).Passive sampling is a technique based on the free flow of analyte molecules from the sampled medium to a collecting medium, as a result of difference in chemical of the analyte between the two media (Górecki and Namienik, 2002). The exchange of analytes between the sampled medium and the collecting medium is usually governed by Fick's second Law of diffusion which postulates that the flux goes from regions of high concentration to regions of low concentration, with a magnitude that is proportional to the concentration gradient. The amount, *M,* of the analyte transported by diffusion in time, *t* (s) when the concentration is linear and the collection efficiency is 100%, can be described by the expression (Górecki and Namienik, 2002):

$$M = U\ x\ t = \frac{DA}{L}\ C_0 t \qquad (2.1)$$

Where U is the diffusive transport rate (mol/s), D is the molecular diffusion coefficient of the analyte (cm^2/s), A is the cross-sectional area of the diffusion path (cm^2), L is the total length of the diffusion path (cm).

The term $\frac{DA}{L}$ is often considered to be the Sampling rate R_S.

Analytes are trapped or retained in a suitable medium within the sampler referred to as the receiving phase and this can be in different forms such as a chemical reagent or a porous adsorbent (Vrana *et al.*, 2005).

The exchange kinetics between a passive sampler and the water phase can be described using a one compartment, first order kinetic model.

$$C_s(t) = \ C_W \frac{k_1}{k_2}(1 - e^{-k_2 t}) \qquad (2.2)$$

Where $\mathrm{C_s(t)}$ is the concentration of the analyte in the sampler at exposure time t, $\mathrm{C_W}$ is the analyte concentration in the aqueous environment, $\mathrm{k_1}$ and $\mathrm{k_2}$ are uptake and offload constants respectively.

During field deployment of samplers, two main accumulation regimes can be described in the operation of passive samplers – kinetic/linear and equilibrium regime and this can also be used as the basis of their classification (Salim and Górecki, 2019). In kinetic regime, migration of the analytes occurs continuously from the sampled medium to the collecting medium until the process is stopped by the user. The amount of analyte retained by the sampler is assumed to be proportional to the product of the sampling time and the analyte concentration. In the initial phase of the sampler exposure, the rate of desorption of analytes from the receiving phase to water is negligible and equation (2) can then be reduced to:

$$C_s(t) = \ C_W k_1 t \qquad (2.3)$$

Which can in turn be arranged into an equivalent relationship

$$M_s(t) = \ C_W R_S t \qquad (2.4)$$

Where $M_s(t)$ is the mass of analyte accumulated in the receiving phase after exposure time (*t*), R_S is the proportionality constant also referred to as the Sampling rate. This is the product of the first-order rate constant for uptake of analyte k_1 and the volume of water that gives the same chemical activity as the receiving phase.

In the equilibrium regime, the analyte uptake continues until the sampler reaches equilibrium with the surrounding concentration. In this case, the exposure time is sufficiently long enough to allow for the establishment of thermodynamic equilibrium between receiving and the water phase (Lee and Hardy, 1998). Equation (2.1) in this case is reduced to:

$$C_s(t) = \ C_W \frac{k_1}{k_2} = C_W K \qquad (2.5)$$

Where K is the phase water partition coefficient, this is permits for the estimation of the dissolved analyte concentration.

2.5.5 Types of passive sampling devices

Passive samplers are commonly classified on the sampling regime of operation they belong to, the types of matrices they are used to evaluate and their designs (Salim and Górecki, 2019). A number of passive sampling devices have been developed each designed for specific target pollutants and the type of environmental matrix (soil, water and air), below is a list of common passive sampling devices for organic water pollutants (Marć, Śmiełowska and Zabiegała, 2017).

2.5.5.1 *Semi Permeable Membrane Device (SPMD)*

Hughkings *et al.* (1990) first reported the design and study of SPMD as a new method for monitoring of lipophilic pollutants. The design of SPMD illustrated in **Figure 2.2** consists of thick walled (50-100 µm) flat polyethylene membrane tube containing a neutral, high molecular weight lipid such as triolein. Dimensions for a standard SPMD are 2.5 cm width by 91.4 cm length enclosing 1 mL of lipid. Low density polyethylene membranes have cavities or transient holes in the range 5-10 Å only allow for dissolved organic compounds of low-molecular weight can diffuse into the lipid enclosed. SPMD is suitable for extraction of hydrophobic non-polar compounds such as polycyclic aromatic hydrocarbons, polychlorinated biphenols and pesticides with partition coefficients (log K_{OW}) between 3-6 (de la Guardia and Armenta, 2011).

The SPMD sampler can be deployed at extended periods of time to integrate long time data, (Pogorzelec and Piekarska, 2018) successfully applied the SPMD in monitoring of PAHs at different stages of a WWTP at monthly intervals over a year. The major drawback with this method is that following extraction of compounds into the triolein, an extra step is engaged to re-extract the compounds from triolein into organic solvents which increases analysis time (Huckins *et al.*, 1999) and use of large volumes of organic solvents (Nyoni *et al.*, 2010). Application of SPME was demonstrated by (Gilli *et al.*, 2005) for assessing toxicity of polyaromatic hydrocarbons in drinking water.

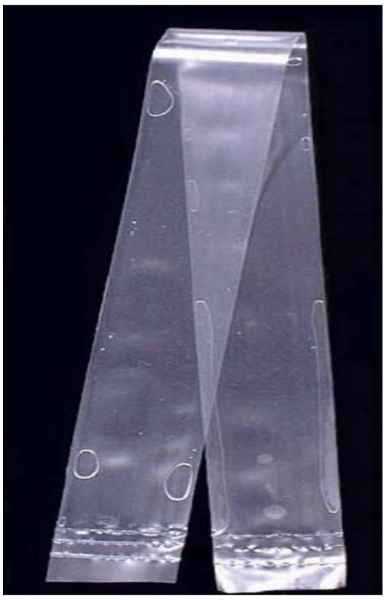


Figure 2.2: Design of SPMD device (Hughkings *et al.* (1990))

2.5.5.2 Chemcatcher®

The Chemcatcher® passive sampler was reported by Kingston *et al.* (2000) as a novel passive sampling device for TWA measurement of organic pollutants in water. The configuration of Chemcatcher® comprises of three components, the polytetrafluoroethylene (PTFE) or polycarbonate support (PC) support device, a diffusion-limiting membrane layer and a receiving phase – solid phase extraction disk. The membrane is mainly used to protect the extraction disk from bio-fouling. Pollutant accumulation into the receiving phase occurs through diffusion during the kinetic or equilibrium phase (Vermeirssen *et al.*, 2009).

Various designs of combinations of diffusion-limiting membrane and receiving phase are present for application of both organic and inorganic pollutants. For low polar to non-polar organic compounds, the styrene divinylbenzene-reverse phase sulphonate (SDB-RPS) disk, styrene divinylbenzene exchange (SDB-XC), C_{18} disks are commonly used receiving phases as they have a high affinity and capacity for the compounds. The receiving phases can be coupled with the cellulose acetate (CA), low-density polyethylene, polysulfone and polethersulfone as diffusion-limiting membranes (Vrana *et al.*, 2005).

A relatively new disk format known as the hydrophilic-lipophilic (HLB-L) disk has gained attention as a sorbent for Chemcatcher®. It comprises of a specific ratio of two monomers – hydrophilic N-vinylpyrrolidone and lipophilic divinyl benzene. This disk provides a high capacity for the retention of polar analytes (Castle *et al.*, 2018). The advantage of Chemcatcher® is that the receiving phase is bound to an inert polymeric disk matrix which prevents leakage during field deployment and loss of material during processing (Grodtke *et al.*, 2021a). Incorporation of the HLB disk as a receiving phase of the Chemcatcher® brings desirable combined benefits sampling a wide range of polar organic pollutants and the handling benefits of Chemcatcher® (Petrie *et al.*, 2016).

This type of sampling devices have been found to be ideal for sampling pharmaceuticals, steroids, pesticides, alkylphenols and polybrominated flame retardants. (Rimayi *et al.*, 2019) applied the chemcathers for the screening of emerging pollutants in South African rivers, in their study they identified the presence of pharmaceuticals, personal products and pesticides. (Grodtke *et al.*, 2021b) deployed Chemcatcher® in river water and detected triazine herbicides in the concentration range 0.3-30.6 ng/L.

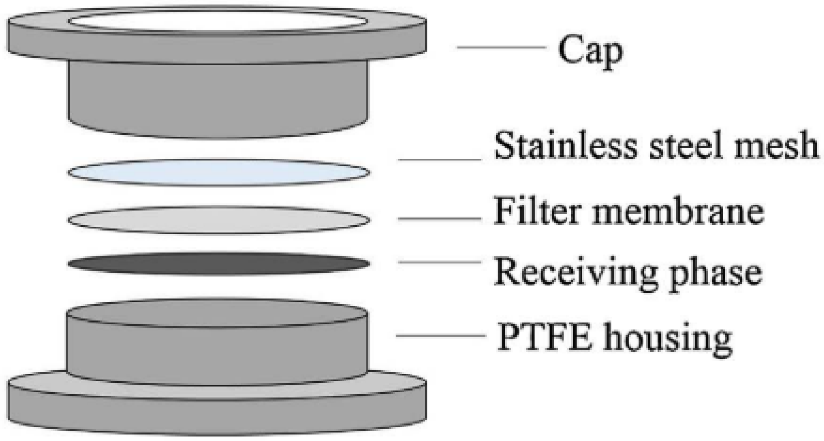


Figure 2.3: Configuration of the Chemcatcher® passive sampler (Gong *et al.*, 2018)

2.5.5.3 Diffusive gradients in thin film sampler (DGT)

The DGT sampler was first reported in 1994 for determination of zinc in sea water (Zhang and Davison, 1994). The design of the sampler is a PTFE top and base as outer components enclosing three layers, a filter membrane consisting of resin-impregnated gel layer, diffusive gel and filter membrane stacked on the base as shown in **figure 2.4**. The analytes of interest pass through the membrane filter and diffusive gel and accumulate on the binding gel (Gong *et al.*, 2018). The incorporation of the diffusive gel layer to control analyte transfer makes this sampler unique to other passive samplers (Guibal *et al.*, 2017).

This type of sampler was widely reported for in-situ detection of metals and inorganic compounds in aquatic environments. (Chen *et al.*, 2012) reported the first use of passive samplers incorporating a diffusive hydrogel to sample organic compounds in water. (Guibal *et al.*, 2017) also reported the in-situ calibration and application of DGT samplers for the analysis of anionic pesticides in river water.

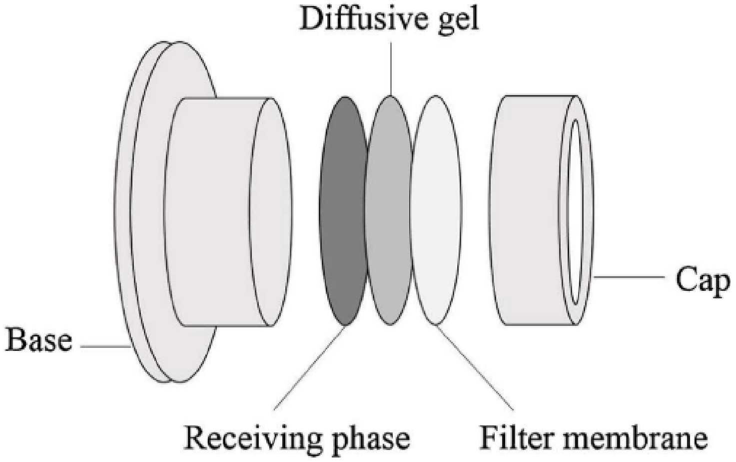


Figure 2.4: Configuration of the DGT sampler (Gong *et al.*, 2018)

2.5.5.4 Membrane Enclosed Sorptive Coating (MESCO)

This are sampling devices consisting of a membrane which encloses polydimethylsiloxane (PDMS) coatings or coarse silicone material that are embedded in a fluid as sampling phases for target analytes (Paschke *et al.*, 2007). The MESCO sampler has two versions as shown in **figure 2.5**, MESCO I that has a stirrer as the receiving phase and the MESCO II that uses a silicone tube as the receiving phase (Paschke *et al.*, 2007). The target organic compounds from the aqueous phase through the membrane and are retained by the thin PDMS layer on the stir-bar or the silicone phase The coated stir-bar is then obtained from the enclosing membrane then directly analysed by thermal desorption or solvent back extraction (Van Pinxteren *et al.*, 2010).

The benefits of using this sampler include simplicity, loss-free separation of the collector phase and analysis with further processing steps through thermal desorption or solvent microextraction (Paschke *et al.*, 2007). MESCO samples have been found to be ideal for the collection of PAH, PCB and pesticides from the environment (Marć *et al.*, 2017).

The major drawback about using PDMS-coated stir bar enclosed in a dialysis membrane bad is that the membrane is susceptible to microbial degradation and has relatively poor thermal and chemical stability which results in sampler damage when deployed in environmental eater bodies (Paschke *et al.*, 2007).

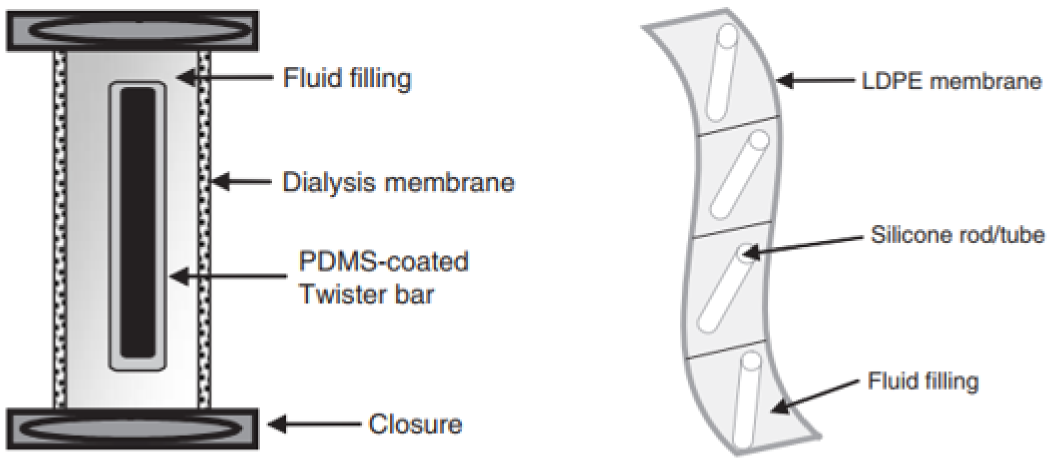


Figure 2.5: Schematic of MESCO sampler designs (MESCO I left and MESCO II right) (Paschke *et al.*, 2007)

2.5.5.5 Polar Organic Chemical Integrative Sampler (POCIS)

POCIS sampler was developed at the Columbia Environmental Research Centre (US Geological Survey) and its patent was granted in the US in 2002. (Alvarez *et al.*, 2004) described the structure of the POCIS sampler to consist of 3 parts: 100 mg Sorbent, polyethersulfone membranes (pore size 100 nm and thickness 130 nm) and the two stainless steel rings that holds the membrane and sorbent together. The polyethersulfone membranes serve as semipermeable barrier between the aqueous environment and the receiving phase, the membrane prevents the accumulation of solid particles, colloids but allowing the compounds of interest to pass through.

Two configurations of POCIS are commercially present each of them containing a different sorbent : pesticide-POCIS uses a mixture of three solid sorbents as opposed to other samplers, the composition is as follows (Oasis HLB (hydrophilic-lipophilic-balanced copolymer [poly(divinylbenzene)-co-N-vinylpyrrolidone]) or 80:20 (m/m) ISOLUTE® ENV + (hydroxylated polystyrene-divinylbenzene copolymer) and Ambersorb 1500 (carbon lightly dispersed on S-X3 Biobeads)) which is used for sampling most pesticides, natural and synthetic hormones. Pharmaceutical-POCIS makes use of a single sorbent (100 mg Oasis HLB resin) and is designed for sampling of most pharmaceutical compounds (Gong *et al.*, 2018).

The principle behind operation of the POCIS is the concentration difference, the uptake process includes transport through the water boundary layer and membrane then by transport to the sorbent(Booij and Chen, 2018). POCIS sampler was deployed by (Amdany *et al.*, 2014) for the determination of pharmaceuticals and personal care products in wastewater.

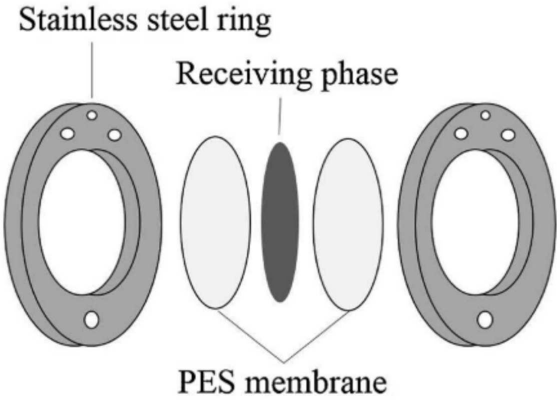


Figure 2.6: Configuration of the POCIS sampler (Gong *et al.*, 2018)

2.5.6 Optimisation of passive samplers

Calibration of passive sampling devices is essential to characterize the behaviour and achieve chemical-specific and sampler-specific sampling rates and to determine sampler-water partition coefficients in order to predict the TWA water concentrations of contaminants (Garnier *et al.*, 2020). The rate of chemical uptake relies on analytes physio-chemical properties, sampler design Chemical and environmental variables such as temperature, flow rate, turbulence and bio-fouling of the sampler surface (Huckins *et al.*, 1999).

Calibration of passive samplers is performed by exposing samplers to known analyte concentrations for fixed periods under controlled environments, the application of Performance Reference Compounds (PRCs) and passive flow monitors this can be performed through field application or through laboratory based set-up (Alvarez *et al.*, 2004).

Laboratory calibrations are conducted under controlled conditions such as temperature, flow rate, pH and salinity and the absence of bio-fouling (Aguilar-Martínez *et al.*, 2008). When samplers are deployed to real environmental matrices, the conditions are not identical, and this results in non-ideal uptake rates. Performance Reference Compounds (PRCs) are used to correct the non-ideal uptake rates between water and the receiving phases (Charriau *et al.*, 2016).

2.5.6.1 Static depletion

This is a design in which the passive samplers are exposed to a pre-spiked solution at the beginning of the experiment (Thomatou *et al.*, 2011). Using the first order kinetics (equation 1), it was noted that with time that there was a decrease in analyte concentration and the sampling rate R_S could be estimated. Static exposures have been used in the calibration of SPMDs (Booij, Vrana and Huckins, 2007). This design is simple, low cost and easy to incorporate environmental variables (Wang *et al.*, 2020).

2.5.6.2 Static renewal

The spiked exposure medium is periodically removed or renewed (daily or several day frequency) (Thomatou *et al.*, 2011). This design may be used when static or continuous flow designs are not ideal and this instance may occur when a sampler results in excessive depletion of the aqueous phase, or when problems occur in maintaining stable aqueous concentrations during flow through exposures (Chen, Zhang and Jones, 2012). As an attempt to minimize the reduction of analyte concentration due to uptake into the samplers during batch exposure, the frequency for renewing the exposure medium should be high and the solution concentration should be measured at the start and end of each renewal period. When there is less change in analyte concentration during renewals, this allows for a direct modelling of the sampling rate by equation (2.6) below (Thomatou *et al.*, 2011).

$$C_s(t) = \frac{M_S R_S t}{M_s} \qquad (2.6)$$

2.5.6.3 Continuous Flow design

This design is mainly aimed to prevent the depletion of the aqueous solution by continuous supply of freshly spiked water to the exposure chamber where the samplers are deployed under matching hydrodynamic conditions and aqueous concentrations. When calibration is performed, the sorption of dissolved organic or inorganic matter should be negligible as to prevent analyte overestimation in the aqueous solution.

The samplers are gradually removed from the chamber to assess the analyte sampling rate. With decreasing sampler numbers in the chamber, the flushing rate might be reduced if the hydrodynamic condition is kept constant. When aqueous concentrations can be maintained constant, the R_S and $C_S(t)$ may be obtained by curve fitting of equation (2.6). If it is not possible to maintain aqueous concentrations, a second order polynomial function outlined in equation (2.7) could be used to describe the concentration change in the sampler.

$$\frac{C_S(t)}{K_{mw}} = \left(C_0 - \frac{C_1}{k_e} + \frac{2C_2}{k_e^2}\right)[1 - exp(-k_e t)] + \left(C_1 - \frac{2C_2}{k_e}\right)t + C_2 t^2 \qquad (2.7)$$

Where C_0, C_1 and C_2 are polynomial function constants

2.5.7 Applications of passive samplers

2.5.7.1 Chemical Monitoring

One of the goals of the Water Framework Directive is to is to improve the water quality by reversing, when necessary, the degradation trend of underground and surface waters by gradually reducing the discharges of substances that have been classified as priority pollutants (Miège *et al.*, 2015). This can be achieved by the use of efficient and cost-effective monitoring tools that can provide the required information for the assessment of water contamination. Passive samplers can be applied for integrative sampling of contaminants as they can be deployed over extended periods of time (weeks to months) in water bodies. Tapie *et al.* (2011) applied POCIS for monitoring the release of pharmaceuticals, pesticides, phenols and hormones in Baïse River (Garonne basin, southwest of France).

2.5.7.2 Quantification of Concentrations in water

Passive samplers can also be applied to calculate the TWA concentrations of contaminants in the aqueous phase (Vrana *et al.*, 2007). Contaminant concentrations in the environment are not constant and can fluctuate depending on their sources over time and this can be achieved effectively with the use of passive over grab sampling. In the study conducted by (Ahrens *et al.*, 2018), three different passive samplers were employed to determine pesticide concentrations that were in the National pesticide monitoring programme of Sweden two catchment areas that were characterized by agricultural activities.

2.5.7.3 Estimate of organism Exposure

Passive samplers have the capacity to determine the truly dissolved contaminant fraction of contaminants. The dissolved fraction of contaminants is the most bioavailable (Morrone *et al.*, 2021). Monitoring the concentrations of contaminants in aquatic environments provides direct evidence for bioavailability and the contaminants potential for ecological and human health risk (Joyce *et al.*, 2016). Biomimetic sampling using passive samplers can mimic the partitioning of contaminants between the pore water and the organism (Vrana *et al.*, 2005).

2.5.7.4 Bioassays

Bioassay analysis of water samples requires sampling of several litres of water since organic contaminants are present in low concentrations in the aquatic environment (Lissalde *et al.*, 2016). The contaminant rich extracts obtained from the elution of receiving phases of passive samplers can be subjected to toxicity testing using bioassays that give information on toxic and ecotoxic risks associated with the sampled media (Vrana *et al.*, 2005). Following deployment of POCIS in river water, Tapie *et al.*, 2011 eluted the sorbent from the sampler then performed bioassay. In their study, they assessed estrogenic, (anti-)androgenic and dioxin-like activities of the extract based on MELN(MCF-7) cells stably transformed with the firefly luciferase gene under the control of endogenous oestrogen receptor.

2.6 Analytical methods for identification and quantification of organic pollutants in water

Environmental matrices are complex and contain a range wide range of chemical classes present in trace levels and over the years, more emerging contaminants have been identified in the environment with the advancement of analytical methods (Madikizela, Ncube and Chimuka, 2020). Chromatographic techniques such as liquid chromatography (LC) and gas chromatography (GC) coupled to mass spectrometry (MS) are the most employed methods for determination of emerging contaminants in environmental matrices as they offer sensitivity and selectivity for the detection of these compounds at µg/L to ng/L levels (Clarke, 2017).

Mass spectrometry in the most powerful analytical technology that is used for the identification of unknown organic or inorganic compounds, determination of structures of complex molecules, and quantitation of low concentrations of known compounds (Clarke, 2017). Mass Spectrometers operate by converting the analyte molecules to a charged ionized state with subsequent analysis of the ions and any fragment ions that are produced during the ionization process on the basis of their mass to charge ratio (*m/z*) and modern configurations are based on speed of analytes, time and rate of reaction (Pitt, 2009). The choice of ionization technique is has to be taken into consideration and this mostly depends on the physio-chemical properties of the compounds of interest (Alves *et al.*, 2013).

Electron spray impact (ESI) is a technique commonly used in commercial LC-MS systems in which a stream of liquid containing the sample is passed through a narrow capillary maintained at 3-5 kV and nebulized at the tip of the capillary to form a fine spray of charged droplets (Banerjee and Mazumdar, 2012). The droplets are rapidly evaporated by application of heat and dry nitrogen then leaving the residual charge to the analytes (Banerjee and Mazumdar, 2012). The ionized analytes are then transferred into a high vacuum of the mass analyser via a series of small apertures and focusing voltages. This technique is used for polar and non-polar analytes of moderate molecular weights such as pharmaceuticals, perfluorinated compounds (Fischer *et al.*, 2012). This is considered as a “soft” ionization source as relatively little energy is imparted to the analyte hence little fragmentation (Banerjee and Mazumdar, 2012). ESI is highly sensitive to matrix effects and this can impact the ability of LC-MS data to be quantitative, it is essential for elimination or compensation of matrix effects when developing methods for this source (Pitt, 2009).

Atmospheric pressure chemical ionization (APCI) is also an LC-MS ionization method similar to ESI as the liquid sample containing the analyte is passed through the capillary then nebulized at the tip. However, APCI uses a corona discharge pin is located near the tip of the capillary to ionize gas and solvent molecules present at the ion source which then react with the analytes at the ion source through charge transfer (Banerjee and Mazumdar, 2012). This technique is highly applicable to thermally stable molecules that cannot be ionized well with ESI and less polar and non-polar analytes such as hormones and polybrominated diphenyl ethers. The limitations with APCI are that it results in singly charged ions which limits the effective mass range and may be undesirable for compounds that can be thermally broken down or displaced (Nguyen, 2018).

Atmospheric pressure photo-ionization (APPI), the solvent is initially vapourised in the presence of a nebulizing gas such as nitrogen then enters the source under atmospheric pressure to form an aerosol (Banerjee and Mazumdar, 2012). This is exposed to a UV light source that emits photons with energy level that is enough to ionize the target molecules leaving out the background molecules. Dopants such as (toluene and acetone) are added to the sample prior MS detection to improve the ionization efficiency. The APPI source has the capacity to ionize compounds that both ESI and APCI cannot ionize and non-polar compounds such as polycyclic hydrocarbons, steroids, and mycotoxins (Primpke *et al.*, 2020).

Electron ionization (EI) is an ionization process used in most GC-MS systems, the ionization place in the gas phase by interactions of molecules with accelerated electrons from a resistively heated filament (Desfontaine, Veuthey and Guillarme, 2017). Sufficient energy is transferred to the organic compounds to form a positively charged molecule and excess energy transferred causes fragmentation of molecular ion resulting in a series of fragment ions that are unique to that molecule within those conditions (Pitt, 2009). This technique is widely used for relatively volatile samples that are thermally stable and have relatively low molecular weight. The major drawback with this technique is that extensive fragmentation occurs resulting in little or no molecular ions (Banerjee and Mazumdar, 2012).

Chemical Ionization (CI) is also commonly used in GC-MS systems, this technique uses interactions between a reagent gas (such as methane, isobutane, or ammonia) and sample molecules in the gas phase (Smith, 2013). The reagent gas undergoes electron ionization and releases molecular ions which react with the sample molecules leading to its ionization through adduct formation. This is a relatively softer gas-phase ionization technique compared to electron ionization (Clarke, 2017).

The selectivity of a mass spectrometer is reflected by the mass resolution, this is the ability to discriminate between two ions with very small differences in their m/z (Sandau *et al.*, 2003). Mass spectrometers are versatile and can range from a simple quadrupole with an electron multiplier for single *m/z* detection to a high-resolution mass spectrometer with the capability to collect and distinguish compounds over a large *m/z* range (Fischer *et al.*, 2012). An MS instrument that is capable of providing resolution power more than 10,000 is considered as a high-resolution mass spectrometer (HRMS). Higher instrument resolution results in increased mass accuracy and the ability to avoid interference from compounds of similar mass that may also be present in the sample (Clarke, 2017).

The quadruple mass analyser consists of a set of four metal rods located between the ion source and the detector. The linear quadrupole mass analyser consists of four hyperbolic or cylindrical rods that are placed in a radial array in which opposite rods are positive or negative direct charge potential at which an oscillating radio frequency is superimposed (Desfontaine *et al.*, 2017). This allows the transmission of a narrow band of *m/z* along with the axis of the rods. By varying the voltages with time, it is possible to scan a range of *m/z* values thus obtaining a mass spectrum. Ions can be set to undergo fragmentation by collisions with an inert gas through a process termed as collision induced dissociation.

This configuration is applied in triple quadruple mass spectrometer in which a collision cell is placed between two quadrupole mass analysers, this offers specificity of the analysis over single stage mass analysis (Clarke, 2017). Because of their low cost, this are the most common mass analysers. The single quadrupole is the simplest and cheapest, robust and requires relatively low maintenance. The major limitation with this type of mass analyser is that is limited to unit mass resolution and cannot detect compound masses with high precision which leads to numerous chemical formulas and false identification in mass spectral libraries (Taylor *et al.*, 2020).

Time of flight (TOF) Analyser operate by accelerating ions through a high voltage. The velocity of the ions and the time taken to travel through the flight tube to reach the detector depends on their *m/z* values. When the initial accelerating voltage is pulsed, this results in the output of the detector as a function of time can be converted into a mass spectrum. TOF mass analysers are considered as high-resolution mass spectrometer (HRMS) and have a mass accuracy for small ions (M < 2000 Da) around 1-10 ppm and large ions (10,000 < M < 80,000 Da) at around 100 ppm and are also characterised by high scan rates and dynamic range (Oetjen *et al.*, 2017).

Ion trap analysers use three hyperbolic electrodes to trap ions in a three dimensional spacing using static and radio frequency voltages. Ions are then sequentially released from the trap based on their *m/z* values to create a mass spectrum (Smith, 2013). The orbitrap mass analyser is the most recently developed analyser that offers high resolving power in the range 100,000-240,000 Da with excellent mass accuracy below 1 ppm (Oetjen *et al.*, 2017). This operates in two modes, the Fourier transform mode (FT) and the Fourier Transform-ion cyclotron resonance MS (FT-ICR-MS) (Liu *et al.*, 2021). The issue with these types of mass analysers is that their scan rates are relatively slower, are very expensive and the FT-ICR-MS is complex and takes up large lab space (Chau *et al.*, 2008).

Hybrid Mass Analysers use a combination of two or more different mass analysers in design and are therefore termed as “hybrid designs” (Clarke, 2017). When the third quadrupole of a triple quadrupole MS is replaced by a TOF, the resulting hybrid analyser is a hybrid quadrupole time-of-flight (QTOF) mass spectrometer. In this instrument design, the mass analyser performs precursor ion selection while the TOF mass analyser performs product ion analysis. The Q-Trap instrument design is formed by the combination of a quadrupole together with a linear ion-trap (García-Córcoles *et al.*, 2019).

2.6.1 High Pressure Liquid Chromatography – Mass Spectrometry (HPLC-MS)

The use of LC-MS techniques allows for determination of high polar to non-polar contaminants without the need for derivatization through the use of varying ionization sources (Pérez-Fernández *et al.*, 2017). A wide range of emerging contaminants can be monitored through LC-MS techniques. In studies conducted by (Maldaner and Jardim, 2012) to determine the concentrations of pharmaceuticals and pesticides in water bodies, liquid chromatography tandem mass spectrometry with electron-spray ionization was used. Multiple reaction monitoring (MRM) was used to confirm and quantify low concentrations of the compounds in water.

Pinasseau *et al.* (2019) employed the ultraperformance liquid chromatography (UHPLC) coupled to a quadrupole time of flight mass spectrometer (Q-TOF) for target screening of emerging contaminants in water. This approach enabled them to efficiently identify 101 suspect compounds and confirm 40 target compounds. LC-HRMS is considered to be the best method for target and non-target screening of emerging contaminants in water bodies for its ability to assign molecular formulae for unknown compounds and added confidence for positive identification in quantitative work (Bataineh *et al.*, 2021).

2.6.2 Gas Chromatography-Mass Spectrometry

Gas chromatography (GC) is an analysis technique that is mostly used for the reparation of volatile, semi volatile and thermally stable organic compounds in samples (Manirakiza *et al.*, 2002). It can also be used for non-volatile compounds but they an extra derivatization step is required and such a step can be time consuming and introduce side reactions and complicate the identification process (Morales *et al.* 2012). Different groups of emerging contaminants have been successfully analysed using GC-MS approaches.

GC-MS methods have allowed for determination of pesticides in water samples, Gakuba *et al.* (2019) used gas chromatography coupled to a mass spectrometer for the detection of organochlorine pesticides in river water. They applied single ion monitoring (SIM) mode monitoring 3 target ions for each compound for the identification of pesticides. The presence of extensive libraries in GC allows for confirmation of unknown compounds in samples (Bataineh, Schymanski and Gallampois, 2021).

2.7 CHALLENGES WITH URBAN POLLUTION

2.7.1 Economic challenges

The improper design and operation of wastewater treatment plants in most developing countries still remains an issue to date as conventional methods are still being used for treatment of incoming waste. Studies have shown that most conventional wastewater treatment plants lack the capacity to remove all the contaminants in water, especially the class of emerging contaminants. It is therefore important for implementation of modern technologies in WWTP, and the decision about their improvement is highly influenced by direct capital and operation costs (Awad, Gar Alalm and El-Etriby, 2019).

The Arad urban wastewater treatment plant in Romania was found to discharge effluent into a highly sensitive stretch of the Mures River which was a nutrient sensitive area designated for special protection of birds. Upgrades on seven treatment plants, rehabilitation of reservoirs and sewage network cost EUR 18 million, this resulted in significant reduction of organic and nutrient pollution load entering the river (EEA, 2021).

2.7.2 Health Concerns

The introduction of raw and/or untreated faecal waste into surface waters which are sometimes sources of drinking water. This introduces pathogens into water and resulted in water-borne diseases such as gastroenteritis, cholera, viral hepatitis, typhoid fever, bilharziasis and dysentery, these diseases are the root cause for high child mortality rates (Jabeen *et al.*, 2015). Water contamination also results in fish contamination, fish are primary food sources to human, and the consumption of contaminated fish has been reported to result in food ailments depending on (Deb, 2018).

Contaminated irrigation water may be a source of foodborne pathogens on fruits and vegetables and this is the case in most developing countries in which irrigation with untreated or insufficiently treated wastewater is a common practise (Steele and Odumeru, 2004). An investigation conducted by (Ackers *et al.*, 1998) when residents in Montana were laboratory-confirmed with *Escherichia coli* 0157:h7 infections revealed that patients had consumed lettuce from farmyards using contaminated water for irrigation. Sahota (2018) emphasizes that the consumption of ready to eat crops and vegetables that are irrigated with sewage contaminated water pose consumers to faecal coliforms, Escherichia coli and diarrheagenic Escherichia coli.

The Hennops river is contaminated with both raw and treated sewage (Oberholster, Botha and Cloete, 2008), use of this water for irrigation is a health concern.

2.7.3 Degradation of aquatic biodiversity

Water pollution is one of the main causes of loss of biodiversity in river water (Betts *et al.*, 2020). The introduction of emerging contaminants and microplastics may lead to acute exposure of contaminants to the aquatic species leading to their death and some contaminants have been linked to the alteration in the reproduction capability of fish, this hinders the rate at which fish multiply therefore leading to their extinction (Sibanda *et al.*, 2015).

Sewage contamination in rivers causes eutrophication due to algal blooms depletes oxygen in water thus killing aquatic organisms such as fish and amphibians (Subramaniam *et al.*, 2018).

CHAPTER 3: INTERVENTION'S METHODS TO SOLVE URBAN POLLUTION – STAKEHOLDER AND COMMUNITY PARTICIPATION

3.1 INTRODUCTION

While this project was able to avail important information about the chemical condition of the Hennops River basin and its water resources, a chemical analysis was considered not enough to understand the causes and effects of the polluted and poorly managed or maintained river basin. Therefore, while chemistry helped us understand some of the issues the river faces, this project included a human geography component to better understand the issues contributing to the overall problem, while also exploring some options for better management of the river basin. This chapter presents the findings of this project in relation to the role of stakeholder engagement and community participation in the management of the Hennops River Basin. This chapter presents the most current findings from literature, activities, and the application of the project's methodology. Ground-truthing activities, the proceedings of meetings, interviews, workshops, as well as clean-up initiatives and activities with various stakeholders and community members will be reported on in this chapter.

3.2 TERMS OF REFERENCE

While not estranged from the chemical analyses' findings presented in the previous section, this component of the grander project employs and draws from key theoretical considerations and terms of reference. It is therefore important to highlight these terms before exploring the methodological considerations and empirical evidence of this component.

3.2.1 Integrated Water Resource Management (IWRM)

The challenges of South Africa's River systems observed through case studies such as the Hennops River basin prompt the theorising of what water challenges exist nationally as well as globally. Through the pressures of climate change and population growth, it has been predicted that many water scarce areas around the world will continue to face worsening water challenges (Distefano and Kelly, 2017). Furthermore, Misra (2014) argues that Africa is one of the most vulnerable regions to climate change and its potential repercussions on the continent's water resources. Through their predictions, the IPCC support that changing, unpredictable precipitation patterns and rising temperatures will exacerbate Africa's water scarcity and stress (Niang *et al.*, 2014). Therefore, a need for effective water resource management has arisen, leading to the conceptualisation of different water resource management approaches.

Since 1977, water resource management has been presented as a key discussion point in global development conferences and summits. Water resource management and global perspectives thereof have evolved throughout history, culminating into what can be perceived today as different approaches under different conceptual frameworks (Lankford, 2008; Mukhtarov, 2008; Rahaman and Varis, 2005). Modern approaches to water resource management have included different perspectives and considerations including how water should be identified in socio-economic contexts as well as environmental governance (Rahaman and Varis, 2005). As a result, Integrated Water Resource Management (IWRM) has become a contemporary concept used to describe the ideal approach to water resource management.

IWRM – an approach to water resource management has been praised and supported for its effectiveness (Herrfahrdt-Pähle, 2013; Grigg, 2016). Supporting notions of sustainable development, IWRM has been considered as a solution to addressing water demands while considering environmental and social factors (Thomas and Durham, 2003). The concept of IWRM extends to encompass a large number of considerations and has ultimately been argued as a completely new paradigm through which water resources can be managed (Meran *et al.*, 2021). Furthermore, IWRM supports an interdisciplinary approach, involving elements of physical science, engineering, sustainability science, and social science (Grigg, 2016).

Stakeholder and community engagement and participation has now become a cornerstone of IWRM principles around the world, as well as the concept as a whole. For example, Delozier and Burbach (2021) argue that stakeholder engagement is a critical for addressing long-term water resource planning. Furthermore, Ward (2013) is of the opinion that IWRM opens up water governance to other social actors including NGOs, water users, as well as other stakeholders. Altogether, the whole concept of IWRM has been argued as a participatory approach to water resource management, with some such as Badham *et al.* (2019) arguing that stakeholder and community participation is what defines the IWRM principles, making them stand out when compared to other water resource management planning.

In South Africa, IWRM is a key part of the country's water policy (Funke *et al.*, 2007; Van Koppen and Schreiner, 2014). Since as early as 1998, IWRM has been viewed as an approach to address past water challenges related to equality. However, water governance in South Africa, particularly at a local level is questionable, given case studies such as the Hennops River basin, where it is observable that water governance and the involvement of social actors is not apparent.

3.2.2 Community-Based Natural Resource Management (CBNRM)

CBNRM is a key concept which is embedded into IWRM as demonstrated in the arguments of Ward (2013) and Badman *et al.* (2019). It is a concept described as a solution to resource management through the participation of stakeholders and communities (Armitage, 2005; Measham and Lumbasi, 2013). The concept has existed for a long time and has been implemented in different ways internationally in the management of various natural resources and ecosystem services. CBNRM does not have a standard definition and has therefore taken different forms through its implementation in different ways across the globe. However, a few key points form the basis of what CBNRM approaches aim to achieve when addressing a particular natural resource.

Natural resource management tends to take the form of a top-down approach, with authorities put in place to manage a particular resource. Under the concept of CBNRM, the opinions, viewpoints, and knowledge systems of communities play an important role in how a natural resource is managed (Armitage, 2005). Addison *et al.* (2019) argues that through CBNRM, the governance of natural resources is altered to include a multi-level approach. In this, they argue that stakeholders and communities, particularly at a local level, are given more control over natural resources. Furthermore, Baddianaah and Baaweh (2021) are of the opinion that CBNRM supports the decentralising of natural resource management, to allow communities the ability to manage their own common resources. The premise behind this concept and its implications on natural resource governance is that local communities understand their surrounding environment better than an overarching, remote authority (Brosius *et al.*, 1998). Reid (2016) further argues that through indigenous knowledge systems, communities can adapt their resource management according to challenges they face. This allows for resource management to be sustainably managed despite local as well as global challenges (Brosius *et al.*, 1998; Reid, 2016). CBNRM has been noted in literature as a prominent approach to the management of wildlife, however, the concept has also been adapted to manage common resources like water, being incorporated into river basin management plans (Anokye and Gupta, 2012; Armitage, 2005; Eduful *et al.*, 2020; Richards and Syallow, 2018; Taylor, 2009).

It is argued that river basin management in South Africa can benefit from a management framework which includes CBNRM. In particular, the Hennops River basin supports several communities who benefit from its resources. At the same time, the river is also affected by the human activity which takes place around it, eventually contributing to the pollution problem which is addressed in the current study. As literature suggests, CBNRM seeks to balance conservation with sustainable utilisation of resources (Kellert *et al.*, 2000). Therefore, CBNRM was a concept embraced throughout this study. Furthermore, moving forward, CBNRM can play an important role in maintaining and conserving the wellbeing of the river, while also ensuring that communities benefit from its resources equally.

3.2.3 Participation Action Research (PAR)

IWRM, integrating the ideals of CBNRM, must involve the participation of stakeholders and communities who will be able to sustain a framework through which the Hennops River basin can be managed. Therefore, the concept of Participation Action Research (PAR) is argued as a vital theoretical consideration in this regard. PAR, as a key concept underlying the current study and is described as collaboration between researchers and participants to understand, as well as work together to find solutions (Baum *et al.*, 2006). At the same time, the participants themselves are allowed the power to change their situation and act.

PAR has also been described as Participatory Rural Appraisal (PRA) in the past, however, the underlying precepts remain the same. As an important part of PAR (or PRA), participants are encouraged to meditate on their current experiences, lives, and situation, and act towards making changes (Chambers, 1994). As its earlier form, the concept was set around raising awareness in communities about issues which affect them, and then encourage them to take action (Chambers, 1994). As the concept developed, its role in research has now been described as a method through which participants collect and analyse data, drawing from their own experiences and perceptions, resulting in them taking action (Baum *et al.*, 2006). This concept differs from other approaches to research, essentially empowering the participants to be, in their own way, the researchers of a particular study.

This concept is therefore argued to work hand-in-hand with CBNRM, which, as earlier described, seeks to empower stakeholders and communities to manage natural resources. In relation to the current project, stakeholders and communities were encouraged to assess their lived experiences and meditate on the issues that they face in relation to the polluted Hennops River. Participants, as part of a community-based effort, will be encouraged to make decisions and take action to manage their river basin, as the findings of this project are further explored through additional research and implementation. Therefore, it is argued that together with CBNRM and PAR, effective Integrated River Basin Management (IRBM) can be realised as part of efforts towards IWRM of the Hennops River catchment.

3.2.4 Integrated River Basin Management (IRBM)

Although it has been considered difficult to define, the concept of IRBM has been argued as a reformed approach to river basin management, where improved planning and action is involved in sustaining the wellbeing of a river basin (Watson, 2004). The concept focuses on the dynamics of river basin management and the structures which are put in place for management (Nielsen *et al.*, 2013; Rijke *et al.*, 2012; Watson, 2004). As literature suggests, the concept of IRBM is concerned with the governance of water resources and the role of different stakeholders and authorities in managing a river basin (Watson, 2004). The concept has been used to describe different efforts and projects across the world, with some of these projects being complex in nature and involving different elements and considerations (Eduful *et al.*, 2020; Nielsen *et al.*, 2013; Richards and Syallow, 2018; Rijke *et al.*, 2012; Watson, 2004).

IRBM is often used together with IWRM and involves different levels of authority and key stakeholders and decision-makers. Furthermore, IRBM is increasingly involving the role of stakeholders and participants for renewed approaches to river basin management (Carr, 2015). These movements towards a participatory river basin management plan seek to decentralise decision-making, mobilising stakeholders to implement their own decisions related to river basin management. In essence, these movements within IRBM draw from the precepts of CBNRM, promoting empowerment and a consensual approach to river basin management. Therefore, the term IRBM relates back to the current study as a concept embodying an effective approach to the pollution problem of the Hennops River basin. As other studies have demonstrated, IRBM involves the participation of different players in society, and each catchment or river basin involves a unique approach to governance and management of water resources (Eduful *et al.*, 2020; Nielsen *et al.*, 2013; Richards and Syallow, 2018; Rijke *et al.*, 2012).

Considering the above, a lot has been drawn from other efforts which have aimed to engage IRBM as an approach to managing water resources. Furthermore, some of the efforts reviewed and studied in the existing literature base also include case studies where CBNRM and PAR have been adopted as part of IRBM and IWRM plans. It is therefore important to go through the existing literature and highlight some of these case studies which can be learned from.

3.3 CONTEXTUALISING THE LITERATURE ON RIVER BASIN MANAGEMENT

3.3.1 River basin management in a global context

New approaches to river basin management have been of interest for some time in the recent past. Some of the examples in the literature base include projects and programs which have been implemented around the globe to address specific environmental and socio-economic concerns around water resource management and river basin management. As an example well covered in the literature base, the Water Framework Directive (WFD) in the European Union represents one of the world's largest, longest standing, river basin management directives or policy frameworks (Hering *et al.*, 2010). The WFD was inspired by the US Clean Water Act of 1977 and was implemented in 2000 in the EU for the main purpose of addressing the integrity of aquatic ecosystems (Hering *et al.*, 2010).

Although aquatic ecosystems and biota are a focus of the WFD, the approach to river basin management the framework takes is what can be drawn from for the current study. As it has been noted, under the WFD, EU Member States are required to involve stakeholders and communities in decisions around river basin management (De Stefano, 2010). Furthermore, the WFD was formed on the foundations of stakeholder engagement itself, without which, the program cannot succeed (De Stefano, 2010). Altogether, the WFD approaches river basin management in ways to address both ecological or environmental concerns, while allowing for the security of socio-economic wellbeing (Hering *et al.*, 2010).

A key example of how the WFD has reformed water resource management in the EU is the case study of the Danish Water Councils. In 2013, long after the establishment of the WFD, the Danish government, initiated a new approach to river basin management through the formation of water councils for different catchment areas in the country (Graversgaard *et al.*, 2017). These water councils were formed to manage a catchment which the members of the council had interest in. Council members included a balance between river protectors (activists, NGOs and environmentalists), and those with an economic interest in the water resources of the catchment (fisheries, industries, agriculturalists and other organisations). Those with an interest in the river basin were encouraged to become members of the council to contribute to the management of the basin's water resources. Furthermore, councils were also encouraged to incorporate their own knowledge systems in the management of their river basin of interest. The implementation of the Danish Water Councils has had a number of benefits. Firstly, it is noted that action is more likely to take place through the council's decisions rather than through the previous top-down approach. Furthermore, it has been argued that costs of river basin management are much better managed through the Danish Water Councils. Although only one example of the many initiatives in Europe which follow from the WFD, the case study of the Danish Water Councils can be drawn from as a success case study.

While the Danish Water Councils case study is an example of effective IWRM and IRBM, the same is not observed across the EU under the WFD. The main reasons for this have been related to the framework's policy in general, which is argued to not sufficiently support stakeholder engagement (De Stefano, 2010). It has further been argued that the WFD does not sufficiently address learning and knowledge practices, lacking rigid management goals and resources to address river basin management altogether (Dawson *et al.*, 2018). It is therefore argued that continued engagement with policy and practice is required to improve approaches to IRBM. At the same time, the Danish Water Council case study is a key example which illustrates that integrating CBNRM and PAR in IRBM is possible.

Although a policy framework like the WFD does not exist in Africa, the river basin management strategy adopted in the Densu River basin, Ghana, is key to consider in relation to the current study. The Densu River basin has been experiencing a gradual degradation in water quality mainly from anthropogenic activities over the years (Anokye and Gupta, 2012). Much like the Danish Water Councils, a council was formed to address the issues around the Densu River basin. The Densu Basin Board (DBB) was formed in 2004 as a decentralised management approach for the management of the river basin with the objective to protect water resources (Eduful *et al.*, 2020). The DBB was composed of different stakeholders from government agencies, local community members from different municipalities, NGOs and traditional authorities. Stakeholder engagement in this regard functioned as an established system through which decisions were made and actions took place. Therefore, management of water resources in the basin has been distributed, with community members benefiting from developed infrastructure set up by key stakeholders, NGOs, and companies, while being maintained by the community itself. Community members contribute in various ways to the upkeep of infrastructure, understanding that it is only themselves who reap the benefits.

In the case of the Densu River basin, the focus of stakeholder and community participation has been to address pollution. Unlike the Danish example, the Densu River basin example expresses the role of communities in IRBM. This case study has inspired the work of this project and acts as an example of IRBM incorporating CBNRM in Africa. Following from the criticisms of the WFD, the Densu River basin case study addresses some of the concerns raised regarding IWRM and IRBM in the EU, involving learning and knowledge practices of communities through a different structure and framework for river basin management. Furthermore, this case study demonstrates that river basin management based on the theoretical frameworks, IWRM, CBNRM and PAR is possible in developing African countries.

The case study of the Mara River basin, Kenya, is yet another example in Africa of IWRM and IRBM integrating CBNRM. The case study highlights a participatory framework which has been supported by communities under a structure that does not impose authority on other, poorer community members. Water laws in Kenya have recognised the importance of stakeholder engagement and communities in the maintenance of water resources in the country. Therefore, Water Resources Users Associations (WRUAs) were set up in several key river catchments of the country (Richards and Syallow, 2018). WRUAs are essentially community led groups focused on promoting the well-being of a river system and its ecosystem services. WRUAs are mostly responsible for decision-making, catchment management, water monitoring and conflict resolution. Alongside WRAs (Water Resource Authorities), WRUAs manage sections of the Mara River basin communicating the sentiments of communities but also carry out actions funded by donors or sponsors. WRUAs as participatory components have been beneficial for the well-being of the Mara River basin, with members of the community protecting their natural resources and even developing their area of interest.

This case study emphasises the importance of the community in decision-making and action. Furthermore, a multi-level management framework is also promoted including the poorer population, which is not necessarily the case regarding the WFD example earlier discussed. Although the strategy of implementing WRUAs has been beneficial for communities, it has been argued that financial support is vital for the further development and sustainability of these participatory frameworks (Richards and Syallow, 2018). In this regard, the support of authorities, organisations and NGOs is crucial in supporting participatory frameworks. This point will be considered when discussing findings related to the participatory framework formulated for clean-up and management of the Hennops River System and its water resources. In this regard, key stakeholders, industries, organisations, leaders, and authorities have been engaged with as the project progressed. Much like in the Mara River basin case study, community members continue to be considered in decision-making, however, key stakeholders have been encouraged to provide resources for initiated responses to identified problems. The take-home point in this regard is that an effective stakeholder engagement or participatory framework needs to be sustainable in terms of resources. These resources must be provided by identified stakeholders and leaders who will support but not control the project. These points form a critical part of the discussion presented at the end of this chapter.

3.3.2 Water resources and river basin management in South Africa

Securing effective water resource management approaches in South Africa is complex given the status and future of the country's water resources. South Africa is among the most water scarce countries in the world, given the hydrological and climatic situation (Molobela and Sinha, 2011; Knight, 2019). Through the pressures of climate change and population growth, it has been predicted that many water scarce areas around the world will continue to face worsening water challenges (Distefano and Kelly, 2017). Furthermore, Misra (2014) argues that Africa is one of the most vulnerable regions to climate change and its potential repercussions on the continent's water resources. Through their predictions, the IPCC support that changing, unpredictable precipitation patterns and rising temperatures will exacerbate Africa's water scarcity and stress (Niang *et al.*, 2014). Unfortunately, these predictions affect South Africa as well. This goes beyond considering the socio-economic factors that affect the effectiveness of implementing IWRM frameworks and strategies, which have already been highlighted as a key problem observed in a Sub-Saharan Africa context. Socio-economic as well as environmental aspects affect how water is viewed, distributed, and used in South Africa. This ultimately affects how the resource is managed under the current water policy. Therefore, an overview of the main water challenges in South Africa is necessary to highlight the context of the current study.

Although climate change has and is affecting South Africa's water resources, geographically, the country has been argued as a water-scarce region (Bischoff-Mattson *et al.*, 2020; Herrfahrdt-Pähle, 2013; Naidoo *et al.*, 2016). While geographical aspects contribute to the natural distribution of water across the country, it has been argued that socio-economic and governance issues form the core reasons for the country's perceived water scarcity (Knight, 2019). Growing water demands and inefficient management and distribution of the resource continues to affect South Africa's water resources essentially creating the problem of water scarcity altogether (du Plessis, 2017; Funke *et al.*, 2007; Otieno and Ochieng, 2004; Swatuk, 2005). Additionally, South Africa's water resources are further stressed through other environmental issues. While this includes the observed threat and impact alien invasive species have on water (Le Maitre *et al.*, 2000; Le Maitre *et al.*, 2002; Van Wilgen *et al.*, 2012), a more compelling argument is presented when considering the impact of human or economic activity and pollution on the resource in South Africa.

The problem of water pollution in South Africa is so vast, that no one study has been able to a review on the challenges the country faces. Some of the major pollution problems South Africa faces includes acid mine drainage, eutrophication as well as direct pollution through effluent, emerging contaminants, and other waste (McCarthy, 2011; Oberholster *et al.*, 2008; Van Ginkel, 2011; Matthews, 2014; Simate and Ndlovu, 2014). The sources of pollution vary greatly across the country; however, industries, human activity and different land uses can be attributed to contributing to the various types of pollution as highlighted in different studies (Akcil and Koldas, 2006; Oberholster and Ashton, 2008; Oberholster *et al.*, 2008; McCarthy, 2011).

Acid mine drainage is at the forefront considering the impacts of human activity on water resources in South Africa. As the country's primary economic activity, past exploitation and long-term unsustainable mining practices have left South Africa's water resources vulnerable to heavy metal contamination and acidification (Naicker *et al.*, 2003; Akcil and Koldas, 2006; McCarthy, 2011; Simate and Ndlovu, 2014). As a previous study suggests, acid mine drainage has had a direct impact on water quality in mining areas such as Johannesburg (Naicker *et al.*, 2003). Although it has been demonstrated that its severity is mostly within the vicinity of mining areas (Tutu *et al.*, 2008) it has been argued that the impact of acid mine drainage extends even beyond mining areas (McCarthy, 2011). The threat of acid mine drainage on South Africa's water resources is ever-present, however, it is only one piece to the grander puzzle of water challenges the country faces.

As mining in South Africa continues to contribute to the challenge of acid mine drainage, other land uses in the country play a role in further polluting water resources. One problem worth mentioning is the threat of eutrophication. Essentially, eutrophication refers to the enrichment of water bodies with an excess of nutrients (Van Ginkel, 2011). Eutrophication of water bodies is related to the occurrence of cyanobacteria and algal blooms which renders the water hazardous for consumption or use. Studies have suggested that all of South Africa's major water bodies are affected by eutrophication and subsequent cyanobacterial or blue-green algal blooms (Matthews, 2014; Matthews and Bernard, 2015). The causes of eutrophication are extensive as nutrient enrichment can be attributed to different sources however, the most common cause of eutrophication is the release of effluent into water systems (Oberholster and Ashton, 2008; Van Ginkel, 2011; Harding, 2015). As such, several cases of effluent affecting water bodies have been observed and highlighted over the years (Oberholster *et al.*, 2008; Sibanda *et al.*, 2015; Rimayi *et al.*, 2018). This brings into context the root problem related to eutrophication – insufficient wastewater treatment.

Recent research echoes the point that South Africa's wastewater treatment strategy is not performing optimally (Teklehaimanot *et al.*, 2015; Gani *et al.*, 2021). Poorly addressed wastewater has been argued as a key source of pollution, even competing with the severity of acid mine drainage (Atangana and Oberholster, 2021). Unlike acid mine drainage, the impact of wastewater disposal into South Africa's rivers has been a phenomenon experienced across the country at several catchment areas, not just in areas where mining takes place (Swart and Pool, 2007; Oberholster *et al.*, 2008; Seanego and Moyo, 2013; Baloyi *et al.*, 2014; Gumbo *et al.*, 2016; Agunbiade and Moodley, 2016; Agoro *et al.*, 2020). As a root cause of this issue, it has been observed that effluent originates mostly from poor performing wastewater treatment plants who cannot effectively deal with sewage from surrounding urban areas (Oberholster and Ashton, 2008). As a common problem across almost every province of the country, the reality of wastewater having an impact on the country's water resources is alarming. This challenge speaks to the current state of the country's water infrastructure, but more so, to the country's inefficient water resource management strategies (Knight, 2019).

Water challenges in South Africa undeniably have negative impacts on the environment and the country's water resources, leading to the exacerbation of the experienced, natural water scarcity. Most of these challenges highlighted above have socio-economic root causes. Developing countries like South Africa have growing water demands because of urbanisation, population growth and advances in economic development (Larsen *et al.*, 2016; du Plessis, 2017). A key consideration related to South Africa's water demands, therefore, is infrastructure. It has been argued that South Africa's water infrastructure, like in other parts of the world, is inadequate to support demands while it continues to age (McDonald *et al.*, 2014). Furthermore, it has been argued that South Africa lacks the funding models to support and improve water infrastructure and infrastructure management (Ruiters and Matji, 2015). While infrastructure and support thereof have been related to South Africa's water challenges, concern has also been focused on the governance and management of water resources (Van Koppen and Schreiner, 2014).

An example can be cited considering past experienced water challenges in South Africa and their relationship with socio-economic factors. The Cape Town 'day zero' event of the mid-2010's was a severe case where the city was adversely affected by drought. During this event, water supply in the city of Cape Town was limited to a few supply points, with a looming date of when the city would completely run out of water (Rodina, 2019). While climatic factors were the root cause of this issue, several socio-economic concerns were revealed, exposing the reality of most water management strategies in South Africa (Knight, 2019; LaVanchy *et al.*, 2021). The country's water management strategies were tested, demonstrating a lack of resilience to weather major catastrophic water crisis events (Rodina, 2019). At the same time, it has been observed through the 'day zero' event that social inequality, political struggles, and poor communication had exacerbated Cape Town's drought (Robins, 2019; Bischoff-Mattson *et al.*, 2020). This event highlights the idea that South Africa's approach to water resource management is lacking in some areas. However, this is not apparent in all critiques of South Africa's water law.

South Africa's water policy is argued to be one of the most progressive in the world (Colvin *et al.*, 2008). Being based on the principles of IWRM, South Africa's water policy addresses key issues including a devolution or decentralised approach as well as a catchment-level plan for water resource management (Pollard and du Toit, 2008). Pollard and du Toit (2008) highlight that South Africa's water policy addresses the complexity of South Africa's water challenges, essentially suggesting that sustainability and equity can be achieved through strategies it encourages. For example, the policy's stance and support or stakeholder engagement is argued to be able to contribute to better decision making as well as improve water monitoring. Altogether, South Africa is not estranged from the ideas of IWRM, in fact, the concept's principles are well-embedded in the country's approach to water resource management and addressing the challenges highlighted in this section (Anderson *et al.*, 2008; Colvin *et al.*, 2008; Pollard and du Toit, 2008; Molobela and Sinha, 2011).

Although Pollard and du Toit (2008) argue for the value of South Africa's water management policies, some argue that the country faces issues related to implementation (Anderson *et al.*, 2008; Colvin *et al.*, 2008; Molobela and Sinha, 2011). It is argued that the institutions necessary for the application of IWRM have not been established in some catchment areas (Colvin *et al.*, 2008). At the same time, some institutional structures have been put in place, leading to the successful management of their associated river basins, but this is not national-wide, with some catchment areas performing better than others (Anderson *et al.*, 2008; Colvin *et al.*, 2008). This has been related to IWRM and public participation as part of South Africa's water resource management strategies, being argued as insufficiently implemented (Anderson *et al.*, 2008; Colvin *et al.*, 2008; Pollard and du Toit, 2008). Therefore, while South Africa's water policy is argued among the best in the world (Pollard and du Toit, 2008), implementation is an issue that continues to hinder its potential (Anderson *et al.*, 2008; Colvin *et al.*, 2008). There is therefore a need to review how policy is enacted on the ground to establish the challenges and opportunities related to involving stakeholders and communities in water resource management.

South Africa faces multiple challenges related to the security of its water resources. Apart from being affected by hydrological and climatic conditions rendering the country a water-scarce region, human activity also contributes to the country's water challenges. The recent case study of Cape Town's day-zero event is an example highlighting these challenges, both environmental and social. Although arguments have been made about the country's challenges related to water resource management, South Africa's policies are some of the most progressive in the world, embedding key principles of IWRM. Therefore, South Africa's water policy supports the need to involve social actors in water resource management. A resulting argument is therefore made in relation to implementation.

The current study seeks to explore social dynamics in relation to the challenges around implementing IWRM strategies and the principles of South Africa's legislation. Different socio-economic factors as well as issues in governance around the management of river basins such as the Hennops had not been studied until this point. Instead, the challenges the river basin faces are estranged from the social dynamics which take place within it. This study seeks to add to the scientific body of literature around South Africa's water resources by linking social aspects to the situations observed and understand the potential of social actors to address the challenges at hand.

3.3.3 Gaps in literature: A case of the Hennops River basin

As literature suggests, there have been global movements towards better implementation of IWRM and IRBM, involving the participation of stakeholders and communities. This includes the WFD, a well-studied policy initiative of the EU. While the initiative has been praised for its innovative approach to public participation and decision-making, implementation has been a question, with suggestions that the WFD has been placed beyond the capacity of the public and their resources. At the same time, case studies such as that in Denmark demonstrate the potential of IWRM and the WFD in improving water quality monitoring strategies and involving stakeholders and communities in decision-making. Therefore, the WFD is an example of an initiative embodying the key concepts highlighted in this literature review.

As the WFD is an example of a European approach to IWRM, CBNRM and IRBM, literature covers evaluations of similar strategies in Africa. Ghana has moved towards incorporating IWRM and therefore stakeholder and community participation in the way the country manages water resources. Some arguments suggest that some challenges exist in Ghana's new water resource management approach, but at the same time, the applied strategies exhibit potential. As in the case of the Densu River basin, a catchment-level approach has been argued valuable for managing pollution challenges in the densely populated area. The challenges that the Densu River basin faces resonate with the challenges the Hennops River basin faces. Therefore, as a gap in current understandings, the effectiveness of similar strategies is yet to be evaluated in relation to the Hennops River basin. At the same time, an evaluation of the role and potential of stakeholders and communities in the Hennops River basin still needs to be addressed. Through an understanding of water resource management in Sub-Saharan Africa, important gaps are highlighted in relation to understanding the local water challenges river basins in South Africa face.

Through a study of literature around South Africa's water resources, several studies highlight the natural challenges the country faces in terms of water scarcity. To exacerbate the climatic and hydrological challenges, human activity has had a serious impact on South Africa's water resources. This relates to different economic activities including mining which have been associated with challenges such as acid mine drainage. Furthermore, South Africa's river systems are threatened by pollution, and this has been related to a myriad of sources.

What adds complexity to South Africa's water resources and the management thereof is that the country's water policy has been argued as sound. With a legislative framework that is supported by IWRM and initiatives to involve stakeholders and communities in water resource management, why are some areas like the Hennops River basin encountering challenges that do not reflect progress in policy? What is behind the observably poor state of the Hennops River basin? What are the challenges associated with the implementation the strategies in policy? Why are communities and stakeholders still estranged from the frameworks in policy? These are some of question which highlight the shortcomings of our current knowledge. The case study of the Hennops River basin, brings these issues to light in a new way.

Arguments have suggested that IWRM, CBNRM and IRBM are necessary to address the challenges the country faces in terms of water scarcity and water pollution. IWRM itself is a concept which, as highlighted, has been used in other spaces to address issues very similar to those experienced at the Hennops River basin. At the core of this idea is an argument towards the importance of stakeholder participation in and IRBM at a local level (Mirumachi and Van Wyk, 2010). However, it is suggested that a reform of policy is not essential given that literature argues for the value of South Africa's water law. Being incorporated into South Africa's legislation, IWRM, CBNRM and IRBM have not exhibited their true potential in the context of local and national water challenges. At the same time, literature does not demonstrate the true value of PAR in the context of water resource management or even IWRM. For this reason, this component of the project approached the case study of the Hennops River through PAR, with active research venturing into the spaces which relate to the grander problem.

CHAPTER 4: METHODOLOGY A – STAKEHOLDER'S ENGAGEMENT

4.1 MATERIALS AND METHODS

A combination of data sources was drawn from following initial ground-truthing exercises and engagement with community members. This report presents the findings drawn from (a) a rapid appraisal of literature and ground-truthing, (b) the proceedings from stakeholder engagement workshops, (c) observations from a community workshop and, (d) the results following several clean-up campaigns. Each data source includes the findings drawn from interviews, discussions, observations, and other forms of engagement. The materials and methodology employed to gather data are therefore presented in this section.

4.1.1 Rapid appraisal of literature and ground-truthing

A rapid appraisal or rapid review of literature has many uses and has been argued as an effective data collection method (Ganann *et al.*, 2010). The process involves reviewing past literature to identify areas where research continues to evolve and provide results, while also identifying areas where there are perceivable research gaps. Through a rapid appraisal of literature, more data can be gathered from literature sources in less time.

Specific themes and concepts were considered during an appraisal of literature around similar projects. It was the interest of this appraisal to identify frameworks and approaches to river basin management which have been implemented globally, regionally, as well as locally. Much of the raw findings of this rapid appraisal were presented as the review of literature of this report (section 3.3). However, findings were also translated into a set of objectives which would then be considered during further data collection as well as the formulation of a potential framework for managing the Hennops River basin. The data collected through this method therefore guided ground-truthing exercises, further engagement with stakeholders and communities as well as initiatives which followed. A rapid appraisal was therefore important to understand the role that stakeholders and communities have and can assume in relation to river basin management.

Literature included academic journals and books, but also information from internet sources and media publications. Internet sources and media publications provided information on current affairs as well as guided sampling and the identification of potential key stakeholders and community members.

The rapid appraisal of literature guided engagement and ground-truthing exercises. In this regard, organisations such as NGOs were engaged with, who provided information about what is being experienced within the Hennops River basin. NGOs also aided in identifying other key stakeholders and communities which need to be involved in the river basin's management. Furthermore, through ground-truthing, key problem sites were identified within the Hennops river basin such as the Kaalspruit tributary and its regions flowing through the Tembisa area. Further engagement with the community continued following ground-truthing.

4.1.2 Stakeholder meetings and workshops

4.1.2.1 Initial stakeholder meeting and Root Cause Analysis

Following the ground-truthing exercises conducted in the earlier stages of the project, community members were engaged with, who ultimately provided more information on the different organisations, groups and individuals who are associated with the management and have an interest in the Hennops River Basin. Further engagement was initiated with the identified stakeholders to better understand their interest in the Hennops River basin and what their current role is in the management of the river basin. These key stakeholders were then invited to join a stakeholder workshop hosted by the Wits research team. Several community leaders, NGOs, residents, and religious representatives were invited to participate in the planned activities for the day. An invitation was designed by the Wits Research Team and disseminated to the identified stakeholders, groups and individuals representatives (**Figure 4.1**).

A program or agenda was created which included items for the duration of the workshop. A summary of the program is provided in Table 3.1. The program focused on introducing stakeholders and organisations to the larger project, while also sought to gather information on their observations, lived experiences, concerns, challenges and past initiatives. The workshop was presented in a semi-structured form, allowing for stakeholders and representatives present to voice their opinions freely without the limitation of a rigid structure. However, each item planned for the day was allotted a specific duration for the purposes of maintaining an orderly event.

As listed in **Table 4.1**, the program included an introduction done by Prof M. Simatele. This was followed by a presentation done by Thabiso Letseka of some of the preliminary chemistry findings of the Wits research team. All present individuals and groups were offered the opportunity to comment and ask questions. This was followed by a discussion around important topics to gather information from those who attended the meeting about their opinions, observations and experiences.

A key part of these discussions was a Root Cause Analysis (RCA) which was facilitated by the Wits research team. RCA can be defined as a framework through which systematic causes can be identified (Percarpio *et al.*, 2008). Furthermore, RCA is also described as a process to categorise identified causes (Rooney and Vanden Heuvel, 2004). The processes involved with RCA are argued to be important tools in understanding environmental impacts. In this regard, root causes are defined as specific underlying problems which lead to a larger observable issue. Root causes are also considered to be manageable and preventable, therefore, addressing these causes should result in addressing the main problem (Rooney and Vanden Heuvel, 2004).

RCA was applied as identified causes were therefore ranked according to their perceived contribution to the overall issue at hand. Stakeholders and representatives were then asked to name some of the important organisations and institutions who should be part of decision-making and management of the river basin as well as further events such as clean-up campaigns. Finally, discussion was opened for attendees to share any recommendations and further comments on the topic. As noted in **Table 4.1**, two tea breaks or ice breakers were part of the program, and the meeting was concluded with a vote of thanks and lunch.

Table 4.1. Stakeholder workshop program including the different items and times.

Time	**Activity**
	Part 1
08:30-09:00	Morning tea and issuing of consent forms
09:00-09:15	Introduction: by Prof M. Simatele
09:15-09:45	Presentation: introduction of the project by the Wits Research Team
09:45-10:00	Question and answer session
10:00-10:30	Tea break
	Part 2
10:30-11:15	Discussion points about challenges and observations: - What is the current status of the Hennops River? - Why have these problems occurred?
11:15-12:00	Listing and ranking of identified problems
12:00-12:30	Listing of important institutions and organisations
12:30-13:00	Recommendations and additional comments
13:00-13:15	Vote of thanks, closing remarks (Wits Research Team)
13:15	End of meeting (lunch)

Figure 4.1. Flyer advertising stakeholder meeting

The above-described meeting set the stage for further investigation around the root causes of the Hennops River basin's pollution crisis. Furthermore, this meeting helped identify key challenges and opportunities related to a potential management framework for the Hennops River basin. This meeting allowed for key themes to be identified, which were then further explored over the course of the project.

4.1.2.2 Stakeholder workshop: Hennops Revival

The research team was invited to participate in a stakeholder workshop which ran over two days. This workshop was hosted by Hennops Revival, an NGO which was previously engaged with, and was attended by approximately 70 delegates from at least 40 different private corporations, government offices and interested stakeholder groups. The first day of the workshop focused on presenting some of the challenges faced in terms of the management of the Hennops River basin. Different government officials presented information relating to their work, role, and opinions on the Hennops River basin's current state. Government offices who gave talks on the day included representatives of the City of Tshwane municipality. Representatives presented their own data related to the state of the Hennops River basin but also presented their observations on the root causes of the pollution problem. The second day of the workshop focused on some of the solutions to the perceived problems. These solutions specifically related to the potential of private sector buy-in and participation. Furthermore, solutions presented focused on addressing key pollution sources, as will be discussed in subsequent sections.

This workshop served to corroborate findings from previous engagements, but also triangulate findings related to identified themes. The information yielded through this workshop allowed for further evaluation of the various root causes previously identified but also allowed for a more in-depth understanding of cause-and-effect relationships. The findings gathered through engagements with stakeholders during this workshop also highlighted key issues in governance which have contributed to the problem observed and the lack of participatory efforts. As will be presented in subsequent sections, the findings of this workshop exposed important disconnects between governance and the role of communities and stakeholders.

4.1.3 Community workshop

Together with the local municipality and NGOs, a community workshop was facilitated in the Tembisa area, at the Tembisa Civic Centre Council Chambers. The community workshop was open to all interested community members and was led by local NGO, EnviroCare Tembisa. The workshop was also attended by local figures of authority as well as businesses with an interest in the community. Furthermore, a representative from the Wits research team was given the opportunity to engage directly with the community through a verbal presentation and discussion.

Several goals were associated with this community workshop. Through the workshop, awareness was raised about some of the issues the community faces. The community was also provided with information related to the findings and observations of the current project. In this regard, the community was made aware of the chemical challenges the Hennops River basin faces as well as the observed challenges noted through ground-truthing. As the workshop allowed for direct engagement with the community, more was learnt about the level of environmental awareness of the Tembisa community. In this regard, community members were allowed the opportunity to share their own experiences and sentiments around waste management, water resource management, and the general management of their urban spaces in relation to the Kaalspruit tributary. Finally, the workshop also allowed for the dissemination of information about future initiatives, opportunities and clean-up events.

The workshop's program was brief. The workshop was held from 10:00 to 13:00. The program included talks from various groups including the Department of Correctional Services, EnviroCare NGO, an associated industry, and the Wits research team working on the current project. Community members were also provided literature sponsored by EnviroCare NGO. Flyers for the Wits research team's upcoming clean-up event were also distributed at the workshop.

4.1.4 Clean-up campaigns

4.1.4.1 Supported initiatives downstream

To better understand the role of stakeholders and organisations, the Wits research team joined with two NGOs in their clean-up campaigns or community initiatives at downstream locations within the Hennops River basin. **Figures 4.2** and **Figure 4.3** are posters and programs circulated by the two NGOs, Fresh NGO (**Figure 4.2**) and Hennops Revival (**Figure 4.3**), to advertise their events. Both events focusing on bringing various communities together to remove solid waste from the Hennops River itself. It was important to support these events as Hennops Revival and Fresh NGO are the two most well-established NGOs within the Hennops River basin. By learning from the activities and initiatives of these NGOs downstream, more can be done to empower NGOs in the Tembisa area upstream. The Wits research team participated in the events, engaging in clean-up activities and providing information on the current project. The Wits research team also provided equipment such as gloves, supporting the activities of the initiatives. Both initiatives were attended by several community members, business representatives, stakeholders, and authorities. Furthermore, they were supported by the same stakeholders and organisations who participated in clean-up activities as well as provided resources such as equipment and refreshments.

Several professionals, stakeholders, community leaders, authorities and businesses were engaged with through informal interviews during the events. Individuals and groups engaged with shared their opinions on (1) the current state of the river basin, (2) their contribution to its clean-up and management, as well as (3) their interest in being part of a larger river basin management strategy. These engagements provided details about past clean-up activities as well as the current involvement of communities and stakeholders in managing the river basin. Furthermore, engagement with authorities and leaders provided information on their role in managing the river basin.

Various community members and stakeholders were asked about their opinions on potential future campaigns and their effectiveness in addressing the larger problem. Participants were also asked about what they believe some of the causes and repercussions of the larger problem are according to their observation and understanding. These campaigns served as examples of some of the efforts being made to clean the river basin. Furthermore, these examples inspired initiatives hosted and supported by the Wits research team later upstream, in Tembisa.

Figure 4.2. Flyer circulated advertising Fresh NGO’s clean-up event

Figure 4.3. Clean-up campaign poster (left) and program (right) by Hennops Revival NGO

4.1.4.2 Hosted and supported initiatives upstream

A major clean-up campaign was planned and hosted in Tembisa by the Wits research team on 15 July 2022. Branded as a Wits University centenary event, the initiative focused on removing solid waste from one of the most polluted areas along the Kaalspruit tributary. The selected site bridges the formal residential area, Esiphethweni with the informal settlement, Vusimuzi. Because this location is densely populated, both spaces generate large amounts of waste. While Esiphethweni is serviced by municipal waste removal, the informal settlement, Vusimuzi, is not. Therefore, the community in the area resorts to illegal dumping with Vusimuzi disposing its waste in the Kaalspruit tributary, and Esiphethweni contributing to the waste build-up by dumping any excess waste residents might have. Waste build-up in the area also encourages littering, further exacerbating the problem. **Figure 4.5**. is a site map of the area where the event took place. Marked on this map is the focus area of clean-up activities as well as Vusimuzi informal settlement, to highlight the proximity of the settlement to the polluted area along the tributary. The community of Esiphethweni is North of the focus area.

Different organisations, businesses, authorities, and other groups were invited to participate in the initiative. A flyer (**Figure 4.6**) was distributed to the community through EnviroCare NGO. The distribution of flyers and advertising of the event was also carried out during the community workshop. A digital copy of the flyer was also attached to communications with different organisations and groups. Posters were also made and put up in strategic locations around Esiphethweni. The event was also advertised through Wits University's official website (**Figure 4.7**).

In planning the event, an event brief was drafted which ultimately addressed key concerns around the organisation and management of the event. This included concerns such as site planning on the day, a program for the day, roles, and responsibilities of those attending, expected results, expected weather conditions on the day, etc. The event brief was sent to key stakeholders and organisations who needed more information of how the event was to take place and how they could contribute to its planning.

The event was attended by a host of organisations, groups, and representatives. Student and staff volunteers from Wits University also participated in the event. A volunteer handbook was also drafted to inform volunteers of their responsibilities and provide additional health and safety information. All attendees were requested to sign a register before participating in clean-up activities. A health and safety information sheet was also distributed. All attendees were asked to sign indemnity forms before continuing with clean-up activities. Before clean-up activities, a few key stakeholders and organisations were given the opportunity to do talks and presentations. This was followed by a 3-hour long clean-up session during which solid waste was removed from the area. Stakeholders and community members were also provided with refreshments and lunch. Some stakeholders also contributed required resources in this regard, i.e., food items were also sponsored by key stakeholders in the Esiphethweni area.

Another event took place on Mandela Day, 18 July 2022. This event was hosted by EnviroCare NGO and Hennops Revival. The Wits research team attended this event, during which further engagement with stakeholders and community members took place. Clean-up initiatives were focused around the Thiteng bridge in Tembisa, under which the Kaalspruit tributary flows. This location is further downstream from Esiphethweni where Wits research team's event took place. Like the other events attended and hosted, this event allowed for the Wits research team to gather more information from businesses, organisations, authorities and community members who were present.

Figure 4.4. Site map of clean-up campaign location

Figure 4.5. Flyer/poster created and distributed to advertise the Wits research team's clean-up event

Figure 4.6. Screenshot taken from Wit University's official website where the event was advertised

4.1.5 Field visits with students and academics

Several field visits were initiated following the activities described in Deliverable Report No.4. These were initiated to raise more awareness of the problems observed but also to re-evaluate the ongoing evolution of the Hennops River basin's state. The different activities of communities and stakeholders were observed to establish the capacity of these agencies following empowerment initiatives of the research team.

Field visits allowed for different groups to engage with the Hennops River basin's social challenges. In particular, students from the University of the Witwatersrand were invited to visit key locations around the Hennops River basin, specifically in the Tembisa area. Furthermore, international academic professionals were also participated in field visits. During these field visits, the state of these key locations was documented considering recent activities and the evolution of challenges such as illegal dumping. Key locations included the previously addressed Thiteng Bridge and the Esiphetweni-Vusimuzi point of interest, both situated along the Kaalspruit. Along with these key locations, a new point of interest was engaged with, that is, a highly polluted residential area in Phomolong, which produces waste being washed into the Kaalspruit through storm water infrastructure. The different groups invited to comment on their own observations and present their own opinions on potential participatory solutions to the problems of the river basin.

CHAPTER 5: METHODOLOGY B – CHEMICAL ANALYSIS

5.1 Chemicals and reagents

Analytical grade nitric acid 65% (w/w), UHPLC Grade Acetonitrile (≥ 99.9%), methanol (≥ 99.9%) and Formic acid (≥ 99.9%) were purchased from Merck (Johannesburg, South Africa). Analytical grade venlafaxine hydrochloride (≥98%), methocarbamol, etilefrine hydrochloride, nevirapine, and carbamazepine, p-vinylbenzoic acid (97%) were purchased as single components in powder form from Sigma-Aldrich, Johannesburg. Multi-element calibration standard-2A, 10 mg mL^{-1}, was purchased from Chemetrix (Johannesburg, South Africa).

5.2 Instrumentation and apparatus

Ultrapure water was produced inhouse using the Millipore DirectQ 3 UV water purification system from Millipore (Massachusetts, USA). Three component Polyetetrafluoroethylene (PTFE) POCIS bodies were manufactured by University of The Witwatersrand School of Physics (Johannesburg, South Africa). The passive sampler device design consisted of PTFE base and cap that screwed together to seal the membrane and the disk based on a design reported by Knutsson (2004). The base had a diameter of 49 mm and screw cap was open in both ends with the front window having a diameter of 55 mm while the back internal diameter was 40 mm and tread depth of 5 mm.

Affinisep Hydrophilic-lipophilic balance (HLB) receiving phase disks (47 mm) were purchased from Anatech (Johannesburg, South Africa) and 0.22 µm PES membranes (47 mm) were purchased from Merck (Johannesburg, South Africa). A Solid Phase Extraction (SPE) setup consisted of Supel-Select Hydrophilic-lipophilic balance (HLB) sorbent tubes (500 mg) purchased from Sigma Aldrich (Johannesburg, South Africa) mounted on a vacuum pump procured from Pall Corporation (Fribourg, Switzerland) and manifold set-up purchased from Phenomenex (California, USA). Vegetable samples were dried in a Memmert oven (Büchenbach, Germany), digested in a microwave digester Anton Paar Multiwave Go Plus (Graz, Austria) and the digestate was analysed on the Inductively Coupled Plasma Optical Omission Spectrometry (ICP-OES) Spectro Genesis (Kleve, Germany).

A Dionex Ultimate 3000 UHPLC Thermo Fisher Scientific (Bremen, Germany) instrument coupled to a Bruker Maxis Impact II ESI-Q-TOF high resolution tandem mass spectrometer equipped with an electrospray ionisation source (Bruker Daltonics, Bremen, Germany) was used for analysis of organic pollutants from both grab sampling and passive samplers. A 20 µL injection volume was used for samples and standards with separation performed on a Luna Omega C18 column (50 mm x 4.6 mm x 3 µm) from Phenomenex (Torrance, CA, USA). The mobile phases reservoirs were filled as follows; Solvent (A) 0.1% formic acid in water, and solvent (B) 0.1% formic acid in acetonitrile. The gradient method was set at initially 5% B for a 1 minute then ramped to 55% B for 6 minutes and maintained constant for 2 minutes. The amount of solvent B was further increased to 95% at 10 minutes then held constant for 2 minutes thereafter allowed to equilibrate to initial conditions giving a total run-time of 14 minutes.

5.3 Sample Collection

5.3.1 Physiochemical, Ecotoxicology and Microbiological sampling

Grab samples for microbiological analysis were collected in sterilized 1 L glass bottles. Powder free nitrile gloves were worn during the sampling to prevent contamination. Sediment samples were collected using a sediment auger and stored in plastic containers. The samples were then transported to the lab in a cooler box and stored at 6°C.

5.3.2 Microplastics sampling

Water samples were collected using a 50-micron mesh plankton net (50 cm mouth diameter) that was deployed in the river for 3 hours as shown in **figure 5.1**. The net was secured by a string on a stable platform such as bridge or tree and suspended to a depth of 50 cm into the river and the water column was sampled horizontally. A flow meter attached to the net to determine the volume of water sampled. The contents of the net were washed from the outside of the net with river water into glass sample jars and capped with aluminium foil lined lids. Jars were rinsed 3 times prior sampling with distilled water in the lab then capped and rinsed with river water at the time of sampling. Sediment samples were collected along the riverbank using a sediment auger from different points to account for small scale variability into 500 mL glass jars that were rinsed in a procedure like that of water samples. The collected samples were transported to the lab for further preparation and analysis.

Figure 5.1. Microplastics Sampling procedure

5.3.3 Organic water pollutants sampling

PTFE Components of the POCIS body were thoroughly rinsed with deionized water and the HLB disks was conditioned by soaking the discs in 50 mL methanol for 30 minutes followed by 100 mL ultrapure water, the PES membranes were treated in a similar approach. The devices were assembled by placing the HLB disk on the body followed by carefully placing the PES membrane on top of the HLB disk ensuring that no air bubbles were trapped between the two surfaces. The assembled samplers were submerged in ultrapure water prior use to prevent drying out of the HLB disk before deployment and during transport. Samplers were deployed at specific points based on accessibility and safety for deployment over a period of 10 days as shown in **figure 5.2**. After retrieval, the POCIS body assemblies were resealed with the PTFE transport lid, ensuring that a small quantity of water remained in the top well of the device. During each deployment and retrieval operation, a field blank sampler was exposed and then resealed and handled subsequently as for the field-exposed devices. Where passive samplers were deployed, grab samples were collected in 500 mL polyethylene terephthalate (PET) bottles for solid phase extraction.

Figure 5.2. Field deployment of POCIS passive samplers (left), POCIS placed inside a cage (right) (Photograph: T. Letseka)

5.4 Sample Analysis

5.4.1 Physiochemical water quality

5.4.2 The conductivity, pH, dissolved oxygen (DO) and Total Dissolved Solids of the samples were analysed and recorded onsite using a Hanna Multiparameter meter (Bucharest, Romania) that was calibrated in accord with the manufacturers' instructions.

5.4.3 Microbiological Analysis

The collected water samples were sent to ARC-Irene Analytical services for microbiological analysis.

5.4.4 Microplastics Extraction

5.4.4.1 Isolation of Microplastics from water samples

In a laminar flow cabin, surface water samples were subjected to wet peroxide digestion, modified from National Oceanic and Atmospheric Administration method (Marine Debris Program, 2015). To each water sample, 30 ml of 0.07M $FeSO_4 \cdot 7H_2O$ and 30 ml of 30% (v/v) H2O2 were added. Samples were allowed to achieve complete digestion for 24-48 h at room temperature. Density separation was performed using the two-step density separation protocol developed by Nuelle *et al.* (2014) for sediment samples and modified for freshwater samples. Forty-five millilitres of saturated NaCl (1.2 g/cm^3) was initially added to the sample, allowed to density separate, and filtered; subsequently, 45 ml of NaI (1.8 g/cm^3) was added, and the sample was allowed to settle before filtration.

5.4.4.2 Isolation of microplastics from Sediments

Sediment samples were oven-dried at 40°C for 7 days, after which the dry masses obtained were measured. In a laminar flow cabin, 10% (w/v) potassium hydroxide solution was added to the dry sediments at a ratio of 1:3 (w/v), the mixtures were stirred for 5 min, covered with aluminium foil, and heated at 40°C for 24 h. Once digested, NaI solution (1.8 g/cm^3) was added at a ratio of 1:3 (v/v), stirred for 5 min, and left to stand for 24 h. Following density separation, supernatants from sediment and surface water samples were filtered through a Whatman® GF/A glass microfiber filter (47 mm diameter, 1.6 µm pore size). Filter papers were allowed to air dry for 24 h in the laminar flow cabin and stored in covered glass Petri dishes.

5.4.4.3 Morphological Characterization

Visual criteria proposed in the literature were adopted to identify microplastics. This includes the absence of cells and organic structure, and metallic lustre. In addition, the "break test" was used to distinguish plastic and non-plastic particles. Tweezers were used to probe individual particles. Plastic particles are flexible and do not break; instead, they bounce or spring when prodded. Particles that broke when touched were excluded. Physical identification of particles was conducted under a Nikon stereomicroscope (Nikon MET SMZ745T) with up to 50× magnification, equipped with an imaging source camera (TIS) USB 3.0. Particle size was determined using NIS Elements-D imaging software Ver 5.30 (Nikon).

A TESCAN Vega scanning electron microscope (SEM) was used to generate high-resolution images of morphological surface structures of different microplastic shapes. The samples were mounted on a carbon tape and coated with gold. Scanning electron microscopy (SEM) images were analysed at an accelerating voltage of 2 kV using a TESCAN Vega TC instrument (VEGA 3 TESCAN software),

5.4.4.4 Polymer Composition

Polymer composition of microplastics was determined using a Horiba LabRam HR Raman spectrometer (Bensheim, Germany) with an Olympus BX41 microscope attachment. The 514.5 nm (green) line of a Lexel Model 95-SHG argon laser was used. The incident light was focused onto the sample using a range of objectives and the backscattered light via a 600 lines/mm grating onto a liquid nitrogen cooled CCD detector. LabSpec (version 5) was used for data acquisition and analysis.

5.4.5 Organic water pollutants analysis

5.4.5.1 Solid phase extraction

A Solid Phase Extraction (SPE) setup was assembled for the extraction of pharmaceuticals from grab water samples. An optimized SPE method reported by Madikizela and co-workers was employed, the HLB sorbent was pre-conditioned with 5 mL of methanol followed by 5 mL ultrapure water. Measured 500 mL volume of water samples were loaded on the SPE cartridge and allowed to flow though at a steady flow (1-2 drops/sec) by use of the adjustment knob on the vacuum manifold. The SPE cartridge was then washed with 5 mL of methanol:water (10:90%v/v) then allowed to dry for 1 minute under vacuum. The analytes were eluted with 5 mL of 2% formic acid in water:methanol (20:80%v/v) mixture which collected and evaporated to near dryness under a stream of nitrogen then reconstituted with 2 mL of water:methanol (90:10%v/v). The extract was filtered 0.22 µm PTFE syringe filters then transferred into 2 mL autosampler vials for LC-qTOF-MS analysis.

Recovery experiments were conducted by spiking river water samples to a concentration of 0.05 µg ml^{-1} as a matrix matched approach. The spiked samples were allowed to go through the SPE procedure as the unadulterated samples.

5.4.5.2 Passive sampling by Polar Organic Chemical Integrative Sampler (POCIS)

Laboratory-based calibration

Components (PTFE) of the POCIS body were cleaned by soaking overnight in a detergent solution then thoroughly rinsed with deionized water. Conditioning of the HLB disk was performed in order to activate and open pores of the sorbent and to ensure optimum intake of analytes. The HLB disks were conditioned by soaking in 50 mL methanol for 30 minutes followed by 100 mL ultrapure water, the PES membranes were treated in a similar approach. The devices were assembled by placing the HLB disk on the body followed by carefully placing the PES membrane on top of the HLB disk ensuring that no air bubbles were trapped between the two surfaces. POCIS calibration was performed in a 5 L-capacity beaker containing deionized water which was spiked to a final concentration of 5 ng mL^{-1} of each analyte.

The mixture was allowed to equilibrate for 30 minutes at a stirring rate of 3000 rpm using a magnetic stirrer to mimic environmental river flow. Four samplers were loaded into the tank with each sampler removed at regular intervals (1 day, 2 days, 4 days and 6 days), after retrieval of each sampler a POCIS body (without membrane and HLB disk) was placed at the initial position of the sampler to maintain flow kinetics of the system. The target compounds were extracted from the dried disks using

40 mL methanol on a glass extraction funnel manifold assembly under gravity. The analyte rich methanol was collected into clean 50 mL centrifuge tubes then the solvent was evaporated to near dryness under a stream of nitrogen then reconstituted with 2 mL of water: methanol (90:10% v/v).

Field deployment of POCIS

Samplers were prepared for field deployment in a similar manner as for lab calibration and on the day of deployment the retaining ring was then screwed over the two components to secure them in place. The assembled samplers were submerged in ultrapure water prior use to prevent drying out of the HLB disk before deployment and during transport. Samplers were deployed at specific points based on accessibility and safety for deployment over a period of 10 days. After retrieval, the POCIS body assemblies were resealed with the PTFE transport lid, ensuring that a small quantity of water remained in the top well of the device. During each deployment and retrieval operation, a field blank sampler was exposed and then resealed and handled subsequently as for the field-exposed devices.

Upon retrieval of samplers from the field in the laboratory, the POCIS were carefully disassembled then PES membrane was discarded while the HLB disk was allowed to dry on a solvent-rinsed aluminium foil for 24 hours at room temperature. The target compounds were extracted from the dried disks using 40 mL methanol on a glass extraction funnel manifold assembly under gravity. The analyte rich methanol was collected into clean 50 mL centrifuge tubes then the solvent was evaporated to near dryness under a stream of nitrogen then reconstituted with 2 mL of water:methanol (90:10%). The sample solutions were transferred into 2 mL autosampler vials for LC-qTOFMS analysis.

STUDY AREA

A total of 10 sampling points from identified major potential point and non-point sources of pollution along Hennops River catchment were investigated as shown in **Figure 5.3**. The upstream area is classified as the areas around the origin of the Hennops river and some of the tributaries that flow into the river. Sampling site S1 (25° 59’ 13.94” S, 28° 13’ 59.18” E) is located along Olifantspruit stream which runs through the Winnie Mandela zone 2, where there is with build-up of municipal waste which is not efficiently removed and sewage leakages that are rarely attended. The sampling site S2 (25° 57’ 35.93” S, 28° 13’ 23.49” E) is a stream that runs opposite Clayville Industrial area which has pharmaceuticals manufacturing industries, food processing factories and beverage production companies while Sampling Site S3 (25° 57’ 27.74” S, 28 °12’ 24.61” E) is located near Thembisa shopping centres. The Olifantsfontein Wastewater Treatment Plant which receives wastewater mainly from Clayville, Thembisa and Ivory Park and has a treatment capacity of up to 105 mega L day^{-1} (Sibiya *et al.*, 2013). The effluent from the Olifantsfontein wastewater treatment plant discharges as a point source of pollution into the Hennops river, the ARC sampling site S4 (25° 54’ 56.19” S, 28° 13’ 58.96” E) is located below the discharge point along the river as it continues to flow further north.

Sampling site S5 (25° 52’ 49.89” S, 28° 14’ 42.91” E) was located along the Sesmylspruit which finds its source as the Rietvlei Dam. The aim was to determine if there are any pollutants from the dam as it joins the Hennops river. The river continues to flow through urban land use sites such as the Centurion Golf Estate, between Centurion Cricket stadium and a recreational water park then enters the Centurion Lake which is a constructed impoundment around the hotels, shopping complex and office blocks. The restricted flow of the Hennops river in the lake results in trapping of pollutants from the upstream areas, the sampling site S6 (25°51’22.30”S 28° 11’ 26.57”E) is located Centurion Lake Sampling sites S7 (25° 50’ 52.38” S, 28° 10’ 44.46” E) is located near the Leriba Lodge and sampling site S8 (25° 49’ 49.43” S, 28° 08’ 41” E) is located near the Royal elephant hotel.

As the Hennops river flows downstream, it is joined by the Rietspruit which the Sunderland Ridge wastewater treatment plant has been found to discharge raw sewage into. Below the confluence of both rivers in Erasmia, there are commercial crop production activities taking place along the riverbed which make use of the Hennops river for irrigation and this location is marked the Vegetable Garden sampling point S9 (25° 49’10.09” S, 28° 04’ 12.43” E). The Swartbooispruit is another tributary that joins the Hennops river which also passes through some other agricultural land use areas, the sampling point S10 (25° 49’ 53.56” S,28°02’25.24” E) was located below the confluence of both rivers.

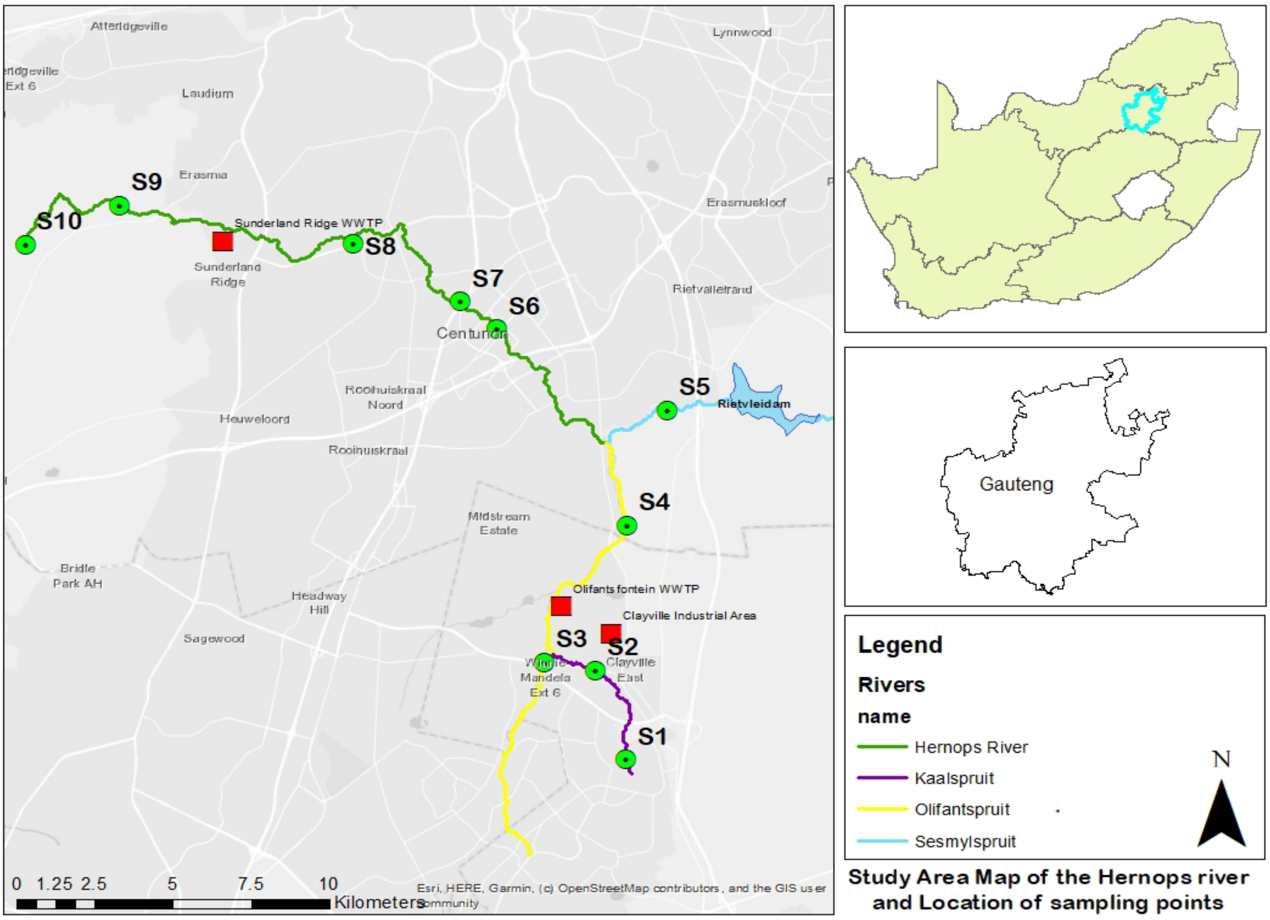


Figure 5.3. Area Map showing the study area sampling sites along the Hennnops river catchment in Gauteng, South Africa.

CHAPTER 6: RESULTS AND DISCUSSIONS A – CHEMICAL ANALYSIS

Water quality results of the Hennops river catchment are presented in this chapter. The results show the status of the Hennops river at the start of the Project before intervention measures were implemented that was conducted from (August 2021-November 2021) and the status of the pollution at the end of the project that was conducted from (July 2022-ovember 2022).

6.1 Physio-chemical and microbiological water quality

Table 6.1a indicates the initial physiochemical water parameters, the lowest pH value recorded was 6.9 recorded at S2 and the highest value was 7.4 that was recorded at S10. The final status results in **Table 6.1b** had a lowest pH value of 7.87 recorded at S3 and the highest value of 8.18 at S8. The trend in pH observed during the initial and finals status showed an increase in pH from upstream to downstream, and the pH of the water was more basic in the final sampling.

Electrical Conductivity values for both the initial and final status assessment were within tolerable limits. conductivity values for the initial status assessment ranged from 242 $\mu S.cm^{-1}$recorded at S2 to 785 $\mu S.cm^{-1}$ recorded at S1. For the final assessment conductivity values ranged from 163.7 $\mu S.cm^{-1}$recorded at S7 to 376.0 $\mu S.cm^{-1}$ recorded at S9. The conductivity values were lower in the final assessment. Total Dissolved Solids (TDS) values for the initial assessment ranged from 115 mg/L recorded at S2 to 399 $\mu S.cm^{-1}$ recorded at S1. For the final assessment conductivity values ranged from 91.5 mg/L recorded at S7 to 164.6 mg/L recorded at S9. The conductivity values have significantly dropped during the final assessment in comparison to the initial assessment.

Dissolved Oxygen (DO) levels were found to be below the ideal quality range for fresh water of 9.1 mg L^{-1}.. S4 revealed the lowest DO value of 1.53 mg/L and S10 had the highest DO value of 6.47 mg/L The DO content is drastically low in the upstream areas as they are point sources of sewage discharge from leaking pipes and wastewater treatment plants which introduces a high content of organic matter leading to a high oxygen demand in the water. DO measurements were only conducted in the initial water quality status assessment.

The data in **table 6.1a and 6.1b** further shows indicates that river water is under microbiological contamination at all sampling points and is unfit for drinking, irrigation, and recreational use as the specifications by DWAF are exceeded tremendously. There is generally high microbiological contamination in the upstream area that arises from the raw sewage spew into the river, site S3 which is located below the Olifantsfontein wastewater treatment plant which discharges effluent into the river has the highest Total Aerobic Count (TAC) 20 000 000 CFU mL^{-1} and S2 had the highest Coliform Count of 900 000 CFU mL^{-1}.

Microbiological however shows a worsening status of the Hennops river as the total aerobic counts are very high in the range 1 500 000-400 000 000 CFU mL^{-1} which are higher than those observed in the initial sampling that reached a maximum of 20 000 000 CFU mL^{-1} in the upstream area. Total coliform count was in the range 78 333-180 00 CFU mL^{-1} while the E. Coli count is in the range (225-14 500 CFU mL^{-1}). The microbiological analysis data shows that the Hennops water quality is still in a poor state that mainly arises from uncontrolled sewage leakages in the upstream areas. Results also suggest that the Hartbeespoort is currently acting as a major sink for upstream pollution as the amount *E. Coli* detected after the dam was low but still present indicating that some pollution still escapes the dam. This is supported by repeated covering of the dam with water hyacinth because of continued pollution from upstream. Interesting, the western channel of the dam has high conductivity and also after the dam wall.

Table 6.1a. Initial Water quality parameters measured at each site of the Hennops river

Sampling Site	**pH**	**TDS (mg L^{-1})**	**Conductivity (µs cm^{-1})**	**DO (mg L^{-1})**	**TAC (CFU mL^{-1})**	**Coliform Count (CFU mL^{-1})**	**E. Coli Count (CFU mL^{-1})**	**E. Coli Detection**
S1	7,06 ± 0.01	399 ± 13	785 ± 60	1,82	2 800 000	670 000	8 600	Positive
S2	6,90 ± 0.03	115 ± 70	242 ± 12	2,87	3 900 000	900 000	20 000	Positive
S3	6,92 ± 0.01	364 ± 15	743 ± 40	1,53	20 000 000	853 333	20 000	Positive
S4	7,12 ± 0.02	379 ± 10	758 ± 16	4,66	3 300 000	82 333	1 200	Positive
S5	7,13 ± 0.01	343 ± 13	690 ± 50	5,04	1 500 000	78 333	225	Positive
S6	7,15 ± 0.02	379 ± 22	758 ± 90	4,37	1 956 667	24 500	225	Positive
S7	7,40 ± 0.03	376 ± 11	768 ± 40	6,47	310 000	8 500	20	Positive

Table 6.2b. Water quality parameters measured at each site of the Hennops river after clean-up.

Sampling Site	**pH**	**TDS (mg L^{-1})**	**Conductivity (µs cm^{-1})**	**TAC (CFU mL^{-1})**	**Coliform Count (CFU mL^{-1})**	**E. Coli Count (CFU mL^{-1})**	**E. Coli Detection**
S3	7.87	153.4	306.6	320 000 000	170 000	2 250	Positive
S5	8,00	95,4	190,9	400 000 000	180 000	1 150	Positive
S7	8,12	91,5	183,7	3 150 000	195 000	1 450	Positive
S8	8,18	187,8	275,8	1 700 000	495	30	Positive
S9	8,16	184,6	376,0	90 000	2 650	4	Positive

6.2 Elemental analysis

Figure 6.1 represents the trace metals data from Spinach (Spinacia oleracea) and Rapeseed seed (Brassica napus) vegetables samples from Commercial vegetable plantations along the Hennops river. No trace metals were detected in water samples collected along the river. This may be primarily due to the low concentrations of such metals in water given the bulk volume of the river. This may require deployment of passive samplers for preconcentration of the trace metals in water. The continuous irrigation of vegetables with contaminated water may lead to the accumulation of trace metals in soil which are in turn taken up by the plant's roots and stored in plant's leaves. This may explain the presence of trace metals in both Rapeseed and spinach samples in contrast with the water samples that did not show any trace metals.

The general trend in detected trace metals is Al > Mn > Cu > Cr > Cd > As > Pb in spinach while in Rapeseed was Cu > Al > Cr > Mn > Pb > As > Cd. Spinach samples had accumulated higher quantities of trace metals than Rapeseed with the exception of lead which was higher in Rapeseed. Both samples contained toxic metals As, Pb and Cr which its hexavalent form is toxic were present in concentrations higher than the recommended permissible limits by WHO. This is a health risk to the consumers of the vegetables grown in the area as the metals pose noncarcinogenic and carcinogenic health effects from their oral ingestion.

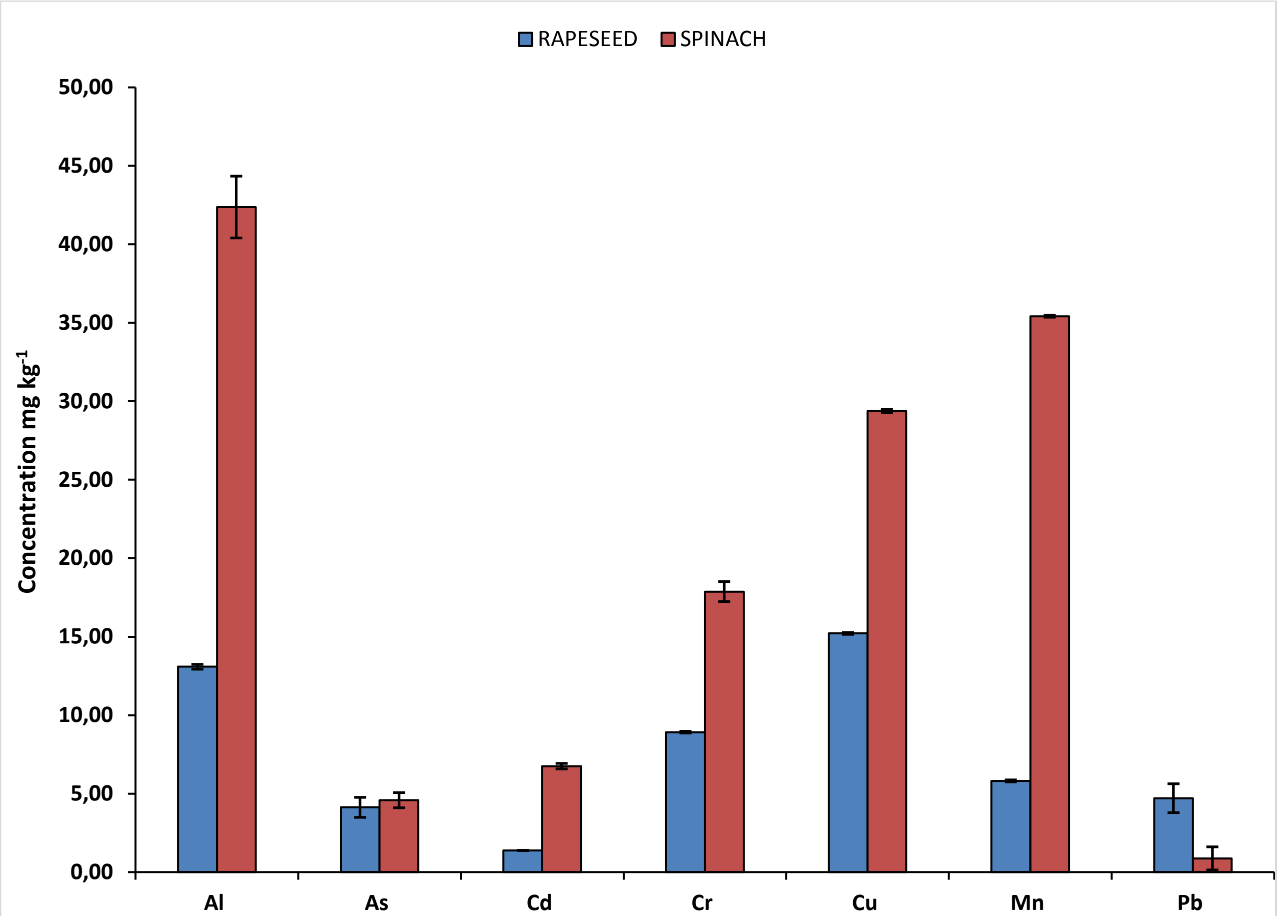


Figure 6.1. Elemental analysis data of vegetable samples irrigated with Hennops river water (n=3).

6.3 Toxicity Analysis

The water samples toxicity collected along the Hennops showed no significant effects on bacterium as mortality ranged from 5 to 30% as shown in **figure 6.2**. The Hennops' sediment samples toxicity was assessed by direct exposure to benthic ostracods (*Heterocypris incongruens*) The effects percentages (%) on ostracods growth after 6 days of direct contact with sediments ranged 100% as shown in **Table 6.2**. These results indicated the maximum mortality of the bioassay and an acute effect. As the individuals did not survive for the test duration, it was not possible to determine the growth inhibition.

Given the toxicity classification of natural waters, the Hennops river samples toxicity is summarized in **Table 6.2**. The data analysis showed that Hennops river water fits mainly in toxicity class **I** – no acute toxic effect (S1) for toxicity class **II** – slightly acute toxic effect (S4, S6, S8, S9, S10). The water samples collected at S1 demonstrated 80% mortality to P. reticulata however the effect level was below 100% as shown in **figure 6.2** and a Hazard Class **III** (acute hazard) was assigned. The minimum acute hazard could be explained by the dilution effect due to incidence periods of heavy rainfall and flooding that may affect biotic or abiotic conditions throughout life environment. A Hazard Class of V (very high acute hazard) was allocated to the sediment samples collected below S1 (upstream) and the S9 (downstream) as the samples produced 100% mortality to Hetereocypris incongruens.

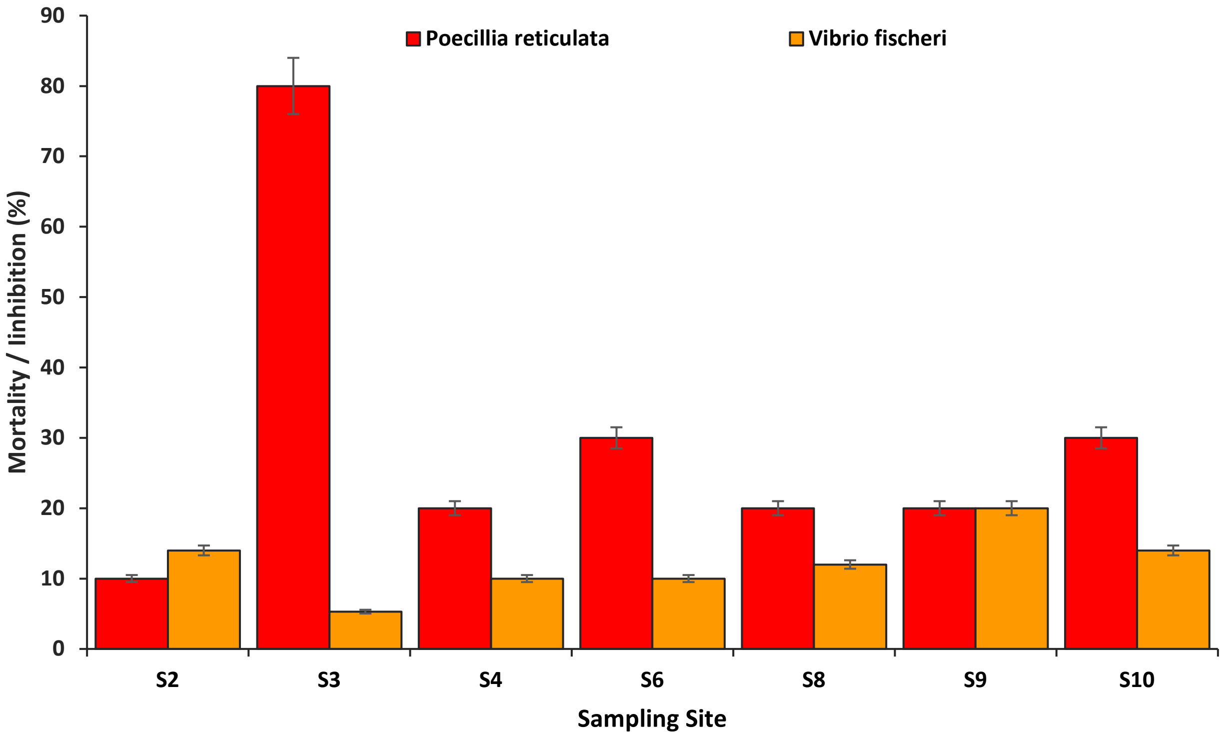


Figure 6.2. Water samples toxicity on *Vibrio fischeri* and *Poecillia Reticulata*

Table 6.3. Hazzard Classification system for natural waters (*Personne et al.,* 2003)

Sampling Site	Hazard Classification	Toxicity Test results
S2	I	14% inhibition at 30 min *V. fischeri exposure*, 0% mortality to *P. reticulata*
S3	III	5,3% inhibition at 30 min *V. fischeri exposure*, 80% mortality to *P. reticulata*
S4	II	10% inhibition at 30 min *V. fischeri exposure*, 20% mortality to *P. reticulata*
S6	II	10% inhibition at 30 min *V. fischeri exposure*, 30% mortality to *P. reticulata*
S8	II	12% inhibition at 30 min *V. fischeri exposure*, 20% mortality to *P. reticulata*
S9	II	20% inhibition at 30 min *V. fischeri exposure*, 20% mortality to *P. reticulata*
S10	II	14% inhibition at 30 min *V. fischeri exposure*, 30% mortality to *P. reticulata*
S3 (Sediment)	V	100% mortality to *Hetereocypris incongruens*
S9 (Sediment)	V	100% mortality to *Hetereocypris incongruens*

6.4 Organic water pollutants analysis

6.4.1 Method Performance and Validation

Method validation for SPE was performed on spiked river water samples at 5 ng mL^{-1} and POCIS method validation was performed on deionized water spiked with 5 ng mL^{-1} of the target analytes. Method performance and validation parameters of each technique are summarized in **Table 6.4**. The correlation coefficient (r^2) was in the range of 0.989 to 0.999 and the linearity was determined in the range 1-100 (ng mL^{-1}) for methocarbamol, carbamazepine, nevirapine, venlafaxine and 5-100 (ng mL^{-1}) for Etilefrine. The POCIS and SPE methods yielded recoveries ranging from 76 to 92% and 73 to 89% for all target compounds, respectively. Despite the recoveries of SPE being lower than POCIS, the standard deviation of the SPE results was lower than that of POCIS indicating that the method offers better reproducibility. The sensitivity of the methods was evaluated, the LOD and LOQ were in the range (0.16 to 1.14 ng mL^{-1}) and (0.57 to 2.12) for POCIS while the LOD and LOQ were in the range (0.1 to 1.64) and (0.19 to 1.82) for SPE.

The uptake curves shown in **figure 6.3** a linear update model for all compounds. The data obtained from the uptake curves was used to calculate the sampling rates R_s as shown in **table 6.3**. The experimental sampling rates of carbamazepine was 0.067 L d^{-1} was found to be lower than the reported value of 0.15 L d^{-1}, venlafaxine had a higher experimental sampling rate of 0.87 L d^{-1} than the theoretical value of 0.11 L d^{-1} which were obtained from POCIS calibrated samplers. There were no literature sampling rates for compounds nevirapine, methocarbamol and etilefrine using POCIS reported on literature and the experimental were compared to a combined membrane assisted solvent extraction (MASE) and molecularly imprinted polymer (MIP) approach. The experimental sampling rates for methocarbamol, etilefrine and nevirapine were (0.26 L d^{-1}, 0.041 L d^{-1} and 0.022 L d^{-1}) respectively while experimental values were (0.0007 L d^{-1}, 0.0018 L d^{-1} and 0.0011 L d^{-1}).

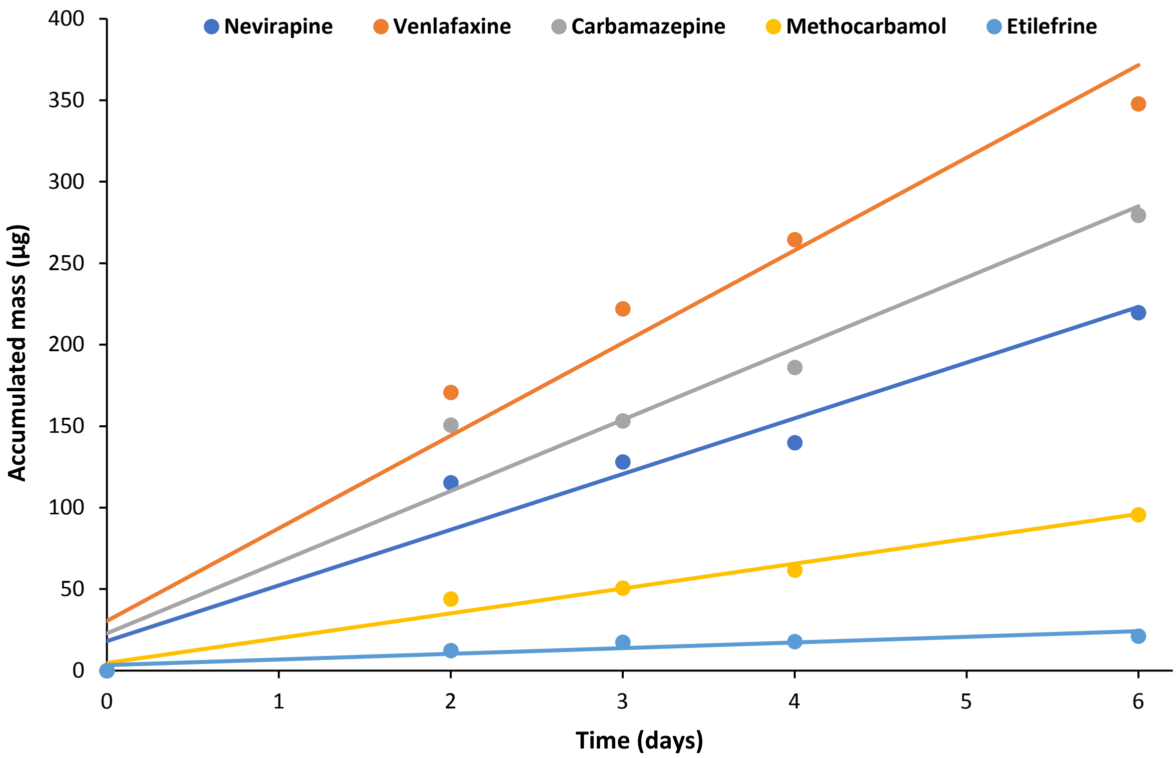


Figure 6.3. Uptake curves showing relationship between accumulated mass of Nevirapine, venlafaxine, Carbamazepine, methocarbamol and Etilefrine over 6 days.

Table 6.4. Estimated sampling rates (Rs) obtained from literature and the current study from the target pharmaceuticals.

Compound	**Experimental Sampling rates (L d^{-1})**	**Theoretical Sampling rates (L d^{-1})**	**Sampler Type**	**Reference**
Methocarbamol	0.26	0.0007	MASE-MIP	(Khulu *et al.*, 2022)
Carbamazepine	0.067	0.15	POCIS	(Wang *et al.*, 2022)
Etilefrine	0.041	0.0018	MASE-MIP	(Khulu *et al.*, 2022)
Nevirapine	0.022	0.0011	MASE-MIP	(Khulu *et al.*, 2022)
Venlafaxine	0.87	0.11	POCIS	(Vrana *et al.*, 2021)

6.4.2 Application of SPE and POCIS in monitoring of target pharmaceuticals in river water

Table 6.5 shows SPE and POCIS sampling data for monitoring target pharmaceutical compounds along the Hennops river Catchment. The concentrations of methocarbamol sampled using both SPE and the POCIS are comparable with the concentrations ranging from (0.10-0.18 µg L^{-1}) using both techniques. There were no detected traces of etilefrine in the POCIS at any of the deployed sites and in grab samples extracted by solid phase extraction there were still no traces detected. This implies that if there is any etilefrine present in the

Hennops river, it may be present at very low concentrations. Both SPE and POCIS offer detection of 4 of the compounds; carbamazepine, methocarbamol, nevirapine and venlafaxine in all the sampling sites.

The general trend of in concentration of compounds is observed to be low in the upstream areas from data collected through grab sampling and SPE. Although there are identifiable point and non-point pollution sources in the upstream areas, the high flow rate of the river rapidly flushes pollutants downstream where there is more river meandering that reduces flow rate and allows for settling of pollutants and enough contact time between samplers and water. The concentration of pollutants is generally low in the upstream from S1 where it is below quantification limits then increases as flow rate decreases as observable in S7,

The findings are in accordance with the study conducted by Khulu and colleagues who extracted and detected all the compounds from the Hennops river using a MASE-MIP approach (Khulu *et al.*, 2022). The presence of these pharmaceutical compounds may be a result of sewage contamination in the river from leaking sewage pipes and wastewater treatment plants. Sampling point S5 that was introduced to determine the pollutants from the Rietvlei dam coming into the Hennops river had the compounds carbamazepine, nevirapine and venlafaxine detected at concentrations (0,04 µg L^{-1}, 0,10 µg L^{-1} and 0,04 µg L^{-1}).

Table 6.5. Analytical Method performance of SPE and POCIS

Compound	**Calibration range (ng mL^{-1})**	**Correlation Coefficient (r^2)**	**SPE Limits (ng mL^{-1})**			**POCIS Limits (ng mL^{-1})**		
			LOD	**LOQ**	**Recovery %**	**LOD**	**LOQ**	**Recovery %**
Methocarbamol	1-100	0.999	0.16	0.37	73 ± 1	0.08	0.10	92 ± 6
Carbamazepine	1-100	0.999	0.19	0.41	84 ± 3	0.17	0.28	87 ± 4
Etilefrine	5-100	0.999	1.14	2.12	68 ± 4	1.64	1.82	76 ± 8
Nevirapine	1-100	0.994	0.74	0.97	89 ± 3	0.12	0.47	86 ± 5
Venlafaxine	1-100	0.989	0.27	0.91	75 ± 2	0.19	0.11	85 ± 8

Table 6.6. Average concentrations of pharmaceuticals at different sampling points along the Hennops river

Sampling Site	Carbamazepine (ng mL^{-1})		Methocarbamol (ng mL^{-1})		Nevirapine (ng mL^{-1})		Venlafaxine (ng mL^{-1})	
	POCIS	SPE	POCIS	SPE	POCIS	SPE	POCIS	SPE
S1	-	< LOQ (0.06)	-	ND	-	ND	-	ND
S2	-	< LOQ (0.02)	-	ND	-	ND	-	ND
S3	-	< LOQ (0.17)	-	0.18 ± .0.02	-	< LOQ (0.01)	-	0.16 ± 0.07
S4	0,60 ± 0.12	< LOQ (0.04)	< LOQ (0,05)	0,10 ± 0.07	N.D	N.D	0,50 ± 0.02	< LOQ (0.04)
S5	0,51 ± 0.13	0.19 ± 0.04	0,11 ± 0.09	0,10 ± 0.09	N.D	N.D	1,19 ± 0.83	< LOQ (0.08)
S6	0,40 ± 0.06	0.12 ± 0.07	0,18 ± 0.10	0,10 ± 0.03	N.D	0.10 ± 0.03	0,20 ± 0.04	< LOQ (0.03)
S7	0,32 ± 0.04	0.13 ± 0.03	0,14 ± 0.03	0,14 ± 0.09	N.D	< LOQ (0.01)	0,44 ± 0.07	< LOQ (0.07)

(–) No data collected

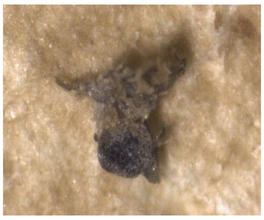
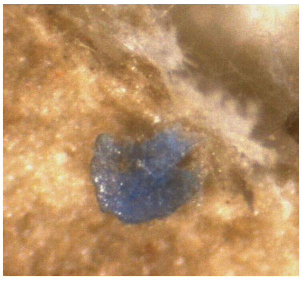
N.D denotes non-detected in the sample (below LOD)

6.4.3 Microplastic Analysis

6.4.3.1 Abundance and distribution of Microplastics in surface water and sediments

A total of 352 and 409 particles were detected in water and sediment samples collected at all sampled points as shown in **figure 6.4 and figure 6.5**, their abundances ranged from 2-11 particles/m^3 and 5-30 particles/g in sediments and water. The most recorded number of microplastic particles was in the upstream area from S1 to S2 where there is extreme occurrence of solid waste dumping and sewage leakages. The establishment of litter traps in water has also allowed for accumulation of plastics which forms microplastics by physical or chemical degradation. Sampling point S6 also showed a spike in the number of particles which may be contributed by the Sunderland ridge wastewater treatment plant. **Tables 6.6** and **table 6.7** show examples of microplastics collected at different sampling points in water and sediment samples.

Table 6.7. Types of Microplastics found along the Hennops river water

Sampling Point	Microscope results	Physical Characteristics
S1		Shape: Fragment Colour: Black Size: 3210 µm
S2		Shape: Fragment Colour: Red Size: 1815 µm
S3		Shape: fibre Colour: Black Size: 1850 µm
S4		Shape: Fragment Colour: Blue Size: 870 µm

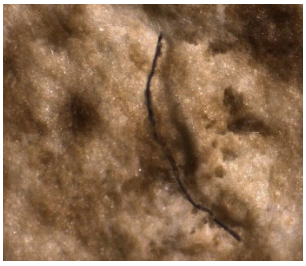
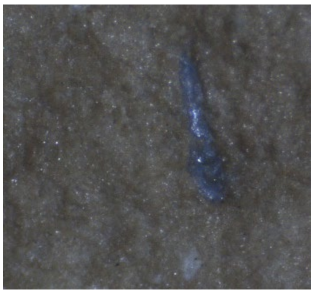
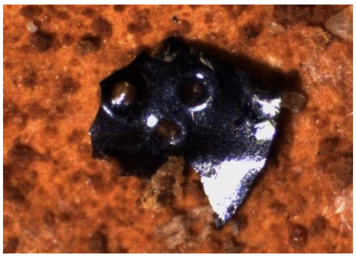
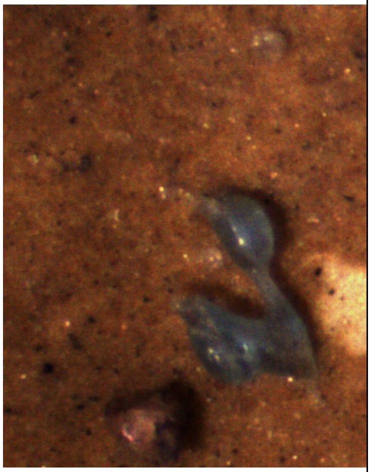
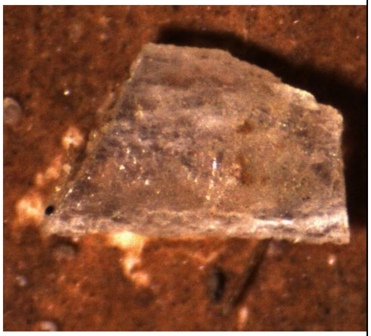
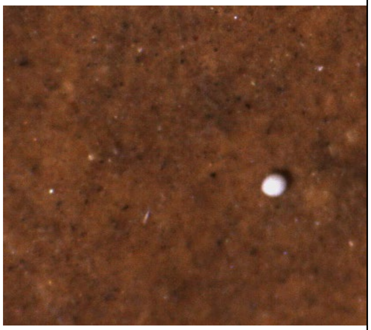
Sampling Point	Microscope results	Physical Characteristics
S5		Shape: Fibre Colour: Black Size: 1916 µm
S6		Shape: Fragment Colour: Blue Size: 540 µm

Table 6.8. Types of Microplastics found along the Hennops sediments

Sampling Point	Microscope results	Physical Characteristics
S1		Shape: Film Colour: Blue Size: 4028µm
S2		Shape: Fragment Colour: Black Size: 1827 µm

Sampling Point	Microscope results	Physical Characteristics
S3		Shape: Fragment Colour: Blue Size: 1658 µm
S4		Shape: Fragment Colour: Red Size: 3210 µm
S5		Shape: Fragment Colour: Transparent Size: 2510 µm
S6		Shape: Pellet Colour: White Size: 720 µm

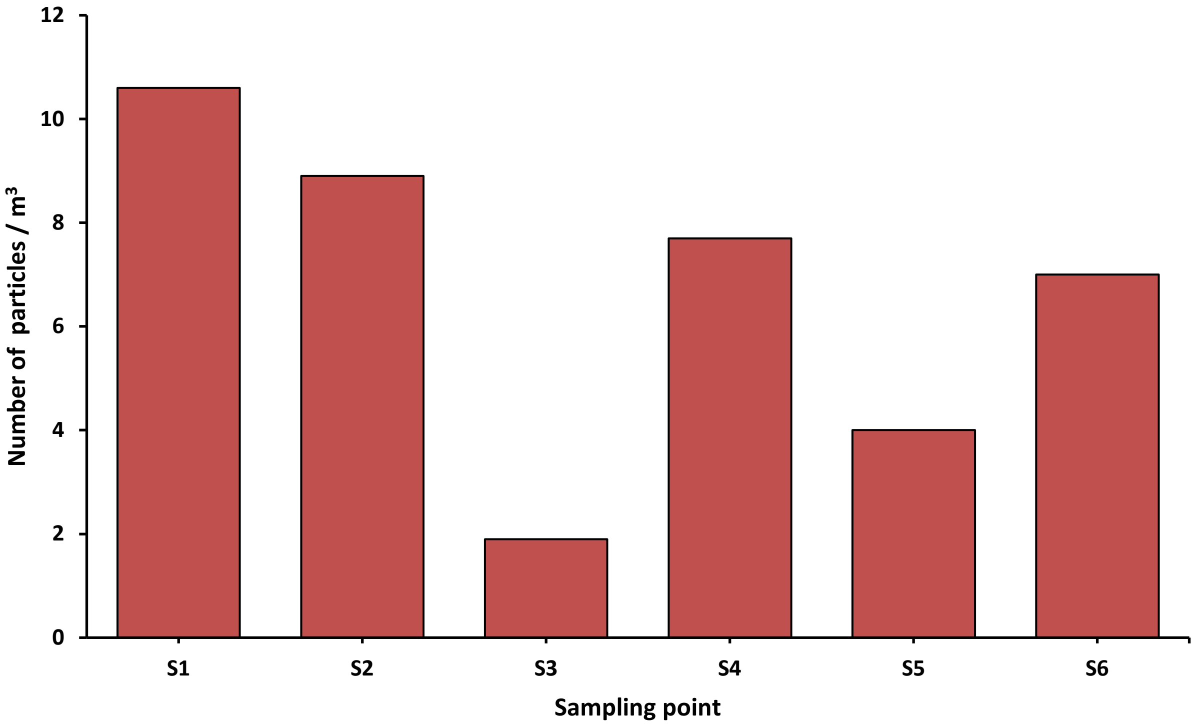


Figure 6.4. Average number of microplastics in Water samples collected at different sampling points

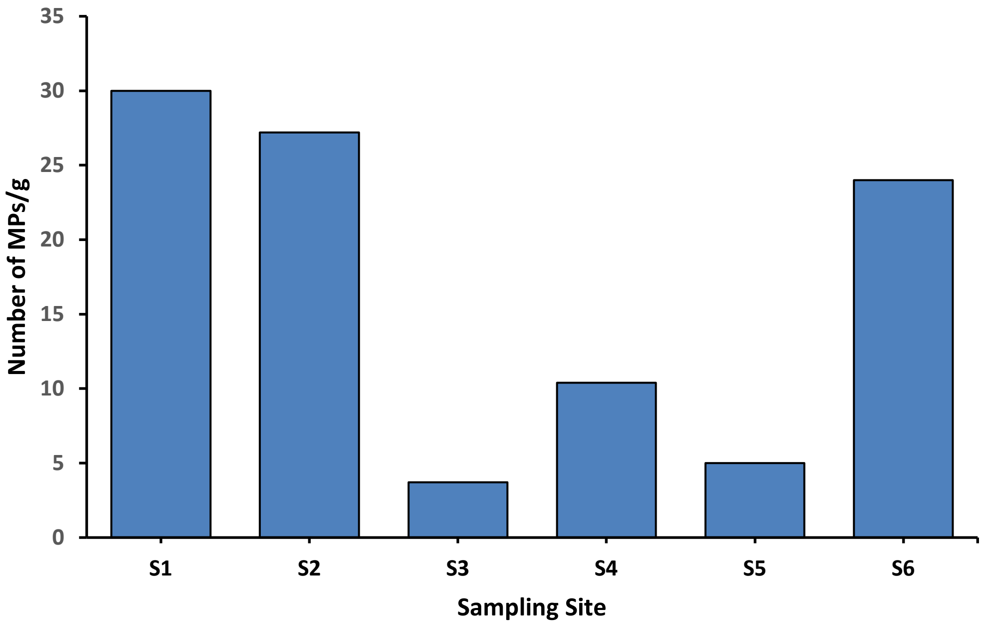


Figure 6.5. Average number of microplastics in Sediment samples collected at different sampling points

6.4.3.2 Shapes of Microplastics

Microplastics were also categorized according to their shapes: fragments, pellets, fibers, films, and foams. **Figure 6.6** shows the proportions of microplastic shapes in sediment and water samples. The predominantly detected shape of microplastics in water and sediment samples were fibres accounting for 80 and 79% respectively. The was a seldom occurrence of fragments (7 and 10%) and films (3 and 8) with pellets being the least detected (4 and 6%) in water and sediments respectively. Microplastic fibres in the environment are introduced by clothing, textile, industrial and daily life emissions, of which textiles and domestic emissions should be the main source of MPs in surface water. Film and fragment MPs were mainly derived from the decomposition of plastics produced in daily life, industrial raw material production and packaging.

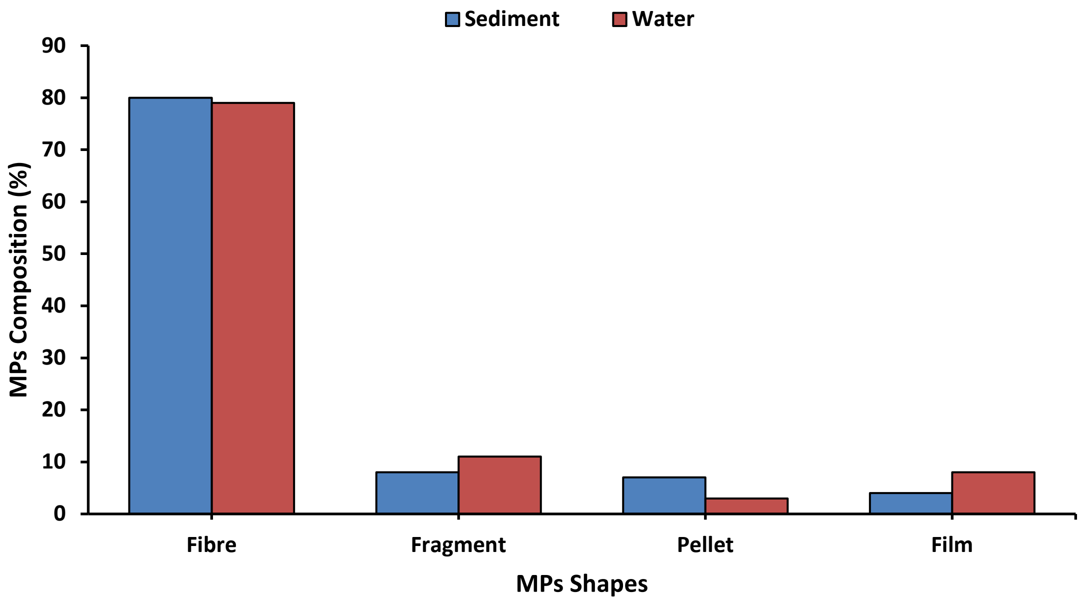


Figure 6.6. Comparison of the distribution of microplastic (MP) shapes in water and sediment samples.

6.4.3.3 Size of Microplastics

Microplastics were classified into six categories according to their sizes: less than 0.5 mm, 0.5-1 mm, 1-2 mm, 2-3 mm, 3-4 mm, and 4-5 mm. The particle size distribution of MPs in water was shown in **figure 6.7**. The order of MPs abundance in water samples based on the shape distribution was as followed: 0.5-1 mm > less than 0.5 mm > 1-2 mm > 2-3 mm > 3-4 mm > 4-5 mm and the abundance order of MPs in the sediments was 1-2 mm > 0.5-1 mm > less than 0.5 mm > 2-3 mm > 3-4 mm > 4-5 mm.

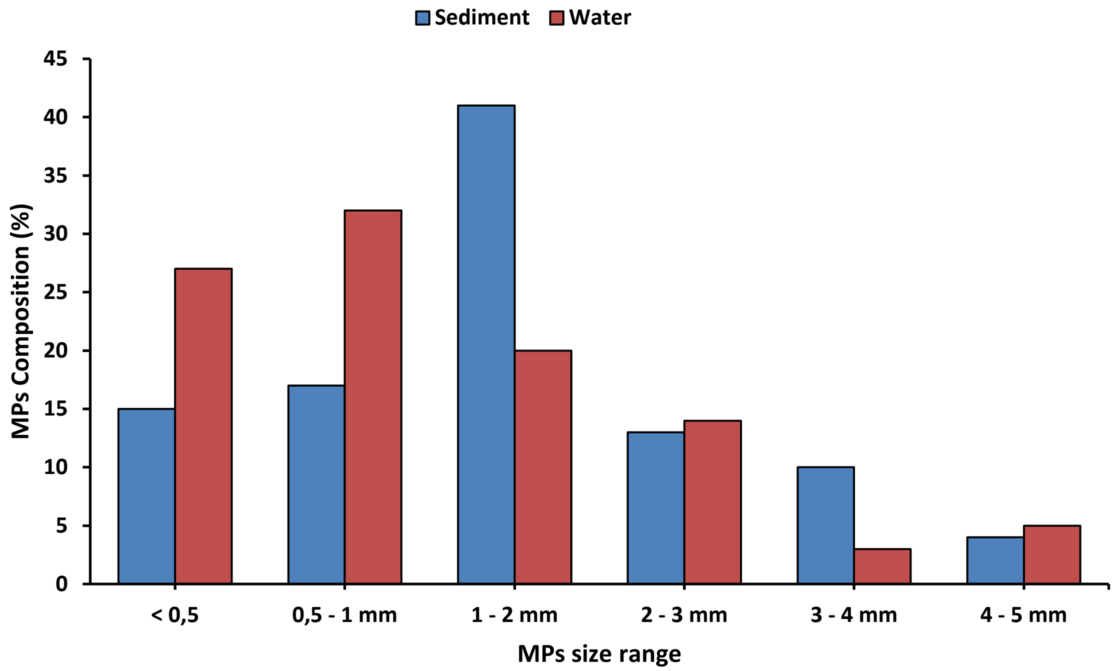


Figure 6.7. Comparison of the distribution of microplastic (MP) sizes in water and sediment samples.

6.4.3.4 Colour of Microplastics

Microplastic particles were grouped into different colour categories: blue, black, red, green, white, and transparent, because these were the most abundant colours; other colours (pink, purple, yellow, and brown) in extremely low quantities were classified as “others” and are represented in **figure 6.8**. The abundance of MPs in blue accounted for the highest, which was 40% in the water and 35% in the sediments. However, MPs that were in black were also frequently present accounting for 25% and 30% in water and sediment samples respectively. MPs in medium in colours white, red, green and transparent were seen less frequently, which made up almost 35% of MPs in water and sediments.

The studies have shown that the surface of dyed plastic particles contains more harmful elements,

such as heavy metals, persistent organic pollutants and pathogens (Duis and Coors, 2016b), and would be released into the environment under a series of environmental effects. In addition, the intake of MPs is affected by the colour of plastics. Marine organisms were more likely to ingest bright colours or plastic particles that were similar in colour to food, especially MPs; made them similar to the natural foods that biota could ingest (Hidalgo-Ruz *et al.*, 2012).

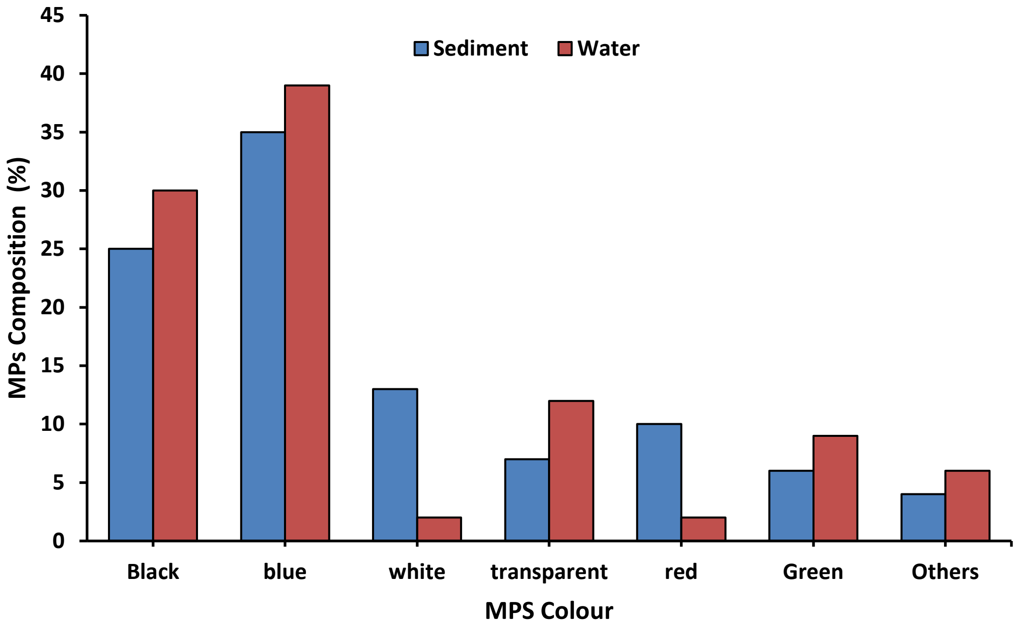


Figure 6.8. Comparison of the distribution of microplastic (MP) colour in water and sediment samples.

6.4.3.5 Surface morphology

Identification of surface textures on plastic particles enables distinction between the processes of mechanical and oxidative weathering. The surface texture of selected microplastics of various shapes was examined trough SEM analysis as shown in **figure 6.9-figure 6.11**. **Figure 6.9** shows fractures on a filament particle, fractures are generally formed through a process known as stress corrosion cracking. This process occurs when a critical strain is exceeded and crazing (fine cracks on surface) results (Jemec *et al.*, 2016). Crazing may transform into micro-cracks due to fibril breakage and propagate to a critical size at which point catastrophic failure occurs and a fracture develops as shown in **figure 6.10**. Plastic particles can be dragged or scratched as the river flows resulting in grooves. Grooves are long, narrow indentations caused by a tool moving over a plastic particle or the particle being dragged on the riverbed as seen on the fibre in **figure 6.10** and a fragment in **figure 6.11** (Drummond *et al.*, 2022).

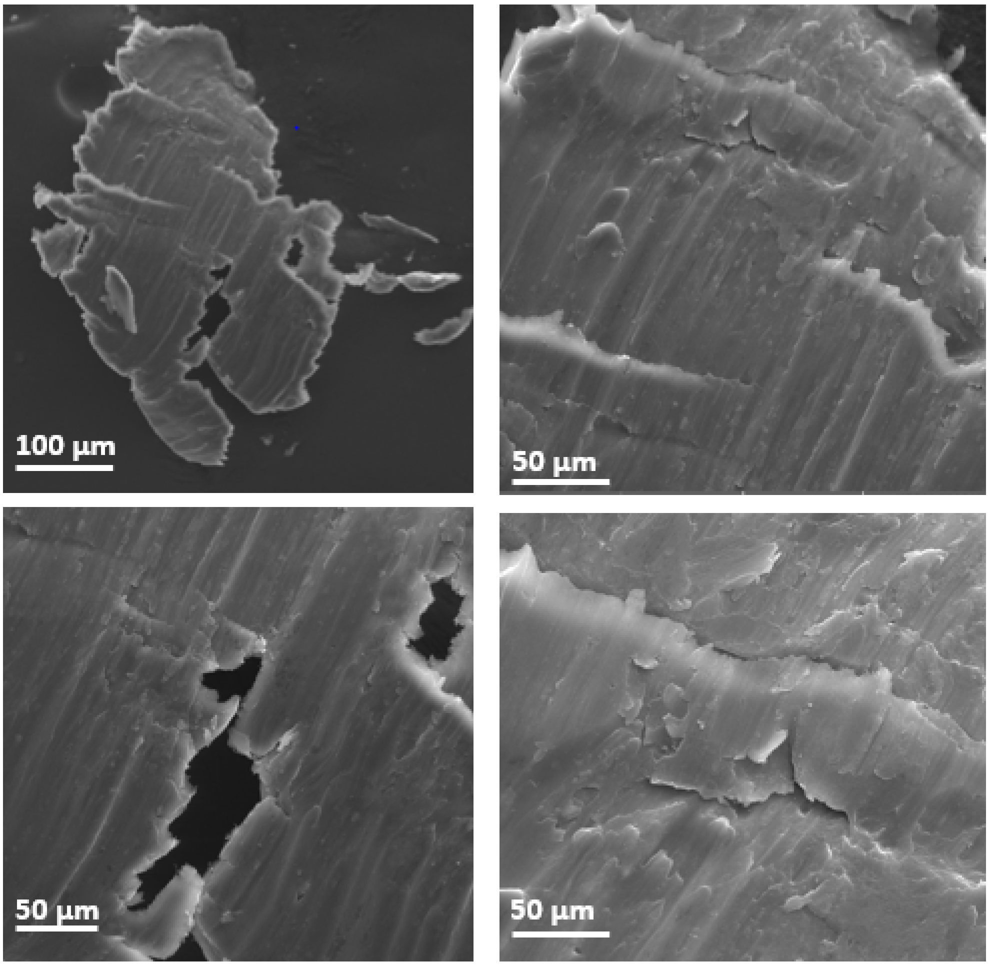


Figure 6.9. Scanning electron microscopy images of a microplastic film

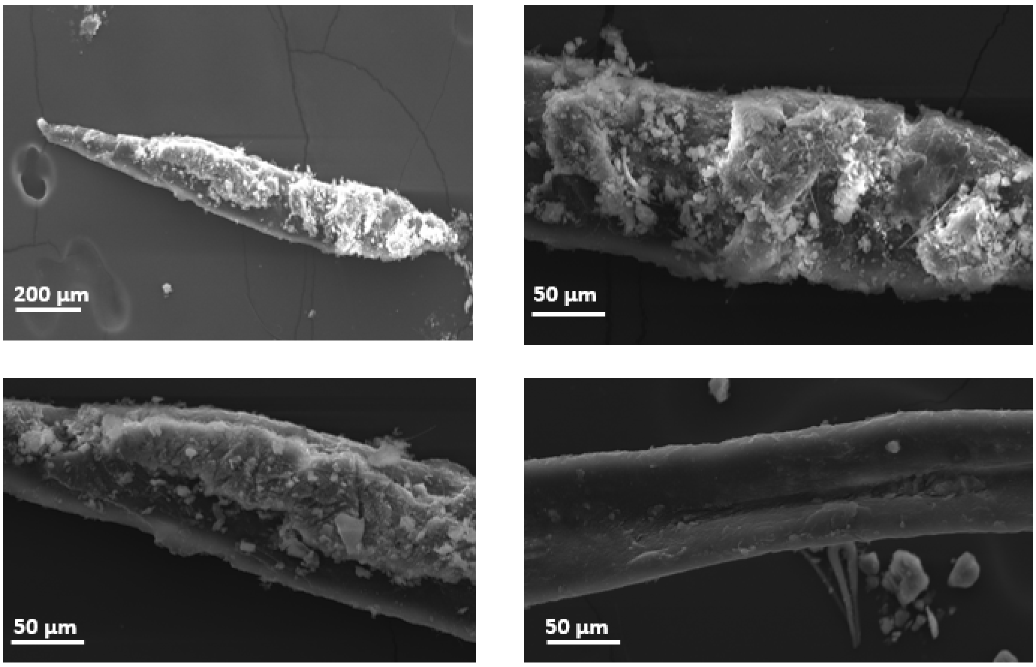


Figure 6.10. Scanning electron microscopy images of a microplastic fibre

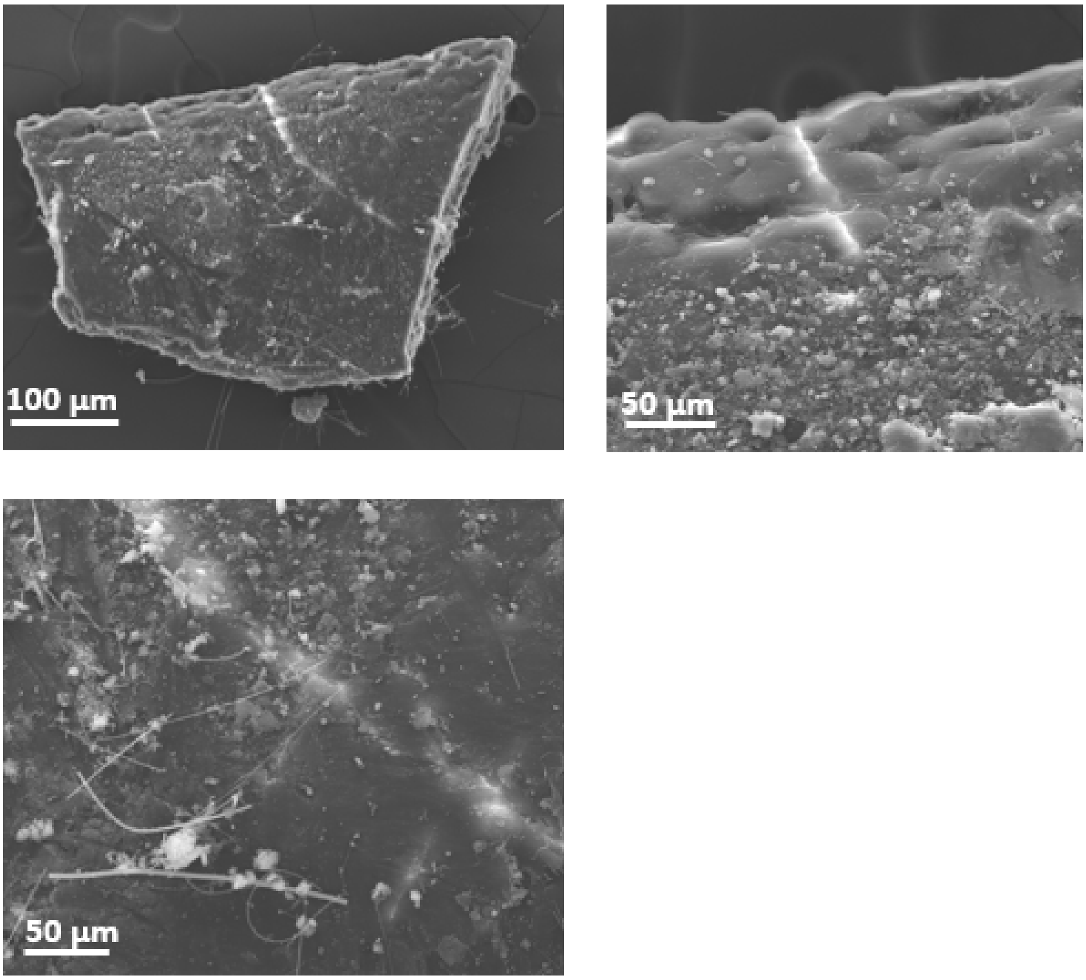


Figure 6.11. Scanning electron microscopy image a microplastic fragment

6.4.3.6 Identification of Microplastics

Suspected microplastic particles were analysed by Raman Spectroscopy, which has been widely employed in identifying microplastic polymers due to its high reliability in determining chemical compositions of unknown plastic fragments. **Figure 6.12-6.15** shows Raman spectra of common polymers analysed in microplastics, the sample spectra are shown in blue, and the corresponding reference spectra are plotted in orange. Five polymer types were identified polyethylene (PE), polypropylene (PP), high density polyethylene, (HDPE), polyester and polystyrene. The predominant polymer type in surface water was PE (48.6%), and that in sediment was PP (52.7%). PE and PP were the most abundant polymer types in both phases, and as these also the leading polymers in plastics production.

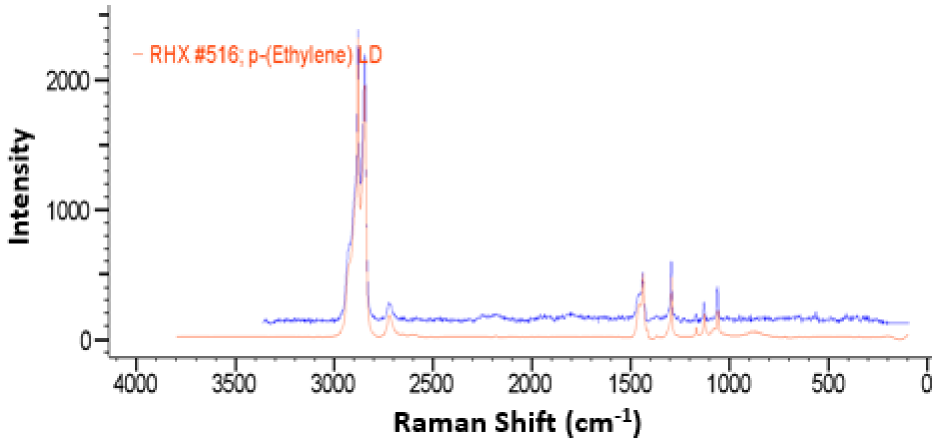


Figure 6.12. Raman spectra of low-density polyethylene (LDPE)

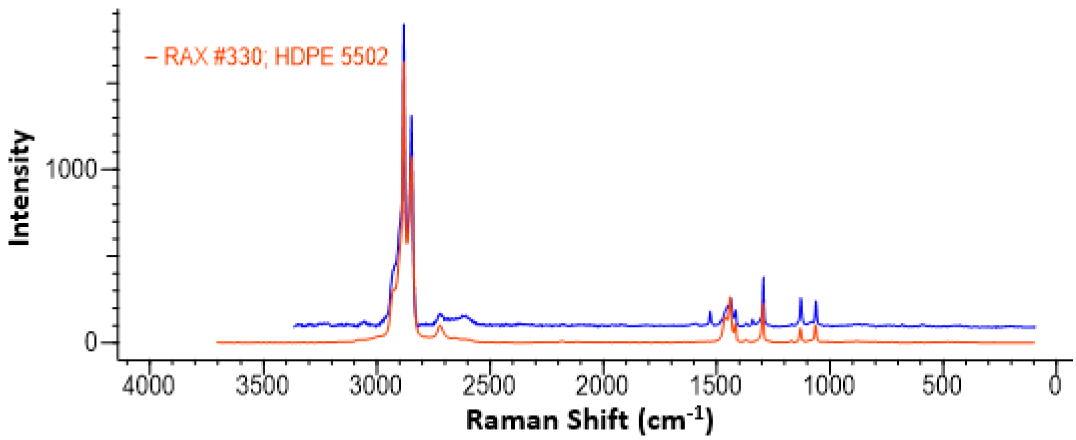


Figure 6.13. Raman spectra of High density polyethylene (HDPE)

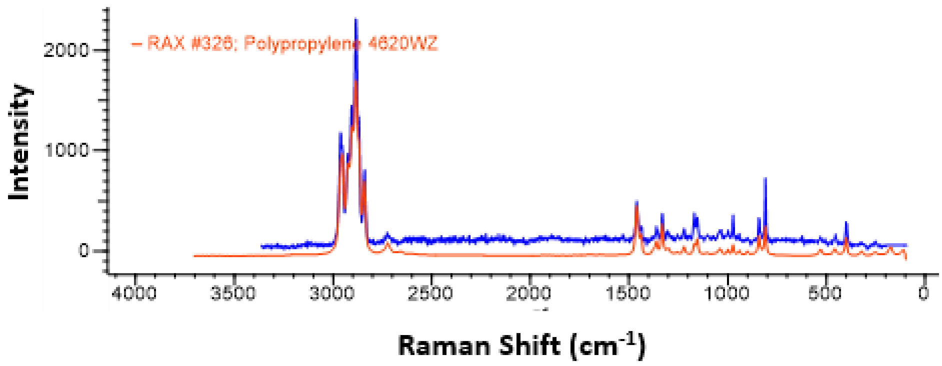


Figure 6.14. Raman spectra of Polypropylene

6.4.3.7 Toxicity and Risk of Identified microplastics

Microplastics that were recovered from water and sediment samples fibrous, in small sizes (0.5-1 mm) and coloured (dyed). These characteristic nature of microplastics are a concern as aquatic organisms are attracted and consume small, fibrous microplastics as they have a resemblance to their prey. Smaller sized microplastics have also been found to end up in aquatic organisms' muscles and liver and their fibrous nature allows them to be embedded in the tissue and digestive systems of organisms

CHAPTER 7: RESULTS AND DISCUSSIONS B – STAKEHOLDER'S ENGAGEMENT

7.1 FINDINGS AND OBSERVATIONS

The following is a report on findings after applying the methodology of this component. While the findings of the rapid appraisal of literature were presented in previous sections supporting the terms of reference and theoretical considerations of this study, this section focuses on the findings of the stakeholder workshops, the community workshop as well as engagement with communities and stakeholders through clean-up campaigns and additional capacity building activities which followed.

7.1.1 Stakeholder workshops

7.1.1.1 Initial stakeholder meeting and Root Cause Analysis

This stakeholder meeting was attended by various stakeholders and key community members who have an interest in the wellbeing of the river basin. **Figures 7.1** and **7.2** are some photographs taken during the stakeholder meeting. The first part of the meeting included introductions and presentations. The second part, however, involved the application of a RCA, as previously described. Before exploring the findings related to the RCA, meeting delegates were given the opportunity to articulate their observations of the current state of the Hennops River basin. **Table 7.1** provides a list of some of the key points made during the meeting. These are listed according to a logical order and not as they were presented during the meeting.

Figure 7.1. Prof. Simatele doing the introductory presentation of the initial stakeholder meeting

Figure 7.2. Photograph taken during the RCA of the stakeholder meeting

Table 7.1. List of observations about the state and happenings within the Hennops River basin

	Points made by attendees/stakeholders
1.	The river's state is "absolutely terrible" – Water perceived as septic and pitch black
2.	The river's worst state can be observed in Winter with more sewage being brought downstream
3.	Summer is characterised by plastic/ solid waste pollution
4.	Vandalised pump stations can be observed near where samples were taken for chemical analyses
5.	Informal settlement is very prominent within the river basin
6.	Municipal services such as waste removal are not provided to informal settlements
7.	Illegal dumping is observed and is very prominent in the river basin
8.	Proper sanitation is not provided for community members near the river
9.	Agriculture is still practiced in the area

	Points made by attendees/stakeholders
10.	People are not aware of the extent of pollution in the area
11.	Problems are very old and no one is addressing them

From the listed points, a few key observations were made before engaging in the Root Cause Analysis. Firstly, stakeholders and community members perceive the Hennops River basin to be heavily affected by pollution. The pollution of the Hennops River is perceivable to anyone, according to the comments of the delegates at the meeting. Through further discussion, it was stated that the samples drawn for chemical analyses were taken from key locations which exhibit the level of pollution observed by stakeholders and key community members. Seasonality also plays an important role, with pollution through effluent discharge observed during Winter, and solid waste quantities within the river peaking during Summer. It was further suggested that during Winter months, the impact of effluent on the river renders it in its worst observable state. However, during Summer, rains wash solid waste down the drainage basin, downstream where pollution accumulates. Therefore, two levels of pollution can be related to the state of the Hennops River and its drainage basin. Furthermore, two sources of polluted can be related to the state of the river basin, i.e., raw sewage effluent, and solid waste.

The meeting's delegates made it clear that they believe the river is affected by settlement, industry, and activities along its banks, particularly upstream along tributaries like the Kaalspruit and Olifantspruit. A link was drawn between solid waste pollution and illegal dumping along the banks of the river and its tributaries. At the same time, economic activities including sand mining was mentioned as another contributor to the observed state of the river basin. Furthermore, illegal dumping was presented as an issue that stems from several sources and problems that have not been addressed. This point will be further elaborated on during the presentation of findings related to the RCA. However, a strong link was made between illegal dumping, solid waste pollution and the subsequent condition of the Hennops river itself, particularly downstream.

Despite the perceivable condition of the river, stakeholders and community members emphasised that people are not aware of the extent of the pollution in the area. This also related to the idea that authorities, municipalities, and leaders are not active or show a lack of interest in the management of the Hennops River. Both economic and social activities continue within the river basin despite their potential impact on the river and its water resources. This was illustrated through the example of agriculture, which was noted as an activity making use of the Hennops river basin's water resources for food production despite the poor and hazardous quality of the water. It was also supported that the state of the Hennops River basin has not been optimal for a very long time, therefore, the issues behind its pollution are long-standing and have never been addressed.

After a discussion on the state of the Hennops River basin, Stakeholders and key community members were asked to reflect on what they believe the main problems are. Problems were then ranked by stakeholders and community members, highlighting the most important problems, followed by consequential problems. **Table 7.2** provides a list of the unranked problems summarised and highlighted during the workshop.

Table 7.2. List of identified problems – problems not ranked

Problem	**Description of problem**
Dumping (landfill and plastic dumping)	Waste being dumped into the river – origin was discussed in relation to lack of service delivery and continuous informal settlement – includes infilling of wetlands and illegal waste dumping
Illegal settlements	Stakeholders expressed concern on the alarming number of households along the river banks
Lack of service delivery	Waste management was argued to be a major concern, leading to illegal dumping of waste

Problem	Description of problem
Poor performing wastewater treatment works	Community members and stakeholders have stated that wastewater treatment works upstream are poor performing
Lack of education or awareness	People affected by the issue of the polluted Hennops River basin are not aware of their impact nor how they are impacted on by the situation
Infrastructure – poor maintenance or lack there of	Relates back to poor performing wastewater treatment works, sanitation and other services
Lack of political will and involvement	Authorities seem not aware of the issues around the Hennops River. Not much is being done to change the situation
Poor implementation of policy and law	Law is not enforced by authorities. This leads to issues such as illegal dumping and informal settlement
Lack of funds and support	Related to lack of political will and involvement of authorities and industries
Lack of activism and activists	Despite the lack of political will, not enough action is being taken to address issues. There appears to be a fear of authorities
Lack of a proper agenda	No framework or structure is apparent in managing the Hennops River basin
Lack of commitment	Related to lack of political will, funds and support.
Lack of corporate social responsibility	Industries and businesses are not concerned about the impact of their activities on the Hennops River

The above listed issues were then ranked according to importance. Delegates at the meeting identified five items from the list above and considered them the most important problems underlying the management of the Hennops River basin. These five items were:

- Lack of service delivery
- Infrastructure – poor maintenance or lack there of
- Lack of political will and involvement
- Poor implementation of policy and law
- Lack of education and awareness

These listed problems were regarded by stakeholders and community members as the greatest contributors to the worsening of the situation of the Hennops River basin. Furthermore, the five listed problems related to governance and management. While these problems were discussed as important contributors to the larger issue, they were argued to be more indirect issues which influence the development of the various causes of the problem. These issues also have a direct relationship to the development of the problem and have a ripple effect, triggering other problems.

Lack of service delivery was regarded as an important contributor to the dumping issue observed in the river basin. Since people do not have access to waste management services, they resort to illegal dumping. It was further discussed that illegal dumping was an organised activity which authorities are not aware of. According to the stakeholders and key community members attending the meeting, communities are not aware of their impact on the river basin and the environment. Lack of service delivery is also related to poor sanitation and poor performing wastewater treatment works.

Lack of and poor maintenance of infrastructure was regarded as an issue which relates to sanitation and wastewater treatment works, but also the lack of housing, poor town planning, and consequent lack of service delivery. Lack of infrastructure underlines these issues, ultimately contributing to the pollution and mismanagement of the river basin.

Lack of political will and involvement as well as poor implementation of policy and law were raised as key contributors to illegal or informal settlement, illegal dumping, and lack of corporate social responsibility. The lack of political will also relates to consequent problems such as the lack of funds and support, lack of a proper agenda, lack of commitment, lack of activism and activists. This issue was also considered relating to the poor implementation of policy and law, which essentially would be supported by authorities and leaders. Poor policy and law enforcement is considered as a reason for continued illegal dumping as well as the misuse and abuse of water resources within the river basin.

Finally, it was discussed that authorities, communities, industries, and organisations are not aware of the issues causing the pollution of the Hennops river basin. Therefore, no action is being taken to address the identified problems and their causes. Lack of awareness also relates to the activities of industries along the river and corporate social responsibility. At the same time, some are aware of the issues, for example, the stakeholders present at the meeting, however, because of the lack of support and political will, these few groups and organisations have little influence on the larger problems and causes.

Following from the ranking of these issues as primary driving factors or contributors, the resulting problems were identified as:

- Dumping
- Lack of corporate social responsibility
- Poor performing wastewater treatment works
- Lack of funds and support
- Lack of a proper agenda
- Lack of activism and activists
- Lack of commitment

Informal and illegal settlement, however, was classified as a wicked problem that relates to many of the above issues in different, complex ways. Firstly, the informal settlement of people near tributaries and the river itself is not being addressed at all. Some of these settlements have been built in areas which pose a danger to residents. This involves issues beyond that which was identified in the context of the Hennops River basin. For example, it was stated that some settlements have been built on old landfills, with some built on the floodplains of the river, and others built under powerlines. For this reason, informal settlement was considered a whole problem on its own, subsequently contributing to the pollution of the Hennops River. Furthermore, informal settlements are not being serviced by the municipality because of their legal status. Therefore, informal settlements resort to dumping as a means of waste disposal through the complex networks highlighted earlier. Furthermore, a question of rights was highlighted in terms of the right of informal settlers to the city and its services. Therefore, informal settlements were discussed and considered a wicked problem, which relates to more than the other causes and problems highlighted.

As a consequence of the five main causes or contributors highlighted earlier as well as the wicked problem of informal settlements, dumping was considered the first consequence and problem noted along the tributaries and main river of the Hennops River basin. Solid waste dumping was related to the community itself as well as industrial activity along the river. This point brought into discussion the lack of corporate social responsibility of businesses along the river, who appear to exploit water resources and pollute them. It was also argued that while businesses along the river contribute to the pollution, poor wastewater treatment works upstream are a concern that has been observed by stakeholders and community members.

The highlighted problems are made worse through the lack of support, commitment, and proper framework around river basin management. For this reason, these issues were highlighted as adding to the larger problem since no action is being taken to address the five contributors previously highlighted. The above suggests that the root causes of the Hennops River pollution are related to governance, River basin management, awareness, and a lack of structure. The root causes identified were critical in considering causes and effects, and will be further discussed in subsequent sections.

7.1.1.2 Further engagement through stakeholder workshop hosted by Hennops Revival

Further engagement with community and local authorities yielded important findings related to perceptions on river basin management as well as some of the governance challenges associated with the Hennops River basin. As highlighted above, despite efforts made to address the pollution of the river basin, contributing factors are left unchecked or addressed. In previous reports, this was presented as a lack of political will, lack of service delivery, and a general lack of interest on the part of government. However, through further investigation, it has been noted that there are several key issues that need to be considered should governance of the Hennops River basin be properly addressed.

During the stakeholder workshop held by Hennops Revival, most government representatives are of the opinion that a lack of resources is the underlying cause for the ineffectiveness of initiatives and activities of government and stakeholders. In this regard, government representatives report that their offices are not sufficiently funded and thus, their activities are limited. Through further investigation, a key finding was noted related to the governance of the Hennops River basin in relation to policy and practice.

Through engagement with the Hennops River forum as well as government officials, it was noted that the Hennops River basin forms part of the larger Limpopo catchment area. This catchment area, to date, is under the mandate of the Department of Water and Sanitation and is not managed by its own Catchment Management Agency (CMA). For this reason, institutions such as the Hennops River forum are not functioning as intended by policy, and this will be further discussed in subsequent sections. This was a key finding in relation to the governance challenges the river basin faces. Although some stakeholders believed the absence of a CMA should not impair the interventions of government, this point does shed light on the disconnect between government and communities.

7.1.2 Community workshop

The following are findings gathered from a community workshop held in Tembisa. As described in previous sections, following engagement with organisations, authorities, and NGOs, the community of Tembisa was engaged with through a community workshop. The workshop was attended by approximately 50 community members, most of whom were youth. **Figures 7.3** and 7.4 are photographs taken during the workshop.

Figure 7.3. Wits research team member, Lucien James, presenting a talk at the community workshop

Figure 7.4. A photograph of the group of community members present during a question-and-answer session

7.1.2.1 Level of awareness within the community

Through engagement with the community, it was ascertained that community members in Tembisa are aware of some of the problems and root causes highlighted during the stakeholder meeting, however, communities are not aware of their environmental consequences. This is particularly true in the context of environmental conservation and wellbeing. For example, community members expressed their concern about illegal dumping and the lack of municipal services in Tembisa.

Several community members attending the workshop attested to witnessing illegal dumping and poor waste management practices around their residential areas. Furthermore, community members expressed discomfort, stating that their current living conditions are plagued by solid waste pollution. This suggests that community members are very aware of some of the root causes and problems highlighted during the stakeholder meeting. When asked about the nature of illegal dumping, community members suggested that through their observation, people find it easier to dispose of waste through dumping than waiting for municipal services which are not always present. Community members also suggested that there is a lack of awareness within their community leading to the spread of illegal dumping activities. Further discussion also revealed that services such as health care and education are also impacted by the environmental conditions in Tembisa. While community members demonstrated an understanding and awareness of how environmental issues affect their community and surroundings, many were not aware that the pollution of the Kaalspruit tributary affects downstream areas and the entire Hennops River basin.

From the community workshop, it was learned that a level of awareness is present within the community. However, environmental concerns of the community are limited to their own surroundings, with communities unaware of the impact of root causes and problems on other areas downstream and further away.

7.1.2.2 Interest in participation

Several community members present at the workshop were youth, many of whom are unemployed. Since many of these youth are unemployed, they demonstrated an interest in helping their community while seeking out employment. After providing more information on the current project and its findings, community members expressed interest in participating in potential initiatives to address the environmental issues they face. Although community members, especially the youth expressed an interest in participation, some of their concerns were observed during the workshop.

A key concern among community members was their positionality and role in relation to authorities, elders, and community leaders. In this regard, community members argued that there is need for more intervention from government, community leaders, and local organisations. Community members expressed that, local organisations do not have the resources and power to make a difference in their community. While community members are interested in participating in initiatives to manage the Hennops River basin, many feel that government and leaders are in a better position to address environmental issues. For this reason, community members demonstrate that they themselves do not address issues around their community. These sentiments, therefore, are related to presumptions the community has around power and authority in their urban spaces.

Another concern was incentive. Many community members felt that their participation in environmental initiatives should be rewarded. This demonstrated the lack of awareness the community has about the impacts of the problems they face and repercussions of addressing these problems through action. For some community members, participation was seen as a form of employment, not as a means to address issues they themselves face. These concerns, however, were not universal, with some community members displaying interest in participation, understanding the importance of their own voice and actions to make a difference within the Hennops River basin.

7.1.3 Clean-up campaigns – Downstream initiatives

The following are findings gathered during the two initiatives attended in the downstream areas of the Hennops River basin. These findings relate to (a) the overall participation of organisations, stakeholders, and communities in these events, (b) the viewpoints of participants about the management of the Hennops River basin, (c) the observed impact of the events on the surrounding communities and the environment as well as the impact the Wits research team made through these events and their project.

7.1.3.1 Participation of stakeholders and communities

As the bigger event, several businesses, organisations, municipal representatives, and figures of authority were present at the event hosted by Hennops Revival in Centurion. Approximately 200 people participated in Hennops Revival's event which also included members of the community. **Figure 7.5** is a photograph taken at the event. **Table 7.3** lists organisations who were present and engaged during the event. **Table 7.3** also includes data on reasons why the organisation, representatives, or figures of authority participated in the event, according to what was gathered during engagement. Representatives from the groups in **Table 7.3** were engaged with through informal discussions or interviews. Fresh NGO's event was attended by fewer organisations. Some of these organisations included ERWAT, a German documentary team, and the Wits research team.

Figure 7.5. Photograph taken during Hennops Revival's event. Participants and volunteers participating in the Jerusalema dance after clean-up activities

Table 7.3. List of main organisations and stakeholders present at Hennops Revival's clean-up event

Name of stakeholder/ organisation/department	Type of organisation	Reason for participation
Hennops Revival	NGO	Host of event
AESwitch	Business – IT	Part of a business initiative to contribute to environmental wellbeing
Blue Swirl Recycling	Business – Waste management and recycling	Partners with Hennops Revival for all initiatives in the area
OUTsurance	Business – Insurance	A business in the area with an interest in the wellbeing of the river
Mars, Incorporated	Business – Food	A long-standing partner of Hennops Revival
City of Tshwane	Municipality	Supports Hennops Revival's initiatives
South African Water Chamber	Private organisation	Has interest in governance of water resources in South Africa
SDA Church, Winnie Mandela, Tembisa	Religious organisation	Invited to join by the Wits research team
Wits University	Educational institute	Represented by the Wits research team

7.1.3.2 Viewpoints of participants

While some of the organisations listed are long-standing partners of Hennops Revival, some participated in the initiative as they have a direct relationship or interest in the water resources of the river basin. When asked why they've engaged in the initiative, some answers suggested that their participation was frequent as a supporter and partner of Hennops Revival. As an example, representatives and employees of AESwitch stated that the clean-up event was part of their own drive to make a difference in the environment. In contrast, representatives of OUTsurance stated that their participation was to make a difference in the environment since their building was along the banks of the river. Differently again, the SDA church of Tembisa joined the event having been invited by the Wits research team, but also as long-time friends of Hennops Revival. Therefore, there was a mix of reasons behind the participation of the different organisations and businesses present.

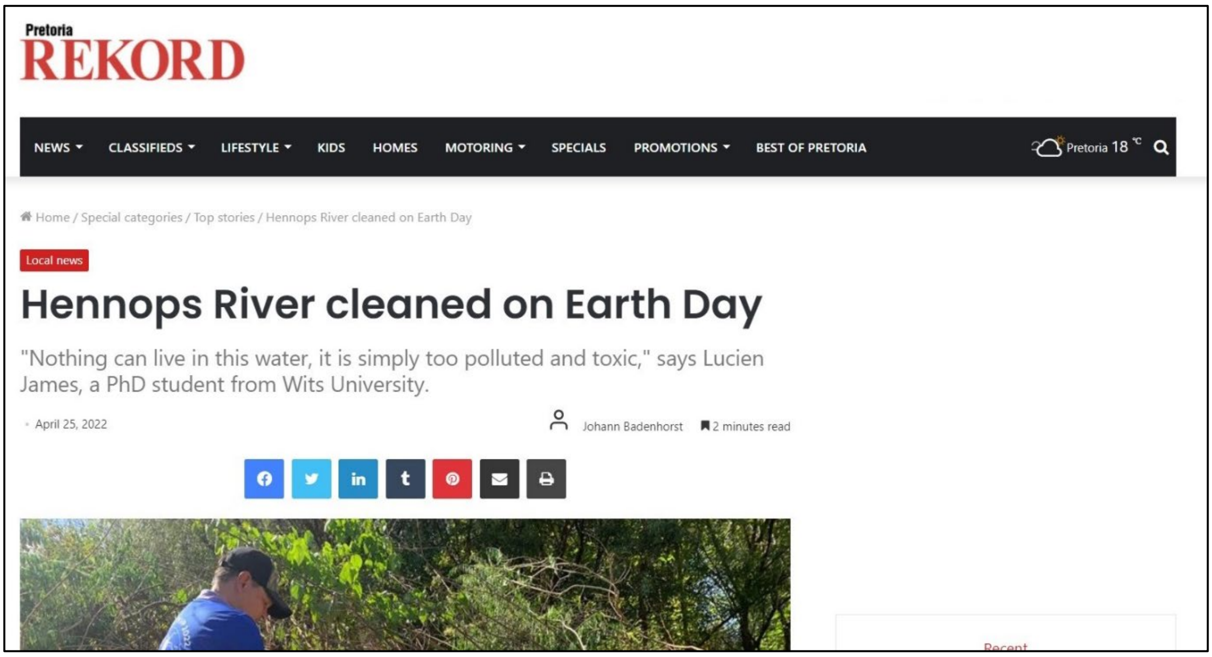
When asked about how they feel about the current state of the Hennops River basin, most participants expressed concern and anger about the conditions observed at the clean-up site. A representative from Blue Swirl Recycling, for example, stated that the condition of the river basin is a result of neglect, not only in upstream areas, but even downstream. The representative stated that, according to his understanding, resources are available for the improvement of conditions, however, these resources are not being managed effectively. As a recycling business, the representative from Blue Swirl Recycling expressed their potential support for future initiatives to make a difference, however, they stated that besides through Hennops Revival, their services were never called upon. The representative also indicated that much of the solid waste found in the river can be addressed through recycling and a proper management strategy.

In relation to the management of the Hennops River basin, representatives of the City of Tshwane municipality and the ward councillor of the area that was cleaned, were approached, and engaged with. According to the sentiments and understanding of the authoritative figures engaged with, no strategy currently exists to manage the Hennops River basin. As a result, the Hennops River basin is neglected and is only addressed through the clean-up initiatives of NGOs such as that attended on the day. The ward councillor stated that they receive many complains about the condition of the river, but little is done about this by higher authorities and government leaders. Furthermore, representatives of the municipality stated that not enough financial support is contributed to the management of the Hennops River basin, despite its potential in the tourism and recreation industry. Representatives also expressed the need to empower and support NGOs such as Hennops Revival to continue their work around the Hennops River basin.

7.1.3.3 Impact made through campaigns

Through the two events, awareness was raised, and their respective focus areas were cleaned. During Hennops Revival's event, the Wits research team presented a talk on the current project to raise awareness about the observed state of the Hennops River basin. As part of this presentation, the need for a sustainable management framework was expressed and some information related to the chemical analyses was relayed to the community and stakeholders. The Wits research team's contribution was also publicised through the Pretoria Rekord where Lucien James was featured in the article (**Figure 7.6**). The project was further publicised through documentaries recorded during both, Hennops Revival's event as well as Fresh NGO's event.

Through clean-up activities at Hennops Revival's event, over 200 refuse bags of solid waste were removed from the focus area on the day (**Figure 7.6**). Excess vegetation was removed from around the focus area. Although a large amount of solid waste was removed from the river during Hennops Revival's event, the observed condition of the river was much worse upstream during Fresh NGO's event. Cleaning litter traps in the Olifantsfontein area, solid waste removed included more than plastic waste (**Figure 7.7**). The Wits research team noted that dead animals and pets were among the waste items removed.



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Hennops River cleaned on Earth Day

"Nothing can live in this water, it is simply too polluted and toxic," says Lucien James, a PhD student from Wits University.

April 25, 2022 · Johann Badenhorst · 2 minutes read

Figure 7.6. Article in the Pretoria Rekord featuring Lucien James of the Wits research team (see https://rekord.co.za/415589/hennops-river-cleaned-on-earth-day/)

Figure 7.7. A photograph of some of the refuse bags filled with waste during Hennops Revival's clean-up event

Figure 7.8. Photograph taken at Fresh NGO's clean-up event. Sollid waste can be seen trapped along the river by litter traps set up by the NGO

7.1.4 Clean-up campaigns – upstream initiatives

The following are findings related to observations made during the Wits research team's clean-up campaign in Esiphethweni, as well as a clean-up campaign that was hosted by Hennops Revival and EnviroCare NGO held on Mandela Day. This section will focus on findings gathered from the Wits research team's event in

Esiphethweni while drawing from additional observations made during the Mandela Day event. These findings relate to (a) the overall participation of organisations, stakeholders, and communities in these events, (b) the viewpoints of participants about the management of the Hennops River basin, (c) the observed impact of the events on the surrounding communities and the environment as well as the impact the Wits research team made through these events and their project.

7.1.4.1 Participation of stakeholders and communities

Several organisations including NGOs, governmental offices, local groups and organisations, as well as staff and student volunteers from Wits university participated in a clean-up branded at a Wits centenary event. This event was hosted by the Wits research team who extended invitations to different groups, organisations, and representatives previously engaged with. **Table 7.4** lists organisations who were present at the event.

Table 7.4. List of main organisations and stakeholders present at the clean-up event hosted by the Wits research team

Name of stakeholder/ organisation/department	**Type of organisation**	**Reason for participation**
Wits University	Educational institute	Host of event
EnviroCare NGO	NGO	Key partner of Wits research team
ERWAT	Company – largely owned by government	Interest in water resources and environmental management of Hennops River basin
Department of Water and Sanitation	Governmental department	Interest in management of water resources of the Hennops River basin.
Water Research Commission	Research organisation	Interest in Wits research team's project
Global Change Institute	Research organisation	Represented through Wits research team itself
South African Police Service	National police force	Invited to event by NGO partner
Greenpeace	Environmental organisation	Invited to event by NGO partner and Wits University
4-Room Art Gallery	Local art forum	Invited to event by Wits University and NGO partner

Although different organisations and stakeholders participated in the clean-up event, it was noted that the surrounding community did not participate in anticipated numbers. In this regard, residents of Esiphethweni and Vusimuzi paid very little attention to clean-up activities and avoided the event altogether. This was despite efforts to advertise the event in the area. At the same time, community members who were present at the community workshop were present at the event despite some of them residing in other areas of Tembisa.

A similar pattern was observed at Hennops Revival's Mandela Day event further downstream regarding participation. The event was attended by many stakeholders and organisations, some of which came from far away. Coca-Cola was also present at this event with the large business sponsoring equipment and refreshments. However, community attendance of this event was minimal, with even less community members participating in clean-up activities than the Wits research team's event. Despite not being supported by community members as anticipated, both events were attended by a large group of people who participated in clean-up activities.

7.1.4.2 Viewpoints of participants

While the event in Esiphethweni allowed for engagement with various environmental and research organisations, this event was also attended by representatives of the Department of Water and Sanitation (DWS) and ERWAT. These representatives were engaged with to learn more about the sentiments and views of government and figures of authority.

Arriving at the site, representatives of the DWS demonstrated a lack of awareness of the severity of pollution in areas like Esiphethweni. When asked about their opinions about the site, representatives expressed concern that the site was too heavily polluted, and that clean-up on the day would make very little difference relating to long-term goals of river basin management. Representatives suggested that further engagement with the surrounding community was necessary, and that a change in mindset was needed to make a long-term impact. Representatives indicated that it would be necessary to have a round-table discussion with stakeholders, NGOs and other organisations to consider possible long-term solutions. Furthermore, it was suggested that more interaction with the community itself was necessary to raise more awareness.

An important point raised by DWS representatives was that service delivery in the area was noticeably less than expected. While sanitation, albeit limited, is provided to residents of both Esiphethweni and Vusimuzi (**figure 7.9**), waste management options such as recycle bins and waste collection points within these urban spaces were argued fewer than expected. DWS representatives therefore referred to municipal waste management services being partly responsible for the issue faced. Further engagement with the municipality was therefore suggested.

Since it was earlier suggested that wastewater treatment was also affecting the wellbeing of the Hennops River basin, ERWAT was invited to the Wits research team's clean-up event and engaged with. ERWAT representatives presented a talk on the day of the event and expressed their dedication to protecting water resources. ERWAT representatives, like DWS representatives, were not aware of the severity of pollution in areas like Esiphethweni. Again, like DWS representatives, ERWAT representatives suggested that the real issue faced in the area was solid waste pollution, not effluent discharge. This was despite the fact that raw sewage was observed flowing directly into the river a few metres away from the focus area of clean-up activities. Engagement with ERWAT, therefore, demonstrated that the company is not aware of the living conditions in areas like Esiphethweni and Vusimuzi, nor is ERWAT aware of how these areas affect water quality.

From a business standpoint, Coca-Cola expressed their interest in reducing solid waste through their own environmental policies and goals. Representatives from Coca-Cola expressed the need to conserve and manage the river basin's water resources as the business has an interest in water resources for its own productivity. Although not directly related to the challenges of the Hennops River basin, the company, through their support and actions, demonstrated an interest in a potential river basin management strategy.

Figure 7.9. Photograph of chemical toilets in Vusimuzi informal settlement. Raw sewage is still observed running alongside these.

Representatives from the environmental organisation Greenpeace, were also engaged with during the event in Esiphethweni. Representatives displayed sentiments of surprise, anger and confusion around the state of the environment in the area. The sentiments displayed also demonstrated that environmental organisations like Greenpeace also lack awareness of conditions in areas like Esiphethweni and Vusimuzi. Members of Greenpeace were very active in clean-up activities being among the groups best represented in numbers at the event. After the event, a Greenpeace representative suggested that further stakeholder and community engagement was necessary, particularly with industries. In this regard, the representative argued towards improved corporate social responsibility of companies producing consumable goods. Greenpeace representatives also expressed concern around the lack of waste management services, corroborating with the viewpoints of DWS representatives.

Finally, concerns around the lack of community engagement in initiatives was raised by NGOs as well as representatives of the Water Research Commission (WRC). NGOs noted that current and previous initiatives have an average of 200 participants, with less than half being community members. A representative of the WRC provided some detail on the living conditions in Tembisa stating that most community members in the area are tenants of households and do not concern themselves with the wellbeing of the environment. Furthermore, WRC representatives argued that Tembisa is too densely populated, leading to large amounts of waste production and therefore, illegal dumping. An emphasis was placed on getting communities involved in clean-up initiatives and raising more awareness.

7.1.4.3 Environmental impact made through campaigns

Clean-up activities during the Wits event in Esiphethweni made a noticeable environmental impact. Community members, stakeholders, organisations, and other volunteers took part in clean-up activities along a bridge between Esiphethweni and Vusimuzi as well as along the banks of the Kaalspruit tributary as seen in **Figure 7.10**. As seen in **Figure 7.11**, the focus area was covered in solid waste before clean-up activities took place. Clean-up activities resulted in the focus area, particularly around the bridge between Esiphethweni and Vusimuzi, being cleared of majority of solid waste items which would have otherwise washed downstream. To illustrate the results of clean-up activities, **figure 7.12** is a before-after picture created demonstrating the environmental impact made through the event. A total of 250 refuse bags of waste were removed from the area. Solid waste items removed from the focus area were not limited to plastic waste items, but also included larger items including a bathtub.

During the Mandela Day event, a similar environmental impact was made with large amounts of waste being removed from the area around Thiteng bridge. The bridge, like other locations along the Kaalspruit, remains an illegal dumping area which is in need of intervention through a long-term waste management solution.

Figure 7.10. Photograph of volunteers, stakeholder representatives, and community members participating in clean-up activities along the Kaalspruit banks in Esiphethweni, Tembisa

Figure 7.11. Photograph of Esiphethweni-Vusimuzi bridge covered in solid waste pollution

Figure 7.12. A Before (left) – After (right) image illustrating the noticeable impact made through clean-up activities at Esiphethweni, Tembisa

7.1.4.4 Social impact made through campaigns

Several social impacts were made through the Wits research team's clean-up initiative. This related to (1) empowerment and recognition of key stakeholders and organisations, as well as (2) public awareness of the current project.

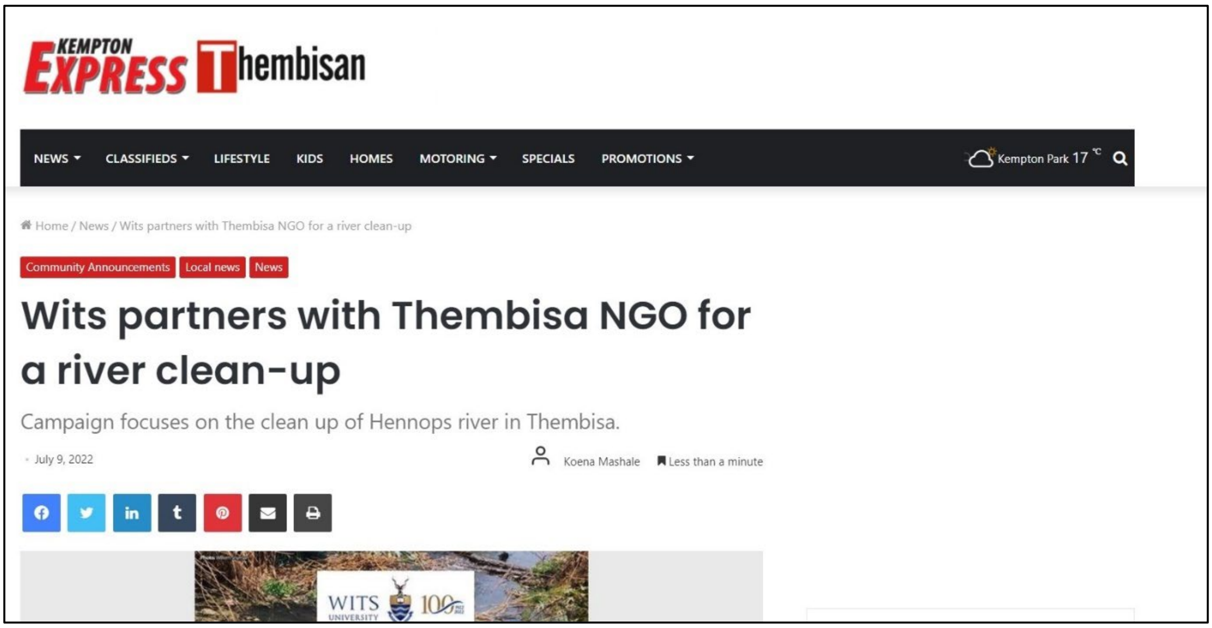
The Wits research team worked closely with EnviroCare NGO, a key stakeholder in Tembisa. Unlike Hennops Revival, the NGO's public image is not as noticeable despite their many efforts to improve environmental conditions in Tembisa. Therefore, EnviroCare was empowered through branding and equipment provided by the Wits research team. The NGO was provided with two large banners (photographed in **Figure 7.13**), t-shirts (**Figure 7.14**), and a branded cap for their key representative (**Figure 7.15**). Some equipment such as gloves were also donated to EnviroCare after the event as a form of support towards future initiatives. EnviroCare was also advertised and publicised during the event as a partner of Wits University and the Wits research team during the event in Esiphethweni.

Figure 7.13. Photographs taken of banners supplied to EnviroCare. Left – Banner put up at Mandela Day event, Right – Close-up image of the banner itself

Figure 7.14. Photograph of T-shirts supplied to EnviroCare

Figure 7.15. Photograph of Samuel Mashimbyi of EnviroCare wearing supplied branded cap

Public awareness of the current project was also driven through the clean-up initiative in Esiphethweni. As previously mentioned, the event was branded as a Wits centenary event and was advertised to the public through Wits University's main social media platforms. The campaign was branded under the slogan "help our rivers" and was advertised through many platforms including social media and local newspapers and magazines (**Figure 7.16** and **7.17**). The event itself was also covered in local newspapers (**Figure 7.18** and **7.19**). The event was further publicised through Newzroom Afrika, who broadcasted the event as part of national news (**Figure 7.20**).



KEMPTON EXPRESS Thembisan

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Home / News / Wits partners with Thembisa NGO for a river clean-up

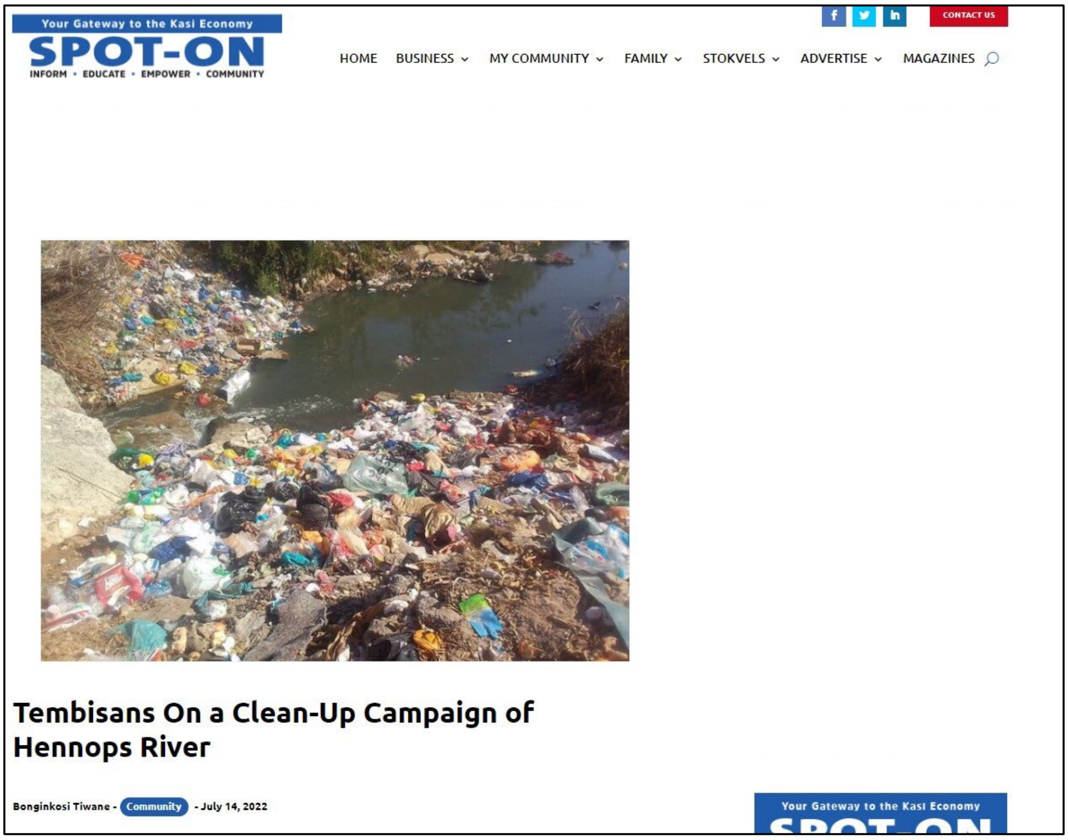
Community Announcements | Local news | News

Wits partners with Thembisa NGO for a river clean-up

Campaign focuses on the clean up of Hennops river in Thembisa.

July 9, 2022 Koena Mashale Less than a minute

Figure 7.16. Article published through the local newspaper, Kempton Express/Thembisan, advertising the Wits research team's event (see https://kemptonexpress.co.za/336226/university-to-clean-up-river-for-campaign/)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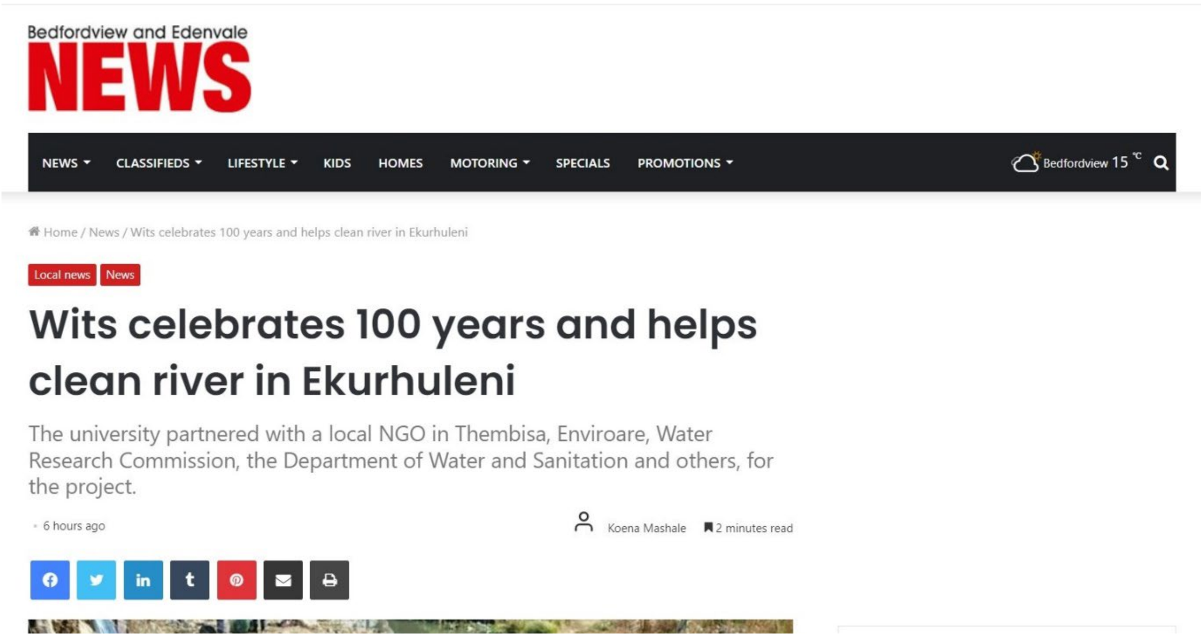
Tembisans On a Clean-Up Campaign of Hennops River

Bonginkosi Tiwane - Community - July 14, 2022

Figure 7.17. Article published through the local magazine, Spot-On Mag, advertising the Wits research team's event (see https://spotonmag.co.za/2022/07/tembisans-on-a-clean-up-campaign-of-hennops-river/)


Bedfordview and Edenvale
NEWS

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Home / News / Wits celebrates 100 years and helps clean river in Ekurhuleni

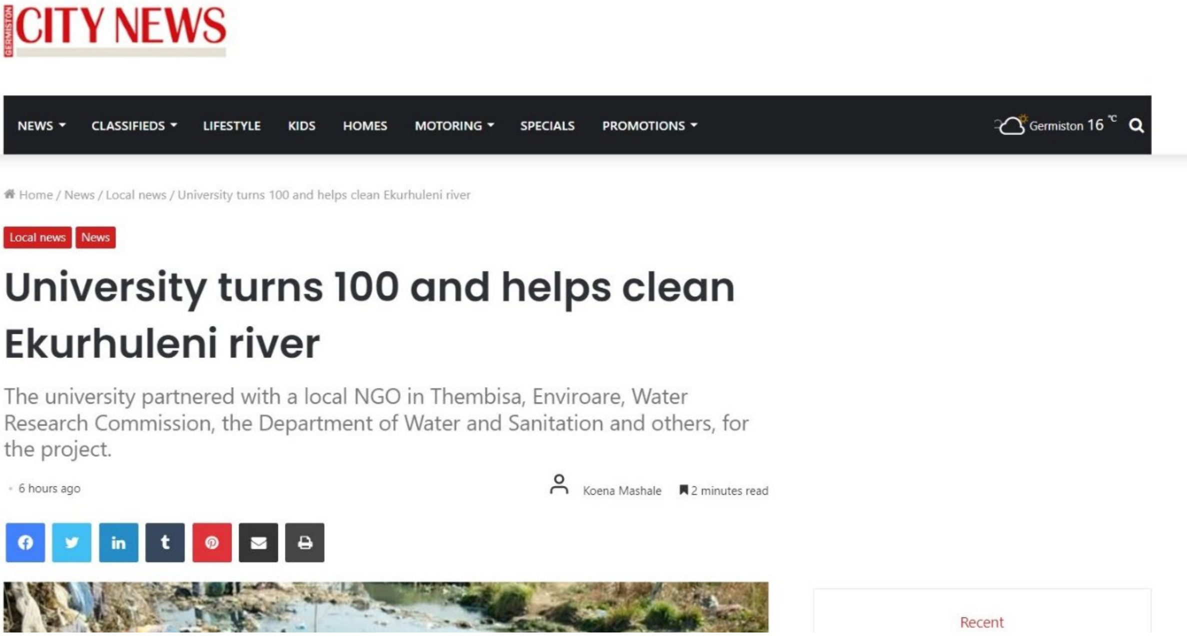
Local news News

Wits celebrates 100 years and helps clean river in Ekurhuleni

The university partnered with a local NGO in Thembisa, Enviroare, Water Research Commission, the Department of Water and Sanitation and others, for the project.

6 hours ago Koena Mashale 2 minutes read

Figure 7.18. Newspaper article in the Bedfordview and Edenvale News (see https://bedfordviewedenvalenews.co.za/496259/wits-cleaning-up-hennops-river-for-the-better/)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Local news News

University turns 100 and helps clean Ekurhuleni river

The university partnered with a local NGO in Thembisa, Enviroare, Water Research Commission, the Department of Water and Sanitation and others, for the project.

6 hours ago Koena Mashale 2 minutes read

Recent

Figure 7.19. Newspaper article in the Germiston City News (see https://germistoncitynews.co.za/292939/wits-cleaning-up-hennops-river-for-the-better/)

Figure 7.20. Photograph of Lucien James being interviewed by Newzroom Afrika during the clean-up event in Esiphethweni, Tembisa

7.1.5 Revisiting clean-up sites

Following the various initiatives reported earlier in 2022, each of the previously addressed sites yielded different observable changes. The section will focus primarily on comparing the Thiteng bridge and the Esiphetweni-

Vusimuzi sites following clean-up campaigns. Additional observations will also be presented relating to some of the perceived and documented root causes.

The Thiteng bridge was visited a month after the clean-up initiative which took place on 18 July 2022. The site was observed to be in much better condition, with very little waste being dumped into the Kaalspruit flowing under the bridge. It was noted that after the clean-up initiative hosted by Hennops Revival, the bridge is now under the surveillance of community leaders and government officials who are ensuring its maintenance. A visible difference was noted, however, sporadic illegal dumping is still noted in the area. However, the site is an example of the potential of community and stakeholder participation for river basin management, albeit extensive commitment to the site has been necessary as observed.

The same result was not observed at the Esiphetweni-Vusimuzi site. After having been addressed through the clean-up initiative of the research team together with EnviroCare Tembisa and the University of the Witwatersrand community, the site has seen further deterioration with its worst observed state being noted in October 2022, that is, three months after the clean-up initiative. At the same time, EnviroCare Tembisa reported being involved in regular clean-ups of the site, taking place once every month since the research team's initiative in July. For illustration purposes, **Figure 7.21** illustrates a visual comparison of the site directly after the clean-up initiative, two months after the initiative, and three months after the initiative. As observed in these illustrations, the amount of solid waste had continued to accumulate after the clean-up initiative despite EnviroCare Tembisa's reported activities at the site.

Through field visits, a survey of a site in Phomolong, Tembisa was conducted. Phomolong was observed as a key site from which large amounts of solid waste is produced and dumped along storm water infrastructure, eventually leading to the pollution of the Kaalspruit. Like other spaces within Tembisa, Phomolong continues to contribute to the pollution of the Hennops River basin. Very similar to conditions reported in Esiphetweni-Vusimuzi, Phomolong also includes informal settlements. Together with formal residential spaces, the community of Phomolong continues to pollute the area, with minimal service delivery observed.

It was however noted by key informants that evidence of service delivery is present, however, many of the students and academics who visited the area together with the research team noted that the observed evidence demonstrates an insufficient amount of support given to such areas. Students also pointed out the lack of concern of the community for water resources and infrastructure. **Figure 7.22** is an image taken of a skip which was observed within the informal settlement of Phomolong. Despite being present, the skip was abandoned and left empty. Solid waste was observed being dumped around the skip. Furthermore, it was not clear if the skip is being emptied as it was observed in the same position over consecutive months.

The above observations demonstrated the effectiveness of clean-up initiatives. As will be discussed, these findings can be related to social and governance challenges and opportunities which need to be considered to achieve effective participation in river basin management.

Figure 7.21. Evolution of the state of the Esiphetweni clean-up site over 3 months following initiative

Figure 7.22. Improper waste dumping in Phomolong

7.1.6 Capacity building and awareness

As part of this study's efforts, students from the University of the Witwatersrand and international professionals were invited to participate in field visits to the key sites described. This was to raise awareness but also encourage the support of NGOs working in the community such as EnviroCare Tembisa. Students and professionals were given tours, hosted by EnviroCare Tembisa, to key problem areas such as Phomolong and Esiphetweni-Vusimuzi. Geography and Environmental studies second to Honour's year students were invited to visit Tembisa as part of field work activities. **Figure 7.23** is an image taken during a field visit. Honour's students are pictured in Phomolong, together with representatives of EnviroCare Tembisa, and a member of the research team.

Students and professionals expressed their concern about both the living conditions in Tembisa, as well as the condition of the Hennops River basin. As part of their viewpoints, students and professionals suggested further investigation in relation to policy and practice, as well as the governance of the Hennops River basin. This was followed up by the research team through further engagement with different institutions and organisations.

Field visits also acted to boost awareness of potential groups of interest, but also help empower the activities of EnviroCare Tembisa. As previously highlighted, the activities of the NGO still need support should their efforts be as effective as those of Hennops Revival. For this reason, field visits and engagements acted as capacity building activities, boosting the image of the NGO and the power of community-led groups.

Figure 7.23. Site visit in Phomolong by Envirocare representatives and University of the Witwatersrand students

7.2 DISCUSSION AND CONCLUDING REMARKS

The section will draw from findings presented in the previous section to formulate a discussion and argument towards a potential framework for managing the Hennops River basin. This section will consider (1) the root causes and challenges according to stakeholders, (2) awareness and potential support from communities, and (3) potential of different initiatives and interventions as part of a framework. Together, a conceptual model for managing the Hennops River basin will be presented drawing from theoretical considerations.

7.2.1 Root causes and Cause-and-Effect analysis

7.2.1.1 Governance challenges: Need for a CMA and repurposing of the Hennops River Forum

As highlighted by stakeholders and communities, lack of service delivery, poor infrastructure, lack of political will, poor implementation of policy, and lack of awareness are the root causes related to the observed state of the Hennops River basin. Most of these root causes relate to governance and challenges in government. No research has been done prior to this, therefore, these findings are key to understanding the dynamics around the management of the Hennops River basin.

As observed through engagement with stakeholders and communities, water resource management in Tembisa is highly reliant on the input of government. For this reason, communities and stakeholders seem to be distant from water management challenges and opportunities. While problems such as a lack of service delivery, poor infrastructure, poor implementation of policy and law, and lack of awareness contributes to the creation of problems such as illegal dumping and informal settlements, lack of political will only exacerbates the problems around the current state of the Hennops River basin. Communities and stakeholders expect support from government, however, they themselves lack the will to participate in initiatives towards improving conditions around the river basin. Furthermore, the initiatives of local organisations are poorly supported by communities and lack the necessary resources. This relates to the power communities associate with government as the sole entity in charge of environmental issues.

Unfortunately, this phenomenon has been noted as a particular problem related to river basin management, with government, rules and regulations hindering the progress of participatory river basin management (Van der Brugge *et al.*, 2005; Euler and Heldt, 2018). **Figure 7.24** illustrates the key observations related to the Hennops River basin's current management model. As noted through engagement, communities rely on the intervention and actions of government due to their level of awareness around environmental issues. Community members, although observing the problems around them, believe that government will address issues such as illegal dumping and pollution of the environment. Furthermore, communities do not fully understand their potential to make a difference and expect that any intervention from their part should be rewarded. As illustrated in **Figure 7.24**, the community regards government as the overarching power in charge of the Hennops River basin, with themselves at the bottom of all governance, accepting the repercussions of the decisions of government and other entities like businesses and local leaders. Communities recognise the initiatives of local organisations but do not support them, hence, there is a disconnect between organisations and the community. Organisations act on their own, with their initiatives poorly supported by both government and communities. As illustrated in **Figure 7.24**, organisations exist in a conceptual vacuum, independently from each other, disconnected from communities and the government. There is therefore a strong disconnect between government leaders, local organisations, and communities resulting in a lack of understanding of how each can play a role in river basin management. This ultimately relates to issues around awareness and empowerment, as will be discussed in subsequent sections.

Two solutions to the problematic model illustrated in **Figure 7.24** are therefore proposed following the application of this project's methodology. Firstly, to address this observed governance issue, decentralising water management is a potential solution to appropriating power to other entities in the model including the community. The decentralising of water management has been practiced and studied in other areas of the world, including South Africa's neighbouring country, Mozambique (Inguane *et al.*, 2014). Decentralisation of natural resource management has been argued as an effective means to increase the participation of stakeholders (Inguane *et al.*, 2014). Decentralisation of water resources has also been argued an important approach to Integrated Water Resource Management and furthermore, is supported by South Africa's water policy altogether.

A major challenge associated with the governance of the Hennops River basin is argued to be the absence of a Catchment Management Agency (CMA) in charge of the Limpopo Water Management Area under which the Hennops River falls. While further research is necessary to establish the overall challenges associated with the absence of the CMA, it is clear that the management of the Hennops River is not able to be governed as per the National Water Act of and National Water Resources Strategy 2, which are the two key policy documents related to river basin management in South Africa. As such, the Hennops River basin is under the direct governance of the Department of Water and Sanitation. This means that a regional presence in the management of the Hennops River basin is not present. It is therefore argued, while South Africa's water policy is argued one of the best in the world (Pollard and du Toit, 2008), the Hennops River accounts for a region in the country which is not sufficiently being addressed by said policy. The establishment of a CMA may present new opportunities in how the river basin is managed, decentralising its governance, and allowing for the support of regional initiatives.

As **Figure 7.24** suggests, organisations such as businesses, NGOs and other entities exist within a conceptual vacuum, disconnected from each other, and concerned with their own goals. It is therefore argued that for the purposes of decentralisation, but also to connect and unite different entities and organisations, an institution needs to be appropriated this responsibility. As it stands, South Africa's water policy supports that established forums in different catchment areas must take accountability in this regard. With further revision of policy and further engagement with different stakeholder groups, it has been noted that the Hennops River Forum represents a key part of river basin management as per policy. In this regard, the Hennops River Forum is meant to represent the institution which would be responsible for community and stakeholder decisions. Policy suggests that forums such as the Hennops River Forum were founded for the purpose of allowing for participatory initiatives, community decision-making, as well as facilitating communication between stakeholders, communities, and government. At present, it is not certain that the Hennops River Forum is achieving these objectives. In fact, engagement with key members of the forum suggests that the forum's role is not clear, mostly due to a lack of political will from government who should be supporting the initiatives of forums.

Finally, all of the above suggests that policy in the context of the Hennops River basin is yet to be implemented efficiently. Several challenges related to the presence and role of institutions continue to add complexity to the governance of the Hennops River basin.

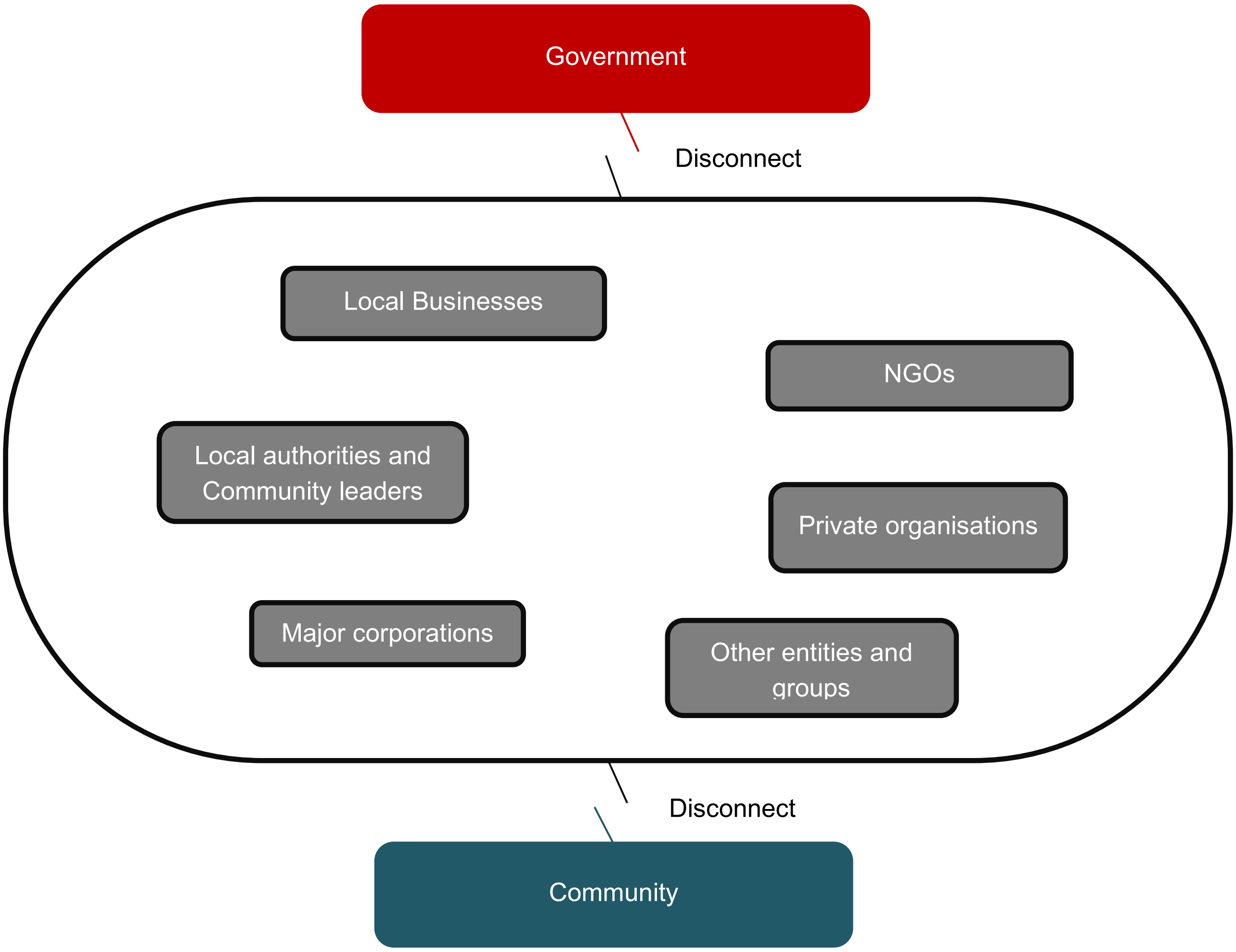

Figure 7.24. Current Government-Community-stakeholder relationship

7.2.1.2 Governance model: Government-Forum-Community

Figure 7.25, therefore, presents a conceptual model of what a governance structure around a decentralised management framework would look like. Firstly, like in **Figure 7.24**, three different groups exist, one representing government, one representing communities, and the last, representing a middle-ground for consultation with stakeholders and communities, the Hennops River Forum. Power is distributed equally between communities, government, and the HR Forum, with each having their own responsibility within a cycle instead of hierarchical model. Communities will be responsible for decision-making and relaying information about their observations and concerns. The HR Forum, as a collective institution of different businesses, NGOs, and other organisations, should respond to the concerns and decisions of the community by implementing the necessary actions and initiatives. These actions and initiatives may involve community and stakeholder participation through formulated solutions. The actions and initiatives of the HR Forum will then be communicated to government who will provide further support and empowerment to the HR Forum, interested stakeholders, as well as the community. The community will therefore respond to government, relaying feedback after the implementations and initiatives.

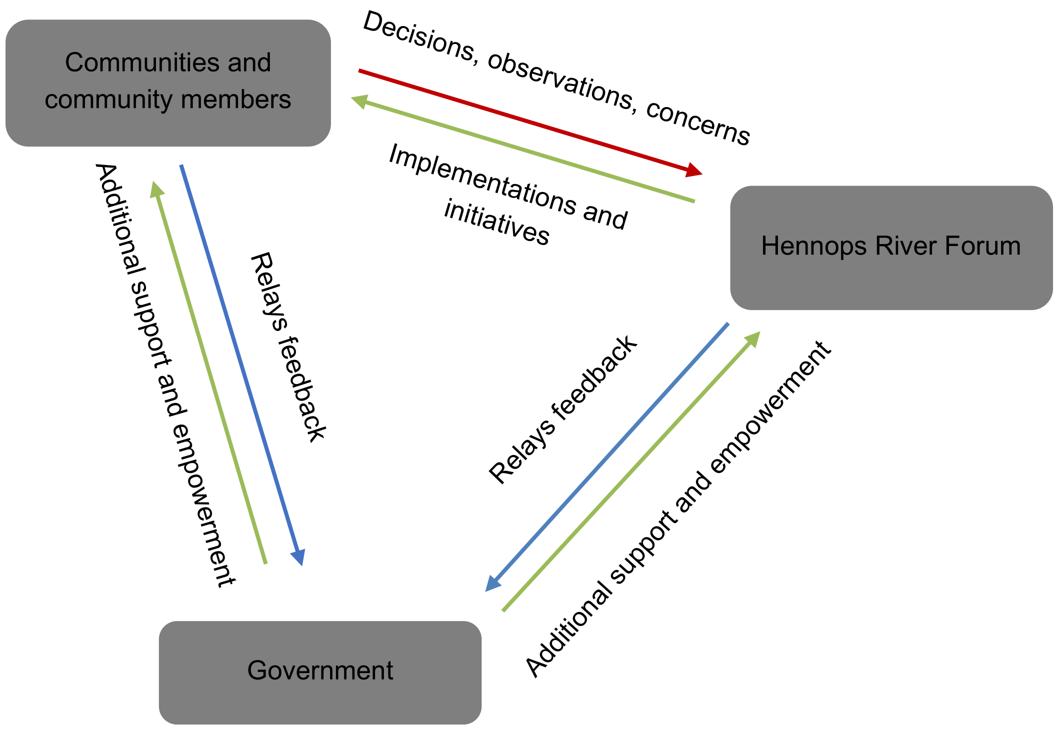

Figure 7.25. Ideal model for the governance of the Hennops River basin

As its main purpose, this conceptual model and governance structure is argued here to be the solution to the deeper governance challenges the Hennops River basin faces. These need to be addressed before any further considerations are made. This conceptual model decentralises power and river basin management and appropriates two main responsibilities to government. In this regard, government will be responsible for responding to relayed feedback by providing support and empowerment to both, communities and the HR Forum. Challenges and opportunities will be addressed through communities' participation, either in decision-making or initiatives on the ground. Initiatives on the ground will be supported and hosted by stakeholders who are part of the HR Forum. In this regard, initiatives of different NGOs and businesses will focus on addressing the challenges and opportunities communities raise as most pressing. To improve governance, and implement policy, considerations around the establishment of a CMA is also advised to strengthen this model.

7.2.1.3 Cause-and-effect analysis: Challenges on the ground

A Causal Reality Tree was drafted to better illustrate the relationship between the perceived challenges and potential root causes. Considering **Figure 7.26**, three main challenges have been noted in relation to the Hennops River's pollution problem. These three are, (a) illegal dumping, (b) poor performing wastewater treatment works, and (c) lack of service provision, that is, in relation to sanitation and waste removal. Through further study, each of these three are related to different causes, which have been highlighted through the themes and codes identified during stakeholder meetings, workshops, and engagements. It is important to note that the main undesirable effects highlighted in **Figure 7.26** are supported by literature and past studies which demonstrate that South Africa, as well as the most part of Africa, face the same challenges (Iroegbu *et al.*, 2020).

Considering observations, it is argued here that illegal dumping and the lack of service provision need to be considered separate problems. In this regard, the observations made at Phomolong, where service delivery is present but not used, emphasises this point. Furthermore, the improved state of Thiteng following clean-up is argued the result of additional law enforcement, and not the result of added service delivery in the area. Therefore, illegal dumping and the lack of service provision are considered two separate challenges the river basin faces.

The poor chemical state of the Hennops River, as suggested in previous sections, is the result of poor performing wastewater treatment works. Again, this fact is supported by literature suggesting that other river basins face similar challenges (Amoah *et al.*, 2020; Iloms *et al.*, 2020; Iroegbu *et al.*, 2020). Following engagement with stakeholders, two factors contribute to this undesirable effect as highlighted in **Figure 7.26**. Firstly, a lack of infrastructure or the poor maintenance thereof, is a direct cause of sewage spills, poor sewage treatment, and the overall poor performance of wastewater treatment facilities, services, and infrastructure. While this undesirable effect relates to the poor performance of wastewater treatment facilities themselves, it also relates to the lack of sufficient infrastructure in Tembisa to support the population, which has been noted by engaged community leaders. Infrastructural insufficiency has therefore been identified as a key cause of the Hennops River's pollution, contributing to both, poor performing wastewater treatment services, as well as contributing to the lack of service provision.

Infrastructural insufficiency is not the sole cause behind poor performing wastewater treatment. As previously alluded to, the challenges faced within the Hennops River basin also relate to a lack of law enforcement. The lack of law enforcement contributes to the continued poor performance of wastewater treatment works, but also to the worsening of the illegal dumping challenge observed. While the lack of law enforcement contributes to challenges observed, it is not considered a root cause, but instead a contributing factor to the worsening of conditions. Therefore, as will be further discussed, law enforcement is identified here as an avenue through which the Hennops River's challenges can be alleviated in part, together with addressing the root causes of the grander problem.

Two additional undesirable effects are noted as independent from the root causes of the larger problem. Both effects require additional research as they represent wicked problems or challenges that are founded in aspects outside the scope of this study. In this regard, informal settlements were noted as a key contributing factor to illegal dumping. However, since illegal dumping is a challenge observed in formal residential areas all the same, the presence of informal settlements cannot be considered a root cause of the problem. In this regard, addressing informal settlements may not yield a significant change to the overall illegal dumping situation. At the same time, informal settlements are linked to a number of challenges beyond the scope of this study including urban expansion, overpopulation and poverty (Huchzermeyer, 2010; Niva *et al.*, 2019).

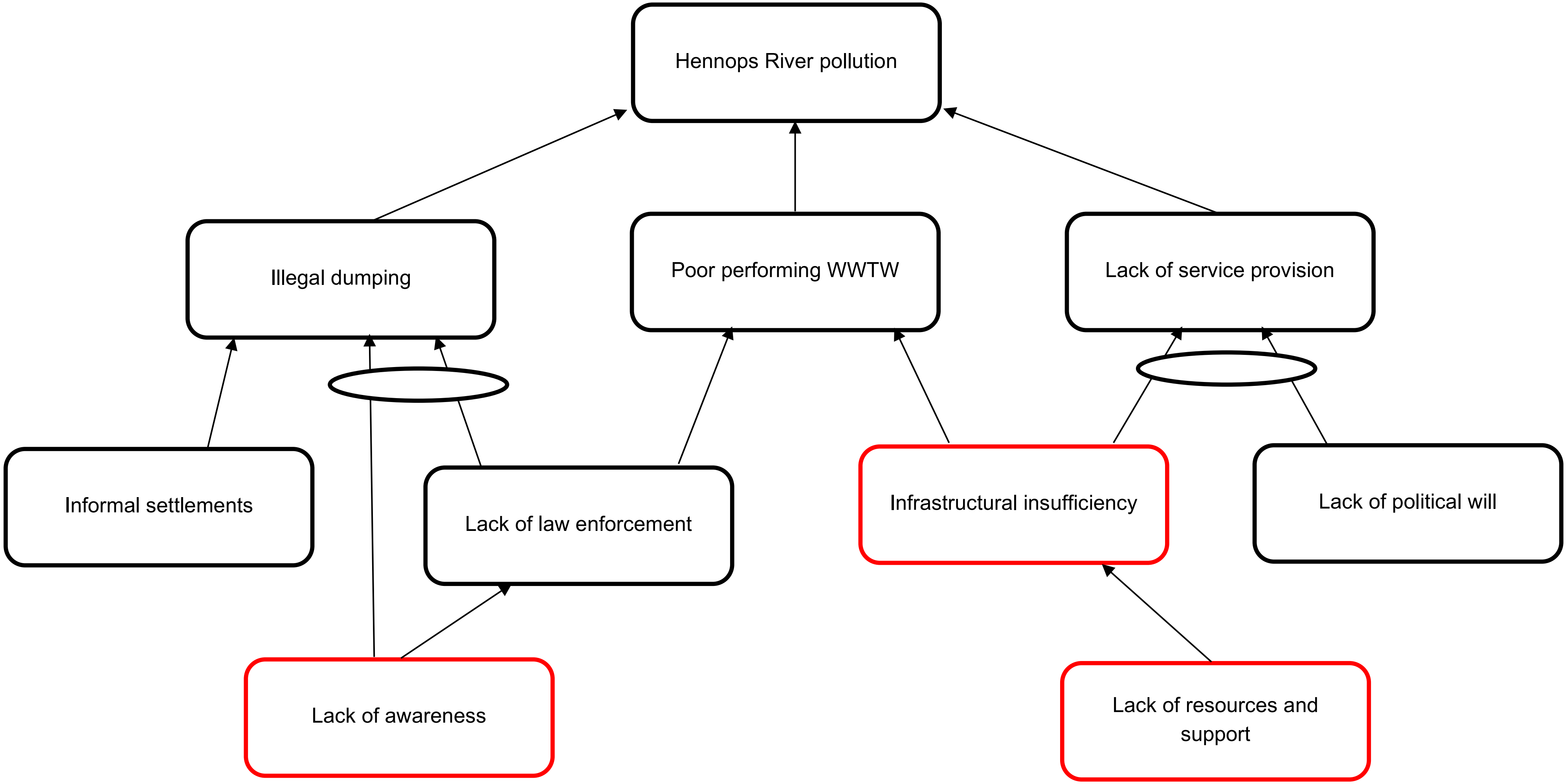

Figure 7.26. Causal Reality Tree considering root causes and undesirable effects as per engagement and observations

The second additional undesirable effect noted as independent from the root causes of the larger problem is a lack of political will. As will be discussed, the lack of political will is related to the complex working of water governance, which were investigated as part of this study's review of policy and practice. While this will be discussed in more detail in subsequent sections, it is not linked to the root causes identified as part of this study. Instead, the lack of political will is a complex issue which relates to the implementation of horizontal and vertical structures needed for water governance. Furthermore, the scope of this study limited further investigation in this regard as this point also relates to poor waste management, how waste is addressed, and the complexity of municipal rendered services.

Therefore, as illustrated in **Figure 7.26**, root causes, excluding infrastructural insufficiency, have been identified through this study relating to the worsening state of the Hennops River basin. Firstly, a lack of awareness is argued as a main cause of illegal dumping, coupled with a lack of law enforcement. Furthermore, the lack of law enforcement is also argued the result of a lack of awareness. Illegal dumping in areas such as Esiphetweni-Vusimuzi continues to take place as residents of the area are unaware of the severity of their activities on the river basin itself. Furthermore, community leaders themselves are unaware of the challenges, and when they are aware, they are unaware of potential solutions to the problem. It is therefore argued that more awareness is needed should participatory interventions be fruitful in the Hennops River basin. For this reason, this report also showcases some of the capacity building and awareness activities initiated over the past few months. However, more outreach is needed to address awareness in communities.

Perhaps argued as the most serious of the root causes is a lack of resources and support. As a key theme identified in this study, stakeholders suggest that interventions and the management of the Hennops River basin are strongly tied to the amount of resources and support attributed to them. In this regard, the activities of stakeholders continue to yield little progress as they are not supported by the community nor enough private sector partners. This has been observed through the effectiveness of the activities of NGOs such as Hennops Revival in comparison to the efforts of NGOs such as EnviroCare Tembisa. Furthermore, infrastructural insufficiency has been linked to the lack of resources as well, with the theme being identified during several engagements with municipality representatives as well as organisations such as ERWAT. Therefore, the lack of resources and support is considered a root cause to the ongoing Hennops River basin challenges.

7.2.2 Addressing the lack of awareness and support

While a solution to the Hennops River basin's management is presented as part of this argument, several important considerations need to be accounted for. As previously noted, awareness has been observed as a particularly challenging issue. This is not a novel issue having been encountered in other studies related to stakeholder engagement (Stave, 2003). Although several stakeholders, including businesses and NGOs, show interest in participating in the management of the Hennops River basin, several more have the potential to participate as well. An important reason why stakeholders participate in initiatives and management of the river basin is because they have a good level of awareness around how the river basin contributes to their wellbeing. This was observed when engaging with Coca-Cola, EnviroCare, Hennops Revival, Fresh NGO, and OUTsurance. The same, unfortunately, cannot be said for communities who seek further incentive when approached and asked to participate. Therefore, there is a need for awareness around how the river basin and its resources is beneficial to both stakeholders and communities.

At the heart of this idea is the concept of commoning. The concept of commoning, as previously argued, supports that natural resources be governed by participants for their own wellbeing (Euler and Heldt, 2018). Furthermore, under the concept commoning, is the idea that all groups and participants have an interest in a common natural resource which each, as individual entities, work towards securing for their own benefit (Euler and Heldt, 2018). Through experience and observation, it is not sustainable to invite communities and stakeholders to initiatives and interventions towards managing the Hennops River basin. Most potential participants, in this regard, lack the level of awareness to understand how they benefit from the management of the basin's water resources. This leads to some members of the community seeking additional incentive and support for their participation in an activity which they feel is the responsibility of government alone. Through commoning, communities and stakeholders would take an interest in the Hennops River basin and its water resources for their own wellbeing, leading to self-organised actions and participatory approaches (Euler and Heldt, 2018). Commoning is therefore argued here as a potential means of sustaining participatory actions towards managing the Hennops River basin as part of a long-term initiative.

For commoning of the Hennops River basin to take place, not only is a decentralising of power necessary, but more awareness needs to be raised in key communities and among key stakeholders. Communities need to understand how they benefit from the Hennops River basin and why it is important to protect these resources for their own wellbeing. Much like in the case of the various stakeholders who participate in initiatives such as Coca-Cola and OUTsurance, the community needs to be made aware of the value of the Hennops River basin to them as potential participants in its management. As seen in examples in Europe, awareness played a key role in helping sustain participatory initiatives (Euler and Heldt, 2018). Once understanding the value of the Hennops River basin and the potential benefits it may have to the community, self-organisation and decision-making power will follow as per past research (Euler and Heldt, 2018).

Through the current project, efforts were made to raise awareness in communities and among stakeholders. This was done through the community workshop, which ultimately motivated some community members to take interest in initiatives as observed. Furthermore, more organisations participated in clean-up campaigns as publicity was raised for these events. However, much more awareness is needed if commoning of the Hennops River basin is to be promoted. In this regard, groups and organisations who already have a sufficient level of awareness can facilitate this process of encouraging the community to take interest in the Hennops River basin. This relates back to the repurposing and empowerment of the Hennops River Forum.

Further support and empowerment are argued here as necessary for the Hennops River Forum to assume its rightful role as per policy. As observed through engagement with EnviroCare, the NGO is active in addressing environmental issues in Tembisa, however, this organisation lacks the support and publicity needed to raise more awareness. This has led to many of their initiatives not fairing as well as others. Through the initiatives and support of the Wits research team, EnviroCare was empowered to continue their work. Further empowerment could broaden the influence of such NGOs and groups who would, through the support of the Hennops River Forum, raise more awareness and encourage commoning of the Hennops River basin, with participatory decision-making and action being self-organised within the community.

Therefore, as argued previously, a change in governance is necessary, decentralising the influence of government and allowing stakeholders and communities to participate in a river basin management strategy. However, commoning is a concept worth considering as this process takes place. More awareness within communities and the empowerment of organisations and groups such as EnviroCare, Hennops Revival, and Fresh NGO is needed. Empowerment of these groups will not only aid in the repurposing of the Hennops River Forum on the ground to represent local organisations and stakeholders, but these organisations will also aid in raising awareness, further promoting self-organised decision-making and participation within communities.

7.2.3 A participatory management framework for managing the Hennops River basin

Should the above be considered and effectively addressed, this study argues for the benefits of a reflective participatory management framework. A reflective cycle based on the principals of Participation Action Research (PAR), as defined by Baum *et al.* (2006), is presented (**Figure 7.27**). This reflective cycle is a model example of a stakeholder and community engagement process as part of a sustainable river basin management framework. The model was created considering the principles of Community-Based Natural Resource Management (CBNRM), Integrated Water Resource Management (CBNRM), and Integrated River Basin Management (IRBM). Essentially, this model is presented to exemplify an ideal participatory process, with different stakeholders, government and communities participating in river basin management.

As illustrated in **Figure 7.27**, several processes in the participatory cycle have been addressed through the methodology of the current project and key findings have been noted. The first step in the process involves the identification of key problems affecting the river. Through stakeholder meetings and community workshop, it has been learned that stakeholders and communities hold valuable information regarding the root causes and challenges faced in the Hennops River basin. For this reason, this step has been addressed through the current study. The second step, in a similar way, has been addressed by the current study. In this regard, chemical analyses and findings thereof provide information about potential pollution sources which continue to challenges the Hennops River basin. The findings of this project must therefore be presented to interested stakeholders and communities who will, through the institutional framework of the Hennops River Forum, act to address challenges.

However, because of observed governance challenges, the third step in the reflective cycle cannot be addressed. In this regard, information related to challenges must be communicated to communities and stakeholders, who through the HR Forum, make decisions. As the role of the HR Forum has not been properly established, partly due to the absence of a CMA of the Limpopo WMA, the proper decentralisation of government and representation of the community and stakeholders is not being effectively addressed. Therefore, this step requires further support of the HR Forum, interested stakeholders, and communities.

Similarly, the fourth step in this reflective cycle requires the addressing of community and stakeholder decision-making. Besides for the need for the repurposing of the Hennops River Forum, this step requires raising more awareness and further support of stakeholders and the forum as well. Raising awareness and attaining further support will allow for commoning of water resources, as argued in previous sections. Communities and stakeholders will then be able to relay feedback to government, who will be able to support initiatives to address concerns and identified challenges.

The fifth step in this cycle will involve the mobilisation of stakeholders and communities who will address identified challenges through initiatives such as clean-up campaigns. While the current study partially addressed this step through the mobilisation of stakeholders and communities during clean-up campaigns, these activities at the present moment, are unsustainable as findings of this study indicate. Active community interest and support is required to yield long-lasting results and address challenges effectively. Through this step, the commoning of water resources is once more argued critical. Therefore, root causes related to the lack of awareness and lack of support must first be addressed before such a model is sustainable.

The final step in this process involves the re-evaluation of the state of the Hennops River basin following mobilisation and engagement initiatives. This has been partially addressed through this project but requires the autonomy of stakeholders and communities for this framework to be sustained. In this regard, further support of the Hennops River Forum as a representative institution as well as key stakeholders is necessary to allow continued re-evaluation of the evolution of the Hennops River basin. The re-evaluation of the Hennops River basin will require a comprehensive and well-supported monitoring strategy. While this is not covered in this project, further engagement with the HR Forum as well as interested stakeholders may yield important insight on the possibilities in this regard.

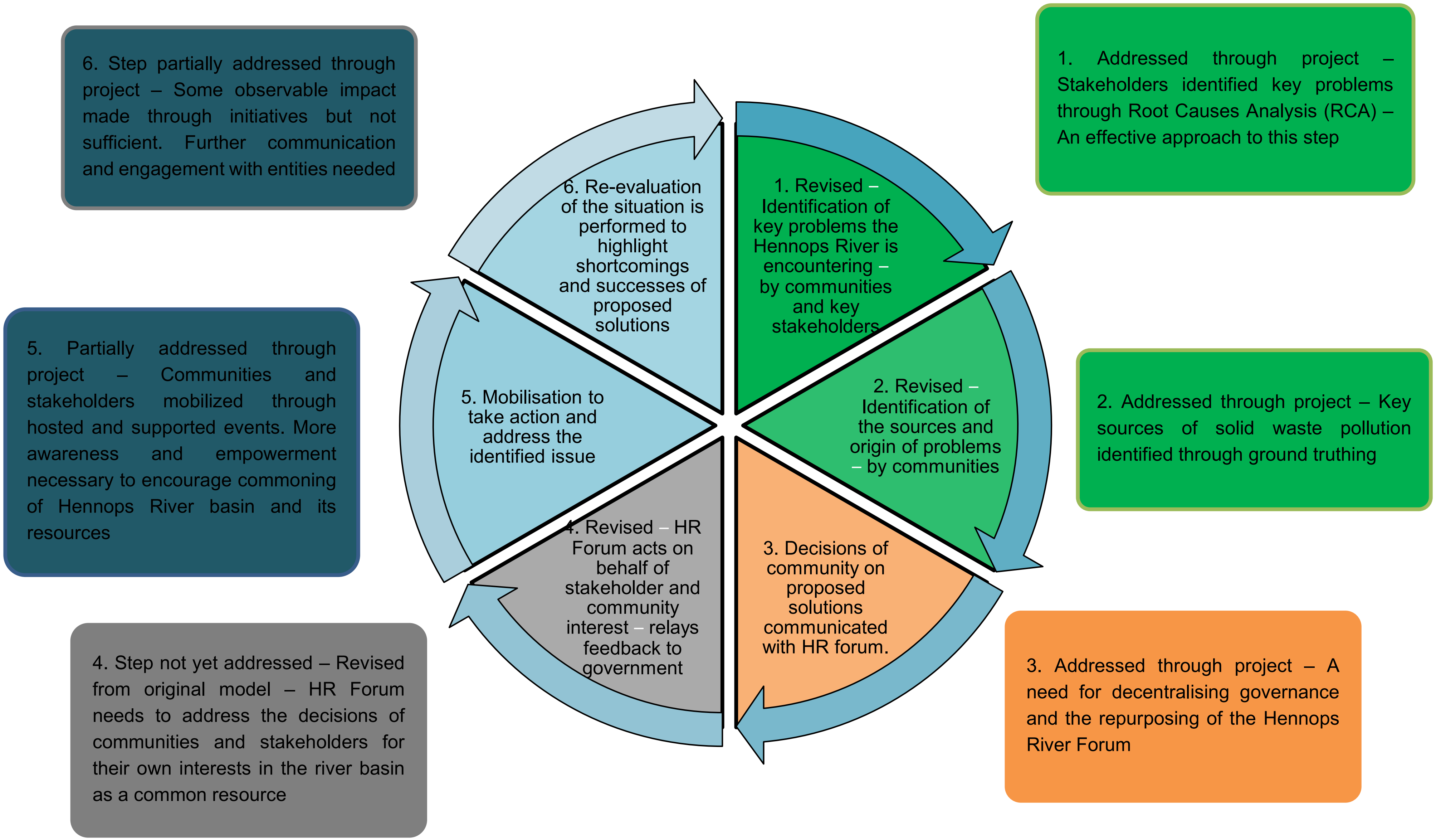

Figure 7.27. Final proposed reflective model for the participatory management of the Hennops River basin

7.2.4 Concluding remarks

To sum this chapter up, after engaging with the chemical component of this project, this component considered challenges and opportunities related to stakeholder and community engagement and participation. A methodology including a rapid literature appraisal, ground-truthing, stakeholder meetings, community workshop, and clean-up campaigns was implemented. This methodology aimed at learning more about the root causes related to the Hennops River basin's pollution. Furthermore, this project also sought to mobilise stakeholders and communities towards creating a sustainable management framework for the river basin.

The findings of this project suggests that root causes related to the poor management of the Hennops River basin and its subsequent pollution challenges are strongly related to governance and a lack of awareness among stakeholders and communities, and most importantly, a lack of support. Root causes are further exacerbated through a lack of political will and other challenges like informal settlements. No management framework is currently in place, leaving the Hennops River basin subject to identified challenges such as illegal dumping, poor wastewater treatment, as well as lack of service provision.

Several clean-up campaigns were supported and hosted to involve and mobilise communities and stakeholders in participatory efforts, but also to raise awareness and empower local organisations. These events were publicised widely to raise awareness and communities were invited to join. Many stakeholders were unaware of severity of the issues the river basin faces. Furthermore, community members demonstrated a lack of interest in participatory efforts within their community. Essentially, the overall chemical findings of this study suggest that not much of an impact has been made through initiatives. At the same time, some initiatives fared better than others having been supported to a further extent.

It is argued here that the Hennops River basin faces a number of governance challenges. These must first be addressed should an effective management strategy like the one presented in the previous section be implemented. This is relating to the establishment of a CMA of the Limpopo WMA, as well as the repurposing and further support of the Hennops River Forum. In addition, the lack of awareness within communities and among stakeholders continues to act as a root cause of the current state of the Hennops River basin. More awareness needs to be raised before the proper management of the river basin is possible. Finally, more support and empowerment are necessary to allow initiatives within the Hennops River basin to be effective. Furthermore, additional support will also aid in improving infrastructural integrity, which has been noted as a serious problem for local leaders and other authorities.

With all of the above considered, the Hennops River basin can then be addressed through the formulated reflective cycle. As a six-step process, this framework addresses key concerns relating to the potential of participation in the context of water resource management. Considering the relationship between government, communities and stakeholders, this model represents an effective way to address the challenges of the Hennops River in a sustainable way. Further refining of this model can take place as it is implemented.

CHAPTER 8: CITIZEN SCIENCE AND COMMUNITY ENGAGEMENT

8.1 INTRODUCTION

Following from a presentation of the different results and subsequent discussions, this section aims to formulate a link between the chemical and social science components of this study. In this regard, some key observations and understandings will be presented and evaluated. In essence, this chapter presents findings around lessons learned through the various investigations and engagements conducted, drawing links between different initiatives and their potential in inspiring citizen science initiatives and other forms of community engagement involving participation. As part of the considerations made in this chapter, a way forward for stakeholder engagement as well as chemical analysis of the Hennops River basin are presented.

8.2 LESSONS LEARNED FROM STAKEHOLDER ENGAGEMENT THROUGH CLEAN-UP CAMPAIGNS

As previously captured in other chapters, this project engaged with and supported several clean-up campaigns, one of which was organised by the research team itself. This clean-up campaign, that is, the event held in Esiphetweni-Vusimuzi, will be considered specifically in this section, demonstrating the strengths, weaknesses, opportunities and challenges associated with holding and hosting clean-up campaigns as part of river basin management initiatives. Also considered as part of this section are the viewpoints and opinions of stakeholders who host campaigns on a regular basis. Community sentiments following the clean-up campaign in question will be considered to gauge the value of such initiatives in inspiring and promoting citizen science initiatives which can lead to the regular monitoring of the river basin. Altogether, this section hopes to shed light on the realities of clean-up activities and participatory actions and their effectiveness at the present moment.

8.2.1 Health and safety concerns

Before the effectiveness of clean-up campaigns can be considered, overall health and safety considerations are important to note. Firstly, because of the current state of the system's water resources, interaction with the Hennops River basin needs to account for ethical considerations. While clean-up campaigns are currently being held on a regular basis, because of the lack of awareness within communities, health and safety become important considerations when arguing for the effectiveness of clean-up campaigns as well as the future and potential of citizen science within this space. For example, during the clean-up campaign of Esiphetweni-Vusimuzi, the research team had to account for large expenses towards health and safety through the provision of equipment and Personal Protective Equipment (PPE). Community participants, as well as some stakeholder group participants are unaware of the dangers of the water of the Hennops River basin, given its current chemical state as captured in this report. This was problematic since the current state of the river basin hindered engagement with the river system and is here argued, will hinder the potential of citizen science initiatives aimed at monitoring the chemical state of the system. As such, engagement in this regard is currently limited to key stakeholders such as NGOs who are more equipped and knowledgeable of health and safety concerns. Furthermore, key stakeholders are currently being supported by different organisations to conduct analyses, however, this has been limited to a very few groups within the river basin.

It is therefore argued that, because of current health and safety concerns, the participation of community members and stakeholders in chemical analyses and monitoring must be approached with caution. As learned through this project's engagements, communities and stakeholders are better equipped and knowledgeable to address other concerns such as solid waste management around the river. Chemical analyses and monitoring at this point is best reserved to individuals and groups more aware of the dangers of the river system's water resources.

8.2.2 Ethical considerations

The current study obtained ethical clearance to conduct clean-up initiatives through the PhD research of Lucien James. However, this clearance did not permit for engagement with minors and children. At the same time, children and the youth are also affected by the challenges the river basin faces, and may therefore have an interest in river basin management themselves. It is argued here that, firstly considering the observations in relation to health and safety, the youth may present new opportunities towards engaging in participatory initiatives. While it is still argued that the health and safety of minors and children should be considered first and foremost, the youth can engage with the problem through raising awareness and engaging with local stakeholders to learn about how they can contribute to citizen science as they get older and more knowledgeable of the challenges their community faces.

Several NGOs and stakeholder groups have expressed interest in mentoring and guiding the youth to learn more about water resource management. In this regard, some activities, such as those of Hennops Revival and partner stakeholders have engaged youth through clean-up campaigns and citizen science. However, as part of the Esiphetweni-Vusimuzi campaign, this was avoided for ethical reasons.

8.2.3 General observations

Considering the above, this section presents a general overview on the potential of communities and stakeholders in citizen science and engagement moving forward towards the future of river basin management of the Hennops River basin. This section will also consider the effectiveness of clean-up campaigns to address the challenges of the Hennops River basin.

Firstly, as noted through chemical analyses and direct observation, the river basin's water quality had not improved following after the clean-up campaign. Instead, conditions seem to have worsened since the event, with even more dumping activity being observed at the location which was originally addressed. As highlighted in previous chapters, this is highly related to the lack of awareness and service delivery in key polluting urban spaces. In this regard, it is argued that clean-up campaigns such as the one conducted in Esiphetweni-Vusimuzi will not be sufficient to address the challenges that the river basin faces. As such, considering long-term solutions to the challenges observed, awareness campaigns are better suited to educate the community and interested stakeholders. Furthermore, clean-up campaigns do allow for observable changes to be made to the environment, as noted in previous chapters, however, more awareness is necessary to address root causes and related undesirable effects contributing to the larger problem at hand.

In relation to citizen science potential, the engagement in clean-up campaigns has established the value of stakeholder participation. Key stakeholders such as NGOs continue to demonstrate their potential in addressing the challenges that the river basin faces. As such, the empowerment and support of their own initiatives are vital to support the ongoing transformation of the Hennops River basin. In turn, stakeholders have the potential to inspire action within communities.

8.3 LESSONS LEARNT IN COMBINING CHEMICAL ANALYSIS WITH STAKEHOLDER PARTICIPATION IN RELATION TO SOLVING CATCHMENT RIVER POLLUTION

8.3.1 When is chemical data analysis and stakeholder engagement combination needed?

It is the research team's view and experience that in situations where some form of pollution of the river system is known, chemical measurements alone add little value in trying to solve the problem. It is better to combine chemistry and stakeholders' engagements so that keys issues are identified in relation to the cause of the problem and steps are subsequently taken to address the problem. This is applicable to most of South Africa's polluted river system. It is necessary to obtain further details of the various forms of pollution at a chemistry level, but this must be combined with stakeholder engagement. Thus, at this stage, the two must be seen as complimenting each other. Every chemical measurement that gives new forms of chemical pollution then should help in bringing more stakeholders and give urgency in solving the problem. Thus is our view that chemical measurements alone are needed when detailed transport and fate studies of certain chemicals is needed to close any gap on possible potential toxicity that may not yet be known or carried out to inquire the possible pollution that is suspected to be happening.

8.3.2 Experiences of actual research teams on the project

Multi-disciplinary research teams are required work together and supporting each other to address the issue at hand. As a key component of such endeavours, social relationships are also important to form spaces to address various aspects of future projects. In this case during stakeholder engagement and clean-up campaigns, the natural scientists were also present to support our social scientists' team. This worked very well. That also helped natural scientist appreciate community engagements and social science aspects as a discipline. This could be said also of social scientists that also was much enriching working with natural scientist and being on ground together where things are happening and appreciate more on role of chemical data and its measurements.

8.3.3: Experiences on the role of media, stakeholders' engagement, and chemical measurements

The media plays key role especially in the social sciences field where various stakeholders and key partnerships is needed. Essentially is needed in every aspect. It helps translate chemical measurements in a language that can be understand and this can reach as many people as possible. This helps to raise awareness of the depth of the problem to bring urgency in finding a solution. It is needed to advertise any clean up campaigns to bring as many stakeholders as possible and disseminate actual clean up campaigns caried out and this can bring more stakeholders and key partners as experienced during our project. Actual advertisements of the clean-up campaigns helps bring more key partners since many players what to associate with things already happening on the ground.

8.3.3 Reactions of community and stakeholders

Communities and stakeholders demonstrated keen interest in the results of chemical analyses performed in this study. As observed during the initial stakeholder meeting, many stakeholders were unaware of the severity of the problem. As such, chemistry holds value in reporting to stakeholders the reality of the problem that they are currently faced with. However, because of the profound lack of awareness within communities, this information holds little weight without the raising of awareness in relation to key issues such as illegal dumping. As observed through an analysis of viewpoints of stakeholders, the state of the river basin is known to all because of the current severity of the challenges the river basin faces. Therefore, chemical findings have value to knowledgeable and active stakeholders, who themselves engage in monitoring of the river system and its water resources.

For much of the community, the environmental challenges observed in their surrounding environment are not as important as the socio-economic challenges they encounter in their households. Therefore, before community members can take an interest in the value of chemistry to monitor their environment, they first need to take an interest in their surrounding environment itself. It is here argued that further empowerment of key stakeholders will increase the capacity of these groups to involve more community members.

8.3.4 The importance of key partnerships and collaborations

It is important to note the value of key partnerships in fostering future projects in addressing the challenges of the Hennops River basin. In this regard, it is here presented that key informant stakeholders such as Hennops Revival, EnviroCare Tembisa, and Fresh NGO continue their work within the river basin. However, these stakeholders need support from government, the private sector, and communities, hence the need to consider governance challenges as highlighted in previous chapters. Furthermore, these key stakeholders played an important role in supporting the activities of this project and should be further empowered to contribute to establishing the management framework here proposed.

The research team, through the various social engagements undertaken, was able to network with a range of stakeholders and bring different organisations together to learn about and address the challenges of interest. In this regard, key partnerships were formed, for example, between Wits University and EnviroCare Tembisa. This partnership was further strengthened through capacity building such as field trips for other academics and students. In this sense, more connections were established between different key stakeholders, addressing a big challenge reported, that is, governance. Clean-up campaigns also had the potential to achieve this, bringing more people closer to the problem.

Therefore, it is the researchers' opinion that further social engagement with different stakeholders will only strengthen connections and lead to future collaborations. These collaborations will aid in raising awareness, which is currently understood as the biggest hindrance to the effectiveness of the Hennops River's management. As such, it is envisaged that NGOs and private sector stakeholders will play a key role in community participation and the support thereof. Furthermore, collaborations between academic institutions such as Wits University and NGOs can be further adopted for other engagement initiatives which will support the ongoing development of participatory action.

8.3.5 Monitoring and chemical analyses: towards a management framework

Bridging the gap between the chemistry and social science components of this project, chemistry will play an important role in monitoring the river basin's ongoing transformation. At the same time, the river basin's wellbeing is tied strongly to governance and awareness challenges. Therefore, chemistry must be considered a tool, rather than a solution to the problem being faced. More engagement and research in the social sciences is necessary to inspire and support initiatives related to the monitoring of the river basin, and chemistry can contribute to establishing good indicators for change.

As previously presented, a reflective cycle for managing the Hennops River basin can be implemented through which chemistry and chemical analyses can aid in recording successful initiatives and progress in improving conditions. However, given the findings of this project, it must be expected that changes will only be observed following rigorous addressing of the root causes as argued as part of this study. Therefore, it is argued that the management of the river basin has to consider key governance challenges before monitoring and mitigation methods can be applied. In this same sense, as it currently stands, citizen science is limited to measuring the severity of the problem, not measuring any significant changes. Changes can only be expected once key root causes are addressed.

CHAPTER 9: CONCLUSIONS & RECOMMENDATIONS

9.1 CONCLUSIONS

<< These are the logical inferences that can be drawn from the information contained in the report. This section should *not* simply repeat the facts or findings of the report. This section *interprets* those findings and explains their implications. >>

The study first showed that it is possible to combine chemical measurements with stakeholders' engagements at the same time in trying to address pollution of river systems in South Africa such as Hennops river basin. One important requirements is that the two teams leading the social sciences and natural sciences are able to work together and give each other chances to lead their respective tasks as per project deliverables. This then brings a powerful synergy as was seen during with Wits 100 celebration clean-up at Esiphetweni, Tembisa. This event brought a lot of key partners needed to address the situation on the ground together. Some partners presented their own input knowledge to the problem which the research team could therefore carefully consider.

Some of the conclusions of the study can be summarised as follows:

i. The media was found to play a very critical role in helping publicising the status of pollution of the Hennops river and helped to inform various stakeholders about the possible clean-up campaigns and activities on different days. However, the role of the media in changing behaviours within the communities, which are a source of the problem has been observed to be very minimal. Its impact was more on the outside where potential key partners have come on board like Coca Cola, Tshwane Municipality, Water Research commission and other government departments. Also, there is a danger that media can be used by NGOs as a source of fund raising for clean-up campaigns which is good, but this must be matched by its impacts on the ground.

   Thus, targeted interactions with actual communities and with key partners is needed to try and come up with ways on how to change community behaviours upstream. Essentially, various layers of communities need to be targeted like children in Schools, Youth, and women.

ii. The role of NGOs and clean-up campaigns was observed to play an important role but has got mixed results on the ground. Further, there is a bit of fragmentation in the way various NGOs are active in areas of work. For example, the research team encountered three NGOs working in the area which includes Hennops Revival, the biggest and with most partners on board but works mainly in centurion area who run occasional clean-up campaigns upstream. Then there is EnviroCare based in Tembisa where the source of the problem is and led by some community leaders and community volunteers. This is the most critical one but is poorly funded with little key partners, has no website and little access to the media. The third one is Fresh NGO managed by William but focuses on putting traps just below upstream as the Hennops river leaves Tembisa towards centurion. NGO organisations need to work with social scientist so that proper assessment is done on the impact of their work and how it could be strengthened further. In the current form, very little social scientists are on board despite Gauteng having many higher education institutions.

iii. The results of chemical analysis before and after the start of the clean-up campaigns shows that in most cases clean-up campaigns have minimal long-term impacts. This is mostly due to the small impact intermittent clean-up campaigns have on the environment, given that these take place rarely, on occasions, being seasonal or centred around major events like earth day, Wits 100 celebrations etc. Thus, there is no sustained operations. Not all key partners are also present during these campaigns like Ekurhuleni municipality representatives and local councillors of the area and other stakeholders with the community itself including churches.

9.2 RECOMMENDATIONS

<< Recommendations are based on the findings and the conclusions. They indicate what action should be taken to overcome the problems that have been investigated. They should link to the original aims of the work and purpose of this report. Try to link the recommendations to the conclusions you have noted above. Particularly important recommendations are those that describe follow-on research that may be necessary. >>

Based on the findings and conclusions, the following recommendations are suggested:

i. Firstly, future research and participation should be focused on addressing the root causes noted in this study. In this regard, engagement activities should be refocused to address the lack of awareness among community members and stakeholders. While clean-up campaigns are essential for the eventual addressing of the pollution problem it is envisaged, and supported through the findings of this study, that raising awareness that effect behavioural change will address undesirable effects which lie deep within communities such as Tembisa.

ii. Governance challenges and the implementation of policy must be at the forefront of future endeavours to address participatory action. As observed, a disconnect is present at all levels and between different governmental, community, and stakeholder entities. Therefore, the establishment of key institutions such as a CMA and the repurposing and supporting of already-standing institutions is paramount for policy to be effectively implemented.

iii. Further research on different areas within the Hennops River basin is necessary. This study considered in much more detail, the realities of Tembisa and the Kaalspruit tributary. However, further research will be able to explore this area in finer detail, or at a smaller scale. In this regard, future research can explore important relationships between stakeholders and the river basin, particularly considering the actions and lifestyle of community members. At the same time, more research is necessary to consider the localised effects of industrial activity on the Hennops River basin, which this study does not address in detail.

iv. A key finding has been that NGOs hold an important role in the future of the Hennops River basin. Without their continuous efforts, awareness and action would be non-existent. As it stands however, NGOs are poorly supported by the private sector and their respective communities. It is therefore recommended that the root problem related to a lack of funding and support be addressed through the support of key NGOs such as EnviroCare Tembisa, Hennops Revival, and Fresh NGO. More efforts to gather support from the private sector for NGOs is necessary, and this can be achieved through raising more awareness among businesses, corporations, and industries.

v. This study exemplified the power and potential of key partnerships through the engagement activities initiated. Further research needs to be supported to further establish the potential of key partnerships to address the grander problem. Considering that well-supported initiatives are able to gather a fairly large following, key partnerships will aid in supporting these types of initiatives. Therefore, further social science research is needed for the unpacking of the potential of partnerships, considering the current activities taking place within the river basin.

vi. It is clear that the challenges the Hennops River basin faces ultimately affect the Hartbeespoort Dam, which has previously been studied as water source facing multiple challenges. In this regard, efforts to address the Hennops River's pollution challenge will have knock-on effects on other water resources in South Africa. However, further engagement with the problem and potential solutions is highly recommended. Further research may include the partitioning of the Hennops River basin into smaller areas where assessments can take place.

vii. Some potential avenues of chemical research may include studying dissolved oxygen within the river, some physical chemical properties linked to dissolved oxygen and nutrients in the river from upstream all the way to downstream to Hartbeespoort Dam and how these change in different seasons. This is important as can serve as further warning on the ability of the whole catchment to sustain biota.

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APPENDIX A:

Table 9.1: LC-MS Operating conditions

Parameter	**Details**	
LC flow gradient	**Retention /min**	**% Composition B**
	0	5.0
	1.0	5.0
	6.0	55.0
	8.0	55.0
	10.0	95.0
	12.0	95.0
	13.0	5.0
	14.0	5.0
Flow rate	0.3 $ml.min^{-1}$	
Column temperature	25°C	
Capillary Voltage	2500 V	
End plate offset	500 V	
Nebulizer pressure (N_2)	2 Bar	
Drying gas (N_2)	8 $L.min^{-1}$	
Drying Temperature	300°C	
Mass range	30-1000 Da	