The impacts of climate change in relation to plastic waste on the Umgeni River system.

School of Engineering

Submitted in fulfilment of the requirements for the degree of Master of Science in Engineering,

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PREFACE AND DECLARATION

I, Muhammad Khan, hereby declare that this dissertation, submitted in partial fulfilment of the requirements for the degree of Master of Science in Engineering to the University of KwaZulu-Natal, is a result of my own research and investigation and that it has not been previously submitted by me for a degree at this, or any other institution or university.

Furthermore, I, Muhammad Khan, affirm that I have made use of the WROSE Model for data analysis and recommendations. It is understood and accepted that the WROSE (Waste to Resource Optimisation and Scenario Evaluation) Model is a licensed trademarked Waste Management Decision Support model/tool developed by UKZN (Prof. Cristina Trois) since 2010. This may include further know-how and intellectual property.

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Muhammad Khan

Date:

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ABSTRACT

The use of plastics and plastic by-products have become so profusely common in everyday life of society that the issues attached to its recycling, disposal and preventing contamination to our soils, rivers and oceans have become a global concern. The amounts of plastic waste in the form of macro- and micro-plastics have reached a level of threat to our rivers and oceans' waters, posing detrimental impacts on our aquatic life, as the marine species are mistaking the plastic debris wastes for food and subsequently affecting human health. Plastic waste in the marine environment is a rising global concern, and it is connected to various environmental and socio-economic consequences. Plastic debris found in marine environments primarily originates from land-based sources, and it is estimated that annually 4 – 12 million tonnes of improperly managed plastic waste enter the marine environment. This research focuses on plastic waste along the Umgeni river before it reaches the ocean. This research proposes undertaking a study at the Umgeni river system to monitor the amounts and characterisation of waste retained at the litter boom system and provides suggestions of optimised locations for the placement of litter booms to maximise the collection and removal of plastic waste. Furthermore, it looks at the valorisation of plastic waste using the WROSE model.

Keywords;

Plastic debris, marine waste, Umgeni river, WROSE model

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LIST OF ABBREVIATIONS

DEA – Department of Environmental Affairs

FRED – Floating Robot for Eliminating Debris

GHG – Greenhouse Gas

HDPE – High-Density Polyethylene

IPCC – Intergovernmental Panel on Climate Change

LDPE – Low-Density Polyethylene

PET/PETE – Polyethylene Terephthalate

PP – Polypropylene

PS – Polystyrene

PVC – Polyvinyl Chloride

WROSE – Waste and Resource Optimisation Scenario Evaluation model

WWF – World Wide Fund for Nature

CHAPTER 1: INTRODUCTION

1.1. Preamble

The biosphere's oceans are one of the most significant and vital, life-supporting environments (Gattuso et al., 2018). They serve as a home to a wide variety of living organisms, provide a crucial role in maintaining the climate, and contribute to global food security and aid global economies (Gattuso et al., 2018). The present and future increase in average worldwide temperatures is projected to severely impact vital marine ecosystems and ecosystem services (Hoegh-Guldberg et al., 2018, Gattuso et al., 2018).

There are varying degrees of sensitivity for different ecosystems regarding ocean acidification, rise and warming in sea levels (Gattuso et al., 2015). The severity of these effects will upsurge due to events occurring concurrently, such as ocean acidification, deoxygenation and an increase in sea levels (Pörtner et al., 2014). As mentioned, all of these impacts scale to carbon dioxide emissions (Gattuso et al., 2018). Ocean acidification is one of the chief issues which is caused by carbon dioxide emissions and can have adverse impacts on the development, survival, physiology and growth of marine invertebrates (Dupont et al., 2013)

According to the Intergovernmental Panel on Climate Change (IPCC), the world's oceans have seen an average increase in sea temperature of 1.5°C in post industrialisation times (Hoegh-Guldberg et al., 2018). Such small changes in temperature could negatively affect the ocean's ecosystems and their ability to function (Hoegh-Guldberg et al., 2018). The effects of climate change can be seen in terms of ocean acidification. Over the past 50 years, the global oceans have become 30% acidic, with an average mean decrease in pH from 8.2 to 8.1 (Bellio, 2014). This can be attributed to an increase in carbon emissions, subsequently causing an increase in carbon dioxide uptake by oceans, which is presently at nine billion metric tons per annum (Bellio, 2014). A notable irregularity found is that the Indian Ocean has an acidity level ranging from 8.1 to 7.7 and, on average, is 10% more acidic than the Pacific and Atlantic oceans (Bellio, 2014).

These impacts, coupled with human-based interactions such as overfishing, pollution, destructive fishing and coastal development, have detrimental effects (Gattuso et al., 2015). A primary environmental concern is water pollution, which predominantly has been caused by humans (Al-Ghassani et al., 2013). Water systems have several pollutants entering them, including sewage, industrial waste, heavy metals and fertiliser run-off. However, a persistent material found in the ocean is plastic, consisting of 60 – 80% of all marine litter (O'Brine and Thompson, 2010).

Additional to all the multiple human pressures impacting aquatic ecosystems, the plastic debris build-up is one that has the most detrimental effect (Wagner et al., 2014). On estimate, the annual average of plastic waste entering the ocean is between 4 – 12 million tonnes (Sussarellu et al., 2016). Plastic materials degrade from macro- plastics into micro-plastic particles due to currents, wave action and exposure to sunlight amongst other environmental factors. Micro-plastics can be defined as particles of plastic smaller than 5mm in diameter (Ziccardi et al., 2016). When ingested by living organisms, it can become a severe problem (Sussarellu et al., 2013). There are currently approximately 250 000 tonnes of floating micro-plastic pollution in the world's oceans (Sussarellu et al., 2016). Additives such as; flame retardants, ultraviolet stabilisers, colourings and accumulated persistent organic pollutants (POPs) can be found in micro-plastics. These substances, when ingested, are harmful to marine organisms (Sussarellu et al., 2013).

The consumption of micro-plastics by humans via food can result in severe long-term effects if it is ingested on a consistent basis over a period of time (Sharma and Chatterjee, 2017). These effects are hazardous and not only occur because micro-plastics are extremely difficult to degrade within the human body, but also as micro-plastics are vectors of heavy metals and other pollutants (Sharma and Chatterjee, 2017). The long-term human ingestion of micro-plastics causes an alteration of chromosomes, leading to obesity, cancer and infertility (Sharma and Chatterjee, 2017).

Plastics' effects on aquatic life are detrimental and cause the loss of significant fauna and flora (Wabnitz and Nichols, 2010). The influx of wastes, more especially plastics, entering river systems will rapidly increase due to climate change due to frequent flooding from higher rainfall or an increase in sea levels (Gündoğdu et al., 2018).

1.1.1. The Plastic Passage to the Ocean

Substantial amounts of plastic waste that originates from land-based sources are transported to marine environments through rivers' pathways (Schmidt et al., 2017). It can be noted that the source and fate of land-based plastic waste remain understudied; however, riverine plastic waste is currently an emerging field.

The entry of riverine wastes can include discharge from boats, dumping along riversides, effluents from sewage plants, stormwater drainage, and rural and urban run-off (Williams and Simmons, 1999). On average, it is estimated that worldwide, about 80% of solid beach waste originates from adjacent rivers (Araújo and Costa, 2007). The predominant waste along riversides and in rivers are plastics while other waste streams are found in considerably lower abundances (Lechner et al., 2014, Schmidt et al., 2017). The large abundance of plastic waste is not only due to their widespread use but also due to their characteristics, such as their buoyancy and extreme persistence (Derraik, 2002, Moore, 2008).

Once waste debris enters a river it can become trapped in riparian vegetation (Ivar do Sul and Costa, 2013), retained in the river system by becoming buried in the benthic sediments (Nel et al., 2018, Hurley et al., 2018), washed over the river banks during high flow rate events (do Sul et al., 2013) or eventually transported out to the ocean (Veerasingam et al., 2016, Hurley et al., 2018).

The composition and abundance of waste along riversides and in rivers are additionally determined by economic or social activities and land-use along the stream or coastal area (Williams and Simmons, 1999, Shimizu et al., 2008, Carson et al., 2013, Lechner et al., 2014). Oceanic and climatic conditions, chiefly wind, wave motion, tidal dynamics and nearshore currents are determining factors in the deposition and movement patterns of floating waste in coastal areas (Browne et al., 2010, Doong et al., 2011, Carson et al., 2013). River plastic quantities show high correlation with factors such as population density, waste water treatment, stormwater drainage, urbanisation and waste management which can be attributed as sources for plastic debris in freshwater systems (Best, 2019).

Numerous studies have been conducted in recent years to quantify plastic pollution in rivers such as the Seine River (Gasperi et al., 2014), the Thames River (Morritt et al., 2014), the Los Angeles River (Moore et al., 2011) and the Saigon River (Lahens et al., 2018, van Emmerik et al., 2019). However, the majority of studies tends to be more focused on European and North American rivers, as almost 70% of studies on riverine plastic have been conducted in first world countries (Blettler et al., 2018). This regrettably does not represent the locations in which recent models predict the largest contributors for marine plastic pollution are (Lebreton and Andrady, 2019).

Therefore, there is a need for research in these areas which are under-represented in literature. An essential prerequisite for optimal retrieval of plastic waste is understanding the origin, fate, and pathways of plastic waste.

1.2. Study Area: The Umgeni River Catchment

The Umgeni river is one of the major river systems in South Africa and the most extensive system in KwaZulu-Natal (Adeyinka and Moodley, 2020). The Umgeni catchment has a surface area of 4349 km^2 (Namugize et al., 2018). It is one of the most polluted rivers in South Africa, and contributes to a significant amount of pollution entering the Indian Ocean as indicated in Figure 1.1.

The Durban Green Corridor, a non-profit organisation, has developed an innovative way to collect the plastic wastes along the course of the Umgeni River and tributaries (Mail, 2020). This organisation has implemented a ‘’litterboom’’ system to retain plastic waste and prevent it from entering the marine environment. However, there are inefficiencies in the placement of the booms and only a few avenues in which the current collected waste is being utilised.

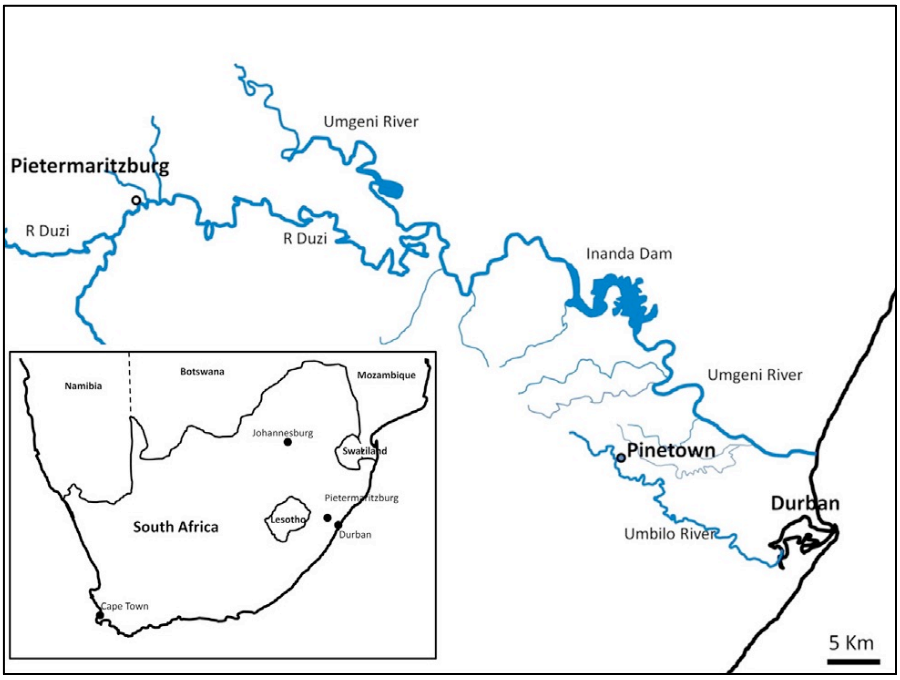

Figure 1.1. Location of the Umgeni River (Adapted: (Baker et al., 2015)).

1.3. Problem Statement

This research aims to determine and quantify the amount of waste generated along the Umhlangane tributary to determine possible entry routes to the Umgeni river system; it further seeks to suggest how the plastic waste collected along the river system be valorised efficiently and effectively.

Key research questions:

- What is the quantity and composition of solid waste within the Umhlangane tributary?
- What are the entry points for plastic waste?
- What is the potential impact of climate change on waste in the Umgeni river system?
- What are possible sustainable avenues for the collected waste plastics to be utilised by the eThekwini municipality?

1.3.1. Aims and Objectives

1. To understand the quantity and character of solid waste within the specified Umhlangane catchment.
    a. To determine the waste that is entering the catchment.
    b. To determine the quantity and character of waste that is captured by the current litter booms.
2. To determine the hotspots for waste entry into the specified Umgeni catchment.
    a. To utilise GIS/Remote sensing data to determine hotspots for entry.
    b. To utilise this information for the placement of future booms.
3. To determine the effect of climate change on waste.
    a. To determine the effects of climate change on waste streams found at the litter booms.
4. To determine possible avenues for the use for the plastic waste collected at the litter booms.
    a. To utilise the WROSE model to find scenarios for the valorisation of plastic waste.

1.3.2. Rationale

This research will include a working prototype model for the collection and characterisation of riverine waste, which will promote the creation of a system for waste management explicitly based on riverine litter.

To prevent waste from reaching the ocean, it is imperative to remove pollution along the path of our rivers, which acts as a conveyor for waste into oceans. This research has the potential to contribute to the comprehensive reduction of ocean plastic as the method built using this case study can be scaled across the entire Umgeni catchment and other rivers.

1.4. Research Design and Methodology

This study is fractured into five phases to address its objectives:

Phase I: Literature Review

In this phase, a comprehensive literature review looks at waste streams found in riverine systems and focuses primarily on marine plastics. It further looks at mapping techniques and South African waste legislation.

Phase II: Case study and Mapping Exercise

A case study analysing the study area will be drafted to conceptualise this research's problem statement further. GIS and other mapping skills will be utilised to map out the various zones along the river, indicating entry zones and other factors contributing to plastic wastes.

Phase III: Waste Characterisation and Quantification

A waste stream analysis will be carried out to characterise and quantify waste along the Umhlangane tributary entering the Umgeni River. This will further be correlated to the effect of climate change events on the quantities of waste.

Phase IV: Valorisation of Plastic Waste

Based on the previous phase's data, this will be used with the WROSE Model to develop possible sustainable scenarios and avenues for the plastic waste generated.

Phase V: System Recommendations

With the data obtained in the previous phases, recommendations will be made to address possible flaws or disadvantages of the litter boom system, and suggestions on how to further enhance this system's capabilities will be addressed.

1.4.1. Layout of thesis

This study is six-fold and is structured, as indicated below in Figure 1.2.

Introduction

- Preamble Introducing the Research background
- Rivers as conduits for waste
- Aims and Objectives of the study

Literature Review

- Waste and Climate Change
- Waste fractions entering oceans
- Plastic waste management
- Riverine Plastics
- South African legislation

Brief overview of the methdology

- Phase I: Literature Review
- Phase II: Case study and Mapping Exercise
- Phase III: Waste stream analysis
- Phase IV: Valorisation of Plastic waste
- Phase V: System recomendations

Case study and Mapping Exercise

- Detailed methodology
- The study area and waste managment along the Umhlangane tributary
- Mapping of the Umhlangane tributary

Results and Discussion

- Waste Characterisation and Quantification
- Effects of climate change on the quantity of plastic waste
- Plastic Waste Valorisation
- WROSE Model

Conclusions

- Concluding statements

Figure 1.2 Thesis overview

1.5. Scope and limitations of the study

This research analyses the methods of minimising the amounts of plastic waste reaching the ocean. However, it is limited to focus on surface plastics and wastes; therefore, not considering the benthic plastic accumulation nor the effect of micro-plastics. Furthermore, the water's physicochemical properties and flow rate along the course of the Umgeni river do not fall within the scope of this study. It should also be noted that due to the study being undertaken during a global pandemic the waste patterns and quantities may be skewed due to different consumer habits and purchases, due to restrictions on their movement, and their economic situation.

1.6. Conclusion

This chapter provides an overview of the scope of this study. It further indicates the aims and objectives that guided the research and a layout of the thesis.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

As defined in the Introductory chapter, this research's primary objective is to determine the waste streams, entry pathways, and valorise plastic wastes in the location of the Umgeni River. This chapter introduces the concept of waste streams found in riverine environments and provides an overview of both current waste barrier technologies in river systems and a background into plastic waste.

2.2. Waste and climate change

Any item, product or material that is discarded, unwanted or is not considered useable for its original purpose can be regarded as waste (Tchobanoglous et al., 1993). The White Paper of Integrated Pollution and Waste Management for South Africa defines waste as "*An undesirable or superfluous by-product, emission, or residue of any process or activity, which has been discarded, accumulated or been stored for the purpose of discarding or processing. It may be gaseous, liquid or solid or any combination thereof and may originate from a residential, commercial or industrial area*" (Deat, 2000).

The need for effective and efficient waste management arises as waste is produced daily as an outcome of human activities (Tchobanoglous and Kreith, 2002). Improper and insufficient waste management consequently results in severe health, aesthetic and environmental issues (Tchobanoglous and Kreith, 2002). Components of different waste streams may be reused or transformed into energy or useful products using advancing technology and waste recovery methods (Ostrem et al., 2004, Matete, 2009).

Waste generation generally does not have a positive impact on climate ((UNEP), 2010). Human activity, coupled with their waste generation, produces an increase in greenhouse gas (GHG) concentrations in the atmosphere (Bessou et al., 2011). It is projected that this will result in a substantial heating of the earth's surface (IPCC, 2018), and further global climate changes in the coming decades (Wuebbles and Jain, 2001).

Greenhouse gases (GHG) - which are attributed to climate change and the three leading gases generating the most significant contribution to global warming - are methane, carbon dioxide and nitrous oxide (Kweku et al., 2017). All three gases are products present at the different stages of the management and disposal of wastes. Waste content contains organic materials - such as food, wood, paper and vegetative matter - which are consumed by microbes resulting in its decomposition (Lee et al., 2017). Over time the organic matter is decomposed by the microbes and methane, carbon dioxide and other gaseous compounds are released as a by-product into the atmosphere (Li et al., 2011).

Every waste management practice produces GHG, either directly (from the process itself) or indirectly (through energy consumption) (Koakutsu et al., 2012). The overall climate impact of a waste system depends on the net GHG emissions and GHG savings (Koakutsu et al., 2012). Another contribution to the GHG emissions of carbon monoxide and carbon dioxide is the uncontrolled burning of waste in landfills (Rim-Rukeh, 2014).

Landfills historically have been located on lower geographical heights, along coastal zones and floodplains due to its easy access and proximity to the populace (Brand et al., 2018). Weather patterns are changing especially changes in precipitation and the intensity of storm events – which is likely to be further intensified with global warming (Koakutsu et al., 2012). Thus these low-lying landfill sites are at risk of coastal or fluvial flooding (Koakutsu et al., 2012, Cooper et al., 2013).

It is predicted that climate change will increase sea levels, which will result in an increased saline intrusion into estuaries, more tremendous storm surges and increased coastal flooding (Doody, 2013). Climate change is likely to be a significant factor in riverine, pluvial and coastal flooding (Organization, 2002). Low-lying coastal landfills, where currently fortified from the sea, are at risk due to coastal squeeze to flooding and erosion (Möller and Spencer, 2002). The flooding will increase the leachate's volumes and cause a leachate leakage into the immediate environment (Suflita, 1992).

Reducing the need for landfills will better equip the waste sector to impacts caused by climate change (Corvellec and Hultman, 2012, Eneh and Oluigbo, 2012). This can be achieved by reducing the quantity of waste generated, such as banning plastic bags (Xanthos and Walker, 2017) and by diverting higher proportions of waste through recycling and reuse (Eneh and Oluigbo, 2012). Only waste that cannot be recycled or reused should be disposed of in landfills capable of withstanding climate change impacts.

2.3. The Waste hierarchy

The waste hierarchy concept is a concept that prioritises the reduction, recycling, and reuse of wastes over landfill disposal (Van Ewijk and Stegemann, 2016). It was incorporated in the 12th Sustainable Goal adopted by 193 United Nation Countries in the 2030 Agenda for Sustainable development (UN, 2015). The goal states " By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse" (UN, 2015).

The waste hierarchy was implemented in the National Waste Management Strategy of South Africa in 2006, as indicated below in Figure 2.1. This waste hierarchy consists of five levels namely;

1. Waste avoidance and reduction – this level aims for items to be designed in a manner that minimises their waste components.
2. Reusing of waste - this level refers to the removal of waste from the waste stream for its utilisation in a similar or different purpose without changing its form or properties.
3. Recycling - includes the separation of materials from the waste stream and its processing as raw materials or products.
4. Recovery – this level comprises of reclaiming specific components or materials, or generating energy using the waste.
5. Disposal and treatment – the final level of the hierarchy which involves waste being treated and / or disposed of in landfills - all dependent on the most appropriate environmentally friendly technique for its final disposal.

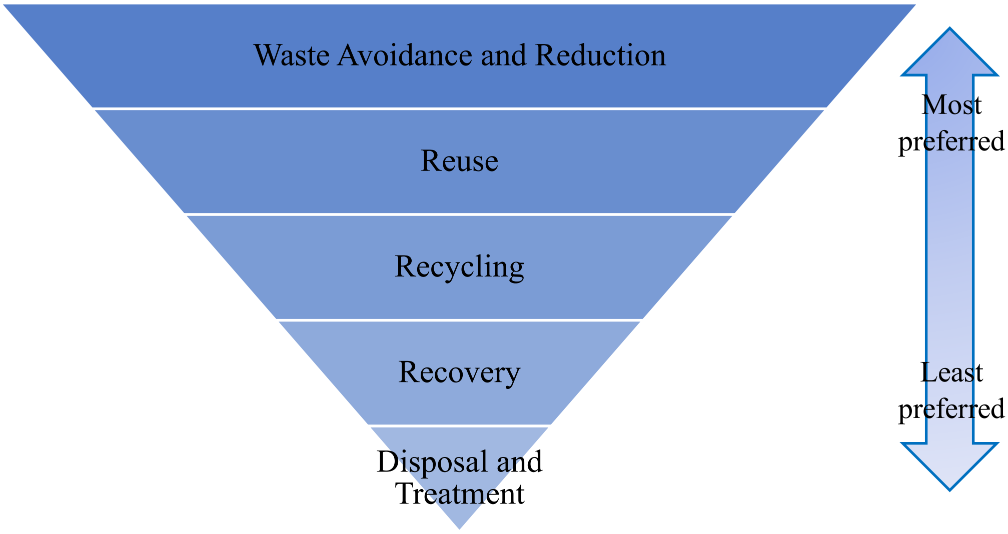

Figure 2.1. Waste Hierarchy (Adapted: National Waste Management Strategy of South Africa (DEA*)).*

2.4. Waste streams

Various types of waste may be formed from a range of sources such as; industrial, commercial, residential, construction and demolition, municipal services and agricultural activities (SAWIC, 2015). Depending on the classification conducted in terms of the National Waste Classification and Management Regulations, Waste may be classified as General or Hazardous. Waste is created because a product has fulfilled its single intended purpose and no longer has a use by the consumer (Pongrácz and Pohjola, 2004). Waste prevention is seen as the most significant event in the waste hierarchy; however, it generally receives the least priority in resource allocation and effort (Van Ewijk and Stegemann, 2016).

The composition of solid waste varies significantly from area to area (Abdel-Shafy and Mansour, 2018). These variations depend chiefly on the type of lifestyle, waste management regulations, economic stability and industrial activity (Abdel-Shafy and Mansour, 2018). The composition and amount of waste generated are critical for determining the appropriate management and handling of wastes (Abdel-Shafy and Mansour, 2018).

2.4.1. Glass

Glass is an inorganic amorphous solid which is generally transparent or translucent (Helmenstine, 2020). They do not have crystalline internal structures and are usually brittle, hard solids, impervious to the natural elements (Britannica, 2020a, Helmenstine, 2020). Glass is formed by cooling molten materials such as silica sand with sufficient speed to prevent the creation of visible crystals (Britannica, 2020a).

The chief advantage of utilising glass is its ability to be formed in a variety of shapes related to specific final use requirements, consumer needs and aesthetic wants (Robertson, 2013). Glass containers have the property of inertness, in which no particle can pass through it. It further has no foreign odour or taste (Sacharow and Brody, 1987). Glass also does not react with environmental elements, oxidise, corrode or deteriorate (Sacharow and Brody, 1987).

Thus, glass is considered as a benchmark in the food packaging/utensil industry with its transparency seen by consumers as an advantage (Schaschke, 2011). According to Consol South Africa, more than 3.1 million tonnes of glass is consumed per annum in South Africa. Two-thirds can be diverted from landfills and be reused. Glass only accounts for 4.5% of waste in South Africa (Consol, 2020).

Recycling of glass has environmental, social and economic benefits. It can be recycled endlessly without degrading its chemical properties or functionality (Aguilar-Jurado et al., 2019). The recycling of glass waste can curb global warming by saving landfill space and reducing the carbon emissions involved with the transport of materials for its manufacturing. Approximately 670kg of carbon dioxide emission into the atmosphere, is prevented for every tonne of recycled glass (FEVE-Recycling, 2016). The recycling of glass reduces land pollution and encourages a circular economy (Aguilar-Jurado et al., 2019).

2.4.2. Cardboard/Paper

Cardboard and paper are considered one of the primary needs of an advanced industrial and civil society (Abdollahbeigi, 2020). Approximately more than 18 million different cardboard types are produced globally, with the primary use of packaging (Rosenmai et al., 2013, Sturaro et al., 2006). Most household items and dry foods are packaged in cardboard packaging (Villanueva and Wenzel, 2007, Czerny, 2017). Carboard has a considerably greater weight than paper, giving it the advantage of strength over the paper in the packaging industry (Czerny, 2017).

Paper has many functions in current society; however, two main functions are in use to protect products during transfer and distribution; and the transfer of information (Ozaki et al., 2004). The manufacturing of paper and cardboard involves numerous steps and types of chemical and mechanical treatments of wood (Czerny, 2017). Paper and cardboard are made from cellulose fibres that are sourced from trees (AZoCleantech, 2008).

According to the South Africa State of Waste report (2018), paper accounted for 4% of the total waste generated for 2017 (DEA, 2018). Cellulose and hemicellulose from paper and cardboard are considered significant biodegradable fractions in municipal solid wastes placed in landfills (Pommier et al., 2010). Thus, this contributes to higher GHG emissions as methane and carbon dioxide emissions occur in landfills due to the breakdown of biodegradable wastes (Lombardi et al., 2006). Recycling paper assists diverting this waste stream from landfills (Tam and Tam, 2006). Paper and cardboard are generally reprocessed to form new paper or cardboard products based on the quality of the fibres and purification process (Hendriks and Pietersen, 2000).

South Africa recovered approximately 1.2 million tonnes of recyclable paper in 2019, making the country's paper recovery rate of 68.5% (RecyclePaperZA, 2020). This recovery of paper and cardboard waste diverted waste from landfill sites and saved 3.6 million cubic meters of landfill space (RecyclePaperZA, 2020). Furthermore, it supplemented local informal collectors and assisted local industries. These recovered wastes were used to generate new products such as tissue, cardboard boxes and paper bags (RecyclePaperZA, 2020).

2.4.3. Organic/ Vegetative matter

Organic waste streams are generated in the paper industry, food industry, agriculture and household level (Polprasert, 1989). It includes an extensive variety of the waste that can be recycled back into the natural environment by the activity of micro-organisms (Cofie et al., 2006). Organic wastes can be viewed as a valuable resource rather than a problem if managed correctly as they can be transformed into marketable products with extensive economic and environmental opportunities (Asian_Productivity_Organization, 2007).

Organic waste is a useful resource; however, it can become an environmental hazard if not managed appropriately. This is in the form of GHG's, the transmission of pathogenic micro-organisms, heavy metal contamination, inorganic and organic substances which are hostile to the health of both the public and environment (Polprasert and Koottatep, 2017).

There are vast economic and environmental gains from waste minimization and recycling (Nizami et al., 2017). Some of these benefits include reducing the transportation and generation of energy expenses, decreasing the demand for new raw resources, and minimal waste being disposed of in landfills, thus lowering the rate at which the landfill is filled (Kibler et al., 2018). Recycling of organic waste is considered as a sustainable technique of repurposing and diverting a large fraction of waste from being landfilled and being put to a useful purpose (Ikhlayel, 2018).

It is estimated that 55% of organic material waste is produced in developing countries. Thus, recycling is essential and its use in composting is considered across the globe as a technique to reduce landfilling of these wastes (Troschinetz and Mihelcic, 2009). Organic food waste in South Africa generally gets landfilled. According to World Wide Fund for Nature (WWF), South Africa generates 10 million tons of food which end up as waste every year. This is approximately a third of the total amount of food produced in South Africa annually (Oelofse and Nahman, 2013). The Council for Scientific and Industrial Research has estimated this loss at approximately R61.5 billion (Oliviera, 2013).

2.4.4. Metal

Metals are generally crystalline solids characterised by high thermal and electrical conductivity as well as its ductility and malleability (Britannica, 2020b). The mechanical properties of metals are generally attributed to imperfections or defects in their structure, such as hardness, ability to resist repeated stressing, ductility, and malleability (Britannica, 2020b).

Metal tinplate was initially used for various shaped boxes and canisters and is one of the oldest packaging materials (Emblem, 2012). It was the solution that consumers needed in finding a material that was light, non-toxic and strong (Hansen and Serin, 1999). The world market for metal containers is approximately 400 billion units (Emblem, 2012).

Metal is used in packaging for food, drinks, dry products, aerosols and electronic products (Emblem, 2012, Uhlig and Revie, 2000). There are four metals that are frequently used in the packaging of foods: aluminium, chromium, steel and tin (Robertson, 2013). Majority of metal packaging used in the food industry are for wet products such as fish, meat, fruit, vegetables and milk-based products (Emblem, 2012).

Drink cans may either package carbonated or non-carbonated liquids (Emblem, 2012). Majority of drinks stored in metal cans have a low level of heat processing, such as pasteurisation, to ensure a products longer shelf life (Emblem, 2012). Metal cans are generally referred to as tin cans although majority are not made up of tin but mainly steel (Robertson, 2013). Aerosol cans are made of a metal material and its use ranges from toiletries and personal care products through foodstuffs to household scents/pesticides, building products and paint (Emblem, 2012).

Metal waste accounted for 7.4% in the general waste content for South Africa in 2017 (DEA, 2018). The recycling of metals into new metal is a high priority due to the materials inherent value (Emblem, 2012). The reuse of metal is more difficult than with other packaging materials because metals are generally recycled on an atomic level (Emblem, 2012). Once re-melted, waste metals are indistinguishable from new metal that is smelted from the raw material ore, and these waste metals can be re-melted an infinite amount of times while retaining its original properties (Emblem, 2012).

2.4.5. Textile

Textile waste is referred to a material that is deemed unusable for its original purpose by the consumer (Newell, 2015). It may include textile industry waste - formed during the production of clothing, textile or fibres - and consumer waste; which is generated during the consumer usage and disposal (RedressDesign, 2014).

Textile waste can be categorised based on their sources into post-consumer waste and pre-consumer waste also referred to as production waste (Teli et al., 2014, Farrer, 2011). Post-consumer textile waste is generated when a piece of clothing comes to the end of it first use life cycle and it generally consists of used garments and domestic textiles (Pandit et al., 2019). The bulk of textile wastes -estimated as 98% - in developing countries end up being disposed in landfills (Hawley, 2006). There is no formal textile recycling occurring in South Africa and landfill rates are exponentially increasing necessitating a solution (TRC, 2019). Between 10-20% of fabric material is wasted in the textile production process in South Africa (TRC, 2019).

Mechanical approaches for textile recycling include material reuse for production of new textile products, spinning yarns from fibres taken from textile wastes, and producing non-woven materials from textile waste (Fletcher, 2008). For the mechanical treatment, textile waste is shredded and opened to collect single fibres (Langley et al., 2000). The second approach to textile recycling involves chemical processes (Jeihanipour et al., 2010).

Recycling of post-consumer textiles is the process to redesign textile waste that cannot be reused (Young et al., 2004). Clothing, furnishing and upholstery textile recycling does not only assist in reducing environmental impacts but it also assists increase profit margins as it reduces energy consumption and the need for raw materials (Pandey et al., 2020).

2.4.6. Rubber

Rubber is an elastic substance gained either from the excretions of certain tropical plants which is stabilised with preservatives or it can be gained from natural gas and petroleum (Gent, 2012). Due to its elasticity, toughness and resilience it is generally used as a constituent in motor vehicles, aircraft and other mechanical machinery (Gent, 2012).

The main chemical constituents of rubber are elastomers which are large molecules that have the ability to be stretched to great lengths and maintain its original shape (Britannica, 2020c).

The management of rubber wastes is very difficult for municipalities to handle (Yehia, 2004). Furthermore, the recycling of rubber waste is a difficult process and even general methods that are used for thermoplastic materials may not be used to refuse rubber (Yehia, 2004). It is therefore of importance to attempt to recycle rubber waste as this waste is not biodegradable and has multiple negative impacts on the environment (Kearney, 1992).

2.4.7. Plastic

Plastic is a synthetic material made of hydrocarbons that can be moulded into solid objects of almost all shapes and sizes (van Emmerik and Schwarz, 2020). The basis of plastics, which are various petrochemicals, is formed by cracking crude oil (van Emmerik and Schwarz, 2020). Numerous kinds of plastic products have become a crucial part of today's lifestyle (Kumar et al., 2018). In the past 50 years, plastic production has increased tremendously (Kumar et al., 2018). According to PlasticsEurope (2018), it is approximated that 348 million tons of plastic were generated globally in 2017.

Sectors utilising plastics can be categorised into packaging, electronics, building, textiles, and transportation (van Emmerik and Schwarz, 2020). Heavier and more expensive materials like glass, aluminium and steel have been replaced by plastics due its competitive qualities (van Emmerik et al., 2019). Plastics can be found in numerous of configurations, depending on the type of chemical resins used (van Emmerik and Schwarz, 2020). Main polymers produced can be divided into 7 subcategories as indicated in Table 2.1 below. These main polymers are Polyethylene terephthalate (PET/PETE), Polypropylene (PP), high- and low- density Polyethylene (HDPE and LDPE), Polyvinyl chloride (PVC) and Polystyrene (PS) (PlasticsEurope, 2018).

The largest constituent of the plastic waste is polystyrene, polypropylene and polyethylene terephthalate (Tapkire et al., 2014). According to Babayemi et al. (2019) plastic waste in South Africa constitutes 12% of municipal solid waste which is equivalent to 630 000 tonnes of plastic wastes. Furthermore of this figure approximately 90 000 - 250 000 tonnes of this plastic waste contributes to marine waste (Jambeck et al., 2015).

Table 2.1 Plastic types and their identification codes (Adapted: (Pawar et al., 2016))

Resin identification code	Name of Plastic	Applications
1 PETE	Polyethylene terephthalate (PET or PETE)	Drinking water bottles, soft drink bottles, food jars plastics films, sheets
2 HDPE	High Density Polyethylene (HDPE)	Shopping bags, food containers, woven sacks, plastic toys, milk bottles, detergent bags
3 V	Polyvinyl chloride (PVC)	Pipes, hoses, sheets, wire, cable insulations, multilayer tubes
4 LDPE	Low Density Polyethylene (LDPE)	Plastic bags, zip-lock bags
5 PP	Polypropylene (PP)	Disposable cups, bottle caps, straws, yoghurt containers, car parts
6 PS	Polystyrene (PS)	Disposable cups, fast food packaging, trays, foams, packaging
7 OTHER	Miscellaneous Plastics	CD, melamine, shoe soles

2.4.7.1. Polyethylene terephthalate (PET or PETE)

Polyethylene terephthalate (PET or PETE) is a thermoplastic polyester that is used in a wide range of products from textile fibres, bottles, films to other moulded items (Gupta and Bashir, 2002, Emblem, 2012). Depending on the processing and thermal dispensation PET may exist in either an amorphous or crystalline form - with the former more commonly used (Emblem, 2012).

PET is extensively used in both residential and industrial zones due to its competitive properties to other materials such as its low costs, high impact and tensile strength, and its high stability (El Essawy et al., 2017, Zander et al., 2018). Furthermore, PET production can produce a large quantity of various grades of an extensive assortment of molecular weights in a single multiproduct polymerisation plant. Thus, this property of PET - amongst others - can be attributed to its widespread use (Nadkarni, 2002).

The quantity of various PET products are increasing in production and use, which results in higher quantities of polymeric waste (Jankauskaite et al., 2008), but this increase and disposal have led to major environmental issues (Zhang and Wen, 2014). These large quantities of PET waste can cause serious environmental pollution (Jankauskaite et al., 2008). The common methods for the disposal of this waste is incineration and landfill (Song and Hyun, 1999). However, both methods are harmful to the environment, with incineration contributing to global warming (Zander et al., 2018).

There are multiple techniques to recycle PET beverage bottles, which includes methods of physical recycling such as re-melting PET waste or chemical recycling such as aminolysis, hydrolysis or glycolysis (Jankauskaite et al., 2008). The recycling of plastic is vital to reduce the rapidly increasing volumes of waste stockpiling in landfills and to produce materials from low cost sources by converting plastic waste into useable materials (Jankauskaite et al., 2008).

PET wastes have a slow rate of natural decomposition and is considered as non-degradable under normal conditions (Edge et al., 1991, Zhang et al., 2020). Procedures to biologically degrade PET waste exist however these techniques are complex and expensive (Awaja and Pavel, 2005). Physical recycling occurs by processing PET waste into granules or pellets which is washed to remove contaminants and then melted to form new products (Jankauskaite et al., 2008). During this process the main polymer retains its original properties and is not altered (Jankauskaite et al., 2008). However, PET that undergoes the process of recycling tends to be more sensitive to thermal and hydrolysis degradation compared to virgin plastics (Scheirs, 1998).

Due to recycling, some mechanical and thermal properties of the PET material will decline (Awaja and Pavel, 2005). Thus, recyclers add additional antioxidants or other additives and even virgin plastic pellets to the recycled resin to attain more durable end products (Fisher, 2003, Hahladakis et al., 2018).

2.4.7.2. High Density Polyethylene (HDPE)

High-density polyethylene (HDPE) is a thermoplastic material made up of hydrogen and carbon atoms linked together to form products with high-molecular mass (Kumar and Singh, 2013). HDPE is produced using a low-pressure process and an initiator to maintain its chain formation which thus results in an unbranched linear structure (Emblem, 2012).

HPDE is more crystalline than low-density polyethylene and thus has a more opaque, rigid and greater tensile strength (Emblem, 2012). It is considered as the world's third largest plastic commodity in terms of volume (Kumar and Singh, 2013). HDPE has a good moisture and oxygen barrier (Emblem, 2012).

The extensive uses of HDPE can be attributed to numerous factors such as its competitive properties to other plastics; its ability of resistance to impact damages at room temperatures, and cooler temperatures of the refrigerator and freezer and it is also relatively inexpensive (Selke, 2019a). HDPE has a very low glass transition temperature and has enough rigidity to allow for products to be produced with relatively slim thickness so the product/packaging weight is lower and thus costs are reduced (Selke, 2019a). HDPE has an excellent chemical resistance especially to polar elements and it makes a resilient barrier to water vapour (Selke, 2019a).

Thus, is its widespread application in nearly all liquid detergent bottles as well as heavy duty items such as pallets, drums and crates and other common products such as packaging for pharmaceutical products, cosmetics, toiletries, and chemicals (Emblem, 2012, Selke, 2019a). The most notable use is in milk and dairy packaging (Emblem, 2012). The main limitation to its use is that it adversely affects the environment (Satlewal et al., 2008).

2.4.7.3. Polyvinyl chloride (PVC)

Polyvinyl chloride (PVC) is produced through the polymerisation of vinyl chloride which is itself produced through the chlorination of ethene (Emblem, 2012). It is the second largest production volume of thermoplastics (Janajreh et al., 2015). It is largely amorphous and has a good optical clarity (Emblem, 2012).

PVC products were first marketed in the advent of 1930 (Mulder and Knot, 2001). The first products were shock absorber seals and tank linings, followed by coated textiles and flame resistant cable insulation (Mulder and Knot, 2001). PVC products are coated with polyvinylidene chloride to improve its poor moisture barrier and it adds the benefit of it being readily heat sealable (Emblem, 2012).

The practicality and properties of PVC was the reason for its widespread use into the consumer market (Mulder and Knot, 2001). Some of these properties are its insultation properties, relative non-flammability, resistance to humidity and several chemicals (Mulder and Knot, 2001). Furthermore, the choice of compounding with numerous additives producing rigid and elastic plastics, various processing techniques and its reasonably low price made it a useful commodity (Rosato, 2011). Given the usefulness of PVC products over the years, the production and market for its products has projected considerably (Mulder and Knot, 2001).

The collective properties; chemical, physical and weathering has made PVC a universal polymer with usage in plumbing, flooring, roofing, packaging, cable insulation, emerging medical products and bottling (Janajreh et al., 2015). This wide range of usage however, creates an issue of postconsumer disposal taking into account the mounting plastic problem (Janajreh et al., 2015). Several organisations globally have played a role towards sustainability and environmental protection and have advocated the Vinyl industry on reaching a common ecological goal by reducing the quantities of raw materials, minimising the environmental consequences and reducing energy consumption (Andrady, 2003).

PVC plays a part in plastic recycling and is generally re-processed into various short-life products (Subramanian, 2019). However, the costs associated with the recycling process of PVC packaging are considerably high (Niaounakis, 2019).A key issue with the recycling of PVC is its high chlorine content and the great levels of plasticiser which is added to the polymer (Niaounakis, 2019). Consequently, PVC requires separation from other plastic groups prior to mechanical recycling (Niaounakis, 2019).

The consumer usage and volume of production of PVC products as well as recycling initiatives vary between different geographical locations however an increase in awareness and legislation in landfill restrictions is needed to be implemented. Furthermore, the incineration in landfills and disposal sites of PVC products are harmful as it results in hydrochloric acid and dioxins (Emblem, 2012, Niaounakis, 2019). Given these issues, several producers have resulted to alternative materials for packaging, however, PVC still remains widely used in the construction industry (Emblem, 2012).

2.4.7.4. Low Density Polyethylene (LDPE)

Low density polyethylene (LDPE) is generated under a high pressure procedure and has a combination of short and long branched chains (Emblem, 2012). It is polymerised from ethylene and in contrast to HDPE has an extensive branched structure, a mixture of both short and long branches, which affects its crystallisation (Selke, 2019b, Emblem, 2012). LDPE has a crystallinity of approximately 50 – 65% (Emblem, 2012), which gives it a lower density in comparison to HDPE, and makes it more flexible and softer, as well as decreasing its barrier capacities (Selke, 2019b).

LDPE has an excellent balance of strength, flexibility, cost, barrier properties and a wide range of other preferred properties (Sastri, 2013). Furthermore, it has good impact strength, excellent tear and stress crack resistance and is chemically inert (Selke, 2019b, Sastri, 2013). LDPE has a hazy appearance, and melts at lower temperatures than HDPE, an advantage when it is applied as a heat seal layer in flexible packaging (Selke, 2019b).

LDPE was introduced into the market in the later part of 1940 and became widespread in the use for common commercial packaging (Selke, 2019b). And today the LDPE market continues to dominate with an estimated consumption of 75% for packaging film manufacturing, injection moulding items and extrusion coating (Subramanian, 2019). It also has applications in sterile blister packs for drug packaging (Sastri, 2013).

LDPE's excellent oil and chemical resistance, coupled with its reasonable costs, make it suitable for application in multiple flexible packaging (Selke, 2019b). LDPE makes up approximately 64% of the world's plastic material produced in the form of bottles and packaging which is normally discarded after a single use (Sudhakar et al., 2008). However, polyethylene is a highly degradation-resistant plastic (Subramanian, 2019). It does not display any visible biodegradation when disposed of in soil (Selke, 2019b).

Plastic bags made of LDPE are thus accumulating in the environment due to its low degradability, creating a bigger pollution hazard and utilising space in landfills (Subramanian, 2019). Recycling LDPE waste material generates a stream of recycled plastic which is highly consistent and homogenous (Knight and Sodhi, 2000). However, it is considered economically unfeasible to recycle LDPE plastic waste as the waste is generally always contaminated (Bonhomme et al., 2003).

2.4.7.5. Polypropylene (PP)

Polypropylene (PP) is a versatile thermoplastic material, compatible with various processing methods with key applications in both rigid and flexible packaging (Emblem, 2012, Bailey and

Brauer, 1995). PP is regarded as one of the lightest polymers and is capable or undergoing a variety of manufacturing procedures such as general purpose extrusion, extrusion blow moulding, injection moulding and expansion moulding (Crawford et al., 2017).

PP is produced under high-temperature with the cracking of propane and petroleum hydrocarbons (Koerner et al., 2007). It is one type of thermoplastic that has an increasing market demand due to its characteristics of low density and costs, high heat distortion temperatures and versatile physical properties (Selvakumar et al., 2010). Due to its cost-effectiveness and properties, PP is a common thermoplastic used across the geosynthetic industry (Koerner et al., 2007).

It has an enhanced stiffness and a higher melting point this is significant as it allows for PP to be used for hot-fill applications (Selke, 2019a, Selke, 2019b). The first marketing PP plastic container was used for an oxygen sensitive food product, with ethylene vinyl alcohol as the barrier material allowing hot-filled liquid could be poured into it (Selke, 2019a). Similarly, PP is used in packaging of contents that require heating prior to use and thus PP packaging allows for microwaving (Selke, 2019a).

PP is one the fastest increasing commodity of thermoplastics, with growing market demands and production – exceeded only by PET and PVC (Harper, 2000, Graves, 1996). It is utilised in an extensive variety of applications such as spun-bound non-woven, fibres and tapes (da Costa et al., 2005). Its chemical resistance includes resistance to majority of organic solvents, except for strong oxidising agents. Softening may arise however, due to the saturation of hydrocarbons and chlorinated solvents (Maier and Calafut, 1998).

One notable application of PP is in the food industry as containers and food packaging (Zaferani, 2018). Other common uses include syrup bottles, yoghurt containers, bottle caps, and straws (Selke, 2019a). The use of this material in packaging is due to its high resistance against enzymatic degradation, biodegradation or microbial degradation – postconsumer disposal however results in environmental harms contributing to white pollution (Kamrannejad et al., 2014). The consumer demand for PP is rapidly increasing and therefore it is one of the most common micro-plastic waste existing in the marine environment (Crawford et al., 2017).

2.4.7.6. Polystyrene (PS)

Polystyrene is an amorphous polymer and has high clarity, colourless and with a poor barrier to moisture and gases (Niaounakis, 2019, Emblem, 2012). It is manufactured from a styrene monomer and is the product of polymerisation of phenyl ethene (Buschow et al., 2001). Polystyrene softens at approximately 75ºC and becomes liquid at 100ºC, thus it is convenient to produce (Emblem, 2012).

It readily accepts ink and thus is used in gravure or flexographic printing and dry offset letterpress or screen printing for three-dimensional components (Emblem, 2012). The common forms of polystyrene used widely across industry are expanded polystyrene (EPS), general purpose polystyrene (GPPS), syndiotactic polystyrene (SPS) and high impact polystyrene (HIPS). GPPS also known as crystal styrene is very brittle and is used widely (Emblem, 2012). HIPS is one the mostly used polystyrene form in the packaging industry (Emblem, 2012).

Polystyrene is a plastic that is widely used for packaging and there is difficulty associated with its disposal and recycling (Bekri-Abbes et al., 2006). It has good dead-fold properties, and its poor gas barrier is an advantage for packaging fresh produce (Niaounakis, 2019). It is also thermoformed into trays, and sandwich packs (Forrest, 2016). The poor properties of polystyrene are beneficial for products that respire; as they assist in the prevention of the build-up of moist air in the packaging which can cause fungal growth (Emblem, 2012).

EPS is a lightweight material with good compression resistance and strength to moisture. It further is a good insulator against both temperature fluctuations and shock and is generally used in the application for fast food packaging, boxes for seafood, and for delivery of chilled and frozen foods; in horticulture as cell packs for budding plants and also as support to fragile products such as glass wear, china, electronic items and household appliances (Emblem, 2012)

Polystyrene is used widespread across industries from the food industry to the construction industry and the health care sector (Buschow et al., 2001). This widespread use results in greater quantities of postconsumer wastes. Polystyrene has a low density and this allows for environmental elements such as the wind to easily scatter it (Chaukura et al., 2016). This causes it to be easily displaced into rivers. Furthermore, a large quantity of polystyrene in developing countries are disposed into landfills or by incineration and not recycled (Chaukura et al., 2016). This is due to polystyrene being relatively cheap and the recycling procedures to convert the polystyrene into lower value products such as recycled resin or fuel oil are complex (Chaukura et al., 2016).

Polystyrene is resistant to decomposition and is highly stable (Li and Xu, 2020). The persistence of polystyrene results in multiple environmental impacts including the entanglement of fauna causing reduced feeding capacity, strangulation and ingestion (Rochman et al., 2013, Davis, 2012). Furthermore, due to its low volatility and biodegradability, once it enters into the digestive system polyaromatic hydrocarbons begin to accumulate and can result in carcinogenic health disorders (Sese et al., 2009, Zhou et al., 2010).

2.5. Plastic waste management

Originally plastic was used to produce items that had a long lifespan. However, as time progressed, so did the growing consumer demand, resulting in higher proportions of plastics produced for single-use purposes (Andrady et al., 2015, Jambeck et al., 2015). As more plastic debris amasses in our environment, the environmental hazards associated with poor waste disposal becomes more defined and is a growing concern (van Emmerik and Schwarz, 2020). Since plastic products are produced to last and be durable, poorly disposed waste remains in the environment for a prolonged time (Andrady, 2003). Plastic pollution poses pressure on sensitive systems such as aquatic life, human health and ecosystems (Derraik, 2002, Conchubhair et al., 2019).

As described by the International Solid Waste Association (2009): ‘‘…the waste hierarchy is a valuable conceptual and political prioritisation tool which can assist in developing waste management strategies aimed at limiting resource consumption and protecting the environment’’. Consequently, precedence is asserted to waste minimisation, re-use, recycling, waste-to-energy, and finally landfill.

2.5.1. History of plastic production

In the advent of the 1900s, the globe welcomed an era known as the "Plastic Age" (Thompson et al., 2009). Initially, plastics were made up of natural materials such as ebonite, shellac, gutta-percha and celluloid (Brydson, 1999). An economically functional synthetic polymer in 1907 called bakelite – a resin beneficial for insulating properties - was developed (Brydson, 1999, PlasticsEurope, 2013). The production of plastics became industrialised by the mid-1940s, and the production rate was recorded globally per annum as nearly 1.5 million tonnes (Barnes et al., 2009, Claessens et al., 2011). The producers of plastic started to use coal to produce nylons, resins and polystyrenes (Brydson, 1999). However, petroleum became the chief raw material by the 1960s for production (Brydson, 1999). Moreover, the signs of the threat that plastics posed to the environment, such as the ingestion in aquatic life started becoming apparent during this period (Carpenter and Smith, 1972). Presently approximately eight per cent of our production of oil is utilised in the production of plastics (Thompson et al., 2009).

In 2006, the worldwide manufacturing levels of plastic were approximately 245 million tonnes (PlasticsEurope, 2008), rapidly cumulating to 270 million tonnes in 2010 (PlasticsEurope, 2012), and 280 million tonnes by 2011 (PlasticsEurope, 2013). The levels of production presently surpass 300 million tonnes, a level which is considered unsustainable (PlasticsEurope, 2016). Rochman et al. (2013) projected that should existing trends of plastic manufacturing remain at this proportion, the collective total weight of plastics made by 2050 will be 33 billion tonnes.

2.5.2. Uses of plastics and its characteristics

Plastics are utilised for practically all types of products and can attribute its popularity to its low cost and technical versatility (Streit-Bianchi et al., 2020). The characteristics which make plastics highly sought-after to society includes its high insulation and durability, low mass, transparency, and resilience to biological breakdown (Wabnitz and Nichols, 2010).

The production of plastic is inexpensive, while its transportation costs are relatively small due to its low mass, and it has a prolonged usage due to its resistance to biodegradation (Brydson, 1999). Plastics dominate the packaging industry, and it is used extensively in electrical and electronic equipment, construction, agriculture and also its common usage in household items and medical supplies (PlasticsEurope, 2018).

2.5.3. Impacts of macro-plastic

The typical interactions of aquatic life with macro-plastics (>5mm in size) are indicated across literature which highlights the entanglement in plastic waste by large mammals (Stelfox et al., 2016) and specific moulded plastic waste (Werner et al., 2016), the ingestion of plastic particles when mistaken for food (Andrady, 2011). Furthermore, impacts indicate that crustaceans select smaller plastic wastes for the use as transportable shelter (Benton, 1995), while other invasive species "hitch hike" using ocean plastic waste as rafters and passage through geographical areas (Gregory, 2009).

Research in marine plastics have indicated that cetaceans suffer harmful effects from plastic debris (Fossi et al., 2018), and a large percentage of bird order have notably been entangled in plastic fishing gear that had been disposed of improperly.

Kühn et al. (2015) reported in a comparative review to the report made by Laist (1997) that the numbers of bird, mammal and turtle species with recognised entanglement reports inclined from 21% to 30% over the period - 100% species of marine turtles, 67% species of seals, 31% species of whales and 25% species of seabirds with extensive increases in species data accounts for fishes (89 species) and invertebrates (92 species). Baleen whales (9 of 13 species) and eared seals (13 of 13 species) appear to be the mammals largely affected by entanglement.

2.5.4. Impacts of micro-plastics

Micro-plastics range in size from 0.1 µm to 5 mm – and it can be either produced small and then passed into aquatic environments through wastewater (Napper et al., 2015), rivers and runoff or as a consequence of the physical breakdown and weathering of macro-plastics (Jambeck et al., 2015). Micro-plastic particles can variate in shape (films, fibres, beads, fragments), plastic characteristics and in colour (He et al., 2018).

Micro-plastic pollution poses an adverse threat to marine life via entanglement and ingestion (Wright et al., 2013). Incessant degradation and fragmentation of micro-plastics in the marine environment results in an extensive range of particle sizes (Enders et al., 2015), which can be ingested by a correspondingly large variety of marine organisms, for example: humpback whales (Besseling et al., 2015), all 7 species of marine turtle (Duncan et al., 2017), harbour seal (Rebolledo et al., 2013), numerous pelagic and demersal small and large fish (Lusher et al., 2015, Nadal et al., 2016, Tanaka and Takada, 2016), blue mussel and lugworms (Van Cauwenberghe et al., 2015), gooseneck barnacle (Goldstein and Goodwin, 2013), Norway lobster and prawns (Murray and Cowie, 2011), zooplankton (Desforges et al., 2015) and fish larvae (Steer et al., 2017). Trophic transfer is also considered to be a significant pathway for micro-plastics in higher trophic levels (Nelms et al., 2018).

2.5.5. Fragmentation and buoyancy of plastics

It is tough for fungi and bacteria (microflora)– to breakdown synthetic plastics (Billingham et al., 2000), thus this results in plastics having a longer lifecycle in the aquatic environment in comparison to natural materials (Barnes et al., 2009). In the marine environment the mechanical breakdown of plastics can occur by environmental factors such as wave action and direct wearing with rock and sand particles as they flow through water bodies, resulting in fragmentation (Corcoran et al., 2009).

The element found in sunlight, Ultraviolet B, assists in a chemical breakdown of plastic debris via a process of photocatalysis, which breaks the bonds which hold together the polymer chains (Fendall and Sewell, 2009). However, when plastic is manufactured certain additives are utilised to avoid these degradation reactions, extending their lifecycle especially if the designed produced is designed to be frequently visible to sunlight such as camping equipment (Claessens et al., 2011). Plastics that enter aquatic marine current systems are further protected from sunlight as a result of the cooling effect that water offers, thus shielding plastic particles from Ultraviolet B (Barnes et al., 2009).

The buoyancy of plastics will determine their vertical dispersal in the water column (do Sul et al., 2014). Most plastic materials are positively buoyant in seawater (Lobelle and Cunliffe, 2011). Biofouling however, may make plastics heavier causing them to sink over time (Lobelle and Cunliffe, 2011).

2.5.6. Plastic pollution along the South African coastline

The South African shoreline spans approximately 3 400 km in length and contains around 300 estuaries (Harrison, 2004). A few of these estuaries are situated within the prominent industrial centres along the coastline, in which fall as plastic waste basins whereby plastics can accrue and accumulate chemical toxins (Ryan et al., 2012). Durban, which is sited in KwaZulu-Natal is among one of the country's principal industrial centres (Ryan et al., 2012).

Pressures to estuaries in KwaZulu–Natal include freshwater abstraction, sewage outlets or spills, habitat loss, sedimentation, mouth closures, chemical inputs and plastic pollution (Forbes et al., 1997, Forbes and Demetriades, 2008). Little to no research has been conducted on the latter threat to the South African shoreline. However, Ryan and Moloney (1990) tested

52 beaches along the Western Cape coast and noted that plastics made up 90% of debris, primarily in the form of fragments, polystyrene and pre–production pellets. Ryan (1988) research indicated an average of 3 640 plastic particles/km^2 in waters off the same coast. This was composed mostly of fibres, foams, pellets and fragments. These were indicated to most likely be conveyed by the Agulhas current flowing along the eastern coastline of South Africa (Ryan, 1988).

The only quantitative data on micro-plastics previously found in marine systems in South Africa is indicated by Lamprecht (2013). Lamprecht (2013) investigated two shores along Table Bay in the Western Cape, and it was indicated that plastics represent 93% of the total debris and these were comprised mainly of Styrofoam, pellets and fragments. A few non–urban coasts in South Africa may also have high proportions of plastics (Lamprecht, 2013).

2.5.7. Local distribution along Durban

The Durban coastline contains a total of 16 estuaries along its course and stretches for a length of 80 km (Forbes and Demetriades, 2008). All these estuaries besides four are temporarily open-close estuaries (Forbes and Demetriades, 2008). The permanently open estuaries are the Isipingo, uMkhomazi, Durban Harbour and Umgeni estuaries – and has a higher probability for plastics to be conveyed through these water systems (Forbes and Demetriades, 2008). When these plastic wastes leave the estuary system the inshore currents and wave action control whether these plastic debris are deposited along the beach as strandline debris or it is carried out further to sea. The occurrence of the Durban eddy, a semi-permanent cyclonic lee eddy, is a significant factor that can accumulate plastics exiting from estuaries. This is a result due to the redirection of the Agulhas current which flows southward however, due to the shape of the shoreline which surrounds Durban this current is then forced to turn back up the coast (Cawthra et al., 2012). The plastics may accumulate in this eddy as was found in a previous study by Moor et al., (2001) for large oceanic gyres.

Durban is a city with a high population and the extensive use of plastics is common. The pollution of macro-plastics has become a general sight in the estuaries and beaches along the coast of Durban. Data from Ezemvelo KwaZulu-Natal Wildlife indicate that annual coastal clean-ups for Durban marine environments are high in plastic load. It found in 2013 that 34 180 kg of waste was collected over a 320 km stretch of KwaZulu-Natal beaches, and in 2016 it collected for the distance of 162 km 17 460 kg of litter waste.

Majority of this waste was plastic and packaging material, cigarette butts, plastic bags and food containers. These plastics are macro-plastics which can be removed by beach clean-up crews, however, the quantitative amount of the extent of micro-plastics in estuaries and on the beaches of Durban are not known. In spite of beach clean–up projects, low weight plastics are transported from dump sites back into the ocean via storm water drains or via aeolian transport (Wabnitz and Nichols, 2010).

Durban is an urban city that had been industrialized and developed around the harbour and majority of the city's storm water drainage systems empty into the harbour. A high volume of industries in the area also utilise micro-plastics which may enter river systems. A greater amount of interactions in the system occurs with the biota as there is a higher plastic concentration (Clark et al., 2016). In the Durban Harbour the remaining area of the Bayhead mangroves are protected due to it having a natural heritage status (Forbes et al., 1997). This is an area that is utilised as a nursery area for juvenile fish, however it is also vulnerable due to its close proximity to the city centre (Forbes et al., 1997). In the past there existed a larger mangrove forest, however due to development with the harbour a large portion of the natural habitat was destroyed (Cyrus and Forbes, 1996). It is evident that there is a high discharge of plastic in the area and that there is a biodiversity of fish that frequent it.

2.5.8. South African Waste Management System

The constitution of South Africa (Act 108 of 1996) founded the Bill of rights that warrants that everyone has the right to an environment that is not harmful to their well-being and health (RSA, 1996). The South African government promotes a combined approach to waste management and pollution as a vision of development that is economically and environmentally sustainable (Makgae, 2011). Waste in South Africa is presently administrated by numerous legislations including; Environment Conservation Act (Act 73 of 1989), The South African Constitution (Act 73 of 1989), The National Environmental Management Act (Act 107 of 1998) and the Waste Act (Act 59 of 2008) (Reddy, 2016).

This sustainable vision advocates a healthy, clean environment and a stable, growing economy – by avoiding, minimising and mitigating waste and pollution (Makgae, 2011). However, in South Africa key problems in waste management include inadequate or no waste collection services for a great portion of the population, few recycling and waste minimisation initiatives, illegal dumping, lack of airspace at landfill sites, unlicensed waste management activities, lack of regulation and waste information, and poor enforcement of relevant waste management legislation (Nahman and Godfrey, 2010).

Waste management in the past in the Republic has been poorly coordinated and underfunded (Makgae, 2011). South Africa, as a developing country is faced with the challenge to meet high standards in service delivery with limited resources (Matete and Trois, 2008). In 2000, an act was developed that requires municipalities to strive to ensure that basic services are provided to the local regions in a financially and environmentally sustainable manner – known as the Local Government Municipal Systems Act (Act 32 of 2000) (Matete and Trois, 2008). To address the issue of lack of finance, the National Waste Management Strategy enforces the Polluter Pays Principle (Makgae, 2011). The Polluter Pays Principle states that the individuals who damage the environment must take the responsibility of the expenses of such damage (Luppi et al., 2012). Furthermore, all waste generators have to bear the associated costs with the waste they produce – this not only includes the direct costs such as waste collection, treatment and disposal but also the external costs such as health and damage costs (DEAT, 1999).

2.6. Riverine Plastic

Rivers are identified as the main conveyors for land-based plastic pollution to enter oceans (Lebreton and Andrady, 2019). The sources for plastic debris in and in close proximity of freshwater bodies are directly proportional to human activities (Best, 2019). There are strong correlations between quantities of river plastics with urbanisation, population density, waste management and wastewater treatment (Best, 2019). Plastic debris enters freshwater systems through direct dumping or natural element conveyance; natural processes include rainfall-induced, surface run-off and wind (Bruge et al., 2018, Best, 2019, Tramoy et al., 2019).

2.6.1. Adaptation and Mitigation Technologies

As plastic waste accrues at a rapid rate in the world's oceans, there is an immediate need for sustainable and efficient solutions for remediation to the situation. One such solution is the mobilisation of innovative technology that either avert plastics from entering waterways or to gather riverine and marine plastic waste (Schmaltz et al., 2020). Below are innovative technologies that are implemented in various geographical zones.

2.6.1.1. Waterway litter traps

Waterway litter traps are buoyant cages that capture debris and waste as it is directed into the trap (RiverNetwork, 2020). They generally work without mechanical assistance, utilising the flow of the water body to fill the trap (Schmaltz et al., 2020). The litter traps are used in rivers and streams – joined to one end of the channel, or at the centre of a non-navigable stream, secured to either side of the river bank with a cage structure collecting the guided buoyant debris (RiverNetwork, 2020). They may in most cases prevent conveyance of boats however it does not impede the movement of water (RiverNetwork, 2020). Examples of this type of technology include the SCG-DMCR Litter Trap, and the Bandalong Litter Trap.

The SCDG-DMCR litter trap was implemented at the mouths of rivers and canals along the Andaman Sea and Gulf of Thailand coast (Nation, 2019). The prototype of this litter trap is formed using PET pipes and netting with gates that allow for the entrapment of wastes – it can contain up to 700kg of waste (Nation, 2019). The Bandalong litter trap is a floating device which is strategically placed along waterways to hold waste. It is implemented in waterways that are wider than 2 metres and can be viable in waterbodies that are subject to tidal action, streams and channels (Bandalong, n.d, StormWaterSystems, n.d).

The benefits of waterway litter traps are that they are capable of operating without mechanical assistance, does not impede water flow, does not cause upstream flooding, and are effective in most cases, as the captured debris does not become dislodged (Bandalong, n.d). However, maintaining these traps can become costly depending on the site in which it is installed (RiverNetwork, 2020).

2.6.1.2. River Booms

A river boom system is a temporary floating barrier that retains waste and other floating debris and utilises the movement and velocity of the water to collect the debris for accessible collection (RiverNetwork, 2020). The boom collects surface level objects as they collide with it and divert them towards the river bank (Miliute-Plepiene et al., 2018). River booms are simple and are identified as cost-effective and efficient structures (RiverNetwork, 2020). In a water system, the boom is placed at a 30- to a 45-degree angle and combined with the water current, all surface-level objects flow into the boom and are directed to the point where the boom is anchored to on shore. Examples of boom projects implemented are the Alpha-MERS and the Durban Green Corridors Litter Boom Project.

The Alpha-MERS litter boom system is a system that is implemented in India. It has been designed to use the natural flow of water to carry debris to the river bank from where it is recovered. These systems are designed to withstand the seasonal and nonseasonal harsh weather phenomena (AlphaMERS, n.d).

The Durban Green Corridors Litter Boom Project is located in South Africa Durban; the project recently added two new litter booms to their existing six booms, which span the Umgeni River and its tributaries (Northglen, 2020). The litter booms are made from large PVC pipes or eco-bricks anchored across the river (LitterBoom_Project, n.d). These booms are placed strategically to collect surface wastes.

2.6.1.3. Air Barrier

The air barrier is a technique that is still in its beginning stages and is only implemented in a limited number of areas. The air barrier employs the use of a bubble curtain which acts as a screen to prevent plastic waste from passing. This barrier is achieved by forcing air through a diffuser to produce a bubble curtain (Zielinski, 2011). A concept that utilises an air barrier to mitigate waste is the Great Bubble Barrier (GBB). The GBB is based on an idea to filter out plastic debris from rivers by utilising a bubble curtain (Spaargaren, 2018). The setup for this technology is utilising a long tube that is placed diagonally across the river bed, and air is pumped through it, creating a wall of bubbles (Spaargaren, 2018). The bubble barrier induces an upwards push, which carries debris to the surface of the water (Bubble Barrier, n.d.). The positioning of the barrier diagonally allows for the barrier to strategically use the natural current to divert the waste to the river bank (Bubble Barrier, n.d.).

2.6.1.4. Vacuum

The HoolaOne uses pumps and vacuums to gather seawater and sand more swiftly, filters it and expels the clean sand - free of plastic contaminants - back to the beach (Brestovansky, 2019). HoolaOne provides an innovative and efficient way to clean polluted plastic areas that were not possible to clean before (HoolaOne, n.d). The HoolaOne technology was developed to assist in extracting minute pieces of plastic marine debris from sea sand (Brestovansky, 2019). The machine is capable of processing approximately three gallons of sand per minute (Peters, 2019).

Some benefits of this technology are that it can collect micro- and macro- plastics, separate matter, and its ability to treat high volumes in short periods of time (HoolaOne, n.d).

2.6.1.5. Drones and Robots

Autonomous technology is revolutionising modern society. The waste sector in recent years has employed the use of modern drones and bots to mitigate the pollution. Autonomous robots are able to function independently and clean at a quicker rate and more effectively than any human is capable (Ellis, 2018). Some examples of this innovative technology currently employed include the Floating Robot for Eliminating Debris (FRED) and BluePhin.

FRED is a large robot unmanned and semi-autonomous which is powered with renewable energy (solar and wind) (Thomson, 2019). It is designed to remove buoyant debris from waterbodies and marine environments such as rivers, oceans and bays (Clear Blue Sea, n.d). FRED is capable of harvesting a wide range of plastic waste using different sized forks for debris of varying sizes (Thomson, 2019).

BluePhin technology was developed in 2018 and is employed in the UAE; it is reviewed as one of the world's most technologically advanced waste management solutions (de Leon, 2020). It is a smart robot that can retrieve the floating debris in water bodies (BluePhin, n.d). It has been advanced with artificial intelligence that allows it to differentiate and collect plastic, algae and other debris in an attempt to eradicate marine pollution (de Leon, 2020). Furthermore, it has a power time of 6-8 hours per clean-up and is capable of collecting the physio-chemical properties of the water body and the surroundings it is placed in, such as water pH or water and air quality (BluePhin, n.d).

2.7. The Waste Resource Optimisation Scenario Evaluation Model (WROSE)

The Waste Resource Optimisation and Scenario Evaluation (WROSE) model is a model that was formulated to assist the waste management sector in the decision-making procedure for executing alternate treatment options for waste (Trois and Jagath, 2011). The model was developed to assist municipalities to align with legislation by achieving the execution and implementation of the waste hierarchy into solid waste management practices (Kissoon, 2018).

Furthermore, the WROSE model was developed to assist in achieving zero waste and to promote a circular economy (Kissoon, 2018). The model factors in the emission rates to determine GHG impacts and landfill saving space; to determine the amount of space that can be saved for the different waste stream scenarios (Reddy, 2016). The model can also project possible potential expenses and profits from these scenarios (Reddy, 2016). This model considers the global drive towards sustainable development and includes economic, environmental, institutional and social factors in implementing waste management strategies (Kissoon, 2018). This model is relevant to this study to give purpose to waste materials, as opposed to dumping in landfills. Furthermore, it promotes a sustainable approach to maintaining a clean environment, in an around the Umgeni catchment.

2.8. Conclusion

Human activity generates wastes; therefore, effective and efficient waste management planning is required to offset its production. Poor waste management results in severe health and environmental issues. Waste is a problem that is faced globally and thus is the prevalent international adoption of the waste hierarchy. The subsequent chapters will review possible scenarios for managing waste sustainably.

CHAPTER 3: METHODOLOGY

3.1. Introduction

In this chapter, the methods of data collection and analysis employed for the study are briefly discussed. The location of the selected sampling sites and the frequency and timing of sampling is indicated. The aims and objectives of this study are to quantify and establish waste entry points to the Umgeni river system and make system recommendations of the existing booms and the waste management strategies employed.

3.2. Study area

The municipality of eThekwini is situated in the province of KwaZulu-Natal, one of the nine provinces that form South Africa. KwaZulu-Natal hosts the second largest population in the country, with over 10 million inhabitants (Census, 2011). The region is characteristically warm with a sunny sub-tropical climate. It has an average temperature of 27 ^{o}C in summer, an average of 16 ^{o}C in winter, and an average rainfall of just over 1000 mm/year, mainly received during the summer season (Ndlovu et al., 2021).

The Umgeni River is one of the major river systems of the KwaZulu-Natal province, as indicated in Figure 3.1. The Umgeni catchment has a surface area of 4349 km^2 and an approximate length of 257 km (Namugize et al., 2018). Its waters discharge into the Indian Ocean at the Umgeni Estuary.

The Umhlangane River is located upstream of the Umgeni Estuary. It is a tributary of the Umgeni River and has an approximate length of 50 km. Along the river banks of Umhlangane are located residential and industrial areas River Horse Valley, Springfield Park, Avoca, Kwamashu and Phoenix.

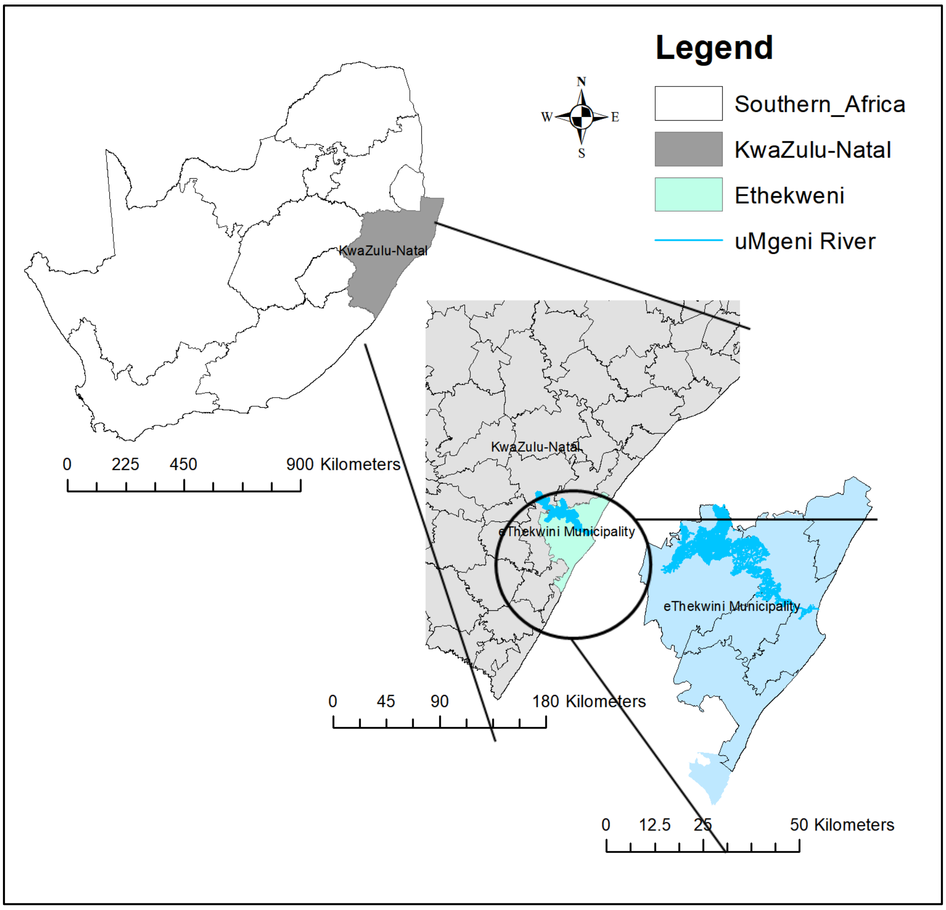

Figure 3.1 Map overview of the study area.

3.2. Phase I: Literature review

The preceding chapter contained the literature review, which highlighted the background for this study, and covered topics such as waste and climate change, the life cycle of plastics, waste management strategies, riverine wastes and marine debris, amongst other key topics. This information was obtained from various books, journals, case studies, theses, governmental publications, and policy frameworks and then collated logically to complement the study.

3.2. Phase II: Mapping exercise and case study

The focus area for the case study was determined by consultation with members of the DGC. Based on the information provided, a radius surrounding the location of all the functional litterbooms was drafted. This area served as the basis of the subsequent maps to be projected. The functional booms along the river course were the Peter Road, Johanna Road, SPCA, Connaught and M4 litterbooms.

The geographical locations of all the various implemented litterbooms were also obtained and recorded. Data were obtained from the eThekwini GIS portal in the form of shapefiles. The selected data were then exported into the ArcGIS v10.4 software, where the researcher utilised various GIS techniques to model and projected the selected study area.

Maps to indicate the waste entry into the Umgeni River and Umhlangane catchment were then projected around locational pins for the 5 operational litterbooms. The following key areas are observed for waste entry; land use zones, transportation routes, stormwater drainage and informal settlements near the water body. Other maps were also projected to indicate the location of all 10 litterbooms employed by the DGC.

3.3. Phase III: Waste stream analysis

To determine a focus area and methodology for the study, various literature was examined, and members of the DGC were consulted. Due to ease of accessibility and availability of recorded data and operating within the local restrictions for the COVID19 pandemic, the primary fieldwork was concentrated at 2 of the operational litterbooms, namely, the Johanna Road and SPCA litterbooms.

Waste stream analysis was carried at the booms for the selected timeframe of 7 days to provide a "snapshot" characteristic analysis of the waste found in the river. The total waste removed from the booms per day were measured and recorded. Waste retained at the booms were extracted and placed along the river bank, as seen in Figure 3.2. It was then categorised into the following categories:

1. Glass
2. Cardboard/Paper
3. Organic/ Vegetative matter
4. Metal
5. Textile
6. Rubber
7. Plastics
   i) PETE
   ii) HDPE
   iii) PVC
   iv) LDPE
   v) PP

vi) PS

vii) OTHERS

8. Residual

Figure 3.2 Waste extraction and characterisation along Johanna Road litterboom

The categorised wastes were then placed into bin bags accordingly and weighed using a digital suspended scale. The data was recorded and further subjected to statistical analysis using SPSS.

The data was tested using Kolmogorov–Smirnov test. It was noted that the data was not normally distributed despite log and square root transformations. A non-parametric Mann-Whitney U test was used to determine if a significant difference in the quantity of waste exists between the two litterbooms.

To address the relation between precipitation and the quantity of waste. Datasets were obtained from the DGC, which contained PET data from the onset of 2020. This data was then projected alongside precipitation data which was provided by the eThekwini municipality. The precipitation datasets were collected from the Kennedy Road weather station within a 2km range from the study site. The data was then subjected to SPSS testing to determine if a correlation between rainfall events and the quantity of PET waste exists. A non-parametric Kendall's tau b statistical test was used to indicate the correlation. Probability values $p < 0.05$ was considered to show any correlation. To further illustrate areas that can be affected by climate change events, a map indicating the 100-year flood plain was projected using ArcGIS v10.4.

3.4. Phase IV: Utilisation of the WROSE Model

The WROSE model provides information of technical, environmental and economic implications and impacts to the user for varying waste management scenarios (Kissoon, 2018). This study employed the WROSE model to provide scenarios for better and sustainable management of plastic waste. The WROSE model employs 5 scenario outcomes for waste, as indicated in Figure 3.3. For this study, various scenario models were made and detailed for each of the subcategories of plastic wastes. These models were then projected and detailed. Presently only PET waste is sent to a recovery facility, while all other plastics are subjected to scenario one and are sent to the landfill. The data was then processed in the WROSE model based on the designed scenario models and the output data represented.

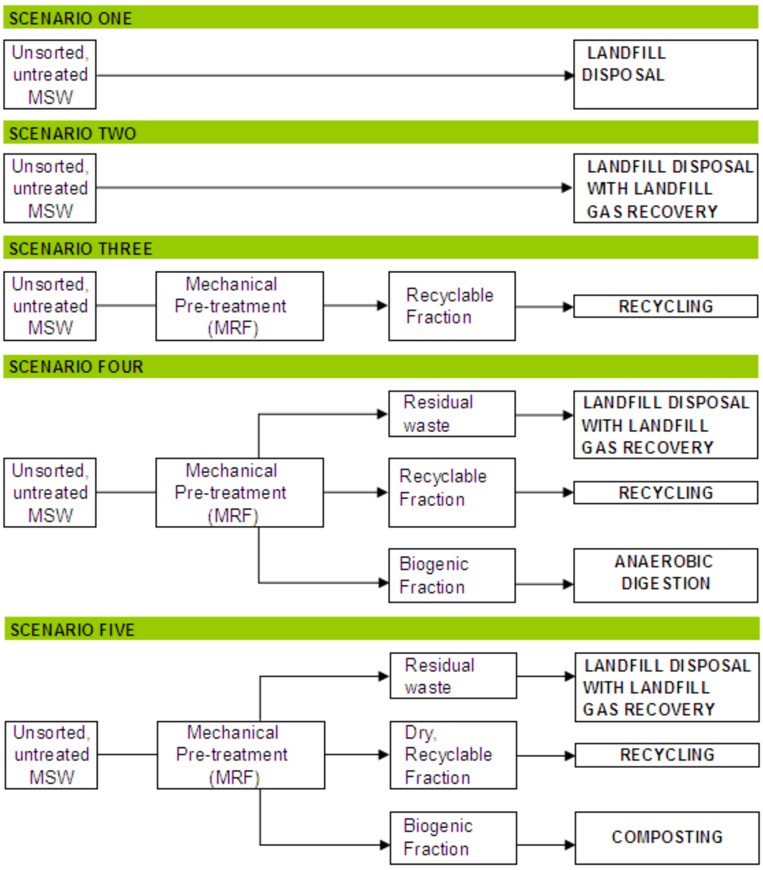

Figure 3.3 WROSE model scenarios (Trois and Jagath, 2011)

3.5. Phase V: System recommendations

To provide system recommendations, the booms were observed at varying times and under different environmental conditions. Any deficits and design shortfalls were noted. To address the operation of the waste management system employed at the litterbooms, key workers and members managing the booms were consulted. This material was further substantiated with the information gathered in the course of the study.

3.6. Limitations of the study

The following limitations were identified for the given study; however, these may not fully encompass any shortcomings that may occur during replication of the study or those that were not identified during this research endeavour. The study was undertaken amid the global COVID19 pandemic, which may result in the alteration in the purchasing patterns of consumers, an increase in demand for medical supplies, and the restriction of movement of people. All these factors may have an impact on the amounts and types of waste found during the fieldwork.

The data collected at the SPCA litterboom may indicate an increase or decrease to the average quantity of waste accumulated at the litterboom due to the roadworks along the Inanda Road (M21) bridge - an extension of the lanes - which may cause a restriction of waste due to impeding water.

3.7. Conclusions

This chapter provided a methodological framework upon which this research study complies. The discussion of the research methodology outlined the subsequent chapters, which further presents the aim and results of the study.

CHAPTER 4: CASE STUDY AND MAPPING

4.1. Introduction

This chapter reviews the study area and factors related to this research. It provides background and an overview of the Umgeni River catchment.

4.2. The Umgeni and Umhlangane tributary

The industrialisation and urbanisation of economies coupled with human settlements have contributed to the pollution of inland freshwater sources in urban zones (Suthar et al., 2010). The water quality of freshwater systems such as the Umgeni and Umhlangane Rivers in eThekwini, have been significantly influenced by varying polluting sources. These polluting sources include urban wash-off, agricultural drainage, industries, effluent return, insufficient sanitation services, mining and human settlements (DEAT, 2006).

The Umhlangane Tributary is located upstream from the Umgeni Estuary and discharges into the Umgeni River, as indicated in Figure 4.1 below. The Umgeni River has a surface area of 4349 km^2, making it the largest catchment in the KwaZulu-Natal region (Namugize et al., 2018). It supplies water to more than 3.5 million people and assists in developing economic production in the province (WRC, 2002). There are numerous informal settlements located along its banks, with a high density of population concentrated along its course. The development of transport routes along the river impacts the concentration of waste entering the river, especially during rainfall events whereby stormwater drainage wash litter into the river.

Figure 4.1 The Umhlangane Tributary and Umgeni River (Adapted Google Earth Pro, accessed 04.01.2021)

4.3. Durban Green Corridors

The DGC is a non-governmental organisation that aims to maintain green spaces and collaborates with local communities in providing an environmentally green society. The DGC has employed the use of litterbooms along the course of the Umgeni catchment to collect waste and prevent it from entering marine environments.

4.3.1. Analysis of the system

The DGC implemented ten litterboom systems along the course of the Umgeni River. The structure and implementation are discussed in the subsequent subheadings,

4.3.1.1. Litterboom locations

As mentioned previously, the DGC has developed the infrastructure for 10 litterbooms. However, only 5 litterbooms are currently functional. The geo-locations for the booms are indicated in Table 4.1 below and further projected in Figure 4.2.

Table 4-1 Litterboom GPS locations and operational status

	Boom name	Geo-location	Operation status
1.	Athlone bridge	-29.809211, 31.032125	Out of order
2.	Beachwood mangroves	-29.809573, 31.037965	Out of order
3.	Connaught	-29.809663329, 31.0161306399	Functional
4.	Johanna Road	-29.7964609987, 30.9933533366	Functional
5.	Johanna Road (Boom 2)	-29.79663, 30.992989	Out of order
6.	M4	-29.8093278015, 31.0378286174	Functional
7.	Peter Road	-29.7894471193, 30.9969009112	Functional
8.	Quarry Road	-29.803236, 30.97508	Out of order
9.	River Horse Valley	-29.774302, 31.000756	Out of order
10.	SPCA	-29.8059962147, 30.9954276275	Functional

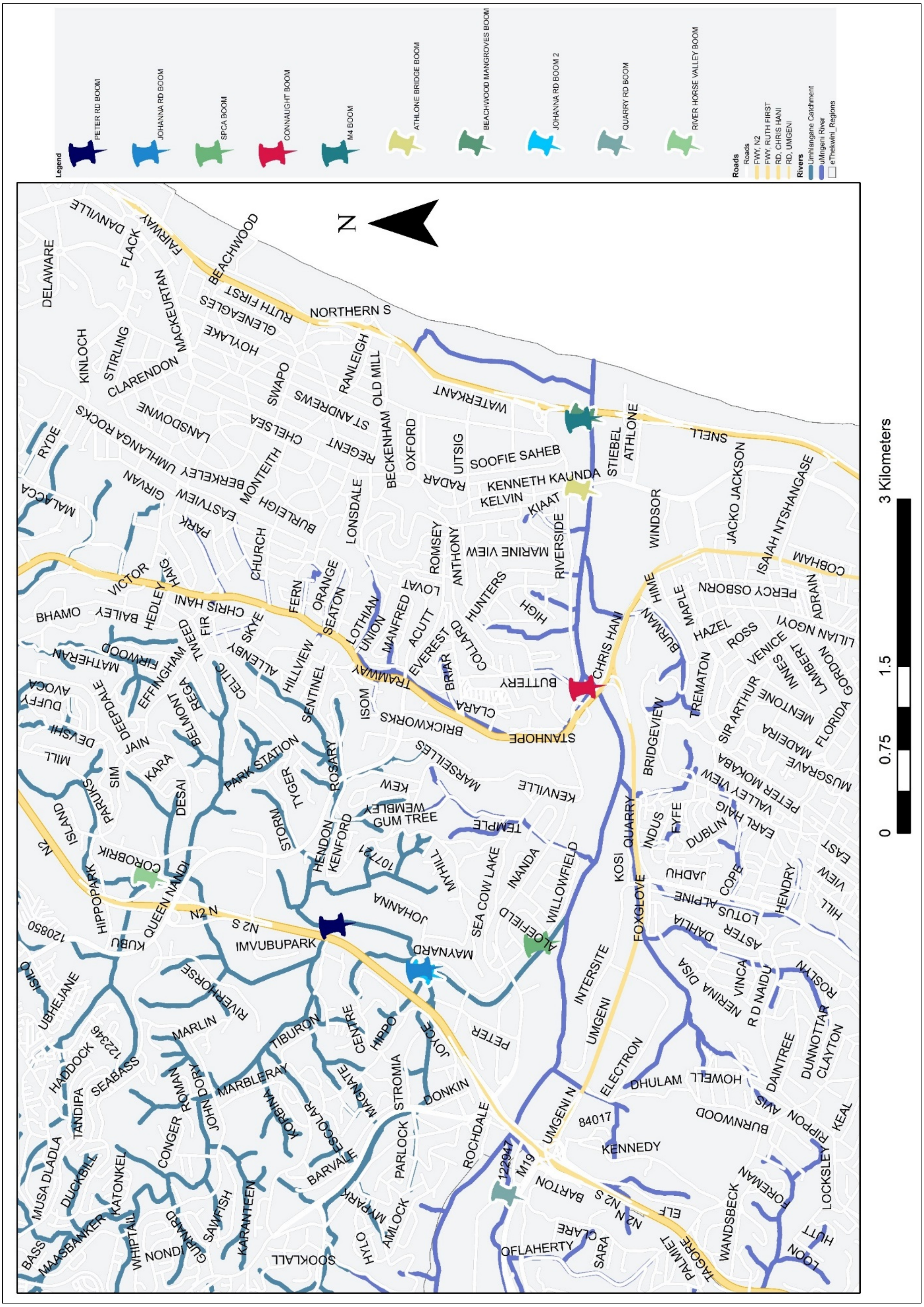

Figure 4.2 Location of litterbooms

4.3.1.2. Litterboom design

The litterbooms are designed either utilising a 900 mm PVC pipe (as indicated in Figure 4.3) or a line of 2L stuffed PET plastic bottles capsuled in a mesh material. The later design structure is produced using cut up pieces of plastics, and it is stuffed into the PET bottle, as shown in Figure 4.4. These prepared PET bottles are then encapsulated in a plastic mesh, as indicated in 4.5. The DGC terms this design as the "Eco-brick" boom.

Figure 4.3 PVC litterboom design

Figure 4.4 Design of the "Eco-brick"

Figure 4.5 "Eco-brick" litterboom

Both litterboom designs are secured to the river bank using a nylon rope. The rope is tied to one end of the pipe/mesh (as seen in Figure 4.6 in the case of the PVC pipe) and then connected to a solid structure on either end of the riverbank, such as a wooden peg in the ground, a boulder or a tree.

Figure 4.6 Litterboom structural implementation

4.3.1.3 Litterboom waste management system

The litterboom team generally consists of two waste pickers (Jabulani and Sfiso) and one waste collector who drives the DGC vehicle to uplift collected waste. The team is managed by DGC team member Siphiwe who oversees the maintenance and running of these booms.

The booms, as mentioned previously, consists of the PVC pipe/"Eco-brick", an anchor and a connection rope. These contraptions are placed horizontally across the river width so when litter contacts the floating boom, it is directed to the side of the river bank with the river's natural flow, as seen in Figure 4.7. The existing litterbooms locations were based near informal settlements, stormwater drainage outlets, or the river's confluence areas. The basis of its location near informal settlements also includes promoting local initiatives educating the inhabitants.

Figure 4.7 Positioning angle of the litterboom

Accessibility is one key factor in employing the litterbooms. Some litterbooms such as the Peter Road and M4 litterbooms are accessed primarily using a canoe or alternatively walking through the riparian zone along the river for a considerable distance from the road. This proves difficult to remove trapped wastes from the site.

All the booms are monitored and managed manually regularly. The management of the waste from the litterboom is carried out on a regular basis. The waste pickers utilise a metal net attached to a long pole (Figure 4.8) to scoop out waste from the litterboom (as shown in Figure 4.9). This waste is then deposited on the riverbank, where it is left to accumulate. The booms are not necessarily entirely emptied in a single day.

Furthermore, the booms are not serviced daily. Once the waste on the river bank reaches a considerable amount, the waste pickers remove the PET waste and collect it in large polyethylene bags. The remainder of the waste categories are placed into bin bags and disposed of by municipal services.

Figure 4.8 Tool used to scoop out litter from the boom

Figure 4.9 Waste picker extracting waste from the litterboom

The PET waste is then transported to the KwaMashu beneficiary centre, where it is recycled. Once a delivery is made, the data of PET mass collected is then recorded on a JetPoint system to maintain a record. Overall the resources utilised to manage these litterbooms are elementary and may have some shortfalls.

4.4. Waste entry into the river

Plastics and other wastes enter aquatic environments from various land-based sources. Street litter and mismanaged waste can be directly blown into water bodies. These wastes can also be transported into rivers as part of urban run-off during rainfall events. South Africa is ranked by Jambeck et al. (2015) as the 11th worst offender concerning wastes entering the ocean. This is due to the countries high waste production per capita combined with poor waste management – thus ranking it 3rd worst on the continent. The following subheadings look at 4 categories of routes waste can enter water bodies: land use zones, road network, stormwater drainage, and informal settlements proximity to the water system.

4.4.1. Land-based activities

Waste floating in the river body or present along the riverbank can be attributed to human activities along the water body (Armitage, 2007, Carson et al., 2013, Gasperi et al., 2014, Hoellein et al., 2015, Carpenter and Wolverton, 2017). More significant debris concentrations or household items are generally the outcomes of residents dumping waste along the riparian zone (Rech et al., 2015, McCormick and Hoellein, 2016).

Waste categories generated can be correlated to the type of human activity in the vicinity and the level of waste management. To illustrate the land activities occurring along the river's length, a zoning layer was created and exhibited in Figure 4.10.

It can be indicated that transportation routes, industrial parks, residential zones, informal settlements and commercial zones are scattered nearby along the river's length. Recreational parks found at the Umgeni Estuary and further upstream are generally strewn with litter, swept into the river by winds. The industrial zones along the course are serviced by municipal waste services regularly. However, there exist several informal dumping spots sandwiched between the river and industry.

The municipality generally services the residential area located on the northern banks of the river. It is considered a middle-income area, so the residents should be capable of storing and managing their waste until it is collected. The irregular servicing and lack of resources coordinated to zones of informal settlements along the river have resulted in multiple dumping spots.

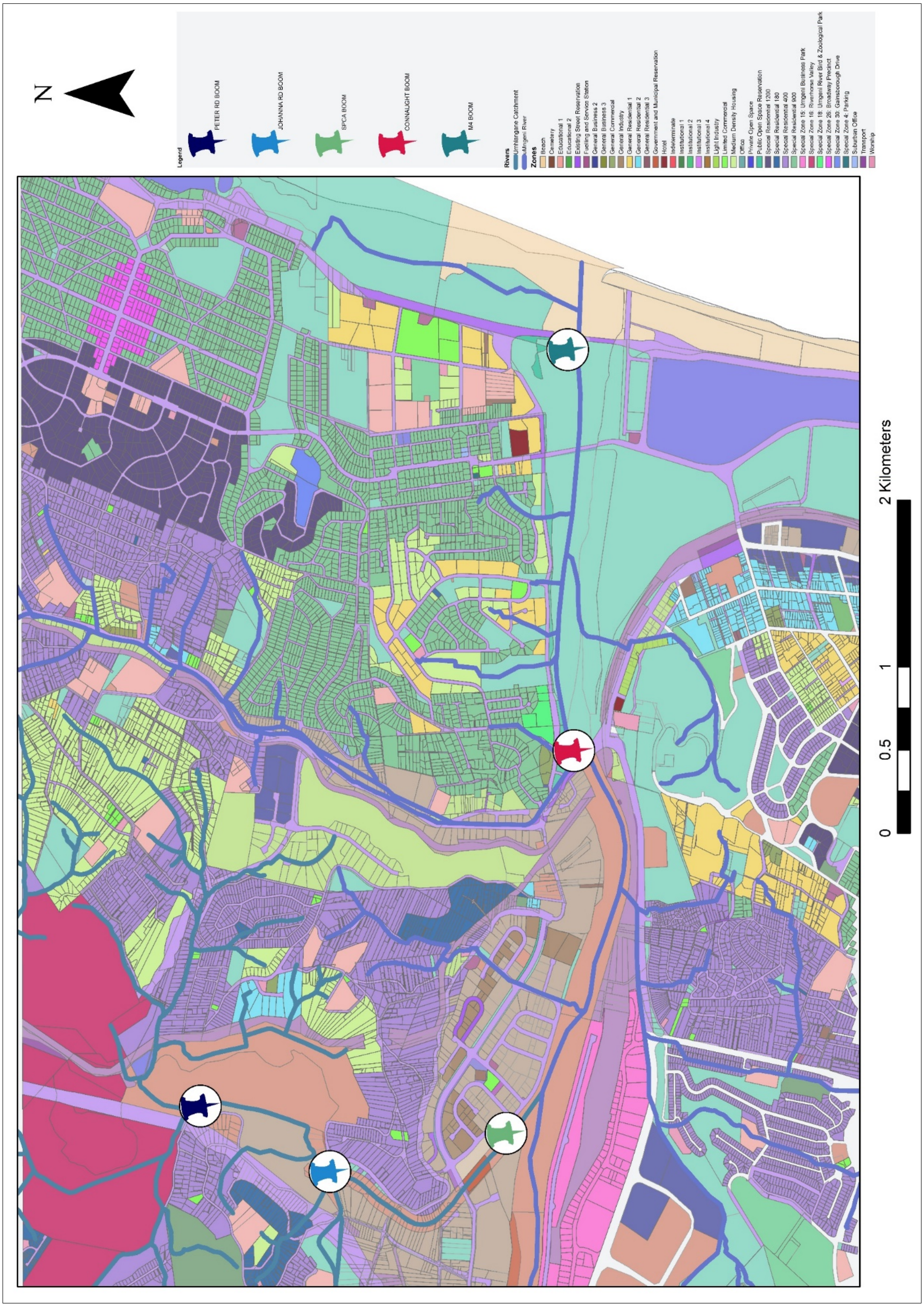

Figure 4.10 Land use zones

4.4.2. Transportation routes

Roads are designed for interactions between people and their environments (Council, 2005). They are created to network access to resources, join communities, allow for locomotion to work, and enable the exchange of goods and services (Council, 2005). However, the dumping of litter on sidewalks and along curbs is a common issue. These wastes often get washed off during heavy rains or are blown by winds into neighbouring water bodies.

Willis et al. (2017) found that rivers had a greater concentration of waste debris in areas along public roads. Figure 4.11 highlights the large network area of road which falls close to the river catchment. The positioning of the litterbooms in relation to the road network and the river mouth can also be noted in an attempt to maximise the effort to impede waste. To further illustrate the likelihood of waste being transferred into rivers from roads due to its distance, Figure 4.12 exhibits a buffer zone from the central point of the river width.

Due to the river having irregular widths at varying points of its flow, the central point was utilised, so in some instances, the 10m buffer may indicate the entire width of the river. The buffer zones indicate the small area that acts as an intermediate between waste disposed along the road and the water body in distances of 10m, 20m and 30m.

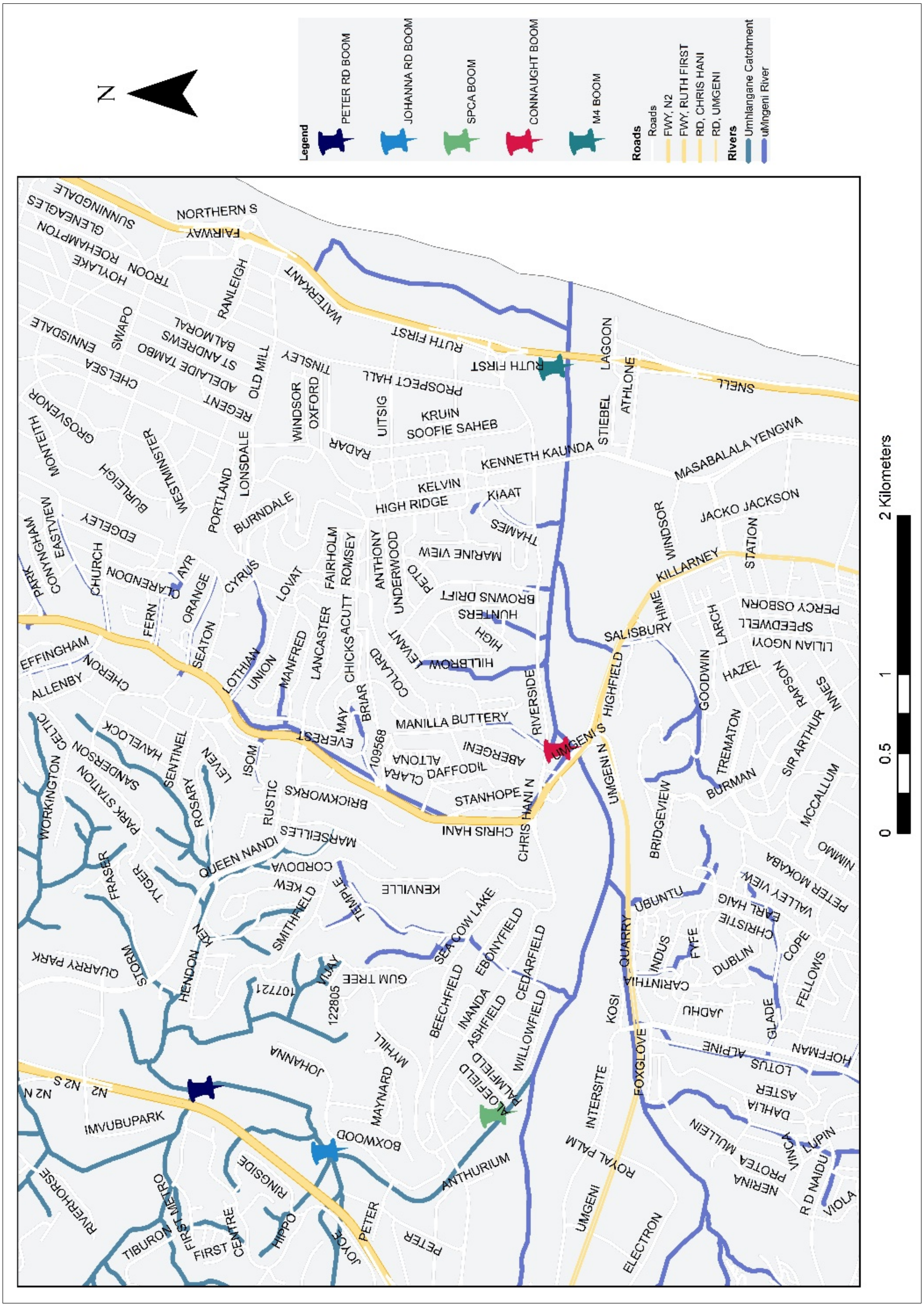

Figure 4.11 Road network neighbouring river catchment

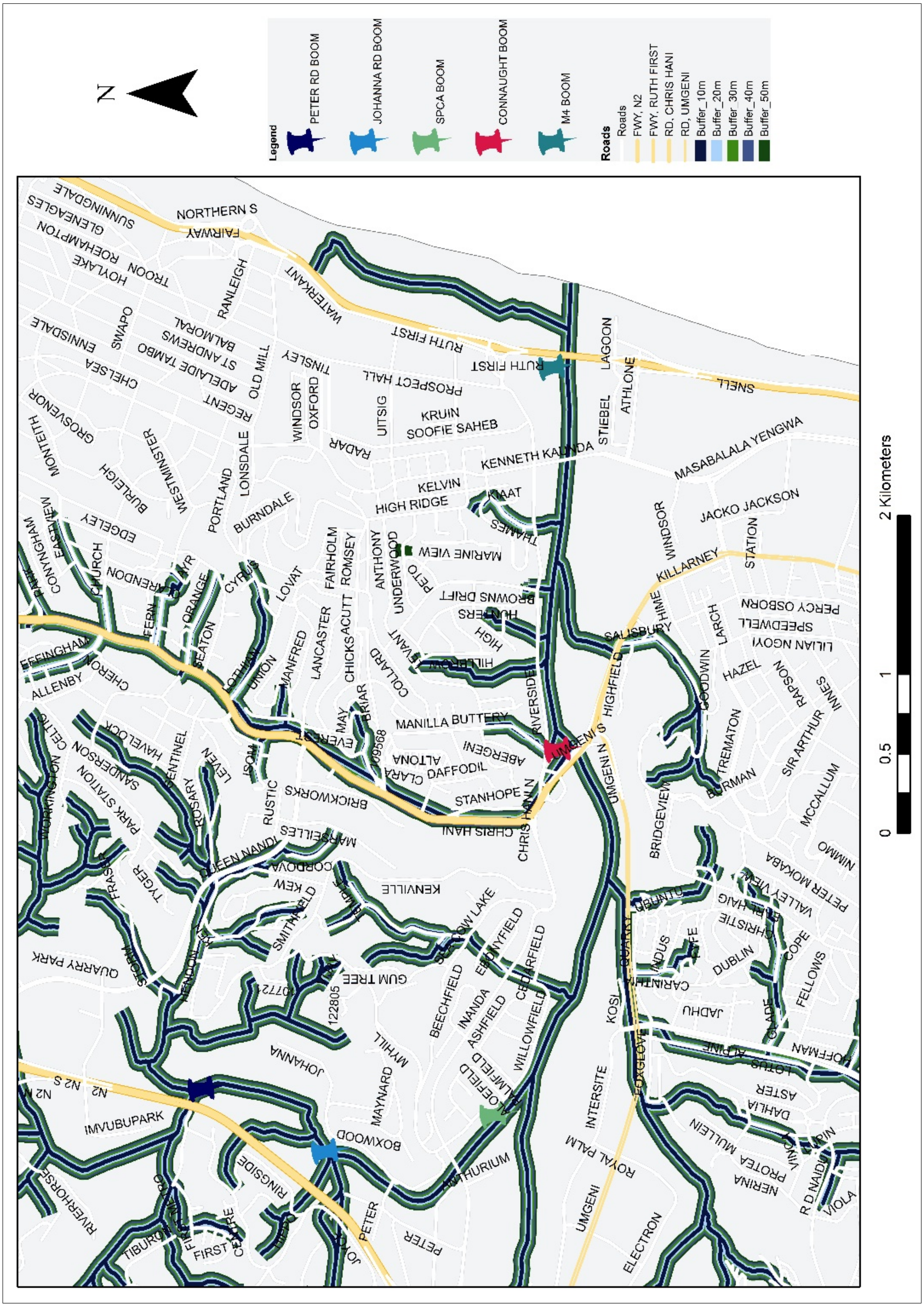

Figure 4.12 Buffer zone around river catchment

4.4.3. Stormwater drainage and population dynamics

As societies become industrialised and the population statistics increase drastically, thus the amount of waste generated increases (Hoornweg et al., 2013). Society, in general, has illustrated a lack of concern for proper waste management as seen across the city of Durban, where recreational areas are strewn with waste materials.

Improperly disposed waste debris is swept into stormwater drains during rainfall events or heavy winds (Moore et al., 2011). Once in the stormwater drainage system, the debris can travel via the drainage channel into streams, rivers and estuaries until it reaches the open ocean. However, some of this waste is retained in the environment along the way. Some waste debris becomes trapped in vegetation along the river banks, strewn on the beaches or buried in benthic sediments. These can cause long term harms to the environment. A study conducted in Cape Town indicated that large amounts of macro-litter were concentrated in stormwater drainages and were eventually washed out into the ocean as part of urban run-off (Marais et al., 2004).

To provide an understanding of stormwater drainage and its outputs, Figure 4.13 was projected. It can be noted that stormwater drainage along the water body drains into a large portion of the Umgeni River system. However, this is most evident in the tributaries and smaller streams that feed into the greater Umgeni system.

Furthermore, to illustrate an understanding of the population dynamics these stormwater drainages service, an overlay indicates the populations that border the perimeter of the river. Research conducted in South Africa at the onset of the 2000s found that stormwater drainage systems contributed to the transfer of substantial amounts of litter into the environment (Armitage and Rooseboom, 2000, Marais et al., 2004, Armitage, 2007).

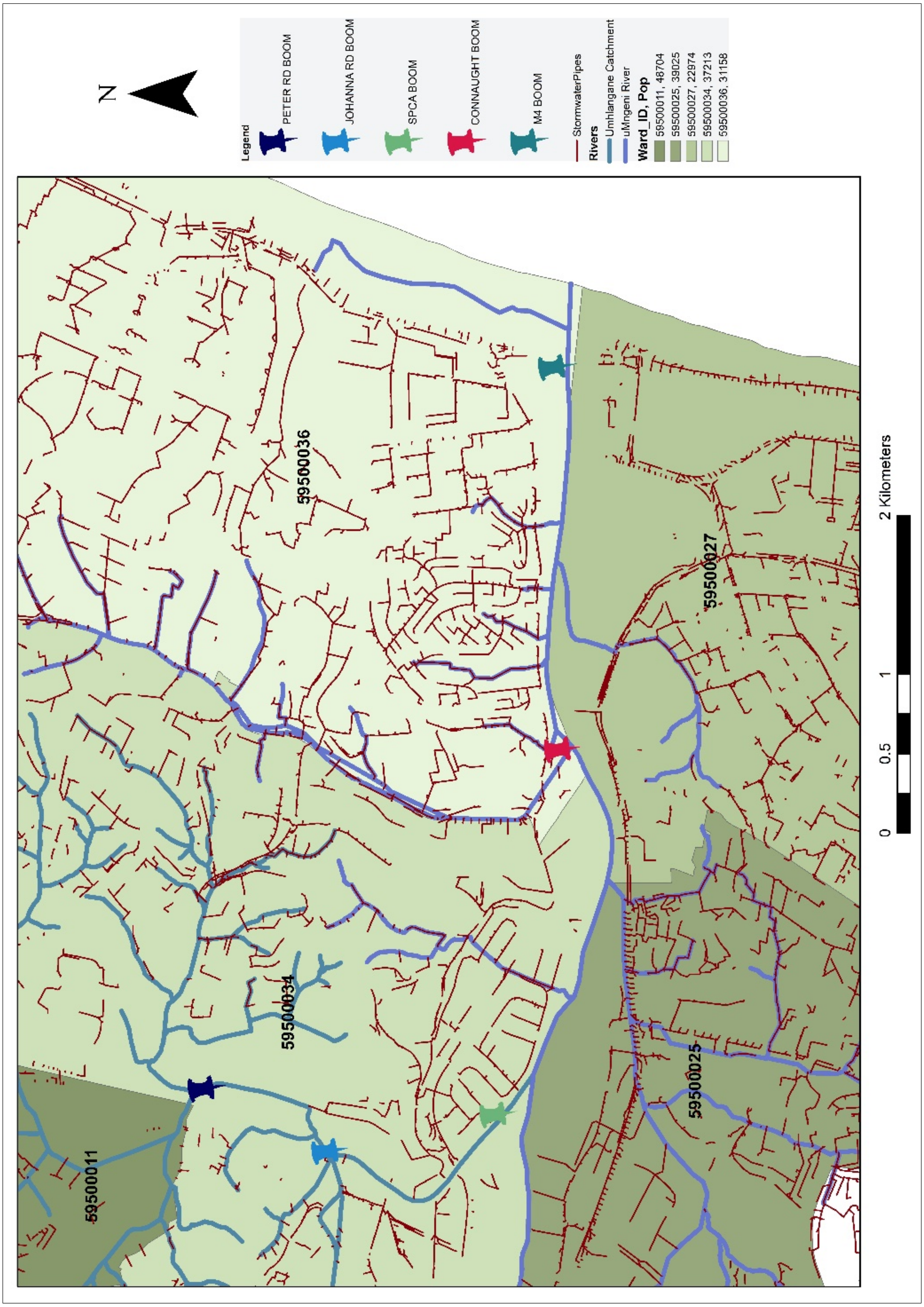

Figure 4.13 Stormwater drainage and population map

4.4.4 Settlements location

Waste disposed of human settlements is considered one of the largest sources of water pollution globally (Luanratana and Visvanathan, 2017). The littering of waste items by inhabitants of settlements without access to infrastructure and sewage matter is a significant concern for riverine pollution (Franz and Freitas, 2012, Wu et al., 2018). Densely populated settlements are noted for severe pollution as waste is directly disposed of into water sources (DWAF, 2002).

The waste management services and systems in informal settlements are limited, and this further exacerbates the situation. The lack of formal road access in some of these settlements makes it difficult for service delivery. South Africa's excessive waste generation combined with its poor waste refuse collection and disposal practices is a threat to its development.

To understand some of the types of litter entering the Umgeni catchment, informal settlements located along the river's course are illustrated in Figure 4.14. This projection provides an understanding of waste matter that is already in the Umgeni system and hotspot areas that require attention. Based on the projected map, it is evident that many settlements are concentrated in the upper river portion.

The location of these settlements in proximity to the river is significant as they can be educated and empowered to assist with the efforts of waste management systems. In addition, this study employs the WROSE model, which advocates a sustainable way for these inhabitants to generate a basic income while assisting in environmental clean-ups.

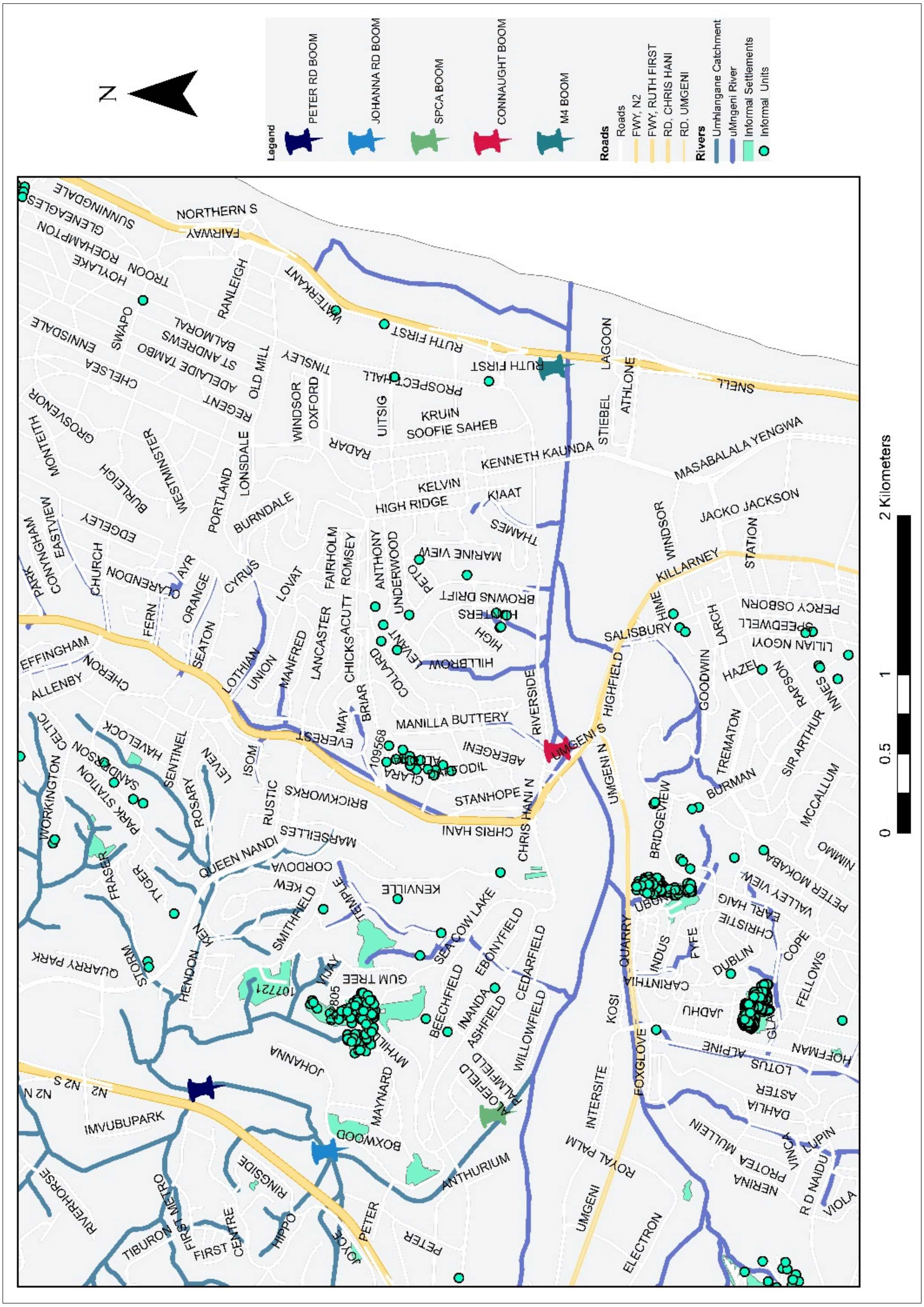

Figure 4.14 Informal settlements location along the river

4.7. Conclusions

This chapter provided an overview of the litterboom management system and possible waste entry routes into the river catchment. It indicated 4 possible entry routes for the Umgeni River and projected maps to illustrate them.

CHAPTER 5: RESULTS AND DISCUSSION

5.1. Introduction

This Chapter provides data analysis and presentation of the research results. It covers descriptive statistics and inferential statistical methods used to analyse the waste streams in this study. Statistical analysis of the data was done using SPSS Version 24.

5.2. Characterisation and quantification of waste

Characterisation of waste composition within a system is the first step in designing a sustainable and successful waste management structure. The following data reports findings at the specified litterbooms.

5.2.1. Johanna Road litterboom

The Johanna Road litterboom cumulated a total of 347kg of all waste streams over the entire timeframe. The most notable composition of waste mass is plastics, as exhibited in Figure 5.1, which accounts for approximately 200kg of all waste collected over the given timeframe. This amount represents 58% of all waste streams, as shown in Figure 5.2. This is significant because it indicates that a large proportion of waste disposed of and entering the river system is plastic.

Plastic waste is followed by organic waste, accounting for 110kg and representing 32% of the total waste. The significant change in mass between plastics and organic wastes can be seen as it accounts for a difference of approximately 26%. The large proportion of organic waste is due to large portions of the riparian zone being removed due to human activities along the river and the dumping of garden matter by neighbouring homes into the water body. These high amounts of organic waste can threaten the water body resulting in eutrophication and eventually hypoxic conditions. The third most frequent waste stream is glass, with a mass of approximately 8kg representing 4% of the total waste collected.

Furthermore, the significant difference between the two waste stream groups glass and organic material of 28% can be noted. The waste streams metals and residual waste constitute approximately 2% of the total waste and 8kg and 7kg respectively. Waste streams cardboard/paper, textile and rubber account for the lowest mass categories, of 4.6kg, 3.15kg and 0.3kg, respectively. These groups are shown to have minor proportions in the total waste accumulated.

Days 1 and 3 account for the highest collection of waste streams plastic and organic matter. It can also be noted that day 2 accounts for the highest amount of glass waste collected and significant proportions of plastics and organic waste.

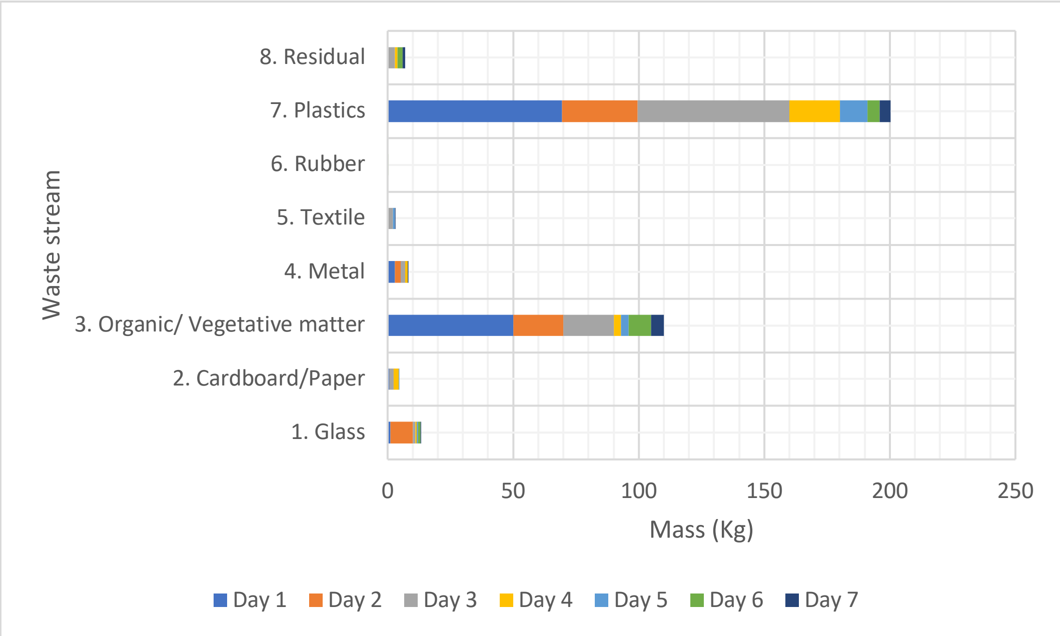

Figure 5.1 Johanna Road litterboom waste stream composition and mass per day

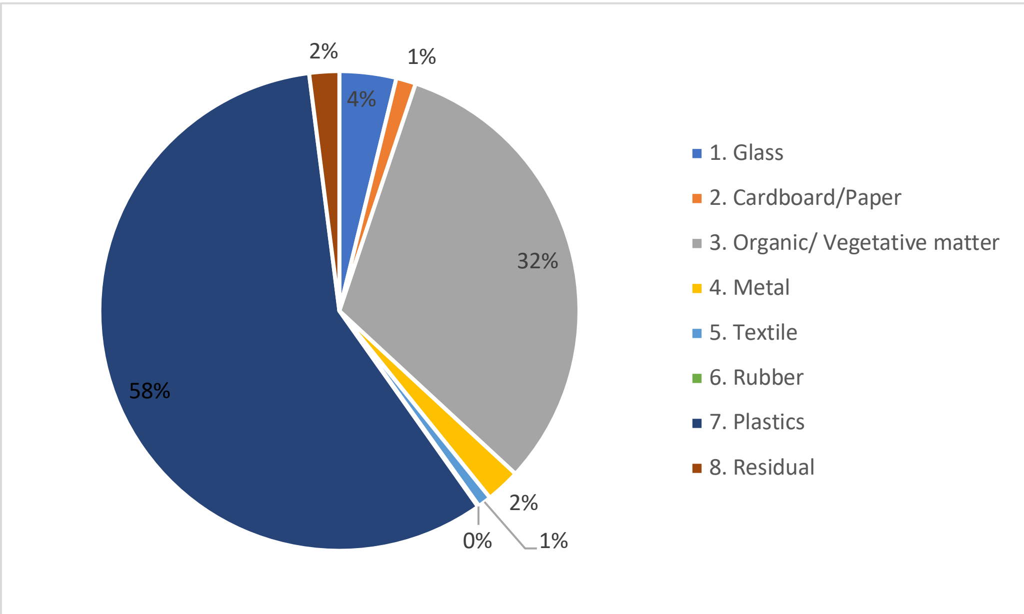

Figure 5.2 Waste composition at the Johanna Road litterboom

As mentioned, waste stream plastics account for 58% of all waste accumulated at the Johanna Road litterboom. Of this sum, PET waste accounts for the highest mass of approximately 89kg of all plastic collected and 44% of total plastics, as shown in Figures 5.3 and 5.4. PS follows with a summative mass of approximately 46kg representing 23% of all plastics. This indicates a decrease of 21% in plastic mass between PETE and PS. HDPE follows closely, accounting for 18% of all plastics and a mass of 36kg. PP, PVC and LDPE account for the lowest amounts of plastics over the period, with cumulative masses of approximately 14kg, 10kg and 4kg, respectively. Other plastics only accounts for 1% of all plastic.

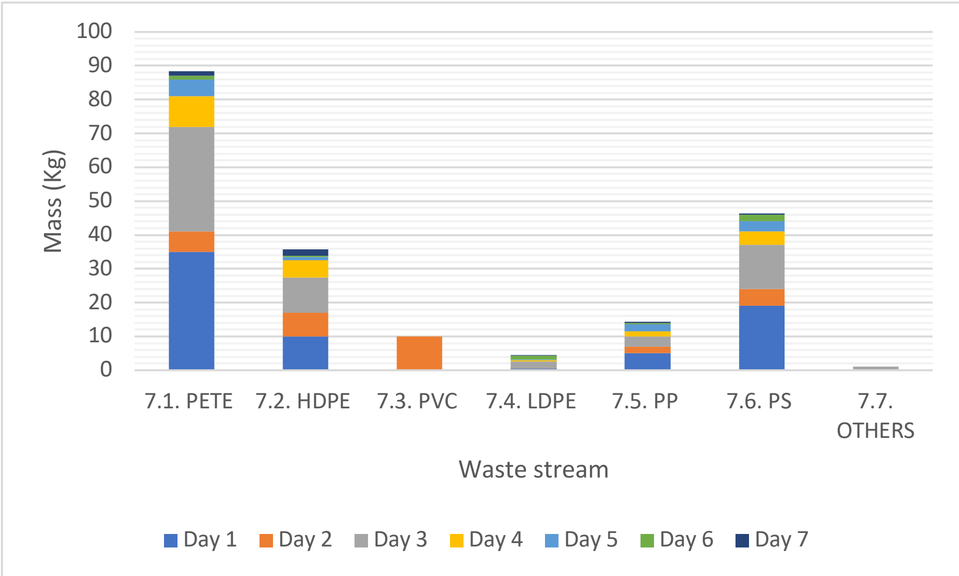

Figure 5.3 Johanna Road litterboom plastic waste mass per day

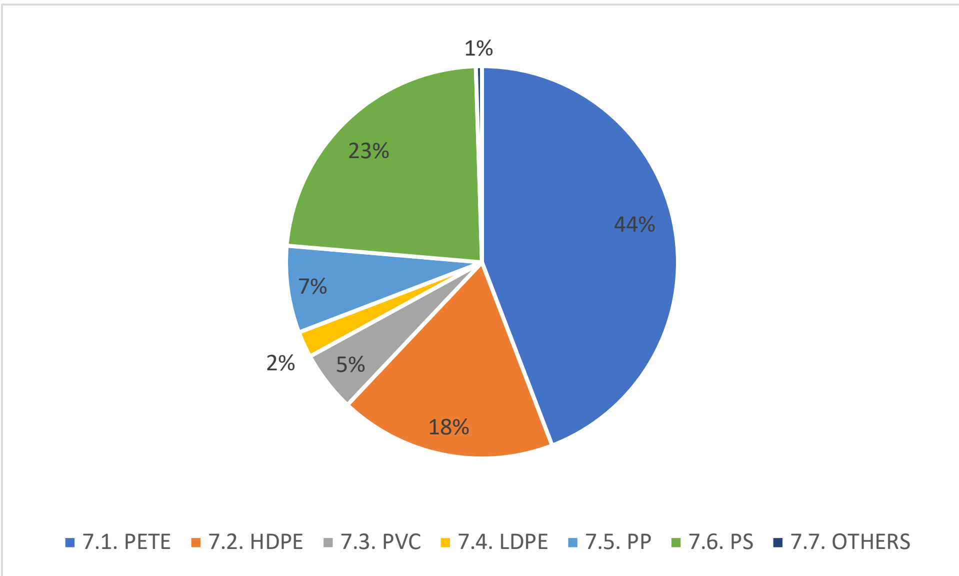

Figure 5.4 The proportion of plastic types at the Johanna Road litterboom

5.2.2. SPCA litterboom

The SPCA litterboom had relatively fewer data over the entire timeframe. Days 1 and 2 of the study found that there was no waste present at the boom. Lack of debris could be due to waste washing over or under the boom before the days recording. Alternatively, this could be due to the road works located further upstream, preventing waste from passing further downstream.

The cumulative mass of waste collected over the period is approximately 41kg. The most occurring waste stream was plastics, which accounted for 25kg collected over 7 days, as seen in Figures 5.5 and 5.6. Plastics represent 63% of all waste present. This is followed by organic waste with a cumulative mass of 11kg accounting for 27% of total waste.

There is a significant difference in the mass of the second and third most occurring waste streams of 22%. Rubber accounts for 2kg, represented by 5% of total waste. The waste streams cardboard/paper, textile and metals account for the least occurring waste mass with respective masses of 500g, 500g and 10g. Residual wastes accounted for 30g of mass.

Day 3 of the study yielded the most waste mass collected, followed by day 4. Days 1 and 2, as mentioned above, yielded no waste.

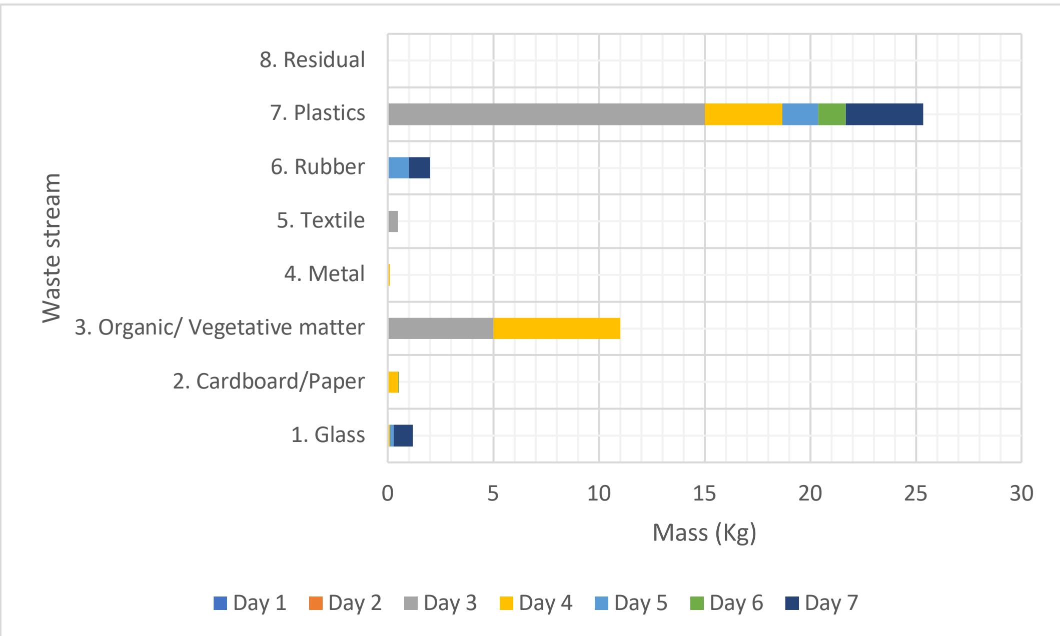

Figure 5.5 SPCA litterboom waste stream composition and mass per day

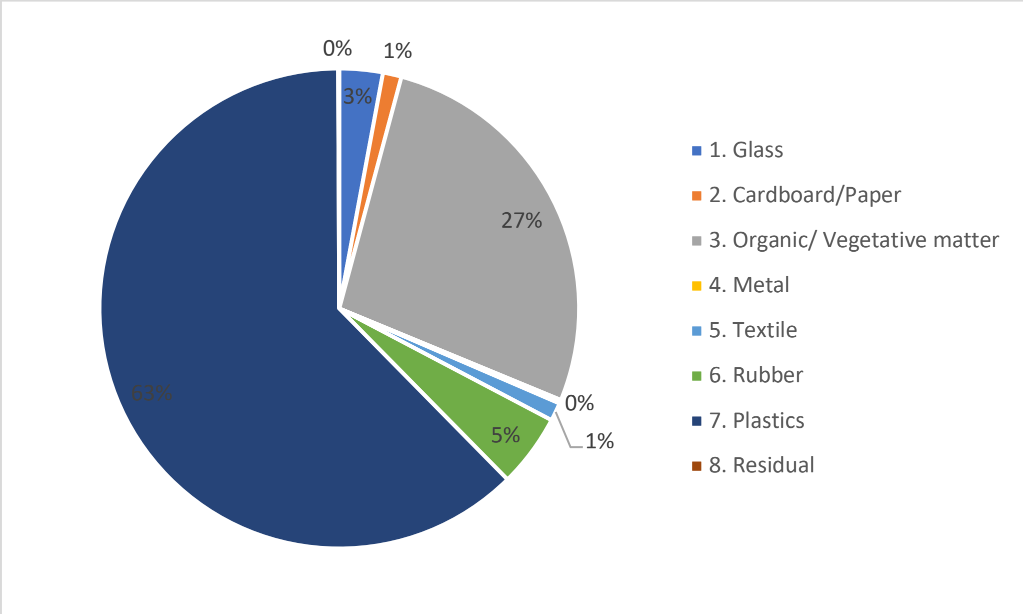

Figure 5.6 Waste composition at the SPCA litterboom

PET waste accounts for 45% of the most occurring plastic at the SPCA litterboom, whereby it has a mass of 11kg, as indicated in Figures 5.7 and 5.8. This is followed by HDPE, which accounts for 6kg and 23% of all plastics. PS and PP account for 19% and 11%, respectively, with corresponding masses of 5kg and 3kg. LDPE only accounts for approximately 500g, while PVC and other plastics were not present at the SPCA litterboom.

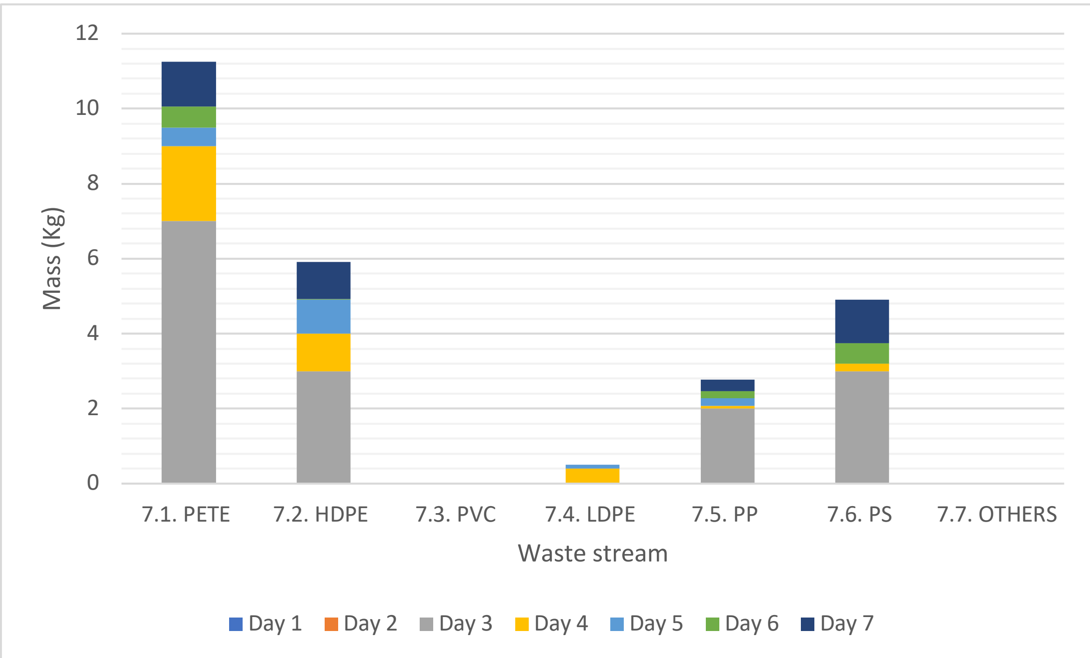

Figure 5.7 SPCA litterboom plastic waste mass per day

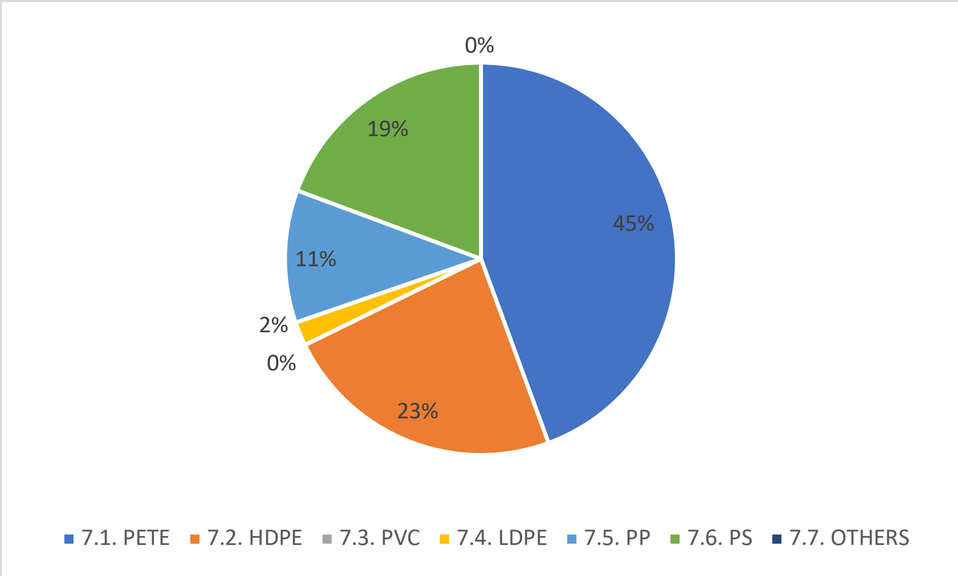

Figure 5.8 The proportion of plastic types at the SPCA litterboom

5.2.3. Comparative data

Mann-Whitney U-test was used to test if there is a significant difference in the quantity of waste between Johanna Road litterboom and SPCA litterboom. The test results suggest a statistically significant difference between the quantity of waste found at the Johanna Road litterboom and the SPCA litterboom ($z=-2.750$; $p = 0.006$). Therefore, the null hypothesis is rejected.

The weak correlation can be due to the inefficiency of the litterbooms during heavy rainfall events. It is common for the litterbooms to become dislodged from the riverbank during heavy rainfall events, thus allowing for large amounts of waste to go unrecorded until repaired.

The differences in waste quantities further seen as waste amounts between Johanna Road and SPCA litterbooms accounts for a difference of 306kg of total waste. These differences are equivalent to approximately 44kg/day more waste accumulating at the Johanna Road litterboom than the SPCA litterboom.

The most occurring wastes at both litterbooms were plastics and organic matter. The highest proportions of plastic present at both litterbooms were PET, HDPE and PS. These plastic groups are significant as they are so commonly used in everyday items.

5.3. Effect of climate change events on the amount of PET waste

The effects of climate change are becoming more imminent as time progresses. Climate change assists in causing the global temperatures of the world's oceans to increase, thus catalysing and intensifying the hydrological cycle (Huntington, 2006). These significant changes will drastically increase the intensity and frequency of severe precipitation events (Koakutsu et al., 2012).

These changes will cause an increase in the flooding of riverbanks. Improperly managed waste will consequently be washed into water bodies. Figure 5.8 illustrates the 100-year floodplain that affects the Umgeni catchment. A 100-year flood is a flooding event that has a probability of 1% occurring in any given year. With the effects of climate change, the probability of these events occurring increases. It can be noted that a large portion of the industry, residential areas and commercial zones fall within the range of the floodplain.

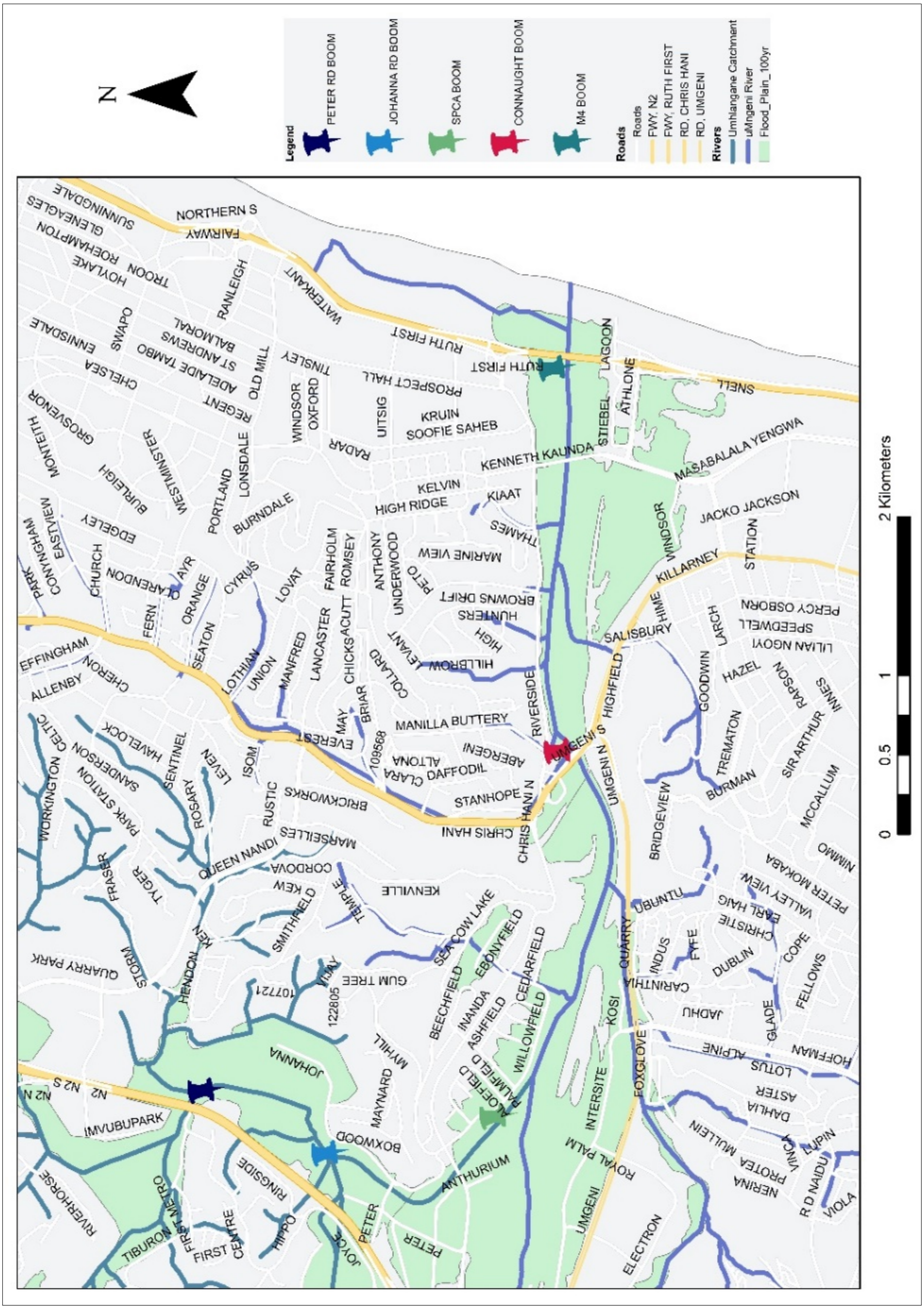

Figure 5.9 100-year floodplain

To establish if a correlation occurs between PET waste and rainfall events, data collected from the Johanna Road litterboom was graphed on the same axis as rainfall, as shown in Figure 5.9. This data does not indicate a clear correlation; however, the graph indicates that during spike events in rainfall, the mass of PET also rapidly increases.

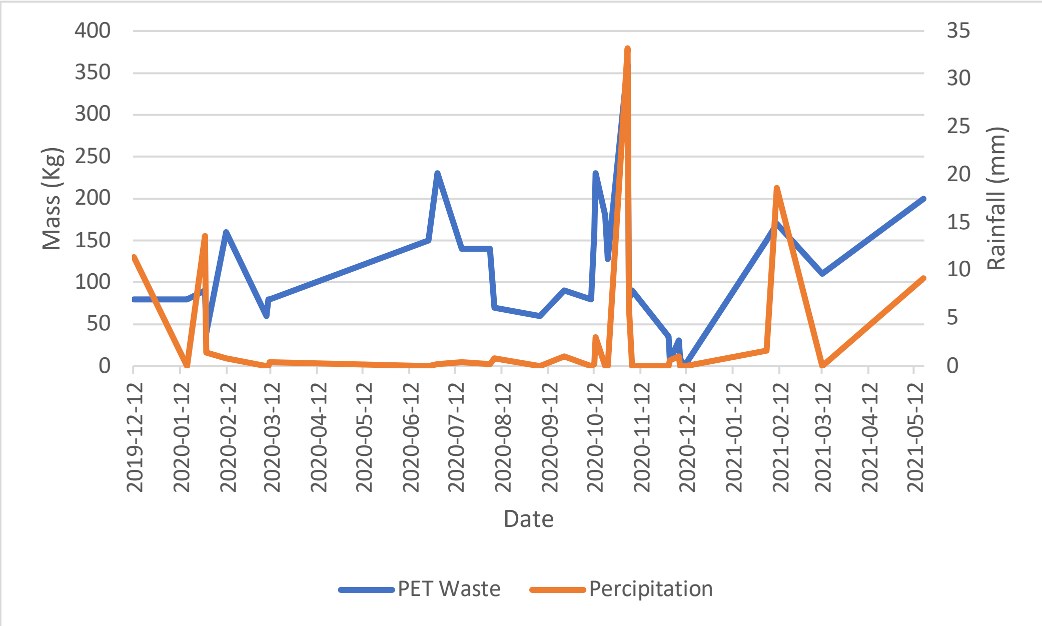

Figure 5.10 Rainfall vs PET waste

Kendall's tau b analysis was used to establish if a correlation exists and the strength of that correlation. Kendall's tau b analysis indicated a weak positive correlation (0.303) exists between rainfall events and the amounts of PET waste found in the river system ($p<0.05$). This signifies that the mass of PET transferred into the river system increases; this can be due to poor waste management along the riverbanks and surface runoff or stormwater draining into the river.

5.4. Valorisation of plastic wastes

The competitive characteristics of plastics make them a desirable material convenient for both handling and transportation. Their material properties permit them to be easily formed into various shapes. Plastics, however, are harmful due to their long lifespan and toxic properties when disposed of into the environment. The process for correctly handling and disposing of plastics is required while deriving maximum benefit.

This study found that plastics are abundant in the Umgeni River system, which warrants scenario WROSE models as indicated in Figures 5.11 to 5.16. The scenario models indicate paths that waste pickers and DGC members can undertake to utilise the waste entirely. Presently the DGC only recycles PET wastes while the remaining plastic groups are landfilled. In an attempt to aid them in the decision-making process, the following WROSE models can be used.

The use of the model is simple; the user has to select the path best suited to their needs and based on the quantity of the input to reap maximum yields. All waste removed from the river system will have to be subjected to more refined categorisation. All models account for plastic waste beyond recovery or heavily contaminated; these wastes can be disposed of into landfills. Furthermore, all models account for community engagement; community upcycling should be promoted and be a key route for plastic waste.

Community upcycling refers to modifying plastic waste into new products that can be sold for monetary value. Examples of upcycling plastics exist throughout Africa, such as upcycling PET bottles into plastic jewellery or plastic packets into school bags. As indicated in the previous Chapter, a considerable number of informal settlements occur along the course of the river; community engagement will provide them with the ability to develop the local economy.

All plastic types can undergo thermal recycling and be used to generate energy. However, this path can emit toxic fumes; thus, it must be conducted in a controlled environment. It is a commonly practised waste reduction and energy recovery technique (Al-Salem et al., 2009). It is often used for contaminated or hazardous-goods packaging.

PET, HDPE, PVC, LDPE and PP can undergo mechanical recycling. This process entails collecting, sorting, washing, and grinding plastic material (Ragaert et al., 2017). This procedure can produce pellets which can then be used mixed with virgin material to manufacture new plastic products.

HDPE, LDPE, PP, PS can undergo chemical recycling – pyrolysis. The pyrolysis process breaks down plastics into various basic hydrocarbons by heating them in the absence of oxygen (Patni et al., 2013). The use of a distillation process allows for a range of products to also be produced, from light oils and gas to heavy wax (Naik et al., 2010).

PVC, PP, PS can also undergo chemical recycling – purification. This process is whereby plastics are dissolved in an appropriate solvent, following procedures to separate the polymer from contaminants and additives (Knappich et al., 2018). Once the polymer dissolves, it can be crystallised and eventually reformulated into new plastic.

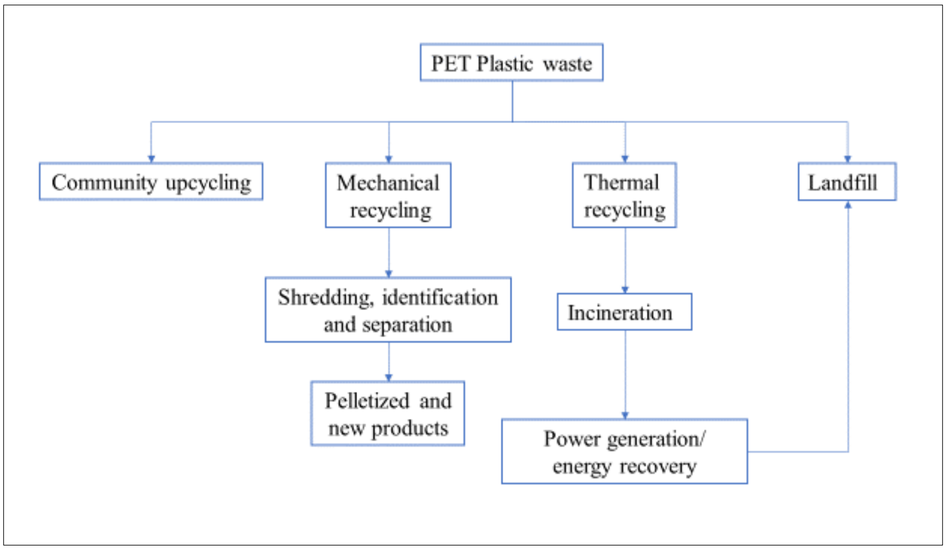

Figure 5.11 Scenario model for PET wastes

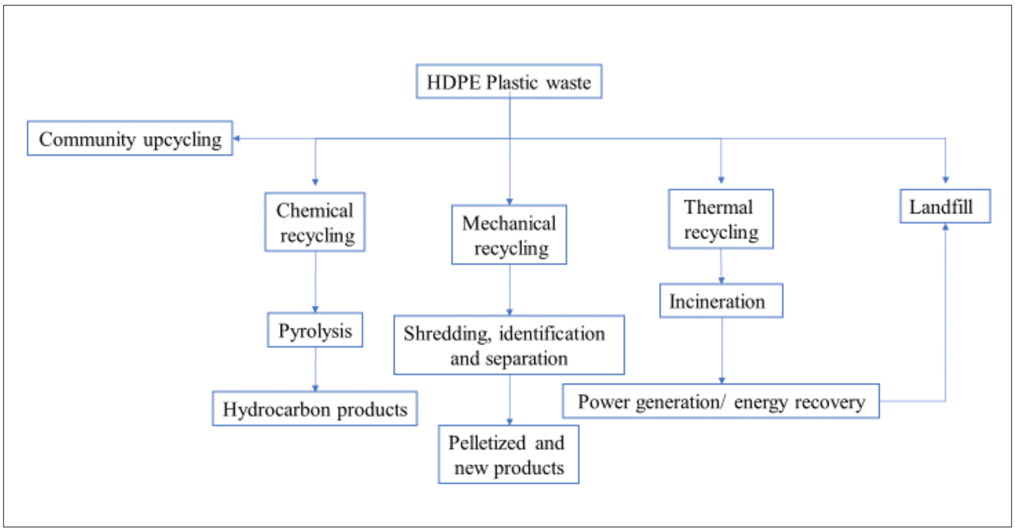

Figure 5.12 Scenario model for HDPE wastes

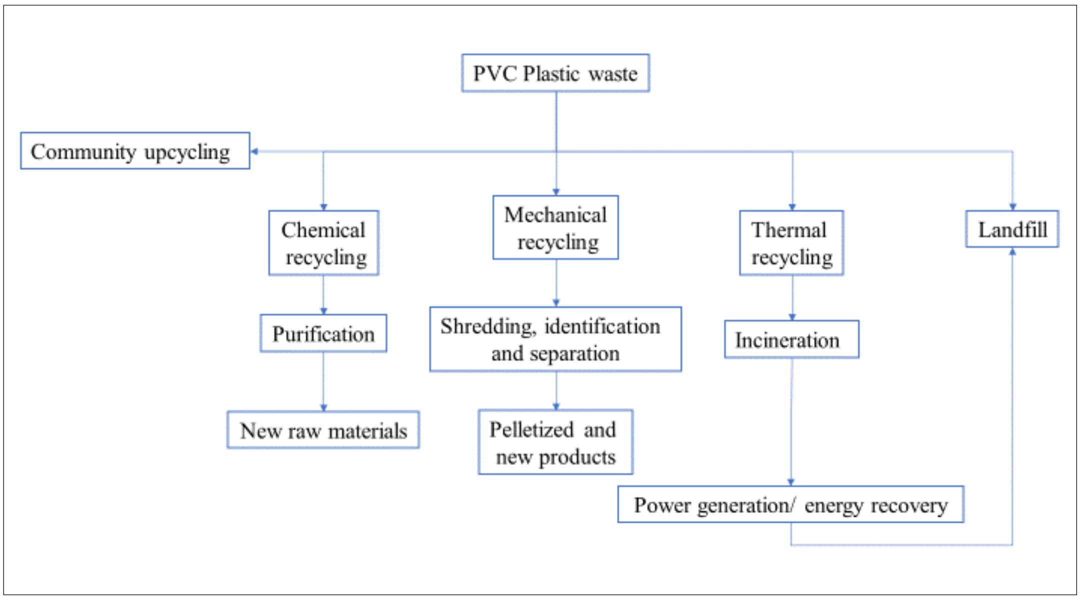

Figure 5.13 Scenario model for PVC wastes

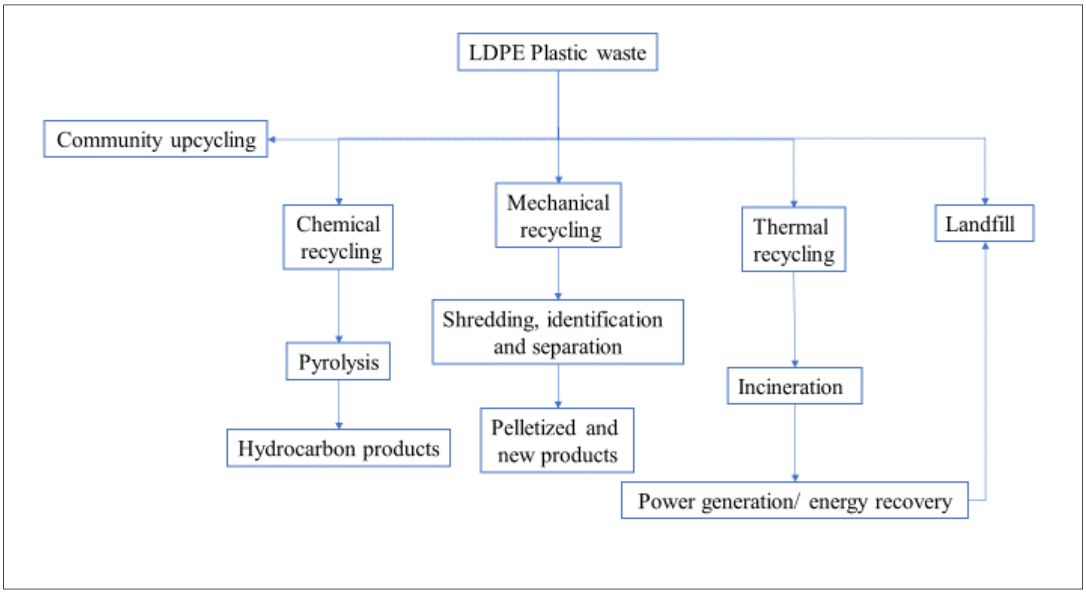

Figure 5.14 Scenario model for LDPE wastes

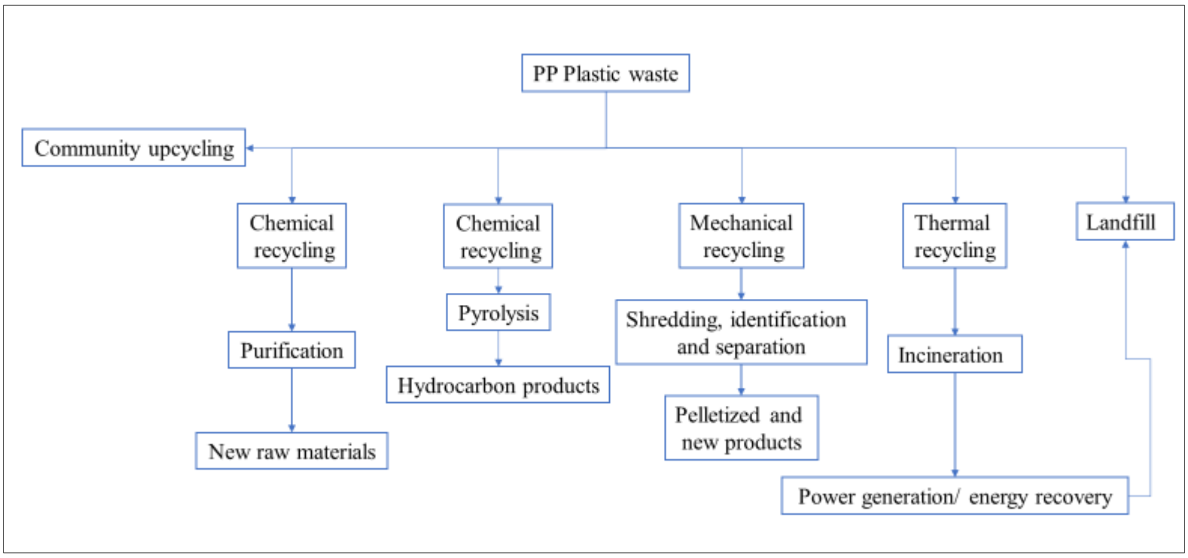

Figure 5.15 Scenario model for PP wastes

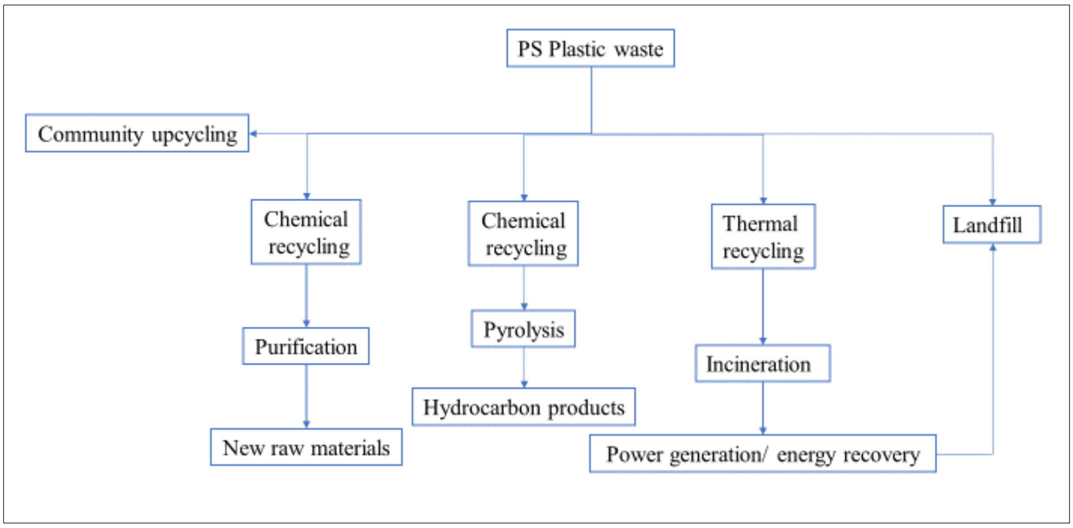

Figure 5.16 Scenario model for PS wastes

5.5. System gaps and recommendations

Through analysing the litterboom system, the following gaps have emerged:

1. The design of the litterboom requires immediate optimisation that is sturdy enough to withstand heavy rain events as the current system gets washed out during heavy rains. A more solid grounding is required to hold the litterbooms to either side of the riverbank.
2. The design of the litterboom has to incorporate and take into account low water levels in the river. When the discharge level is low during certain hours of the day, waste escapes under the boom, as indicated in Figures 5.17 and 5.18. A possible solution would be to attach a suspended secondary PVC pipe of a smaller width to the litterboom, so this will float over the river surface when discharge levels are low.
3. Data recording needs to be timeous and accurate. Currently, there lacks efficient information on long term waste stream quantities. An effective recording system needs to be implemented, preferably a datasheet that allows all waste pickers to input their collection, and this can be collected at the end of every week and collated.
4. More staffing is required to manage the booms to remove waste every day or every second day.
5. Waste extracted from the boom needs to be sorted and removed from the riverbank immediately. The current waste management system strategy employed piles up removed wastes until it reaches a sizeable amount – only then it is removed. This system allows waste to fall back into the river and degrade into micro-litter in the riparian zone, as indicated in figure 5.19. This micro-litter is then left unattended as they become burdensome to remove. It is essential to safely remove and store waste away from the water body at the earliest possible scenario.

Figure 5.17 Waste escaping under litterboom

Figure 5.18 Close-up gap under litterboom

Figure 5.19 Waste degrading to micro-litter

5.6. Conclusions

The outcomes of this Chapter answered the critical questions of the research. It found that plastics PET, HDPE and PS were the significant waste streams polluting the river body. Furthermore, it found a correlation between rainfall and the amounts of PET waste.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

In this research, the characterisation of riverine wastes found in the Umgeni catchment was assessed. Analysis of the different types of plastic riverine waste groups and their magnitudes was carried out, a novel work that has not been studied extensively to date. Parts of the WROSE model had been employed to establish potential outcomes for these plastic wastes. PET, PS and HDPE polymers were the most occurring plastic types in the waste stream. These wastes can offer local communities' opportunities to uplift their financial burdens while providing a cleaner environment. This ideology will strengthen the idea of a circular economy.

The aims and objectives of this study have been fulfilled. The aims of the study were:

1. To understand the quantity and character of solid waste within the specified Umhlangane catchment.

   This aim was fulfilled in Chapter 5, in which fieldwork to establish waste streams and the amounts of waste entering the river system were carried out. It was found that plastics were the dominant waste stream in the water body. Furthermore, it was identified that PET, HDPE and PS were the most occurring plastic grades found in the system.

2. To determine the hotspots for waste entry into the specified Umgeni catchment.

   To determine waste entry into the river system was extensively done in Chapter 4; GIS techniques and methodology were employed to map out possible hotspots for waste entry. It concluded that roads, land-use zones, stormwater drainage and human settlements play significant roles in determining the amounts of waste in a water body. The closeness of these factors to the river will further increase the probability of waste entering the system if no waste management strategies exist.

3. To determine the effect of climate change on waste.

   To addresses this aim, Chapter 2 literature review highlighted various literature which referred to the impacts of climate change on the environment. Furthermore, Chapter 5 mapped out the river floodplain and the extent to which it will affect surrounding areas due to intense rainfall and flooding. This map enables the reader to get a broad idea of zones that will be affected, and subsequently, should no waste management strategies be employed in these regions, unattended wastes will be carried into the ocean during these climate change events. Chapter 5 also reviewed the relationship between rainfall events and the quantity of PET waste. It concluded that a weak correlation existed. The correlation may have been weak as a result of inefficiencies at the litterbooms during rainfall events.

4. To determine possible avenues for the use of the plastic waste collected at the litter booms.

   This aim was addressed in Chapter 5 utilising the WROSE scenarios. It emphasised including community engagement in all the scenarios, as the community should play a vital role in helping clean the river system and maintain it long-term.

This research also identified system flaws of the litterbooms and in the waste management strategy implemented. It provided a comprehensive literature review to provide a background to concepts discussed.

6.2. Suggestions for future research

This research primarily focused on macro-litter/macro-plastics – in riverine environments in eThekwini. However, there is much need for research into micro-plastics and their quantity in the Umgeni catchment. There are also other coastal cities in South Africa where high densities of waste are improperly managed, namely, East London and Port Elizabeth (Ryan, 2018). It is crucial to identify point sources of waste while utilising a finer scale sampling. Another approach is collecting both macro- and micro- waste samples to establish correlations between them and their concentration comparison upstream vs downstream in a river catchment. The concept of freshwater plastic pollution is a vast topic with multiple branches that require research, particularly in the African context.

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APPENDIX 1

Mann-Whitney Test

Ranks

	Site	N	Mean Rank	Sum of Ranks
Quantity	1.00	7	10.57	74.00
	2.00	7	4.43	31.00
	Total	14		

Test Statistics[a]

	Quantity
Mann-Whitney U	3.000
Wilcoxon W	31.000
Z	-2.750
Asymp. Sig. (2-tailed)	.006
Exact Sig. [2*(1-tailed Sig.)]	.004[b]

a. Grouping Variable: Site

b. Not corrected for ties.

Kendall's tau b Test

Correlations

			Mass_Kg	Rainfall_mm
Kendall's tau_b	Mass_Kg	Correlation Coefficient	1.000	.303*
		Sig. (2-tailed)	.	.020
		N	34	34
	Rainfall_mm	Correlation Coefficient	.303*	1.000
		Sig. (2-tailed)	.020	.
		N	34	34

*. Correlation is significant at the 0.05 level (2-tailed).