WHAT ARE THE SOURCES, NEGATIVE IMPACTS AND MITIGATION MEASURES REGARDING MICROPLASTIC POLLUTION?
A CASE STUDY OF THE DURBAN HARBOUR

Princess Mbalenhle Ngcobo

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ABSTRACT

This study aims to present mitigation measures to the problem of microplastic pollution in the Durban Harbour. Before proposing measures to mitigate microplastic pollution in the Durban Harbour, the report will first assess the sources of microplastics and their environmental effects on the study site. The growing population has been accompanied by an increase in plastic waste in the environment. Poor waste management systems, especially in developing countries, have resulted in microplastic pollution in water systems. As a result, high levels of microplastics have been reported in South African water bodies. The high concentration of microplastics in the environment can pose adverse effects on biota, including humans.

This study followed a qualitative research approach and made use of a single case study research strategy as part of the research methods. Five interviews were conducted with microplastic experts, including those researching microplastics in the Durban Harbour. The interviewees were selected through purposive sampling. The study findings suggest that the Durban Harbour received microplastics from different sources, including the three rivers (such as uMbilo, uMhlatuzana and aManzimyama rivers) and harbour activities (such as fishing, cargo spillage and recreational activities). As a result, everyone has a role to play in addressing the issue of microplastics in the Durban Harbour. This study affirms the need for collaboration between experts from different disciplines, the government, industries and communities. Urban Managers can employ the GET matrix (which stands for Governance, Education and Technology) to effectively address pollution in the harbour.

DECLARATION

I, Princess Mbalenhle Ngcobo, declare that this Research Report is my own unaided work being submitted for the degree of Master of Urban Studies in Urban Management at the University of Witwatersrand, Johannesburg, South Africa. I have not previously in its entirety or in part, submitted it at any university for a degree.

Signed:

09 January 2023

DEDICATION

My God, my strength and provider.

ACKNOWLEDGEMENTS

I thank God's grace and wisdom for enrolment in Master of Urban Studies in Urban Management. My appreciation goes to my family for their ongoing support throughout my studies. I thank Mr Nelson Machipisa, for his unending support and cheerfulness, without even knowing me. Most of all, the guidance, patience and support I received from my supervisor, Dr. Brian Boshoff.

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LIST OF ACRONYMS AND ABBREVIATIONS

CBD	Central Business District
CSR	Corporate Social Responsibility
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EPR	Extended Producer Responsibility
EU	European Union
KWWTW	Kwamashu Wastewater Treatment Works
MSW	Municipal Solid Waste
NGOs	Non-Government Organisation
NWWTW	Northern Wastewater Treatment Works
NWA	National Water Act (No. 36 of 1998)
NWRS	National Water Resource Strategy
MWI	Mismanaged Waste Index
POP	Persistent Organic Pollutants
PCCPs	Personal Care and Cosmetic Products
UKZN	University of KwaZulu-Natal
UV	Ultraviolent
UWWTW	uMhlatuzana Wastewater Treatment Works
US	United States
WHO	World Health Organization

WRC	Water Research Commission
WWTWs	Wastewater Treatment Works

UNITS

cm	Centimetre
km	Kilometre
L	Litre
m	Metre
mm	Millimetre
<	Less than
>	Greater than
µm	Micrometre

CHAPTER 1: INTRODUCTION

Introduction

Increasing microplastic concentrations and their impacts have become a global concern in the marine and terrestrial environments (Karbalaei, Hanachi, Walker and Cole, 2018; Sharma *et al*., 2020; Wang *et al*., 2020; Zhang *et al*., 2020). However, in recent times researchers have started to explore the spread, accumulation and environmental effects of microplastics (Thompson *et al*., 2004; Thompson, 2015). Numerous studies on microplastic pollution have been conducted in the marine environment, but microplastic pollution in harbours have received little attention (Naidoo, Glassom and Smit, 2015; Nel, Hean, Noundo and Froneman 2017).

In South Africa, microplastics have been found in harbours, coastal zones, beach sediments, freshwater, different marine species and other biotas (Preston-Whyte, Silburn, Meakins, Bakir, Paruk, Mdazuka, Mooi, Harmer and Doran, 2021). Preston-Whyte *et al*. (2021) concluded that there is high microplastic pollution in the Durban Harbour, located within Durban Bay Estuary in KwaZulu Natal (KZN), because it is surrounded by a number of human activities. Harbours act as a source of microplastic pollution for the neighbouring marine environment (Naidoo *et al*., 2015; Preston-Whyte *et al*., 2021). This study intends to present mitigation measures that urban managers and experts can introduce in addressing the problem of microplastics in the Durban Harbour through a review of microplastics' sources and environmental effects. The first section of the introductory chapter looks at the background, problem statement and rationale, and objectives of the study. The second section discusses the main research question and sub-questions, expected findings and the methods used in the study.

Background

Global plastic production and use have been rapidly growing since the 1950s (Karbalaei, Hanachi, Walker and Cole, 2018; Zhang *et al*., 2020). Plastics are part of our everyday life, from water bottles to airplanes and spaceships, because of their durability, low cost, lightweight, and versatility (Karbalaei *et al*., 2018; Sharma *et al*., 2020; Zhang *et al*., 2020).

Unfortunately, this high production and use of plastic products have been accompanied by a large number of plastic waste (Karbalaei *et al*., 2018; Zhang *et al*., 2020). Global plastic waste is expected to reach 270 million tonnes (tons) by 2060, raising a lot of environmental concerns (Zhang *et al*., 2020). When plastics enter the environment, they continuously break down into small particles and fragments known as microplastics (Karbalaei *et al*., 2018). The term microplastic was first introduced by Thompson in 2004, referring to very small plastic particles and fibres with sizes less than 5 mm (figure 1) (Karbalaei *et al*., 2018; Zhang *et al*., 2020).

Microplastics of different types have been found in the environment, not only in the marine soils, air, harbours, ground and drinking water, but also in foods, such as sugar, sea salt milk, beer, and honey (Sharma *et al*., 2020; Wang *et al*., 2020). Recently, the COVID-19 pandemic is leading to a rise in disposable masks (made of polymers) that ends up in waste, which contributes to environmental pollution as they can release microplastics into the environment. (Sharma *et al*., 2020). As a result, many regions like the United Kingdom and the Netherlands have introduced legislation that bans the production and use of microplastics, including microbeads (Karbalaei *et al*., 2018).

Figure 1: Microplastics. This photo displays microplastics in their different categories, types and sizes. Microplastics can be seen by the naked eye and some microplastics are so tiny that they can only be seen under a microscope (Abreu and Pedrotti, 2019).

The persistence of microplastics in the terrestrial and aquatic environment is of increasing concern in South Africa (Preston-Whyte *et al.,* 2021). The Durban Harbour receives water from different inputs from upstream (see figure 2) (*ibid*.). Water entering the harbour comes from the uMbilo, uMhlatuzana and aManzimyama rivers, canals and stormwater drains from the surrounding industries and the Durban Central Business District (CBD) (Preston-Whyte *et al*., 2021). As a result, a high amount of microplastics has been reported in the Durban Harbour (Naidoo *et al*., 2015; Preston-Whyte *et al*., 2021). For example, in 2020, Preston-Whyte *et al*. (2021) conducted research on the Durban Harbour, where they sampled surface waters and sediments from selected sites within the harbour and discovered a high microplastic concentration (Preston-Whyte *et al*., 2021).

Furthermore, Naidoo *et al*. (2020) discovered that juvenile fish within the Port of Durban consume a considerable amount of microplastics. Even though the negative impacts of microplastics on the environment are still being researched, existing evidence shows that there is scope for significant harm to the marine environment. Ingestion of microplastics by aquatic organisms such as fish, crabs, oysters, mussels, and seabirds can cause behavioural fluctuations, physical impairment and can affect their growth (Sharma *et al*., 2020). Microplastics can be transferred to humans through the food web, which poses inevitable human health such as reproductive abnormalities, cancer and can affect brain function (Karbalaei *et al*., 2018; Zhang *et al*., 2020). Thus, urban managers should adopt a holistic approach to address microplastics at their source.

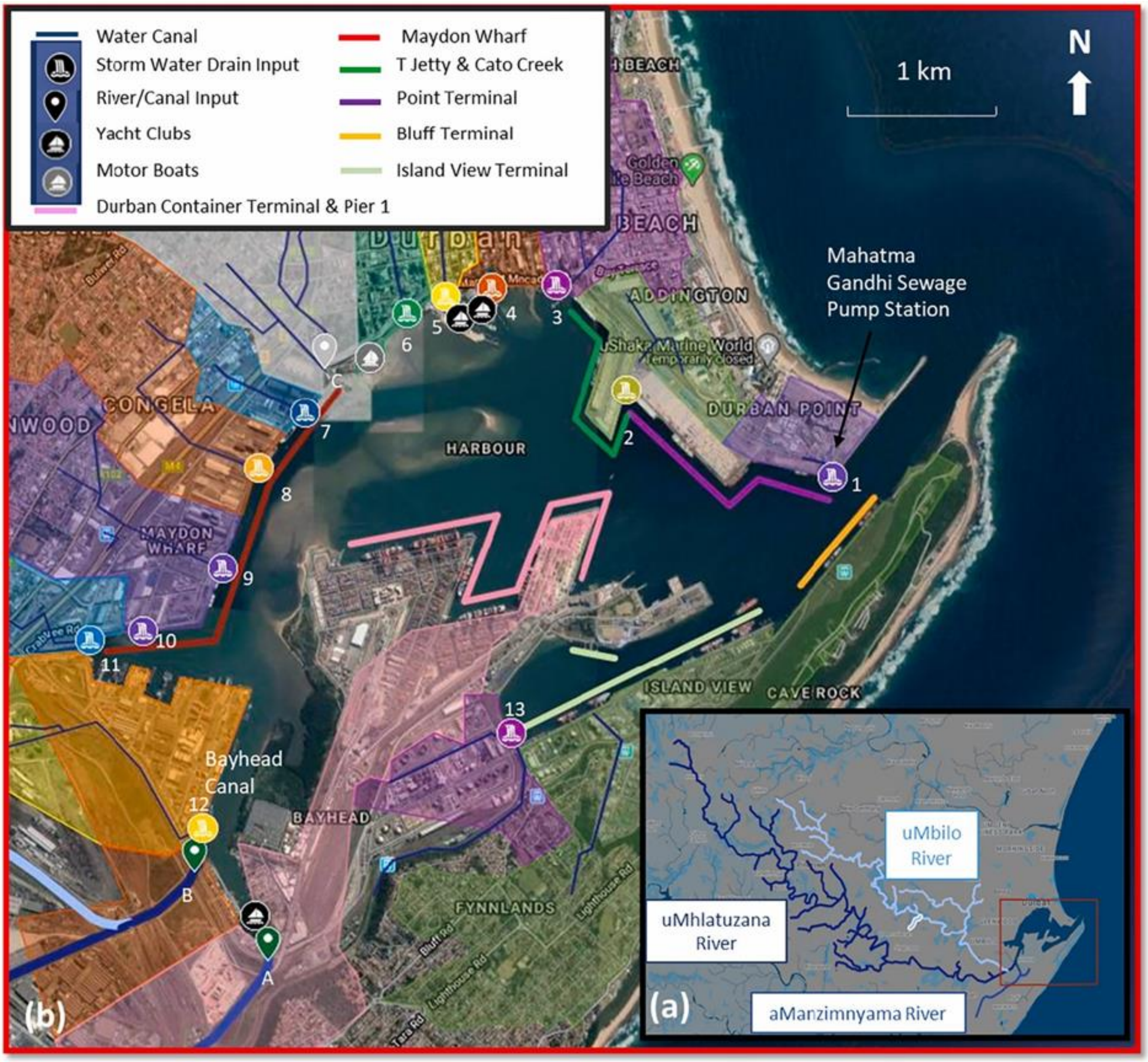

Figure 2: Sources of microplastics in the Durban Harbour. This diagram shows the Durban Harbour catchment and the three rivers entering the harbour (a). The numbers represent stormwater drains and the alphabet represents rivers (b). Source: Preston-Whyte *et al*. (2021)

Problem Statement and Rationale

Microplastics are pollutants and can be harmful to the Durban Harbour environment (Picó and Barceló, 2019). The issue with microplastics is that they do not easily degrade into harmless particles (Sharma *et al*., 2020). Microplastics are a problem in the Durban Harbour because high concentrations of microplastics have been reported and microplastics have been found in aquatic animals such as juvenile fish (Naidoo *et al*., 2020; Preston-Whyte *et al*., 2021). As stated in the previous paragraph, this poses health effects on these aquatic animals (Sharma *et al*., 2020). The problem is further complicated by the fact that microplastics in water can attach to chemicals that are harmful to marine life before they are ingested (Amelia, Khalik, Ong, Shao, Pan and Bhubalan, 2021). It is important that we start dealing with these issues before they get worse as more and more microplastics enter the harbour. In addition, microplastics are a big problem because they have been reported in seafood and can potentially harm human health. There are many studies documenting the effects of microplastics in the marine environment, but few studies explore microplastics in harbours (Preston-Whyte *et al.,* 2021). Likewise, limited studies have explored the problem of microplastics in the Durban Harbour. As a result, we have gaps in knowledge, especially about microplastic impacts in the Durban Harbour.

The study of microplastics in the Durban Harbour recently emerged, and that applies to South Africa as a whole. Other countries, especially first world countries, have more information and understanding of microplastics in the environment. Thus, they have introduced regulations and policies to deal with microplastics (Nikiema and Asiedu, 2022). Microplastics have been included in the existing international regulations, including the Basel Convention and United Nations Environment Assembly (UNEA) Resolutions to combat the spread of microplastics in the environment (Wang *et al*., 2018; Lamichhane *et al*., 2022 and Nikiema and Asiedu, 2022). Coupled with that, countries like the Netherlands, United States (US), Sweden, Australia, New Zealand, Italy Canada, have banned the use of microbeads in Personal Care and Cosmetic Products (PCCPs) (Wang *et al*., 2018; Picó and Barceló, 2019; Lamichhane *et al*., 2022 and Nikiema and Asiedu, 2022).

However, these international regulations and national policies are not satisfactory because there is no specific international legislation that focuses only on microplastics (Wang *et al*., 2018). Onyena, Aniche, Ogbolu, Rakib, Uddin and Walker (2021) argued that global efforts to tackle the issue of microplastics are limited to weak and fragmented acts. Also, the national policies only focus on primary microplastics, particularly microbeads (Wang *et al*., 2018). This means they are targeting one source of microplastics which is PCCPs (*ibid*.). For South Africa, regulations and policies to dealing with microplastics, are yet to be introduced. As a result, there is a need for legislation, regulations, and policies to deal with all categories and types of microplastics from international legislation and regional and national policies.

Objectives of the Study

The available data reveals that there is a considerable amount of microplastics in the terrestrial and aquatic environment, including harbours in South Africa (Naidoo *et al*., 2015; Bouwman *et al*., 2018; Preston-Whyte *et al*., 2021). This research aims to evaluate the presence of microplastics in the Durban Harbour, and the primary objectives of this research are:

- To review and analyse the existing literature on microplastic pollution in the Durban Harbour.

- To look at the presence and different sources of microplastics in the Durban Harbour.

- To review the impact of microplastics on the environment.

- To examine mitigatory measures to microplastic pollution, specifically for the Durban Harbour.

Main Research Question

Broadly, this research attempts to answer the following question: What are the sources, negative impacts and mitigation measures regarding microplastic pollution?. This question is broken down into three different sub-questions, which include:

1. What is the source of microplastics in the Durban Harbour?

2. What are the impacts of microplastics on the environment?

3. How can urban managers address the issue of microplastics entering the Durban Harbour?

Expected Findings

Globally, harbours have been reported to have a high amount of microplastics due to human activities. The Durban Harbour is surrounded by different human activities, which are potential sources of microplastics. One might find that the major source of microplastics comes from the three rivers entering the Durban Harbour. This could be because these rivers are surrounded by densely populated areas. Also, many people are unaware of microplastics and their environmental impact. As a result, littering is not seen as a problem. Furthermore, high levels of microplastics in the harbour might have a negative impact on the fishery industry because microplastics can cause negative effects on marine species like mortality. We can also expect microplastics to pose a negative impacts on human health, especially after eating microplastic-contaminated seafood. As a result of these potential negative impacts, this calls for urban managers to work together with experts of different disciplines to address microplastic pollution in the Durban Harbour.

Methods

In undertaking this research, I followed a qualitative research approach. The research utilised a single case study research strategy to have an in-depth understanding of the sources of microplastics within the Durban Harbour. The case study took a descriptive form. In addition, I made use of relevant published and unpublished sources, including grey literature. As part of the research methods, five interviews were conducted with microplastic experts, including those who have done research on microplastics in the Durban Harbour. Table 1 below shows the profile of the interviewees with regard to their profession and institution. The objectives of the interviews were to get detailed information and an understanding of microplastic pollution in the Durban Harbour and derive solutions from the interview findings.

Table 1: Profile of the interviewees. This table presents the profile of the microplastic experts Interviewed. Its highlights their profession and the institution or organisation they work in.

Interviewees	Profession	Institution/workplace
Microplastics experts 1	Researcher	Centre for Environment, Fisheries and Aquaculture Science (CEFAS) Lowestoft, United Kingdom
Microplastics experts 2	Professor in Zoology focusing on ecotoxicology applied to various biological systems	Northwest University, South Africa
Microplastics experts 3	Senior Lecturer in the School of Life Sciences	University of KwaZulu-Natal, South Africa
Microplastics experts 4	Researcher and postgraduate in Biological Science	University of KwaZulu-Natal, South Africa
Microplastics experts 5	Postdoctoral researcher in the School of Health Sciences and also a Founder and managing director of a Non-Profit Organization	University of KwaZulu-Natal, South Africa

The interviewees were selected through purposive sampling. Tongco (2007) justifies the use of purposive sampling because it is a form of nonprobability sampling that is most effective when studying a domain with knowledgeable experts. The population of microplastic experts in South Africa is very small and difficult to access, especially those who have done research on the Durban Harbour, as a result, snowball sampling was also utilised. I created an interview guide for the interviewees, but I did not follow it strictly during the interviews as new issues emerged while engaging with the interviewees. Moreover, I made three visits between August and December 2021 to the Durban Harbour, where I took a transect walk across the harbour. My first visit was on Thursday, the 19th of August 2021. My second visit was on Thursday, the 18th of November 2021.

My last visit was on Friday, the 17th of December 2021. All my visits were in the morning because taxies going around the Durban Harbour were available in the morning.

My analysis of the information began during the interviews and fieldwork in the Durban Harbour. It continued with the transcription of interviews, editing and review of my fieldwork. This follows the argument that analysis in a case study strategy starts during data collection and runs through multiple stages in the research process (Creswell, 2009). I used a thematic approach to analyse the data because it is good for describing information. Thematic analysis is a technique for examining "qualitative data that involves identifying, analysing, and reporting repeated patterns within a data set" (Kiger and Varpio, 2020:2).

Ethical Considerations

The study followed the research policies and ethical procedures of the University of the Witwatersrand. As part of this, it ensured that research was conducted in an ethical manner. Before the commencement of the study, I applied for formal ethical clearance from the university and was granted permission to continue with my research and conduct interviews (Appendix 1). Participants agreed to be part of the study and signed the consent forms (Appendix 1). As I stated in the participant information sheet, confidentiality was guaranteed as the information shared by the participants was held securely and not disclosed to anyone else. Participants were aware that I could not fully guarantee anonymity because they may be identifiable due to their expertise or their position in an institution, but I anonymised their names. Before starting the interviews, I briefly explained the aims and objectives of the research to all participants. All Interviews were conducted in English, a language that all participants understand. I recorded each interview with the participants' consent and permission. I recorded the interviews with the aid of an audio recording device. In cases where consent to record was not given, I took notes of all the points raised by the interviewee in a shorthand notebook.

Limitations of the Research

Due to the one-year duration of the taught master's programme, the scope of this research is limited to what could be accomplished in the six months of study. When conducting my research, I was faced with a few challenges. Firstly. I wanted to interview microplastics experts, Durban Harbour officials and the eThekwini municipality officials, but I only managed to interview microplastics experts. I tried to get Durban Harbour officials and the municipality officials but was unsuccessful. I was transferred from one person to the other without securing an interview with anyone. Consequently, the study could have had more in-depth analyses, findings and recommendations. Although I managed to get hold of some microplastic experts, it was very difficult to interview a variety of microplastic experts, because microplastic pollution is a new area of study in South Africa. Secondly, although I have made every effort to ensure that the varied literature compiled and analysed for this research is factual and from reliable sources, it is difficult to determine how accurate some information used may be. Thirdly, it also took a lot of work to find information that focuses on the social, economic and environmental impacts of microplastics. Lastly, it was challenging to compare different findings on the level of microplastics in different harbours across Africa, because there is no standardised method for measuring microplastics in the environment.

Conclusion

The use of microplastics has grown exponentially over the years. Coupled with that, microplastic research has increased in the past few years. However, the is still a need for more research on this subject. The aim of the study is to introduce solutions to address microplastic pollution in Durban Harbour. It is important that we get a better understanding of microplastic pollution in the Durban Harbour. Understanding the sources of microplastics and the effectiveness of existing measures to microplastics will lead to appropriate solutions that urban managers can implement in the Durban Harbour.

CHAPTER 2: LITERATURE REVIEW

Introduction

Microplastics are an emerging pollutant in the environment. Their impacts on the environment, especially human impacts, are yet to be discovered (Montoya, 2015). The is a need for more research on microplastic pollution. This literature review explores in more detail the different sources of microplastics and their impacts on the Durban Harbour. The first section looks at the conceptual framework used in the study. The second section explores the different sources of microplastics in the Durban Harbour. The different sources are categorised into land-based sources and sea-based sources. The third section discusses the factors that influence the number of microplastics in water bodies. The fourth section examines the negative impacts of microplastics on the environment. The fifth section outlines the effectiveness of existing solutions to microplastics. The last two sections look at waste management and microplastic research understanding internationally, in Africa and the Durban Harbour

Nowadays, plastic is part of our everyday life. Plastic is used in packaging, householder, personal cleaning product, cosmetics, construction, agricultural activities, and even clothing and footwear (Karami, Golieskardi, Ho, Larat and Salamatinia, 2017). Plastic production worldwide was projected "to reach 322 million metric tons by 2015" (Karami *et al*., 2017:1). Undoubtedly, plastics dumped in the environment never degrade completely but continuously break down into smaller particles known as microplastics (*ibid*.). Microplastic particles are a relatively new area of concern, and there is no consensus on which sampling and analysis techniques should be used (Lassen *et al*., 2012; Chen *et al*., 2020).

There are many different techniques that are used to quantify and analyse microplastics in the environment, hence it becomes difficult to compare the levels of microplastics in different areas or harbours and within the same area or harbour (Lassen *et al*., 2012; Karlsson, Kärrman, Rotander and Hassellöv, 2020). As a result, researchers need to agree on which methods should be used for measuring and monitoring microplastics in the environment worldwide. All the different methods have their shortfalls when it comes to accurately measuring microplastics, for instance, most studies that have been done in the marine environment use manta trawls (figure 3) for sampling. Manta trawls is a net system with "a rectangular aperture that is 16 cm high and 61 cm wide and has a 3 m long 335 mm net with a 30 10 cm2 cod end" (Eriksen, Liboiron, Kiessling, Charron, Alling, Lebreton, Richards, Roth, Ory, Hidalgo-Ruz and Meerhoff, 2018:2). A manta trawl is designed to collect particles ≥333 μm in the top ten centimetres of the water column, this means that microplastics that are smaller than 333 μm will be left out (Lassen *et al*., 2012). This limitation is concerning because research has shown that particles smaller than 333 μm have negative impacts on marine biota (*ibid*.).

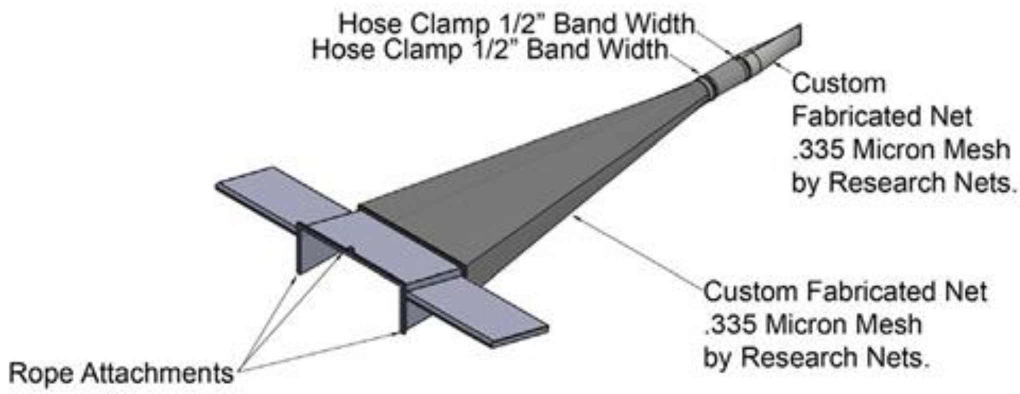

Figure 3: Manta trawl and its different parts. This is one of the different tools used to collect and sample microplastics in water. Source: Eriksen *et al*. (2018)

Conceptual Framework

I developed a conceptual framework for this study (figure 4), drawing on the key literature reviewed. This research aims to present solutions to the problem of microplastics in the Durban Harbour, and the conceptual framework is structured around the cause and effects concepts. Following the structure of the conceptual framework, the research will first look at microplastic sources in the Durban Harbour, which include land-based sources and sea-based sources. In addition to these sources, there are factors that influence the level of microplastics and the environment. These factors include population density or human activities and seasonality. The existence of microplastics in the environment can have a social, economic, and environmental impact. The environmental effects are broken down into two aspects: impact on marine species and human health. Furthermore, the mitigatory measures for microplastics depend on the microplastic sources in the Durban Harbour. Urban managers can utilize a decision-supporting tool known as the GET matrix, which stands for Governance, Education and Technology.

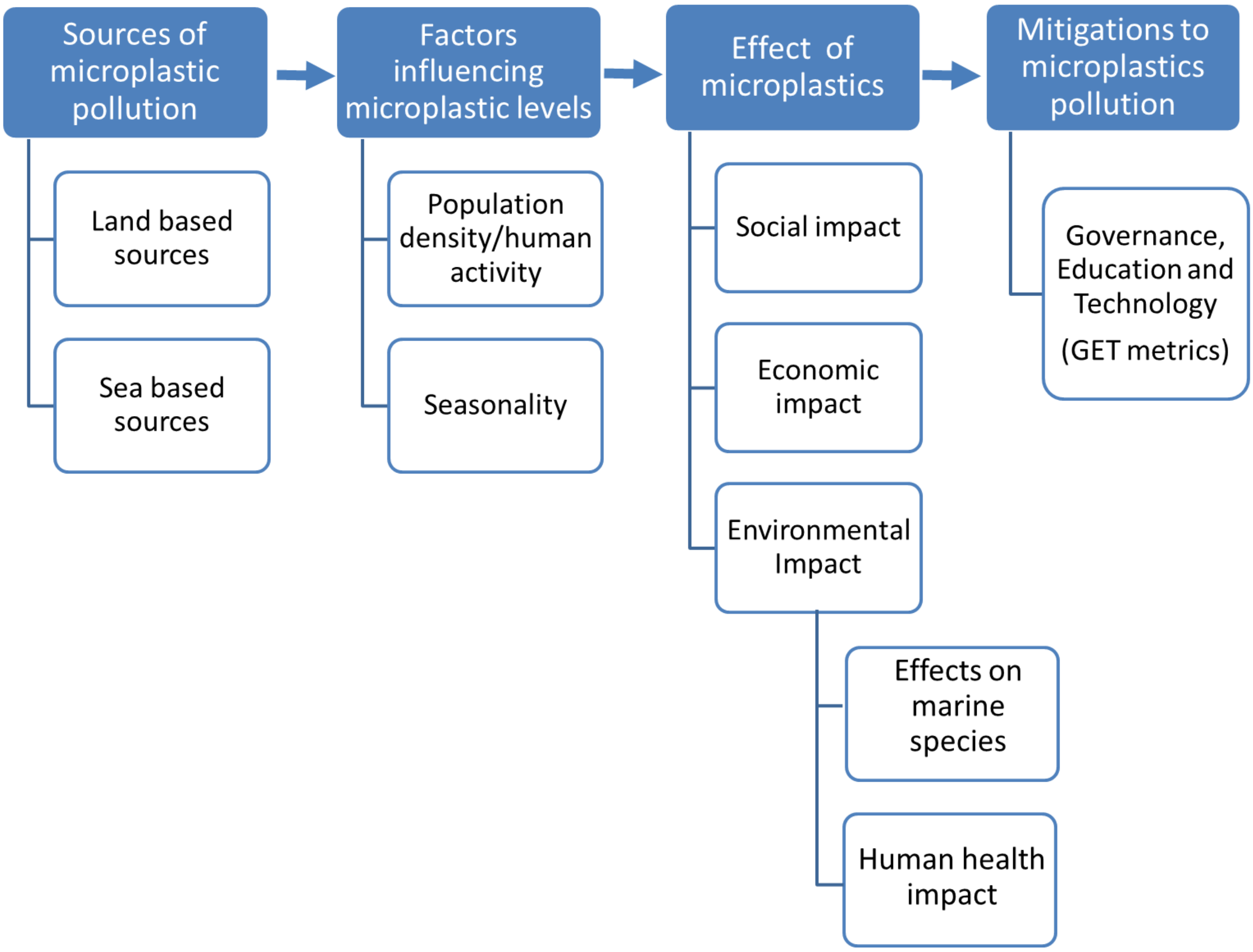

Figure 4: Conceptual framework for this study. It is drawn from the literature review in this chapter. Source: Ngcobo (2021)

Different Categories of Microplastics

Primary Microplastics

Microplastics are released into the environment in two different categories, including primary microplastics and secondary microplastics (Montoya, 2015; Boucher and Friot, 2017; Ha and Yeo, 2018). Primary microplastics refer to plastic particles that are purposefully produced to be less than 5 mm for a specific purpose, such as adding them to scrubbing agents and rinse-off cosmetics (figure 5) (Lassen *et al.*, 2012; Montoya, 2015; Ha and Yeo, 2018). Some microplastics are produced by the abrasion of large plastic objects, such as the erosion of the tyres of a car or the abrasion of synthetic fabrics when washing them (Montoya, 2015).

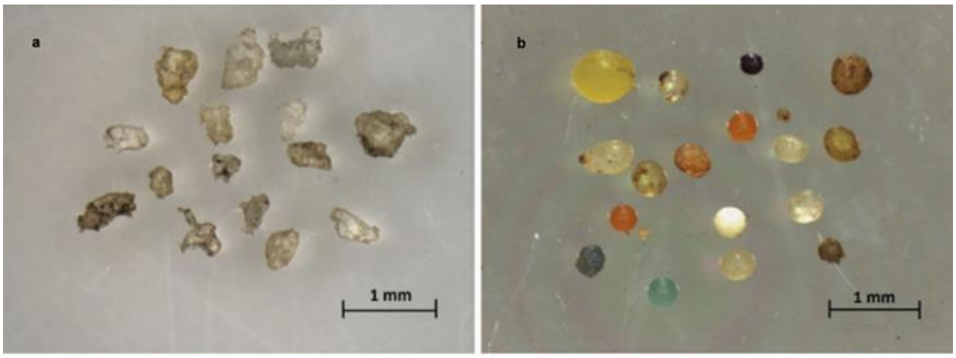

Figure 5: Primary microplastics. These microplastics are produced as tiny beads, known as microbeads and pallets. Source: Koyuncuoğlu and Erden (2021)

Secondary Microplastics

Secondary microplastics refer to plastic particles that originate from the breakdown of larger plastics to a size of less than 5 mm after being exposed to environmental processes (figure 6) (Lassen *et al.*, 2012; Boucher and Friot, 2017; Ha and Yeo, 2018). Within these categories, there are different types of microplastics, including films, foams, pallets, nurdles, microbeads, fragments, filaments, sheets and microfibres, as shown in figure 7 below (Sartain, Wessel and Sparks, 2018). Microfibres are plastic-based threads that are thinner than human hair (Byrne, 2018). Certain products shed microfibres during their lifetime, for example, they wash out of our synthetic clothes. Most of these tiny fibres are derived from polyester and other common microfibres, including nylon and acrylic (*ibid*.). They are present in our carpets, curtains, and other household textiles, as well as our clothes (*ibid*.).

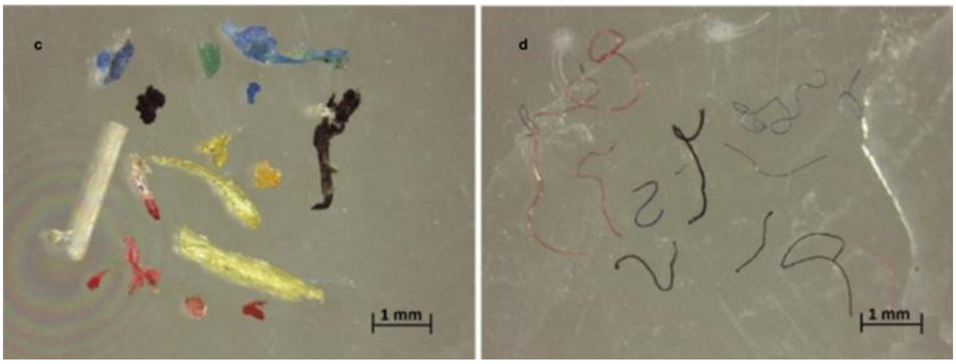

Figure 6: Secondary microplastics. These microplastics break down from plastics due to weathering processes. Source: Koyuncuoğlu and Erden (2021)

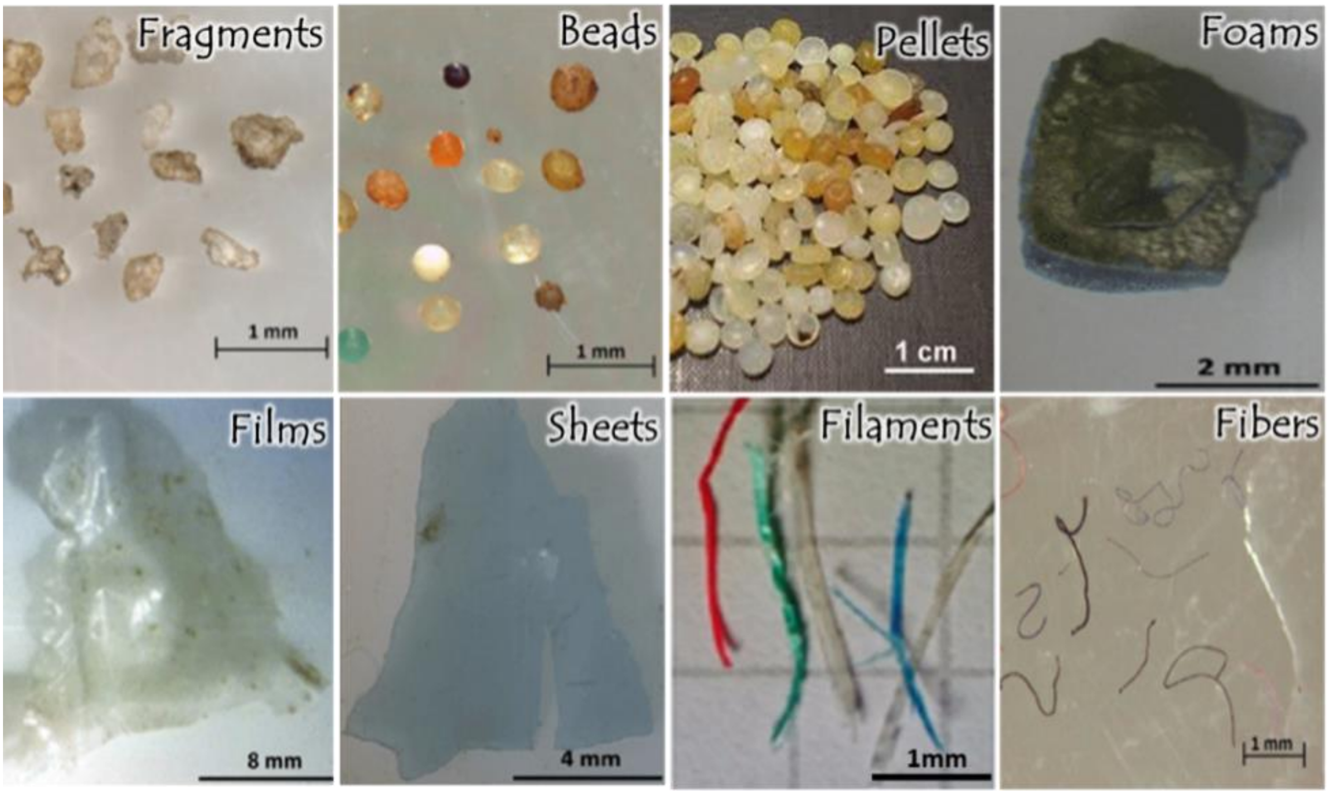

Figure 7: Different types and shapes of microplastics. There are many different types of microplastics, from fragments to fibres. Beads (also known as microbeads) and pallets are categorised as primary microplastics. Fragments, foams, films, sheets, filaments and fibres are categorised as secondary microplastics. Source: Koyuncuoğlu and Erden (2021)

Sources of Microplastics

There are various sources of microplastics in harbours and the marine environment, from land-based to ocean-based sources, as shown in figure 8. Land-based sources are the primary sources of microplastics, including handling during production and maintenance of plastic, medical application, landfill site, abrasion and erosion of synthetic rubber tyres, domestic wasting and indoor particulate emission, personal care product and wastewater treatment plant (Karbalaeiet *et al*., 2018). Ocean-based sources include fishing, Spillages of cargo and recreational activities (ibid.).

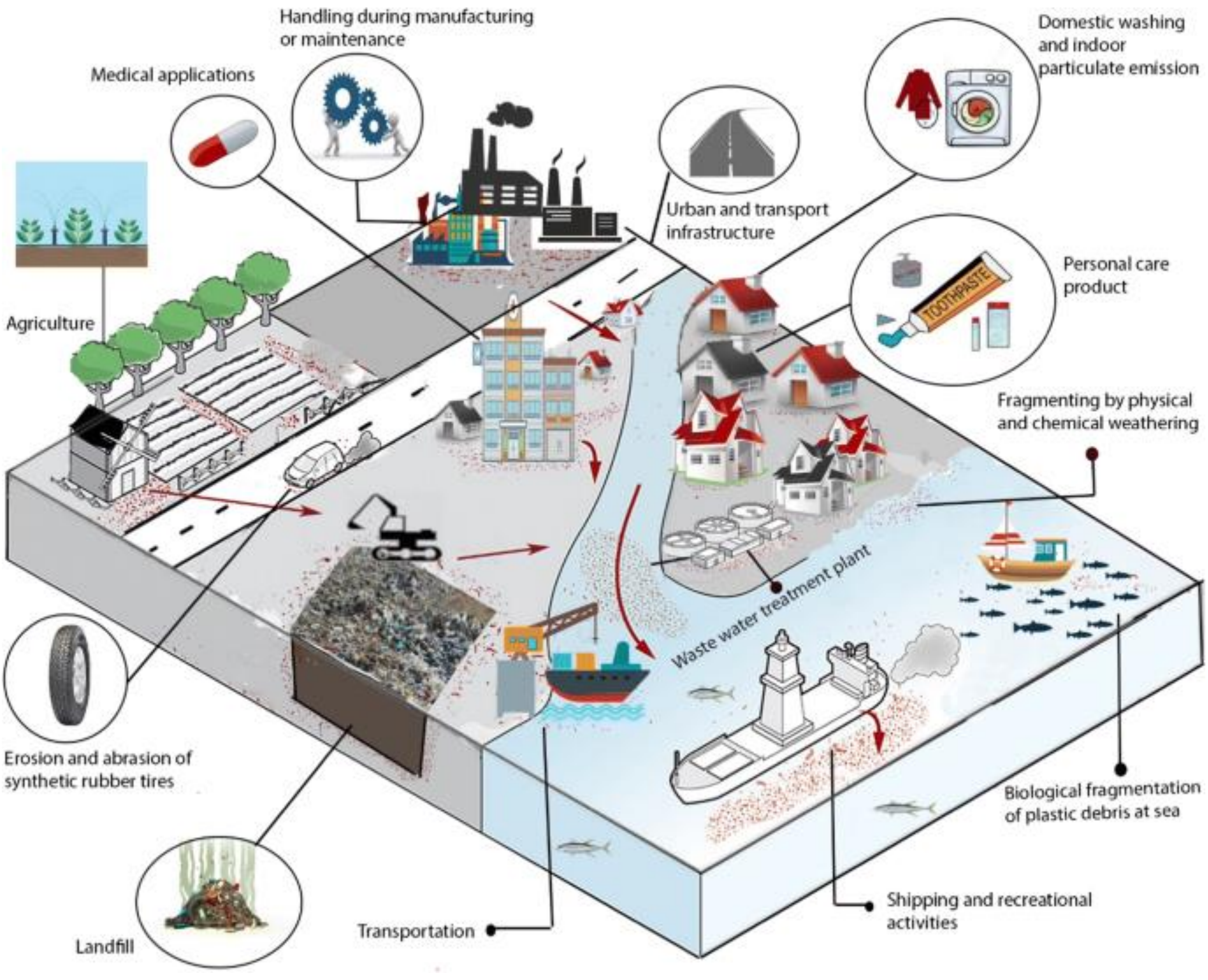

Figure 8: The different sources of microplastics in water bodies include land-based and ocean-based sources. This diagram shows that many sources of microplastics originate

from the land, including medical applications, agricultural activities, commercial use and transport infrastructure. Source: Karbalaei *et al*. (2018).

Land-based Sources

Wastewater Treatment Plants

Wastewater Treatment Plants (WWTPs) fail to remove large quantities of microplastics and contribute significantly to the abundance of microplastics in the environment (Murphy, Ewins, Carbonnier and Quinn, 2016; Nel, Hean, Noundou and Froneman, 2017). In most cases, secondary and tertiary treatment plants can remove 94% of microplastics, while primary treatment plants can only remove 65% (Burns and Boxall, 2018). As a result, WWTPs are regarded as one of the most dominant point sources of microplastics in the aquatic environment (Karbalaei *et al*., 2018). Most studies reported that the most dominant source of microplastics in WWTPs is domestic washing (microfibres) and the use of personal care and cosmetic products (PCCPs) (*ibid*.). Without a doubt, synthetic clothing releases a large number of microplastics, especially during washing (de Villiers, 2019). The other sources of microfibres include the degradation of cellulose acetate in cigarette butts and the breakdown of fishing equipment such as nets and ropes (de Villiers, 2019). Furthermore, many PCCPs, especially rinse-off products containing microplastics end up in wastewater streams where they are not removed thoroughly and then released via treated wastewater effluents into rivers and ultimately reach the ocean (Leslie, 2014; Guerranti, Martellini, Perra, Scopetani and Cincinelli, 2019).

Hao *et al*. (2019), Wang *et al*. (2019) and Zhang and Chen, (2020) carried out studies and discovered that WWTPs can remove and block large amounts of microplastics during the first treatment steps. Nonetheless, Murphy *et al*. (2016) stated that although sewage treatment plants could catch or remove more than 90% of microplastics, there would still be a lot of microplastics. For example, Murphy *et al*. (2016:5803) sampled a secondary WWTW in Glasgow and found that the WWTW could release an estimated 65 238 500 microplastic per day into the final effluent despite its high removal rate. The situation could be worse in South Africa because the state of WWTPs has deteriorated in such a way that around 40% of the nation's effluent is left untreated (Verster and Bouwman, 2020).

Personal Care and Cosmetic Products

In recent years, there has been a growing interest in the presence of microplastics in Personal care cosmetic products (PCCPs), which contribute to microplastic pollution all around the world (Lassen *et al*., 2012; Leslie, 2014; Burns and Boxall, 2018). A wider variety of plastic ingredients are used by personal care and cosmetic industries in their products, such as deodorant, moisturizers, toothpaste (as shown in figure 9), shampoo, wrinkled cream, soap, nail decorations, facial masks, shaving cream, makeup (such as eye shadow and lipstick), sunscreen and children's bubble bath (Lassen *et al*., 2012; Leslie, 2014; Guerranti *et al*., 2019).

Personal care cosmetic products with microbeads may contain a very high amount of plastic particles. For example, the United States of America (US) conducted a study in 2013 on microplastics in facial scrub tubes and recorded approximately 350,000 microplastics (Lassen *et al*., 2012). In addition, a study conducted in Dutch recorded an average of 6,400 plastic particles per gram of toothpaste (*ibid*.). Microbeads are one of the dominant microplastics found in PCCPs (Guerranti *et al*., 2019). For example, research conducted in Beijing, China, discovered high levels of microplastics in facial cleansers and shower gel products (Lei, Qiao, Liu, Wei, Qi, Cui, Yue, Deng, and An, 2017). Based on the PCCPs used in China, it is estimated that 39 tonnes of microplastics were released into the environment (Lei *et al*., 2017). This highlights the need to understand the characteristics of these plastic ingredients, their function, and their environmental effects (Leslie, 2014).

Figure 9: Microplastics in toothpaste. This image shows microplastics (microbeads) in toothpaste (tiny particles in light blue). Source: Barrett (2019)

Moreover, plastics can easily be collected for recycling, unlike microplastics such as those found in PCCPs, which are impossible to collect (Leslie, 2014). As a result, urban managers should introduce upstream regulations and encourage consumers to buy PCCPs that do not have microplastics to reduce their emissions into harbours. Some countries, like the United States, introduced a Microbead-Free Waters Act of 2015 to prohibit the use of microbeads in rinse-off products (Guerranti *et al.*, 2019).

Agriculture

Agricultural activities can be considered as one of the sources of microplastic pollution in water bodies. However, research on microplastics in agriculture has largely been overlooked (Pukclai, 2020). Overall, research on microplastic pollution in agricultural soils is still emerging, and there are many knowledge gaps in this research area (Kumar *et al.*, 2020). Recently, scientists have uncovered that agricultural soils could actually hold more microplastics than the ocean basin (Pukclai, 2020). According to Pukclai (2020), agricultural lands are likely to be the most plastic-contaminated places, besides landfill and urban spaces.

Furthermore, one of the sources of microplastics in agricultural activities is the degradation of agricultural plastic products such as those used for plastic mulching (figure 10) (Horton, 2017). The use of sewage sludge in agricultural land as a fertiliser is also one of the sources of microplastics in agriculture (Horton, 2017; Karbalaei *et al*., 2018). "Sewage sludge is the by-product or residue resulting from the treatment of wastewater released from various sources, including businesses, homes, medical facilities, industries, and street runoff" (Twardowska, Allen, Kettrup and Lacy, 2004: unpaginated). There is evidence supporting the fact that wastewater sludge used as a fertiliser could contribute to soil contamination (Pukclai, 2020). In addition, these microplastics can enter watercourses due to direct land runoff or drainage via purpose-built ditches and can enter into the river (Whitehead, Bussi, Hughes, Castro-Castellon, Norling, Jeffers, Rampley, Read and Horton, 2021).

Figure 10: Agricultural plastic mulching. This photo shows plastic mulching, which is the covering of plants or soil with plastic to increase yields, fruit quality and reduce paste pressure. Source: Steinmetz et al. (2016) and Horton (2017)

Landfill Site

With the increasing production and consumption of plastic materials, plastic waste is on the rise, and by 2050, there will be approximately 12 billion tons of plastic waste discarded (Su, Zhang, Wu, Zhan, Shi and Xie, 2019). Plastic waste has become an essential part of municipal solid waste (MSW) because of the lack of systematic waste classification and low recycling rates, and the problem is worse in developing countries (Su *et al.*, 2019). Plastic waste in landfills accounts for 20% of MSW (Wang *et al.*, 2015). As a result, landfills are viewed as the primary reservoir of microplastics, including primary and secondary microplastics (Su *et al.*, 2019). The occurrence of microplastics in landfills could pose negative impacts on the surrounding environment, because microplastics can be transported from the landfill to the surrounding environment via air-borne pathways or both (*ibid.*). Without a doubt, negative impacts on the surrounding communities would worsen in areas with poor management, such as African countries. Therefore, it must be emphasised that there is a need for proper waste management in order to limit the amount of plastics and microplastics in landfill sites. According to Kataoka *et al.* (2019) open landfill sites that are located close to the rivers could also be the major sources of microplastics in rivers, for instance, the plastics littered on the landfill site may fragment into microplastics and then released into the river due to rainfall or strong wind (Kataoka *et al.*, 2019).

Stormwater System/ Run-Off

Car Tyres

Another major source of microplastics comes from the abrasion of tyres when driving (Boucher and Friot, 2017). The outer parts of tyres are made up of a matrix of synthetic polymers, such as Styrene Butadiene Rubber (approximately 60%) which is mixed together with many other additives and natural rubber (*ibid.*). During driving, these particles are wiped away by wind and can make their way into nearby water bodies (*ibid.*). Also, these microplastics can be washed away during rainfall into the stormwater drainage and eventually reach the harbour (*ibid.*). Moreover, research conducted in South Africa discovered Automotive tyres are one largest sources of plastic leakage due in large part to the microplastics produced by tyre abrasion (IUCN-EA-QUANTIS, 2020). It is unclear how microplastics eroding from tyres end up in the ocean, however, researchers from Norway and Sweden pointed out that a larger number of microplastics in the ocean originate from car tyres (*ibid*.).

Road Markings

Furthermore, microplastics also come from the weathering and abrasion of road markings by cars (see figure 11). Different types of markings (which contain microplastics) are used on the road, such as epoxy, thermoplastic, paint and preformed polymer, and paint (45%) is the most dominant type globally (Boucher and Friot, 2017). These road markings are applied throughout the lifecycle of road infrastructure, from its development to its maintenance, which means the weathering of microplastics from these markings occurs every day (*ibid.*). As a result, these microplastics are either spread by wind or washed away by rainfall into stormwater drainage and eventually pollute water bodies, including harbours (Boucher and Friot, 2017; Karbalaei *et al*., 2018).

Figure 11: Road paint with microplastics. This image shows road abrasion between road paint and tyres (made of microplastics), resulting in a release of microplastics from road paint and tyres. Source: https://pixels.com/featured/skid-marks-ryan-jorgensen.html

Formation from Textiles

It is clear from the literature that textiles made of synthetic polymers represent one source of microplastics (Lassen *et al*., 2012). Microplastic fibres are shed from synthetic textiles, such as clothing, curtains, furniture, carpets and other household textiles (synthetic cleaning cloths) during everyday use (*ibid.*). Microplastic particles are formed and released from the textiles due to wear and tear of the products during normal use and during washing, where textile fibres are ripped loose in laundry machines (*ibid.*). Therefore, the main sources of microfibres discharged with sewage are considered to be textiles and non-woven cloths used for cleaning purposes (*ibid.*).

Marine-based Sources

Fisheries

The fisheries industry uses a wide variety of plastics in its activities (Lusher and Pettersen, 2021). The use of fishing equipment and the breakdown of misplaced and abandoned gear result in the release of microplastics into the environment (*ibid*.). Moreover, discarded, abandoned or misplaced fishing gear is considered the primary source of plastics from the fisheries industry, but it is unclear how much of a contribution they make overall (*ibid*.). Climatic conditions, winds, and water currents can cause the fishing gear to become stranded, lose its bearings, or break loose during routine fishing in deep and surface water (*ibid*.).

Spillages of Cargo

In addition to raw plastic materials used to create other products, a wide variety of goods containing plastic particles are transported in containers (Lusher and Pettersen, 2021). Severe weather at sea can be hazardous for cargo ships (*ibid*.). Ships can roll, pitch, and heave due to waves in the open sea, which also jeopardises the stability of the vessel (*ibid*.). Additionally, containers that are loaded incorrectly hinder their stability. Container ships that are stacked are consequently subjected to strong movements and run the risk of falling into the ocean (*ibid*.). When shipping containers are lost, plastic products or microplastics (especially primary microplastics like microbeads and pallets) are released into the marine environment (*ibid*.). The amount of microplastics is bound to increase as plastic products slowly breakdown into microplastics, especially if they are left in the environment for a long time (*ibid*.).

Recreational Boating

Recreational boating, including fishing and sea-based leisure activities, brings a lot of plastics into the marine environment due to littering and unintentional loss of products (Lusher and Pettersen, 2021). Moreover, plastic bags, fishing equipment, consumer goods, bottles, and food containers make up the majority of items used on recreational boats (*ibid*.). According to Lusher and Pettersen (2021), littering includes the intentional disposal of plastic waste into the ocean and the transportation of plastic waste to and from the shorelines. Overall, recreational boating can be considered as one of the major marine sources of microplastics in the environment.

Factors that Influence Level of Microplastics in Waterbodies

Population Density and Human Activities

The level of microplastics in water bodies, including harbours, is influenced by the surrounding population density and human activities (Nel, Hean, Noundou and Froneman, 2017). Higher concentrations of microplastics have been recorded nearer major cities, as shown in figure 12. Similarly, higher levels of microplastic concentration have been reported in areas with high anthropogenic activity (Nel *et al*., 2017). For instance, Nor and Obbard, (2014) reported a positive correlation between microplastic concentration and human activities in Singapore mangroves, where low microplastic concentration was associated with lower levels of human activities.

Likewise, in the research conducted in the five urban estuaries of KwaZulu Natal, Durban Harbour being one of them, it was discovered that there is a positive correlation between the level of microplastics and the surrounding population (Govender *et al*., 2020). Isipingo and uMngeni estuaries, which are surrounded by a high population density, have the highest levels of microplastics, compared to St. Lucia and the Durban Harbour, which have low population densities (*ibid*.). In contrast, Lake Hovsgol, located in Mongolia, is characterized by a low population density and limited human activities and is reported to have a high concentration of microplastics (Shahul, Bhatti, Anuar, Anuar, Mohan and Periathamby, 2018). Also, Wang, Ndungu, Li and Wang (2017) looked at the relationship between microplastic pollution in urban lakes and distance from the city centre and reported a negative correlation between the two.

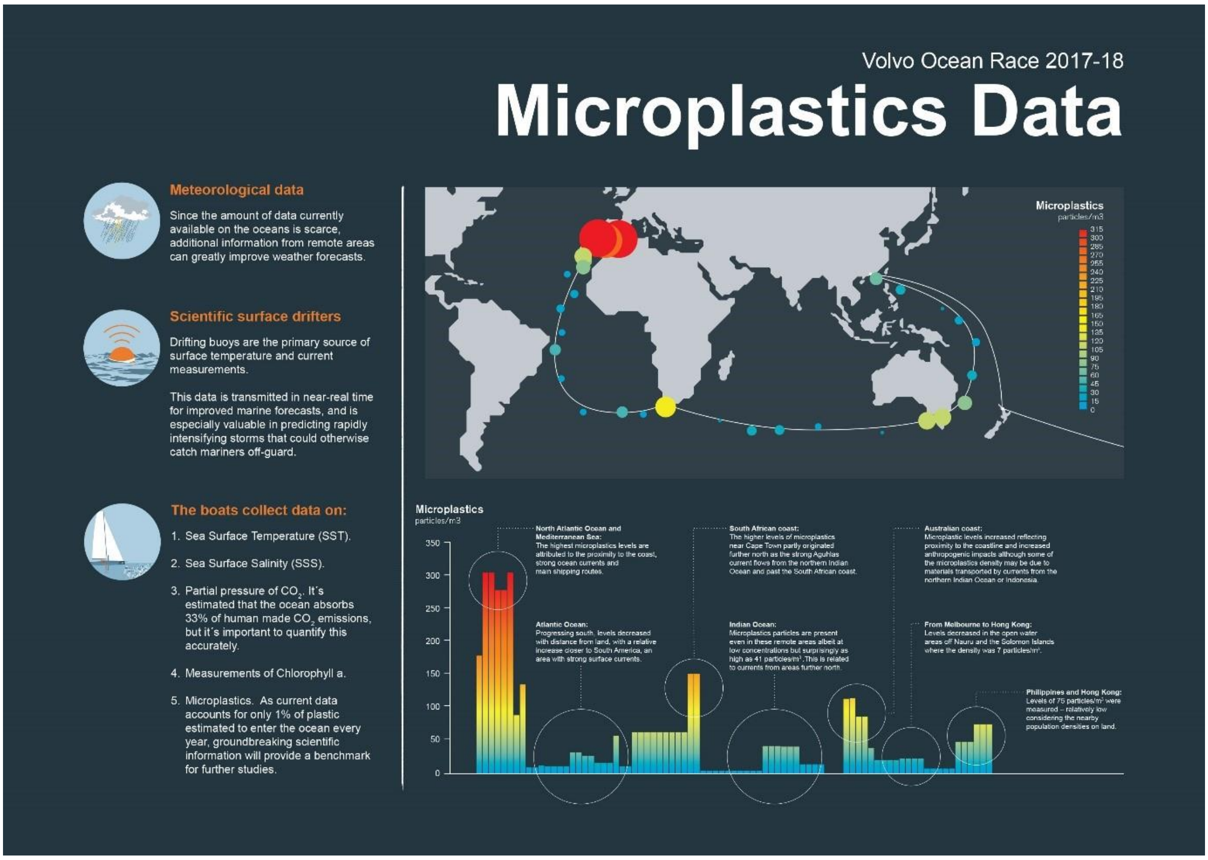

Figure 12: Microplastic concentration around the world. This diagram shows high levels of microplastic reported close to major cities around the world. Source: https://archive.theoceanrace.com/en/news/11350_Higher-concentrations-of-microplastics-found-nearer-major-cities-new-data-reveals-.html

Seasonality and Microplastic Levels

Seasonality significantly affects microplastic concentration in water bodies, with high concentrations in wet seasons compared to dry seasons (Gerber, 2017; Govender *et al*., 2020; Dalu, Banda, Mutshekwa, Munyai and Cuthbert, 2021). For instance, a study on the "characterisations of sediment microplastic pollution in a subtropical river system in southern Africa" recorded the highest levels of microplastics and most diverse in the wet season "(mean range 76.0 ± 10.0–285.5 ± 44.5 microplastic kg-1)" as compared to the dry season "(16.5 ± 4.5–27.0 ± 5.0 microplastic kg-1)" (Dalu *et al*., 2021:6). Govender *et al*. (2020) made an important argument that there are hydrological factors, including an increase in the river flow (as a result of precipitation) that affects the level of microplastics in estuaries. For example, in the study conducted in the five urban estuaries of KwaZulu Natal, the microplastic concentration was three to fourteen times higher during the wet season in the three estuaries (including Isipingo, uMngeni and Durban Harbour) (Govender *et al*., 2020). This is because the three urban estuaries are known to receive a large amount of inputs from stormwater drainage systems (*ibid.*).

Environmental Effect of Microplastics

Microplastic particles are potentially more environmentally damaging compared to larger pieces of plastics because of their small size (House of Commons Environmental Audit Committee, 2016). Thus, they can easily be consumed by different marine species and can be transferred up the food web to humans (Barboza *et al*., 2018). Sometimes, marine organisms confuse microplastics with food or prey because of their size and colour (Barboza *et al*., 2018; Sartain *et al*., 2018). The following sections unpack the effects of microplastics on marine species and human health.

Impact on Marine Species

Large and small invertebrates, such as larvae and planktonic organisms at the bottom of the food web, have been recorded to be contaminated with microplastics (Barboza *et al*., 2018). For example, sampled fish and plankton in the Baltic Sea were recorded to have a high concentration of microplastics (Burns and Boxall, 2018). In addition, 70 Mullet *Mugil cephalus* in the Durban Harbour were sampled, and 51 mullets (73%) were contaminated with microplastics (Naidoo, Smit and Glassom, 2016). Mullets can potentially transfer microplastics to species at high trophic levels because they are consumed by carnivorous fish and birds entering the coastal systems (Naidoo *et al*., 2016). Moreover, marine organisms that consume microplastics can suffer from a reduction in nutrient intake, reproductive impairment, an increase in oxidative stress, growth impediment and increased mortality, which pose a significant threat to biodiversity and the environment (Ha and Yeo, 2018; Prasath and Poon, 2018).

Microplastics cause danger to marine organisms and ecosystems through various approaches (Amelia, Khalik, Ong, Shao, Pan and Bhubalan, 2021). In the environment, microplastics can act as vectors or carriers of harmful contaminants or pollutants such as heavy metals, organic matter, additives, pathogens and hydrophobic organic compounds (figure 13) (Ha and Yeo, 2018; Amelia *et al*., 2021; Bezerra *et al*., 2021). This is because microplastics have a larger surface area compared to plastics, they can adsorb and transport much more pollutants (Ha and Yeo, 2018). As a result, microplastics can transport these contaminants over a long distance from one area to the next (Amelia *et al*., 2021; Bezerra *et al*., 2021). In addition, there is a potential for these contaminants to be transferred to marine biota (such as fish) after consuming a pollutants-bound microplastic (Figure 14) (Amelia *et al*., 2021). As shown in figure 14, fish that is exposed to contaminated microplastics can suffer negative impacts from the contaminants (which include physical damage and neurotoxicity) and the microplastics itself (like egestion inefficiency, and intestinal and kidney blockage) (*ibid*.). According to Amelia *et al*. (2021), a pollutant-bound microplastic could endanger food safety for the human population (figure 13).

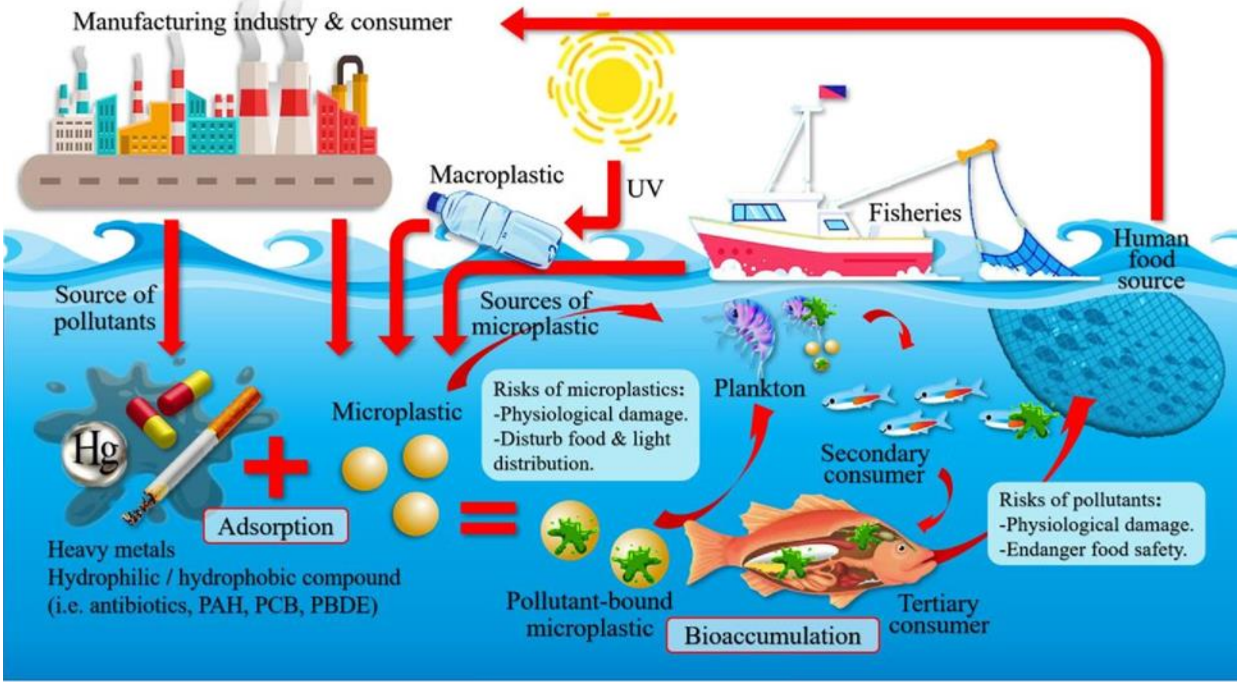

Figure 13: Microplastics pathway. This diagram illustrates the paths of microplastics, from their sources to their general impact on organisms and ecosystems. It also shows microplastics binding with pollutants such as heavy metals and creating pollutant-bound microplastics, and their impact on marine species. Source: Amelia et al. (2021)

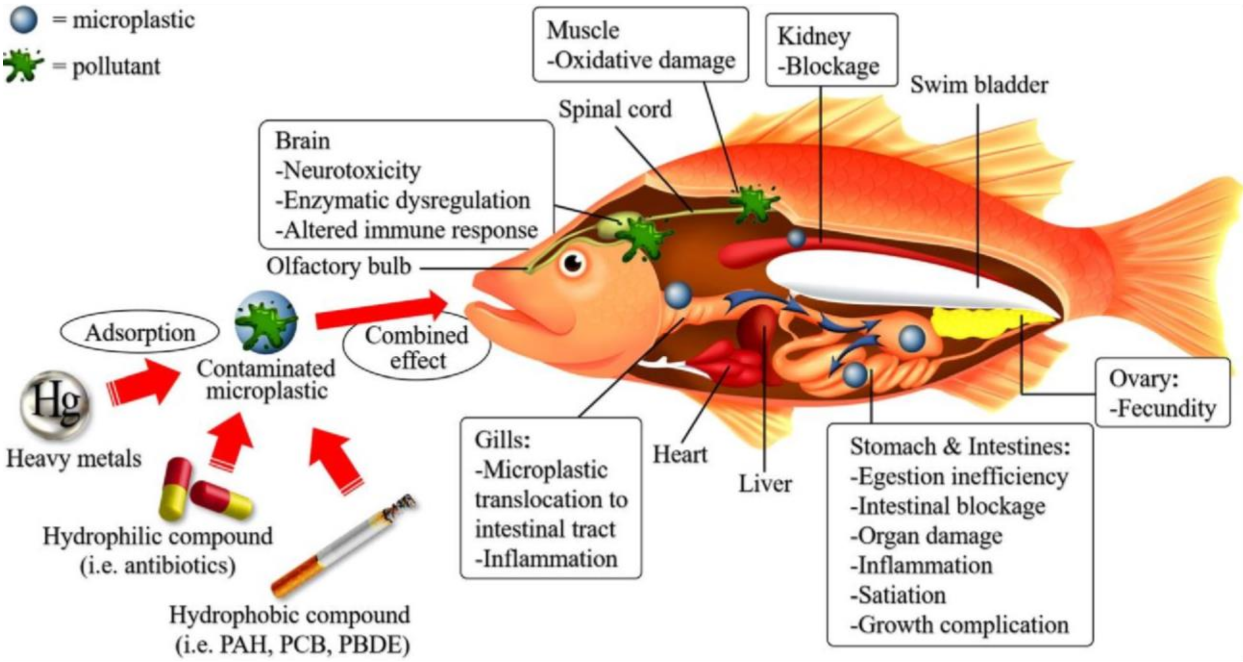

Figure 14: Marine ingestion of pollutant-bound microplastics and associated impacts. This diagram demonstrates the ingestion of pollutant-bound microplastics by marine

organisms (fish in this case) and the individual effects of pollutants and microplastics. It also illustrates the pathways of contaminants and microplastics inside marine organisms. Source: Amelia et al. (2021)

Human Impacts

Since microplastics are ubiquitous in the environment, this raises much concern about their negative impact on humans and marine species (Vethaak and Legler, 2021). Microplastics have been recorded in seafood consumed by humans, including fish, shellfish, invertebrates, bivalves, crustaceans, oysters, and mussels (Montoya, 2015; Karami *et al*., 2017; Barboza *et al*., 2018). Beaumont *et al*. (2019) state that humans consume microplastics when they eat the entirety of a contaminated organism, as well as the gut. Microplastics have also been found in commercial fish, for example, a market in Makassar, Indonesia, had 28% of processed fish contaminated with microplastics (Smith *et al*., 2018). Similarly, a study conducted in South African waters sampled 593 small pelagic fish (which is commercially important) and found a total of 813 microplastics in 406 fish (Bezerra *et al*., 2021). Since a large portion of South Africans' diet is composed of small pelagic fish, especially canned sardines (pilchard), this raises a lot of concern from a human health point of view (*ibid*.). Unfortunately, small pelagic fish are particularly significant due to their critical role in marine food webs (*ibid*.). Small pelagic fish are also the most abundant and valuable fish in South Africa (*ibid*.). This means that marine species that prey on small pelagic fish are also exposed to microplastics and the whole food web, including humans. Furthermore, Vethaak and Legler (2021) argue that the ingestion of microplastics by humans can result in a variety of biological effects, such as DNA damage, cellular damage and physical toxicity (figure 15), which leads to the secretion of cytokines, inflammation, immune reaction, oxidative stress, and neurotoxic and metabolic effects.

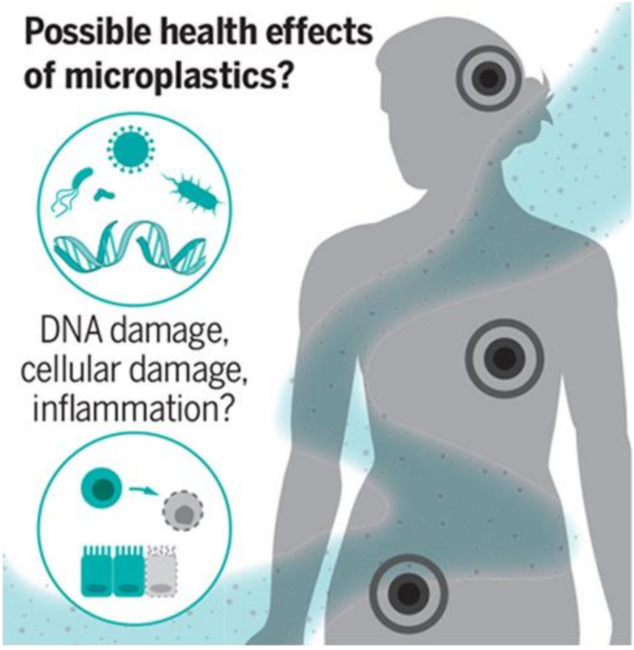

Figure 15: Impacts of microplastics on humans. This image shows the possible health effect on humans after being exposed to microplastics either by drinking water or consuming food contaminated with microplastics. Source: Vethaak and Legler (2021)

It is clear from the literature that there are different arguments regarding the impact of microplastics on the environment. As seen from the above paragraph, some authors believe that microplastics have a severe environmental threat. On the one hand, Karbalaei *et al*. (2018), Zhang *et al*. (2020) and Vethaak and Legler (2021) argue that microplastics have a negative impact on human and marine species. On the other hand, Shahul *et al*. (2018) and Beaumont *et al*. (2019) argue that eating seafood that is contaminated with microplastics has a minimal effect on human health. In addition, Burton (2017) argues that the negative impacts of microplastics on the environment are overstated. He highlights that microplastic concentration on the environment is very low to present an environmental risk. He further argues that this much ado about the environmental risks of microplastics is misinforming and misleading policymakers, such as the banning of microbeads in some countries (Burton, 2017). Even though the impact of microplastics on our health is uncertain, it cannot be ignored because it might cause detrimental effects in the future. As a result, a precautionary principle is applicable in this case.

Existing Mitigatory Measures to Microplastic Pollution

International Policies

Policymakers at all levels of government have swiftly translated several strategies to reduce microplastic and microbead use into international and national regulations (Tables 1 and 2) (Lamichhane, Acharya, Marahatha, Modi, Paudel, Adhikari, Raut, Aryal, and Parajuli, 2022). It is important to note that there is no specific international legislation regarding microplastics, however, there are international policies that speak to microplastic pollution (Tables 1) (Wang, Zheng and Li, 2018; Lamichhane *et al*., 2022). For instance, The United Nations Environment Assembly's first session (UNEA I, 2014) raised the issue of plastics, including the persistence of microplastics in the marine environment. As a result, the UNEA I adopted "Resolution 1/6 on marine plastic debris and microplastics" and asked for a study to be conducted in this area (Wang *et al*., 2018:902). Subsequently, UNEA II approved Resolution 2/11 in 2016, which requested an evaluation of the viability of international, regional, and national policies and approaches to fight marine microplastics and plastic waste (*ibid*.).

Table 2: International instruments for microplastic pollution. Microplastics were added to the Basel Convention of 1989. Between 2014 and 2017, the UNEA introduced three resolutions to reduce microplastics in the environment.

International instruments	Time	Specific contents
Basel Convention	1989	Include plastic waste and microplastics issues into the Basel Convention workstream at COP 13 (Plastic waste in Annex II Y 46 (Household wastes) and Annex VIII (Non-hazardous wastes)).
United Nations Environment Assembly (UNEA) I	2014	Resolutions 1/6: put forward the issue of "Marine plastic debris and microplastics".
UNEA II	2016	Resolutions 2/11: measures to reduce marine plastic litter and microplastics
UNEA III	2017	Resolutions 3/7: combating the spread of marine plastic litter and microplastics.

Source: Lamichhane *et al*. (2022)

In 2017, UNEA III adopted Resolution 3/7, which stresses the importance of eliminating the high release of plastic debris and microplastics into the oceans (*ibid*.). The resolution also emphasizes the importance of preventing the detrimental effects of microplastics on marine ecosystems and human health (*ibid*.). Furthermore, in 2017, at the 13th Conference of Parties, the Basel Convention included "plastic and microplastic issues in the Basel Convention on the Transboundary Movements of Hazardous Wastes and their Disposal "(*ibid*: 903). The aim is to encourage regional centres to work on preventing microplastics from entering the environment (*ibid*.). Undoubtedly, scholars and the public have become increasingly concerned about microplastic pollution in recent years, but there is still a big need for clear policy and governance mitigation measures (Alimi *et al*., 2021; Onyena, Aniche, Ogbolu, Rakib, Uddin and Walker, 2021).

There are limited studies on the review of international and national policies on microplastic pollution. According to Onyena *et al*. (2021), global efforts to tackle the microplastic problem have been restricted to weak and fragmented acts. The fragmented nature of the global collaboration needed to tackle the issue of microplastics demonstrates how highly decentralised the international system is (Onyena *et al*., 2021). Moreover, Onyena *et al*. (2021) made an important argument that despite the international corporation's contemporary effects, we still need an adequate international action plan to deal with the increasing microplastic concentrations in the environment.

National Policies and Interventions

Several developed countries have enacted legislation and adopted measures to address microplastic pollution at the national level (Wang *et al*., 2018; Lamichhane *et al*., 2022; Nikiema and Asiedu, 2022). These countries passed laws to gradually ban the production and sale of microbeads in PCCPs (Table 2) (Nikiema and Asiedu, 2022). The Netherlands was the first country to ban microbeads in rinse off PCCPs in 2012 (*ibid*.). In 2015, the Netherlands, together with the other four European countries, including Sweden, Australia, Luxembourg and Belgium, were concerned about the potential effects of microplastics on human health and called for the European Union (EU) to ban microbeads from PCCPs (Montoya, 2015; Wang *et al*., 2018; Onyena *et al*., 2021). In the same year, the United States (US) introduced the Microbead-Free Waters Act of 2015 and various bans in the following years (Table 2) (Burns and Boxall, 2018; Nikiema and Asiedu, 2022). Many countries (such as Canada, Australia, Sweden, United Kingdom, New Zealand, Thailand, South Korea, France, and Italy) followed and introduced bans on microbeads (Wang *et al*., 2018; Lamichhane *et al*., 2022 and Nikiema and Asiedu, 2022).

Table 3: National policies and interventions to microplastic pollution. National policies and interventions introduced by developed countries over the past few years. These policies aim to limit the amount of microplastics entering the marine environment by focusing on microbeads in PCCPs.

Countries	Year	Policy
Netherlands/ The Dutch Plastic Soup Foundation	2012	"Beat the Microbeads" campaign. To remove plastic microbeads from personal care products
Austria, Belgium, Sweden, Netherlands, Luxembourg (Multi-national)	2015	These countries issued a joint statement requesting a ban on microbeads in personal care products. **Purpose of Ban:** Protecting marine ecosystems, including seafood, from contamination, **The impact:** The countries forwarded their joint call on eliminating microbeads in cosmetics and detergent to the European Union's Environment Ministers. Some companies have shown a commitment to stop using microplastics and microbeads in their products
United States	2015-2019	Microbead-Free Waters Act 2015 **Cosmetics**: Ban on manufacturing rinse-off products containing plastic microbeads – July 1, 2017. Ban on introduction or delivery of rinse-off products containing plastic microbeads – July 1,2018 **Non-prescription drugs:** Ban on manufacturing rinse-off products containing plastic microbeads – July 1, 2018. Ban on introduction or delivery of rinse-off products containing plastic microbeads – July 1, 2019
Canada	2016-2019	SOR/2017-111 Microbeads in Toiletries Regulations **Cosmetics**: Ban on manufacturing and importation of toiletries containing microbeads – January 1, 2018. Ban on the sale of toiletries containing microbeads – July 1, 2018 **Natural health products and/or non-prescription drugs:** Ban on manufacturing and importation of toiletries containing microbeads – July 1, 2018 Ban on the sale of toiletries containing microbeads – July 1, 2019
Australia	2017	Voluntary removal of microbeads – 1 July 2017
Sweden	2018	Ban on microbeads in rinse-off products – January 1, 2018
United Kingdom (UK)	2018	Plan to ban on rinse-off cosmetics products containing microbeads – 2018
New Zealand	2018	World Trade Organization notified of draft regulation: ban on microbeads in personal care products – 2018
Taiwan Province, China	2018	Ban on the manufacture and import of products containing microbeads –January 1, 2018
South Korea	2018	Ban on the use and sale of plastic microbeads in all cosmetics – July, 2018
Italy	2020	Ban on microbeads scrub particles in cosmetics

Source: Wang *et al*. (2018), Lamichhane *et al*. (2022), and Nikiema and Asiedu (2022)

The national bans on microbeads in PCCPs led to large manufacturing companies phasing out the use of microbeads in their productions (Nikiema and Asiedu, 2022). Therefore, microbeads are now being replaced by different abrasives, such as microcrystalline cellulose, silica, and perlite (*ibid*.). These policy interventions by developed countries are needed to deal with the issue of microplastics. However, Guerranti *et al*. (2019) pointed out that a national ban on microplastics in PCCPs, only in some countries, is not sufficient to address the issue of microplastics, because of their prevalence and threat to the environment. Furthermore, Wang *et al*. (2018) made an important argument that the first world countries' solutions to microbeads are mostly limited to PCCPs. These policy interventions are not satisfactory because they only focus on one type of microplastic, which is microbeads. As a result, there is a need for more policy interventions and regulations that will target all types of microplastics.

South African Policies and Interventions

As discussed in the previous section, many countries have introduced a ban on microbeads to limit the high concentrations of microplastics in the environment (Montoya, 2015). Nonetheless, no policy or regulation to address the issue of microplastics exists in South Africa, including the eThekwini municipality. Regardless, South Africa has measures that indirectly limit the amount of microplastics in the marine environment. These measures focus on dealing with plastic pollution, which is a source of secondary microplastics in water bodies (Prata, Silva, Da Costa, Mouneyrac, Walker, Duarte, and Rocha-Santos, 2019).

Extended Producer Responsibility

Extended Producer Responsibility (EPR) is a policy principle that makes producers responsible for the end-of-life management of their products and packaging" (Arp, 2021:52). EPR will be very useful in supporting and strengthening the enabling environment for waste management that is sustainable and the move towards a circular economy (Arp, 2021). The voluntary EPR in South Africa has been in place since 2000. However, the voluntary EPR did not work well because of adverse selection, lack of accountability, and moral hazard (Franckx, Van Acoleyen, Vandenbroucke, Hogg, Holmes, Montag, Taylor and Coulthurst, 2008). In South Africa, the mandatory EPR scheme (published in 2020) has finally replaced the old voluntary EPR scheme. But, because of the need for further industry engagement, the implementation was postponed, and the amended regulations were published in May 2021 (Arp, 2021). Since the mandatory EPR is fairly new, its effectiveness is yet to be seen. Recommendations in Chapter 5 will outline measures the government can take to ensure that the EPR effectively mitigates microplastics in the environment.

Awareness and Clean-ups Initiatives

There are many interventions and policies for plastic pollution in South Africa. Specifically, the eThekwini municipality has government projects and Non-Governmental Organizations (NGOs) that carry out waste collection projects and clean-ups around the ocean and the Durban Harbour, especially after heavy rains (de Kock, Sadan, Arp and Upadhyaya, 2020). These NGOs include the Breathe Ocean Conservation, Source 2 Sea Initiatives, The Blue Port, Wild Ocean and Adopt a River Community and others. In addition, these NGOs play a significant role in increasing awareness of plastic contamination in water systems within the eThekwini municipality. However, microplastics are not yet on the agenda of government projects and NGOs. Even though clean-ups are essential for dealing with plastic pollution, they are not enough, because they do not deal with the cause of this pervasive problem (Prata *et al*., 2019; de Kock *et al*., 2020). Thus, there is a need for government projects and organisations to raise awareness and educate people about microplastic pollution and its impact on the national, provincial, and local scales.

Waste Management

Since microplastics originate from plastics, this means that poor waste management plays a big role in microplastic pollution in the environment. As a result, it is important to understand the concept of waste management. As part of waste management, materials are collected, transported, processed, recycled or disposed of, and monitored

(Bacinschi, Rizescu, Stoian and Necula, 2010). Importantly, the waste hierarchy principles are paramount to the sustainable management of solid waste (Ali, Talmizi, Wahab, Rijal, Abd Rased and Saleh, 2021). Ever since the hierarchy was introduced, it has been represented in many several ways, but "the general principle is to prevent and prepare waste for reuse and move "towards reduction, reuse and recycling, known as the 3Rs" (figure 16) (Ali *et al*., 2021:2). According to the waste hierarchy, waste management strategies are classified according to how effective they are in minimizing waste. This includes using "the 3Rs: reduce, reuse, and recycle" (*ibid*.:2). Undoubtedly, integrated or sustainable waste management (figure 17) is essential for preventing plastic leakages until the environment that will eventually breakdown into microplastics. Therefore, the amount of waste should be reduced, and more should be recycled to limit the amount of waste being disposed into landfill sites.

Figure 16: Waste hierarchy. This diagram shows the different levels of dealing with waste, moving from the top to the bottom of the hierarchy. Prevention (at the top of the hierarchy) is the most preferable action and disposal (at the bottom) is the least preferable action for dealing with waste. Source: https://ec.europa.eu/environment/topics/waste-and-recycling/waste-framework-directive_it

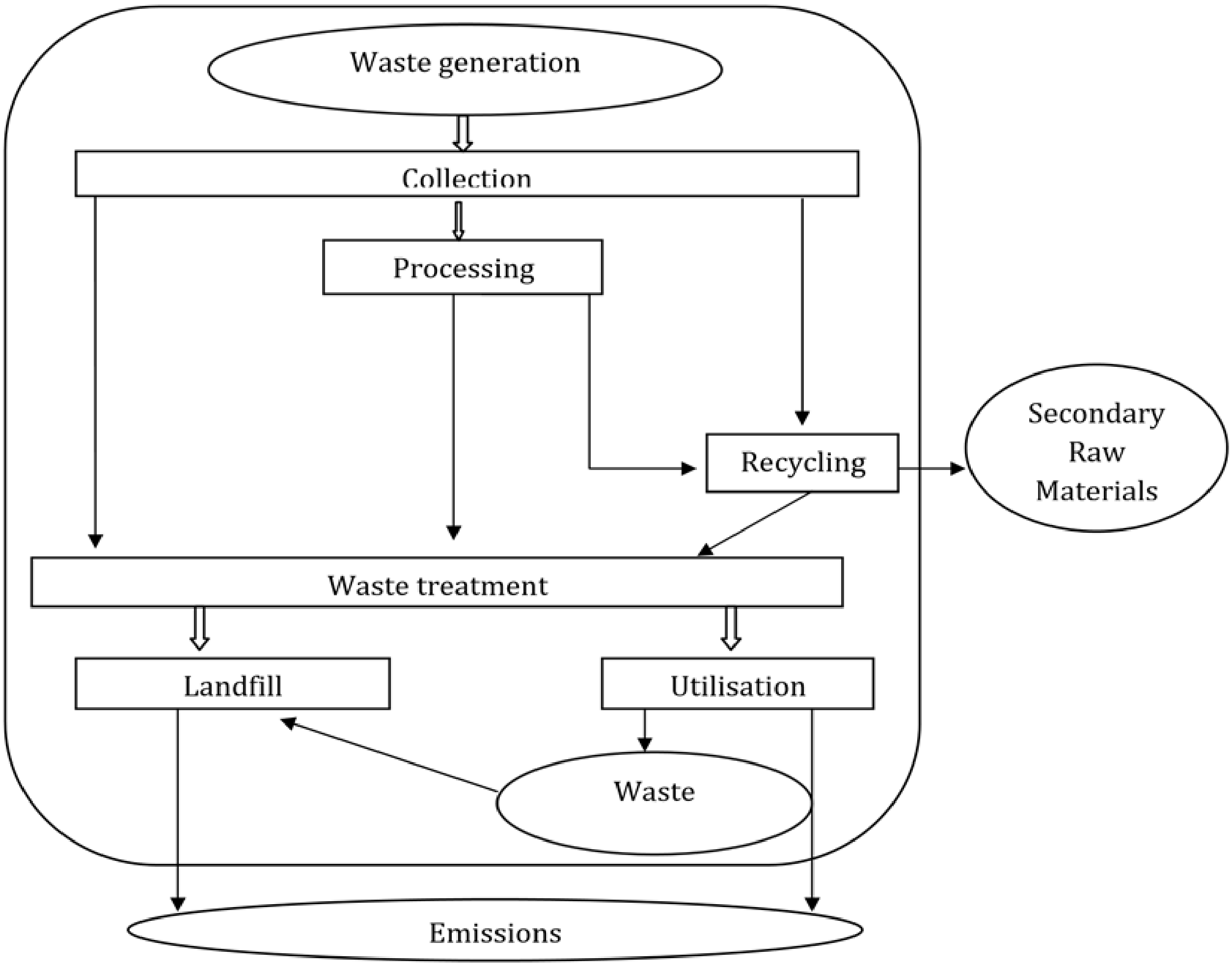

Figure 17: Integrated waste management. This waste management system starts from waste generation down to landfill and emissions. This diagram demonstrates the processes that we should follow, from waste being generated, collected, and processed to it being recycled, treated, utilised and thrown into landfills. Source: Kubanza (2010)

According to Verster and Bouwman (2020: 26), South Africa was ranked "11th on a list of countries contributing to marine plastic in 2010". The loss of plastic to the South African environment is because of logistical challenges in outlying communities and informal settlements, littering, poorly managed waste and lack of infrastructure for waste removal (Verster and Bouwman, 2020). These factors also contribute to microplastic pollution in South Africa (Verster and Bouwman, 2020). Moreover, mismanaged waste in the eThekwini municipality ranged between 31% to 50% in 2018, as indicated in the diagram below (figure 18) (IUCN-EA-QUANTIS, 2020). The relatively high Mismanaged Waste Index (MWI) is because South Africa mostly uses dumpsites and unsanitary landfills (*ibid*.). In addition, a fifth of the waste collected is poorly managed and this, coupled with the uncollected waste, makes this situation worse (*ibid*.).

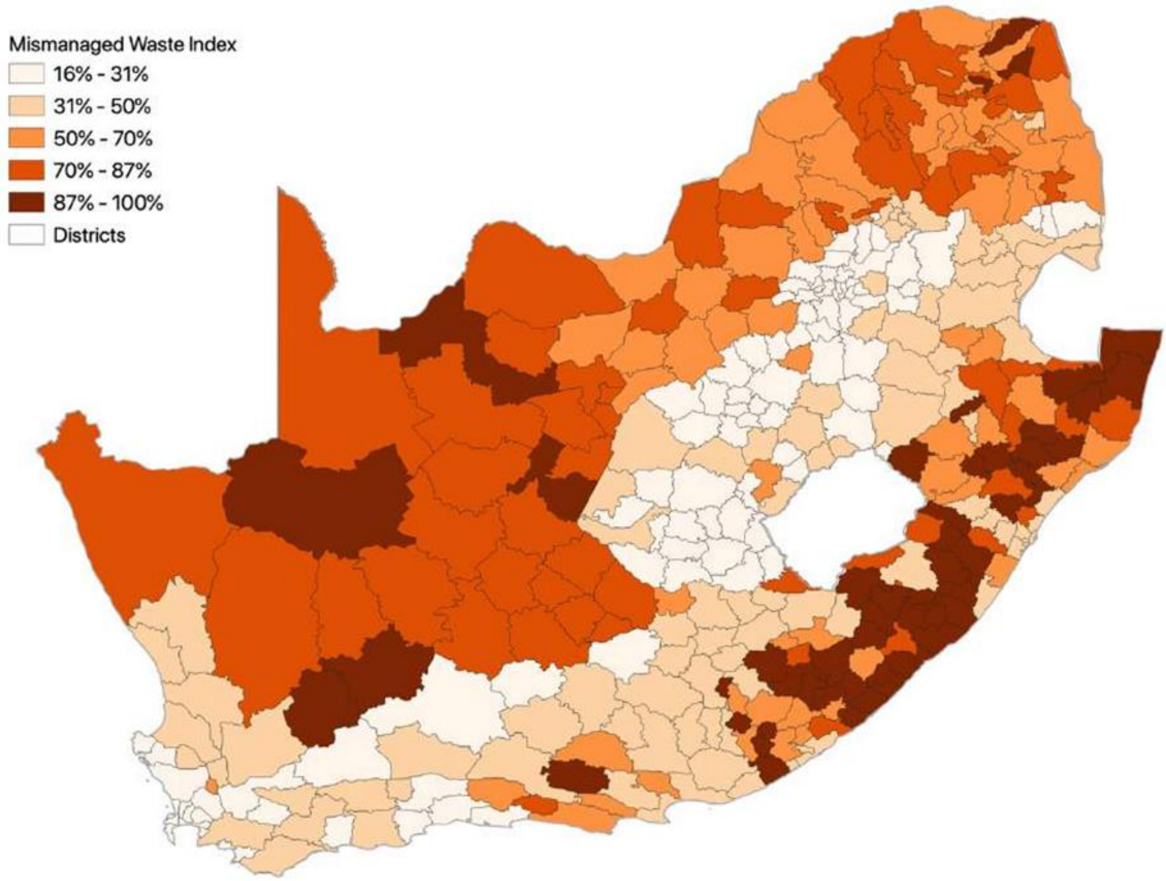

Figure 18: Mismanaged Waste Index (MWI). This map displays the mismanagement of waste in different municipalities in South Africa. Usually, MWI tends to be very low around big cities (around 20%) and in other areas, ranges from 70% to 80. Source: IUCN-EA-QUANTIS (2020)

Microplastics as a Focus of Attention

Ryan (2015) pointed out that concerns about the environmental impact of plastic litter are not new, but they can be traced to the 1970s-80s, together with the small plastic fragments. In response to growing public concerns about plastic pollution in the ocean, microplastics have become a topic of discussion among policymakers and the general public (Bujnicki *et al*., 2019). Furthermore, society saw the need to deal with the plastic problem due to the negative impact of plastics on marine species and the overall ecosystem (*ibid.*). However, not much was achieved because plastic production and plastic litter still increased (*ibid.*). With societal interest in curbing the plastic pollution problem, one would expect an increase in plastic research. However, plastic research was temporarily stopped in the 1990s (Bujnicki *et al.*, 2019). As a result of increased public awareness of the North Pacific garbage patch and Thomson and co-workers' study on microplastics, research surged once more (*ibid.*).

Microplastics Research Understanding

Globally

Research on microplastic pollution has been conducted in every part of the world, in every continent, including Africa (Dahms, van Rensburg and Greenfield, 2020). According to Bouwman (2021), microplastics and their effects on marine species have been extensively studied in developed countries, but there is a substantial knowledge gap in developing countries such as South Africa. As a result, we do not fully understand the impacts of microplastic pollution on the ocean and freshwater systems, and the impact may be even greater in developing countries where many communities still rely on the land and natural waters for their livelihoods (Verster, Minnaar and Bouwman, 2017). Recent international studies also show atmospheric fallout as a source of microplastic contamination (Bouwman, 2021).

Globally, the risks and negative impacts of microplastics in water systems are unknown and yet to be discovered (Verster, Minnaar and Bouwman, 2017). However, as microplastic levels continue to increase, this raises a lot of concerns about the quality of aquatic resources, especially in water-scarce countries like South Africa (*ibid.*). Importantly, this highlights the need for further research on the risks and effects of microplastics (*ibid.*). In response to the raising concerns, a project was undertaken in 2017 by the South African Water Research Commission to derive research priorities (*ibid.*). Meanwhile, there is an urgent need for proper waste management and improved recycling across the country (*ibid.*).

The public is being educated more about microplastics over the internet. Prata *et al.* (2019:5) explored "the trends on the keywords 'microplastics' and 'microbeads' on search engines and social media" from 2004 to 2019 and discovered that over the years, more people are becoming aware of microplastics as more information on microplastics is being shared in the news and on social media (see figure 19). The graph below shows that the highest peaks are from articles shared on social media, with more people interacting, liking, and sharing the information. Moreover, the highest peak with regard to "microbeads" occurred in 2016, when the first ban on microbeads was introduced (Prata *et al.*, 2019). This shows that urban managers can use the internet to educate people in the eThekwini municipality about microplastic pollution.

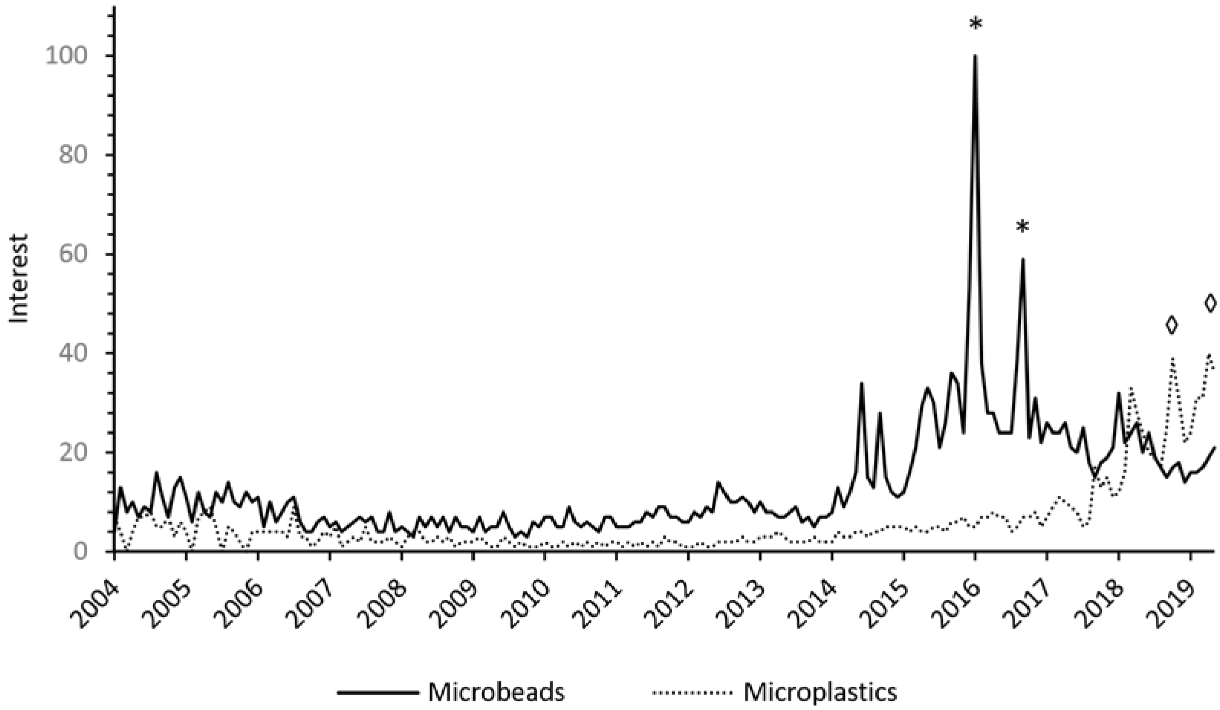

Figure 19: Microplastics and microbeads google search. This graph illustrates the trends of a google search for microplastics and microbeads on google between 2004 to 2019. Source: Prata et al. (2019)

In Africa

As with other continents, Africa is not immune to the current global crisis of plastic pollution (Alimi *et al.*, 2021). Approximately 172 million tons of plastics consumed was from 1990 to 2007 within the 33 countries (from the available record) out of 54 nations in the continent (*ibid*.). Alimi *et al*. (2021) argue that the high rate of plastic consumption in Africa has been accompanied by poor waste management and ineffective policies. As a result, the African continent has been ranked as the major continent with mismanaged plastic (Alimi *et al*., 2021). Furthermore, since freshwater bodies cover only about 9% of the African continent compared to other continents, there is a need for proper waste management policies that will protect these freshwater bodies (*ibid*.). Undoubtedly, the African continent is faced with many challenges and microplastic pollution presents an additional challenge to the African population (*ibid*.).

Surprisingly, the term "microplastics" was first used by Ryan and Moloneys in Africa in their study titled "Plastic and other artefacts on South African beaches: temporal trends in abundance and composition" during the 1990s (Alimi *et al*., 2021:2). However, the word microplastics was widely accepted by researchers only after Thompson published a report in 2004, looking at the occurrence of microplastics in sediments surrounding Plymouth, United Kingdom (*ibid*.). Even though the first study that reported on microplastics in water environments was in Africa, microplastic research in Africa is just beginning (Alimi *et al*., 2021). However, over the last decade, Africa has become more aware of microplastic pollution.

In Africa, few studies have analysed the distribution, sources and impacts of microplastics in organisms (see figure 20), thus, there is a limited understanding of the environmental effects of microplastics in the African continent (Alimi *et al*., 2021). As shown in figure 20 below, more research has been conducted in the ocean compared to the terrestrial environment in the African continent. Coupled with that, there are more studies on microplastics in surface water, especially in the marine environment, as compared to studies on microplastics in sediments (*ibid*.). The fact that fewer studies have been conducted on microplastics in organisms contributes to our lack of knowledge on the impact of microplastics on African organisms. The studies conducted in the African continent used different methods to measure and analyse microplastics, which makes it difficult to compare findings from different countries (*ibid*.). Furthermore, the number of publications on microplastic pollution has been increasing since 2015, and in 2020 there was a rapid increase in publications, as depicted in figure 21.

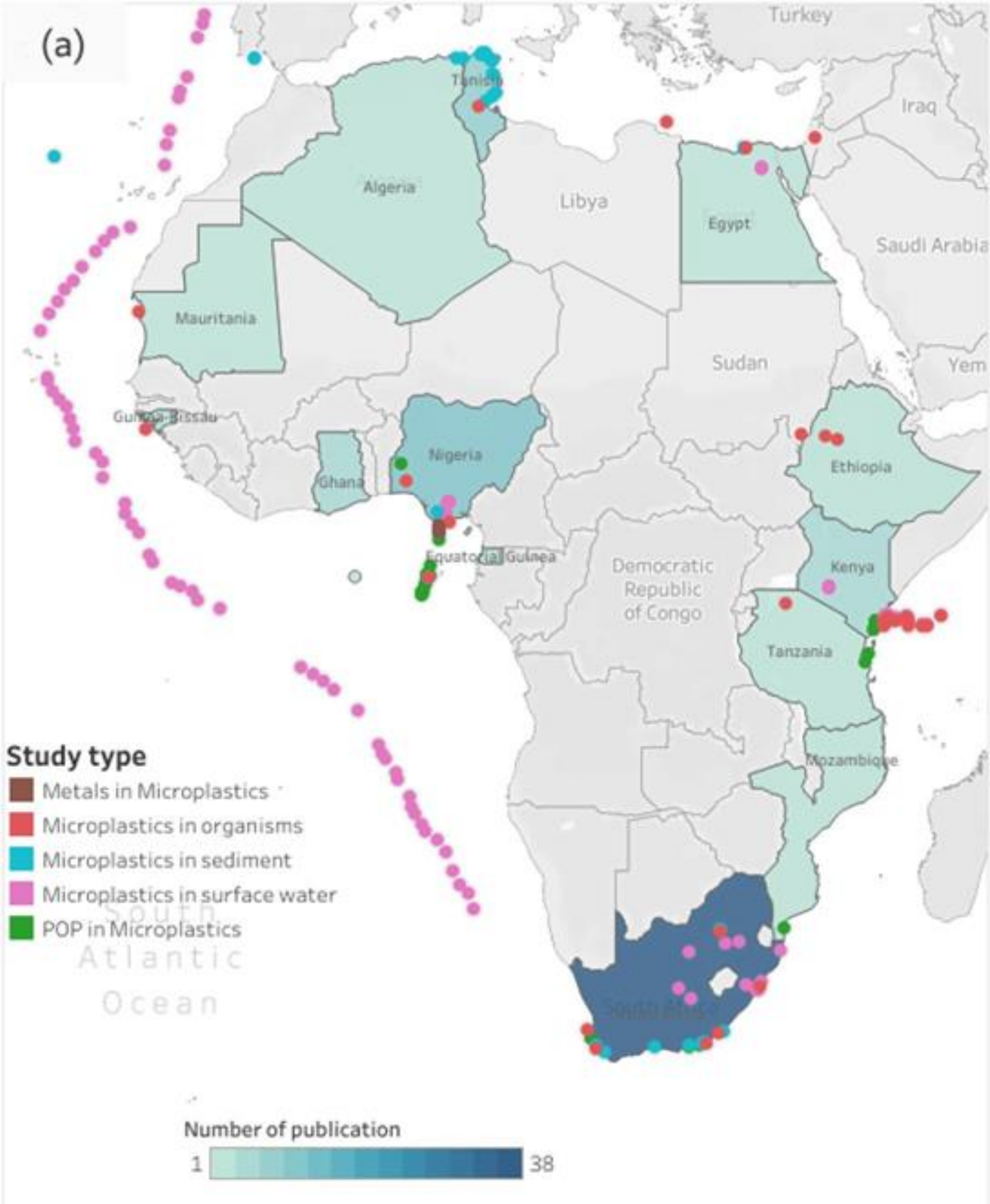

Figure 20: Spatial distribution of microplastic studies across Africa. The types of studies conducted in Africa include microplastics in organisms, microplastics in sediments, microplastics in surface water (dominant studies), metals in microplastics and POP (persistent organic pollutants) in microplastics. Source: Alimi et al. (2021)

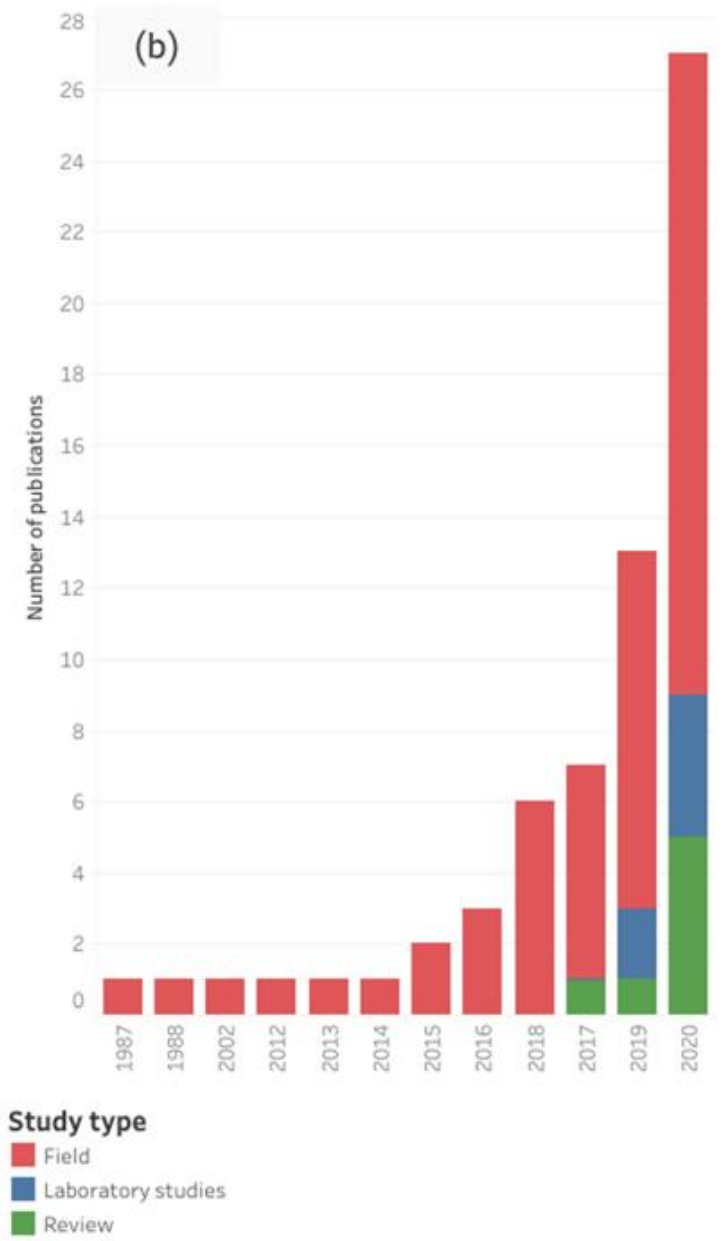

Figure 21: Distribution of yearly publications in Africa. This graph shows the trend of microplastic studies, and the type of studies conducted in Africa until 2020. Field studies on microplastics emerged in 1987. From 2015, the number of field studies increased, and from 2017 review studies emerged, followed by laboratory studies in 2019. This graph shows the growth of knowledge in different types of studies. Source: Alimi et al. (2021)

Globally, most studies on microplastic pollution have been conducted in the marine environment compared to the terrestrial environment, and the same applies to Africa. As demonstrated in figure 22, 37 studies have been conducted in the aquatic systems compared to freshwater systems with only 22 studies. In Africa, South Africa is the leading country in microplastic research, with 26 publications. On the other hand, South Africa and Nigeria (with 8 publications) are the only countries that have conducted research on microplastics in surface water, sediments, and marine and freshwater organisms. Since we now have a bit of understanding of microplastics in marine and freshwater sediments, surface water and organisms, it is about time to start looking at ways of mitigating microplastics in the environment.

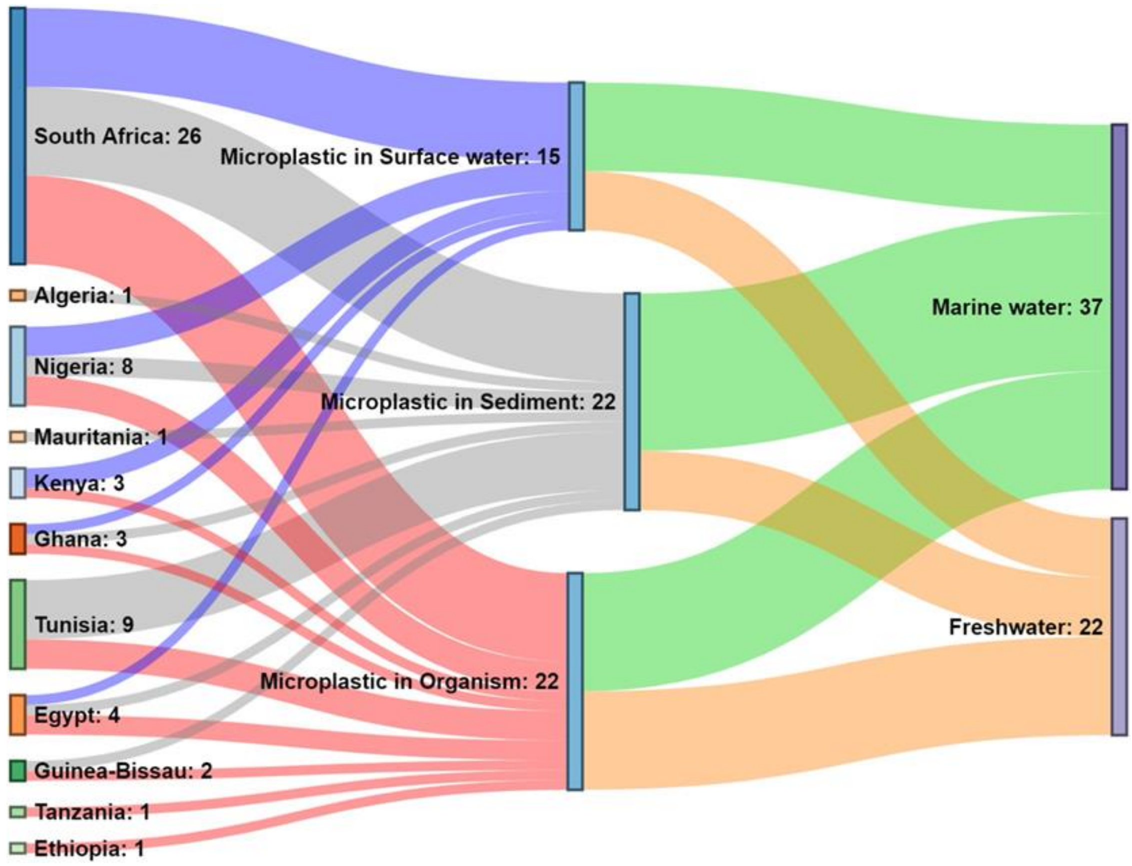

Figure 22: Distribution of publications reporting the abundance of microplastics in various environmental compartments. More research has been done in the marine environment and South Africa is the leading country in microplastic research in Africa. Source: Alimi et al. (2021)

In South Africa, Durban Harbour

South Africa is a developing country with a growing research effort on microplastics. Freshwater microplastics are unknown, and South African studies on marine microplastics are limited, but being pursued (Verster *et al*., 2017). According to Bouwman (2021), South African researchers still do not clearly understand microplastics in terms of how they are released, transformed, and transported. Verster *et al*. (2017) argue that even though the full environmental and biological impacts of microplastics in South Africa are not yet understood, the potential threats to biota and the environment should not be ignored.

The fact that South Africa is rich in natural biodiversity raises the need to quantify microplastics in the freshwater and marine systems (Verster *et al*., 2017). Recently, several studies have shown that all organisms within the food chain can potentially ingest microplastics, regardless of their feeding strategy (*ibid*.). This has the potential to affect the natural biodiversity in South Africa, thus, the impact of microplastics should not be taken lightly. Furthermore, several studies have measured the concentration of microplastics along the coastline of the South African coast. As one would expect, microplastics are highly prevalent near major coastal cities, including Cape Town and Durban (*ibid*.).

Considering the strong interactions between terrestrial organisms (including humans) and aquatic environments, the limited knowledge of South African aquatic microplastics is concerning (Verster *et al*., 2017). The growing research on microplastics, especially in the city of Durban, is paramount because high concentrations of microplastics have been recorded, as stated in Chapter 1 (Nel *et al*., 2017). Only a few studies have been done in the Durban Harbour, but we can expect an increase in the number of studies as more research is being done in the country. Several universities in South African are undertaking research on plastic and microplastic pollution, including "the Rhodes University, University of Kwa-Zulu Natal, North-West University, University of Cape Town and University of South Africa" (Verster *et al*., 2017:535). As more universities conduct research on microplastics, urban managers should start looking at mitigatory measures to avoid the unprecedented effect of microplastics in biota.

The Systems Approach

The Systems approach (also known as the Systems theory) is one of the management theories introduced in the 1950s (Jackson, Hitchins and Eisner, 2010). The systems approach is based on the generalization that everything is interconnected and dependent upon one another (Cooper, Eastman, Johnson and Kortanek, 1971; Jackson *et al.*, 2010). Therefore, a system is made up of related and dependent parts that create a cohesive whole when they work together (Jackson *et al*., 2010). According to Jackson *et al*. (2010), the systems approach views the world as containing interconnected systems and subsystems. In this case, the eThekwini municipality can be viewed as a system consisting of subsystems (departments). All these subsystems are interrelated and interdependent on each other, which means whatever happens in one subsystem will affect the other subsystems, thus, the whole system (Jackson *et al*., 2010). As a result, for the city to function well, there must be a balance between the subsystems (Cooper *et al*.,1971; Jackson *et al.*, 2010).

The eThekwini municipality is faced with many challenges, such as political strife, poor management, poor infrastructure maintenance, sewage pollution and corruption (Abrahams, 2020; Dawood, 2022). These challenges harm the functioning of the municipality, which means addressing the issue of microplastics will take a lot of work. Corruption is one of the major challenges faced by the city of Durban, and it is very problematic, because it harms the environment (Cordier, Uehara, Baztan, Jorgensen and Yan, 2021). Cordier *et al*. (2021) highlight that corruption can increase pollution by affecting the stringency of environmental regulation and enforcement. In addition, corruption in eThekwini municipality takes away the money that was supposed to improve and develop communities. The millions that disappear could have been invested in awareness campaigns about microplastic pollution, clean-ups, waste management strategies and waste removal infrastructure.

Conclusion

Globally, there are different sources of microplastics in the environment, from land-based to ocean-based sources. This means that tackling the issue of microplastics requires collaboration from different stakeholders. Moreover, there are two factors that influence the levels of microplastics in water bodies, including population density and seasonality. Since microplastics are a new area of study, there is a lot we still need to learn about the impacts of microplastics on the environment, especially on human health. The adverse effects of microplastics on aquatic animals and the potential impacts on human health have resulted in the introduction of international and national policies. However, South Africa has no policies for dealing with microplastic pollution. The existing policies have effectively reduced microplastics in the environment but are not satisfactory, because they deal with a portion of microplastics. Therefore, there is a lot we still need to do to deal successfully with this pervasive issue.

CHAPTER 3: STUDY CONTEXT

Introduction

Microplastics are a global problem and have been reported in every part of the world, including the Durban Harbour. Since microplastics originate from different sources, it means that sources of microplastics may differ from one place to the next. As a result, it is vital that we understand the context of this study. The first part of this chapter looks at the background of the Durban Harbour, population density and land use in the Durban Harbour catchment. The second part discusses the weather and climate in KwaZulu Natal (KZN) and looks at the Durban Harbour Catchment.

Background of the Durban Harbour

The Durban Harbour is located on the east coast of South Africa, KwaZulu-Natal, in the city of Durban, as depicted in figure 23 below (Rautenbach and Theron, 2018). The harbour is located at the core of Durban's Central Business District (CBD) (*ibid*.). In sub-Saharan Africa, the Durban Harbour is the major shipping terminal, and in the Southern Hemisphere, it is the fourth-leading container terminal and has diverse activities, including dry bulk, fishing and maritime activities, see figure 23 (South African History Online (SAHO), undated). Durban Harbour is a natural harbour, and it still preserves the shape of the original bay (SAHO, undated). Furthermore, mangrove swamps surrounding the Durban Harbour provide the ideal environment for many animal species (ibid.). In addition, the Durban Harbour attracts a lot of tourists, because of its central location, picturesque setting, and immense size (Rautenbach and Theron, 2018.).

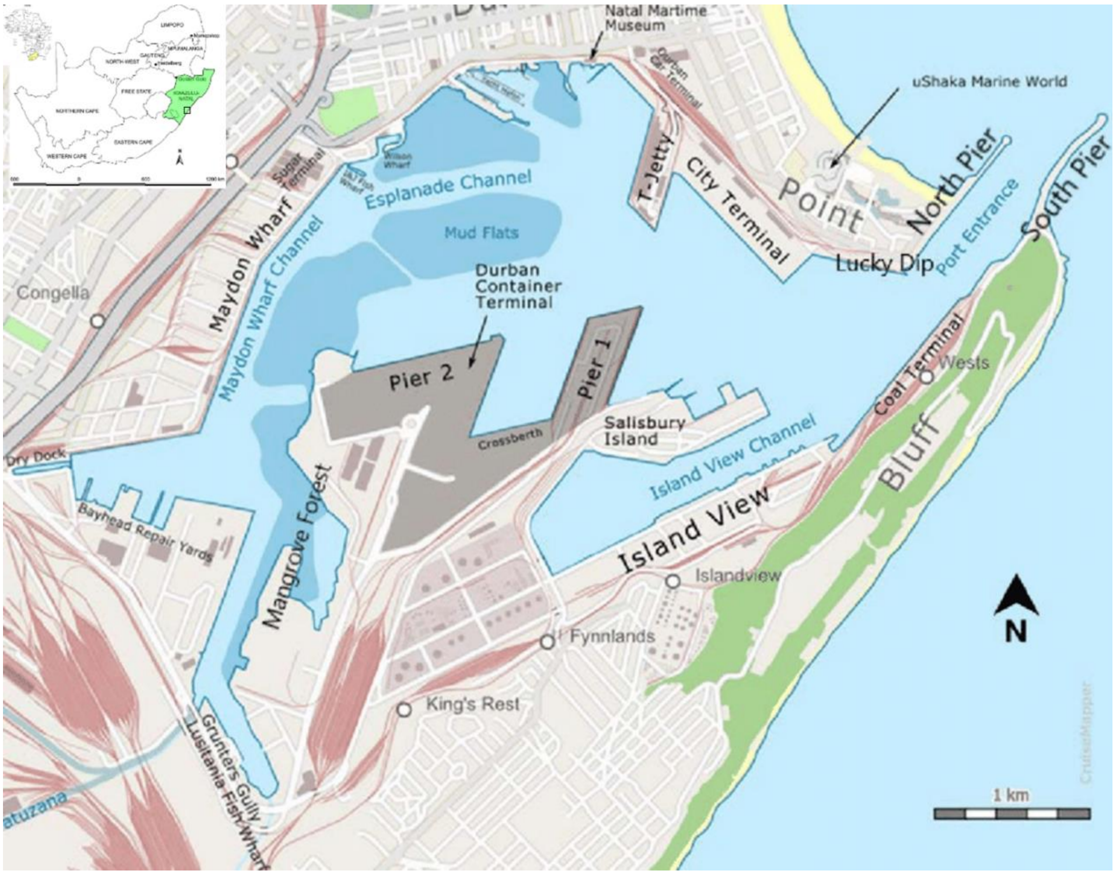

Figure 23: Locality map for Durban Harbour. The map shows the Durban Harbour and its different places (including, Salisbury Island, containers terminal, Mangrove Forest and Maydon wharf). Source: Kalina, Mbereko, Maharaj and Botes (2019)

The Durban Bay was first discovered in 1497 by a Portuguese explorer Vasco de Gama, when he was searching for a route to India, he came across the Port of Durban Bay (SAHO, undated). However, the Port was initially established in 1824 by British men from the cape colony (World Port Source (WPS), undated). During the 1860s, the railway arrived in the Port of Durban, connecting the harbour to the town (WPS, undated). The Durban Port grew rapidly after gold was discovered around the harbour (*ibid*.). Initially, the Port of Durban served as a bunkering port for ships (ibid.). As it grew, marine-related industries moved into the harbour (*ibid*.) In addition, chandlers, stevedores and shipbuilders set up different shops in the harbour, and a dry dock was built figure 24 (WPS, undated).

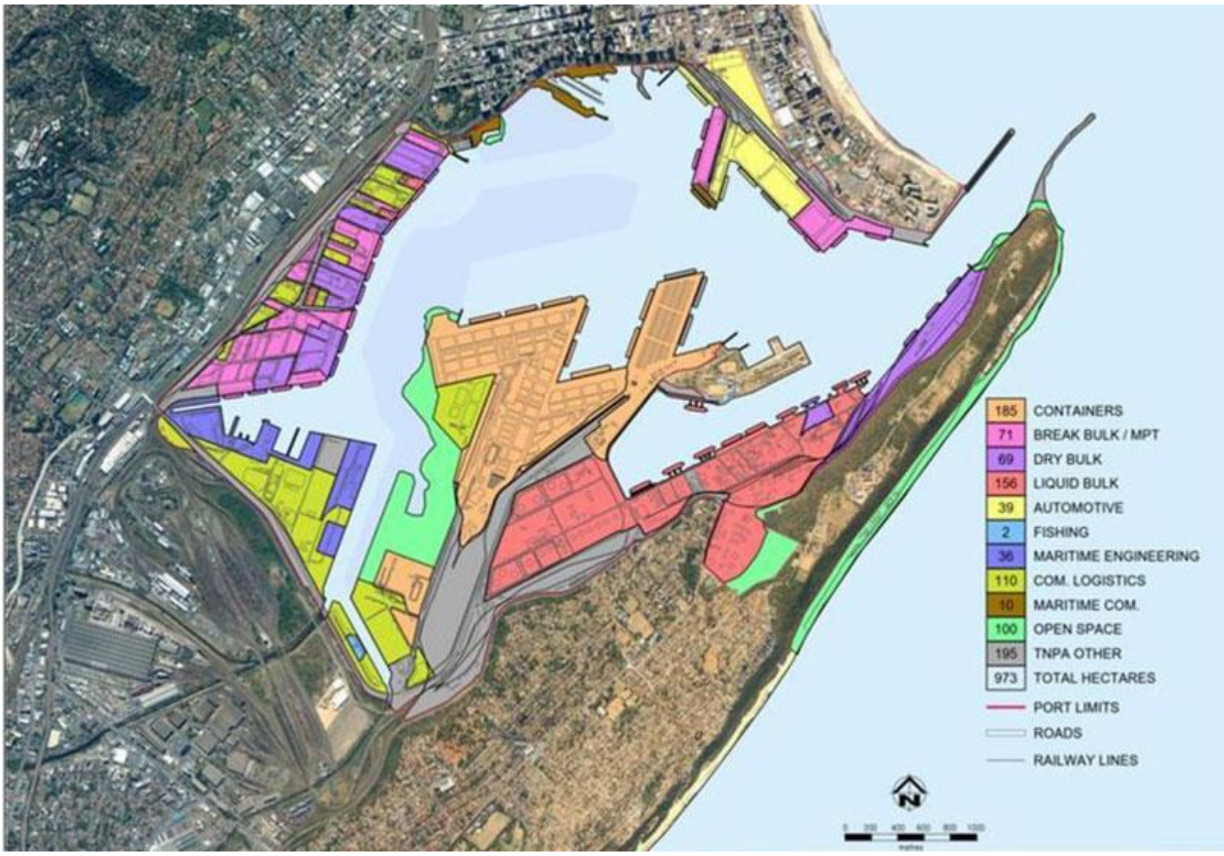

Figure 24: Activities in the Durban Harbour. This image illustrates the different activities, including the Durban container terminal, Dry and liquid Bulk, maritime engineering and fishing. Source: Kalina *et al*. (2019)

Population Density for Durban Harbour Catchment

The KZN region is one of the fastest-growing regions in South Africa (Stats SA, 2017). In 2017, it was ranked as the second most populated province in the country, with 11 million residents, with the majority located in the eThekwini municipality (General Housing Survey, 2017). Between 2001 and 2011, the population density within the eThekwini municipality grew at an average annual percentage of 1.13% every year, from 3.09 million to 3.44 million, respectively (Integrated Development Plan (IDP), 2020/2021). Statistics South Africa (Stats SA) projected the population density of the eThekwini municipality from 2020 to 2024 and it is estimated to increase to 4,164,503 million by 2024 (see table 4 below) (*ibid.*).

Table 4: Population projections for eThekwini municipality from 2020 to 2024.

Year	2020	2021	2022	2023	2024
Population Total	3947020	4004603	4059719	4112675	4164503

Source: eThekwini Municipality Integrated Development Plan (IDP) (2020/2021)

The eThekwini municipality is divided into 4 functional regions, which include the Central, North, South, and Outer West, as depicted in figure 25 (Musvoto, Lincoln and Hansmann, 2016). The Central region (where Durban Harbour is located) has the highest population (34%), followed by the North region (33%). The South region accounts for 23%, and the outer west has the least population of 11%, see figure 26 (Sutherland, Robbins, Scott and Sim, 2013). Undoubtedly, the ever-growing population raises many concerns about the microplastic levels in water streams, especially in the Durban Harbour, as more population is found in the Central region. One would expect an increase in the level of microplastics in the environment as the population increases with more people utilizing plastics and microplastics and this could get worse with poor waste management.

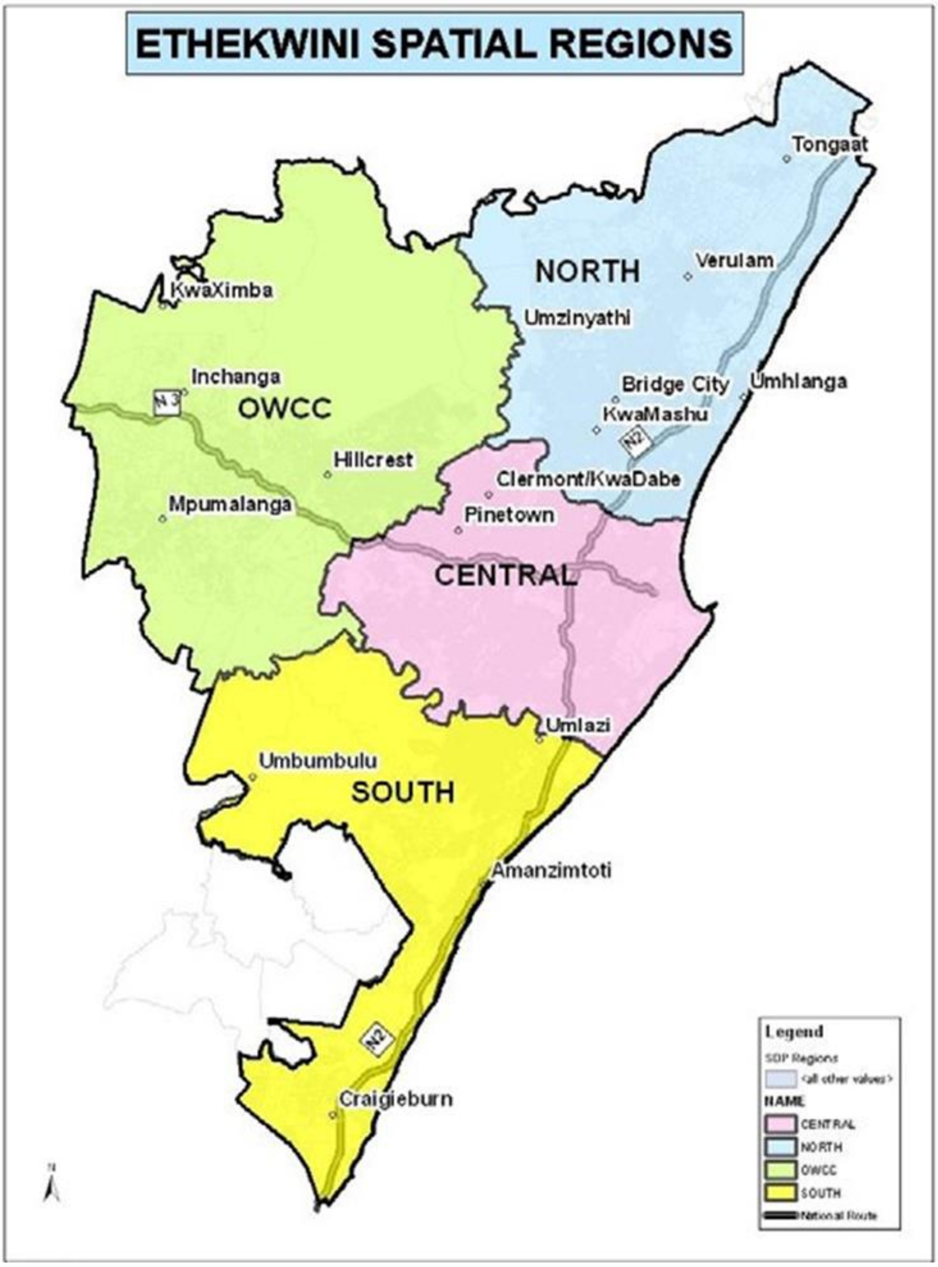

Figure 25: Spatial regions in the eThekwini municipality. The 4 spatial regions and their towns. Source: Sutherland *et al*., (2013)

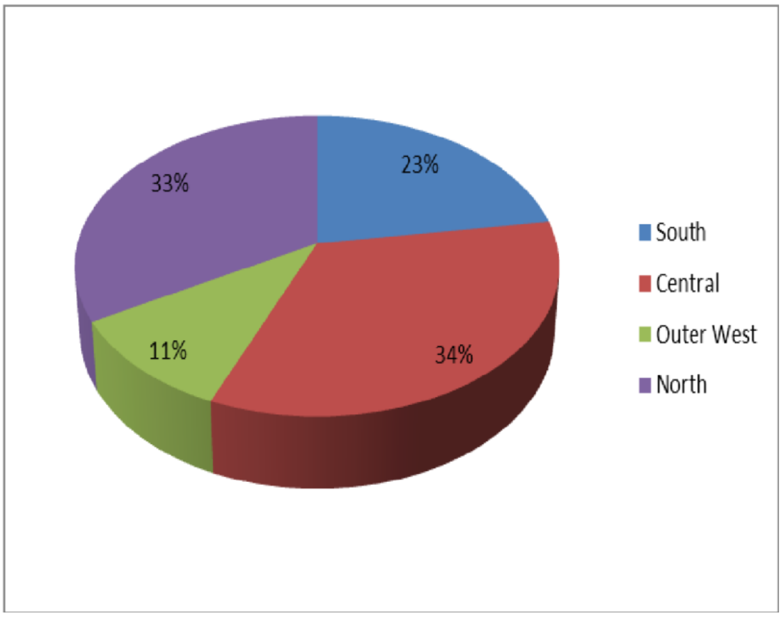

Figure 26: Spatial distribution of the population within the 4 regions in eThekwini municipality. Source: eThekwini Municipality IDP (2020/2021)

Land-Use and land-Cover in the Durban Harbour Catchment

The eThekwini Municipality is characterised by a broad range of land uses, such as urban, rural and informal settlements, accompanied by economic activities, transport, and public and social infrastructure (Khathi, 2018). The dominant land cover within the Durban Harbour catchment is residential and industrial areas which account for more than 70% of urban development, see figure 27 (Moodley, 2014). The natural vegetation covers 23% of the broader catchment, the remaining portion of the catchment is mostly covered by subsistence agriculture, accounting for 6% and the remaining 2% comprises of degraded bushland (*ibid.*). As we can see from the map below, the three rivers are urbanised as they are surrounded by mostly residential and industrial areas, which could be the major sources of microplastics in the Durban Harbour. Even though agricultural land covers 6% of the catchment, it's still contributing to the microplastic levels in the Durban Harbour. Most agricultural plots are located close to the rivers, and we can see the uMhlatuzana river passing through some agricultural plots.

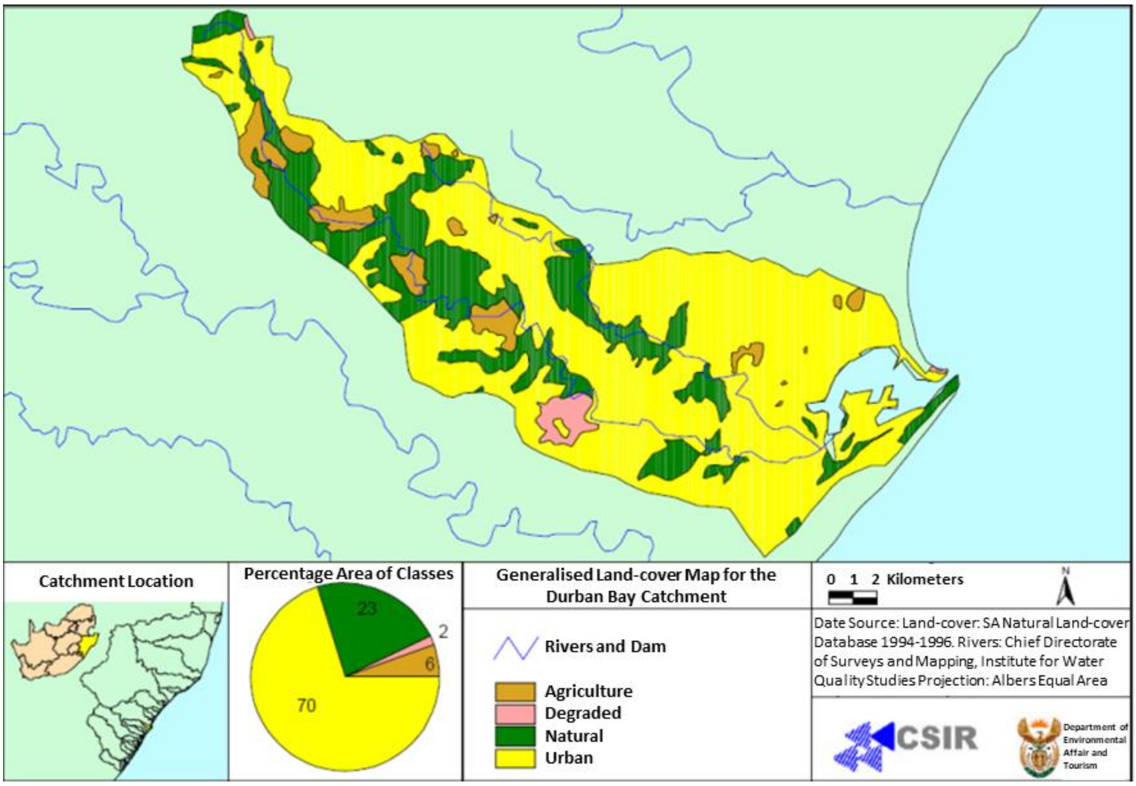

Figure 27: Generalized land cover map for the Durban Harbour Catchment. This map shows land cover (including residential areas, subsistence agriculture, degraded bushland and natural vegetation), rivers and dams. Source: Moodley (2014)

Weather and Climate

In KZN, the average summer temperature ranges from 27°C in January to March and 16°C in May and July. The province has a warm subtropical climate with an average annual rainfall of 1054mm, mainly in summer (Figure 28) (Moodley, 2014). The eastern side of South Africa is characterised by high rainfall, and rainfall decreases as you move to the west side (*ibid*.). The KwaZulu Natal province receives rainfall between 601mm to 1,200mm. It is estimated that 80% of the annual rainfall occurs during the summer months, causing the catchments to flood regularly and causing high river flows in the steep hinterland(*ibid*.). As the catchments flood frequently, the three rivers carry a lot of waste straight into the harbour. Therefore, freshwater inflows into the harbour during the summer will likely increase, resulting in higher levels of microplastics in the harbour.

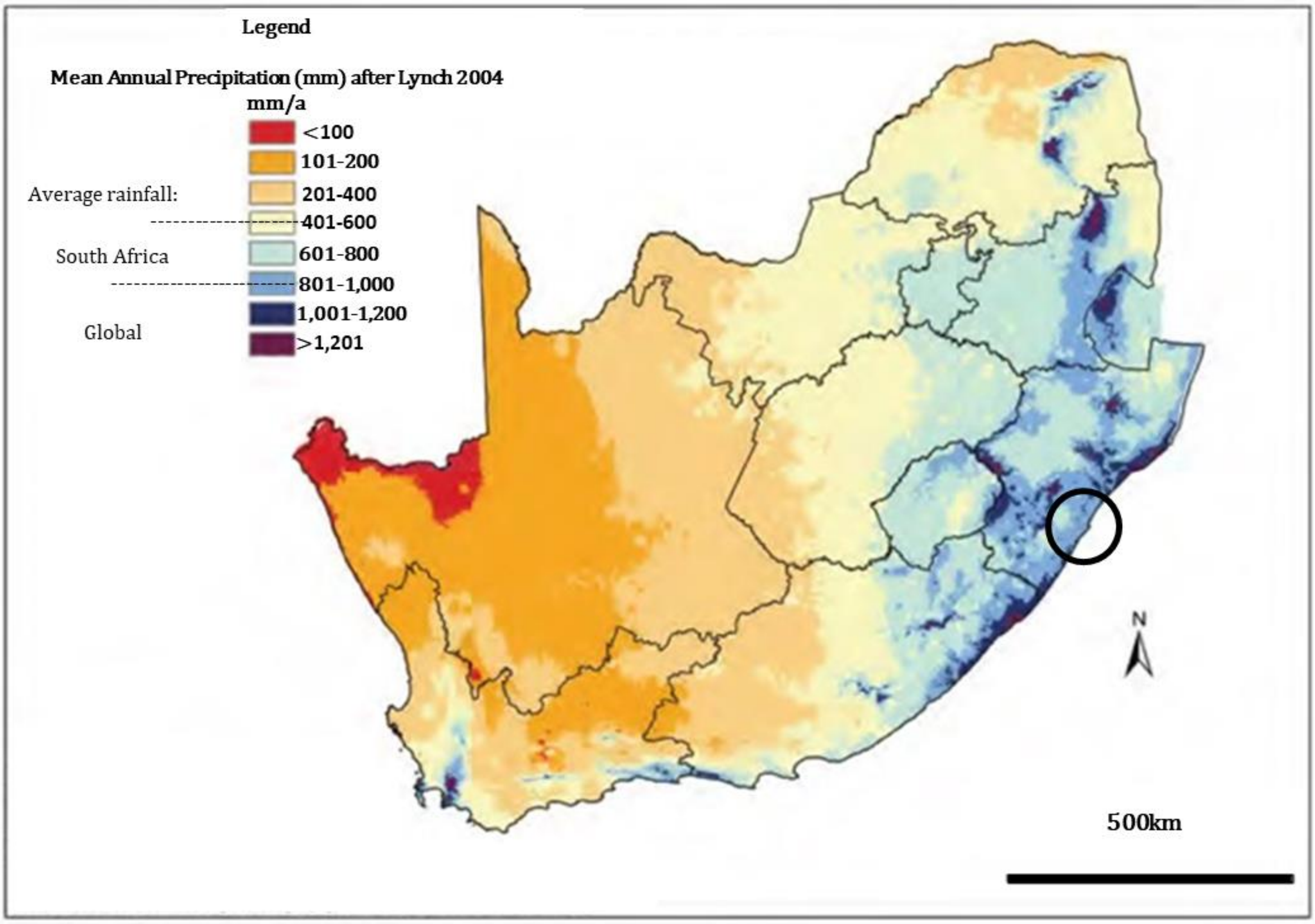

Figure 28: Average annual rainfall in South Africa. This map illustrates South Africa's average annual rainfall, with Durban Harbour highlighted in a black circle. Source: Moodley (2014).

Durban Harbour Catchment

Durban Bay has been categorised as an estuary bay, and an estuary bay is a large tidal system that receives freshwater input and water from the ocean (Department of Environmental Affairs (DEA), 2015). Estuarine bays are the rarest estuarine type in the country, with only Richards Bay, Durban Bay and Knysna falling within this category (DEA, 2015). The Durban Bay consists of three river catchments, which include aManzimnyama, uMbilo and uMhlatuzana river catchments, as seen in figure 29 (Moodley, Pillay and Pather, 2015; Moodley, Pillay, Pather and Ballabh, 2016). The three rivers are located at the center of the urban and industrial zone, which make them largely urbanized river systems (Moodley, 2014; Moodley *et al*., 2016). These rivers are the main freshwater systems draining the different catchments into the Bayhead Canal of the Durban Harbour (Moodley, 2014; DEA, 2015; Moodley *et al*., 2015; Moodley *et al*., 2016). This means that the three rivers bring a lot of waste into the Durban Harbour, including plastic and microplastics.

Figure 29: Rivers in the Durban Harbour Catchment. This map presents the three rivers (uMbilo, uMhlatuzana and aManzimnyama) within the broader Durban Harbour catchment. Source: Moodley *et al*. (2016)

The uMhlatuzana river catchment covers about 113 km^2 and has a length of about 50 km, which makes it the largest river catchment in the Durban Harbour catchments (Naidoo, 2013; Moodley *et al*., 2016). Moreover, the uMbilo river catchment is approximately 67 km^2 in size and 35 km in length, while the aManzimnyama river catchment is only 15 km in size and 5.5 km long, making it the smallest catchment (Naidoo, 2013; Moodley *et al*., 2016). Combined, the three rivers' catchment areas cover about 250 km^2, which falls completely within the boundaries of the eThekwini Municipality (DEA, 2015). Anthropogenic land use has resulted in deterioration of river health in these catchments due to the increase in water usage in the last few years (Moodley, 2014). In addition, four Wastewater Treatment Works (WWTWs) are also present in the Durban Harbour catchments, which discharge wastes directly into the three rivers (Moodley *et al*., 2015).

Conclusion

There are many activities in the Durban Harbour, like fishing and maritime engineering. The Durban Harbour is located in the central region, which has the highest population compared to the other regions. The Durban Harbour catchment is dominated by residential and industrial areas. Moreover, the Durban Harbour is located on the east side of South Africa, which receives high rainfall, especially during summer. The three rivers in the Durban Harbour catchment cover a large area. As a result, the Durban Harbour receives water input from different sources, including the three rivers. The various activities, population density and land in the Durban Harbour catchments could contribute to microplastic pollution in the Durban Harbour.

CHAPTER 4: FINDINGS AND ANALYSIS

Introduction

The Durban Harbour is different from other harbours in the world because it receives inputs from three rivers, including the Amanzamnyama river, Umbilo river and uMhlatuzana river. These rivers bring a lot of plastics and microplastics into the Durban Harbour. This means everyone should be involved when dealing with microplastics in the Durban Harbour because of these different sources. To get a better understanding of microplastics in the Durban Harbour, five interviews were conducted with microplastic experts. This chapter will first discuss the sources of microplastics in the Durban Harbour. Secondly, it looks at the factors that affect microplastic concentrations in the Durban Harbour such as population density and seasonality. Thirdly, it discusses the effects of microplastic in the Durban Harbour, including ecological, social and economic impacts. Lastly, its looks at the mitigatory measures proposed during the interviews.

Sources of Microplastics in Durban Harbour

Before looking at the mitigatory measures to dealing with microplastics, we need to understand the primary sources of microplastics in the Durban Harbour. It is clear from the interviews and literature that the Durban Harbour receives microplastics from different sources, which means that dealing with them will be very challenging and require collaboration between the government, industries, and the community.

All harbours around the world receive microplastics from the land (land-based sources) and the ocean (ocean-based sources) (Romeo *et al*., 2015). This is in agreement with what the respondents said, they all mentioned that the Durban Harbour receives microplastics from the surrounding catchments (land-based sources) and their operations (ocean-based sources). The land-based sources include industrial and commercial activities, Wastewater Treatment Works (WWTWs), the three river catchments, CBD, and agricultural activities. Ocean-based sources include fishing, Spillages of cargo, recreational activities and dredging. All respondents consider the sources above as possible primary sources of microplastics in the Durban Harbour. As stated by Romeo *et* *al*. (2015), harbours are a major interface between coastal cities and the sea, thus, they are often under heavy anthropogenic pressure. Coupled with that, harbours are important hotspots for human-meditated environmental stress, which may increase microplastic concentration in these harbours and that makes harbours special in this case (Romeo *et al*., 2015). It is clear that there a many human activities centred around the Durban Harbour, which fuels the high concentration of microplastics.

According to the interview responses, a large number of microplastics come from the heavy industries in the CBD, the surrounding areas, and the industries within Durban Harbour itself. This is in line with Govender *et al*. (2020) statement that the Durban Harbour is largely surrounded by industries. This makes sense because Durban Harbour is a heavily industrialized Port, and many industries make use of plastics and microplastics in their operations. In addition, there is a lot of plastic and microplastic shipping within the Durban Harbour, and spillages are more likely to happen, for example, pallet (microplastic) spillage occurred in the Durban Harbour in 2018 when two container ships collided (Moodley, 2020).

All respondents highlighted that many plastics and microplastics enter the Durban Harbour via the three rivers, including the Amanzamnyama river, Umbilo river, and uMhlatuzana river. These rivers drain industrial, commercial, and residential areas, including rural areas and informal settlements, resulting in more plastic waste in the rivers because of poor waste management. Durban Harbour is a bit similar to the harbour of Nieuwpoort in that the harbour of Nieuwpoort reported high concentrations of microplastics because of the several rivers (more than six rivers) that are connected to the harbour (Claessens *et al*., 2011). This shows that the rivers play a significant role when it comes to microplastic concentrations in harbours and the ocean, and that tells us about the interventions needed to limit the amount of microplastics in the environment.

Respondents also alluded to the fact that the three rivers receive industrial wastewater discharges from the surrounding industries, effluent from stormwater drains, and wastewater discharges from the Wastewater Treatment Plants (WWTPs). As discussed in Chapter 3, there are four registered WWTPs within the Durban Harbour catchments (Moodley *et al*., 2015). As a result, the WWTPs discharge effluents, contaminated with microplastics, into the river systems of the uMhlatuzana and Umbilo catchments, and it goes straight into the harbour. The four WWTPs may be one of the major sources of microplastics in the Durban Harbour, since Karbalaei *et al*. (2018) argue that WWTPs are regarded as one of the most dominant point sources of microplastics to the aquatic environment. Furthermore, Verster and Bouwman (2020) argued that about 40% of South Africa's effluent is left untreated because of the deteriorating WWTPs, which makes the situation worse. This means that the WWTPs in the eThekwini municipality fail to remove larger quantities of microplastics, posing a threat to the environment.

Most of the informal settlements in the Durban catchment are located along the riverbanks (figure 30). Microplastic experts 1 and 3 Highlighted that these informal settlements do not have access to basic services, including potable water, lack of waste management systems, stormwater drains and wastewater drains. Waste in these areas is not collected and they need proper bins to dispose of waste. As a result, it is disposed of directly and indirectly into the rivers. According to the literature (Verster and Bouwman, 2020), the absence of waste removal infrastructure, informal settlements, poorly managed waste, urban run-off and littering has resulted in a loss of plastic waste in the South African environment. Since these informal settlements are located along the rivers, larger quantities of waste, including plastics, make their way into the river and eventually into the Durban Harbour. In addition, during heavy rains, a larger number of plastics lying around in the informal settlements make their way into the rivers.

Figure 30: Informal settlement along the Umbilo river. Source: created from Google Earth (2021)

As stated in Chapter 2, marine activities influence the levels of microplastics in the ocean (Karbalaeiet *et al*., 2018). All respondents mentioned that there are a lot of maritime activities in the Durban Harbour, which could be major sources of microplastics, for example, shipping, industrial activities, boating cruise activities, fishing, ship repairs dredging and restaurants. During shipping and recreational activities (boating cruises), plastics and microplastics can be directly and indirectly discarded into the harbour (see figure 31. This picture shows plastic waste inside the harbour waters, which might have been discarded by someone who was in the yacht or someone walking by. We can expect more waste inside the harbour during the holiday seasons when more people are in the harbour and enjoying the harbour activities.

Figure 31: Waste inside the Durban Harbour. This image shows waste inside the harbour, which could originate from recreational boating. Source: Ngcobo (2021)

Fishing is allowed in the Durban Harbour but is restricted to certain areas, as shown in figure 32. The respondents highlighted fishing as one of the sources of microplastics in the Durban Harbour. They also argue that the fishing gear and ropes that are used break down into microfibres contributing to the level of microplastics in the harbour. According to the literature, discarded, abandoned or lost fishing gear (including ropes and nets) are considered one of the sources of microplastics (particularly microfibre) in the ocean (de Villiers, 2019; Lusher and Pettersen, 2021). Fishing in the Durban Harbour is not extensive since it is only restricted to certain areas, thus, fishing might not be one of the primary sources of microplastics in the harbour, but it still contributes. More research is needed in this regard to examine the impacts of fishing on microplastic levels in the Durban Harbour.

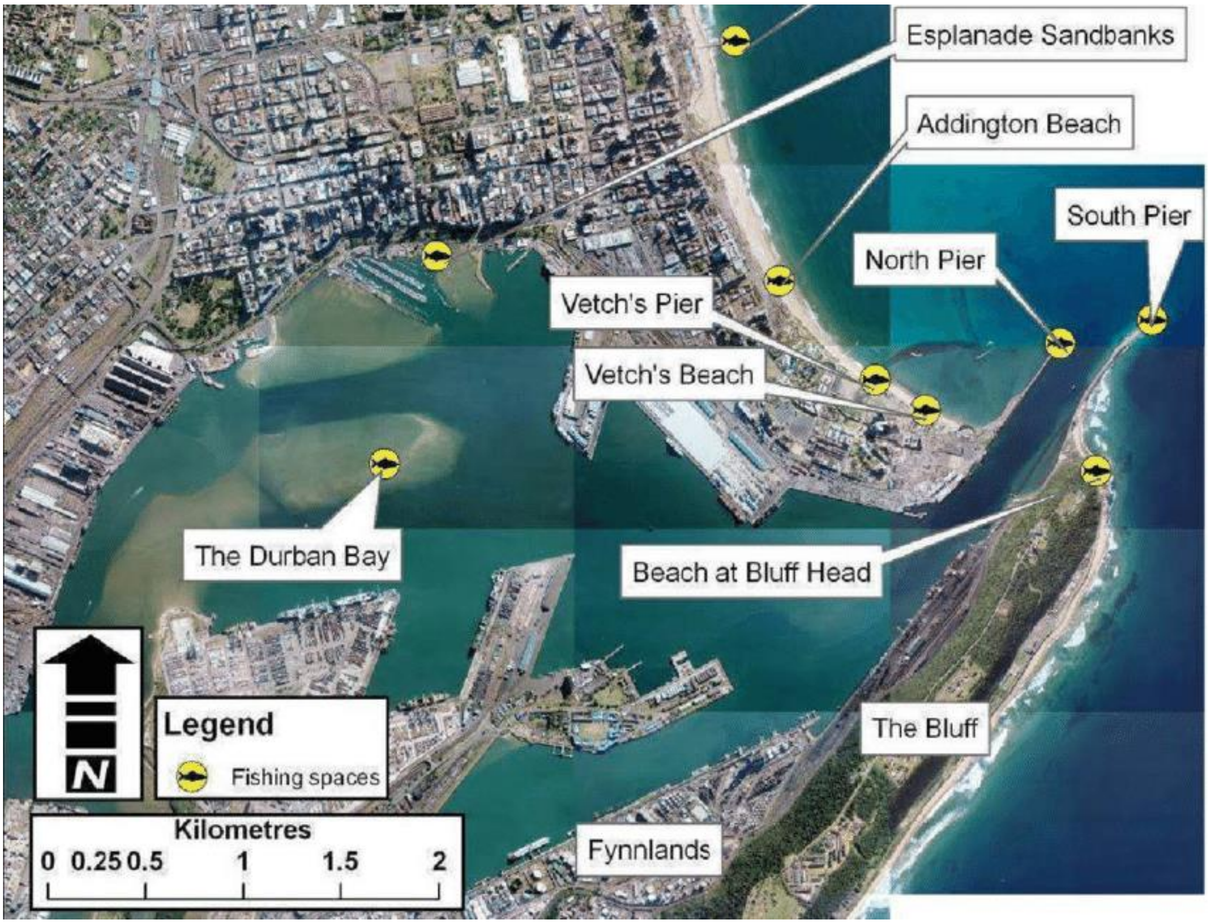

Figure 32: Fishing spaces in the Durban Harbour. This map displays areas where fishing is allowed within the Durban Harbour (like Durban Bay and Addington Beach). Source: Kalina *et al*. (2019)

There are many restaurants in the Durban Harbour, which attracts a lot of people. Consumers discard plastic waste into the harbour (intentionally or unintentionally), and some waste is poorly discarded on the floor and makes its way into the water (see figure 33). Microplastics expert 4 mentioned that Wilson Wharf has a lot of people because of the restaurants there. These restaurants make use of plastics that could be poorly discarded and make their way into the Durban Harbour, where they can eventually break down into microplastics. Microplastic expert 4 also stated that if one were to walk there during a low tide, one would see a lot of plastics that have accumulated there, and many discarded plastics have been transported to Wilson Wharf by the wind.

Figure 33: Restaurants and waste inside the Durban Harbour. The trash inside the harbour could originate from the surrounding restaurants due to littering. Source: Ngcobo (2021)

Overall, many activities in the Durban Harbour cause plastic pollution. Because of poor management within the harbour, these plastics float all over the harbour and eventually breakdown into microplastics (figure 34). As highlighted in Chapter 2, a daily collection of waste within the harbour does occur (as represented in figure 35) as part of the Blue Port Project, which was introduced in 2019 (International Union for Conservation of Nature (UICN), 2021). The project employs local youth from surrounding communities, and the youth collects, monitors and tracks waste to understand the movement of waste in the Durban Harbour (UICN, 2021). This project helps limit the amount of waste in the harbour, but it is not enough because it is nearly impossible to collect all waste within the harbour. Also, clean-ups are time-consuming, and some waste is hard to reach, especially if it is in water. As a result, it is important that we prevent microplastics from reaching the Durban Harbour because prevention is better than cure.

Figure 34: Waste pollution in the Durban Harbour. These images show waste around the Durban Harbour and floating in the Royal Yacht Club. Source: Ngcobo (2021)

Figure 35: Collection of waste in the Durban Harbour. This image shows the youth collecting trash in the Durban Harbour, as part of the Blue Port Project. Source: Ngcobo (2021)

Factors Influencing levels of Microplastics in the Durban Harbour

Population Density

There are different views on the relationship between population density and the level of microplastics in the Durban Harbour. Within the five respondents I interviewed, three agreed that population density greatly influence the amount of microplastics in the Durban Harbour. They stated that the Durban Harbour is different from other harbours in the world because it is located right next to the Central Business District (CBD) with a high human population, which includes the people living and working there. They also pointed out that there are heavy industries occurring in and around the Durban Harbour, and the harbour has three rivers that flow into it, each of these rivers drains industrial, commercial and residential areas, and they pass through larger areas that do not receive service delivery such as proper waste management systems. As a result, these rivers carry a lot of plastics and microplastics, amongst other pollutants, within them. In addition, if we look at the rural areas and informal settlements, they do not have proper bins and proper infrastructure, thus, their waste goes straight into the rivers.

Moreover, the interviewees' arguments closely align with what some scholars say about the relationship between microplastics and population density. For example, Nel *et al*. (2017) point out that population density and human activities influence the level of microplastics in water bodies, including harbours. For instance, Govender *et al.* (2020) found a positive correlation between population density and microplastic concentrations in the five urban estuaries of KwaZulu Natal, including Durban Harbour. Similarly, Nor and Obbard (2014) reported a positive correlation between microplastic concentration and the level of human activities in Singapore mangroves.

In contrast, the other two respondents had a different take. On the one hand, microplastic expert 2 argued that the relationship between the two factors is an assumption that is not always true because even agricultural areas are still exposed to plastics, and even rivers in isolated areas do have a high amount of microplastics which might originate from upstream. Microplastic expert 2 also stated that since microplastics are very tiny, they can be transported via air, which means that even isolated areas far away from industries and surrounded by a low population are also prone to have a high amount of microplastics in their water systems. This agrees with other studies that reported a negative correlation between the two factors. For example, Wang *et al*. (2017) reported a negative correlation between microplastic pollution in urban lakes and distance from the city centre. Likewise, Lake Hovsgol in Mongolia is reported to have high concentrations of microplastics, even though it is characterised by a low population density and limited human activities (Shahul *et al.* 2018).

On the other hand, microplastic expert 3 pointed out that there is no correlation between microplastics and population density, because the amount of microplastics in the environment depends partly on population, but a lot of it depends on the level of waste management that there is in any particular society. He made an example that if we have a community with a high population but with proper waste management, they will have relatively little microplastic in the environment, but if there is a reasonably small population but no waste management, they are going to have a lot of plastic and microplastics in their environment. Furthermore, microplastic expert 3 argued that the level of microplastics in the environment is influenced by a balance between waste produced, waste managed and waste that becomes pollution when it enters the environment. Therefore, the relationship between the levels of microplastics and population density is not straightforward, but it depends on many factors that need to be investigated.

I agree with microplastic expert 3 in that the level of microplastics in the environment depends not only on population density but also on many factors, such as waste production and the availability of waste management systems. There may not be a correlation per se, but population density and human activities might influence the microplastic concentrations in the Durban Harbour. Since there is poor waste management and insufficient infrastructure for waste removal in the Durban Harbour catchments, it means more waste (like plastics and microplastics) ends up in the environment (Verster and Bouwman, 2020). Moreover, as stated in Chapter 3, eThekwini municipality has a high population density, which makes this situation worse because it means there are many people making use of plastics which is never properly disposed of and managed (General Housing Survey, 2017). As a result, more plastics in the environment slowly break down into microplastics and eventually enter the Durban Harbour.

Seasonality

Seasonality is one factor that influences the level of microplastics in water bodies. However, no research has been conducted on the relationship between seasonality and the level of microplastics in the Durban Harbour. Four out of the five respondents argued that it is highly likely that there is a link between seasonality and the level of microplastics in the harbour. They alluded to the rainfall factor and the river velocity. This aligns with Govender *et al*. (2020) findings, where they discovered that there were more microplastics in the Durban Harbour during the wet season. As discussed in Chapter 3, South Africa has high summer rainfall, which means river velocity in the three rivers increases. As a result, Microplastic experts 3 and 4 stated that more water is flushed into the harbour, and there is probably more plastic and microplastic being carried with it and accumulating more into the harbour.

According to Microplastics expert 1, in South Africa and any other country with a strong signal for rainfall, one can expect to see a link between microplastic levels and seasonality. Microplastics expert 1 pointed out that seasonality within the port of Durban has a huge impact when it comes to plastics, and because of that, it is highly likely that microplastics will show a seasonal signal as well. Similarly, Microplastic expert 3 stated that the first heavy storm brings down a lot of plastics that were either buried further upstream or on the riverbanks of the three rivers into the Durban harbour. Furthermore, microplastic expert 4 raised an important point that there are a lot of storm water drains within the Durban Harbour catchment, thus, if there is more rainfall, it is going to bring all of that litter from upstream straight into the Durban Harbour. Microplastic expert 1 pointed out that the CBD also brings in a lot of plastics into the Durban Harbour when it rains, for example, looking at the Durban CBD, the rainfall washes the road clear of plastics and microplastics (including those that break off from car tyres and road marking paint) into the storm water drains straight into the Durban Harbour.

Clearly, we can expect two things to happen during rainfall in the Durban Harbour. Firstly, some plastics slowly break down into microplastics as they are transported into Durban Harbour. Secondly, we might have microplastics that have settled further upstream coming down into the Durban Harbour at the same time. Microplastics expert 1 highlighted that even after heavy rains, there will still be a high signal of microplastics, because plastics will still be breaking down into microplastics, as plastics take a long time to fully clear out. However, microplastics expert 2 does not see any link between the two factors and argues that some studies did not find any link between seasonality and microplastics because, within the marine environment, there is already a lot of microplastics that have accumulated over time. As a result, if you add a little bit in a short time, you will not see an effect because the microplastic levels are already so high. Microplastics expert 2 further made an example that if there are 10,000 microplastics in water and it rains and plastics get into that water and there are now 10,200 microplastics, in that regard, it is statistically impossible to say that is due to seasonality.

I agree with the four microplastic experts that seasonality influences microplastic concentrations in water bodies. The Durban Harbour receives water input from a number of storm water drains and the three rivers that cover a large area hand because of this, we can expect more waste (especially plastics) in the harbour. Figure 36 shows Durban Harbour after heavy rains, this happened after a heavy storm in March 2021 (Guy, 2021). It would have been a different story if there were proper waste management systems in these catchments, maybe there would not be so much waste in the Durban Harbour after heavy rains, but unfortunately, that is not the case. As mentioned in Chapter 3, eThekwini municipality experiences 25 degrees to 30 degrees Celsius of sunlight during summer, thus, we can expect more microplastics in the Durban Harbour as plastics continue to breakdown to microplastics from being exposed to high Ultraviolent (UV) rays.

Figure 36: Pollution in the Yacht mole, Durban Harbour. This happened after a heavy storm in 2021. The storm transported waste from upstream into the Durban Harbour. Source: Guy (2021)

Impact of Microplastics in the Durban Harbour

Ecological Impacts

The negative impacts of microplastics on the environment are still being explored globally. There is a lot we do not know about the effects of microplastics in the Durban Harbour. Thus, the is a need for more research in order to understand these impacts. It is clear from the interviews that the effects of microplastics in the Durban Harbour are very hard to pinpoint. According to microplastic expert 1, microplastics in the Durban Harbour are a straight pollutant, and they carry other contaminants with them. Similarly, microplastic expert 5 stated that microplastics are a big problem because their large surface area attracts other toxic contaminants to attach to them. These arguments align with Ha and Yeo (2018), Amelia *et al*. (2021) and Bezerra *et al*. (2021), who argued that microplastics could carry toxic contaminants like additives and heavy metals. This means that animals exposed to microplastics will suffer from impacts caused by microplastics and the pollutants they carry with them (Amelia *et al*., 2021).

The interview responses indicated that the effect of microplastics in the Durban Harbour would be more direct to the aquatic life. For example, if the zooplankton eats microplastics, marine species that eat zooplankton are affected, and the food web also gets affected (Barboza *et al*., 2018). In addition, microplastic experts 3 and 5 emphasised that invertebrates like crabs or sand prawns living in the Durban Harbour could all potentially suffer negative effects, such as slow growth and tissue inflammation, both from directly ingesting microplastic or from effects on the food chain (Vethaak and Legler, 2021).. However, these negative impacts are very hard to quantify in the environment. Nevertheless, it is clear from the interviews that the aquatic animals at the bottom of the food web are exposed to microplastics, affecting both the food web and the food chain in return. This means humans are also exposed to microplastics and could suffer negative impacts (Vethaak and Legler, 2021).

According to Beaumont *et al*. (2019), as microplastics and associated pollutants contaminate the food chain, aquatic animals like shellfish and fish stocks can suffer from lethal and sub-lethal effects. The information gathered from the interviews also demonstrates that the presence of microplastics in the harbour could have sublethal effects. In other words, animals consuming microplastics, microplastics are reducing their health and growth. Microplastic expert 3 elaborated that, over time, this will negatively affect the whole population of these animals, causing a knock-on effect up and down the food web (Barboza *et al*., 2018). This raises a lot of concern for biodiversity in the Durban Harbour because it is a diverse biological hub for many species (Guastella, 1994). Having discussed the ecological impact of microplastics, the following section takes this analysis further by examining the potential economic and social impacts of microplastics in the Durban Harbour.

Social and Economic Impacts

Globally, we do not know much about the social and economic impact of microplastics, and no study has been done in South Africa that looks at the economic and social effects of microplastics (Verster *et al*., 2017). Therefore, it was a bit difficult for the respondents to predict these effects in the Durban Harbour. Three of the five respondents stated that microplastics that are 5 mm are big enough to be visible and cause a significant aesthetic effect, especially in recreational areas. Microplastic expert 5 highlighted that microplastics visible to the human eye have negative implications on tourism. Certainly, people do not want to go to the beach where there is a lot of litter. This might have unprecedented impacts because the Durban Harbour is a tourist attraction with many activities.

Over and above that, all respondents argued that people who practise subsistence fishing in the harbour are exposed to microplastics when consuming contaminated seafood, which can negatively impact their health (Vethaak and Legler, 2021). Two respondents argued that mussels in the Durban Harbour have been reported to have high levels of microplastics and because people eat the entirety of a contaminated mussel, they eat microplastics too. This resonates well with Beaumont *et al*. (2019: 191) argument that "the consumption of microplastics by humans will occur when the entirety of a contaminated organism (anchovies, mussels, sprats, oysters), including the gut, is eaten." Even though we do not know how extensive fishing is in the Durban Harbour, nor if there are restaurants that catch their fish in the Durban Harbour. If restaurants fish there, that could exacerbate the impacts of microplastics because more people are exposed to these toxic pollutants. Microplastic expert 3 made an important argument that microplastics can be transported from the Durban Harbour to the ocean (East Coast beach) where there is commercial fishing happening and this means that people consuming this contaminated seafood would suffer the impact. He further argued that this could also have an economic impact because if people are aware of the potential impacts of microplastics, they will end up not buying seafood, which will affect the seafood industry, thus affecting the economy.

Moreover, microplastic experts 4 and 5 stated that as people become more aware of microplastics, they will slowly migrate from Personal Care and Cosmetic Products (PCCPs) such as toothpaste containing microbeads. In that sense, it could affect the economy where there is less demand for these types of products. Therefore, what I can pick up from the interviews is that most of the social and economic impacts of microplastics in the Durban Harbour are indirect impacts that should be taken into consideration when dealing with microplastics.

All respondents emphasised that the economic effects of microplastics come in as the cost of removing microplastics from the environment. Microplastics are very difficult and expensive to collect because of their small size, even when the beaches are being cleaned, most microplastics are often left behind (Leslie, 2014). In that case, they continue to contaminate the environment. For example, there was a big spill of plastic pellets in the Durban Harbour in 2017. Another big economic cost, highlighted by microplastic experts 1, comes in when the government has to introduce solutions, such as putting filters in the washing machine to prevent microfibres from entering the environment directly or via WWTPs.

Mitigatory Measures to Microplastic Pollution in the Durban Harbour

As mentioned in the literature review, there is an argument regarding the banning of microbeads in PCCPs. Some argue that the banning of PCCPs is unnecessary because it does not contribute much to limiting the number of microplastics in the environment.

This argument is based on most studies that discovered that the dominant type of microplastics is microfibers and not microbeads (Karbalaei *et al*., 2018). Thus, other researchers are arguing against the banning of microbeads. However, all respondents saw the need for the South African government to follow countries like Sweden, Canada, New Zealand and France in the banning of microplastics in personal care products. They argued that banning microbeads will help limit the amount of microplastics in the environment or specifically in the Durban Harbour.. I also agree with them because it is better to start doing something now, because later might be too late.

The fact that other countries like the United Kingdom and the United States of America have introduced policies that ban the use of microbeads shows their willingness to deal with the issue of microplastics. Microplastics expert 2 argued that this is a miserable failure from our government because some countries are at least doing something to deal with microplastic pollution. Banning microbeads will be the first step to dealing with these pervasive issues. Also, microbeads are an addition to PCCPs, which means we can do without them. They are not necessary and can easily be replaced by something.

Mitigatory Measures Proposed by Respondents

Regarding the mitigatory measures that can be taken to deal with microplastic pollution in the Durban Harbour, all respondents proposed measures that can be implemented to deal with microplastic pollution. According to the respondents, it must be noted that once microplastics are in the environment, it is extremely difficult to collect from the environment. It depends on their size, some microplastics of a certain size can be taken out of the harbour, especially if they float, but it would be an immense amount of work and very expensive.

The interview responses indicated that a very immediate effective solution to microplastics is preventing or minimizing plastic waste entering the Durban Harbour. That is crucial because limiting the number of plastics entering the harbour means there will be no plastics breaking down into microplastics. The aim is to limit the amount of microplastics being added to whatever is currently in the Durban Harbour. The target of solutions should be upstream because a lot of plastics come from upstream on the Durban Harbour catchments. However, a considerable amount of macroplastics also come from the Durban Harbour itself. A lot can be done to prevent plastics from entering the Durban Harbour, and the conclusion chapter will take this further by looking at the actions that urban managers can take.

On the one hand, some respondents argued that the government should be at the forefront of dealing with the issue of microplastics in the Durban Harbour. Still, it is not only government that has to take responsibility for dealing with this issue. Respondents also highlighted that the industries that produce and use plastics and microplastics must also take responsibility, and the extended producer responsibility (EPR) will play a significant role in ensuring that industries are held responsible for the disposal of their plastic products. Recently, South Africa introduced mandatory EPR on the 5th of May 2021, which is a good start.

On the other hand, some respondents argued that it is not the government, but the people in academia, such as microplastic experts should be at the forefront of dealing with microplastics in the Durban Harbour. This is because microplastic experts are aware of microplastics and they can teach government, industries, and communities about microplastics since it is a new field of study. This is vital because people need to be fully aware of microplastics to see the need to do something about them. We cannot expect them to take responsibility for something they do not know, but if they know better, they can do better.

In South Africa, it has become a norm to say that the government should take the lead in solving all the problems faced by the country. But is the government able, or is it feasible for the government to take the lead in dealing with these problems? For example, even with dealing with microplastics in the Durban Harbour, some respondents stated that the government should take the lead. But, there is extreme doubt whether the government could fully take responsibility. Given the issues of corruption, politics, and all the factions and intra and inter-party strife in the municipality, it does not seem to be capable of doing that. With regard to corruption, the KZN province is the 2nd most corrupt province in the country, and corruption affects the functioning of the city (Abrahams, 2020).

When looking at the political issues and intra and inter-party strife, eThekwini remains an area of concern regarding political killings (Dawood, 2022). For example, it was reported that a newly elected council member for eThekwini municipality was shot in November before he could serve diligently as a community representative (Abrahams, 2020; Dawood, 2022). Coupled with that, the eThekwini municipality has been faced with municipal sewage pollution affecting South African rivers for many years. For instance, during the New Year holidays, there was an overflow from the sewage treatment works, which resulted in the closure of Durban beaches (Carnie, 2022). Because the city functions as a system (systems approach) we cannot overlook all these issues because every aspect of the city is related to one another, from the economic, social, political to the environmental elements (Jackson *et al*., 2010). As a result, dealing with microplastics will be difficult if the other elements are not functioning well themselves, for instance, corruption takes away the money that can be used to protect the environment by upgrading WWTPs and storm water systems.

Microplastic experts 1 and 3 stated that the Durban Harbour has a role to play by managing the plastics and microplastics going in and out of the harbour. Durban Harbour officials can also strengthen the regulations to monitor the transportation and movement of plastics and microplastics in the harbour. Microplastics should be treated like other potentially toxic chemicals because they are very harmful. This is a crucial point because some of the plastics and microplastics originate from the Durban Harbour itself. The Durban Harbour is currently faced with many problems, including corruption and truck congestion. Late last year, firms signed a petition over extensive delays and congestion caused by the ineffectiveness of the truck booking system and Transnet's poor management of staff leave benefits (Magubane, 2021). This shows that there is a fundamental issue of management that needs attention.

Conclusion

The Durban Harbour has different microplastic sources, including the three rivers. The impacts of microplastics in the Durban Harbour are more directly on aquatic animals. Furthermore, respondents argued that people are also exposed to microplastics from consuming contaminated seafood, and which can potentially affect their health. The socio-economic impacts of microplastics in the Durban Harbour include effects on tourism and seafood industries and the cost of clean-ups. Importantly, the respondents argued that the South African government should introduce a ban on PCCPs containing microbeads. They also pointed out that researchers and scientists have a significant role to play in educating people about microplastics and their impacts on the environment.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

Introduction

Microplastic studies have recently emerged in South Africa, including the Durban Harbour. We still do not know much about microplastics and their impacts on the Durban Harbour. However, with what we know so far, we can start looking at solutions to addressing this pervasive problem. This chapter is separated into two sections. The first section looks at the conclusion of this study. The second section presents recommendations for the problem of microplastics. The recommendation section outlines measures that urban managers can implement to limit the number of microplastics in the Durban Harbour. The GET Matrix, which stands for Governance, Education and Technology, is the best tool to deal with microplastic pollution.

Conclusion

To conclude, this study intended to present mitigation measures that urban managers and experts can introduce in addressing the problem of microplastics in the Durban Harbour through a review of microplastics' sources and environmental effects. The study aimed to answer the question of the sources of microplastics, the impact of microplastics and the mitigatory measures that can be introduced to deal with microplastics in the Durban Harbour. As discussed in the literature review, there are many sources of microplastics in water bodies, such as harbours, which the respondents also highlighted during the interviews. As a result, this highlights the need for collaboration between the different spheres of government, together with industries and communities. In an attempt to answer the research question, the study employed a qualitative research approach and used a single case study research strategy. The study conducted five interviews with microplastic experts, including those who have done research specifically in the Durban Harbour (refer to table 1).

In addressing the main research question, Durban Harbour has different sources of microplastics. As highlighted by the respondents in Chapter 4, the three rivers, including uMbilo, uMhlatuzana and aManzimnyama rivers, directly and indirectly influence microplastic concentration in the Durban Harbour. The former influence occurs when microplastics enter the three rivers through wastewater treatment plants (WWTPs) or industries. The latter occurs when plastics enter the rivers and gradually break down into microplastics, which are transported straight into the harbour. This means that the three rivers are the major source of microplastics in the Durban Harbour. However, the three rivers are not the only sources of microplastics, we also have microplastics breaking down from car tyres and road markings, and some are generated by recreational activities within the harbour, as pointed out in Chapter 2 and 4.

The research findings suggest that microplastics have an adverse effect on the Durban Harbour. The negative effects include ecological and socio-economic impacts. Firstly, the ecological impact of microplastics affects not only marine species within the harbour, but also the broader East Coast beaches, as discussed in Chapter 4. This is because the harbour itself acts as a source of microplastics in the ocean, as microplastics in the harbour are transported to the East Coast beaches. As a result, marine species, including fish, can suffer from biological impacts in these two areas. This also means that people who practice subsistence fishing in the Durban Harbour and East Coast beaches are exposed to these pollutants, resulting in health impacts. Secondly, the socio-economic impacts can be linked to human health impact, because as more people become aware of microplastics, they might stop buying or consuming seafood. This will have and negative impact on the seafood industries in the country.

The different sources of microplastics and their negative impacts in the Durban Harbour show that urban managers have a significant role to play in addressing this issue. However, it is not going to be easy because of the problems (such as corruption, politics, and intra and inter-party strife) faced by the eThekwini municipality, as outlined in Chapter 4. Urban managers are responsible for bringing together and facilitating collaboration between role players in a city. In this case, urban managers must make use of the management tool known as the GET matrix (GET stands for Governance, Education and Technology) to address microplastics in the Durban Harbour. The GET matrix will bring together the government, organisations, industries, and community and usefully work towards limiting microplastic pollution.

Recommendations

GET Matrix

Looking at the different sources and the potential impact of microplastics in the Durban Harbour, it is clear that it will be challenging for urban managers to deal with this issue. However, urban managers within the eThekwini municipality can effectively employ the decision-support tool known as the GET matrix to deal with microplastics in the Durban Harbour. GET stands for Governance, Education and Technology (figure 37). The GET Matrix was developed by the Global Development Research Centre (GDRC) in Japan, and it was developed "in order to analyse and separate the different decisions needed to solve an environmental problem based on its experience in a number of fields and issues" (Srinivas, 2015: unpaginated). Firstly, the governance systems are concerned with the laws, rules, regulations, policies, decision-making, the role of civil society, monitoring and evaluation, and frameworks that are needed to promote environmental sustainability (*ibid*.). Secondly, the education systems are concerned with the awareness, capacity, skills, lifestyle, and information that is required to support environmental sustainability (*ibid*.). Lastly, the technology systems include network infrastructure, waste management, urban design and social services (*ibid*.). Thus, "the GET Matrix is a decision-support tool that provides a big picture of the complex and interrelated actions and actors needed to promote environmental sustainability," and the issue of microplastics needs this supporting tool because of the different sources of microplastics (Srinivas, 2015: unpaginated).

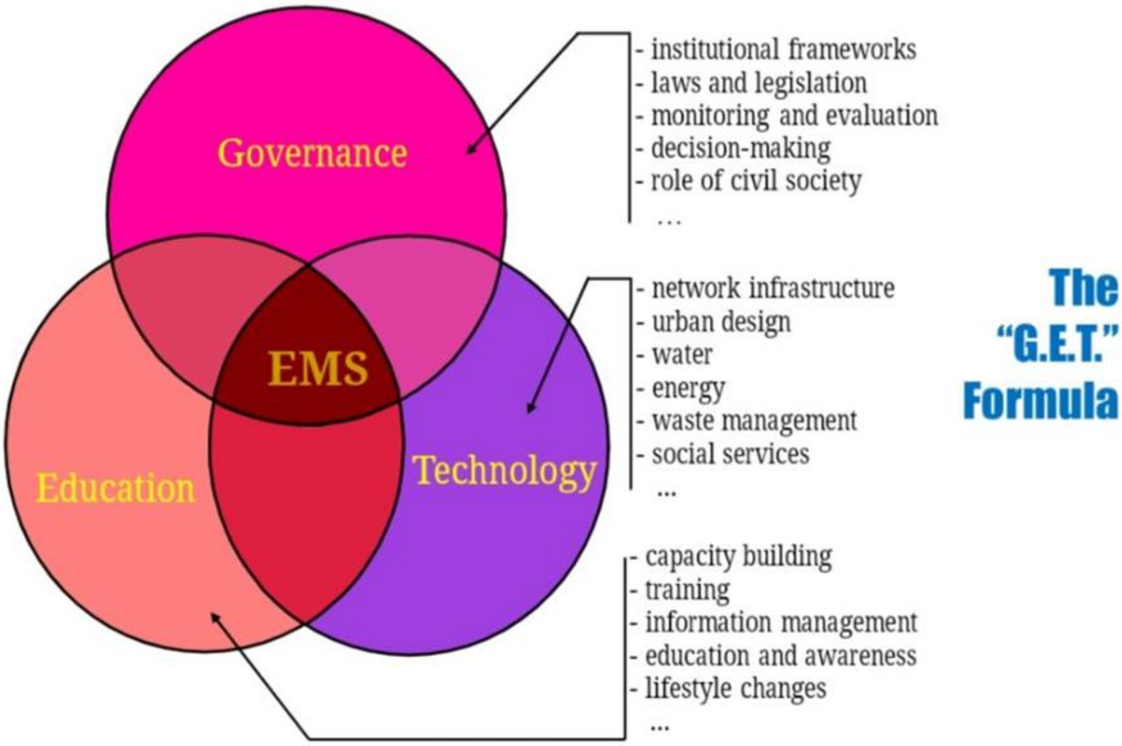

Figure 37: The GET Matrix. This diagram illustrates the three spheres of the GET Matrix. Source: Lecturer slide by Prof. Sihlongonyane (2021)

Governance

Black *et al*. (2019) made an important argument that collective governance, coupled with management systems that make use of different tools (including community involvement), can help mitigate plastics pollution in the environment. This could also be said for mitigating microplastics in the Durban Harbour. Without a doubt, collective governance is very much needed, judging from the fact that the overall eThekwini municipality is poorly managed. The eThekwini municipality needs a management framework and must be able to enforce policies. Furthermore, as stated in Chapter 4, the eThekwini municipality is faced with poor governance, and the first point of reference is to work towards good governance so that the municipality can deal with all the cascading issues, including microplastic pollution. Good governance will allow the local government to introduce and implement policies successfully, followed by consistent monitoring and enforcement of those policies dealing with microplastic pollution. Furthermore, good governance will help in dealing with the social, economic, and environmental problems faced by the municipality, for example, it will help deal with corruption which affects the provision of basic services to the communities. One of the policies the South African government should introduce is the banning of microbeads.

Banning of Microbeads

As stated in previous chapters, some countries have introduced policies for banning microbeads in all their applications, including cleaning products, plastic blasting, printer toners, textile printing, medical applications and automotive molding. Meanwhile, South Africa has done nothing in this case (Abreu and Pedrotti, 2019; Onyena *et al*., 2021). Undoubtedly, an effective legislative approach to microplastics is a good first step. Guerranti, Martellini, Perra, Scopetani and Cincinelli, (2019:75) state that "the problem is global and impossible to be solved by banning products containing microbeads only in some countries, thus, a general ban would be necessary" because microplastics are widespread and very toxic. The ban on microbeads is vital, because it is impossible to collect microbeads on the environment (Leslie, 2014). Therefore, the ban on microbeads is the first and easiest solution for the South African government to introduce.

Waste Management Systems

Waste management is vital in managing plastic waste and microplastics in the environment. As highlighted by the respondents, the state of waste management systems in South Africa is very poor, and the lack of infrastructure makes this situation worse. Thus, the South African government, together with regional and local governments, has a significant role to play when it comes to waste management. The Durban Harbour catchments require proper waste management systems. There is a need for bins and waste collection schemes, especially in rural areas and informal settlements, because uncollected plastic waste makes its way into the Durban Harbour via the three rivers. In order to fight microplastic pollution, the South African government should provide better waste management systems and infrastructure to support recycling (Plastic SA, 2019). This investment will also boost job opportunities as recycling facilities will be able to expand their intake and require more people to handle the waste (*ibid*.). In order to make recycling more accessible, the government should lend a hand to smaller recycling facilities (*ibid*.). Improving the collection and recycling of plastics will benefit not only the environment but also the economy (*ibid*.).

Extended Producer Responsibility

The Extended Producer Responsibility (EPR) policy is useful in fighting plastic pollution as well as microplastic pollution in the environment. As highlighted in Chapter 2, the mandatory EPR in South Africa was recently implemented. This is a good start because it is not only dealing with plastic pollution but also microplastic pollution in the country. For EPR to effectively mitigate microplastics in the environment, it is vital that all stakeholders within the waste management and packaging value chain collaborate for EPR to be successful (Arp, 2021). Most importantly, the government should establish "a monitoring and reporting system" because it is vital for the EPR policy to be effective (*ibid*.:29). Monitoring and reporting are very crucial for assessing the effectiveness of sustainable waste management and the progress towards achieving the EPR targets (Arp, 2021). Significantly, the "monitoring and reporting framework" is instrumental in ensuring that all stakeholders comply with the EPR law (*ibid*.). Furthermore, monitoring and enforcement are crucial because South Africa usually has good policies but poor implementation, which makes the whole policy in vain.

Education

Education can be considered a powerful instrument when fighting against plastic and microplastic pollution. Many people do not know the impacts of plastic waste and they do not even pay attention to the amount of plastic waste they produce in their daily activities (Hanekom, 2020). As a result, raising awareness and educating people about plastics and microplastics is necessary. We need to produce less plastic waste and normalise reusing and recycling products and that can be done through awareness and education. Even though awareness does not guarantee positive action, knowledge of the impact of microplastic pollution may prompt a shift in attitude and values, ultimately resulting in behavioural changes (Hanekom, 2020; Karbalaei *et al*., 2018). Consequently, awareness and education can result in sustained changes in behaviour, which is vital if we want to limit microplastics in the Durban Harbour (Hanekom, 2020).

Consumers can clearly play a vital role in mitigating microplastic pollution when they are educated and aware of microplastic impacts. According to Abreu and Pedrotti (2019), one way to reduce plastic waste in the environment is to buy responsibly. Thus, if people are educated about microplastics, they can choose to buy products that are not packed in plastics and reusable products (Abreu and Pedrotti, 2019). We often hear government authorities and plastic industries saying that citizens are responsible for minimising their waste production. Before saying that consumers should take responsibility for their products, we should make sure that they are aware of the plastic and microplastic impacts on the environment because we cannot expect them to react to something they are not even aware of. Abreu and Pedrotti (2019:66) argued that "consumers can take responsibility for sorting their waste and making sure that end-of-life products are sent for appropriate recycling, where this is available." It will be easy for citizens to take responsibility for their microplastic-containing products where awareness raising is accompanied by appropriate infrastructure to promote this critical change in behaviour.

The non-profits organisation mentioned in Chapter 2, such as Source 2 Sea Initiatives, have played a significant role in increasing awareness of plastic contamination in the water systems within the eThekwini municipality. However, there is a need for organizations to raise awareness and educate people about microplastic pollution and its impact on the national, provincial, and local scale. Moreover, there is a need for sustainable solutions to the microplastic problem within the Durban Harbour. This could be achieved by educating primary and high school learners and university students because it will help in preventing microplastic pollution in the future (preventive action) (Karbalaei *et al*., 2018).

Education and awareness are fundamental to mitigating microplastic pollution in the Durban Harbour because it will be easy to gain political approval and acceptance from the surrounding communities, and both the public and private sector will be committed to mitigating microplastics in the harbour. Kershaw (2015) stated that education and awareness encourage the creation of a circular economy, which treat useless and unwanted plastic waste as a resource. The use of unwanted plastic products will limit the amount of plastics in the environment, meaning there will be fewer or no plastics breaking down into microplastics.

Technology

The Use of the Internet to Educate and Raise Awareness

Prata *et al*. (2019) stated that the internet could be utilized as a useful tool for raising awareness. This educational tool can be used to educate a number of people about microplastic pollution. Social media is very useful in reaching a number of audiences because it now has a significant impact compared to other information platforms (Prata *et al*., 2019). Social media plays a crucial role in creating opportunities for people to engage with the information provided. As pointed out in Chapter 2, Prata *et al*. (2019) explored the word 'microplastics' on social media and discovered that over the years, more information on microplastics has been shared on social media and more people are becoming aware of microplastics. Furthermore, the urban managers within the eThekwini municipality can use social media to educate the public about microplastics and their impacts on the environment. They can also create short educational films about plastics and microplastics and post them on social media. These educational films should also be played on different radio stations and television to educate more people because not everyone has access to smartphones. Undoubtedly, the use of the internet, especially social media, can lead to people actively learning about microplastic pollution in the eThekwini municipality.

Technologies for Preventing and Collecting Plastic and Microplastics

The quick solution to microplastics is to stop producing plastics and microplastics that get into the natural environment in the first place. However, that is not feasible as we need plastics and microplastics for food safety and medical products. Nevertheless, we have plastics and microplastic products that we can do without and replacing them with other natural products carries more benefits for the environment. It is crucial that we go beyond recycling and reusing plastic products to limiting the amount of single-use plastics produced, because they can be used for a short time but persist for centuries in the environment (Bryce, 2021). This means that we need to stop producing non-essential plastic and microplastic products, and this requires collaboration between the government, industries and consumers (*ibid.*). Importantly, all these solutions will occur at a very slow pace and will take a few years to unfold (*ibid.*). Meanwhile, plastics and microplastics will keep on infiltrating the three rivers and flow straight into the Durban Harbour. As a result, there is a need for innovative technologies that will prevent and collect plastics (clean-ups) and microplastics already in the Durban harbour.

Schmaltz, Melvin, Diana, Gunady, Rittschof, Somarelli, Virdin and Dunphy-Daly (2020:3) created the "Plastic Pollution Prevention and Collection Technology Inventory to aid local governments, non-governmental organizations, and other stakeholders in identifying technologies that may help to remediate hotspots of marine plastic pollution". The Inventory focuses on two types of technologies, the first technologies focus on preventing plastic from leaking into the freshwater systems and the aquatic environment (Schmaltz *et al*., 2020). The second technologies focus on collecting plastic waste that is already in the environment (Annexure 1) (Schmaltz *et al*., 2020). This inventory will be very useful for urban managers mitigating microplastic pollution in the Durban Harbour, because it does not only have technologies for plastic pollution but also for microplastic pollution. As we can see in (Annexure 1), there are many different technologies that can be used in addressing the issue of microplastics in the Durban Harbour. It is just a matter of choosing the ones that will work best in the Durban Harbour and the river catchments. Because we are now aware of the different sources of microplastics in the Durban Harbour, it is going to be easier for urban managers to choose the appropriate technologies to deal with microplastics from their different sources. The main focus should be on preventing plastics from entering the Durban Harbour, thus, urban managers should choose more prevention technologies.

Clean-up Boat

Ultimately, effective intervention strategies will combine technologies and tools that can be implemented logistically and economically. Fortunately, litter booms have been installed in the three rivers and have helped prevent a large amount of waste from entering the Durban Harbour (Hlatshwayo, 2021). However, the sole use of booms is not enough because they cannot capture plastic traveling on the surface and require an adequate collection mechanism (Nikiema and Asiedu, 2022). Combining booms with a clean-up boat is the best approach (*ibid*.). As a result, booms should be used in combination with clean-up boats in these three rivers. Clean-up boats use a system of baskets and nets to collect wastes from the river and sea surfaces (*ibid*.). Clean-up boats are also useful in collecting trapped plastic waste (*ibid*.).

Conclusion

Microplastics are toxic pollutants that have the potential to carry other contaminants with them. High levels of microplastics have been recorded in the Durban Harbour and their effects on aquatic animals. Since Durban Harbour is a biological hotspot, the high concentrations of microplastics put biodiversity at risk. In addition, interviews showed the possible socio-economic impacts of microplastics. Thus, there is a need for research on microplastics' economic and social impacts in the Durban Harbour and South Africa as a whole. It is clear from this study that there is a lot we still need to learn when it comes to microplastics, especially their impacts. However, we can start looking at the solution to this pervasive issue with what we know so far. The GET Matrix is a good start for urban managers because it looks at three fundamental parts (governance, education, and technology) to address the issue of plastics and microplastics in the environment.

REFERENCES

Abreu, A. and Pedrotti, M.L., 2019. Microplastics in the oceans: the solutions lie on land. Field Actions Science Reports. The journal of field actions, (Special Issue 19), 62-67.

Ali, N.E.H., Talmizi, N.M., Wahab, S.N.A., Rijal, N.S., Abd Rased, A.N.N.W. and Saleh, A.A., 2021. Solid Waste Management Hierarchy: An Empirical Investigation. *In International Invention, Innovative & Creative Conference (INIIC)*, 1- 8.

Alimi, O.S., Fadare, O.O. and Okoffo, E.D., 2021. Microplastics in African ecosystems: current knowledge, abundance, associated contaminants, techniques, and research needs. *Science of The Total Environment*, *755*, 142-422.

Amelia, T.S.M., Khalik, W.M.A.W.M., Ong, M.C., Shao, Y.T., Pan, H.J. and Bhubalan, K., 2021. Marine microplastics as vectors of major ocean pollutants and its hazards to the marine ecosystem and humans. *Progress in Earth and Planetary Science*, 8(1).

Arp, R. 2021. Extended Producer Responsibility for plastic packaging in South Africa: A synthesis report on policy recommendations. WWF South Africa, Cape Town, South Africa.

Bacinschi, Z., Rizescu, C.Z., Stoian, E.V. and Necula, C., 2010. Waste management practices used in the attempt to protect the environment. In Proceedings of the 3rd WSEAS international conference on engineering mechanics, structures, *Engineering Geology*, 24-26.

Barrett, A., 2019. Plastic Microbeads Bans in 2018.. INTERNET: https://bioplasticsnews.com/2019/01/12/plastic-microbeads-bans-in-2018/, Last accessed in 12 January 2019.

Beaumont, N.J., Aanesen, M., Austen, M.C., Börger, T., Clark, J.R., Cole, M., Hooper, T., Lindeque, P.K., Pascoe, C. and Wyles, K.J., 2019. Global ecological, social and economic impacts of marine plastic. *Marine pollution bulletin*, *142*, pp.189-195.

Bezerra, J.C., Walker, T.R., Clayton, C.A. and Adam, I., 2021. Single-use plastic bag policies in the Southern African development community. *Environmental Challenges*, 3.

Boucher, J. and Friot, D., 2017. *Primary microplastics in the oceans: a global evaluation of sources*. Gland, Switzerland: Iucn, 227-229.

Bouwman, H., Minnaar, K., Bezuidenhout, C. and Verster, C., 2018. Microplastics in Freshwater Water Environments a Scoping Study. Report to the Water Research Commission. Northwest (ZA). Northwest University.

Bujnicki, J., Dykstra, P., Fortunato, E., Grobert, N., Heuer, R.D., Keskitalo, C. and Nurse, P., 2019. Environmental and health risks of microplastic pollution. *European Commission: Brussels, Belgium*, 16-21.

Burns, E.E. and Boxall, A.B., 2018. Microplastics in the aquatic environment: Evidence for or against adverse impacts and major knowledge gaps. *Environmental toxicology and chemistry*, *37*(11), 2776-2796.

Burton Jr, G.A., 2017. Stressor exposures determine risk: so, why do fellow scientists continue to focus on superficial microplastics risk?. Environmental Science & Technology 13515-13516.

Byrne, P., 2018. Microfibres: the plastic in our clothes. INTERNET: https://friendsoftheearth.uk/plastics/microfibres-plastic-in-our-clothes, accessed 14 September 2018.

Carnie. T., 2022. Durban pledges 'aggressive plan' to clean up beach sewage pollution crisis before Christmas holidays. Daily Maverick, 24-26 October.

Chen, H., Qin, Y., Huang, H. and Xu, W., 2020. A regional difference analysis of microplastic pollution in global freshwater bodies based on a regression model. *Water*, *12*(7), 18-89.

Claessens, M., De Meester, S., Van Landuyt, L., De Clerck, K. and Janssen, C.R., 2011. Occurrence and distribution of microplastics in marine sediments along the Belgian coast. *Marine pollution bulletin*, *62*(10), 2199-2204.

Cooper, W.W., Eastman, C.H.A.R.L.E.S., Johnson, N.O.R.M.A.N. and Kortanek, K.E.N.N.E.T.H., 1971. Systems approaches to urban planning: mixed, conditional, adaptive and other alternatives. *Policy Sciences*, *2*(4), 397-405.

Cordier, M., Uehara, T., Baztan, J., Jorgensen, B. and Yan, H., 2021. Plastic pollution and economic growth: The influence of corruption and lack of education. Ecological economics, 182,106-930.

Creswell, J., 2009. *Research Design: Qualitative, Quantitative and Mixed Methods Approach*, 3rd Edition. Sage, Thousand Oaks.

Dahms, H.T., van Rensburg, G.J. and Greenfield, R., 2020. The microplastic profile of an urban African stream. *Science of The Total Environment*, *731*, 138-893.

de Kock, L., Sadan, Z., Arp, R. and Upadhyaya, P., 2020. A circular economy response to plastic pollution: Current policy landscape and consumer perception. *South African Journal of Science*, *116*(5-6),1-2.

De Villiers, S., 2019. Microfibre pollution hotspots in river sediments adjacent to South Africa's coastline. *Water Sa*, *45*(1),97-102.

Dalu, T., Banda, T., Mutshekwa, T., Munyai, L.F. and Cuthbert, R.N., 2021. Effects of urbanisation and a wastewater treatment plant on microplastic densities along a subtropical river system. *Environmental Science and Pollution Research*,1-10.

Eriksen, M., Liboiron, M., Kiessling, T., Charron, L., Alling, A., Lebreton, L., Richards, H., Roth, B., Ory, N.C., Hidalgo-Ruz, V. and Meerhoff, E., 2018. Microplastic sampling with the AVANI trawl compared to two neuston trawls in the Bay of Bengal and South Pacific. *Environmental Pollution*, *232*, 430-439.

eThekwini municipality Integrated Development Plan (IDP), 2020/2021. By 2030, eThekwini will be Africa's most caring and liveable City. eThekwini municipality, KwaZulu Natal.

Gerber, G., 2017. More than just food: mussels as biomonitors of microplastic pollution in the KwaZulu-Natal coastal environment.

Govender, J., Naidoo, T., Rajkaran, A., Cebekhulu, S., Bhugeloo, A. and Naidoo, S., 2020. Towards Characterising Microplastic Abundance, Typology and Retention in Mangrove-Dominated Estuaries. *Water*, *12*(10), 2802.

Guastella, L.A., 1994. A quantitative assessment of recreational angling in Durban Harbour, South Africa. *South African Journal of Marine Science*, *14*(1),187-203.

Guy. D., 2021. Harbour waters getting 'worse, quickly'. *IOL*, 03-6 October.

Guerranti, C., Martellini, T., Perra, G., Scopetani, C. and Cincinelli, A., 2019. Microplastics in cosmetics: Environmental issues and needs for global bans. *Environmental toxicology and pharmacology*, *68*, 75-79.

Ha, J. and Yeo, M.K., 2018. The environmental effects of microplastics on aquatic ecosystems. *Molecular & Cellular Toxicology*, *14*(4), 353-359.

Hlatshwayo, N. N., 2021. New litter boom installed on Durban tributary. *IOL*, 1-3 July.

House of Commons, Environmental Audit Committee., 2016. Environmental impact of microplastics. *Fourth Report of Session,* 2016–17.

IUCN-EA-QUANTIS, 2020, National Guidance for plastic pollution hot spotting and shaping action*, Country report South Africa*

Jackson, S., Hitchins, D. and Eisner, H., 2010. What is the systems approach?. *Insight*, *13*(1),41-43.

Kalina, M.R., Mbereko, A., Maharaj, B. and Botes, A., 2019. Subsistence marine fishing in a neoliberal city: a political ecology analysis of securitization and exclusion in Durban, South Africa. *Journal of Political Ecology*, *26*(1),363-380.

Karami, A., Golieskardi, A., Ho, Y.B., Larat, V. and Salamatinia, B., 2017. Microplastics in eviscerated flesh and excised organs of dried fish. *Scientific reports*, 7(1).

Karbalaei, S., Hanachi, P., Walker, T.R. and Cole, M., 2018. Occurrence, sources, human health impacts and mitigation of microplastic pollution. *Environmental science and pollution research*, 25(36), 36046-36063.

Karlsson, T.M., Kärrman, A., Rotander, A. and Hassellöv, M., 2020. Comparison between manta trawl and in situ pump filtration methods, and guidance for visual identification of microplastics in surface waters. *Environmental science and pollution research*, *27*(5), 5559-5571.

Kataoka, T., Nihei, Y., Kudou, K. and Hinata, H., 2019. Assessment of the sources and inflow processes of microplastics in the river environments of Japan. *Environmental pollution*, *244*,958-965.

Kershaw, P., 2015. *Sources, fate and effects of microplastics in the marine environment: a global assessment*. International Maritime Organization.

Khathi, N.N., 2018. *A critical assessment of the impacts of mixed land-use developments on socio-economic sustainability: a case study of Isipingo, Ethekwini Municipality* (Doctoral dissertation).

Kiger, M.E. and Varpio, L., 2020. Thematic analysis of qualitative data: AMEE Guide No. 131. *Medical teacher*, *42*(8), 846-854.

Koyuncuoğlu, P. and Erden, G., 2021. Sampling, pre-treatment, and identification methods of microplastics in sewage sludge and their effects in agricultural soils: a review. *Environmental Monitoring and Assessment*, *193*(4), 1-28.

Kubanza, N.S., 2010. *Perception and issues of solid waste management in South Africa. A case study of Johannesburg*. Masters' Research Report. Johannesburg: *Department Architecture and Planning*, University of the Witwatersrand.

Kumar, M., Xiong, X., He, M., Tsang, D.C., Gupta, J., Khan, E., Harrad, S., Hou, D., Ok, Y.S. and Bolan, N.S., 2020. Microplastics as pollutants in agricultural soils. *Environmental Pollution*, *265*, 114-980.

Lamichhane, G., Acharya, A., Marahatha, R., Modi, B., Paudel, R., Adhikari, A., Raut, B.K., Aryal, S. and Parajuli, N., 2022. Microplastics in environment: global concern, challenges, and controlling measures. *International Journal of Environmental Science and Technology*, 1-22.

Lassen, C., Hansen, S.F., Magnusson, K., Norén, F., Hartmann, N.I.B., Jensen, P.R., Nielsen, T.G. and Brinch, A., 2012. Occurrence, effects and sources of releases to the environment in Denmark. *Danish Environmental Protection Agency.*

Leslie, H.A., 2014. Review of microplastics in cosmetics. *IVM Institute for Environmental Studies*, *476*, 1-33.

Lei, K., Qiao, F., Liu, Q., Wei, Z., Qi, H., Cui, S., Yue, X., Deng, Y. and An, L., 2017. Microplastics releasing from personal care and cosmetic products in China. *Marine pollution bulletin*, *123*(1-2),122-126.

Li, Y., Li, W., Jarvis, P., Zhou, W., Zhang, J., Chen, J., Tan, Q., and Tian, Y., 2020. Occurrence, removal and potential threats associated with microplastics in drinking water sources. *Journal of Environmental Chemical Engineering*, 104-527.

Lusher, A. and Pettersen, R., 2021. Sea-based sources of microplastics to the Norwegian marine environment. *NIVA-rapport*.

Magubane. T., 2021. Firms sign petition over slow Durban port: complaints over booking system issues, extensive delays. INTERNET:https://www.iol.co.za/mercury/news/firms-sign-petition-over-slow-durban-port-complaints-over-boo , accessed 3 December 2021.

Montoya, D., 2015. *Pollution in Sydney Harbour: sewage, toxic chemicals and microplastics*. NSW Parliamentary Research Service.

Moodley, K., 2014. *An investigation into the pollution status of the Durban Harbour River catchments, KwaZulu-Natal, South Africa* (Doctoral dissertation).

Moodley, K., Pillay, S. and Pather, K., 2015. R characterization of water chemistry and pollution sources of the Umhlatuzana, Umbilo and Amanzimnyama River catchments of Durban, KwaZulu-Natal, South Africa. *Environmental Earth Sciences*, *74*(2), 1273-1289.

Moodley, K., Pillay, S., Pather, K. and Ballabh, H., 2016. Seasonal discharge and chemical flux variations of rivers flowing into the Bayhead canal of Durban Harbour, South Africa. *Acta Geochimica*, *35*(4), 340-353.

Murphy, F., Ewins, C., Carbonnier, F. and Quinn, B., 2016. Wastewater treatment works (WwTW) as a source of microplastics in the aquatic environment. *Environmental science & technology*, *50*(11), 5800-5808.

Naidoo, J., 2013. *Assessment of the impact of wastewater treatment plant discharges and other anthropogenic variables on river water quality in the eThekwini Metropolitan area* (Doctoral dissertation).

Naidoo, T., Glassom, D. and Smit, A.J., 2015. Plastic pollution in five urban estuaries of KwaZulu-Natal, South Africa. *Marine pollution bulletin*, 101(1), 473-480.

Naidoo, T., Thompson, R.C. and Rajkaran, A., 2020. Quantification and characterisation of microplastics ingested by selected juvenile fish species associated with mangroves in KwaZulu-Natal, South Africa. *Environmental Pollution*, *257*, 1-8.

Nel, H.A., Hean, J.W., Noundou, X.S. and Froneman, P.W., 2017. Do microplastic loads reflect the population demographics along the southern African coastline. *Marine Pollution Bulletin*, 115(1-2), 115-119.

Nikiema, J. and Asiedu, Z., 2022. A review of the cost and effectiveness of solutions to address plastic pollution. Environmental Science and Pollution Research, 1-27.

Nor, N.H.M. and Obbard, J.P., 2014. Microplastics in Singapore's coastal mangrove ecosystems. *Marine pollution bulletin*, *79*(1-2), 278-283.

Onyena, A.P., Aniche, D.C., Ogbolu, B.O., Rakib, M., Jahan, R., Uddin, J. and Walker, T.R., 2021. Governance Strategies for Mitigating Microplastic Pollution in the Marine Environment: A Review. *Microplastics*, *1*(1),15-46.

Picó, Y. and Barceló, D., 2019. Analysis and prevention of microplastics pollution in water: current perspectives and future directions. *ACS omega*, *4*(4),6709-6719.

Plastic SA, 2019. Why recycling is better than banning plastic bags. *Plastic SA*, 01-02 November.

Prasath, B.B., Poon, K. and Bb, P., 2018. The Impacts of Microplastics to Environment. *J Environ Hazard*, *1*(101), 1-4.

Prata, J.C., Silva, A.L.P., Da Costa, J.P., Mouneyrac, C., Walker, T.R., Duarte, A.C. and Rocha-Santos, T., 2019. Solutions and integrated strategies for the control and mitigation of plastic and microplastic pollution. *International journal of environmental research and public health*, *16*(13), 2-411.

Preston-Whyte, F., Silburn, B., Meakins, B., Bakir, A., Pillay, K., Worship, M., Paruk, S., Mdazuka, Y., Mooi, G., Harmer, R. and Doran, D., 2021. Meso-and microplastics monitoring in harbour environments: A case study for the Port of Durban, South Africa. *Marine Pollution Bulletin,* 163, 1-13.

Pukclai. P. T., 2020. Microplastics in Agriculture: Challenges for Regulation. *AgriBussiness Global*, 10-14 May.

Rautenbach, C. and Theron, A.K., 2018. Study of the Durban Bight shoreline evolution under schematised climate change and sand-bypassing scenarios. *Journal of the South african institution of civil engineering*, *60*(4).

Ryan, P.G., 2015. A brief history of marine litter research. In *Marine anthropogenic litter*. Springer, Cham, 1-25.

Schmaltz, E., Melvin, E.C., Diana, Z., Gunady, E.F., Rittschof, D., Somarelli, J.A., Virdin, J. and Dunphy-Daly, M.M., 2020. Plastic pollution solutions: emerging technologies to prevent and collect marine plastic pollution. *Environment international*, *144*,106-067.

Sharma, S., Basu, S., Shetti, N.P., Nadagouda, M.N. and Aminabhavi, T.M., 2020. Microplastics in the environment: occurrence, perils, and eradication. *Chemical Engineering Journal*, 1-19.

Shahul Hamid, F., Bhatti, M.S., Anuar, N., Anuar, N., Mohan, P. and Periathamby, A., 2018. Worldwide distribution and abundance of microplastic: how dire is the situation?. *Waste Management and Research*, *36*(10), 873-897.

Smith, M., Love, D.C., Rochman, C.M. and Neff, R.A., 2018. Microplastics in seafood and the implications for human health. Curr Environ Health Rep 5 (3): 375–386.

Srinivas, H., 2015. "A Decision Support Tool: The GET Matrix". *Global Development Research Center* (GDRC), Japan. INTERNET: https://www.gdrc.org/uem/green-const/get-matrix.html, accessed 1 March 2022.

Steinmetz, Z., Wollmann, C., Schaefer, M., Buchmann, C., David, J., Tröger, J., Muñoz, K., Frör, O. and Schaumann, G.E., 2016. Plastic mulching in agriculture. Trading short-term agronomic benefits for long-term soil degradation?. *Science of the total environment*, 550, 690-705.

Su, Y., Zhang, Z., Wu, D., Zhan, L., Shi, H. and Xie, B., 2019. Occurrence of microplastics in landfill systems and their fate with landfill age. *Water research*, *164*,114-968.

Tongco, D., 2007. Purposive Sampling as a tool for informant selection. *Ethnobotany Research and Applications,* 5, 147-158.

Twardowska, I., Allen, H.E., Kettrup, A.F. and Lacy, W.J., 2004. Solid waste: assessment, monitoring and remediation. *Gulf Professional Publishing*.

Walker, T.R. and Xanthos, D., 2018. A call for Canada to move toward zero plastic waste by reducing and recycling single-use plastics. *Resour. Conserv. Recycl*e, *133*, 99-100.

Wang, W., Ndungu, A.W., Li, Z. and Wang, J., 2017. Microplastics pollution in inland freshwaters of China: a case study in urban surface waters of Wuhan, China. *Science of the Total Environment*, *575*, 1369-1374.

Wang, C., Zhao, J. and Xing, B., 2020. Environmental Source, Fate, and Toxicity of Microplastics. *Journal of Hazardous Materials*, 1-12.

Wang, J., Zheng, L. and Li, J., 2018. A critical review on the sources and instruments of marine microplastics and prospects on the relevant management in China. *Waste Management & Research*, 36(10).

Whitehead, P.G., Bussi, G., Hughes, J.M., Castro-Castellon, A.T., Norling, M.D., Jeffers, E.S., Rampley, C.P., Read, D.S. and Horton, A.A., 2021. Modelling microplastics in the river thames: sources, sinks and policy implications. *Water*, *13*(6),8-61.

World Port Source (WPS)., undated. Port of Durban Review and History. INTERNET: http://www.worldportsource.com/ports/review/ZAF_Port_of_Durban_50.php, last accessed 05 November 2021.

Verster, C. and Bouwman, H., 2020. Land-based sources and pathways of marine plastics in a South African context. South African Journal of Science, 116(5-6).

Verster, C., Minnaar, K. and Bouwman, H., 2017. Marine and freshwater microplastic research in South Africa. *Integrated environmental assessment and management*, *13*(3), 533-535.

Vethaak, A.D. and Legler, J., 2021. Microplastics and human health. *Science*, *371*(6530), 672-674.

Zhang, Q., Xu, E.G., Li, J., Chen, Q., Ma, L., Zeng, E.Y. and Shi, H., 2020. A review of microplastics in table salt, drinking water, and air: direct human exposure. *Environmental science & technology*, 54(7), 3740-3751.

Annexure A

Table 5: Plastic and Microplastic Prevention and collection technologies (Bryce, 2021).

The Plastic Pollution Prevention and Collection Technology Inventory.

		Name	Year[3]	Description	Used?	Location invented	References
Prevention: macroplastics	*Stormwater and wastewater filters*	In-line Litter Separator (ILLS)	1999	Trap attached to the drainage system downstream of shopping areas removes litter from passing stormwater	Yes	Australia	Phillips, 1999
		StormTrap TrashTrap	2018	Mesh net system uses water flow to capture and remove trash, floatables, and solids from stormwater and wastewater	Yes	United States	"TrashTrap: Capture floatables with innovative netting systems," n.d.; "TrashTrap Floatables Collection System Guide Specification," 2018
		PumpGuard	2016	Mesh nets remove debris from stormwater and wastewater	Yes	United States	"Pump protection solutions for wastewater, stormwater and combined sewer overflow (CSO) discharges," n.d.; "Pumpguard," n.d.
		Watergoat Trash Trap	2006[4]	Floating boom and net attached to embankments, stormwater outfalls, canals, or creeks collects floating debris	Yes	United States	"Mark Maksimowicz," n.d.; "'Watergoat' trash traps helping curb litter in Augusta," 2018; Parsons, 2017; tfarrell, 2019
		Netting TrashTrap System	1999	Mesh nets capture and remove trash from stormwater and discharge	Yes	United States	Fresh Creek Technologies, Inc., n.d.; "Fresh Creek Technologies Installs 200th TrashTrap Systems," 2010; Turner et al., 2005a, 2005b; United States Environmental Protection Agency, 1999
Prevention: macroplastics	*Stormwater and wastewater filters*	StormX Netting Trash Trap	1995	Commercial grade reusable nets provide full capture of gross pollutants as small as 5 mm in stormwater runoff, including organic materials (such as leaves) that could reduce the levels of phosphorous and nitrogen in water	Yes	Australia	"City of Carrollton, Texas installs StormX netting trash trap," 2012; "StormX Netting Trash Trap," n.d.; Wodalski, 2010
	Miscellaneous leakage prevention	Stow it, Don't Throw It	2012	Tennis ball containers repurposed into fishing line recycling bins for anglers	Yes	United States	"Home: The Stow It-Don't Throw It Project," n.d.; "Stow It Don't Throw It Project," n.d.; Savedge, 2014
		CLEVER-Volume	2019	Sensors allow port authorities to certify the amount of ship waste reported, in comparison to the volume reported to MARPOL inspectors	No	Portugal	"CLEVER-Volume – 3DModelling PT," n.d.; Solana, 2019
Prevention: microplastics	*Miscellaneous removal from wastewater*	Unnamed Invention by Students at Gering High School	2017	Gravity-fed, three-stage attachable filter catches microplastics (*e.g.*, microfibers shed from laundry) before they enter the wastewater	No	United States	Fielder, 2017; "These students found a way to keep microplastics out of your drinking water," 2018
		GoJelly Project	2018	Jellyfish mucus (secreted when they reproduce or become stressed) captures and binds to nano-sized particles, removing microplastics from wastewater	No	Unknown (Funded by European Union)	Diaz, 2019; "GoJelly," n.d.; Javidpour, 2018
Prevention: microplastics	*Laundry balls*	Cora Ball	2019	Balls placed in the laundry machine capture microfibers shed when washing synthetic fibers	Yes	United States	"Cora Ball," n.d.; Kart, n.d.
		Fibre Free	2017	Balls placed in the laundry machine or dryer capture microfibers shed when washing or drying synthetic fibers	No	United States	Chou, 2018; Dunbar, 2017
	Residential wastewater treatment	Lint LUV-R	2016	Water filter on laundry machines captures microfibers when water is drained through the machine	Yes	Canada	Kart, n.d.; Krieger, 2016; "Lint LUV-R washing machine discharge filter," n.d.

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		Name	Year[3]	Description	Used?	Location invented	References
		Showerloop	2012	Filter removes microplastics while primarily filtering water for reuse	Unknown	Finland	"How it works," n.d.; "Make it," n.d.; Young, 2018
Collection: macroplastics	*Large-scale booms*	Ocean Cleanup System	2013	C-shaped boom and screens use currents to corral trash	Yes[5]	Netherlands	BeauHD, 2018; Carr, 2017; Cross, 2019; Edwards, 2016; Gertz, 2014; Hill, 2016; Howard et al., 2019; Knapton, 2017; Leatherman, 2015; Lim, 2018; Miller, 2018; Onorevole, 2016; Papadopoulos, 2019; Ryall, 2015; Shah, 2017; Spary, 2018; "The Ocean Cleanup," n.d.; "Will the Great Pacific Garbage Patch meet its match?", 2018; Wamsley, 2018; Wright, 2018
		Holy Turtle	2018	1,000-foot-long floating unit is towed by two marine vessels and captures floating waste; large vent hole protects marine life	Yes	United States	Kotecki, 2018; SodaStream International Ltd., 2018
Collection: macroplastics	*Drones and robots*	FRED (Floating Robot for Eliminating Debris)	2019	Solar-powered vessel with conveyor belts collects floating debris	Yes[5]	United States	"About – Clear Blue Sea," n.d.; "Meet Fred – Clear Blue Sea," n.d.; Thomson, 2019
		WasteShark	2016	Drone modeled after a whale shark skims the water and collects floating debris	Yes	Netherlands	"Chomping down on trash: WasteShark collects marine debris," 2018; Cook, 2019; Dormehl, 2016; Morjaria, 2019
		Jellyfishbot	2018	Remote-controlled robot collects garbage from waterways	Yes	France	"A jellyfish robot arrives in the Old Port to collect waste," 2019; "Jellyfishbot," n.d.; Franklin, 2018
		Seabin	2013	Automated bucket uses a pump to capture floating debris, including plastic	Yes	Australia	Edwards, 2016; "Seabin, a new kind of floating bin," 2019; "Seabin project—Cleaner oceans for a brighter future," n.d.
		BluePhin	2017	Battery-powered, zero carbon emissions robot uses artificial intelligence to collect floating waste	Unknown	United Arab Emirates	BluePhin Technologies, n.d.
	Boats and wheels	SeaVax	2015	Solar- and wind-powered ship collects plastic and other debris; sensors detect waste and sonar protects fish and other animals from being collected	Yes	United Kingdom	Chow, 2016; Edwards, 2016; "SeaVax Robotic Vacuum Ship," n.d.
		Mighty Tidy	2003	Trash skimming boat scoops plastic from the surface, and a conveyor belt moves waste to a bin	Yes	United States	Babineck, 2003; "News," 2003
		Inner Harbor Water Wheel	2014	Wheel collects trash in the river before it can flow into the harbor	Yes	United States	Hamers, 2019; Krieger, 2016; "Trash wheel project," n.d.
		Versi-Cat Trash Skimmer Boat	2009	Skimmer collects floating and semi-submerged debris in a removable basket for later disposal	Yes	United Kingdom	"Versi-Cat, n.d.; "Water Witch: World Leaders in Waterway Cleanup," n.d.
Collection: macroplastics	*Boats and wheels*	ERVIS	2016	Ship with saucers uses centripetal force to capture and separate waste into five size classes for later disposal	No	India	"Pune: 12-Year-old designs ship to remove plastic from ocean, save marine life," 2019; Think Change India, 2018
		One Earth-One Ocean SeeHamster	2012	Small catamarans (4 × 12 m), equipped with fold-down nets or fishing gear collect debris from inland waters	Yes	Germany	"One Earth One Ocean," n.d.
		One Earth-One Ocean SeeKuh	2016	Nets with 2.5 cm mesh are suspended from catamarans (12 x10 m) and collect plastic waste up to 4 m deep from bays, estuaries, and coastal regions	Yes	Germany	"One Earth One Ocean," n.d.

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		Name	Year[3]	Description	Used?	Location invented	References
		Manta	2016	Ship brings waste onboard for manual sorting and mechanical compacting before being carried to land for processing	No	France	"The Manta, a revolutionary vessel," n.d.
		The Interceptor	2019	Solar-powered catamaran autonomously extracts floating plastics from rivers, using barriers and a conveyor belt	Yes	Netherlands	"How it works: The interceptor," n.d.
		MariClean	2020	Catamaran fitted with a conveyor belt collects debris from seas, straits and bays	No	Canada	Echavez, 2020
Collection: macroplastics	*Detection aids*	Malolo I	2017	Unmanned aerial robot detects marine debris (especially fishing gear) in the open ocean for later collection or satellite tagging	Yes	United States	Mayer, n.d.
		Unnamed GPS Device on Ghost Nets	2019	Vessels place GPS units on ghost nets to mark them for collection	Yes	United States	"Ocean Voyages Institute," n.d.; SMART, 2019
		NetTag	2019	Low-cost transponders allow fishers to locate and recover lost nets	Yes[5]	England	E&T Editorial Staff, 2019
		Wikilimo	2019	Uses satellite imagery to detect major garbage patches in oceans; uses numerical models and machine learning to identify optimum routes for cleaning up garbage patches	No	United States	"Machine learning and satellite imagery based oceanography," n.d.
	Waterway litter traps	Bandalong Litter Trap	2009	Floating device uses waterway currents to capture and guide litter into the trap before it flows downstream	Yes	Australia	"Bandalong Litter Trap," n.d.-a; "Bandalong Litter Trap," n.d.-b; "Storm Water Systems installs first U.S. Bandalong Litter Trap," 2009
		Clear River Litter Trap	2014	Floating device uses waterway currents to capture and guide litter into the trap before it flows downstream	Yes	Netherlands	"Litter Traps," n.d.; "Timeline," n.d.
		SCG Litter Trap	2019	Floating litter trap uses a bypass flap to leverage water flow and pressure to capture and trap floating litter	Yes[5]	Thailand	"'Litter trap' a success blocking trash from the sea," 2019; "SCG's Floating Litter Trap to Prevent Marine Debris Entering Oceans at Rayong Estuaries and Samut Sakhon Canals," 2019
Collection: macroplastics	*River booms*	Clean River Project River Boom	2005	Floating beams create a barrier that collects surface debris along rivers	Yes	United States	Blessing, 2018; "Clean River Project," n.d.
		Bandalong Boom	2015	Floating boom couplings span waterways to capture waste and prevent it from traveling further downstream	Yes	Australia	"Bandalong Boom System," n.d.; "Bandalong Boom System tested by University of Kentucky," 2015; "Bandalong Boom Systems," n.d.
		The Litterboom Project	2017	Large pipes anchored across rivers catch surface-level debris	Yes	South Africa	"About the project," n.d.
		AlphaMERS Floating Barrier	2015	Floating barricade carries debris to the riverbank for manual or mechanical collection	Yes	India	"AlphaMERS Ltd," n.d.
		Plastic Fischer Trash Boom	2019	Boom made of PVC pipe floaters and galvanized steel catching nets collects surface plastics up to 60 cm deep	Yes	Germany	"Our solutions," n.d.

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		Name	Year[3]	Description	Used?	Location invented	References
	Sand filters	Barber Surf Rake	Unknown	Tractor-towed machine removes waste on beaches	Yes	United States	"Surf Rake—Tractor-towed beach cleaner machines," n.d.
		Barber Sand Man	Unknown	Walk-behind sand sifting machine uses a vibrating screen to sift debris from sand and soil on beaches	Yes	United States	"Walk behind sand cleaner: The Barber SAND MAN 850," n.d.
Collection: microplastics	*Miscellaneous capture*	Unnamed Invention by Anna Du	2018	Remotely operated vehicle uses infrared light to detect, photograph, and help remove microplastics from waterways	No	United States	"Anna's World," n.d.; Williams, 2019
		Unnamed Invention by Fionn Ferreira	2019	Combination of oil and magnetite powder binds microplastics for extraction with a magnet	No	Ireland	Bendix, 2019; Nace, n.d.; "What is Fionn About," n.d.
Collection: microplastics	*Sand filter*	Marine Microplastic Removal Tool	2013	Sand is piled on a sheet of fine mesh stretched between two long poles, and the mesh catches plastic and other foreign material while allowing the sand to fall through	Yes	United States	Fisher, 2018; Ward, 2015
Collection: all	*Boat*	OC-Tech	2013	Boat collects oil, microplastics, and other debris using a system of nets and baskets; clean water then flows back into ocean	Unknown	Spain	"OC-Tech: Innovative vessel for cleaning-up activities in marine and fluvial environments.," n.d.; "Products—Ocean Cleaner Technology," n.d.
	Skimmer	Marina Trash Skimmer	2016	Pump in a partially submerged plastic box draws in and catches surface trash	Yes	United States	Faulkner, 2019; Kraimer et al., n.d.; "Marina Trash Skimmers," n.d.
	Vacuum	Hoola One	2019	Vacuums approximately three gallons of sand and debris per minute into a tank that separates particles by buoyancy, allowing for plastic separation and removal	Yes	Canada	"Hoola One – We hand the beaches back to nature," n.d.; "Hoola One microplastic removal machine arrives on Hawaii," 2019; KITV Web Staff, 2019; Mendoza, n.d.; Peters, 2019
	Air barrier	The Great Bubble Barrier	2019	Tubes placed diagonally across the bottom of the waterway create a bubble barrier by pumping air, creating a current that brings debris to the surface and guides it to a catchment system	Yes	Netherlands	"Bubble Barrier," n.d.; "Bubble barrier catches micro-plastics from effluent sewage treatment," n.d.; Thomson, 2019

[3]Year designates the year invented; if the year invented was unavailable, the earliest year that an article about the technology was published was used.
[4]This date was found on the personal website of the inventor.
[5]In testing phase.