UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

AN ASSESSMENT OF LAND–BASED ACTIVITIES AS INPUTS OF MICROPLASTIC POLLUTION IN SOUTH AFRICA'S AQUATIC ENVIRONMENT : A CASE STUDY OF DURBAN BAY HARBOUR AND THE HENNOPS RIVER.

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A dissertation submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Master of Science.

Johannesburg, 1 February 2023

Candidate declaration

I declare that this dissertation is my own, unaided work. It is being submitted for the Degree of Master of Science at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

D.Latcheman

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(Signature of candidate)

1st day of February 2023 at the University of the Witwatersrand, Johannesburg.

Abstract

Microplastics have been identified globally in a diverse range of environments. The extent of information on microplastic pollution in South Africa's context is scarce and lacking. An investigation of microplastic pollution was conducted across the Durban Bay harbour in the KwaZulu Natal province and the Hennops River, Gauteng province in South Africa. Microplastics were detected in all surface water and sediment samples, with abundances up to 80.72 MP/ m^3 detected in surface water samples and 1.76 MP/ g for sediment samples. Fibres and fragments were the most commonly observed morphologies in surface water and sediment samples; with fibres comprising up to 75.68 % in surface waters and 45.54 % in sediments, and fragments comprising up to 19.84 % in surface waters and 41.07 % in sediment samples. Polyethylene, polypropylene and polyester were the most dominant polymers observed in water and sediment samples, and both buoyant and non-buoyant polymers were observed of different morphologies for the study areas of Durban Bay and the Hennops River. Microplastic particles less than 1 mm in diameter were the most commonly observed size ranges relative to microplastic particles greater than 1 mm in diameter. Sites located nearby to river inflows and stormwater drains showed relatively higher microplastic abundances. A spatial analysis of the data showed the water bodies were subject to a wide array of anthropogenic activities which serve as inputs of microplastic pollution. The reporting of microplastic pollution in the selected aquatic systems substantiates real-time data which is required to implement policies to aid mitigating the risks associated with accumulating microplastic levels.

In memory of my brother,

Atul Latcheman
2001 – 2019

And darling friend who became family,

Sapna Koobair
2003 - 2022

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Contents

Table of Contents

List of Figures

List of Tables

List of Abbreviations

ANOVA	Analysis of Variance
BOD	Biological Oxygen Demand
CBD	Central Business District
CSIR	Council for Scientific and Industrial Research
FTIR	Fourier Transform Infrared
g	gram
GC	Gas Chromatography
GDP	Gross Domestic Product
GESAMP	Group of Experts on the Scientific Aspects of Marine Environmental Protection
GF	Glass Fibre
GHG	Green House Gases
GIS	Geographic Information System
m	meter
MP	Microplastic
NOAA	National Oceanic and Atmospheric Administration
NP	Nanoplastic
PA	Polyamide
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyl
PE	Polyethylene
PET	Polyethylene Terephthalate
PP	Polypropylene
PPE	Personal Protective Equipment
PS	Polystyrene
PTFE	Polytetrafluoroethylene
PVC	Polyvinyl Chloride
SA	South Africa
SAHRC	South African Human Rights Commission
UN	United Nations
UNEP	United Nations Environment Programme
USA	United States of America
UV	Ultraviolet
WWTP	Wastewater Treatment Plants
WWTW	Wastewater Treatment Works

1. INTRODUCTION

1.1 General introduction to plastic and microplastic pollution

The durability, wide application and cheap production of plastics have allowed for its incorporation into a variety of products, however these very same design characteristics present as threats to the health of ecosystems (Miller et al., 2021). The increased production and exponential usage of plastic since the beginning of its industrial production in the 1950s, have led to an abundance of synthetic polymers being found across terrestrial, freshwater and marine ecosystems. (Borrelle et al., 2020; Farmen et al., 2021; Kühn et al., 2015; Wang and Wang, 2018). The large volumes of plastics waste accumulation in the environment has developed into one of the most pervasive problems of the anthropogenic era, with as much as 80% of all litter in the oceans being made up of plastic (Hartmann et al., 2019). Plastic has been detected in remote regions, originating from various sources, such as landfills, shipping, tourism, and fisheries; and are transported via ocean currents, wind, sea ice, or biota (Lusher et al., 2015). The ocean has long been looked at as a disposal sites for waste with many estimates suggesting that mismanaged waste on land is mostly responsible (Vanapalli et al., 2021a). The detection of plastic pollution in the marine environment was first reported in the 1970s and its increase in abundance since then has highlighted the adverse anthropogenic impact on the environment (Kühn et al., 2015; Wagner and Lambert, 2018). The persistence of plastic debris adversely affects wildlife by presenting an environmental hazard, which has consequential effects on global economies, biodiversity loss, ecosystem function and human health (Hartmann et al., 2019; Hidalgo-Ruz et al., 2012).

Mismanaged plastic waste leaked into the environment from landfills, littering, fishing and shipping activities has led to marine ecosystems acting as a sink for plastic debris, such as the oceanic gyres of the Great Pacific Garbage Patch (Petersen and Hubbart, 2021). Rivers and estuaries in urban settings are major conduits and collectively account for a large proportion of plastics entering the oceans annually (Naidoo and Glassom, 2019). Plastics can persist in marine and coastal environments due to their long degradation times (Sparks and Immelman, 2020). Over time, the large volume of plastic accumulating in the environment breaks down into smaller polymer fragments known as microplastics (Zhu et al., 2021). Microplastics are items of synthetic or semi-synthetic polymer with average sizes between 1 µm and 5 mm. They are present in a variety of colours, chemical compositions and morphologies such as beads, films, fragments and fibres, each with its own toxicological impact (Booth et al., 2017; Miller et al., 2021). Microplastics are used in industrial processes, personal care and domestic cleaning products and have been found to be present in seafood, sea salt, the air we breathe and drinking water (Kühn et al., 2015). The contamination of global environments by microplastics has gained widespread attention and there have been increased efforts to understand the fate and risk of microplastic in different environments (Pakhomova et al., 2022).

Microplastics are ubiquitous and remain as highly persistent contaminants of the aquatic ecosystem long after they have been introduced into the environment (Miller et al., 2021). The half-life of microplastics is not known with certainty due to the broad variety of polymers used and the variation in environmental conditions (Miller et al., 2021). Microplastics make up the highest count of plastics in the aquatic environment and have been detected across the globe in inland lakes, estuaries, seawater, sediments and remote regions such as the Arctic and deep ocean basins (Guo and Wang, 2019; Miller et al., 2021; Zhu et al., 2021). Studies indicate that microplastics are more abundant in surface water relative to the water column (Guo and Wang, 2019). Contamination of freshwater and marine habitats with microplastics is ubiquitous throughout the world, but high pollution levels generally coincide with heavily industrialised and densely populated areas (Naidoo and Glassom, 2019). The concentration of microplastic pollution is predicted to heighten in the coming years due to the projected increase of synthetic polymer products (Petersen and Hubbart, 2021).

The increased abundance of microplastics may lead to an increase in the risk of detrimental effects caused by microplastic pollution (Petersen and Hubbart, 2021). The small size and high abundance of these small plastic particles make them difficult to remove from the environment allowing for easy infiltration into terrestrial, marine and freshwater systems and as a result are introduced into the food web (Klasios et al., 2021). Microplastics have been found to be readily ingested by freshwater and marine fauna and have wide ranging effects on the health of aquatic biota (Athey et al., 2020; Vanapalli et al., 2021a). There is also a rising potential threat of microplastic particles as a pollutant and as a vector for adsorbed toxic pollutants from the surrounding environment. The issue of microplastics has been recognized in the United Nation Sustainable Development Goals under Goal 14: Life Below Water, which aims to substantially reduce the amount of pollution in the marine environment by 2025 (Pagter et al., 2018).

1.2 Microplastic pollution in the context of South Africa's aquatic systems

South Africa has a coastline length of 3 400 km, with four coastal provinces out of the country's total of nine provinces. The marine environment hosts substantial biodiversity and contributes to the economic sector through fishing, shipping, tourism and recreational activities. South Africa is a water stressed nation with approximately 300 river outlets which vary in their level of urbanisation and sources of pollution. Many communities, such as those dwelling in informal settlements, are directly dependent on freshwater resources, however raw sewage entering freshwater resources is a major concern. The high density population with high consumption of plastic, pose as threats to the network of rivers and tributaries, and ultimately the marine environment. The lack of infrastructure and waste management systems in many areas in South Africa, especially in areas of informal settlements, have resulted in large proportions of unmanaged waste entering the environment (Verster et al., 2017).

Despite South Africa being a large contributor to plastic waste across the globe, the quantitative data available for environmental microplastic pollution in South Africa is relatively limited (Nel and Froneman, 2015). Few studies have been done to investigate microplastic abundances and polymer types in South Africa's aquatic ecosystems. However such studies have been limited as more attention has been paid to the marine environment, outlining the need to identify gaps on microplastic pollution in the context of South Africa's freshwater systems (Pereao et al., 2020). South Africa is a developing country and microplastic research is at its inception, highlighting the increasing importance of understanding the current abundances and potential sources of microplastic pollution in order to implement measures to prevent anthropogenic litter entering the aquatic ecosystems (Verster et al., 2017).

Microplastics have been reported to enter the environment via various pathways, however, highly populated and urbanised areas have been found to have aquatic systems with poorer water quality and higher microplastic abundances. Globally, microplastic pollution has garnered a lot of attention in the last decade. However, there remains a dearth of data describing microplastic pollution in freshwater systems, as well as limited data on discharge from urban stormwater drains and treated wastewater outflows (Sutton et al., 2016). The sources of microplastics have been found to enter via land-based or sea-based sources. A substantive fraction of plastic present in the marine environment originates from terrestrial sources and enter the oceanic environment through freshwater systems such as estuaries and rivers, effluents and run-off from surrounding urban and industrial areas (Sparks and Immelman, 2020). Industrial port environments contain potentially high levels of pollution resulting in the threat of spreading contaminants to the marine and coastal environment (Naidoo and Glassom, 2019). Special attention should be given to the sources of plastic in catchments exposed to a wide array of anthropogenic activities, especially urban areas, to understand key areas for mitigation strategies and for developing applicable management tools and policies.

1.3 Justification for study

Durban Bay and the Hennops River were selected for this study given the dense populations surrounding these sites and the amount of supporting infrastructure such as roads, railways, wastewater treatment plants, stormwater drains and diverse industrial activities. A combination of all these factors is likely to lead to multiple sources of microplastic pollution for these areas making them interesting ecosystems to investigate. The aim of this study is to take a holistic approach to the investigation by looking at surface water and sediment microplastic abundances.

1.4 Aims and Deliverables

Given the increasing concern on microplastic pollution, and its effects, the overarching aim of this study is to increase the cognizance of microplastic pollution. This study aims to provide a baseline description for the potential inputs, abundance and spatial distributions of microplastics in the Hennops River and Durban Bay harbour. There are currently no studies on the extent of microplastic contamination present in the highly polluted Hennops River. On the other hand, Durban Bay, located within the Durban metropolitan area, is subject to expanding anthropogenic activities and industrial activities (Naidoo et al., 2015). The area is also subject to multiple sources of pollution from the numerous stormwater outfalls and river inflows that drain into various areas of the port, making it an ideal site to assess the level of land-based inputs into the oceanic environment (Naidoo et al., 2015). A baseline description of the abundance of microplastics will help to fill the knowledge gaps, and comparisons of spatial patterns with findings from other studies will help to determine whether microplastic pollution in the study areas is a significant problem that requires focused action.

This study uses the estuarine environment of Durban Bay, located in KwaZulu Natal, and the freshwater environment of the Hennops River situated in Gauteng, as case studies. The deliverables from this study aims to detail an investigation into the anthropogenic activities in urban areas, and their impacts on the abundance and fates of microplastics found in surface water and sediment samples. Microplastic particles considered for the purpose of this study were within the size boundaries of 1 μm to 5 mm, as per the recommendations made by the National Oceanic and Atmospheric Administration (NOAA). The upper size limit of 5 mm was chosen from a pragmatic approach by the NOAA due to particles of this size having a greater probability of being ingested by organisms (Hartmann et al., 2019).

1. Mapping the spatial distribution and abundance of microplastics in surface water and sediment samples at different sites in Durban Bay, KwaZulu Natal and the Hennops River, Gauteng.
2. Characterisation of the microplastics extracted from surface water and sediment samples (categorized according to their morphology, size, colour and polymer compositions) found at the sites potentially linked to various anthropogenic activities.
3. Reporting potential accumulation hotspots of microplastics within sediment samples across the harbour in Durban Bay and the Hennops River.
4. Identifying potential land-based anthropogenic activities contributing to the input of microplastic in the aquatic environment.

2. LITERATURE REVIEW

2.1 Plastic and microplastic litter globally

The global production of plastics has increased exponentially over recent decades due to the broad array of applications, versatility and low production costs of plastics and the demand is predicted to continually grow in the coming decades (Bronzo et al., 2021; Duis and Coors, 2016). The production of plastics began in the 1950s and up to 2016, an estimated 8.3 billion metric tonnes of plastic have been produced (Rose and Webber, 2019). The increased plastic production is outpacing the capacity for disposal, recycle and reuse and has raised concern with plastic waste management systems whereby a large portion of plastics is being discarded into the environment where it serves no intended function (Bronzo et al., 2021; Hidalgo-Ruz et al., 2012). The durability of plastics which makes for a persistent and indispensable material is also responsible for the environmental strain from the amount of plastic pollution present in the environment. Plastics can travel between terrestrial and aquatic environments with marine environments functioning as recipients for plastic from land and sea-based sources (Bronzo et al., 2021). Plastic pollution was first reported in coastal environments in the 1970s and studies have shown that oceans act as sinks for plastic debris due to the large volume that travels through rivers that eventually enter the ocean. (Pagter et al., 2018). Marine debris has been defined by the Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) as: '*any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment*' (Agamuthu et al., 2019).

Many countries lack proper infrastructure, waste facilities and waste management practices and as a result struggle with discarding the large volumes of plastic waste (Borrelle et al., 2020). The entry of plastics into the environment is a result of multiple deficiencies across the plastic life cycle, commencing at the extraction of raw materials, followed by polymer design and production to the disposal of plastic materials (Lange, 2021). The after effects of plastic disposal is easily observable due to the large amounts of plastic polluting the environment, however, the true lifecycle toll of plastic materials is not holistically taken into consideration. The production of plastic is largely fossil fuel derived, therefore leading to non-biodegradable materials, and the emission of chemical pollutants and greenhouse gases (GHGs) exacerbates the profound effects of climate change on human and ecosystem health (Adeleke et al., 2020).

The pressures from increased production and consumption of single-use plastics coupled with inadequate waste management in high population density cities have severe ecological and socio-economic consequences. The improper waste disposal of plastic and introduction of microplastic pollution in a multitude of shapes, colours, and polymers to aquatic and terrestrial environments have resulted in environmental protection concerns in many countries throughout the world (Petersen and Hubbart, 2021). The degradation of plastics can take several years resulting in lengthened exposure times of plastics. The breakdown of plastics in the environment into smaller microplastics (MPs) makes these particles more accessible to terrestrial and aquatic organisms. Microplastics are the most commonly found anthropogenic debris found in marine and freshwater environments (Athey et al., 2020). The United Nations Environment Program (UNEP) have established MPs and nanoplastics (NPs) as worldwide contaminants of concern and are amongst the most important environmental issues to be addressed (Petersen and Hubbart, 2021). The particle dimensions of nanoplastics allow for potential penetration across cell membranes. Microplastics have become a pollutant of emerging concern due to their resistance to degradation, ability to adsorb toxicants and their increasing widespread pollution in the environment in conjunction with their small dimensions and risk for ingestion which is a growing concern for marine organisms (Lutz et al., 2021).

Studies conducted across terrestrial, aquatic and atmospheric environments have reported the presence of microplastics in various environmental matrices such as water, air, sand and biota (Huntington et al., 2020). Microplastics have been detected in beaches, snow, in surface-, subsurface- and seafloor water samples and have a tendency to accumulate in coastal zones, estuaries and soils further increasing the complexities of water pollution (Booth et al., 2017). Previous studies have concluded that marine sediments act as a sink and accumulation zone for microplastics with shoreline sediments having higher concentrations than deep sea sediments (Booth et al., 2017). In the years to come, microplastic pollution is expected to increase with the production of plastics on a global scale and the further degradation of these plastics.

2.2 The definition of microplastics

There has been an increase in the research of microplastic pollution in recent years, however, there is a lack of international agreements of size standardisation (Su et al., 2020). Plastic debris are typically categorized into items and particles of macroplastics (> 25 mm in dimension), mesoplastics (between 5 to 25 mm), microplastics (between 5 mm and 1 μm), and nanoplastics (< 1000 nm in their largest dimension) (Cai et al., 2021; McWilliams et al., 2018). The label of 'microplastics' was first used in 2004 and refers to all plastic particles with diameters of 5 mm or less, however, there has been difficulty reaching consensus for the size boundaries of microplastics (Frias and Nash, 2019; Pagter et al., 2018). The National Oceanic and Atmospheric Administration (NOAA) and European Marine Strategy Framework Directive (EMSFD) have proposed that the term of "microplastics" be employed for all plastic particles less than 5 mm, whereas the United Nation Environment Programme (UNEP) and Global Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) frameworks define microplastic dimensions as between 1 μm and 1 mm, with particles smaller than 1 μm being classified as nanoplastics (Besley et al., 2017; Pagter et al., 2018).

The definition of microplastics in this study, in accordance with the NOAA report, includes synthetic polymeric material (produced from hydrocarbon or raw materials), material fibres, monofilament lines and coatings, with size dimensions lower than 5 mm as these have been found to be ingested by biota. Microplastics have been defined as "any synthetic solid particle or polymeric matrix, with regular or irregular shape and with size ranging from 1 μm to 5 mm, of either primary or secondary manufacturing origin, which are insoluble in water" (Frias and Nash, 2019).

Plastic covers a wide range of polymeric compositions and can consist of blends of different synthetic blend types and properties (Weithmann et al., 2018). Identifying the characteristics of microplastics are important for identifying the sources of microplastic pollution. The size, colour, polymer type and morphology (fragments, fibres, pellets and films) of plastic particles may influence their fate and impacts (Weithmann et al., 2018). Characteristic polymers are used to make different products which can aid with identifying the source (Zhu et al., 2021). The most commonly produced polymers include polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC) and polyethylene terephthalate (PET) (Weithmann et al., 2018).

2.3 Sources, pathways and fate of microplastic pollution

2.3.1 Primary and Secondary sources of microplastics

Microplastic sources are largely classified according to primary and secondary sources (Pagter et al., 2018). The distinction between the two classes can help identify the main sources of microplastic pollution. The identification of microplastic sources is critical for implementing regulations to prevent pollution.

Primary microplastics are manufactured as microscopic dimensions for application as industrial pellets, abrasives, and microbeads (Guo and Wang, 2019; Pagter et al., 2018; Petersen and Hubbart, 2021). Primary microplastics are employed as industrial materials, scrubbers and exfoliants in personal care products (such as facial and body scrubs, toothpastes, shaving cream and make-up), and domestic cleaning product additives (Pagter et al., 2018; Petersen and Hubbart, 2021). Industrial pellets constitute the main forms of transporting plastic between producers and manufacturers. The pellets can enter the environment through accidental spillages and poor handling during transportation, which is especially common near ports and in industrialised areas (Zhu et al., 2021). Primary microplastics may also directly enter the environment through streams, surface runoff and discharge from wastewater treatment plants (WWTPs).

Secondary microplastics are fragments derived from larger plastics and are formed through the disintegration and degradation of larger synthetic polymers (Naidoo and Glassom, 2019; Pagter et al., 2018; Petersen and Hubbart, 2021). The breakdown of fishing nets disposed of from fishing activities or fibres from synthetic textiles results in secondary microplastics. Plastics are durable and can take a long time to breakdown from weathering and aging depending on the types of plastic and the conditions they are exposed to (Guo and Wang, 2019). The degradation of plastics can occur via mechanical abrasion (wind, wave and water current action), chemical disintegration (UV degradation) or biodegradation (microbial breakdown) causing physical stress and brittleness (Vanapalli et al., 2021a). There is greater potential for abiotic degradation of microplastic in coastal regions and along shorelines because of the combination of environmental factors such as wave action and UV radiation, therefore it is suggested that coastal areas are the main source of marine generated microplastic (Booth et al., 2017). Secondary microplastics have been found to be prevalent in the environment in comparison to primary microplastics (Booth et al., 2017; Naidoo and Glassom, 2019; Petersen and Hubbart, 2021).

A combination of environmental conditions such as water chemistry, temperature, sunlight and microorganisms determine the kinetics of polymer degradation (Booth et al., 2017). The degradation of secondary and primary microplastics may result in morphological changes such as discolouration, density changes, crystallinity changes and increased surface area which affects their fate and behaviour in the environment (Guo and Wang, 2019). The degradation of plastics into microplastics are influenced by polymer type, physicochemical properties and the presence of additives (Booth et al., 2017). Microplastics can be categorized according to the morphologies of the particles, the morphologies include fragments, pellets, fibres and films (Pagter et al., 2018; Sparks and Immelman, 2020). The sizes of microplastics is also an important factor contributing to the potential ingestion rates of marine biota and is a crucial factor for the health of organisms and subsequently ecosystems (Sparks and Immelman, 2020). Shape and size can affect toxicity, as well as associated chemicals.

The introduction of plastics and microplastics into aquatic ecosystems encompasses a variety of inputs such as fishing waste, packaging litter, beauty products with microbeads, synthetic textiles shedding fibres or rubber from tyres (Zhu et al., 2021). Anthropogenic activities from terrestrial sources are largely responsible for the amount of plastic debris present in the marine environment (Verster and Bouwman, 2020). The widespread distribution of microplastics highlights the need to identify the pathways of these plastics from their sources.

2.3.2 Sources and pathways contributing to microplastic pollution in the marine environment

There are several pathways and a variety of sources responsible for the origination of microplastic pollution in the marine environment (Figure 1) (Naidoo and Glassom, 2019). It is helpful to understand the fate and source of microplastic inputs to inform the implementation of regional policies to aid in reducing the amount of plastic pollution. The point of entry of various microplastic pollution sources into the marine environment can be classified as land-based or sea-based sources (Vanapalli et al., 2021a). Direct sea-based inputs of microplastics entering the marine environment include marine litter released during sea activities including recreational activities and tourism, ghost fishing gear, activities near ports and harbours, offshore industrial activities, discarded plastic equipment from aquaculture activities and accidental spillages during shipping (Sparks and Immelman, 2020; Vanapalli et al., 2021a). Fibres from textiles have also been identified as a large contributor to microplastic pollution. Microplastics can also be introduced into the environment through the utilization and disintegration of products such as tyres, paint, textiles and surfaces composed of or coated with polymers such as artificial grass pitches. These particles are persistent and lightweight allowing for transportation over long distances by means of ocean currents, air currents or biota (Farmen et al., 2021; Huntington et al., 2020).

Studies have shown that over 80 % of microplastics present in the marine environment originate from land-based sources, entering through various pathways such as rivers, effluents and run-off ((Preston-Whyte et al., 2021: Sparks and Immelman, 2020; Zhu et al., 2021). This outlines the need for focused attention towards strategies on reducing microplastic leakages from the identified land-based sources. Land-based sources of pollution encompass illegal dumping and littering, river inflows, sewage outlets and stormwater inputs (Preston-Whyte et al., 2021). Riverine and atmospheric inputs can introduce contaminants from landfills, commercial- and domestic sewage effluents, urban stormwater and agricultural runoff (Farmen et al., 2021; Zhu et al., 2021). Periods of heavy rainfall can result in the contamination of aquatic waterways due to leakages from municipal solid waste deposits in urban areas (Su et al., 2020). These plastics undergo fragmentation during transportation or once they enter the marine environment (Vanapalli et al., 2021a). The UN Environment Programme (UNEP) reported mismanaged solid waste and tyre abrasion as the largest contributors to macro- and microplastic pollution from land-based activities globally.

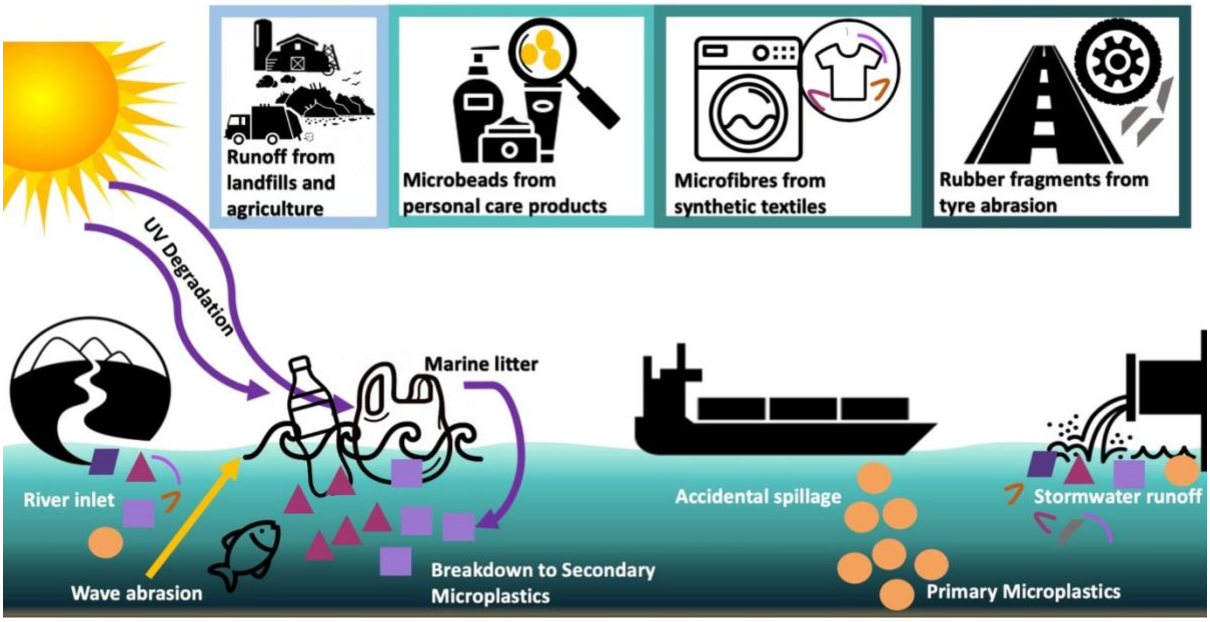


Figure 1. Schematic diagram depicting a selection of sources and pathways of that contribute to microplastic pollution in the marine environment.

Microplastics enter waterways through discharge from waste-water treatment plants (WWTPs) and storm water drains. Storm water drains are a major source of microplastics to aquatic systems; especially when systems overflow stormwater can pick up numerous micropollutants originating from packaging material, degraded road paints and tyre wear from vehicles (Shruti et al., 2021). Traditional WWTPs are not designed to remove microplastics, such as microbeads present in personal care products, enabling them to escape through treatment systems employed at these plants and ultimately enter the marine environment as a result of their microscale particle dimensions and buoyancy (Shen et al., 2019). Microplastics are discharged into the environment via the use of sewage sludge to agricultural soil in countries with adequate wastewater treatment facilities. The microplastic particles concentrate in the biosolids during wastewater treatment, which is used in the application of sludge as fertilizer in agricultural activities (van den Berg et al., 2020). The introduction of microplastics into soil poses threats to soil life as the plastics remain in the soil much longer than soil nutrients (van den Berg et al., 2020). The overuse of sewage sludge as fertilizers for agricultural land potentially leads to anthropogenic enrichment of agricultural land. The pollutants from the soil can enter freshwater systems through run-off, subsequently ending in the marine environment run off placing the risk of microplastic and chemical toxicity and accumulation on biota (Weithmann et al., 2018).

2.3.2.1 Microplastics in rivers

The high volumes of microplastics in freshwater has sparked recent interest in understanding the sources (Su et al., 2020). River inlets and coastal regions in urban areas serve as conduits of microplastic pollution into the marine environment. Rivers, streams and estuaries, more particularly those located in urban settings, are recognized as major contributing sources of microplastics into the marine environment (Naidoo and Glassom, 2019; Vanapalli et al., 2021a). These freshwater environments pose as recipients and transport pathways of microplastics. An estimated 80 % of microplastics present in the marine environment originates from land based sources with rivers being the most dominant pathway therefore investigating the role of rivers as microplastic pollution pathways is of importance (Eo et al., 2018; Mani et al., 2015). The declining water quality and deteriorating integrity of river systems are strongly associated with human-induced changes, particularly changes involving land-usage (Moodley et al., 2015). River systems, especially those situated in urban areas, have been identified as major transport pathways for plastic debris entering the ocean (Su et al., 2020). Rivers act as conduits for microplastics discharged from WWTPs and the concentration found in urban regions is especially high (Bulannga and Schmidt, 2022). Microbeads used in personal care products and domestic cleaning products often end up in rivers due to current clean-up methods employed by wastewater treatment plants that are insufficient at removing such small particles.

Rivers serve as crucial pathways in transporting waste generated inland and in landlocked regions to the sea (Siegfried et al., 2017). This highlights the need to improve the knowledge of point sources, such as WWTPs and stormwater outfalls, in their processes that lead to the pollution of waterbodies with plastics (Siegfried et al., 2017). Non-point sources can also lead to microplastic pollution. These are sources without a direct discharge point and inputs are diffused over a wide area. Examples of non-point sources of pollution include plastic debris entering aquatic systems via surface run-off, precipitation or atmospheric deposition (Siegfried et al., 2017). Non-point sources of pollution can occur over a wide area range and involve complications in characterising these sources due to the processes not being easily governable.

There is a lack of data available on the microplastic discharge from wastewater treatment plants in South Africa, however rivers may lead to a substantial input as WWTPs in USA and Netherlands have reported microplastics discharge of 10^{10} particles per day (Bulannga and Schmidt, 2022). Riverine plastic pollution is expected to worsen in as a result of increased flood risk around the world's rivers. Flooding events of rivers surrounded by poor waste management systems contributes to heightened debris mobilisation resulting in increased plastics entering the marine environment. Heavy rainfall as a result of seasonality changes during the summer seasons, and the risk of climate change, is expected to elevate the extent of land-based pollution inputs into the marine environment (Botterell et al., 2019). It is therefore essential to understand the fate and behaviour of microplastics in river ecosystems, especially rivers located in urban areas. The mitigation of microplastic pollution in the environment requires extensive research efforts in mapping the sources and distribution of microplastics from land-based activities into the marine environment (Su et al., 2020).

2.3.2.2 Microplastics in ports

Estuarine ecosystems are undergoing rapid modification and threatened due to the rising threats from the impacts of urbanisation, industrial development, agriculture and mining activities (Adeleke et al., 2020; Barletta et al., 2019). Urbanised water bodies increasingly exposed to anthropogenic activities, such as harbours, have been shown to be contaminated with microplastics and act as conduits for microplastics entering the marine environment (Preston-Whyte et al., 2021). Ports and harbours have functioned as accumulation hotspots for anthropogenic contamination from surrounding urban areas and industrial activities (Preston-Whyte et al., 2021). Studies have shown that microplastics tend to increase downstream of rivers and accumulates in estuaries (Su et al., 2020). There have been numerous studies that investigated microplastics found in sediments and water in the oceans, however less attention has been directed at investigating microplastic pollution in harbours (Preston-Whyte et al., 2021). It is essential to remediate contaminated sediments to protect human and environmental health (Preston-Whyte et al., 2021). Studies done in densely populated urban cities with high anthropogenic activity and poor waste management infrastructure, such as Chennai and Cochin in India, found major shipping and fishing harbours to have high MP abundances in marine biota (Vanapalli et al., 2021a). Studies conducted along the Belgian coast found microplastic concentrations to be highest in harbours where microplastic abundances of up to 390 particles/kg dry sediment were recorded, which is significantly higher than observed abundances of similar study areas (Claessens et al., 2011).

2.4 What are the implications of microplastic pollution?

Many marine animals, including seabirds, fish, turtles and mammals, are harmed by plastic through ingestion, lacerations and entanglement. However, the ecological and public health effects of microplastics are not fully observable to the naked eye and are still to be fully elucidated (de Villiers, 2018; Kühn et al., 2015). The widespread presence and distribution of microplastics in the environment suggests that these particles frequently interact with biota and the smaller size ranges are available to a broader range of organisms (Vanapalli et al., 2021a). Microplastics are potentially toxic and can adversely impact organisms through bioaccumulation in the food web due to their small size (Guo and Wang, 2019; Tsang et al., 2017). Aquatic organisms at every level are exposed to microplastics but the health risks associated therewith is largely unknown due to variations in plastic size, shape and chemical composition (Miller et al., 2021). Ingestion of microplastic particles compromises their ability to capture and digest food, and reproduce. The size of microplastics is important in terms of potential ingestion rates of marine organisms (Sparks and Immelman, 2020). Microplastics in surface water are within the similar measurement ranges as plankton (1 µm – 5 mm). This results in microplastics being bioavailable for ingestion by a number of lower trophic biota, potentially leading to bioaccumulation by predation in higher trophic levels along the food web (Bulannga and Schmidt, 2022; Guo and Wang, 2019; Sparks and Immelman, 2020).

Marine organisms such as zooplankton, copepods, mussels, oysters, corals, rotifers fish, turtles and seabirds have observably ingested microplastics (Bulannga and Schmidt, 2022; Guo and

Wang, 2019; Tsang et al., 2017). Suspension and filter feeders, such as mussels and clams, are particularly susceptible to microplastic ingestion as these organisms sustain on suspended particulate matter and are ineffectual at differentiating between nutritional food items and indigestible non-food items in similar size ranges (Bulannga and Schmidt, 2022). Microplastics lead to mechanical damages in organisms through obstructing the digestive tract and altering the filtering capabilities of organisms (Farmen et al., 2021; Guo and Wang, 2019). The ingestion of microplastics may lead to the death of organisms as they are affected by exposure to toxic chemicals, lack nutritional food intake and subsequently reduced energy reserves (Guo and Wang, 2019). Microplastics detected in marine and freshwater dietary protein sources may cause potential health risks to humans through ingestion and bioaccumulation (Guo and Wang, 2019). The exposure to airborne microplastics via atmospheric deposition in urban areas has caused public health concerns as the inhalation of plastic dust particles triggers respiratory inflammation (Amato-Lourenço et al., 2020). A recent study found approximately 5 grams of microplastics can be consumed by human individuals based on weekly food and beverage consumption (Senathirajah et al., 2021). The intake of toxic chemicals incorporated in plastic can lead to accumulation in tissues and organs of humans however further research is required to discern the human health implications of ingesting microplastics (Senathirajah et al., 2021).

Microplastic toxicity may originate within two processes. Firstly, the higher surface area to volume ratio and hydrophobicity of microplastics may result in the adsorption of marine pollutants, such as metal ions and organic pollutants. These particles may accumulate onto the microplastic particles and allow them to act as a vector for these toxic pollutants (Guo and Wang, 2019; Tsang et al., 2017). Microplastics can also serve as a vector for microbial pathogens as different conditions enable microorganisms to colonize surfaces of plastics and develop biofilms (Amato-Lourenço et al., 2020; Gopinath et al., 2020). Secondly, additives mixed with polymers during synthesis to improve physical and chemical properties of plastics are inherently toxic and the breakdown of plastic debris into smaller fragments allows for the release of these toxins (Tsang et al., 2017). Microplastics act as vectors for toxic pollutants and pathogens introduce these additives to marine organisms and the food web (Guo and Wang, 2019).

Chemicals and additives are often incorporated into plastic products and packaging to improve properties such as flexibility or fire resistance. While additives may not be of focused attention in the environmental pollution perspective, the recycling of plastics with additives is increasingly complex and poses challenges for adopting a circular economy. Additives comprise of pigments, flame retardants and stabilisers which are incorporated to enhance the plastic product's functionalities and also pose risks to environmental and human health. Plasticizers are toxic substances incorporated in products and these substances accumulate onto plastics from the surrounding seawater (Kühn et al., 2015). The hydrophobic nature of microplastics allows them to adsorb additives and contaminants such as pigments and metal ions from the surrounding environment (Huang et al., 2021; Mani et al., 2015). The biomagnification of toxic chemicals through organism transfers in the food chain leads to increased morbidity, accumulation of toxic substances in the liver, interferences in endocrine functioning and neurotoxicity (Sparks and Immelman, 2020).

The ingestion of microplastic particles alters physiology and impairs development of organisms which has consequences on growth, reproduction and population size (Botterell et al., 2019). The knock-on effects may result in diminishing population sizes for successive generations and subsequently reducing food availability for higher trophic levels (Botterell et al., 2019). Extreme weather events, such as tropical storms, caused by climate change leads to dispersed mismanaged waste between terrestrial and aquatic ecosystems and can increase the abundance of microplastics within seawater and sediments (Botterell et al., 2019). Fluctuations in temperature from climate change may additively impact the effects of microplastics, and place multiple stressors on marine biota such as oxidative stress, immune functioning and thermal stress affecting energy reserves (Botterell et al., 2019). Pristine and well-maintained natural resources are necessary for the consistent operation of aquaculture and fisheries. The potential for growth in the blue economy is hindered by the continuous breakdown of plastic which leads to the growing abundance of microplastics present in waterbodies. The increasing abundance of microplastics subsequently leads to ingestion by aquatic biota which has knock-on effects on global economies (da Costa, 2018).

2.5 The Plastic Industry in South Africa

South Africa has a well-developed plastics market catering to local and global markets with approximately 60 000 employees in the plastics sector (Tsotsi and Jenkins, 2019). The plastic industry is fundamental for South Africa's economy, contributing 2.1 % to the GDP and 21.8 % to the manufacturing sector in 2018 ("Plastics – The Department of Trade Industry and Competition," 2018). The plastics packaging sector is responsible for 52 % of South Africa's plastic market and large proportions of domestic consumption comprises of ethylene from domestic production whereas polypropylene is largely exported due to production exceeding domestic demand ("Plastics – The Department of Trade Industry and Competition," 2018).

South Africa has been ranked as the 11th most contributing country of plastic waste throughout the globe with an estimated 630 000 metric tonnes of trash leakage polluting the marine environment (Bulannga and Schmidt, 2022). The poor waste management system is a result of inadequate waste disposal protocols and the lack of proper infrastructure which results in the leakage of plastic into the environment (Verster et al., 2017). South Africa, similar to many countries across the global, is a water stressed country facing deteriorating water quality at varying extents across its freshwater sources (Morole, 2020). Aquatic systems situated nearby densely populated informal settlements are subjected to escalating levels of pollution from inadequate waste disposal of single-use plastic packaging and other plastic products.

The plastic recycling sector creates approximately 7 800 jobs in South Africa (Plastics SA, 2019). Informal waste collectors account for the self-created livelihoods in the waste sector. The pickers earn their livelihoods from collecting waste found in streets and landfills, or sourced directly from households. The collected items are sold as recyclable waste to formal recyclers (Godfrey and Oelofse, 2017). The collection and recycling of plastic and other wastes are important activities in a circular economy, as they help to divert plastic waste from landfill, thus reducing plastic leakage into the environment. The services of waste collection and recycling are largely the responsibility of municipalities however the informal waste sector has been fulfilling the role. The informal workers are exposed to hostile living and working conditions, with minimal to no financial compensation whilst saving local municipalities costs for landfill space (Godfrey and Oelofse, 2017).

Economic activities, such as the tourism and fishing industries, are heavily dependent on the marine environment (Jain, Raes, et al., 2021; Rose and Webber, 2019). According to a 2021 WWF report, approximately $ 60.72 billion (±28 %) damages in cost was inflicted on South Africa from the lifecycle of plastics that were produced in 2019 (WWF, 2021). The aforementioned damages are inclusive of income, population health, economic sectors such as tourism and fisheries, and costs incurred by the government for clean-up initiatives (WWF, 2021). Plastic pollution and the associated loss of aesthetic appeal of tourism hotspots such as beaches has critical impacts on the economy, with an investigation into the City of Cape Town reporting tourism revenue and employment decreasing by as much as 91 % due to plastic pollution of its beaches (Jain et al., 2021). The City of Cape Town spends R13 million per year on regular beach clean-ups in order to avoid estimated damage R8.5 billion to the tourism sector (Jain et al., 2021).

The extent and type of microplastic pollution in South Africa is largely unknown (Sparks and Immelman, 2020). The predicted growth of microplastic pollution in the forthcoming decades highlights the importance of understanding and identifying main pollution sources (Verster et al., 2017). Rapid population growth coupled with increased urbanisation and poor waste management have led to freshwater systems being threatened. Studies on microplastics in South Africa have reported their detection in freshwater, beach sediments, coastal zones, species of marine commercial fish and other biota (Naidoo and Glassom, 2019; Preston-Whyte et al., 2021; Verster et al., 2017). Microplastics have been detected in seven species of commercially targeted fish from the Agulhas Bank representative of South African fishing grounds along the western coast. Microplastic abundances ranged from 2.8 to 4.6 items/fish with fibres being predominantly reported of sizes from 500 to 1000 µm (Sparks and Immelman, 2020). Sewage sludge and wastewater from residential areas have been associated with higher abundances of microplastic fibres (de Villiers, 2018). Studies in South Africa have shown microfibres to be the most abundant microplastic type in coastal water and beach sediment sites linked to wastewater outfalls (de Villiers, 2018).

3. METHODS

3.1 Study Area

An assessment of microplastic abundance, its key potential sources, and polymer types was carried out by analysing microplastics in sediment and surface water samples. Various sites were sampled along the selected study areas of Durban Bay and the Hennops River to understand the distribution of microplastics in surface water and sediments, and how nearby anthropogenic activities influence the abundance and distribution of microplastics present.

The abundance, spatial distribution and characteristics of microplastics present in surface water and sediment was investigated in Durban Bay and the Hennops River (Figure 2), areas which are heavily subjected to anthropogenic activity. The results from this study will identify potential anthropogenic sources of microplastic input into Durban Bay and the Hennops River, and potentially be used to identify key areas to target for mitigating microplastic pollution.

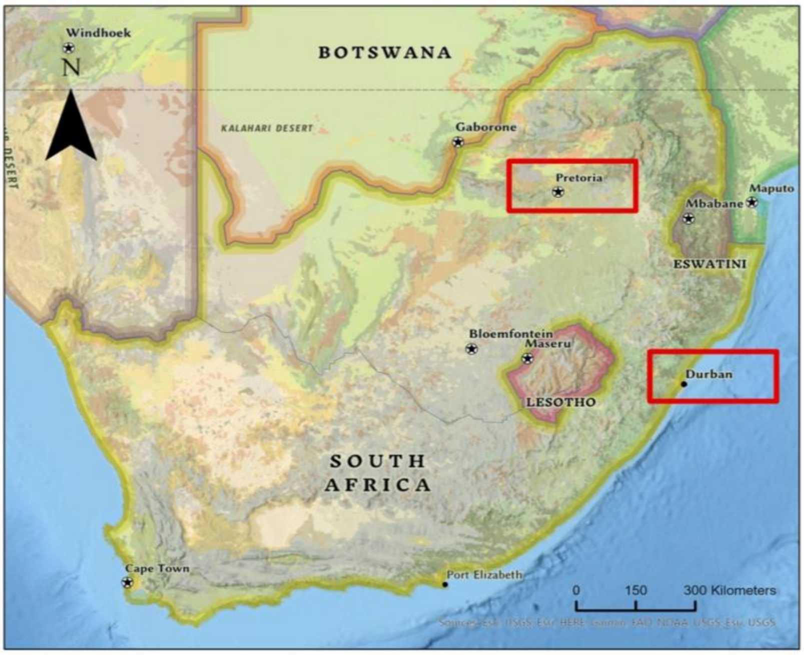


Figure 2. Map depicting the sampling areas selected for this study, namely the Hennops River in the Centurion area, Gauteng and Durban Bay located in Durban, KwaZulu-Natal.

3.1.1 Durban Bay

Durban Bay (29° 52′ S; 31° 04′ E) is an estuarine embayment comprising of the largest port in sub-Saharan Africa, and one of the most economically active international shipping harbours and container handling ports in Africa (Adeleke et al., 2020; Preston-Whyte et al., 2021; Vogt et al., 2019). The estuarine harbour is located on the eastern coast of South Africa in the country's third largest metropolitan of Durban, and drains into the Indian Ocean. Durban is characterised by humid subtropical climate with annual rainfall with an average annual rainfall of 1 054 mm in the hot summer season (between the months of December and February) (Moodley et al., 2015). Durban is a highly urbanised, major industrial and economic hub administered by the eThekwini Municipality in the province of KwaZulu-Natal (Adeleke et al., 2020; Naidoo and Glassom, 2019). The municipality supports a high population density of approximately 3.5 million people, and many inhabitants occupy informal settlements that are densely populated and lacking basic necessities such as piped water, basic health care and sanitation services (Vogt et al., 2018) .

Numerous river inflows and estuaries are subject to a wide array of urbanised and industrialised activities surrounding the harbour, which have led to water rich in contaminants entering the marine environment (Vogt et al., 2018). A number of rivers and canals that flow through and drain the industrial and urban catchment areas of the Durban metropolitan, drain surface run off into the Durban Bay. The major catchments that contribute to perennial freshwater inputs into the Bayhead Canal of Durban Bay are the Umhlatuzana, Umbilo and aManzimnyama rivers (Figure 3.a & b) (Moodley et al., 2015; Preston-Whyte et al., 2021). Debris from waste gets washed downstream into the rivers during heavy rainfall after the build-up of pollution during the winter dry season, resulting in polluted waters of poor quality (Vogt et al., 2018). There has also been an increase in pollution from sewage, storm water, industrial runoff and wastewater outfalls into the harbour. The numerous stormwater outfalls and rivers that drain into the harbour are expected to carry the highest plastic abundances. The stormwater drains from the industries surrounding the harbour and Durban's Central Business District (CBD) are indicated numerically (Figure 3.b) (Preston-Whyte et al., 2021).

The Gandhi Sewage Pump Station located at Durban Point is utilised by the Durban CBD, Berea and neighbouring areas (Preston-Whyte et al., 2021) The stormwater outfall located nearby the Yacht Club (Figure 3, point 4) is an overflow site for the sewage pump station.

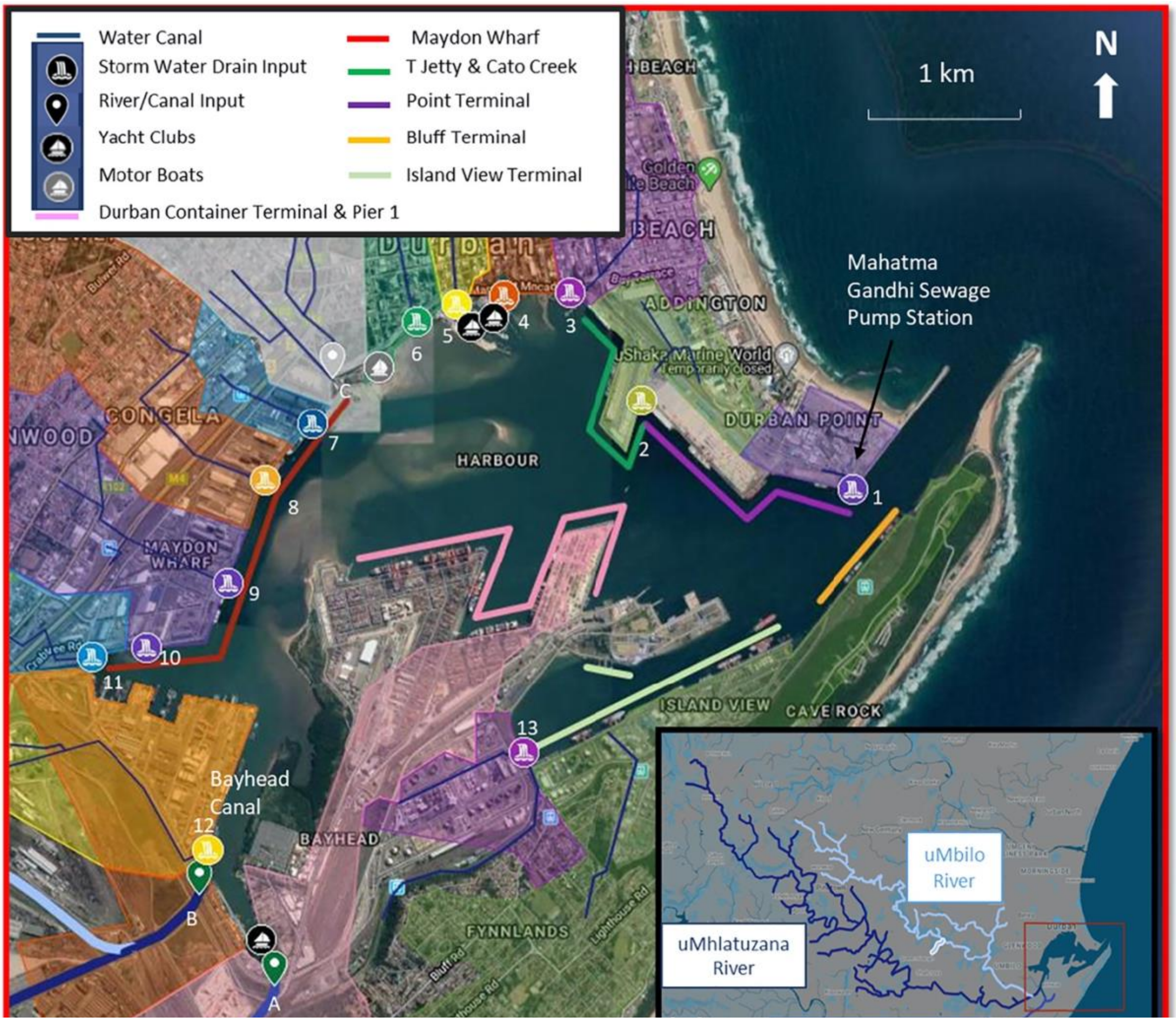


Figure 3. Map depicting Durban Bay with a) rivers and tributaries, b) drainage areas (coloured blocks) and the corresponding land-use activities inputs, stormwater channels and inflows, and river inflows into the harbour. Letters A and B represent the river inflows into the harbour, and numbers 1 to 13 represent the stormwater inlets into the harbour *(Cited from 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, p.111948.)*

The estuarine harbour is highly degraded due to its exposure to anthropogenic activities and surrounding land-usage involving boardwalk restaurants, agricultural activities, dry docks, yacht clubs, industrial development and effluent discharge, which result in contaminants entering the harbour (Adeleke et al., 2020' Preston-Whyte et al., 2021). Anthropogenic activities occurring nearby to the harbour include petrochemical processing and vehicular traffic (Vogt et al., 2019). Shipping activities also form a major contributor which could lead to microplastic pollution in the environment (Vanapalli et al., 2021a). Durban Bay undergoes active dredging for the upkeep of the harbour's operational channels and the sediment is discharged at an offshore site nearby the edge of the continental shelf. Identifying the accumulation zones and distribution patterns of microplastics within sediments will benefit understanding the scale of their potential impact on the environment post dredging activities (Preston-Whyte et al., 2021).

The potential inputs of pollution from shipping activities around Durban Bay include the maintenance of container vessels, bulk and breakbulk cargo, automotive carriers, cruise ships, and smaller fishing and recreational boats (Preston-Whyte et al., 2021). Microplastic pollution can be derived from the activities and land uses typical of the area around Durban Bay (Adeleke et al., 2020). The extensive amounts of pollution directed towards the harbour are a result of inadequacies in the environmental maintenance and management of surrounding areas. Recreational activities (bathing, surfing and fishing) were banned in Durban in 2019 as a consequence of the inflow of untreated sewage into the aquatic environment (Heyden, 2019). An investigation by the Department of Water and Sanitation faulted mechanical pump failures due to malfunctional rakes and the entry of foreign objects into the pump system at the Mahatma Gandhi Pump Station, which resulted in uncontrolled raw sewage leakages into the sea (Heyden, 2019).

3.1.2 Hennops River

The Hennops River, located in the Gauteng Province, is an urban riverine system under pronounced stress driven by heavy pollution from domestic solid waste, industrial effluent and untreated sewage, which is severely impairing its ecological function. The catchment is located between Johannesburg and Tshwane and flows through three large municipal jurisdictions, namely the City of Johannesburg, City of Tshwane and Ekurhuleni Metropolitan Municipality. The Hennops River flows from Kempton Park, through Centurion, into the Crocodile River, and drains into the Hartbeespoort Dam catchment located in a landlocked area that receives urban runoff from densely populated urban regions. Rapid urbanisation, informal settlements, industrial developments and business areas as well as residential areas have led to the deterioration and loss of aesthetic appeal of the Hennops River. The urban regions consist of informal and formal residential-, industrial-, commercial- and recreational areas such as the Irene Country Club, Irene Dairy Farm, Centurion Golf Estate, Centurion Lake and the Hennops Park.

Rapid deterioration of the river has occurred since the beginning of its urbanisation in the 1970s. The river cannot sustain aquatic life and appears in a poor environmental state with high levels of pollution and strong sewage odours due to poor environmental management, and the lack of basic sanitation available for residents dwelling in informal settlements. Poor water quality issues and high levels of pollution in the river have raised concerns about the health risks posed to the inhabitants of surrounding communities.

The South African Human Rights Commission (SAHRC) Gauteng Provincial Office undertook an inquiry into the sewage pollution of the City of Tshwane's rivers, after receiving several documented complaints regarding the levels of pollution and the release of untreated sewage into the Hennops River from malfunctioning WWTPs (SAHRC, 2021). The Olifantsfontein Wastewater Treatment Plant (WWTP) and Sunderland are situated in the Hennops River catchment. Treated effluent from the Sunderland Ridge WWTP is discharged into the Hennops River. The deteriorating water quality has been attributed to the densely populated informal settlements of Tembisa, Ivory park and Rabie Ridge, located in the upper catchment area of the Hennops River. The river receives heavy pollution along these settlements due to the lack of technical facilities, such as inadequate sanitation facilities, poor solid waste management and inefficient storm water drainage. Habitants of informal settlements lack access to sanitation services subsequently causing the build-up and overflow of solid waste into river systems. The sudden rise in population density that is associated with the setup of informal settlements places increasing pressure on the WWTPs which service the area.

There are significant amounts of waste and vegetation debris present along the river. The vegetation debris consists of branches and dead trees which collect alongside the river. Other solid waste debris includes urban litter ranging from cans, bottles, plastic bags, clothing, shoes and tyres. The urban litter that builds up from informal settlements is due to the lack of proper waste collection, handling and removal services. A majority of this debris is discarded directly into the river but may also be flushed into the river during periods of heavy rainfall and flooding. During dry seasons, litter collects in the streets and stormwater drains, therefore, after periods of heavy rainfall and flooding the debris flushes into the river, and plastic builds up along the riverbanks. The Kaal Spruit is one of the most contaminated tributaries of the Hennops River. The stream borders along the densely populated informal settlements of Tembisa and Ivory Park. There is often accumulation of waste from the informal settlements due to poor waste collection from weak organisational structures, poor infrastructural maintenance, the lack of municipal management and funds. Raw sewage is released directly into the Kaal Spruit which feeds into the Hennops River (SAHRC, 2021). The densely populated informal settlements located in the catchment area of the Hennops River possibly influence microplastic pollution and should be noted because wastewater in the surrounding areas often runs directly into the river.

3.2 Sample Collection

3.2.1 Durban Bay Sampling

Surface water and sediment sampling was conducted across 15 sites at Durban Bay on the 18th August 2020 during the dry, winter season. A combination of water and sediment samples were collected at each site in the harbour to provide a robust assessment of microplastic contamination. Sediment and surface water samples were collected using a vessel provided by the Council for Scientific and Industrial Research (CSIR). The sampling sites were selected to cover as much of the harbour as possible to gain an adeqaute spatial understanding of the distribution of microplastics, as well as identify the potential microplastic pollution inputs from different land-based activities.

The land-based activities surrounding the area include effluent of wastewater treatment plants, road drainage, urban runoff, river inlets and agricultural drainage. The table below in conjunction with the map in Figure 3 provide insights into the nearby activities which serve as potential sources of microplastic pollution associated with the various sampling sites.

Table 1. Sampling site coordinates and depths with their locations in Durban Bay and associated anthropogenic activities nearby.

Sampling Site	Coordinates Latitude	Longitude	Water Depth (m)	Location	Nearby Activity
Durban Bay 1	-29.903863	31.008163	1.5	Bayhead	River inflow; Yacht Club
Durban Bay 2	-29.898478	31.004679	3	Bayhead Canal	River inflow; Stormwater Dain
Durban Bay 3	-29.892686	31.006605	7	Bayhead Canal	River inflow; Stormwater Dain
Durban Bay 4	-29.885709	31.006780	7	Bayhead Canal	Stormwater Drains; Shell Petrol Station; Kind Edward Hospital
Durban Bay 5	-29.879045	31.007044	14	Maydon Wharf	Stormwater Drain
Durban Bay 6	-29.871302	31.014386	16	Harbour	Stormwater Drain
Durban Bay 7	-29.869218	31.027294	14	Harbour	Shipping Activity; Cruise Passenger Terminal
Durban Bay 8	-29.874960	31.018762	13	Harbour	Shipping Activity
Durban Bay 9	-29.881358	31.025232	13	Durban Container Terminal & Pier 1	Container Terminal
Durban Bay 10	-29.879390	31.033074	13	Durban Container Terminal & Pier 2	Container Terminal
Durban Bay 11	-29.880742	31.042174	12	Island View	Naval Station
Durban Bay 12	-29.874669	31.048850	12	Durban Point Terminal	Mahatma Gandhi Sewage Pump Station
Durban Bay 13	-29.874823	31.041952	12	Durban Point Terminal	Mahatma Gandhi Sewage Pump Station
Durban Bay 14	-29.865470	31.032881	13	T Jetty & Cato Creek	Quayside Road
Durban Bay 15	-29.864234	31.024148	5	Boatman's Road	Stormwater Drain; Yacht Clubs; Laundry Service

Water Sampling

Surface water samples were collected from each of the 15 sites by towing a conical plankton net alongside the vessel across a 50 meter transect (Figure 4). Sample collection was conducted at sea surface-level using a plankton net (50 μm mesh size, 0.5 m opening size, 1 m length) towed at constant speed alongside the boat vessel. An approximate volume of 10 000 to 20 000 L of water was sampled along each transect. A calibrated flowmeter attachment (Hydrobios mechanical flow meter) was fixed in the centre of the mouth of the net and used to calculate the exact volumes of water that were sampled. The particulates inside the net tube and those retained in the net were sample reduced by washing into a 500 mL glass jar for laboratory analysis. The glass jars with metal lids that were used for sample storage were pre-rinsed with filtered reverse osmosis water. Samples were preserved using filtered 100 % ethanol for transportation and further analysis at the University of the Witwatersrand.

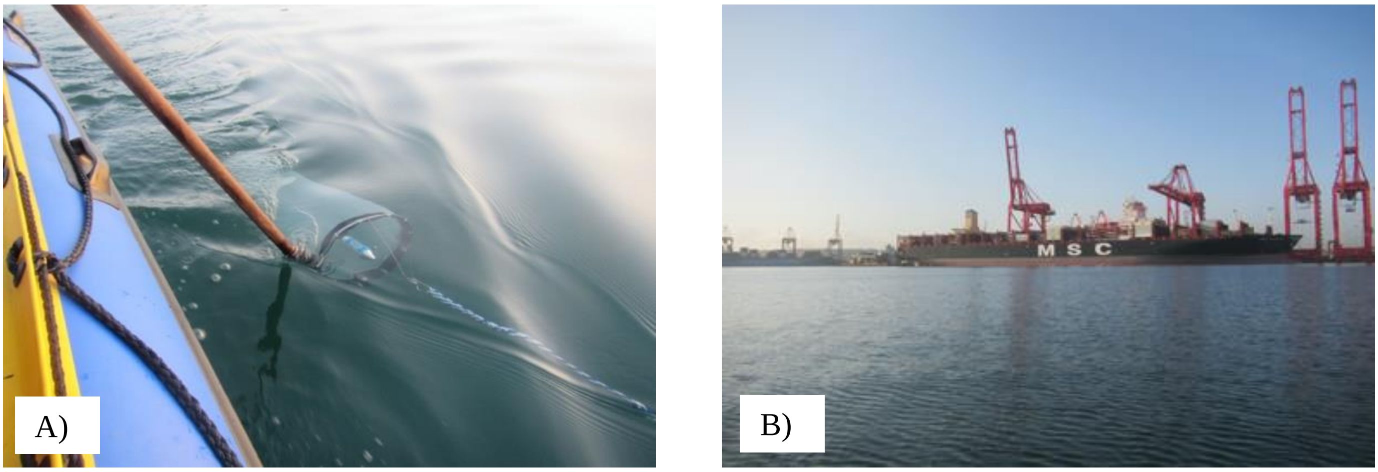


Figure 4. Sampling at Durban Bay A) Deployment of the plankton net used for microplastic surface-water sampling in Durban Bay. B) Photograph of sampling site 7 nearby to a cruise passenger terminal within Durban Bay.

Sediment Sampling

Sediment sampling was performed at each site (n = 15) using a grab sampler in conjunction to the water samples collected on the vessel. At a selected number of sites, two sediment samples were collected to look at small scale variability. The second sediment grab was mixed to uniform consistency in a glass bowl using a stainless steel spoon to determine if mixing had any effect on microplastic results. Approximately 150 g of sediment samples collected were from the top layer of sediment and were placed in Ziploc bags for transportation and storage. Particle size analysis for the sediment at each site was conducted by the CSIR to investigate whether microplastic abundances varied according to the differences in sediment compositions.

3.2.2 Hennops River Sampling

Sampling in the Hennops River in the area of Centurion, Gauteng province was carried out on the 6th – 7th of July 2020. The Hennops River site selection was based on the subjection to various land use activities and anthropogenic perturbance in the area. Sampling was conducted across two sites along the Hennops River (Figure 5) in the dry winter season with no rainfall activity. Approximately 15 – 17 m^3 of surface water samples (n = 2) and 150 g of sediment samples (n = 6) were sampled at each site.

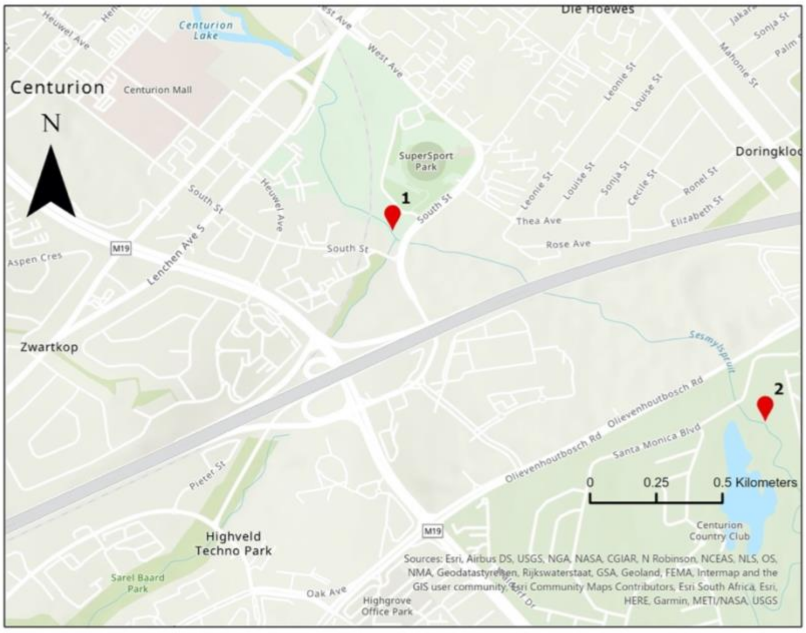


Figure 5. Map showing the sample collection locations, indicated by red markers, along the Hennops River located in Centurion, Gauteng. The red pins indicate where the plankton nets were deployed in the river, sediment samples were collected in the surrounding areas. Samples were collected in July 2020. The base map is produced in ArcGIS Pro.

Table 2. Sampling site coordinates and depths with their locations in Hennops River and associated anthropogenic activities nearby.

Sampling Site	Coordinates		Water Depth (m)	River Width (m)	Nearby Activity
	Latitude	Longitude			
Hennops 1	-25.86228	28.194360	1	21	Sewage Outfall, Informal Settlement, Railway and Road
Hennops 2	-25.86877	28.207010	1	17	Residential Area, Golf Park

The coordinates and surrounding anthropogenic activities associated with the sampling sites in the Hennops River are summarised in Table 2. Sampling site 1 presents evidence of illegal dumping of solid waste along the river. The site is situated in close proximity to the informal settlements and receives pollutants from surface run-off during seasonal rain periods. Informal settlements have inadequate sanitation facilities and minimal access to clean water sources with the build-up of solid waste being common in the area. The site is located nearby to a road and railway with sewage plumes leading directly into river (Figure 6). Water quality and clarity in the Hennops river is poor and carries a strong sewage odour to the extent that no aquatic life can be detected in the area, indicative of raw sewage being pumped directly into the freshwater system.

Figure 6. Photographs depicting Hennops sampling site 1. The site in the river has sewage pipes discharging directly into the river with many solid waste materials and discarded debris (Figure A and B). Sed 1A, 1B and 1C depict the points where sediment samples were collected.

Sampling site 2 (Figure 7) at the Hennops River was conducted over a bridge located near a residential suburb area and a golf estate nearby to a road. A significant hydrological problem in the area is the large amount of debris present (Figure 7.A).

Figure 7. Photographs depicting Hennops sampling site 1. A) Plastic and organic debris along the river bank. B) Bridge over the river where net was suspended from C) Plankton net suspended in the centre of the river with normal river flow conditions.

Water Sampling

Surface water samples were collected using a 50 μm mesh plankton net (0.5 m mouth diameter, 1 m length) deployed in the river for approximately two hours at each site. Microplastics were collected under normal river flow conditions by suspending the plankton net from a bridge over the centre of the river. The upper portion of the mouth of the net was kept at surface level by adjusting the length of the rope. The exact volume of water sampled through the net was calculated by using a flowmeter (Hydrobios mechanical flow meter) attached to the centre of the net mouth during water sampling. All of the material collected in the end of the net after the sampling period was transferred into pre-rinsed 500 mL glass jars using filtered water. The collected samples were transported to the laboratory to initiate sample processing in order to separate the microplastics from other suspended materials.

Sediment Sampling

A total of three surface sediment samples were collected at each site (n = 2) in order to account for small scale variability. Sediments were collected using a stainless steel spatula in approximately 250 g portions along the river bank, and transferred into pre-rinsed glass jars for collection. The collected sediments were tightly packed and transported to the University of the Witwatersrand for further analysis. A procedural blank was collected at each site, which consisted of pre-rinsed glass jars subject to atmospheric deposition of particles by being positioned unclosed for the duration of sediment collection. The jars were fastened afterwards and transported in the same conditions as the collected sediments to measure any contamination that may have occurred during sampling.

3.3 Sample pre-treatment

The wet sediment samples were stored in glass jars and kept in a freezer until subjected to sample processing. The sediment samples were freeze-dried for approximately 48 hours prior to sample processing to obtain the dry weights, and standardise the differences in moisture content between the samples. Approximately 100 g of dry sediment was weighed into triplicate subsamples and transferred into 50 mL centrifuge tubes. The exact weight of each triplicate subsample was recorded. All equipment and glassware were prewashed with filtered reverse osmosis water three times prior to use during sampling and sample processing to avoid contamination.

3.4 Grain size

Grain size compositions of the collected sediment samples were determined by sieving the dried and weighed sediments (100 g), and determining their percentage grain compositions according to the following grain size classes: mud (< 0.063 mm), very fine-grained sand (0.063 – 0.125 mm), fine-grained sand (0.125 – 0.25 mm), medium-grained sand (0.25 – 0.50 mm), coarse-grained sand (0.5 – 1.0 mm), very coarse-grained sand (1.0 – 2.0 mm) and gravel (> 2.0 mm).

3.5 Sample processing

Surface water and sediment samples underwent sample processing and analysis as outlined in Figure 8 below.

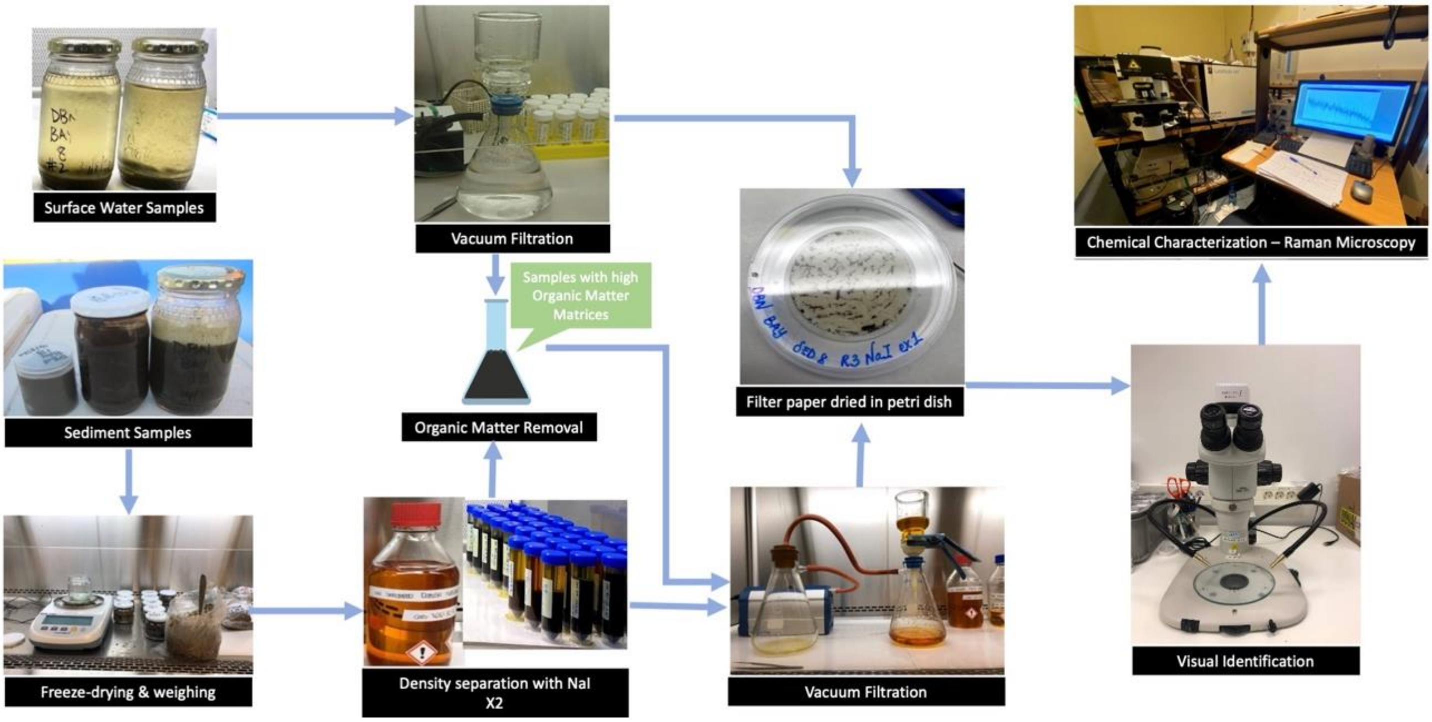


Figure 8. Schematic outline of the sample processing steps taken for sediment and surface water samples to extract and analyse microplastics.

3.5.1 Sediment sample processing

Density separation was used for the separation of microplastics from sediment samples by flotation, followed by vacuum filtration of the supernatant. Many microplastic compositions have densities similar to water (0.83 – 1.1 g/cm^3), whereas many inorganic particles consist of higher densities, therefore salt solutions of sodium chloride are commonly used for extractions (Pagter et al., 2018). Denser solutions (such as sodium iodide, zinc chloride or zinc bromide solutions, etc), are used to extract heavier plastics such as polyvinyl chloride (PVC), polyethylene terephthalate (PET), nylon (PA) and polytetrafluoroethylene (PTFE) (Pagter et al., 2018). In this study a concentrated salt solution of sodium iodide (NaI), with a density of 1.8 g/cm^3, was used to allow for the separation of microplastics and inorganics due to their respective densities. Sample processing methods were adapted from Lusher et al, 2017.

Dry sediments were mixed with a filtered solution of sodium iodide in centrifuge tubes and vigorously shaken to separate microplastics from the sediment matrix. The shaken mixture was left to settle for a 24-hour period to allow for the less dense microplastics to float to the top of the hypersaline solution while the sediment settles at the bottom resulting in high recovery rates of microplastics (Coppock et al., 2017; Hidalgo-Ruz et al., 2012). Sediment samples from each site (n=15 sites for Durban Bay and n= 6 for the Hennops River) were subsampled in triplicates. Density separation was performed in 50 mL centrifuge tubes by adding a filtered, high-density supersaturated solution of sodium iodide (density = 1.8 g/cm^3) to the sediment subsamples. The centrifuge tubes were manually shaken to homogenize the solution and then left to settle over a 24-hour period. After the settling period, the supernatant with the floating microplastic particles was decanted and vacuum filtered using 47 mm Whatmann GF glass fibre filters (0.22 micron pore size).

To increase the recovery of microplastics, the sediment was subjected to a second round of density separation and extraction with sodium iodide following the procedure as described above (i.e. a total of two extractions for each replicate). After filtering, individual filter papers were transferred into respective petri dishes and allowed to airdry prior to visual analysis and microplastic identification. Method blanks were incorporated to account for any contamination using the extraction procedure outlined for microplastics, however in the absence of sediment (only NaI).

3.5.2 Water sample processing

Water samples with minimal organic matter present were directly filtered over a 47 mm diameter Whatmann GF/A glass fibre filter with 0.22 micron pore size paper to retain any microplastics present. Vacuum filtration using a Buchner filter was employed for each water sample to isolate the microplastic particles prior to analysis. The sample container and filter funnel were rinsed with filtered reverse osmosis water to remove any adhered particles. Method blanks were incorporated to account for any experimental contamination whereby the filter paper was rinsed with filtered water. The filter papers were immediately transferred and stored in clean petri dishes to allow for airdrying prior to visual analysis.

3.5.3 Organic Matter Removal

Water and sediment samples with a rich organic matter content in their matrix required an additional sample processing step to efficiently extract the microplastics. Hydrogen peroxide has been found to provide effective organic matter removal and minimal polymer alterations when using low temperatures (below 60 °C) and shorter reaction times (up to 24 h), therefore

3 % hydrogen peroxide was used for this study. Too harsh of a chemical digestion method would result in the disintegration of microplastic particles.

Samples rich in organic matter were individually transferred into conical flasks and subjected to chemical oxidative digestion using hydrogen peroxide at 40 °C. The conical flasks were covered with foil upon the addition of hydrogen peroxide, and left for 24 hours to digest biological material which could hinder the detection of microplastics during characterisation. Once digested, water samples were directly filtered onto filter papers, rinsed with filter water and the filter papers transferred into petri dishes. For sediment samples rich in organic matter, upon the completion of organic matter removal, sediments were washed with filtered water and the water was vacuum filtered onto 47 mm GF/A filter papers. The filter paper with material was immediately transferred to a petri dish and covered for drying prior to visual identification.

3.6 Microplastic visual identification

After the filter papers from sample preparation were dried, visual inspection of all filter papers from samples and blanks was carried out to quantify and sort the suspected microplastics based on their properties. The particles retained on filter papers were viewed under a stereomicroscope (Carl Zeiss Microimaging Gmbh 37081, Axio Imager.m1m Precision Microscope) equipped with digital camera attachment to separate suspected microplastics from other organic material. Identification of microplastics was based on certain characteristics as stated in the step by step guide established by Hidalgo-Ruz et al. (2012). A particle was classified as a potential microplastic if it met with the following criteria 1) no cellular or organic structures were observed in the morphology; 2) fibres had to be evenly thick throughout their length and not tapered towards the ends; 3) fibres had to be a single colour and transparent fibres that had a glass-like texture were excluded; 4) if a particle broke when pressure was applied using forceps, it was not included; 5) fibres were not segmented and did not appear as twisted flat ribbons. Any of the particles which did not meet these requirements during microplastic identification were not included in the count for microplastics.

Suspected microplastics and their characteristics were analysed and recorded according to their colour, dimension (longest and shortest axes were measured) and morphology classes from visual sorting. Morphology identification was based on the shape characteristics of the microplastic particles and were grouped into: fragments (small irregular pieces), pellets (spherical items), films (thin layer) or fibres (elongated). Particles that were identified as potential microplastics were photographed using AxioVision SE64 Rel. 4.9.1 Software on a desktop computer. The particles were placed together on the filter paper using forceps to allow for easier tracing during spectroscopic chemical characterisation.

3.7 Polymer Identification

A Raman microscopy instrument was employed to confirm the polymer composition of visually identified microparticles. A representative subset of suspected microplastic was analysed using spectroscopy. The potential microplastics were randomly selected and the results from Raman were used to confirm the polymer type. A Horiba LabRAM HR Raman spectrometer (manufactured by Horiba Scientific through Jobin Yyou technologies) was used to obtain Raman spectra of each potential microplastic selected. An Argon laser with wavelength of 785 nm was used to cause Raman-effect and a silicon sample was used as a reference spectrum. The data obtained was used to plot the Raman spectra which were manually analysed and compared to a library spectra (SLOPP-E library) to confirm the polymer match. Polymer identities were not extrapolated across all microparticles.

3.8 Contamination mitigation measures

Strict protocols were employed during sample collection and processing in the laboratory environment to minimise and prevent procedural contamination during all stages. Microplastic extractions and analysis were conducted in a laboratory dedicated to microplastic sample processing. All samples were processed in a laminar airflow cabinet to prevent any airborne contamination. All surfaces including the laminar airflow cabinet and microscope were wiped down with filtered water daily before use to remove dust particles. The glassware and labware used for fieldwork and sample processing was rinsed three times using 0.22 micron filtered reverse osmosis water prior to use and in between samples. Samples were kept covered with aluminium foil and metal lids when not in use to avoid exposure to airborne particles from the laboratory environment. Glass and metal equipment was used and plastic equipment was kept to minimal use where possible. Synthetic garments were avoided during analysis, and only natural fibre cotton clothing were used to mitigate the risk of clothing fibres contaminating samples. Reagents used during sample process were vacuum filtered on Whatmann glass fibre filters GF/A (diameter = 47 mm, pore size: 0.22 µm) prior to use. Procedural blanks were incorporated for every five samples processed during each step of sample processing to account for any laboratory contamination occurred during extraction processes. The microplastic particles from the blanks were analysed and corrected for in the microplastic counts from environmental samples. Each particle was identified based on colour and morphology and the counts for the corresponding colour – morphology combination were subtracted for the samples exposed to that sample processing step.

A total of three black, and two blue microfibres were detected across all the blanks for surface water samples; whereas no particles were detected in the blanks incorporated for sediment samples. The microfibres detected in the blanks for surface-water samples were possibly sourced from clothing worn during experimental procedures. Sample correction was applied by subtracting five microfibres of the corresponding colours from surface water samples and all totals presented in the results consist of the corrected values. Field blanks did not present evidence of procedural contamination during sampling, therefore no blank sample correction was applied.

3.9 Statistical Analysis

Statistical analyses were conducted in Excel and R Studio statistical software. Once plastic counts and sample weights were standardised, a one-way ANOVA tests was conducted to determine whether differences in the spatial abundances in sediment samples between stations were statistically significant. The significance threshold was set at $\alpha = 0.05$. A Post-hoc Tukey HSD was applied to determine which sites at Durban Bay had abundance differences that were statistically significant. Statistically relevant differences were considered if the p value < 0.05. One-way ANOVA was chosen and considered the best option to determine how a response (number of microplastics) is affected by the factor of site location.

4. Results and Discussion – Durban Bay

Sediment and surface water samples were collected across various sites in the harbour to investigate the spatial distribution patterns of microplastic pollution. The nearby potential inputs of microplastics, such as river inflows, were noted to identify the contribution of various pathways into the harbour. Microplastics were isolated and characterised from sediment and surface water samples of the 15 selected sites around the harbour. Microplastics of size boundaries smaller than 5 mm were detected in 100 % of surface water samples collected using the plankton net and 100 % of sediment samples collected using grab sampling from all 15 sites across the Durban Bay study area.

The concentrations of microplastics in surface waters and sediments varied considerably across sites and is largely a factor of the surrounding environment. Both sediment and water samples consisted of a majority of secondary microplastics with fibres the most predominant in surface water (75.68 %) and fragments being the most predominant in sediment samples (58.25 %). The most commonly identified polymer consisted of polyethylene for surface water (46.67 %) and sediment (52.38 %) samples. The abundance and distribution of microplastics are highly dependent on location within the harbour and local anthropogenic activities. Sample collection was conducted during Durban's dry season. High input and retention of microplastic in the harbour was observed, especially in the sediments as these act as a sink for microplastics.

4.1 Abundance and spatial variations of microplastics in Durban Bay surface water and sediment samples

4.1.1. Surface water samples

Surface water samples were collected using a 50 µm plankton net. Microplastics were detected in all (100 %) surface water samples with varying concentrations between 4.27 particles/ m^3 to 80.72 MP/ m^3 and an average of 18.82 (± 18.65) particles/m^3 detected across sampling sites. The high population density and multiple sources of industrial waste present surrounding Durban Bay makes the harbour susceptible to pollution. Rivers inflows, stormwater outflows and the numerous industries involving trade with plastic pellets encompass some of the pathways whereby plastic is introduced into the harbour.

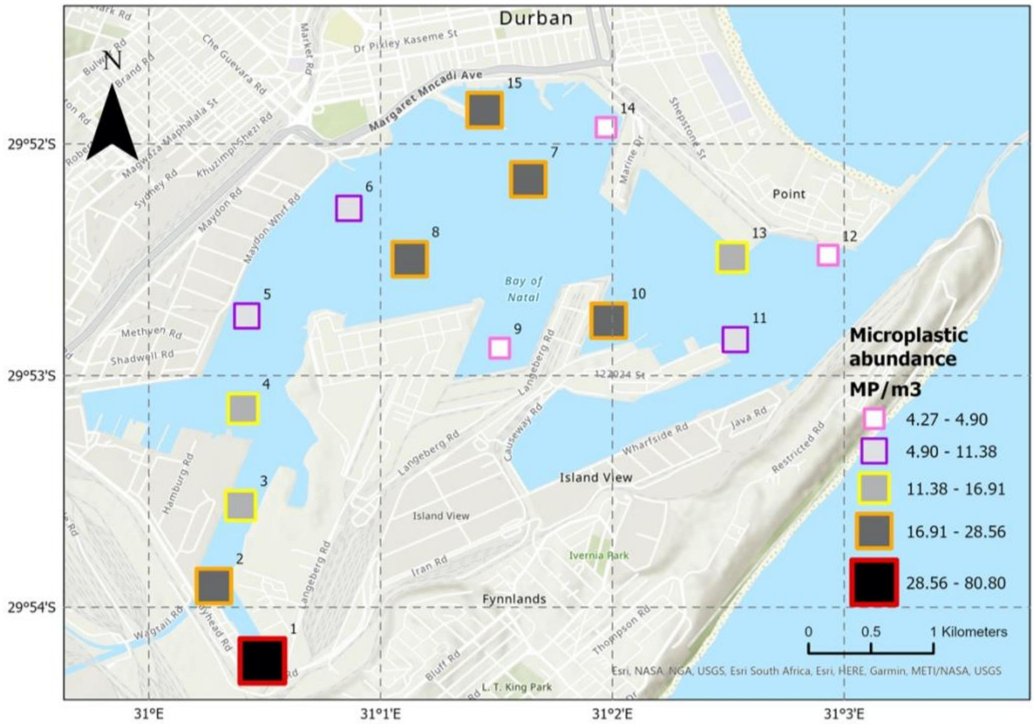


Figure 9. Map depicting microplastic abundance (particles/ m^3) present in samples collected from surface water at Durban Bay. Each sampling site is labelled numerically from 1 to 15.

Greatest microplastic abundance was observed at site 1 (Figure 9) at the river inflow into the harbour at the Bayhead area. The Bayhead Canal is the receiving canal for river inflows of the uMhlatuzana, uMbilo and aManzimnyama catchments, and the poor water quality of the rivers in turn affects the water quality in that part of the harbour. The catchment areas of the rivers are associated with land use including residential, commercial and industrial activities, with dispersed and isolated parcels of recreational parks and nature reserves (Moodley et al., 2015). The spatial distribution of microplastics shows that site 1 has highest microplastic abundance which may be due to the proximity of the river inlets into the harbour and the yacht clubs. Sites 2, 3 and 4 situated in the Bayhead Canal are affected by the close proximity to the yacht clubs and rivers with the high loads of pollution carried into the harbour; the sites are also influenced by the unintentional release of microplastics from the dry docks.

Sites 5 and 6 have potential microplastic inputs from surrounding stormwater drains. Sites 11, 12 and 14 have relatively lower abundances, whereas site 13 has a higher abundance of microplastics due to the site's close proximity to the Mahatma Gandhi Sewage Pump Station. The Mahatma Gandhi Road sewer pump station is one of the largest pump stations in the

KwaZulu-Natal province, and transfers sewage encompassing the Durban CBD, Berea and neighbouring areas of the harbour to a treatment system towards the seaward border of the Bluff. Sites 9 and 10 are located close by to a container terminal, however site 10 has comparatively higher microplastic abundance. This may be due to site 9 being situated within an enclosed space preventing microplastics from travelling across the surface water. Site 15 is located to nearby stormwater drains, yacht clubs and a laundry service which are potential inputs leading to the high microplastic abundances observed. Stormwater has been found to be a distinctive transport route of microplastics contributing approximately 140 times more microdebris than wastewater (Zhu et al., 2021).

Site 7 and 8 located in the centre of the harbour had relatively higher MP abundances in surface water samples. The occurrence of higher microplastic abundances may be attributed to heightened shipping activity which is one of the main contributors to the amount of pollution in the area and may also lead to the transport, deposition and redeposition of microplastics (Vanapalli et al., 2021a). Shipping activity in conjunction with other factors such as the intensity of winds, and the density and morphology of microplastics can also transport and deposit MPs to areas far from their disposal sites (Vanapalli et al., 2021a). The harbour is subject to the north eastward counter currents created from the shape of coastline which can give rise to a semi-permanent cyclonic eddy. The Durban eddy can influence particle concentration and transport during seasonal changes.

Changes in seasonality is a potential driver in the abundance of microplastics present, as periods of rainfall plays an important role in the accumulation of microplastics in aquatic systems (Vanapalli et al., 2021a). Sampling was conducted in the dry summer season, however microplastic abundances may differ in the summer season due to seasonal precipitation resulting in more runoff, and possibly influencing coastal plastic concentrations (Zhu et al., 2021). Durban Bay experiences a large influx of debris into the port during storm events, involving heavy rainfall and flooding, which correspondingly leads to higher concentrations of plastic and other debris entering the harbour through stormwater runoff and rivers (Preston-Whyte et al., 2021).

Sampling depth is of importance as resuspension fluxes in sediments may cause changes in the concentrations of microplastics, and lead to mixing the water column. Highest microplastic abundances have been observed in shallower waters with low water velocity (Gerolin et al., 2020). The sites in Durban Bay with shallow waters (< 10 m) consisted of sites 1 to 4, and site 15 which consisted of relatively higher microplastic abundances; however high microplastic abundances were also observed at sites 7, 8, 10 and 13 whereby the depth of water was greater than 10 m. Water movements, air currents and perturbations from shipping activities, can result in disturbances that may potentially redistribute particles within the water column resulting in the deposition of these microplastics into sediments (Lusher et al., 2015). The ingress of plastics into the port is mainly due to the river catchment and stormwater drainage system that drains into the port. Durban Bay is an industrialised harbour area with multiple sources of pollution, has a total of 47 stormwater drains leading into the harbour and a number of river inlet channels which contribute to the loads of pollution (Naidoo and Glassom, 2019).

4.1.2 Sediment samples

A total of 23 sediment samples were analysed with 1212 microplastics found in 2410 g of sediment. Microplastics were detected across all sites for sediment samples, with an average of 0.447 particles/ g dry weight (dw) across all sites (Figure 10). Sediments provide a long term sink for these contaminants but can be remobilised through events such as flooding, dredging or bioturbation by benthic organisms.

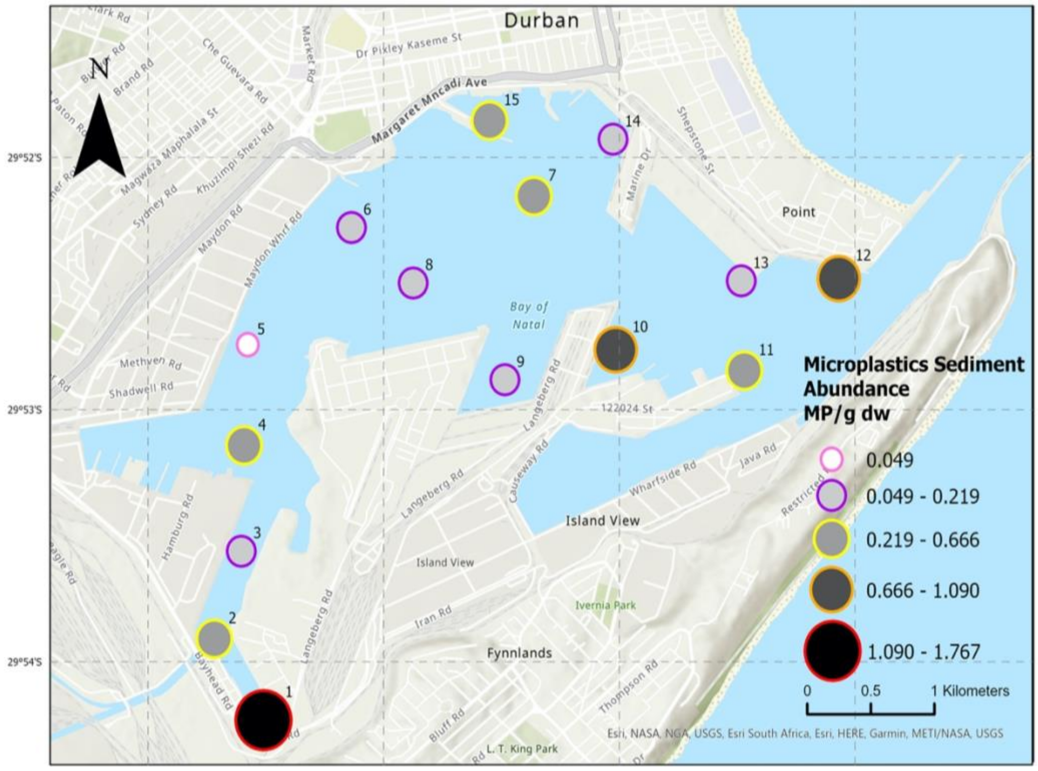


Figure 10. Map depicting microplastic abundance in sediment from at Durban Bay collected using a grab sampler (n = 15).

The highest microplastic abundance was reported in the Bayhead Canal at site 1 with 1.7 MP/ g situated close to the Bayhead Road and river inflows. Sediment samples from site 1 acts as an accumulation zone for predominantly fragments. The distribution of microplastics within Durban Bay is not evenly distributed with abundances ranging from 0.039 particles/ g to 1.76 particles/ g (Figure 10).

The confined movement of water and debris present in the harbour in conjunction with the low flow rates of water in the partially enclosed lagoon of Bayhead may favour microplastic deposition. Occurrences of flooding and dredging activities may result in significant volumes of plastic debris flushing out of the harbour. Site 4 sediments are likely to undergo microplastic accumulation, due to the close proximity to dry docks. High microplastic abundances were also observed at sites 10 and 12, which are located nearby to container terminals and the Mahatma Gandhi Sewage Pump Station, respectively. Sites 7 and 15 which are located nearby to stormwater influxes, also show higher abundances of microplastics, which is indicative of microplastic deposition.

Ports and harbours globally undergo maintenance dredging in order to maintain safety levels for operating throughout the port channels. There are various guidelines in place to track selected pollutants present in dredged sediments as the high levels of pollution from surrounding industrial activities in harbour environments pose the risk of transporting pollutants into the marine environment, with subsequent effects on marine life. The spread of microplastics (< 5 mm) from harbours to other environments through dredging activities remains unmonitored, and the nearby continental shelf may be a recipient of large loads of plastic post dredging events (Botterell et al., 2019). The shelf regions of the marine environment have the most pronounced overlap of microplastics and marine biota and organisms, such as zooplankton, which occupy these regions are at heightened risk of ingesting microplastics (Botterell et al., 2019).

Pollution sources from shipping activities remains unique to specific estuaries with commercial ports, such as Durban Bay estuary, however pollutants, such as microplastics, released from these activities have the potential for long-range transportation, and will adversely affect the surrounding environment (Olisah et al., 2021). The overall poor water quality of Durban Harbour is a result of the runoff from surrounding industrial areas, that enters the harbour via the aManzimnyama River (Olisah et al., 2021). The increase in informal settlements and rising populations in estuary catchments increase the pollution pressure from plastic waste and the contaminants transported by the debris.

Figure 11 depicts sediment compositions from the samples which varied across the sites.
The relationship between mud content and microplastic concentration has not been established, however selected studies have shown a direct correlation between the sediment grain size and the percentage content of mud i.e. sediments with a high mud fraction were found to contain relatively higher abundance of plastics (Pagter et al., 2018). The contribution of mud to the bulk mass of sediment varied widely, from 3.96 % to 93.39 %. The sediment at most sites closest to the river inflows was dominated by mud. Particle size distribution analysis from the collected samples indicate that sediments with largest mud composition (>50 %) are from sites 3, 2, 6, 5, 8, 15 and 10 (listed from highest mud composition to lowest).

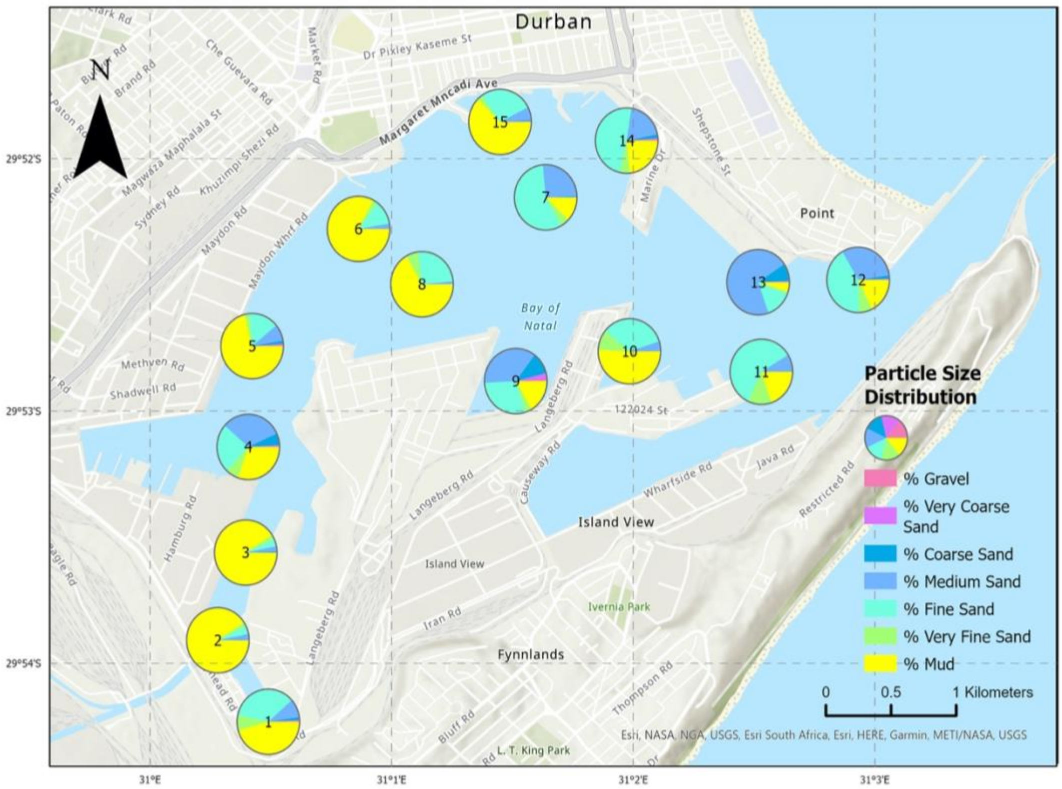


Figure 11. Map depicting particle size distribution of sediments at each site sampled in Durban Bay (n = 15).

Microplastic abundance across these sites do not show trends to mud composition percentages, therefore there is no indication that sediment composition is an influencing variable to the abundance and accumulation of microplastics in Durban Bay's sediment samples. There is a lack of evidence depicting the correlation of sediment grain size profiles with microplastic abundance, and previous studies have reported that there is no evidence correlating sediment grain size to the extent of the microplastic pollution (Pagter et al., 2018). Sediment grain size did not serve as a predictor for microplastic abundance indicating that nearby inputs of microplastics may be a determining factor for microplastic distribution.

A one-way ANOVA analysis showed significant differences between microplastic abundances across sites ($p = 0.000119$, $\alpha = 0.05$). A Post – HOC Tukey test also revealed site differences (Figure 12).

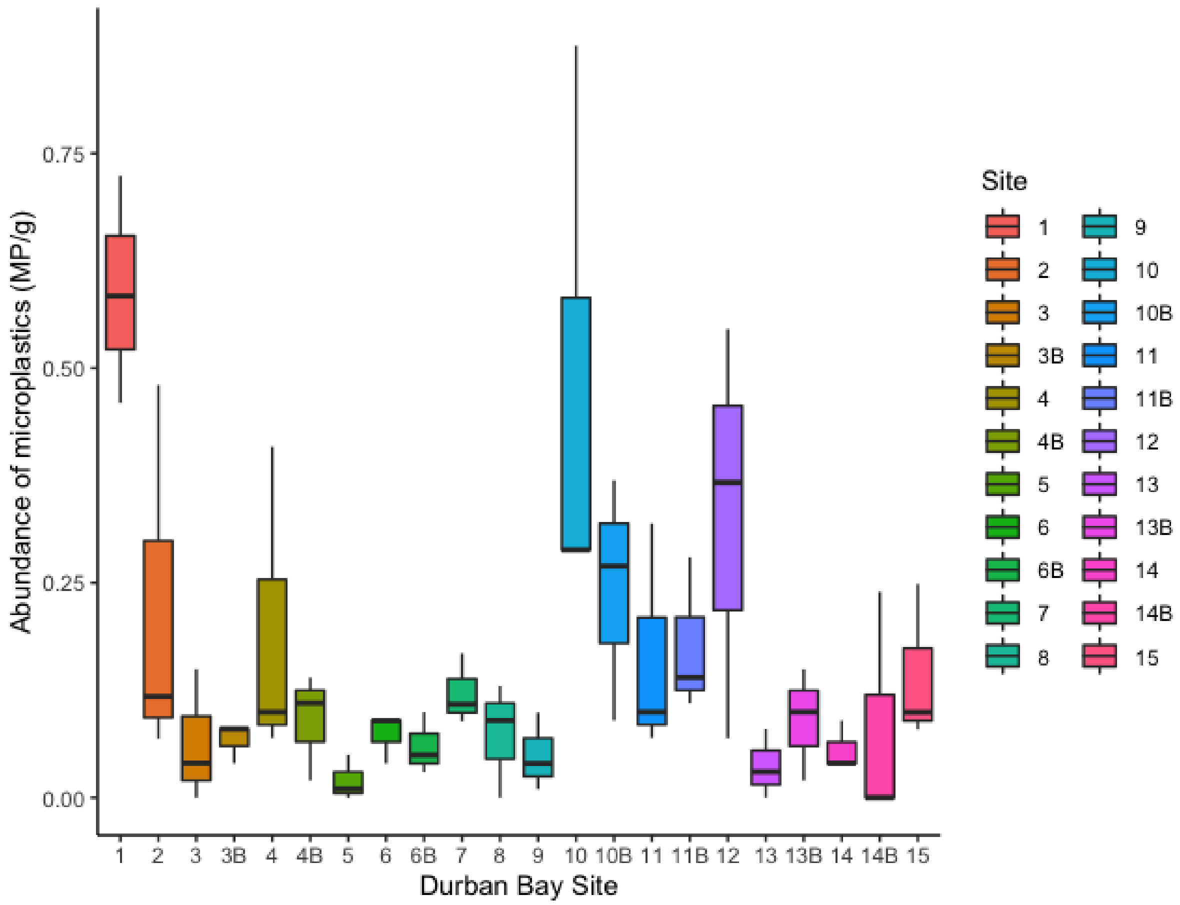
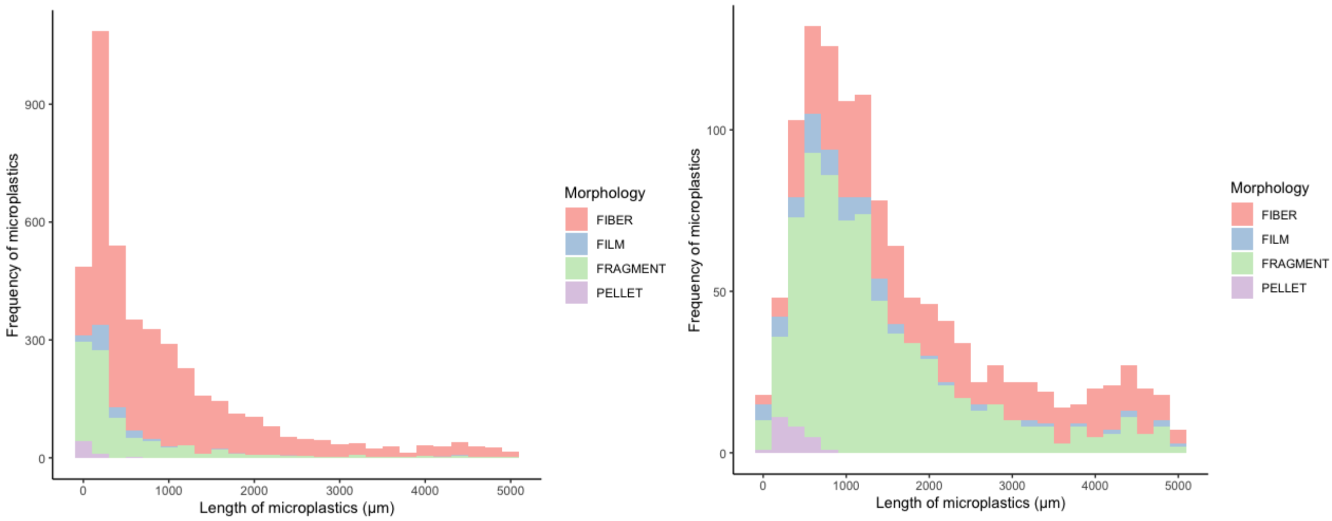


Figure 12. Box plot depicting the spread of microplastic abundances (MP/g) recovered from triplicate samples across sites at Durban Bay.

The location of sampling sites relative to potential sources of pollution, such as built-up urban areas, fishing docks and yacht clubs, is a potential contributing factor which needs to be taken into consideration when identifying spatial distribution patterns of microplastic contamination. Durban Bay is situated in an industrial area, therefore it is expected to contain a higher abundance of microplastics relative to other aquatic systems. Sampling from sites located in the harbour may aid in understanding the spatial abundance differences of microplastics, which allows for assessing microplastic abundance in relation to nearby pollution sources. A one-way ANOVA analysis was conducted to indicate differences between microplastic abundances across sites and was found to be statistically significant ($p = 0.000119$).

4.2 Size distribution

Particle sizes of microplastics were detected between the range of 7.31 µm to 4992 µm. Particle size and density have been suggested as key factors contributing to the microplastic deposition process (Su et al., 2020). The average size of microplastic particles found in water samples in Durban Bay is 1.63 ± 1.23 mm. Surface water has a much lower proportion of particles between the 2 mm to 5 mm size range, whereas sediments follow similar trend patterns however larger proportions are distributed in the 2 mm to 5 mm size range (Figure 13). This may be due to deposition of larger particles to sediments due to size. Surface water consists of predominantly fibres whereas sediments consist of fragments, films and fibres. Fragments tend to sink to sediments, which retains microplastics more to the bay area. The high abundance of smaller microplastics (<2 mm) indicates that particles are likely to continually disintegrate into microscopic-scale particles over time.



A) Water Samples B) Sediment Samples

Figure 13. Size distribution of microplastics Durban Bay in a) surface water samples and b) sediment samples.

The circularity of particle morphology varied inversely with particle size, whereby larger microdebris had more elongated shapes or irregular surfaces, comprising of fibres and fragments, while more circular particles were observed in the progressively smaller particle size ranges (< 1 mm). The widespread presence of microplastic in surface waters heightens the probability of marine biota, which inhabit the same locale, being exposed to microplastic particles. The harbour supports a vast amount of filter feeding organisms, such as copepods and fish, which could actively target microplastics on a colour bias or passively ingest microplastics buoyant in the surrounding surface water. The risks posed by plastics differs based on their size, notably, small-sized microplastics act as vectors of coexisting pollutants owing to their large surface area. Thus, smaller microplastics may pose heightened risks to filter feeding organisms. It is predicted that benthic organisms are likely to be exposed to microplastics, leading to the eventual uptake of the microplastics and transfer along trophic levels, as the harbour serves as a vital nursery ground for 144 species of fish larvae and there have been simultaneous observations of dense zooplankton populations.

4.3 Morphology

A total of 5 578 particles were identified using stereomicroscope visual analysis methods (4 366 from surface water samples and 1 212 from sediment samples). The recovered morphologies of microplastics from Durban Bay consisted of fragments, fibres, pellets and films (Figure 14). The most commonly found morphology in surface waters were fibres (75.68 %), followed by fragments (19.84 %), films (3.28 %) and pellets (1.21 %); whereas fragments constituted the highest proportion (58.25 %) in sediment samples, followed by fibres (33.58

%), films (6.02 %) and pellets (2.15 %) of the microplastics recovered from sediment samples (Figure 15. A & B) respectively.

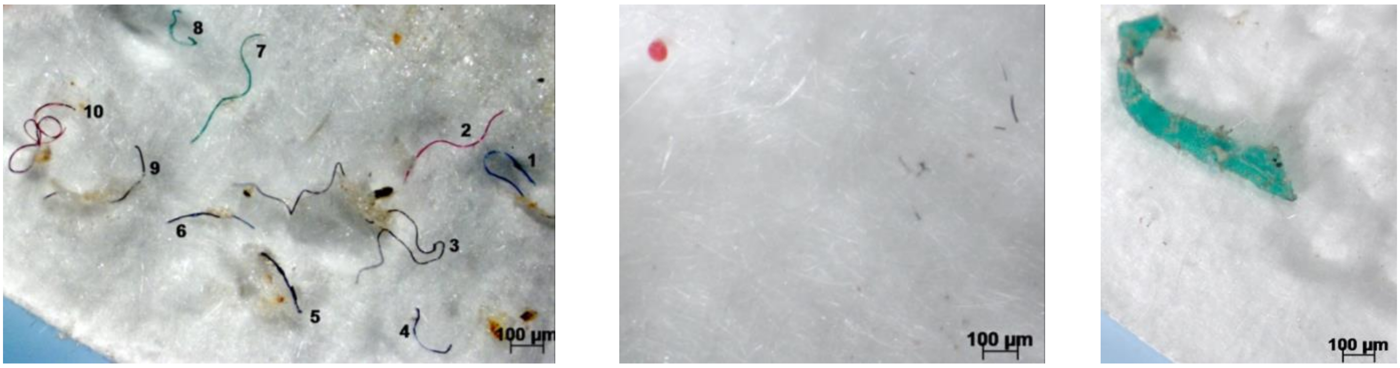


Figure 14. Photograph images of the morphologies of the anthropogenic particles extracted from sediment and surface water samples from Durban Bay identified during visual analysis using a stereomicroscope. A) multiple fibres (multiple colours) B) red plastic pellet C) green plastic fragment.

The results of this study are in alignment with other reports which indicate that fragments were most commonly detected in sediment samples (Matsuguma et al., 2017; Tsang et al., 2017). Microplastics in sediments have been found to show a general trend of being positively correlated to surrounding population densities. Films and fibres are lightweight and can also be carried into the harbour by wind. Discarded fishing gear and angling gear is also a source of secondary microplastics such as fibres and fragments. Investigations of the fishing sector have shown that up to 36 % of plastic used, such as nets and on-board packaging materials, are ultimately discarded into the marine environment (Pucino et al., 2020).

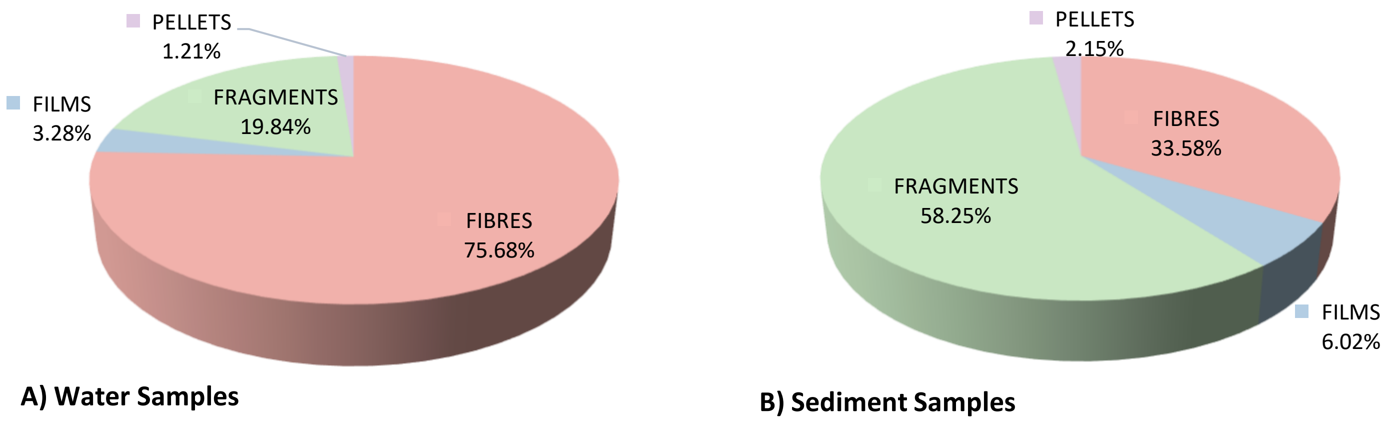


Figure 15. Proportion of microplastic morphologies recovered from samples collected from Durban Bay stations from A) surface water samples and B) sediment samples.

The morphology compositions of microplastics present in sediment samples varied across sites. The morphologies of microplastics were further broken down according to the respective sites for the water and sediment matrices (Figures 16 & 17). It can be observed that while fibres were most commonly found in surface water samples, site 1 had a greater proportion of fragments due to the site's proximity to the river inflows. Marginalised and impoverished communities are especially susceptible to the repercussions of plastic littering and build-up, which include the blockage of waterways and urban drainage systems, causing urban flooding events. Durban Bay is often forced to close after a heavy rainfall event due to the build-up of substantial amounts of plastic debris and other refuse materials, which may potentially result in damages to ships causing additional clean-up and repair costs. This also causes damage to the engines of the ships docked in the area, all of which result in high costs of clean-up and repair. Urban stormwater inlets and treated wastewater has been found to be a major source of fibres, whereas river pathways have been found to be major sources of fragments, however the influx of plastic debris during periods rainfall may result in stormwater drains comprising of a larger proportion of fragments.

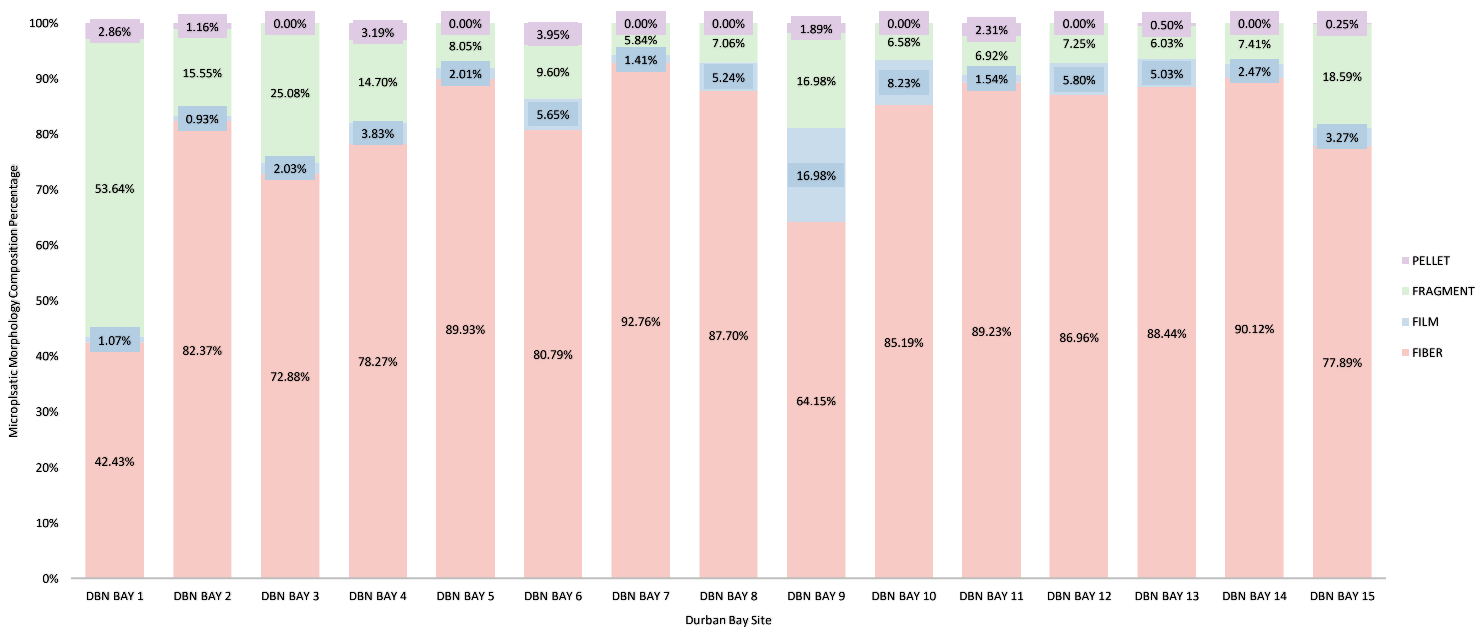


Figure 16. Morphology composition (pellets, fragments, films and fibres) percentages of microplastics observed in surface water samples collected from sites across Durban Bay harbour.

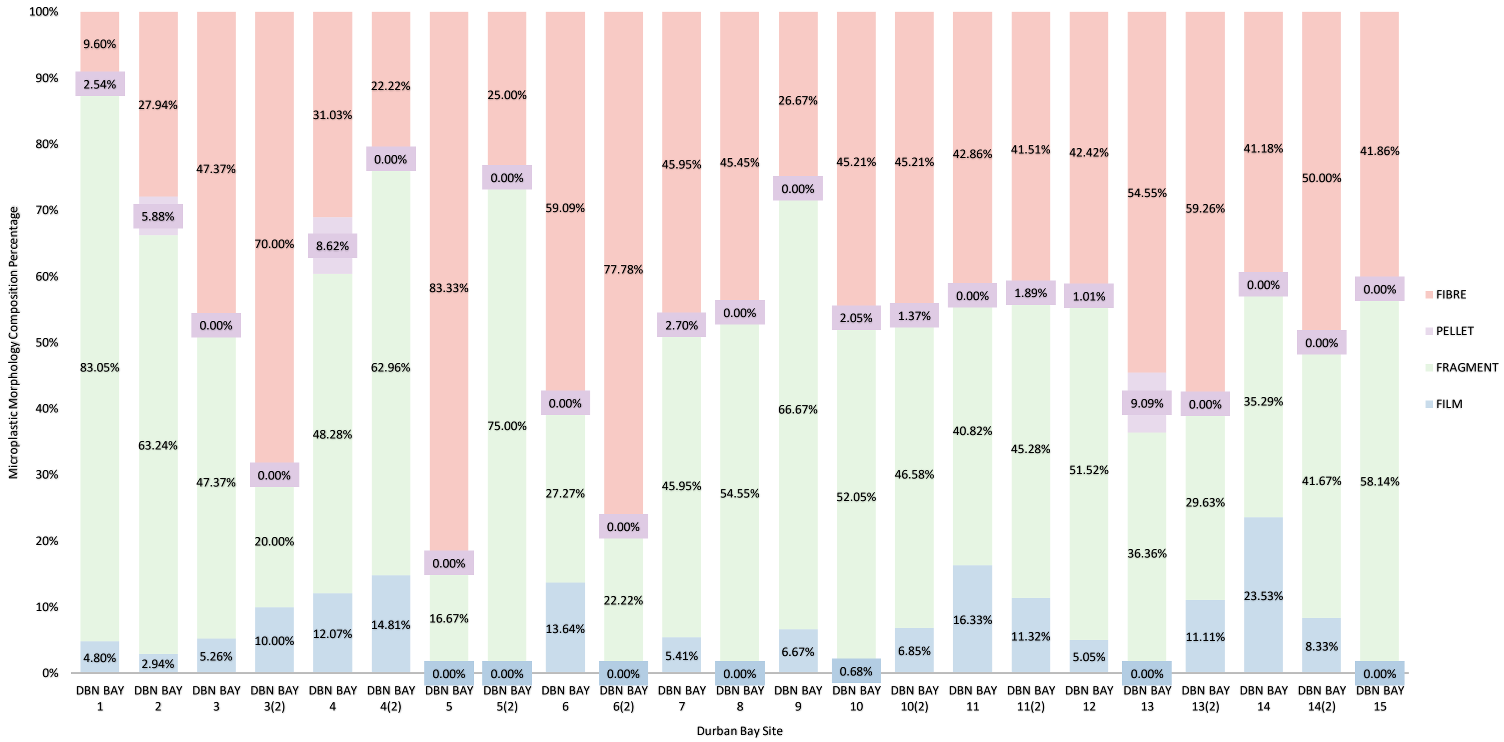


Figure 17. Morphology composition percentages of microplastics observed in sediment samples collected from sites across Durban Bay harbour.

The widespread presence of microfibres in surface water samples may be attributed to the breakdown of commercial fishing nets and textile fibres from domestic wastewater, carried into the harbour from stormwater drains and river inflows. The harbour is located nearby to densely populated urban centres, therefore the inflow of waste from metropolitans in conjunction with activities, such as shipping and commercial activities surrounding the harbour, would likely cause the entry of contaminants into the bay. These fibres may arise from the disintegration of larger materials that are carried over large distances, or by local vessel activity within the harbour. Particle composition of surface water samples were high for fibres across all sites, while sediment samples had high microfibre compositions (> 50 % fibre composition) at sites 3, 5, 6 and 13. These sites are all associated with close proximity to storm water outfalls in the harbour, with sites 3, 5, 6 being closest to the area of the harbour where stormwater drains are clustered together. Site 13 is exposed to the stormwater drain and the Mahatma Gandhi WWTP suggesting input from wastewater is also a potential source of the high amounts of fibres detected in sediment at site 13. Fibres can travel with wind and water currents over long distances from their point of origin, whereas the fate of fragments is usually constrained to locations nearby the location of the point of entry.

The high proportion of fragments present in sediment samples may be the result of degradation due to abrasion and weathering of larger plastic debris. The observed results are indicative of microplastics most likely being a product of the fragmentation of larger plastic debris, such as fishing equipment, and inputs from stormwater and river inflows. The larger plastic debris undergo fragmentation during their transportation over long distances in riverine systems from their different point and non-point sources (Vanapalli et al., 2021a).

The presence of pellets may be indicative of microbeads from cosmetic products and higher proportions were observed at sites nearest to rivers and stormwater drains. Pellets may be introduced through the unintentional release from dry docks or effluent. Films are largely a result of mismanaged single-use plastics that are easily transported via air currents and river flows (Vanapalli et al., 2021a). Films constituted a large portion of plastics in surface water samples; these plastics are dominant in the water column due to their low density and are likely sourced from plastic packaging which is in high demand in South Africa.

4.4 Colour composition

The colour assignment of microplastics is not considered crucial, due to colour differentiation being subjective based on the individual analysing the particles, and does not provide information to visual identification as a standalone variable, however colour may be important in potentially inferring the sources of contamination (Frias and Nash, 2019). Fine particulate matter originating from tyre tread and asphalt from nearby roads can cause cloudiness in water. Colour assignment is also an important characteristic due to the fact that some aquatic species potentially ingest microplastics based on a colour preference behaviour (Frias and Nash, 2019). In this study, the colour of microplastics varied widely, ranging from neutral colours like black, to colours that stand out, such as red and pink (Figure 18). The most commonly detected fragments were transparent (35.55 %), followed by blue fragments (15.44 %) which is in agreement with reports in other studies (Bronzo et al., 2021).

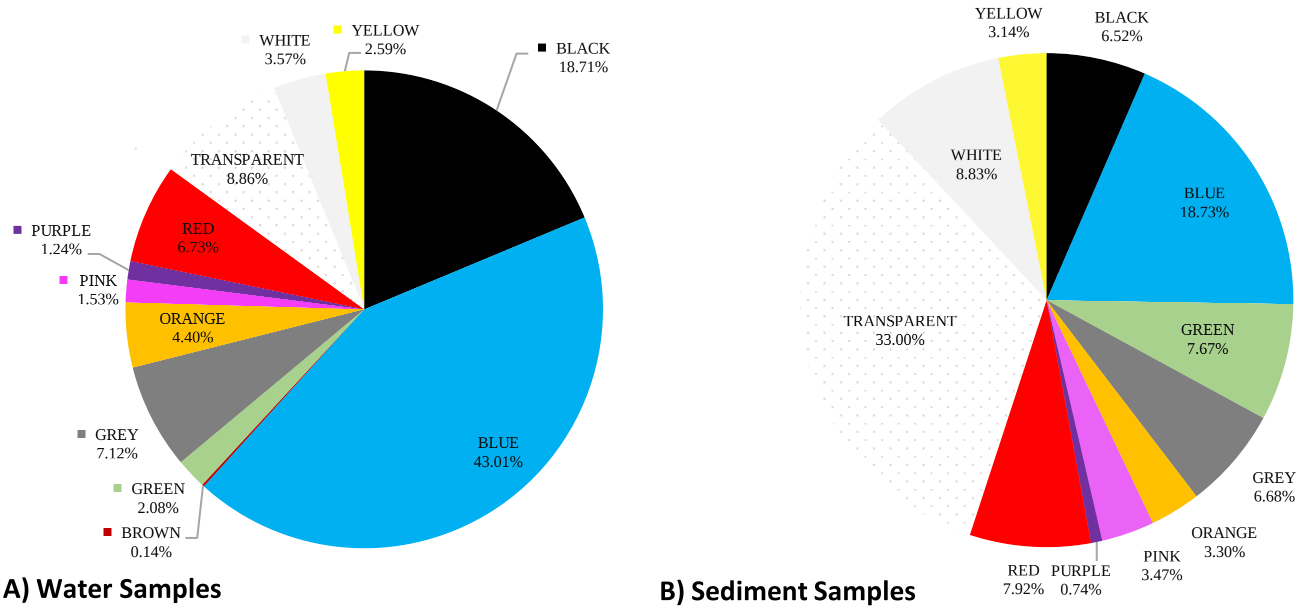
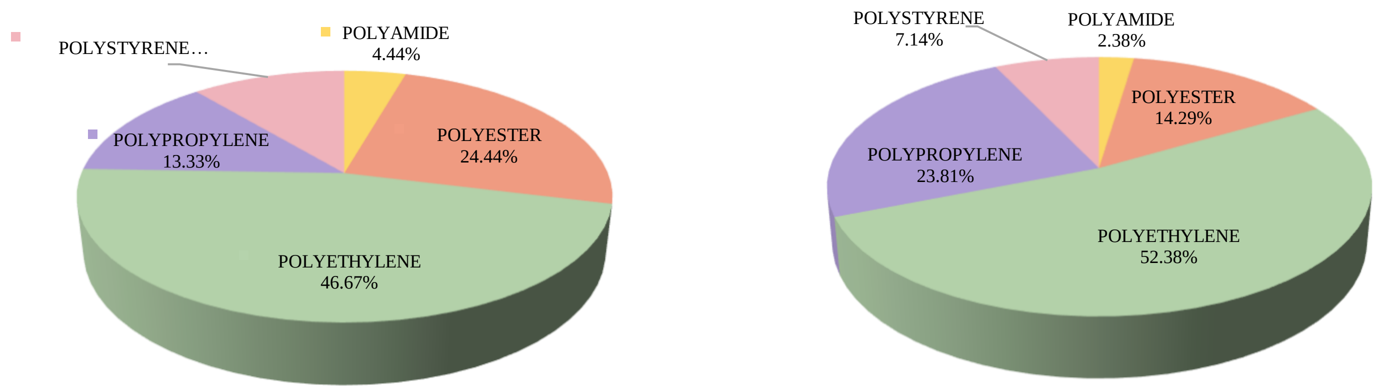


Figure 18. Pie charts indicating the colour assignments for microplastics found in a) surface water samples and b) sediment samples of Durban Bay during visual analysis on a stereomicroscope.

4.5 Polymer composition

The polymer composition of a selected number of microplastics from the Durban Bay samples were identified by Raman microscopy. A total of 45 suspected microplastic particles were subjected to Raman spectroscopy analysis of which polyethylene (PE) was the most abundant polymer type in sediment and surface water samples (Figure 19). Polymers identified in surface water samples consisted of polyethylene (46.67 %) followed by polyester (24.44 %), polypropylene (13.33 %), polystyrene (11.11 %) and polyamide (4.44 %). Sediment samples consisted of the same polymers as the water samples, except in varying proportions with polyethylene being the most common (52.38 %), followed by polypropylene (23.81 %), polyester (14.29 %), polystyrene (7.14 %) and polyamide (2.38 %). Studies conducted in other port environments such as Kuantan port in Malaysia have found polymer compositions of polyester, polystyrene, polyamide, polyvinyl chloride, and polyethylene similar to this study (Khalik et al., 2018).



A) Water Samples B) Sediment Samples

Figure 19. Polymer composition of microplastics detected in selected samples for a) surface water samples and b) sediment samples.

Plastics that are buoyant in fresh and seawater consist of polystyrene in foamed form, high and low density polyethylene, and polypropylene, as their densities are less than the density of water. Particles with higher densities (polyester and polyamide) are likely to sink in the water column, whereas particles that are buoyant are more likely to be transported in surface waters (Guo and Wang, 2019). Dense microplastics in sediments are indicative of sediments acting as accumulation sinks (Su et al., 2020). The presence of dense particles and their inclination to sink towards sediments, as opposed to remaining in and travelling along the water column, suggests the local sources of microplastics. The polymers of varying densities observed in surface waters is also suggestive of storm events, turbulence, air currents, and shipping activities resulting in the redistribution of particles in the water column. The crystallinity and density of microplastics can be altered through weathering and aging, as these properties are not inherent (Guo and Wang, 2019).

While it is difficult to pinpoint the exact sources of these polymers, the identified polymers have a multitude of applications inclusive of textiles, packaging (plastic bags and bottles), fishing nets, rope and microbeads. These fragments may originate from fishing nets, line fibres (polypropylene strands), plastic films, industrial raw materials and pellets. Beads used in facial cleansers, and small polyethylene or polyester fibres of low density, are not removed from treatment screens at wastewater treatment plants, and ultimately end up in the marine environment (Hidalgo-Ruz et al., 2012). A review of studies based on microplastic in the marine environment found that the most commonly identified polymers consisted of PE, PP, and polystyrene, which is frequently consumed for the purpose of packaging (Hidalgo-Ruz et al., 2012). The commercial dry dock facilities located in close proximity to Bayhead may serve as a direct input of polystyrene and polyester from activities, involving ship repairs and maintenance. Polyester fibres from weathered rope discarded from fishing activities, and washing machine effluent, are also origins of microplastics commonly observed. Fibres can be prevented from entering wastewaters through the use of filters for residential and commercial washing machines and lint driers. Banning the use of microbeads in personal cleansing products will also limit the input of beads into aquatic systems.

The fate of microplastic between surface water and sediments is influenced by the size and density of plastics, which affects how these particles are inclined to be transported due to environmental conditions. Microplastics in the upper water column tend to be buoyant as they generally comprise of low density polymer types, and computer modelling has shown that buoyant particles are more likely to be transported out of the harbour (Preston-Whyte et al., 2021). However over time, the buoyancy of plastics can be affected by weathering, leaching of additives and biofouling in the environment, which may lead to these particles sinking to the seabed (Preston-Whyte et al., 2021). Polymer additives also change the density of plastics. Microplastics with high densities, exceeding that of seawater, will readily sink and tend to accumulate in sediments, however pellets subjected to prolonged exposure in the environment can decrease the density of plastic particles (Hidalgo-Ruz et al., 2012). Bottom currents, sediment depth, human activities and redistribution from biota may further influence the distribution of microplastics (Harris, 2020; Xu et al., 2020).

4.6 Comparisons to other studies

Durban Bay harbour is one of 16 estuaries in the eThekwini municipality (Preston-Whyte et al., 2021). Previously conducted studies on five of these estuaries have found Durban Bay to contain the most concentrated amounts of microplastics, with the concentration of microplastics decreasing with increased distance away from the Durban metropolitan centre (Preston-Whyte et al., 2021). The wide variety of anthropogenic activities within the harbour, such as the input of ballast water, ship hull cleaning, stormwater outfalls and river inlets are plausibly the cause of the higher microplastic abundances observed near the city centre (Preston-Whyte et al., 2021). Aquatic systems located in urbanised areas and subjected to vast anthropogenic activities, such as harbours, have been found to be increasingly contaminated with microplastics, and act as a transport route for microplastics entering the marine environment (Preston-Whyte et al., 2021; Su et al., 2020).

Previous studies on microplastic conducted within Durban Bay measured an average microplastic concentration in water samples of 7.03 ± 11.93 particles m^{-3} and average sediment concentrations of 2400 ± 529 particles/kg dry weight of sediment (Naidoo et al., 2020). Juvenile fish inhabiting mangroves in Durban Bay were found to consume significant quantities of microplastics and a maximum of six particles were observed in the fish (Naidoo et al., 2020). Ingested microplastic particles consisted predominantly of fibres and fragments, which are the most commonly detected microplastics within this study (Naidoo et al., 2020). The high abundance of microplastics detected in Durban Bay suggests that biota frequently interact with microplastics, and are at risk for the adverse impacts associated with microplastic ingestion.

Another study by Preston-Whyte et al., reported the abundance and distribution of meso- and microplastics in Durban harbour (Preston-Whyte et al., 2021). Microplastics in the water were sampled using a static immersible water pump and particle filtration system and microplastics were detected in all samples under investigation. The average abundance detected in near surface water was observed as 99.14 ± 36.29 (n = 2) number of particles per m^3. Comparatively, the abundances of microplastics found in surface water in this study were found to be 27 MP/ m^3 to 80.72 MP/ m^3, and an average of 18.82 (± 18.65) MP/m^3. The differences observed in results may be a result of the higher number of sites sampled across the harbour in this study (n = 15), and the high levels of variability among the sites leading to a lower overall average abundance of microplastics detected across sampling sites. The variability observed in the concentrations of microplastics found in Durban Bay in comparison to the other study could be a factor of the differences in sampling and sample analysis techniques adopted. A static immersive pump and particle filtration system with a mesh size of 200 μm was employed for surface water sampling, however sample collection for our present study deployed a 50 μm mesh plankton net across a 50 meter tow at each site (Preston-Whyte et al., 2021). The static pump is employed for point source sampling, whereas net sampling is more useful when sampling large bodies of water in order to eliminate the issue of patchiness.

Our investigation found site 1 in the Bayhead Canal near the river inflow to be most polluted with microplastics in sediments and surface water samples. This was in agreement with other studies, which reported that harbour sediments in the Bayhead Canal and Point Yacht club area, especially nearby to the stormwater outfalls, were highly polluted with microplastics and trace metals (Naidoo et al., 2015). The sediments in Durban Bay were found to contain a higher concentration of microplastics relative to other estuarine ports in the province (Naidoo et al., 2015).

A study investigated the presence of MPs in mussels sold at supermarkets and wholesalers in Cape Town, reported an intensity of 3.8 particles/mussel. The study identified the presence of only fibres (70 %) and fragment (30 %) morphologies (Sparks et al., 2021). Blue (44 %) and black (40 %) microplastics, smaller than 2000 µm were the most prominent particles recorded and the main polymer type was PET fibres (Sparks et al., 2021). Mussels are viewed as bioindicators for an array of contaminants and the implications of MP contamination in mussels raises concern due to their consumption by humans (Sparks et al., 2021). The origins of the mussels used in this investigation were from a selection of mussel farms in Saldanha Bay located 140 km north of Cape Town (Sparks et al., 2021).

4.7 Application

The findings from this study highlight the need for managing stormwater into the harbour in order to improve the water quality in the Bay. Ensuring adequate stormwater management is essential as stormwater outfalls are major contributors of contaminants introduced into the harbour. Strategies need to be implemented to control the pollution of the harbour by litter and other wastes caried in by stormwater from the surrounding areas. Catchment management interventions are required for point and diffuse sources of pollution which include gross pollutant traps and sediment traps for stormwater treatment interventions. The enforcement of illegal pollution incidents and implementing GIS-based system of pollution sources for continuous monitoring is also required to prevent the continuous contamination of the harbour.

Implementations of these regulations will aid in managing the biophysical environment and create opportunities for restoring the existing habitat and prevent the loss of sensitive habitat and the reduction in biodiversity. Managing pollution sources will prevent the potential introduction and spread of invasive alien species (both marine and terrestrial). Managing development activities in proximity to sensitive areas will also prevent the loss of ecosystem goods and services, and the pollution of marine and terrestrial environments. Long term monitoring and management will aid with potentially controlling the microplastic particles in harbours and prevent them from entering other environments such as marine ecosystems and the food web.

The pollution of water, air, land, and sediment leads to adverse health or nuisance effects to residents who live around the harbour and people working in or visiting the harbour. It is necessary to manage water quality impacts and ensure that all possible causes of pollution are mitigated as far as possible to minimise impacts to the surrounding anthropogenic activities. Remediating the contaminated areas earmarked for plastic pollution entry points will aid with minimising the contamination of freshwater resources and sediments.

Conclusion – Durban Bay

The findings of this study showed that 100 % of surface water and sediment samples were polluted with microplastics thus the contamination of harbours places continual risks to the surrounding aquatic environments. Microplastic pollution was assessed at 15 sites across Durban Bay harbour with varying concentrations in surface water between 4.27 particles/ m^3 to 80.72 MP/ m^3 and an average of 18.82 (± 18.65) particles/m^3 detected across sampling sites. The relatively higher microplastic concentrations were observed towards the areas of the harbour located adjacent to river inflows. . Microplastics were detected across all sites for sediment samples, with an average of 0.447 particles/ g dry weight (dw) across all sites. The sediments in harbours are highly polluted, as a result of acting as sinks for fragments that occur from the industries surrounding the harbour whereas fibres are more likely to be carried by surface waters. The most commonly detected polymer type for surface water and sediments was polyethylene. The results of this study give an indication to the sources of microplastic pollution which include shipping activities, river inflows and stormwater outfalls. The effective remediation of polluted sediments is necessary for the preservation of the environment and the health of biota. Identifying the sources of microplastic will aid in the future management of the harbour to mitigate potential long-term risks associated with the accumulation of microplastics and the potential transport of the particles through biota and dredging activities.

5. Results and Discussion – The Hennops River

This study investigated the baseline presence of microplastic contamination in surface water and sediment samples collected from sampling sites along the Hennops River. Microplastics were present in 100 % of surface water and sediment samples. Microplastics found in samples were predominantly fibres and were between 8.13 and 4 924 μm. The close proximity of informal settlements may be a potential input of the large amounts of fibres observed, as rivers are largely used for domestic purposes in informal settlements. Previous studies have found that areas subjected to higher levels of urbanisation and population density are linked to higher microplastic concentrations (Vanapalli et al., 2021a).

5.1 Abundance and distribution of MPs in the Hennops River

Each water sample consisted of approximately 10,000 litres of surface water and the number of microplastics were standardised to m^3. Based on the sites sampled along the Hennops River, the surface freshwater samples were found to contain 26.51 and 12.15 MP/m^3 for sites 1 and site 2, respectively. The sediment samples were found to contain an average of 0.11 ± 0.04 and 0.26 ± 0.10 MP/g for site 1 and site 2, respectively. Analysis of one-way ANOVA for the differences found in microplastic abundance in sediment samples collected at Hennops river between sites 1 and 2 (Figure 20) were not found to be significant (p = 0.0654).

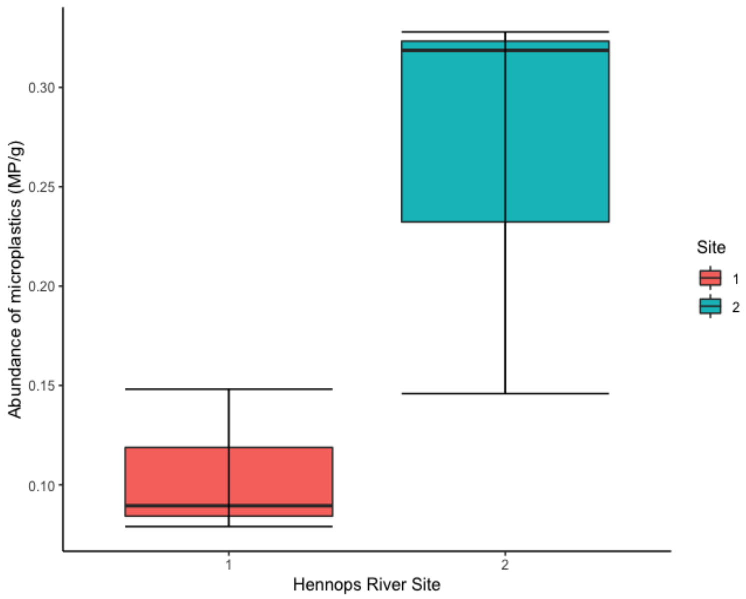


Figure 20. Box plot depicting microplastic abundance (MP/g) in sediment samples collected from the Hennops River.

Studies have shown that rivers function as transport pathways for plastics, especially in highly urbanised areas (Su et al., 2020). Rivers located in urban settings are typically more deteriorated and have links to high levels of MP pollution. Rivers serve as conduits for MP transport, with flow rate being a determining factor in the movement, concentration and fate of MPs (Olisah et al., 2021, Petersen and Hubbart, 2021). The flux of plastics greatly increases in the rainy flood seasons and contribute to the presence of plastic pollution in rivers (Kataoka et al., 2019).

Increased water velocity in river systems may potentially lead to higher abundances of microplastics present in water, whereas rivers with slower flow rates may have a higher concentration of microplastics present in sediments due to the higher amounts of deposition. Microplastics may move laterally and vertically throughout the water column however, microplastics in urban rivers with high flow rates are likely to move horizontally (Haberstroh et al., 2021).

5.2 Grain Size Profile

The correlation of sediment grain size and microplastic abundances has been disproven in a selected number of studies. Some investigations, however, have shown a direct link between the percentage content of mud within the sample and the abundance of microplastics i.e. sites with a larger mud proportion also have a relatively high number of plastics (Pagter et al., 2018). The sediment composition from the Hennops River consisted of largely coarse sand and very coarse sand (Figure 21) with low mud content (< 2%). A linear relationship was found between increasing mud content and abundance of microplastics in sediments in a study conducted for sediments in Danish waters (Strand et al., 2013). For the current study the linear relationship based on mud content indicates approximately 0.11 MP/g for Site 1 and 0.21 MP/g for Site 2. These values resemble the microplastic abundance found for sediments in the Hennops River at 0.11 ± 0.04 and 0.26 ± 0.10 MP/ g for site 1 and site 2, respectively indicating that sediment composition is one of the many drivers of microplastic accumulation in sediments of the Hennops River. Quantitative evidence supporting the correlation of microplastic abundance to sediment grain size composition is still largely lacking, and some studies have shown the the extent of microplastic contamination had no relation to sediment composition (Pagter et al., 2018).

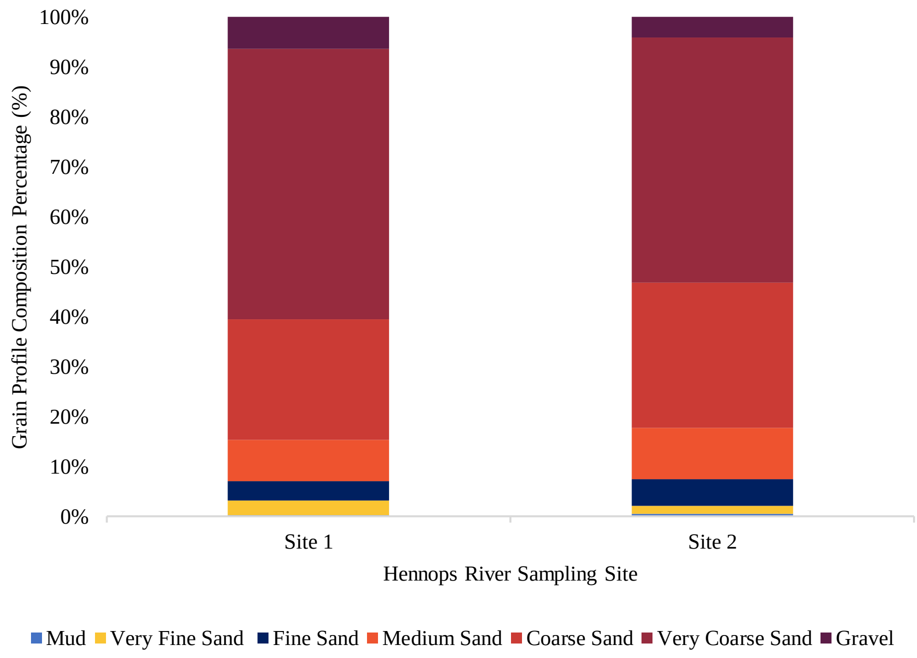


Figure 21. Grain size distribution of sediments collected from sampling sites located along the Hennops River.

5.3 Size Distribution of microplastics collected from the Hennops River

The size fractionation analysis of microplastics indicates the variability of their sizes and morphologies in different matrices (Figure 22). Particle size ranged between 0.81 mm and 4.91 mm with an average length of 1.93 mm. The histogram (Figure 22) indicates smaller microplastic sizes are dominant throughout both water and sediment matrices. For water samples, (Figure 22.A) fibres are observably homogenously distributed. Fibres predominantly make up the larger size classes (> 3000 μm) for surface water samples as a result of having lightweight properties and being easily transported in water, similar to the trends observed for Durban Bay. Sedimentation occurs at slower flow velocities, whereby the particles fall out of suspension and tend to settle in the sediments. Smaller particles are likely to maintain their suspension in the water as observed in Figure 22A, whereby surface water samples were comprised of predominantly fibres. Sediment samples were predominantly composed of film and fragments smaller than 1000 μm (Figure 22B).

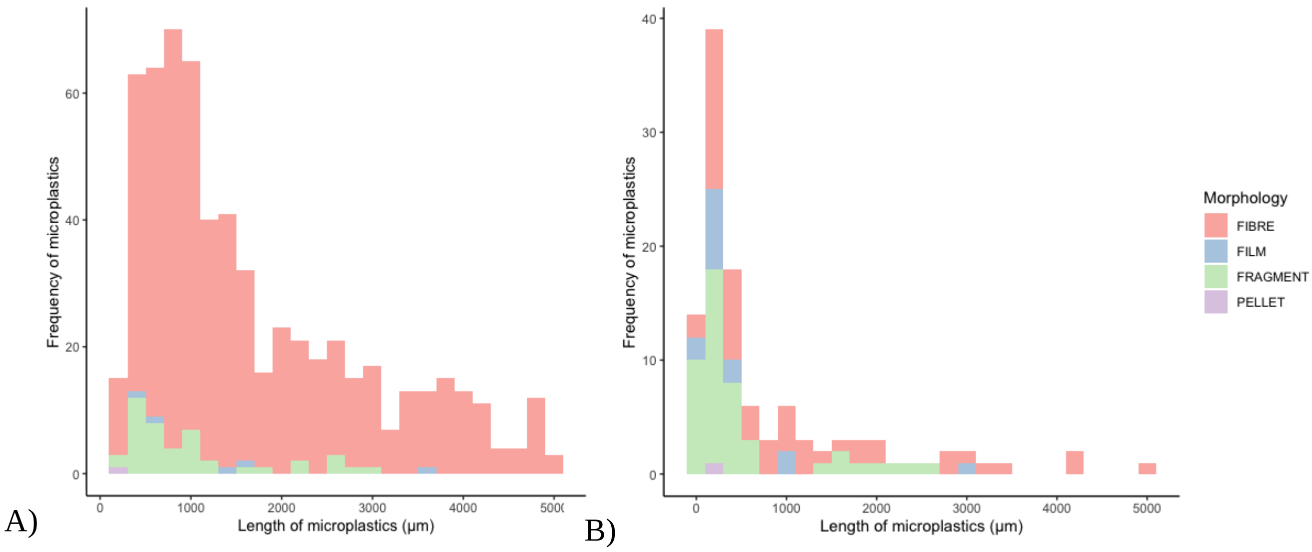


Figure 22. Histogram depicting the frequency of microplastics according to their morphology (fibre, film, fragment, pellet) and classed according to the lengthwise size distribution of microplastics in A) surface water samples and B) sediment samples.

5.4 Morphology of microplastics

Microplastics identified were predominantly secondary microplastics, either fibres, films or fragments were recovered from water-sediment interfaces (Figure 23).

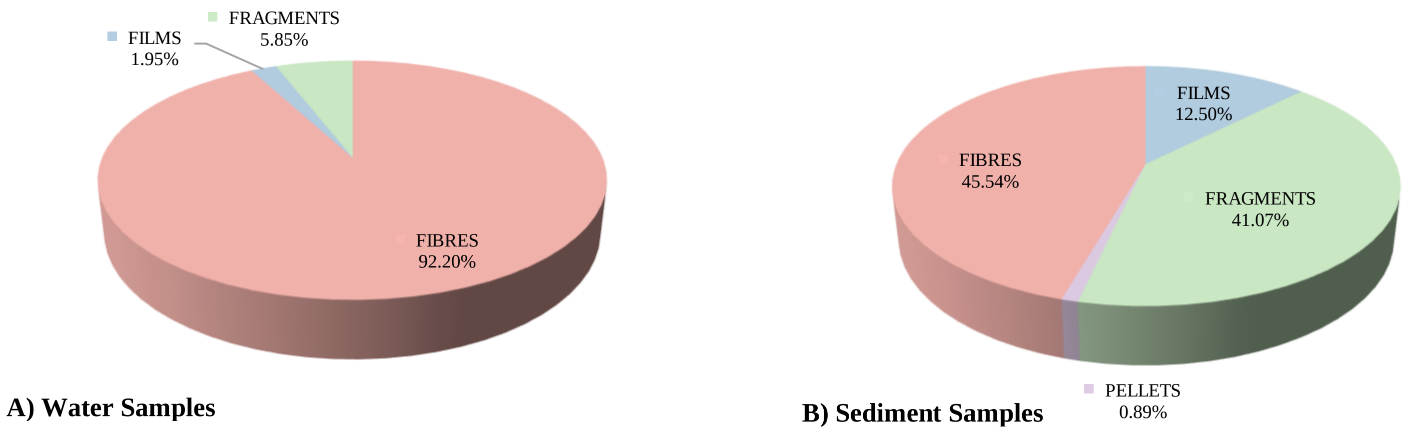


Figure 23. Proportion of microplastic morphlogies recovered from samples collected from the Hennops River stations in 2019 recovered from A) water samples surface and B) sediment samples.

A total of 728 particles were identified using visual identification methods (616 from the surface water samples and 112 from the sediment samples). Three different types of morphologies were identified in surface water samples (fibres, fragments and films; Figure 24.A) with fibres being predominantly observed (92.20 %), followed by fragments (5.85 %) and films (1.95 %).

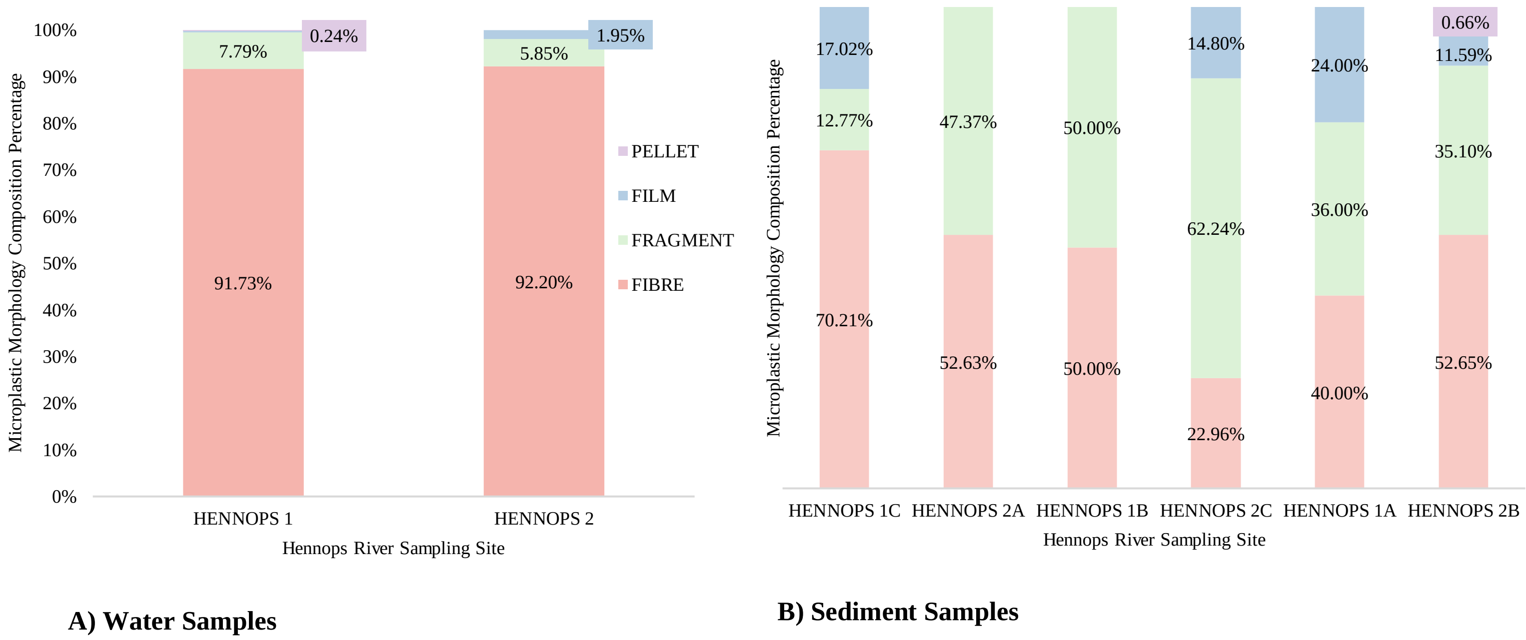


Figure 24. Percentage of microplastic morphologies detected across the Hennops River in A) surface water samples and B) sediment samples.

Fibres were the most dominant particle in both sediment (45.54 %) and water samples (92.20 %) collected from the Hennops River, however sediment samples also had a high proportion of microplastic fragments (41.07 %). The higher proportion of microplastic fragments in sediment samples may be due to the deposition of fragments, especially with the loss of buoyancy over time due to biofouling. The findings of this study are in agreement with the results of other studies, whereby fibres were observed as the predominant morphology of microplastics found in the Vaal and Orange Rivers (Weideman et al., 2019). Studies have also shown fragments to be the commonly recovered morphology (51.3 %) from sediments sampled near urban rivers (Niu et al., 2021).

5.5 Colour characterization of microplastics

Colour identification of microplastics showed that the most frequently observed colour for all surface water samples studied was blue (31 %), followed by transparent (17 %) and black (17

%). For sediment matrices, black (21.43 %), red (15.18 %) and blue (12.50 %) were the most abundantly observed colours (Figure 25). The results are in alignment with other studies whereby the most frequently observed colours were black, blue, red, transparent and white (Mohamed Nor and Obbard, 2014; Zhao et al., 2015).

Transparent pellets are often linked to polypropylene (PP), and white pellets are ascribed to polyethylene (PE), but further chemical analyses are required for conclusive confirmation. Low density PE has opaque colours, while ethyl vinyl acetate corresponds to clear pellets. Colour has also been used as a marker for degradation and time spent in the marine environment.

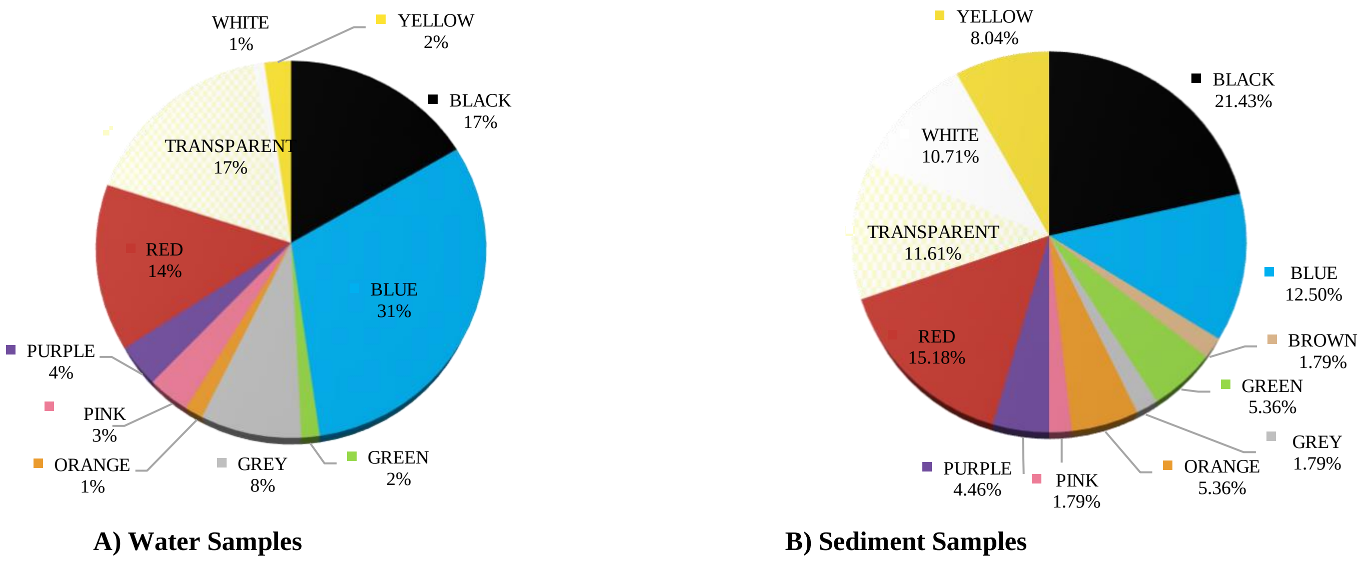
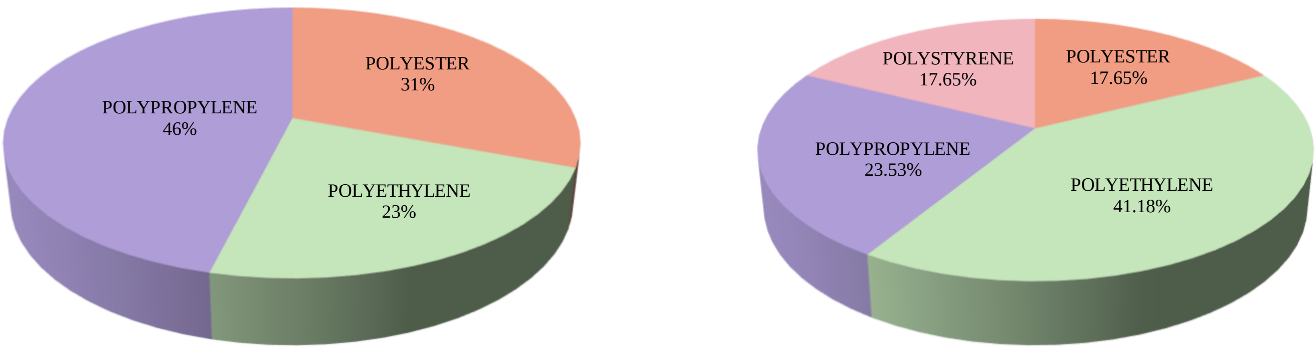


Figure 25. Proportion of colour assignments for microplastics collected from the Hennops River found in A) surface water samples and B) sediment samples.

5.6 Polymer Composition of Microplastics

Microplastics for chemical characterisation were randomly selected and analysed with a micro-Raman spectroscopy instrument (Horiba LabRam) to confirm polymer compositions. Of those particles subjected to Raman analysis, the polymers identified suspended in surface water and sediment samples were PP, PET and PE (Figure 26). These microplastics polymers are commonly found in agreement with microplastic studies conducted in other rivers (Kataoka et al., 2019). PP was most commonly found in surface water samples (46 %), followed by polyester (31 %) and polyethylene (23 %). PE (41.18 %) was most commonly detected in sediment samples followed by PP (23.53 %) and polystyrene (17.65 %) and polyester (17.65

%). The most commonly reported microplastics polymers found in the environment are polyethylene and polypropylene which have low densities (Lusher et al., 2015). The findings are in agreements with the results of numerous studies, where the fibres recorded were conclusive as either polyester, polyamide, polyethylene, polypropylene or rayon (Pagter et al., 2018)



A) Surface Water Samples

B) Sediment Samples

Figure 26. Abundance proportions (%) of microplastic polymer composition detected in selected samples for a) surface water samples and b) sediment samples.

The distribution of microplastics in the water column is determined by the density of microplastics. PE and PP are likely to float due to their densities being less than the density of water. PS and PET are denser than water, and are likely to sink in the water column. The incorporation of additives with polymers can change the density of plastics, thus leading to variations from the expected fate of microplastics (Pagter et al., 2018). The crystallinity and density of microplastics are not inherent properties, and may change as a result of the weathering and aging process, leading to observed distributions varying from what is expected based on density estimates of polymers. Increased residence time of microplastics may lead to microbial formations which may affect the fate and buoyancy of microplastics, as the growth of biofilms leads to an increased density of microplastics (Fazey and Ryan, 2016; Guo and Wang, 2019).

Floating particles are likely to be transported with currents and waves. Particles pick up scum and organic matter, resulting in an increase in their density which affects their fate in the environment. Microplastics in the surface waters of freshwater bodies have been reported to consist of low-density polymer types (Lenaker et al., 2019). The analysis of microplastics in sediments can aid in identifying areas of microplastic accumulation, while point sources of pollution can be identified in through surface water samples which aid in identifying suspected sources of microplastics.

5.7 Sources of microplastics

The accumulation of microplastics in surface water and sediments is dependent on several geographic, environmental and anthropogenic factors. The close proximity of the Hennops river to the garbage dumps is a direct source of plastic pollution in the river. The surrounding area consists of high-density low-income communities wherein residents from the informal settlements often do not have direct access to tap water and as a result, river water is used to wash clothes. One of the largest contributors of microplastics is a result of the washing and shedding of synthetic textiles, which leads to microfibres entering wastewater streams (Henry et al., 2019). The discarded water results in a major source of microfibres that were detected in surface water samples. The improper handling of solid waste from urban areas and informal settlements are also suggestibly major causes of MP pollution. The flow of raw or partially treated sewage into the river, and the close proximity to solid waste dumps, also contributes to microplastic pollution in surface water and sediment samples. The presence of microplastics detected in surface water and sediment samples from the Hennops River can be attributed to the large volumes of mismanaged waste from the urban area and densely populated informal settlements.

The abundance of microplastics have been significantly correlated with urbanised areas and high population density, suggesting that human activities surrounding the river are the main sources of microplastic concentrations (Kataoka et al., 2019). Studies linked to the Hennops River have found low dissolved oxygen, high faecal coliforms and nutrient concentrations – all of which prevent aquatic life from inhabiting the river (Morole, 2020). Studies have found significant relationship between concentrations of microplastics and Biological Oxygen Demand (BOD), which is an environmental indicator of river pollution. Microplastics have accumulated more in polluted rivers with poor water quality, leading to the inference that the origins and pathways of microplastics in river systems have similarities to those of other contaminants (Kataoka et al., 2019). The identification of potential sources (point and non-point of plastics) can be used to inform and improve waste management strategies along the Hennops River and its surrounding areas.

Freshwater scarcity is an issue that is not unique to South Africa. Aged, unmaintained and failing WWTWs have become a common problem for South African municipalities around the country. The release of untreated wastewater has led to freshwater pollution and the depletion of quality water resources. Faecal pollution and solid waste present in water increasesthe risk of infection of various diseases, and microplastics as vectors for microbes, increase the risk of disease travelling across surface waters, posing a health risk to biota and humans.

The City of Tshwane has acknowledged that the WWTP (such as Sunderland) discharges untreated and partially treated, substandard effluent into the Hennops River and surrounding rivers (SAHRC, 2021). The Municipality noted that the effluent quality discharged from these WWTWs has been non-compliant for a period of time due to maintenance and capacity constraints. This negatively impacted the receiving water bodies which serve as resources for downstream users. With the limited waste collection system, open dumps are commonly observed in impoverished communities, placing the inhabitants of neighbouring areas at risk from exposure. Plastic waste can clog sewer lines, resulting in stagnant and contaminated water that may serve as a breeding ground for diseases such as cholera.

Evidence of illegal littering and dumping, which impacts the ecological river health, can be seen in the catchment that drains the surrounding area. This can be related to the insufficient number of solid waste transfer stations associated with squatter camps, and the poorly-maintained housing developments which add strain from dumping problems. Management actions are required that will greatly reduce environmental constraints that is posed by littering and dumping in streams. Improper stormwater management needs to be addressed by including litter traps in the stormwater reticulation network, to prevent the direct input of litter into aquatic systems. The stormwater plans should be maintained and regulated by local municipalities to ensure a sustained system. Diffuse sources of pollution are linked to heavy rainfall, which results in urban run-off carrying pollutants directly into the surface water, completely avoiding WWTPs. The regular maintenance of sewage networks is required to prevent situations where facilities become overloaded, thus resulting in the discharge of raw sewage into aquatic systems, which have repercussions on environmental and human health.

Urban rivers are exposed to high levels of waste generation and poor waste handling, and are often subject to plastic leakage originating from land-based activities. Rivers overlapping with urban regions of large cities are potential carriers of plastic waste eventually into the ocean. Heavy rainfall after dry periods results in the rainwater collecting pollutants along roads, pavements and stormwater systems, and ultimately flushing into the rivers. The dry season can lead to the accumulation of MPs in sediments, which may be later resuspended during periods of rainfall, and subsequently migrate towards the marine environment. The variable sources of microplastics pollution in rivers means that focus is required on measures aimed at cutting emissions of microplastics from known land-based sources.

5.8 Experiment contamination control

Method blanks were incorporated using the sample glass jars and centrifuge tubes for each separation technique. Sample processing contamination from blanks in this experiment consisted of two blue fibres (< 500 μm) present in surface water samples and one red fibre for sediment samples, which may be attributed to clothing. The MPs identified from the blanks were subtracted from samples based on morphology and colour. This was done by summing the laboratory blanks separately for each matrix type and then subtracting the totals from microplastic counts for each set of samples from the respective matrix (e.g., two blue fibres were removed from each surface water sample and one red fibre was removed from each sediment sample). No contamination was detected from blanks incorporated for atmospheric deposition of airborne microplastics during field sampling.

5.9 Limitations

It is acknowledged that the results within the study area of the Hennops River are subject to limitations due to two sites being assessed for microplastic pollution in surface water. The samples were collected under normal flow conditions using a singular plankton net therefore making the collection of water samples across multiple sites difficult. The sample collection process for water samples in the Hennops River was time-consuming, due to ensuring that an adequate volume of water was sampled, and required constant supervision to prevent the risk of equipment theft.

It is difficult to compare results with other studies, as sampling strategies employed may have varied, i.e. microplastics in water samples may not have been measured under normal flow conditions. Despite the limitations of the number of sample sites, the study confirmed the presence of microplastic pollution present in the Hennops River. Sediment samples were collected from various points at each site to provide a robust description of small-scale variability of microplastic abundances between sites. The distribution and fate of microplastics along the Hennops River would be better understood by looking at different sites along the river and conducting more field studies.

Conclusion – The Hennops River

Data presented for the Hennops River provides an initial baseline study and the findings of this study confirm the presence of microplastics within the freshwater system. The presence of microplastics were confirmed in all samples whereby the dominant MPs were small (< 1 mm), of varying colours and consisted mainly of fibres (54.1%) in both sediment (45.54 %) and water samples (92.20 %). Analysis by Raman spectroscopy revealed the presence of four types of polymers in the selected MPs, with the most abundant being polypropylene and polyethylene. There is a need for holistic catchment management and rehabilitative measures to improve the ecological state and water quality of the Hennops River, and further prevent plastic debris from being transported along the river.

6. General Discussion

Microplastics were detected in all samples of surface water and sediment matrices for both Durban Bay and the Hennops River study areas. Areas of sediment deposition of microplastics may give an indication of accumulation zones of microplastics, whereas water column analysis provides insight into suspected input sources of microplastic pollution (Preston-Whyte et al., 2021). The proportion of inadequately managed waste is based on spatially dependent waste generation, whereby the closer to an aquatic system the waste is generated and mismanaged, the greater the probability that it will enter the aquatic environment (Borrelle et al., 2020). The areas for pollution mitigation include stormwater drains, port operations and river inlets as well as the anthropogenic activities that contribute to pollution along the river networks.

The variability and abundance of microplastics is dependent on a number of factors, such as geographical location, seasons, and proximity to areas of anthropogenic activities (Vanapalli et al., 2021a). It should also be noted that during summer seasons of high rainfall, there is an expected influx of microplastics in the environment due to higher debris and water entering the harbour and urban rivers. Rainfall and storm events results in an increase in the influx of plastic debris and have been reported to increase the abundance of microplastics in various aquatic ecosystems, such as rivers and estuaries (Shruti et al., 2021). Heavy rainstorm events cause strain on downstream wastewater treatment plants (WWTPs), and result in sewer overflows containing large amounts of untreated domestic wastewater. The treatment at WWTPs does not remove MPs, as the particles get caught in biosolids. The sludge from WWTPs that traps microplastics has been used in applications, such as farming, which adversely affects soil health (van den Berg et al., 2020).

Densely populated urban areas are subject to multiple sources of microplastic pollution, thus the abundance of microplastic contamination in the environment is expected to be high. Rivers largely contribute to the amount of microplastics present in estuaries, and accumulation hotspots occur nearby to river inflows in estuarine systems. The main sources of microplastic pollution introduction into aquatic systems is attributed to wastewater inflows and stormwater drains, which are heavily influenced by urbanisation and high population density in surrounding areas. Larger plastic debris was evident along the river banks in the Hennops River, and it can be inferred with support from source to sink studies, that these plastic pieces upon entry from their various sources of pollution can disintegrate, accumulate and eventually reach high levels in aquatic environments which can act as a sink for microplastic particles (Vanapalli et al., 2021a). The presence of predominantly secondary microplastics in the Hennops River and Durban Bay is indicative that plastics fragment into smaller particles throughout their transportation before entering the ocean.

It is necessary to evaluate options to reduce MP pollution and recommend policy changes to prevent MP pollution. Stormwater drains have been identified as main sources of pollution therefore pollution prevention actions are necessary. The preventions include trash capture systems, stainless steel screens and green stormwater infrastructure, which uses vegetations and natural processes to filter runoff from storm events. Measures need to be taken which include land clean ups and illegal dumping prevention. The projected plastic growth places extra pressure on waste management capacity, highlighting the need for a shift towards a circular economy. Frameworks and policies need to be directed towards removing the use of single-use plastics and designing plastics which can be recyclable by design.

6.1 Size

Size classes of MPs elucidate the extent of fragmentation and degradation of plastic debris in the environment. The size distribution of this study found smaller size classes (< 2 mm) to be of higher abundance. Microplastic abundance is expected to increase for decreasing particle size, due to the continuous breakdown of plastic debris (Bulannga and Schmidt, 2022). Various studies have identified microplastic peak sizes of 10 μm, <50 μm), 1 mm 2 mm and 100–150 μm (Eo et al., 2018). Size distribution analyses of different microplastic studies have found variabilities in different matrices, whereby a number of studies have found larger microplastic sizes to be predominant in sediment and water matrices, whereas other studies have reported smaller size classes to have higher abundance (Vanapalli et al., 2021b). The observed differences in size class distributions of microplastics may be a factor of sampling and analysis techniques, as described in the example of Durban Bay, where a pump was used in comparison to this study, whereby a plankton net was employed. Microfibres can be understated which can slip through the mesh of the sampling nets due to their morphology (Zhu et al., 2021).

The growing body of literature available shows that the various analytical techniques used to sample, extract and identify particles can greatly influence the reported results of microplastics in environmental samples (Shruti et al., 2021). Neuston nets with mesh sizes around 300 μm have been used widely in water sampling, resulting in microplastics smaller than 300 μm underestimated. In this study small microplastics (< 2 mm) were of the highest density of the total microplastic abundance. The implication of having a high abundance of small microplastics is these particles being biologically available to a wide range of organisms and can be easily ingested (Eo et al., 2018). A negative exponential trend was observed between mesh size and microplastic abundance in surface waters when comparing results of various studies (Hidalgo-Ruz et al., 2012).

The size and colour of MPs can help in understanding their potential for ingestion by aquatic biota. The analysis of MP size distributions is important to understand its potential to bioaccumulate in different species of biota (Vanapalli et al., 2021b). The high concentration of smaller particles observed in samples from Durban Bay and the Hennops River, is of concern due to smaller particles being ingested at a higher efficiency by biota (Bulannga and Schmidt, 2022). Microplastics typically encompass a size range of 1 μm–5 mm, however studies have reported that particles smaller than 100 μm in size comprise of a large proportion of microplastics present in the aquatic environment (Bulannga and Schmidt, 2022). Microplastics can be ingested by organisms by being mistaken for a species' natural prey, or passively ingested during normal feeding behaviour due to similarities in dimension. Zooplankton species have been found to ingest a range of microplastic dimensions from 0.5 to 816 µm (Botterell et al., 2019).

6.2 Morphology

Microplastics were classified according to their morphologies as fibres, films, pellets and fragments. However, it is important to note that different countries or studies may use varying terminologies. The shape and polymer composition of MPs can aid in identifying their sources. Fibres and fragments were the most commonly reported morphologies. Fibres were dominant in water samples for the Hennops River and Durban Bay, and sediment samples for the Hennops River. Sediment samples of Durban Bay predominantly comprised of fragments. A large proportion of sediment samples from the Hennops River also consisted of fragments. This suggests that at present most microplastics originate from secondary rather than primary sources.

Single use plastic items are potential sources of fragments and films. Plastic carrier bags have been identified as problematic in most countries globally, due to their ubiquitous use and propensity to leak into the environment. Personal care and cleaning products may be sources of microbeads. Synthetic textiles and fabrics are sources of fibres, and are predominantly composed of polyester, nylon (polyamide) and acrylic. Fibres can be transported with air and water currents for long distances from their source of pollution, whereas the distribution of fragments is largely limited by the water mass where the source is located. The plastic packaging sector has the highest absolute leakage (i.e. the total amount of leaked plastic) and the highest volumes of mismanaged waste.

Synthetic textiles contribute towards the large amounts of microfibre pollution observed in the environment. The rise of the "fast fashion" industry has led to mass production, exponential consumption and high turnover of clothing synthesised from polyester fibres (Henry et al., 2019). The textile fibres are released into the environment during the production, use and end-of-life disposal as the fast fashion model encourages consumers to view clothing as disposable items (Bick et al., 2018; Henry et al., 2019). The textile industry produces vast quantities of waste (> 92 million tonnes per year), much of which is disposed to formal waste treatment or informal dumps (Niinimäki et al., 2020).

6.3 Colour

Certain colours are more likely to be ingested by biota and are also indicative of the extent of degradation (Vanapalli et al., 2021a). The colour of microplastics could potentially increase their bioavailability due to resemblance to prey items, especially to visual raptorial species. There has been minimal research investigating the effect of colour on microplastic ingestion in zooplankton. Many experiments have used pale-coloured microplastics, which several species of zooplankton have been found to readily ingest. Samples from the field have reported the ingestion of a variety of different colours. Microplastics found within a species of euphausiid and copepods from the Pacific Ocean were predominantly black, blue and red (Botterell et al., 2019). Similarly, a study conducted in the English Channel found predominantly blue microplastic (66%) within the digestive systems of fish larvae and found this matched the colour ratio of microplastic in the surrounding environment suggesting no discrimination based on colour (Botterell et al., 2019).

6.4 Polymer composition

The fate of microplastics depends on whether the particle will float or sink. Buoyant microplastics will accumulate in surface water, however over time these particles will undergo deposition and sink to sediments, due to biofouling and other process which reduce their buoyancy (Su et al., 2020). Microplastics of low specific density are positively buoyant and widely dispersed, thus these particles are likely to spend a long time at the sea surface (or in the water column), where they can be potentially transported over long distances. Overgrowth by micro- and macro-organisms causes an increase in specific density and thus contributes to a loss in buoyancy and sinking of microplastics. In contrast, erosion may lead to decreases in specific density, thereby enhancing buoyancy. Biofouling and erosion cause changes in specific density, affecting exchange processes between different matrices. Due to complex interactions between fouling, erosion, and surface-volume ratios of particles, it can be hypothesized that temporal changes in buoyancy of microplastics depend on particle sizes (Hidalgo-Ruz et al., 2012).

Microplastics of high specific density are negatively buoyant, thus sink more rapidly to the seafloor; consequently, they are expected to accumulate in sediments near their sources.

Lower-density microplastics, such as polyethylene (PE), are likely to be present at the sea surface and therefore encountered by species of zooplankton and suspension-feeders. Transformative processes such as biofouling and animal ingestion are likely to change the density and buoyancy of microplastics, therefore becoming bioavailable to organisms at different layers in the water column. In contrast high-density plastic, such as (PVC), readily settles down and become bioavailable to benthic feeders. Thus the chemical composition of the microplastics is an important characteristic that determines the distribution of microplastics. (Botterell et al., 2019)

The compositions of microplastics in marine environments mainly including PE, PP, PS, PVC, PA, and PET (Guo and Wang, 2019). Polystyrene and polyethylene can adsorb high levels of hydrophobic organic chemicals from surrounding waters making them highly sorptive plastics (Eo et al., 2018). Additionally, older plastics with rough surfaces have more sorption capacity compared to virgin plastics in the laboratory and in the natural marine environment (Khalid et al., 2021).

6.5 Limitations

Despite the large body of work available on microplastics research, there is still a lack of accepted standardised methodologies and harmonized monitoring measures for collecting, extracting, characterising and reporting microplastics in sediment and water samples (Miller et al., 2021). The lack of consistency and standardization poses limitations on the comparisons of results between various studies and datasets, however inferences can be made around the variances and correlations in microplastic abundance observed between studies from the sampling strategy and analysis approach used (Pagter et al., 2018). Sampling with a plankton net may lead to potential underestimation of fibres because of their long and thin shape which may allow it to pass through the mesh of the net. There are also various reporting units used to express microplastic concentrations, further complicating the ability to statistically compare microplastic abundances across reports. Some studies lack the consideration for possible sources of background contamination which may have incurred in the sample extraction process thus reducing the comparability between studies (Pagter et al., 2018). Sample analysis in this study was conducted within a laminar flow hood and careful washing down of the work area with distilled water and alcohol to ensure elimination of airborne contamination. Therefore, efforts should be paid to develop standard methods for statistics studies (Guo and Wang, 2019).

The physical composition of the microplastics was vigorously conducted, however limitations in this study involved the number of suspected microplastics that were subjected to rigorous chemical characterisation using Raman spectroscopy. This was due to the large number of particles identified during visual inspection under the microscope, and the limited time availability for the Raman instrument usage. The visual count of microplastics was only included if the particles met with the criteria outlined in the 'Microplastic visual identification section' listed in the 'Methods' section to ensure that only befitting particles were included. Raman spectroscopy, Fourier-transform infrared spectroscopy (FTIR) and pyrolysis–gas chromatography/mass spectrometry (py-GC–MS) are the commonly used analytical techniques however, these spectroscopic methods are time-consuming making it difficult to identify the chemical composition of all extracted microparticles. Chemical analysis of dyed fibres is better identified using FTIR spectroscopy as the limitations in Raman spectroscopy cannot identify black pigments and can only identify the dye which may mask the underlying polymer composition of the particles.

6.6 Recommendations for future work

The recommendations made for further research on microplastics in Durban Bay and the Hennops River are outlined and justified below to improve future assessment. Looking at the temporal trends in conjunction with the spatial patterns for microplastic contamination will aid in understanding accumulation spots, invariability, as well as the fate and effects of these pollutants.

1. *Implementation of monitoring programmes*

Harmonised and improved monitoring and assessment of plastic debris and microplastic is essential to understanding temporal trends with seasonal changes and exposure pathways.

Systemic change is required to reduce the amount of plastics produced which can be informed by regular, accurate and transparent data monitoring and reporting on plastic material flows throughout the plastics life cycle. Monitoring the marine environment for plastic litter is necessary for assessing the extent and impact of plastic pollution. Microplastics monitoring can be added to existing monitoring programmes to reduce microplastic emissions into the environment. Further monitoring will enhance knowledge on the amount, distribution and degradation of microplastics in the seas and aquatic environments, and enable action to be targeted accordingly.

2. Sample collection taking seasonality into consideration

Sample collection for both study areas in Durban Bay and the Hennops River was conducted during the dry season. Studies have shown that rainy season resulting in higher runoff can lead to an influx of debris into the aquatic system. It may be useful to carry out the sampling during both dry and wet seasons under different seasonal conditions throughout the year to study the temporal and spatial variation of microplastics in each sampling site. This should also take into consideration how the effect of storm events affect microplastic concentrations in waterbodies. This investigation will contribute toward establishing standardized sampling programs and hence to a more comprehensive understanding of the sources, sinks, and fluxes of microplastics in the marine environment. Seasonality concentrations of microplastics have been found to be higher during the wet season than during the dry season (Zhu et al., 2021).

3. Microplastic risk assessment on biota and the ecosystem

Understanding the potential impacts of microplastics across all biological levels is key for the development of effective risk assessments. Scaling this up to infer effects on populations, and ultimately the ecosystem, is challenging but it is the population- and ecosystem-level impacts of microplastics that is of greatest concern. To improve the information for risk assessments, key research areas need to develop a consensus on how best to assess the risks associated with the exposure to particles originating from commercial activities. The occurrence of ingestion in different species will be essential to inform future research and development of policy on plastic pollution. However, there remain some major methodological obstacles that need to be addressed such as standardized methods with defined terminology to aid comparison with other studies. Considering that microplastics cannot be effectively removed from the ocean, future studies are necessary to understand how biological agents (such as epibionts or seabirds) and abiotic factors (UV radiation, wave action, currents) affect the transfer, accumulation, and further breakdown of microplastics and to describe the potential impacts of this debris. Frequent monitoring and better understanding of ecological and health risks will aid in evaluating the risk of microplastics to marine organisms and humans.

6.7 Application

Advancing the current knowledge of microplastic pollution is necessary in identifying strategies to decrease the emissions of microplastics into the environment. Study estimates have shown that the volume of plastic introduced into global aquatic ecosystems is predicted to be 90Mt/ year by 2030 if waste production continues without effective waste management improvements (Borrelle et al., 2020). The production of plastics and its entrance into the ocean is on the rise and, the amount of plastic in the marine environment is predicted to double by 2030 and quadruple by 2050. It is important to implement strategies to prioritize preventing plastic pollution from entering the environment, in order to protect aquatic environments and to reduce the environmental consequences of plastic waste. The data from this investigation can be used to inform effective mitigation for Durban Bay. Due to over 80% of microplastic originating from land-based sources, it is necessary to implement policies informed by an understanding of land-based sources of pollution at a local level. Inadequate disposal of waste and the widespread pollution of microplastics in the environment makes clean-up practically impossible especially in complex matrices such as sediment.

This data provides information that may be useful with regards to decision making in management practices of water resource environments. Stringent policies and regulations need to be implemented in order to achieve the Sustainable Development Goals outlined by the United Nations, specifically Goal 14, whereby the aim is to significantly decrease the amount of pollution introduced into the marine environment, particularly from land-based activities (Pagter et al., 2018). The challenges with addressing microplastic contamination lies in the lack of technical ability with effectively removing microplastics on a large scale once they have entered the environment. Efforts to mitigate the extent of microplastic pollution need to be directed towards the sources of microplastic, especially secondary sources of microplastics. Monitoring programs for water quality require partnerships between industry, stakeholders, science and government. The current linear economic model is responsible for the large amounts of waste, highlighting the need to implement circular economy principles. It is essential to establish policies that promote a sustainable perspective to the production, consumption and disposal of plastics ultimately preventing plastics from entering the environment and causing harm to human health and the environment. Enforceable regulations need to be implemented for the protection and management of water resources, including "polluter pays" strategies and refuse collection.

A ban on the use of microbeads (used as an abrasive) in personal care products in South Africa would prohibit manufacturing, importing and selling microbeads in products. Plastic packaging contributes the most to inland plastic pollution, highlighting the need to limit the use of single-use plastics. South Africa has implemented a levy on the usage of single-use plastic shopping carriers, however further efforts are required, such as the investment in a circular economy (Borrelle et al., 2020). Limiting the use of single use plastics, which typically comprise of low-quality materials with short lifespans, and ensuring that plastic is recyclable will alleviate some of the problems of plastic accumulation. Other actions involve improving waste management by improving waste collection and disposal within landfills to prevent plastic debris from entering into the environment (Borrelle et al., 2020). Much of the focus of waste is often placed on recycling, whereas more efforts need to be directed toward reusing and reducing actions to minimise the amount of plastic packaging.

Virgin plastics are largely dependent on fossil-fuels, which include the use of harmful chemical additives in the production of plastic products. The prevalence and design of single-use plastics form part of unsustainable business models, and is due to circularity not being incorporated into product design. The majority of plastics manufactured are not recyclable and consumers have difficulty making sustainable choices regarding plastic products, due to barriers involving the expensive costs of sustainable alternatives. It is important that strategies implemented for plastic waste management do not transfer the adversities to other materials, such as cutting down trees for paper based single use packaging that contributes to climate change. The disposal of oil-based plastic via incineration is not sustainable and further contributes to the global climate crisis. The production of plastics from row crops, termed as biopolymers, does not make these plastics more biodegradable. Bioplastics do not degrade quickly enough, and degrades into smaller plastic which contaminates compost in agricultural settings.

Waste management deficiencies are leading to the copious volumes of plastic debris discarded into the environment. Advancing the knowledge of unrecyclable compounds in plastic will inform future policies in preventing the use of unrecyclable plastics. Most plastic that is recyclable is often dumped to landfills as there is limited recycling infrastructure and collection capacity. Informal waste collectors and pickers play a vital position in the recycling of plastic waste. The vulnerable and marginalised informal waste sector responsible for collecting and sorting plastics are not adequately compensated or supported for collection services. It is necessary to enable socio-economic development for businesses based on circular economy principles and provide employment opportunities for especially susceptible populations, inclusive of informal waste collectors, women and the youth.

7. Conclusion

The results from this study can be used as an initial assessment to provide a baseline of current environmental microplastic pollution conditions. A measurable amount of microplastic pollution was found in Durban Bay and the Hennops River in all sediment and water samples. Microplastics were categorized according to size, morphology and colour and the distribution across sites was mapped. Fibres were found to be the most common morphology detected, with most microplastic sizes being concentrated in smaller size classes (< 2 mm). The Hennops River was found to transport more microplastics with surface water serving as a conduit for microplastics. Sediments in the Durban Bay harbour acted as a sink for microplastic particles, whereby fragments were commonly observed. Concentrations of plastic were relatively higher at sites nearest to the river inflows of Durban Bay and the stormwater drains. River inlets were identified as important pathways for microplastics entering Durban Bay and thus potentially the marine environment. It is recommended that future work involve monitoring programmes to investigate temporal changes of microplastic abundances, including the possibility of targeting sources of pollution to prevent microplastic accumulation in the environment.

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