Assessing macroplastic abundances, distribution, and human perceptions along the Mvudi River system, South Africa

by

Ronald Mashamba

220827117

A research dissertation submitted in fulfilment of the requirements for the Master of Science degree, School of Biology and Environmental Sciences, Faculty of Agriculture and Natural Sciences, University of Mpumalanga

Supervisor: Dr. Tatenda Dalu

Co–Supervisor(s): Dr Mwazvita TB Dalu, Dr. Ross N Cuthbert (QUB)

NOVEMBER 2023

ABSTRACT

Plastics pollution is a ubiquitous problem that poses a threat to society and the environment. The issue is especially pervasive in the aquatic environment, where large amounts of plastic debris accumulate from numerous anthropogenic pathways. Relatively little is known about the extent of macroplastic in African Subtropical Austral Rivers, where management strategies are lacking. This study quantifies and compares the variation in macroplastic abundance along the Mvudi River, South Africa over four sites and four seasons, and also aimed to assess and understand the pro–environmental behaviour within the Vhembe Biosphere Reserve in South Africa. I observed a non–significant difference in macroplastic abundance and variation across sites and seasons, with pollution therefore widespread across these contexts. However, the diversity of plastic debris (i.e., γ–diversity value) generally decreased according to sites (M1-M4) moving away from Thohoyandou town and seasons winter, spring, autumn, and spring) with most macroplastic items collected during winter, while fewer macroplastic items collected during autumn. We observed high abundances of macroplastic debris on the shoreline compared to the mainstream, with high proportional abundances of plastic bags and film (>57.8 %) macroplastic physical type across all sites and seasons. We also observed a high proportional abundance of the polymer Polypropylene (>25.3 %).

Pro–environmental behaviour has emerged as one of the strategies that can be used to solve the growing environmental issues in line with achieving sustainable development goals. As indicated by responded plastic bags are preferred because they are cheap and easily available. Significantly positive relationship was observed for gender and separating plastic waste and amount of plastic waste generated. Age and education had significant positive relationships with selected variables, however, education and plastic re–use times were negatively correlated. For environmental consciousness behaviour, most variables showed positive significant relationships.

The information derived from this study serves as the baseline for understanding seasonal variations in plastic debris and their driving factors on this and other Subtropical Austral Rivers and, promoting a positive attitude towards the environment, encouraging social norms that promote pro–environmental behaviour, and shows providing access to resources and education can all contribute to reducing plastic pollution through pro–environmental behaviour.

Keywords: African subtropical Austral Rivers, Aquatic environment, Plastics Pollution, Polymer Polypropylene, Pro-environmental behaviour, Seasonal variations, South Africa, Vhembe Biosphere Reserve,

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

First and foremost, I would like to thank the Almighty God for giving me the strength, wisdom, and ability to undertake this dissertation from the start until I complete it. Without him by my side, it would not be possible for this achievement. I would also like to express my gratitude to my supervisor Dr. Tatenda Dalu and my co–supervisors Dr. Mwazvita TB Dalu and Dr. Ross N Cuthbert for their support and guidance in structuring my dissertation, without their guidance my dissertation would not be successful.

I would also like to thank the Aquatic System Research Group (ASRG) for the opportunity and its members for their assistance and my mother for always being there supporting, encouraging, and believing in me toward my MSc studies.

I would also like to express my greatest gratitude to National Research Foundation (NRF) grant number 138206 for financial support on my post–graduate studies research.

DEDICATION

This MSc thesis is dedicated to my mother *Rosinah Simango* who always valued my education, encourages me, and used her last cents to enable me to go to school.

DECLARATION

I, **RONALD MASHAMBA** student number 220827117, hereby declare that the MSc. titled **"Assessing macroplastic pollution abundances, distribution, and human perceptions along the Mvudi River system, South Africa"** has not been submitted by anyone, is my research work and that all sources that I used have been acknowledged by the means of references at the end of this dissertation.

SIGNATURE______________

RONALD MASHAMBA (MR)

DATE………………………………………………….

LIST OF ACRONYMS

ABS	Acrylonitrile butadiene styrene
EPS	Expanded polystyrene
CA	Cellulose acetate
KNP	Kruger National Park
LRC	Luvuvhu River Catchment
MAR	Mean Annual Runoff
PE	Polyethylene
PET	Polyethylene terephthalate
PMMA	Polymethyl methacrylate
PP	Polypropylene
PS	Polystyrene
PU	Polyurethane
PVA	Polyvinyl alcohol
PVC	Polyvinyl chloride
UN	United Nations
WWTP	Wastewater treatment plant
PEB	Pro–environmental behaviour
VBR	Vhembe Biosphere Reserve
DDT	Dichlorodiphenyltrichloroethane

CHAPTER ONE: GENERAL INTRODUCTION

1.1 Background

Plastic products are very cheap materials that are extensively used in everyday applications (Barnes *et al*., 2009). They are categorized into four types mainly based on their size: (i) macroplastics (>25 mm) which include food wrappers, disposable cups plastic pellets and plastic bottles, (ii) mesoplastics are plastics which ranges from 5–25 mm such as virgin resin pellets, (iii) macroplastics which range from 1–5 mm such as microbeads used in cosmetics and (iv) nanoplastics which are less than 0.1 µm (Saraswathy *et al*., 2022).

Global plastic production is increasing at an unprecedented rate. Because of the increase in global demand, it has been estimated that plastic production has increased from 1.6 million tons in 1950 to 356 million tons in 2017 (Plastic Europe, 2017). According to Geyer *et al*. (2017), there are about 6300 million tons of plastic waste have been produced from 2015, of which ~12 % are incinerated, ~9 % recycled and the rest accumulates in our landfills and leaks into the natural environment. The leakage or disposal of plastic products into the natural environment is due to ineffective waste collection rates and illegal dumping in the natural environment, which causes plastic pollution within terrestrial and aquatic environments (Malesa, 2018; Ostle *et al*., 2019).

Plastic pollution is defined as the accumulation of unwanted plastic objects in the environment that pose negative impacts on humans and wildlife (Wang *et al*., 2022). Plastic pollution can cause a diverse range of impacts on humans and wildlife, including biological threats, physical damage, and chemical harm to organisms (Li *et al*., 2021). Most of the effects of plastic on aquatic organisms are via abrasions and entanglement, which reduce the ability of an organism to escape from predator and ability to feed, as well as digestive tract blockage to organisms which accidentally ingested plastic debris (Zhang *et al.*, 2018).

According to Driedger *et al.* (2015), the effect of plastic on organisms differs according to the characteristics such as the shape, size, and polymer of that plastic. Moreover, plastics also have potential implications for the aquatic ecosystem since floating plastic debris in aquatic environments transport alien, pathogen species as well as become a vector of toxic chemicals that can alter the food chain (Lahens *et al*., 2018). Plastic pollution reduces the primary productivity and organisms in a specific aquatic environment depending on the amount of pollution (Rochman *et al*., 2016).

Plastic is a light durable material composed of different polymers, hence plastic pollution is made up of a variety of organic polymers which include polystyrene, polyvinyl alcohol, polyvinyl chloride, nylon, polypropylene, and polyethylene terephthalate (Jaiswal *et al*., 2022). Once the plastic is discarded in the environment, it can travel a distance depending on the shape, size, density, and weight of that plastic debris, whereby wind and water play a major role in the distribution of plastic in the environment (Hoffman and Hittinger, 2017).

Plastic polymers are prone to environmental degradation since they are durable and resistant, thus they accumulate in the aquatic environment and pose impacts (Lambert *et al*., 2014). According to Fischer *et al*. (2016), plastic polymers can be broken down by natural processes such as biodegradation, thermo–oxidative, photodegradation, and hydrolysis, these processes are influenced by temperature and the intensity of ultra–violet (UV) exposure. . The rate of degradation of plastic debris in aquatic and terrestrial environments varies because of the variation in solar radiation, hence plastic debris on land undergoes degradation at rates faster than plastic debris in aquatic environments (Avio *et al*., 2017).

According to (GESAMP, 2016) various sources can introduce plastic debris into the aquatic environment, those sources are categorized into the sea–based sources and land–based sources. Sea–based sources include shoreline recreational activities, and commercial and recreational fishing vessels (Cable *et al*., 2017). Fisheries and aquaculture play a major role in the aquatic environment plastic litter, and fishing gear can be abandoned or discarded during fishing, and plastic debris from ship decks can be blown by the wind or accidentally discarded in the aquatic environment due to inadequate storage (Hoffman and Hittinger, 2017). In land–based sources, plastic debris can be introduced by the littering of bags, plastic bottles, recreational or fishing activities, and any other plastic item along the shoreline (Beaman and Bergeron, 2016).

Plastic users are the key factor in the plastic pollution issue. Understanding consumer purchasing behaviour may help to resolve the plastics problem. A crucial issue that requires attention is how they see product packaging that is no longer useful to them, particularly product packaging made of plastic pollutants (Orset *et al*., 2017; Wan *et al*., 2020). Humans have a duty to protect the environment, yet few people are environmentally conscious: although they are partially aware of the plastic pollution problem, they continue to act in a manner that is not pro–environmental (Hammami *et al*., 2017; Nazareth *et al*., 2019).

Humans have a high level of responsibility since they are the central agent of environmental pollution (Widayat *et al*., 2021). The primary actors are accountable for making welfare the long–term objective of consumption are consumers (Zou *et al*., 2021). Therefore, it's crucial to comprehend the problem before making an environmentally friendly product purchase. Understanding their behaviour after consuming goods packaged with potentially polluting materials, like plastic, is also important (Widayat *et al.,* 2021). It is possible to learn how to address the issue of environmental pollution brought on by plastic waste by observing consumer behaviour when it comes to dealing with product packaging waste (Widayat *et al*., 2021).

1.2 Problem statement

Plastic pollution is a global issue that is increasing at an unprecedented rate, single–use plastics such as lids, food wrappers, plastic bottles, straws, grocery bags cigarette butts are the major contributor to macroplastic pollution. (Sherrington *et al*., 2016). Plastic possesses toxic chemicals such as additives, monomers, and oligomers which can pose diverse health and social impacts (Li *et al*., 2021). In developing countries, plastics are burnt and used as a form of heat during cooking, which directly lead to prolonged exposure to toxic emissions present in particular plastics and poses health impacts on the respiratory, nervous, and reproductive systems of humans (UNEP, 2018). Plastic pollution also has an impact on aquatic ecosystems. For example, plastic debris can block waterways and create a breeding niche for mosquitoes and pests, plastics can also be vectors of toxic chemicals that disturb biogeochemical cycles (Dris, 2017). The entanglement of aquatic animals is one of the major impacts of macroplastic on aquatic ecosystems, which can cause physical trauma and wounds (Dris, 2017). The ingestion of macroplastic debris by aquatic organisms may cause physical and chemical effects which may lead to mortality (Li *et al*., 2021).

Macroplastic pollution also poses negative impacts on tourism activities, the local economy, and water quality (Dalu *et al*., 2019; Brennholt *et al*., 2017). Thus, the availability of plastic debris along the beach imposes costs on beach clean–up (Malesa, 2018).

1.3 Research aim

The aim of this study is to investigate the type, source, driving factors, abundance of macroplastic debris, impacts of macroplastic pollution along the Mvudi River system and human perception toward plastic pollution within the Vhembe Biosphere Reserve

1.4 Research objectives

(i) To assess the distribution, types, and abundance of macroplastic debris along the river system.

(ii) To quantify the seasonal trends in distribution and abundance of macroplastic debris.

(iii) To examine the relationship between the abundance of macroplastic debris, household density (i.e., as a proxy for human population density), and recreational activities.

(iv) To assess the perception of individuals about plastic pollution, its impacts, and practices to reduce plastic pollution.

1.5 Hypotheses

- Concentrations of macroplastic debris along the Mvudi River will be very high during the wet season because of driving factors such as runoffs carrying plastic debris to the river, and when there are many human activities that encourage people to visit the river such as swimming, bathing which increases the chances of plastic litter. The concentration will be low during cold season since people do not usually visit rivers during winter hence fewer activities to encourage plastic litter during the cold season.

- The residents within the Vhembe Biosphere Reserve are not much aware of plastic pollution and its impacts due to it being rural and there won't be any waste recyclers present, and these areas will be associated with poor service leading to illegal plastic disposal and burning.

1.6 The significance and justification of the study

Plastic pollution in the aquatic environment is an emerging global environmental challenge that needs more attention, and land–based sources are a major contributor to aquatic plastic pollution (Van calcar *et al*., 2019). Understanding the spatiotemporal abundance of plastic litter globally and developing future management strategies begins with identifying the distribution of plastic litter in freshwater environments (Cable *et al*., 2017). There is a need to address the distribution of macroplastic debris because it is a global aquatic ecosystem problem and how freshwater bodies and marine are affected to ensure better management strategies (Fischer *et al*., 2016). According to Lahens *et al*. (2018), there is a knowledge gap about the distribution of macroplastics and ecological impacts in African reservoirs, hence data about macroplastic sources, presence, and fate is still limited (Katzenberger, 2015).

This study will add a knowledge base on human perception towards plastic pollution, impacts, abundances, distribution, and status quo of macroplastic pollution in African urban reservoir shorelines. This study will also contribute to international and national conventions such as the Sustainable Development Goals 11 and 15, as the issue of plastic pollution has significant impact on biodiversity integrity. As a result, this study will provide recent status quo documented data about macroplastic debris pollution which can be used by the local municipality to come up with strategies to minimize the abundance of macroplastic debris that exist along the Mvudi River.

1.7 Thesis outline

This thesis is going to be written based on publications and will be divided into five chapters.

Chapter one consists of the general background, the aim, and objectives, the hypothesis and, the significance and justification of the study.

Chapter Two consist of a literature review from different sources.

Chapter Three is the first data chapter on spatiotemporal variation in macroplastic abundances along a subtropical Austral River. This chapter is article structured. It will present, discuss the methods that the researcher used to collect and analyse data. The chapter will also present the results and discussion of the study.

Chapter Four is a second data chapter on Pro–environmental behaviour/human perceptions towards macroplastic pollution, Vhembe Biosphere Reserve, South Africa. This chapter is article structured. It will present the method of data collection, data analysis, the results, and a discussion.

Chapter Five is the general synthesis chapter that ties the entire study together.

The references will be listed at the end of the thesis.

CHAPTER TWO: LITERATURE REVIEW

2.1 Definition and properties of plastic materials

Plastic is a light and durable material made up of different polymers which have large molecules with a long chain (UN Environment, 2018). Plastics are utilized in various household applications such as packaging and medication, the most commonly used plastics are thermoplastics which is made up of a variety of organic polymers which includes polystyrene (PS), polyvinyl alcohol (PVA), polyethylene (PE), polyvinyl chloride (PVC), polypropylene (PP), and polyethylene terephthalate (PET) (Jaiswal *et al*., 2022). Plastic materials are produced by the means of chemical processes where polymers are softened by heat which enables the moulding of various shapes of plastic materials (Plastics Europe, 2017). The olefins, polyethylene (PE), and polypropylene (PP) are primarily used in packaging but are used in all applications. polyvinyl chloride (PVC) is primarily used in the construction industry. Polyesters and PAs (nylon) are polymers used in textiles (Plastics Europe, 2017). Other polymers such as polyethylene terephthalate (PET) are used in packaging, acrylonitrile butadiene styrene (ABS) and polymethyl methacrylate (PMMA) are used in electronics (touch screens), Alkyd (Al) is used in paints, and fibres, expanded polystyrene (EPS) used in the food packaging and construction material (Plastics Europe, 2017).

Plastic materials can persist in aquatic ecosystems for a long period of time due to their physical and chemical nature (Dris, 2017). Chains of monomers are used to make plastics (Vegter *et al*., 2014), hence variations in the physical and chemical properties of the monomers result in differences in the properties of the plastic polymer. The length of the polymer chain affects the material's strength; longer chains provide significantly stronger polymers, and it is these structural characteristics that give plastic polymers their physical properties (Wright, 2015).

2.2 Sources of plastic pollution

Due to extensive anthropogenic activities and growing industrial development on the coasts, plastics are primarily distributed in estuaries and coastal waters, and sediments. However, they also frequently occur in open seas, even in remote and pristine regions like polar areas and deep seas (Baini *et al*., 2018; Zhao *et al*., 2014). According to Lundström and Mrtensson, (2015), the primary sources of plastic debris accumulation in aquatic ecosystems are shoreline littering, such as household and residential activities, tourism, agriculture, wastewater treatment plants (WWTP), landfills, littering, and other economic activities, such as harbor operations runoff from landfills, recreational activities, wind transport from nearby settlements, and accidental and/or overboard fishing gear disposal. The sources of plastic pollution are generally categorized as land–based and sea–based sources, these sources are driven by different modes of transportation to the aquatic environment (Figure 2.1) (Holland *et al*., 2016).

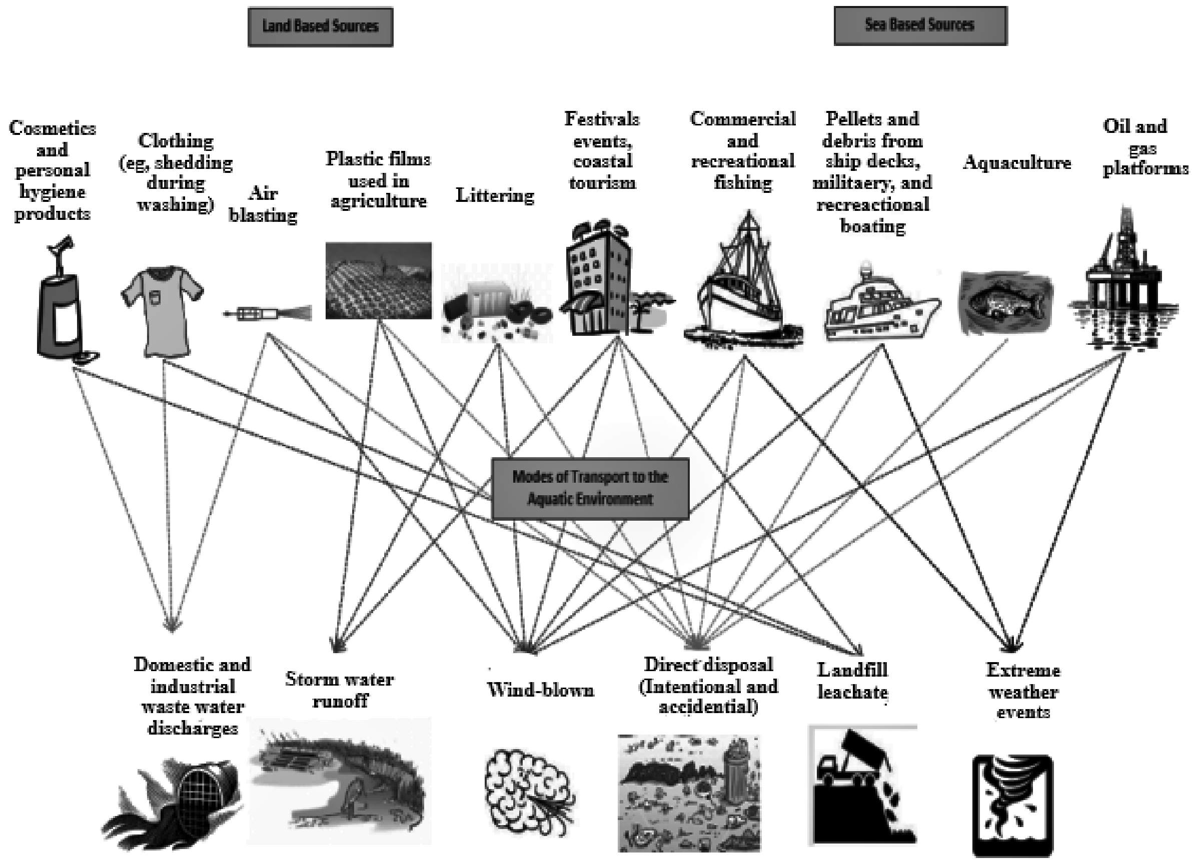

Figure 2.1. Plastic sources and their modes of transport to the aquatic ecosystem (Beaman and Bergeron, 2016; Brennholt *et al*., 2017)

Land– and sea–based sources are major contributors to plastic pollution in coastal and marine ecosystems through in–situ and ex–situ pathways (Thushari and Senevirathna, 2020). Land–based sources are major contributors to plastic pollution in the aquatic and terrestrial environment (Thushari and Senevirathna, 2020). Littering is intentional, it contributes to the disposal of waste into the environment. Most microplastic pollution in terrestrial and aquatic areas is introduced by littering, which includes both small–scale unintentional disposal and large–scale illicit dumping of waste (Lechthaler *et al*., 2020). It is difficult to determine the precise volume of litter released into the environment each year. Ryber *et al.* (2019) estimated that about 0.8 Mt of the amount of littering enters the environment every year with PET bottles being discarded in large quantities followed by cigarette butts which are made up of polymer cellulose acetate (CA) (Turrell, 2020). Cigarette butts are declared at most common waste and estimated that about 4.5 trillion of cigarette butts are released into the environment every year globally, most beaches and urban areas are heavily contaminated by tobacco product waste and cigarette butts (Kawecki *et al*., 2019). Furthermore, the Covid–19 pandemics is another source of litter, dumped single–use masks and gloves are already contributing to plastic litter in the environment, the global increase in single–use plastic such as masks and gloves will intensify marine litter and the impacts associated with them in the aquatic ecosystem (Canning–Clode *et al*., 2020; Patrício Silva *et al*., 2020).

According to Piehl *et al.* (2018), the agriculture sector uses more than 6.5 Mt of plastics every year, most of these plastics are silage films, silo, mulch films, and plastic films for the greenhouse. Plastic mulch films and silage films are mostly used for cultivation protection, when used in contact with agricultural soils they increase their potentiality of being introduced as macroplastic pollution (MaP) in the environment (Lechthaler *et al*., 2020). Since plastic films are made up of PVC and PE are not prone to degradation, hence after mechanical cultivation plastic fragmentation will take place from plastic film left in the soil (Liu *et al*., 2014).

Macroplastic materials enter sewers and wastewater treatment plants (WWTP) in urban areas via surface runoff (Lechthaler *et al*., 2020). The macroplastic is also dumped into sanitary facilities, where it is then flushed into the sewage system, through stormwater overflow tanks in the combined or separation system, macroplastic from a wastewater treatment plant can be released with wastewater into the environment (Kawecki *et al*., 2019). A quantification of macroplastic entering the environment through sewage is currently not possible due to the lack of information on the input of macroplastic into wastewater or the amount of stormwater discharged (Lechthaler *et al*., 2020).

The macroplastic from Landfills close to rivers and coasts enters the environment (Thushari and Senevirathna, 2020). Their proximity to the waterbodies, fragmentation, and degradation of Macroplastic into microplastic, landfills appear to be a potential entrance point (Kazour *et al*., 2019). It is also difficult to determine the input since macroplastic can enter the environment accidentally or during the transport of waste to the landfill (Thushari and Senevirathna, 2020). Abrasion from fishing nets and purposeful or incidental loss of fishing gear also contribute to the discard of plastic into the environment (Jambeck *et al*., 2015). According to Ryberg *et al*. (2019) fishing gear makes up approximately 10 % which is about 640 000 tonnes of marine plastic debris which are discarded in the ocean every year. Aquaculture is another source of entry that contributes to the concentration of plastic in the aquatic environment (Krüger *et al*., 2020).

2.3 Macroplastic debris accumulation, distribution and their relationship with seasons in aquatic environment

Most of studies has shown that macroplastic debris found in aquatic environment originates from diverse sources (Figure 2.1) (Baini *et al*., 2018; Zhao *et al*., 2014). These origins contribute consistently to the influx of macroplastics into rivers, estuaries, and coastal areas, where it accumulates over time due to natural processes like Hydrodynamic processes and the specific features of the surrounding landscape (Beaman and Bergeron, 2016; Brennholt *et al*., 2017).

Investigating these patterns and their correlation with seasonal changes is essential for comprehending the dynamics of plastic pollution (Brennholt *et al*., 2017).

In aquatic environments, the distribution patterns of macroplastic debris are significantly shaped by seasonal fluctuations. For instance, the study by Thushari and Senevirathna, (2020) has observed that rainy season, have higher concentrations of plastic debris because of increased river flow and runoff that carries more plastic waste from inland areas into aquatic ecosystems. Conversely, during dry seasons when river flow reduces, less concentrations may be observed; however, the persistence of accumulated debris is still an issue (Lundström and Mårtensson, 2015).

The spatial distribution of plastic pollution in aquatic systems can also be influenced by the relationship between macroplastic debris and seasons. Seasonal variations in human activities, such as fishing, recreational boating and tourism play a vital role in accumulation plastic waste into aquatic environments, further influencing the distribution patterns of macroplastic debris. Shorelines and coastal areas may experience higher accumulation rates of plastic debris during specific seasons, driven by changes in wave action, wind patterns, and tidal currents (Thushari and Senevirathna, 2020).

2.4 Degradation of macroplastic

Plastic polymers are not prone to environmental degradation and microbial attack, as a result, they accumulate in the aquatic environment where they pose threat to aquatic life (Lundström and Mårtensson, 2015). During the degradation process, macroplastics are broken down into small plastic fragments such as microplastics and nanoplastics which have many impacts on aquatic organisms (Napper and Thompson, 2019). There are several processes that are responsible for the degradation of plastic polymers which includes photodegradation, hydrolysis, thermo–oxidative, and biodegradation (Fischer *et al*., 2016).

According to Chimas *et al.* (2020), the plastic degradation rate depends on other factors such as UV radiation, polymer type, temperature, plastic thickness, physical abrasion, and the environment (Chamas *et al*., 2020). The anticipated rate of degradation in a aquatic environment cannot be easily compared to plastic buried in soil, making it difficult or perhaps impossible to predict the overall period of degradation from a mixture of plastics (Chamas *et al*., 2020). Thermo–oxidative and photo–degradation are the initial processes of plastic degradation in aquatic environments, they are a combination of various chemical processes which are influenced by UV–radiation level exposure (Brennholt *et al.*, 2017; Plastics Europe, 2017). The colour of macroplastic plays a major role since it affects heat accumulation which favours or hinders thermal degradation (Vaughan *et al*., 2017).

2.5 Effect of plastic pollution on the aquatic ecosystem

2.5.1 Ingestion of plastics

According to Ryan *et al.* (2009), aquatic organism ingests macroplastic debris accidentally when feeding. Macroplastic debris ingestion is less visible than entanglement, hence it has been less observed (Hoffman and Hittinger, 2017). Aquatic organisms that consume plastic may experience a variety of impacts that range in severity (Hoffman and Hittinger, 2017). These negative effects include hunger (caused by a gastrointestinal blockage), a false sense of satiety, decreased fitness, behavioural abnormalities, and impacted reproduction and growth (Gall and Thompson, 2015), macroplastic can also block organisms' intestines (Fischer *et al*., 2016). According to Macali *et al.* (2018) other macroplastic debris contains toxic contaminates which can travel with the food chain, especially when ingested by low tropic aquatic organisms like jellyfish. The study conducted by Gall and Thompson (2015) revealed that 233 species of aquatic organisms were affected by ingestion, fish, turtles, crustaceans, seabirds, and echinoderms were the most affected taxonomic groups. They further concluded that ingestion of macroplastic was increasing with the turtle being the most recorded (Gall and Thompson, 2015). Additionally, macroplastic has been discovered in birds and fish in Swiss and French waters, with ingestion rates reaching 12.5 % (Faure *et al*., 2015). However, macroplastic ingestion by aquatic organisms is widespread with limited data in terms of spatial and taxonomic distribution (Windsor *et al*., 2019).

2.5.2 Entanglement in plastics

The effects of entanglement are more visible than those of ingestion, hence aquatic environment entanglements in plastic debris have been recorded many times (Gall and Thompson, 2015). Aquatic organisms such as fish, sharks, turtles, and other vertebrates have been observed stuck in plastic debris especially abandoned fishing gear, due to the size and composition of plastic garbage (Tim van and Anna, 2020). Fishing occurs in riverine systems as well, though not more than they do in oceanic fisheries (Tim van and Anna, 2020). Since entangled organisms and fishing gear have not been frequently recorded in river systems, it is assumed that gear losses are less likely (Tim van and Anna, 2020). However, the entanglement of organisms is not only caused by abandoned fishing gear, macroplastic debris items such as car tires, plastic packing loops, and six packs plastics holders can also cause the entanglement of organisms (Campana *et al*., 2015; Haseler *et al*., 2018). The size, structure, and location of macroplastic debris in the waterbody influence the risk of entanglement (Löhr *et al*., 2017). For instance, plastic debris with a structure like nets that stretch wide in waterbed floors is more likely to entangle many species depending on the strength of that plastic debris and the period of the plastic debris in that specific location (Campana *et al*., 2018). Entanglement by macroplastic debris reduces the ability of an organism to feed, to escape from predators, it also suffocates organisms and causes severe wounds (Zhang *et al*., 2018).

2.5.3 Plastic debris as chemicals carriers

Plastic waste can act as a carrier for hydrophobic contaminants like dichlorodiphenyltrichloroethane (DDT) and polycyclic aromatic hydrocarbons (PAHs) adsorbed from the water bodies (Wright, 2015). The DDT typically bioaccumulates within aquatic food chains after being absorbed from the water column by plankton (Welden, 2015; Holland *et al*., 2016), this accumulation has been noted in many different aquatic organisms (Thompson et al., 2009). Polychlorinated biphenyls (PCBs), which vary in toxicity level and can cause substantial mortality rates of many aquatic species even after a single exposure, may be present in floating plastic debris (Derraik, 2002; Vegter *et al*., 2014; Katzenberger, 2015)

2.5.4 Plastic debris transport alien species

Plastic debris is also responsible for the introduction of alien species in the aquatic ecosystem which has an impact on endemic species since they are capable of out–competing resources with native species once they are introduced in a specific aquatic ecosystem (Cable *et al*., 2017; Lebreton *et al*., 2017). Depending on their physical and chemical properties, macroplastic debris can spread alien species throughout the surface and bottom of water bodies, which could pose a hazard to the local aquatic biodiversity, and if significant non–native biotic mixing takes place, the diversity of aquatic species may decline by as much as 58 % (Derraik, 2002; Thompson *et al*., 2009).

2.6 Impacts of plastic pollution on human livelihood

Human livelihood is directly impacted by macroplastic debris in river systems through increased flood risks and economic losses in most urban areas. Plastic pollution in riverine ecosystems can harm shipping and transport vessels, much like it does in the marine environment (McIlgorm *et al*., 2011; Tim and Anna, 2020). Plastic waste builds up on riverbanks has an impact on tourism or property value, plastic debris has been found to clog sewers and other hydraulic infrastructure in urban areas, raising the flood risk. Recent studies have shown that plastic trash building up in urban drains causes the water level to rise more quickly than biological garbage (Honingh, 2018; Lebreton and Andrady, 2019). It is speculated that river discharge and precipitation affect the pace of movement of plastic debris, therefore, it can be catastrophic if urban drainage systems become blocked during such events (Tim and Anna, 2020).

2.7 Plastic contribution to climate change

According to Zheng and Suh, (2019), plastics are made from fossil fuels hence that is why they emit greenhouse gases in all life cycle stages. Plastic production has increased from two million tons in 1950 to 380 million in 2015 as estimated by Geyer *et al*. (2017). The increase in demand for plastics is because they are very cheap, easy to use, lightweight, and flexible to use in everyday life, the global plastic demand will continue to rise influenced by population growth and economic development, and as a result, it has been estimated that the increase in plastic demand will result in over 56 billion metric tonnes of carbon dioxide equivalent (CO_2e) in greenhouse gas between 2015 and 2050 which makes 10–13 % of the remaining carbon budget (Hamilton *et al*., 2019).

According to Geyer, (2020) More than a billion metric tonnes of carbon dioxide (CO_2) more than 3 % of all worldwide emissions from fossil fuels, were produced in 2015 because of the primary production of plastic. The manufacturing sectors are the most expensive source of GHGs, plastic refining generated 184.3–213.0 million metric tonnes CO_2e globally in 2015 (Hamilton *et al.*, 2019). This is due to the energy–intensive petrochemical process known as cracking, which breaks down saturated hydrocarbons into smaller, frequently unsaturated hydrocarbons called olefins that are then turned into plastic resins (Hamilton *et al*., 2019). During the plastic life cycle, indirect emissions or possible savings must also be considered, for instance, plastic products can result in GHG savings since they are lightweight compared to products made of glass, wood, or metal and emit less CO_2 during transportation (Stefanini *et al*., 2020**).** Indirect emissions which include land clearing for extraction infrastructure, methane leakage, and the subsequent transport of the fuels to refineries, influence the extraction phase of fossil fuels and add to GHG emissions (Hamilton *et al*., 2019). It has been estimated that the extraction and transportation of natural gas for the manufacture of plastic will produce 12.5–13.5 million metric tonnes CO_2e only in the United States (Hamilton *et al*., 2019).

There is a growing interest in using an alternative to fossil fuels as raw materials in creating a circular economy for plastics, this is due to the increased awareness and the understanding of impacts of the mismanagement of waste in the environment (Nielsen *et al*., 2020). Bio–based plastics emerged as one of the sustainable alternatives to replace fossil fuels plastics, according to

European Bioplastics, (2019), the contribution of bioplastics to global plastics production was estimated to be more than 1 % in 2019 and expected to rise. Bio–based plastics have lower GHG emissions compared to fossil fuels derived plastics, this is because bio–based plastics are made from renewable plants (Zheng and Suh, 2019)**.** However, since bio–based plastics are manufactured from biomass, land is needed it grow and cultivate raw materials for their manufacture, a large area of about 61 million ha is required to plant bio–based plastics feedstock (Brizga *et al*., 2020). The required land for bio–based plastics feedstock will damage the biodiversity which will lead to the reduction of species as agricultural major drivers (Newbold *et al*., 2015). Not all Bio–based plastics are biodegradable, some undergo biodegradation under specific conditions, recent studies revealed that the biodegradable process of bio–based plastics stimulates microbial metabolism, which influences the release of carbon dioxide into the waterbody from buried carbon (Geyer, 2020; Sanz–Lázaro *et al*., 2021).

2.8 Pro–environmental behaviour and human perceptions towards plastics

2.8.1 Pro–environmental behaviour

Oturai *et al*. (2022) defined Pro–environmental Behaviors (PEB) as "behaviors that contribute or are perceived to contribute to environmental conservation". PEB can be categorized into elements namely non–workplace and workplace (Azhar and Yang, 2019; Vicente–Molina *et al.,* 2018). Non–workplace PEB refers to an individual's an outside workplace with an idea to minimize the negative impacts on the environment, it often focuses on individual to family level (Collado *et al*., 2019). The workplace PEB comprises individuals participating in an environmentally friendly activity such as awareness campaigns that they are encouraged to by their organization, but on their own will without being forced and employees that are attracted to projects or public studies (Paillé *et al*., 2016).

Understanding PEBs and how to promote them is crucial when it comes to environmental issues where it is widely known that human activity is the primary cause such as plastic pollution and climate change (Muncke *et al*., 2020). Moral and economic drivers are two broad factors that affect PBE (Azhar and Yang, 2019). Moral drivers typically occur when someone's PEB is impacted by their professional ethics or social conscience (Meyer *et al*., 2015), while economic drivers typically start when people realize that PEB affects their personal interests economically. They will choose whether to participate in PEB, such as reducing the use of plastics and improving garbage collection, (Lange and Dewitte, 2019). Social factors such as gender, knowledge, self–efficacy, nature connectedness, and personal and social norms can help to predict pro–environmental patterns (Oturai *et al*., 2022). Rampedi, (2018) stated that geographical location and socio–demographics also have a great impact on PEBs.

2.8.2 Human perceptions towards plastics

According to Carpenter & Wolverton, (2017), Most of the plastic waste found in the environment consists of food packaging plastics such as plastic bags and bottles. Most world–produced plastics are for packaging, therefore knowledge about consumers' preferences and perceptions is the first step needed to be taken in finding solutions to the plastic problem (Plastics Europe, 2017).

According to Lindh *et al.* (2016), packaging serves a variety of purposes, including protecting the goods and communicating the product's qualities. Packaging should be appropriate to reduce environmental impacts since unsuitable packaging increases the amount of food waste, for instance, when Norwegian customers were not happy with the packaging, they would use their own plastic bag to keep the bread fresh and cut down on food waste (Stergaard & Hanssen, 2018). The aspects of the production and transportation of plastic typically have greater environmental impacts than the packaging itself (Wikström *et al.,* 2014). Size, visual, price, and functional qualities of the plastic package, and prior knowledge of the product or brand are deemed to be more significant characteristics of the plastic package (Eldesouky & Mesas, 2014). Respondents to a study from Thailand responded in interviews that the plastic packing material should be non–toxic, resistant, lightweight, transparent, and prolong good product quality when asked directly about it (Silayoi & Speece, 2004).

People are concerned about plastic pollution on their health and well–being, for instance, when litter comes from the general population (such as plastic bottles), it reduces the preference and restorative quality of a given place. Syringes and condoms are two potentially harmful litter items that were perceived to be more offensive on the beach (Wyles *et al*., 2016; Tudor & Williams, 2003). Coastal litter generally appears to have a detrimental impact on the beauty of coastal areas; however, it is observed that beach clean ups could potentially improve this appeal (Corraini, *et al*., 2018).

2.9 Strategies to manage plastic pollution.

2.9.1 Recycling

Due to ineffective waste management, less developed countries are particularly plagued by plastic waste (Ritchie *et al*., 2018). The UN has estimated that only 10 % of African plastic waste makes it to waste facilities, the rest of the waste left to polluting communities or burned in bonfire (Bashir, 2013). Waste management has become a development problem in most African countries such as Kenya, Tanzania, Uganda and Rwanda since the population of people living in cities is increasing (Bashir, 2013).

Recycling can help with effective plastic waste management. Primary, secondary, tertiary, and quaternary recycling are the four different types of recycling processes (Neo *et al*., 2021). Primary recycling, often referred to as closed–loop recycling, involves turning plastic trash into another original product. Open–loop recycling, sometimes referred to as secondary recycling, is the process of downcycling plastic waste into other uses. Mechanical recycling is used for both primary and secondary recycling. Feedstock recycling, also known as tertiary recycling, is the process of dismantling polymers back into monomers or other tiny molecules using chemicals. Quaternary recycling, which also includes co–processing in cement kilns and waste–to–energy (WTE) incineration, involves recovering energy from plastic waste. A Life Cycle Assessment (LCA) could be conducted to estimate the environmental impact of plastic waste EOL treatment, which could serve to make suggestions for better plastic waste management in poor countries (Choudhary *et al*., 2019).

2.9.2 Reuse

Durability is one of the plastic's key attributes. Conversely, it is typically utilized in a disposable manner, which seems contradictory (Heidbreder *et al*., 2019). Therefore, increasing the reuse of plastic products could be the answer to reducing the waste of this long–lasting material. For instance, when a screw–type closure bottle is used it can be readily cleaned and refilled, respondents claimed in interviews that they use plastic bottles "for a purpose other than that for which it was first meant" (Caner & Pascall, 2010).

2.9.3 Reduce

Although recycling and reuse strategies reduce the amount of plastic waste in the environment, they are unable to reduce resource use generally (Beitzen–Heineke *et al.,* 2017). Therefore, it is crucial to cut back on plastic manufacture and use. Customers and sales–people play crucial roles in supply and demand. Recently, so–called "zero waste" grocery stores have shown up; the literature discusses both their advantages and disadvantages (Beitzen–Heineke *et al*., 2017). While addressing children, educators, and the public is also crucial, most of the research concentrating on plastic reduction behaviour mention education about marine litter (Heidbreder *et al*., 2019).

Reduction of plastics can be done in different ways for instance the awareness campaign of marine littering was raised by citizen science initiatives in which individuals were invited to take part in beach clean ups (Syberg *et al*., 2018). In Malaysia, participation in "plastic–free" programs was driven by knowledge and a positive attitude (Afroz *et al*., 2017). Fishermen gained a sense of ownership for "their" beaches and a sense of duty when they encouraged others not to litter and took part in beach clean ups (Brennan & Portman, 2017). School children who participated in plastic–free activities and organized activities as co–researchers saw improvements in their awareness and littering behaviour (Mapotse & Mashiloane, 2017).

2.9.4 Ban

Bans of some types are often used in policy measures and they are one of the most ever introduced successful strategies to reduce the usage of plastic (Synthia & Kabir, 2015). However, it's crucial to consider some possible unexpected outcomes, such as the use of substitute bags (e.g paper). Although the latter may be more or less harmful to the environment than plastic bags, people might view it as being more environmentally friendly (Synthia & Kabir, 2015). This can be done by levying fines or taxes on alternative bags, as it was done effectively in many states of the United States of America (USA) (Wagner, 2017). Bans may have a bad impact on consumers, as a result, this policy amendment can become less politically acceptable (Sharp *et al*., 2010). However, an Australian study shows that customers who heavily relied on plastic bags before a ban began to support the policy after it was implemented, which may be related to the visibility of their favourable environmental benefits (Sharp *et al*., 2010).

2.10 Conclusion

Plastic pollution presents a multifaceted challenge with far-reaching implications for both the environment and human societies. Through an exploration of the literature, it is evident that plastic pollution is a pervasive issue affecting aquatic ecosystems, with diverse sources ranging from land-based activities to sea-based operations. Despite efforts to mitigate its impacts, plastic pollution continues to persist due to inadequate waste management practices and increasing global plastic demand. The degradation of macroplastics into microplastics further exacerbates the problem, leading to widespread contamination of aquatic organisms and ecosystems. Moreover, plastic pollution not only poses direct threats to wildlife through ingestion and entanglement but also serves as a carrier for harmful chemicals and facilitates the introduction of invasive species, disrupting fragile ecosystems and biodiversity.

Beyond environmental concerns, plastic pollution also has significant socio-economic implications, affecting human livelihoods, infrastructure, and public health. The increasing recognition of plastics' contribution to climate change adds another layer of complexity, highlighting the urgent need for sustainable alternatives and waste management strategies. While various strategies, including recycling, reuse, reduction, and bans, have been proposed to address plastic pollution, there remains a critical research gap in understanding the effectiveness and socio-economic implications of these interventions, particularly in the context of African Subtropical Austral Rivers. Additionally, the role of pro-environmental behavior and human perceptions towards plastics in shaping consumption patterns and waste management practices requires further exploration. In the forthcoming chapter, the researcher will spell-out the data collection methods, analysis, and results. This study aims to contribute to a deeper understanding of plastic pollution in African Subtropical Austral Rivers, informing the development of effective management strategies.

CHAPTER THREE: SPATIOTEMPORAL VARIATION IN MACROPLASTIC ABUNDANCES ALONG A SUBTROPICAL AUSTRAL RIVER

***This chapter was published**: **Mashamba R**, Cuthbert RN, Dondofema F, Munyai LF, Wu N and Dalu T. 2024. Spatiotemporal variation in macroplastic abundances along a subtropical Austral river system. Environmental Monitoring and Assessment. 196:273*

3.1. Introduction

Plastic pollution is a major environmental problem that is increasing at an unprecedented rate globally (Galgani *et al*., 2013). Plastic products are very cheap and extensively used in everyday applications (Dalu *et al*., 2019). These items vary in size, colour, shape, and polymer type (Piehl *et al*., 2018). Due to the mismanagement or illegal disposal of plastics, they are often littered into the aquatic environment where they pose threat to ecosystems (Dalu *et al*., 2019; Cao *et al*., 2022). Plastics are the most prevalent, rapidly increasing, and the most dominant aquatic contaminants (Zhu *et al.*, 2018). In particular, large–sized plastic debris, also known as macroplastics (size > 25 mm), are frequently found in aquatic environments (Krishnakumar *et al*., 2018). They enter standing waters and shores through a variety of pathways and activities such as via rivers, aquaculture, shoreline litter, shipping, recreational activities, and fishing, which additionally influence their abundance in the aquatic environment (Lebreton *et al*., 2017).

A myriad of natural factors mediates macroplastic abundance and distribution. Accumulation of plastic debris varies from shorelines to the deep pelagic waters (Beaman and Bergeron, 2016). Further, geographical scale, local environmental conditions, and individual plastic polymer characteristics (i.e., the density of polymers) affect the variability in the distribution of macroplastic pollution (Vegter *et al*., 2014). Vertical variation in macroplastic distribution can occur within the water column due to the interaction between a polymer's buoyancy and water turbulence (Brennholt *et al*., 2017). The density of suspended macroplastic debris tends to increase due to water turbulence caused by storm or flood events (Faure *et al*., 2015). Wind further plays a major role in the spatial distribution of macroplastic (Hoffman and Hittinger, 2017). Studies on global macroplastic pollution show that macroplastic debris can diffuse between countries and continents, float on or below the water's surface, and travel considerable distances (Lundström and Mårtensson, 2015).

Macroplastic debris abundances differ seasonally owing to human activity patterns and differences in water levels, i.e., during summer there are many activities along the shorelines which can result in increased macroplastic pollution, whereas there are fewer activities taking place during the winter season (Avio *et al*., 2017). The shape, size, and buoyancy also influence the distribution of macroplastic debris (Lee *et al*., 2015). Human activities and inland meteorological processes such as wind and rain directly influence the shoreline macroplastic debris accumulation within urban systems (GESAMP, 2019).

Macroplastic pollution effects on aquatic organisms have been observed and include entanglement which can cause suffocation and/or development of severe wounds, and ingestion of plastics leading to various complications (Fischer *et al*., 2016; Cable *et al*., 2017). Organisms that ingest macroplastic can develop sub–lethal effects which can lead to mortality (Cable *et al*., 2017). Macroplastics also serve as carriers of alien species within the aquatic environment (Cable *et al*., 2017), and can transport contaminates such as dichlorodiphenyltrichloroethane polychlorinated biphenyls and polycyclic aromatic hydrocarbons (into the water body where they can be adsorbed

(Katzenberger, 2015). Macroplastic pollution can also have negative impacts on water quality, tourism activities, and impact on the local economy of an area (Dalu *et al.*, 2019).

It is important to determine the distribution of macroplastic debris in aquatic ecosystems because it contributes to the knowledge base on the abundance of global macroplastics and assists in future management planning for aquatic pollution (Fischer *et al*., 2016; Cable *et al*., 2017). There is a particular knowledge gap around the distribution of macroplastics and ecological impacts in African aquatic ecosystems (Lahens *et al*., 2018), and hence data about macroplastic sources, presence, and fate are still limited (Katzenberger, 2015). Hydrodynamic processes affecting macroplastic debris accumulation in urban aquatic ecosystems, particularly rivers, are scarce, and hence more work is required to build an understanding of distribution patterns and factors that cause variation in macroplastic debris across seasons and sites.

In the current study, the Mvudi River that drains most parts of the Thohoyandou town in the Limpopo province of South Africa was chosen because it is subjected to various pollution sources, such as human settlements, water abstraction, riparian brick making, washing, and bathing, subsistence and commercial agriculture, sewage discharge/spillage, and illegal solid waste disposal/dumping. The study aimed to assess the sources, driving factors, types, and abundances of macroplastic debris along the river system. We hypothesized that the macroplastic debris abundances along the Mvudi River will be very high during the summer season because of driving factors such as runoffs carrying plastic debris to the river, and also due to increased human activities such as swimming and bathing which increases the chances of macroplastic debris disposal. We further expected that the macroplastic abundances would be low during the winter season since human use of rivers is reduced when the temperature is low, and hence there would be an absence of activities that could potentially result in illegal dumping of macroplastic debris along the river shores/riparian zones.

3.2. Materials and methods

3.2.1 Study area

The study was conducted along the Mvudi River (30°28’28” E and 23°0’13” S), a tributary to the Luvuvhu River in the Limpopo province of South Africa (Figure 3.1). The river catchment lies at an elevation of between 202 m and 1 506 m above sea level and covers an area of about 5 942 km^2. The Mvudi River passes through the Thohoyandou town and then empties into the Nandoni dam. The river system catchment receives high rainfall during the summer (i.e., February ~284 mm) and low rainfall in winter (i.e., June, ~14 mm) and spring (i.e., September, ~14 mm) seasons. Average temperatures for the catchment range from 20 °C (June, range: 14 – 24 °C) to 24 °C (February, range: 18–28 °C), with low average temperatures of 7.5 °C occurring in July (Dalu *et al*., 2021).

The Mvudi River Catchment is important for agricultural activities such as banana, forestry, avocado, and macadamia plantations in the headwaters; these types of agricultural activities are being practiced in the valleys and lower slopes in the western side and urban settlements on the eastern side (Ramulifho *et al*., 2019), while the riparian vegetation and rivers of this catchment are home of different fauna species (Ramulifho *et al*., 2019). The Mvudi River catchment is subjected to various pollution sources, such as informal and formal human settlements, water abstraction, riparian brick making, washing, and bathing, subsistence and commercial agriculture, sewage discharge/spillage, and solid waste disposal/dumping from nearby communities.

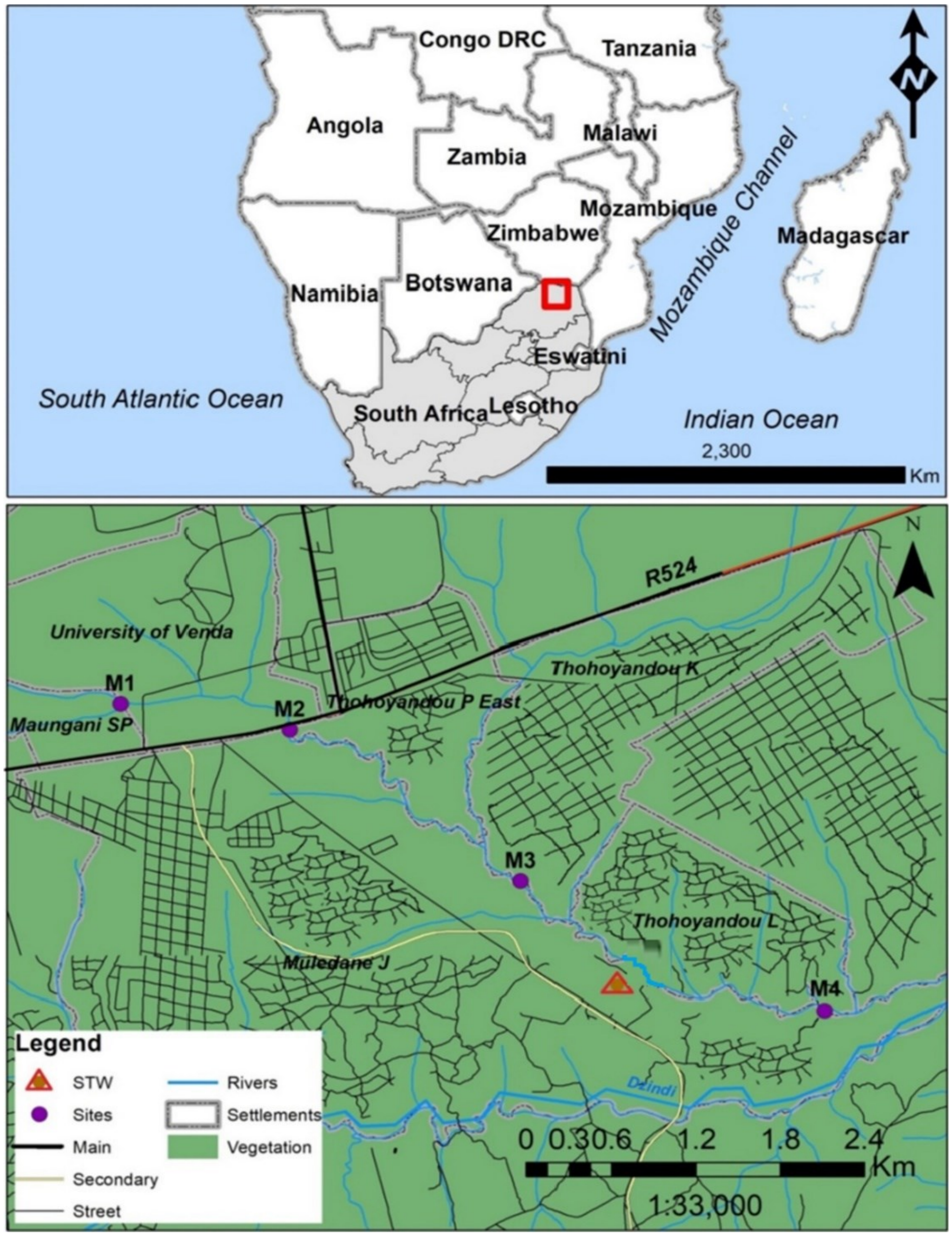

Figure 3. 1. Sampling sites (M1–M4) along the Mvudi River a tributary system, Limpopo province of South Africa

Sampling was conducted at 4 sites, with site M1 located next to the University of Venda and Maungani village. The main activities taking place at this site were water abstraction and car washing. Site M2 was at the edge of Thohoyandou town, with similar site M1 activities—occurring at the site. Site M3 was located between Thohoyandou J and L, upstream of the sewage treatment works, with water abstraction, riparian zone bricking and fishing being the dominant activities, and lastly, site M4 was located downstream of the wastewater treatment works, with brick making and fishing being common. Sampling was conducted at each site (i.e. M1–M4) and season along the per-ennial Mvudi River, across four seasons (i.e. winter, spring, summer, autumn) (Figure 3.1). These 4 sites were chosen because are points where people are able to access the river and undertake activities mentioned. Sampling was conducted at each site (i.e. M1–M4) and season along the perennial Mvudi River, across four seasons (i.e. winter, spring, summer, autumn) (Figure 3.1).

3.2.2 Research design and sampling

A quantitative approach (i.e. riparian and mainstream river surveys) was undertaken to study the distribution of macroplastics (> 2.5 cm) along the Mvudi River system to represent the streams draining the rural town and also in relation to the wastewater treatment works. Riparian and mainstream river surveys were applied as these areas are clearly defined and are zones where high macroplastic abundances are likely to be found. This also facilitated repeatability over time and, in turn, thereby provided a trend assessment (Haseler *et al*., 2018). Such surveys are of particular importance in urban and rural aquatic environments where quantitative baselines for macroplastic pollution are lacking. Accumulation riparian surveys were utilised for this study, where plastic debris was removed from 5 × 5 m quadrats on the mainstream of the river system and on both sides of the mainstem river channel (i.e. 2 riparian zones) by two researchers (Lippiatt *et al*., 2013; Kershaw *et al*., 2019). For obtaining a reliable estimate of the presence and distribution of macroplastic pollution along the riparian zones of the Mvudi River, 4 sampling sites (4 sites × 3 replicates) were randomly selected, with two on each side of the river along the river system (i.e. littoral or riparian zone), and one in the river channel (middle mainstream channel) based on ease of site accessibility. All macroplastic debris present was collected by hand within each quadrat and transferred into labelled bags for further processing within the laboratory.

3.2.3 Processing of samples

Macroplastic debris was separated and categorized into different resin groups before being counted in the laboratory. Resin polymer groups were determined according to Lippiatt *et al.* (2013), Bänsch–Baltruschat *et al*. (2017), and Plastics Europe (2017), methods and classifications. Macroplastics were categorized in relation to their functional origin (e.g., beverage plastic bottles, food wrappers, cleaning product containers, cups, plastic bags) and according to the physical form of the plastic material, either as hard, film, or foam (Lippiatt *et al*., 2013). The different macroplastic polymer groups, functional origin, and physical form were counted for each site and season.

3.2.4 Data analysis

I used a combination of non-parametric and para-metric tests alongside diversity indices to quantify the distribution of plastics among sites and seasons. A PERMutational ANOVA (PERMANOVA) was used to calculate differences in macroplastic debris types across sites (i.e. M1–M4) and seasons (i.e. summer, autumn, winter, and spring), with pair-wise comparisons being done for significant factors. The number of litter 'species' in each plot (a measure of α-diversity; Magurran, 2004; i.e. the number of categories of river litter—within-habitat diversity; Whittaker, 1965) was calculated. The total number of macroplastic debris 'species' in each sample (a measure of γ-diversity; Magurran, 2004) was further calculated for each site. A measure of macroplastic debris 'species' turnover inside each site (i.e. the Whittaker *β*-diversity corresponding to the internal heterogeneity in a 'community' or in a site) was calculated as $\beta W = \gamma/\text{mean } \alpha$ (Koleff et al., 2003). The Shannon–Wiener diversity index (*H′*) and evenness for macroplastics were calculated according to Battisti et al. (2017), and Battisti et al. (2018).

A two-way ANOVA was used to assess macroplastic diversity metrices and abundances, differences within sites (i.e. M1–M4) and seasons (i.e. winter, spring, summer, autumn). All assumptions for a parametric test were met based on the homogeneity of variances and normality assessments. Tukey's post hoc analysis was conducted for significant variables to see which sites were driving the differences. We further examined the differences in macroplastic debris 'communities' and identified the primary species that contributed to the differences using analyses of similarities (ANOSIM) and similarity percentages–debris 'species' contributions (SIMPER) in PRIMER 5.0. To assess differences in polymers and physical form across seasons and sites, a Kruskal–Wallis test was used since the data were found to be violating all assumptions of a parametric test.

3.3. Results

3.3.1 Macroplastic distribution

A total of 358 macroplastic items were collected for this study, with 127 macroplastic items collected during winter, 134 in spring, and 37 in summer, whereas 60 macroplastic items were collected during autumn. Most macroplastic debris were collected in site M1 (Figure 2) whereas the fewest macroplastic debris were collected at M4 (Figure 3.2). Based on PERMANOVA, I observed no significant differences in macroplastic debris across sites (Pseudo–F = 1.114, p(MC) = 0.349) and seasons (Pseudo–F = 1.496, p(MC) = 0.112).

A total of 358 macroplastic items (mean site range 0.55 ± 0.30 (SD) to 1.34 ± 0.92 particles per m2) were collected for this study, with 127 (site mean 1.27 ± 0.35 particles per m^2)) macroplastic items collected during winter, 134 (site mean 1.34 ± 0.92 particles per m^2) in spring, and 37 (site mean 0.55 ± 0.30 particles per m2) in summer, whereas 60 (site mean 0.60 ± 0.51 particles per m^2) macroplastic items were collected during autumn. Most macroplastic debris were collected in site M1 (Figure 3.2) whereas the fewest macroplastic debris were counted at M4 (Figure 3.2). Based on PERMANOVA, we observed no significant differences in macroplastic debris across sites (Pseudo-F = 1.114, p(MC) = 0.349) and seasons (Pseudo-F = 1.496, p(MC) = 0.112).

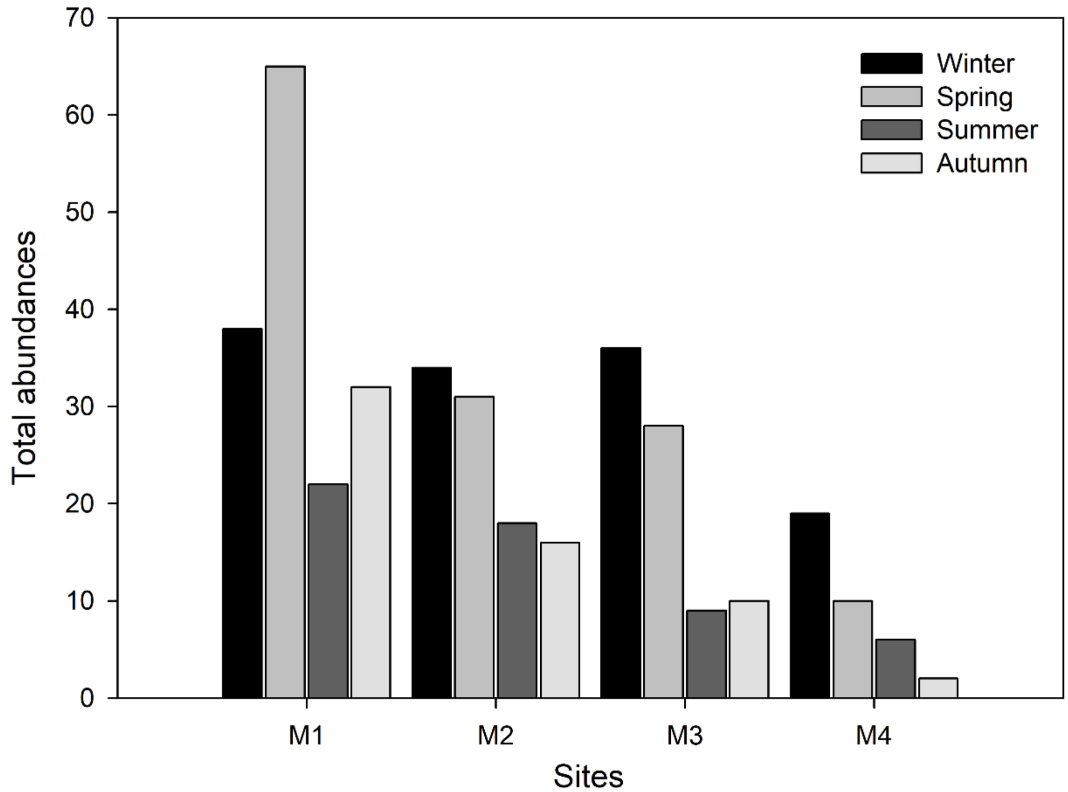

Figure 3.2. Macroplastic debris total abundances per 25 m^2 collected across four seasons (i.e., winter, spring, and summer, autumn) in the Mvudi River system, South Africa

The γ–diversity generally decreased across study sites from M1 to M4 for winter, spring, and autumn. Spring had high γ–diversity (mean range 2.67–8.00), with autumn having lower γ–diversity (mean range 1.00–5.00) (Fig. 3a). The Whittaker β–diversity for all four seasons ranged between 1.75 and 7.25 among seasons, with a variable trend across the study sites (Fig. 3.3b). Shannon–Wiener diversity index had no clear trends across seasons with autumn having low diversity index values (mean range 0.42–1.48). Winter (mean 1.00 ± 0.32) and spring (mean 0.78 ± 0.71) site M4 generally had low Shannon–Wiener diversity index values (Fig. 3.3c). Evenness was high for all seasons except in site M2 during the summer (Fig. 3.3d).

Significant differences for γ–diversity ($F = 4.338$, $p = 0.011$), abundances ($F = 5.604$, $p = 0.003$), and Shannon-Weiner ($F = 5.282$, $p = 0.005$) was observed among the study sites, with significant seasonal differences being observed for γ–diversity ($F = 5.767$, $p = 0.003$), abundances ($F = 4.084$, $p = 0.015$), Shannon-Weiner diversity ($F = 5.733$, $p = 0.003$), Whittaker β–diversity ($F = 3.940$, $p = 0.036$) and evenness ($F = 5.201$, $p = 0.005$). Tukey's pairwise comparisons indicated significant site differences for γ–diversity site M1 *vs* M4 ($p = 0.006$), abundance sites M1 *vs* M4 ($p = 0.002$), Shannon-Weiner diversity sites M1 *vs* M2 ($p = 0.013$) and M1 *vs* M4 ($p = 0.003$). Pairwise comparisons for seasonal differences were observed for γ–diversity spring *vs* summer ($p = 0.015$) and spring *vs* winter ($p = 0.012$), Shannon-Weiner diversity winter *vs* autumn ($p = 0.030$), spring *vs* summer ($p = 0.035$) and spring *vs* autumn ($p = 0.011$), evenness winter *vs* summer ($p = 0.008$) and spring *vs* summer ($p = 0.010$), and Whittaker β–diversity summer *vs* autumn ($p = 0.010$).

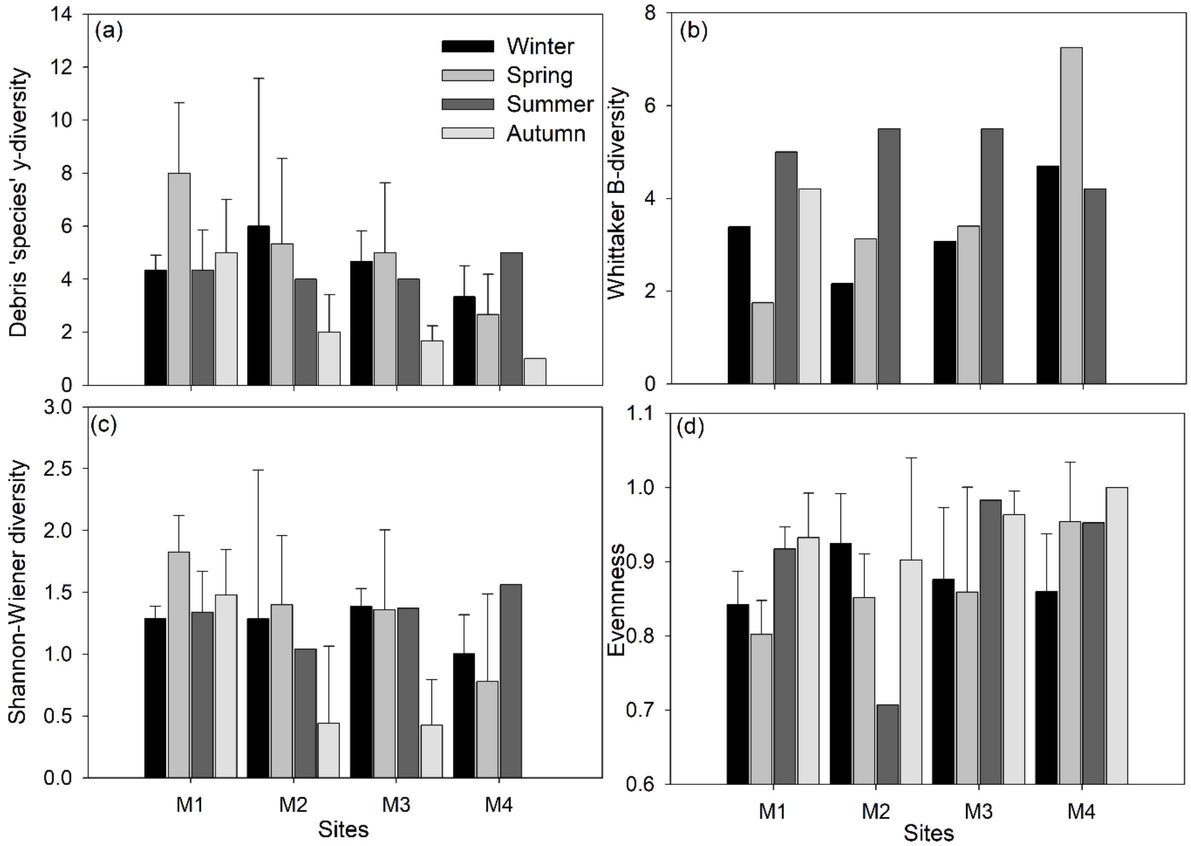

Figure 3. 3. Macroplastic functional groups (a) debris 'species' (γ–diversity), (b) Whittaker β–diversity (c) Shannon–Wiener index, (d) Evenness for four seasons (i.e., winter, spring, summer, autumn). Note due to insufficient sample sizes, the Whittaker β–diversity was not calculated for autumn sites M2–M4

3.3.2 Macroplastic debris functional group and abundance

There were 26 types of macroplastic debris collected across all four seasons, and they varied in terms of functional group, resins, and abundance. Overall, the spring season was more diverse in terms of macroplastic type than all other sea-sons. The most dominant macroplastic debris collected across all seasons were plastic bags (mean range 3.0–55.6%) (Table 3.1). The most dominant macroplastic debris during winter were plastic bags (mean range 12.5–53.0%) like spring (mean range 15.0–39.2%) across all sites, while the food wrappers were the second most dominant. The least observed macroplastic items collected were cigarette filters, soap wrappers, detergent bottles, straws, pill containers, and plastic bottles (Table 3.1). The most dominant macroplastic debris collected during summer were beverage containers (mean range 16.7–36.7%), whereas the least observed macroplastic debris were soap wrappers, plastic rope, and small net pieces, other jugs/containers, detergent bottles, and appliance parts all with one count (Table 3.1). Autumn had the least diverse macroplastic debris observed, with plastic bags and food wrappers being the dominant macroplastic debris collected, similar to winter and spring (Table 3.1). The analyses of similarities (ANOSIM) indicated a low global test value ($R = -0.12$) which sug-gested that dissimilarities were greater within sites than between sites (Table 3.2). The similarity percentages (SIMPER)–debris 'species' contributions indicated that there was an average dissimilarity of 58.0% between sites M1 and M2, and a high dissimilarity of 74.5% for sites M3 and M4. The main dis-similarity debris contributors across sites were food wrappers, plastic rope, and plastic bags (Table 3.2). Similarly, we observed that macroplastic debris' indicated dissimilarities were greater within seasons than between seasons ($R = -0.05$). Average dissimilarity was observed for summer vs autumn (48.5%), while the rest of the seasons had dissimilarity values that ranged from 61.2 to 69.6% (Table 3.2). The main debris dissimilarity contributors across sea-sons were food wrappers, plastic bags, and beverage containers (Table 3.2).

Table 3.1. Macroplastic debris type, resin, and abundances per 25 m^2 found along the Mvudi River across seasons and sites. Abbreviations: LDPE – low density polyethylene, PET – polyethylene terephthalate, PS – polystyrene, PVC – polyvinyl chloride, PP – polypropylene, CA– cellulose acetate, HDPE – high–density polyethylene, PU – polyurethane, ABS – acrylonitrile butadiene styrene

Plastic fragment	Type	Resin group	Winter				Spring				Summer			Autumn		
			M1	M2	M3	M4	M1	M2	M3	M4	M1	M2	M3	M1	M2	M3
Appliances parts	Hard	ABS				8.5 ± 7.5	4.5 ± 4.0	2.0 ± 3.4	2.8 ± 4.8							
Beverage containers	Hard	PET	2.2 ± 3.8	4.9 ± 5.0	4.2 ± 7.2	4.8 ± 8.2	9.3 ± 2.1	10.6 ± 9.4	13.9 ± 12.7	6.7 ± 11.5	36.7 ± 2.62	22.2	16.7	18.9 ± 13.5	33.3 ± 47.1	
Bottle caps	Hard	LDPE	2.3 ± 4.1	3.2 ± 5.5		3.7 ± 6.4	3.8 ± 6.6	2.0 ± 3.4	2.8 ± 4.8	8.3 ± 14.4	3.0 ± 5.2	22.2		5.6 ± 9.6		
cigarettes filters	Film	CA			2.1 ± 3.6			7.8 ± 13.6	2.8 ± 4.8							
Detergent bottle	Hard	LDPE		1.6 ± 2.7			1.0 ± 1.6							11.1 ± 19.2		
Disposable cup	Foam	PS	7.1 ± 12.4	3.3 ± 5.8			3.8 ± 6.6	14.3 ± 24.7			9.8 ± 9.2					
Disposable medical masks	Foam	PP			6.3 ± 10.8											
Foam food containers	Foam	PS	4.4 ± 7.7	9.8 ± 10.0			6.8 ± 6.1	6.7 ± 7.2								
Food wrappers	Film	PP	39.6 ± 15.2	9.8 ± 10.0	12.5 ± 12.5	11.1 ± 19.2	26.8 ± 16.7	4.8 ± 8.2	13.9 ± 12.7	20.0 ± 34.6	16.5 ± 14.2		16.7	26.1 ± 26.7		
Furniture wrappers	Film	PVC		3.2 ± 5.57	12.5 ± 21.7	22.2 ± 38.5	1.9 ± 3.3	2.0 ± 3.4								
Hard food containers	Hard	PET	6.7 ± 11.5		2.1 ± 3.6		9.7 ± 12.0	3.9 ± 6.8								
Maize meal sack	Film	PP					2.6 ± 44		8.3 ± 7.2		6.7 ± 11.5		16.7			
Medicine bottle	Hard	PET							2.8 ± 4.8							
Other jugs/containers	Hard	HDPE	7.4 ± 12.8													
Pill container	Hard	PET					2.0 ± 3.4									
Plastic bags	Film	PP	22.0 ± 22.2	53.0 ± 42.0	12.5 ± 12.5	33.9 ± 30.0	23.1 ± 5.5	39.2 ± 20.0	18.1 ± 18.8	15.0 ± 13.2	3.0 ± 5.2	22.2	16.7	35.6 ± 3.8	66.7 ± 47.1	55.6 ± 50.9
Plastic bottle	Hard	PET		1.6 ± 2.7			2.9 ± 4.9				9.1 ± 15.7			2.8 ± 4.8		

Plastic matt	Hard	PVC					1.0 ± 1.6									
Plastic rope pieces	Hard	PVC		1.6 ± 2.7	38.2 ± 5.2				30.6 ± 39.4	8.3 ± 14.4		33.3	33.3			33.3 ± 57.7
Plastic utensils	Hard	PP		3.2 ± 5.5							6.7 ± 11.5					
Plumbing pipe	Hard	PVC			5.6 ± 9.6				4.2 ± 14.4	8.3 ± 14.4	6.7 ±11.5					
Rubber	Hard	PVC	8.1 ± 7.1	3.2 ± 5.57		11.1 ± 19.2										
Soap wrappers	Film	LDPE		1.6 ± 2.7	4.2 ±7.2	4.8 ± 8.2				33.3 ± 57.7	1.9±32					11.1 ± 19.2
Sponge	Foam	PU						6.7 ± 7.2								
Straw	Hard	PP					1.0 ± 1.6									

Table 3.2. Two–way crossed ANOSIM and SIMPER for testing the groups on macroplastic debris "communities" along the Mvudi River

Groups	Global Test R	Dissimilarity distance (%)	Main dissimilarity contribute debris (%)
Sites	–0.12		
M1 × M2		58.8	Food wrappers (18.86 %), Beverage containers (12.49 %), Plastic bags (8.20 %), Disposable cup (7.16 %)
M1 × M3		69.8	Plastic rope (13.95 %), Food wrappers (12.46 %), Plastic bags (11.16 %), Beverage containers (10.12 %)
M1 × M4		58.0	Food wrappers (16.68 %), Plastic bags (14.27 %), Beverage containers (11.95 %)
M2 × M3		70.5	Plastic ropes (17.15 %), Plastic bags (14.88 %), Food wrappers (12.84 %), Beverage containers (10.89 %)
M2 × M4		71.7	Plastic bags (23.50 %), Food wrappers (13.78 %), Beverage containers (9.78 %), Food containers (7.26 %)
M3 × M4		74.5	Plastic ropes (23.68 %), Plastic bags (17.69 %), Beverage containers (12.13 %), Food wrappers (9.06 %)
Seasons	–0.05		
Winter × Spring		61.2	Plastic bags (11.34 %), Food wrappers (10.20 %), Beverage containers (9.31 %), Furniture covers (7.98 %)
Winter × Summer		67.5	Food wrappers (14.16 %), Beverage containers (12.95 %), Bottle caps (6.48%)
Spring × Summer		63.3	Food wrappers (13.39 %), Beverage containers (11.24 %), Maize meal packages (7.08 %)
Winter × Autumn		69.6	Food wrappers (15.43 %), Plastic bags (15.36 %), Beverage containers (10.18 %), Furniture covers (8.57%), Plastic ropes (8.48 %)
Spring × Autumn		68.1	Food wrappers (15.08 %), Plastic bags (14.61 %), Beverage containers (10.32 %), Plastic ropes (8.74 %), Soap wrappers (8.65 %)
Summer × Autumn		48.5	Beverage containers (18.03 %), Plastic bags (13.75 %), Food wrappers (12.06 %), Bottle caps (8.94 %)

3.3.3 Polymer group variation and macroplastic physical form

Macroplastic debris consisted of 9 different polymers which varied in terms of abundance among sites and seasons (Table 3.1 and 3; Fig.3.4a). The most dominant polymers were polypropylene (PP) (30.4%) and low-density polyethylene (LDPE) (33.7%), while the least observed polymer was polyurethane (PU) (0.4%), cellulose acetate (CA) (1.2%), and acrylonitrile butadiene styrene (ABS) (1.5%) across all seasons (Table3.1; Fig. 3.4a). The polymer abundances differed across sites (Table 3.1). Site M1 was dominated by PP and LPDE during winter (42.2%) and spring (27.7%), respectively, while summer and autumn were dominated by PP (31.8%) and polyethylene terephthalate (PET) (34.4%), respectively. The PU and CA were not observed in site M1 (Table3.1; Fig.34a). The LPDE (41.2% winter; 35.5% spring), PET (61.1% summer), and PP (50.0% autumn) were dominant for site M2.

Significant differences ($p < 0.05$) among macroplastic debris polymers were observed across sites for PU, PS, PU, and PVC, with no significant differences being observed for other polymers (Table 3.3). Significant seasonal differences were observed for PP, PU, and PVC polymers (Table 3.3). The interaction analysis for sites and seasons showed only significant differences for PU ($F = 4.125$, $p = 0.002$) (Table 3.3).

Table 3.3. Two–way ANOVA of the macroplastic debris polymer and physical foam from Mvudi River. Bold values indicate significant differences at p < 0.05 and abbreviations: PP – polypropylene, PET – polyethylene terephthalate, PS – polystyrene, HDPE – high–density polyethylene, LDPE – low–density polyethylene, PVC – polyvinyl chloride, CA – cellulose acetate, ABS – acrylonitrile butadiene styrene, PU – polyurethane

Variable	**Site**			**Season**			**Site × Season**		
	Df	**F**	***P***	**Df**	**F**	***P***	**df**	**F**	***P***
Polymer									
ABS	3	0.618	0.608	3	1.564	0.217	8	1.224	0.316
CA	3	0.621	0.607	3	1.719	0.182	8	0.849	0.568
HDPE	3	1.048	0.384	3	0.156	0.925	8	0.186	0.991
LPDE	3	0.529	0.666	3	0.510	0.678	8	0.319	0.953
PET	3	2.587	0.070	3	0.112	0.952	8	0.535	0.822
PP	**3**	**4.221**	**0.012**	**3**	**4.102**	**0.014**	8	0.410	0.906
PS	**3**	**3.425**	**0.028**	3	1.281	0.297	8	0.597	0.773
PU	**3**	**3.667**	**0.022**	**3**	**5.500**	**0.004**	**8**	**4.125**	**0.002**
PVC	**3**	**5.814**	**0.003**	**3**	**6.776**	**0.001**	8	2.025	0.074
Physical form									
Film	**3**	**3.823**	**0.019**	3	**5.017**	**0.006**	8	0.300	0.961
Foam	**3**	**3.061**	**0.042**	3	2.092	0.120	8	0.672	0.712
Hard	3	2.630	0.066	3	1.324	0.283	8	0.450	0.882

Macroplastic physical forms, namely hard, foam, and film, were observed across all seasons and sites (Table 3.1). The most dominant macroplastic physical form in terms of abundance was film, followed by hard form and lastly, foam form across all seasons and sites (Fig. 3.4b). Significant site differences ($p < 0.05$) were observed for film and form, with similarities being observed for hard form (F = 2.630, $p < 0.05$). Film tended to be high across all sites except in sites M1 (winter), M2 (summer), and M4 (winter). Foam physical form was the least observed across all sites (Table 3.1; Fig. 3.4b). Significant seasonal differences for film (F = 5.019, $p = 0.006$) were observed (Table 3.3).

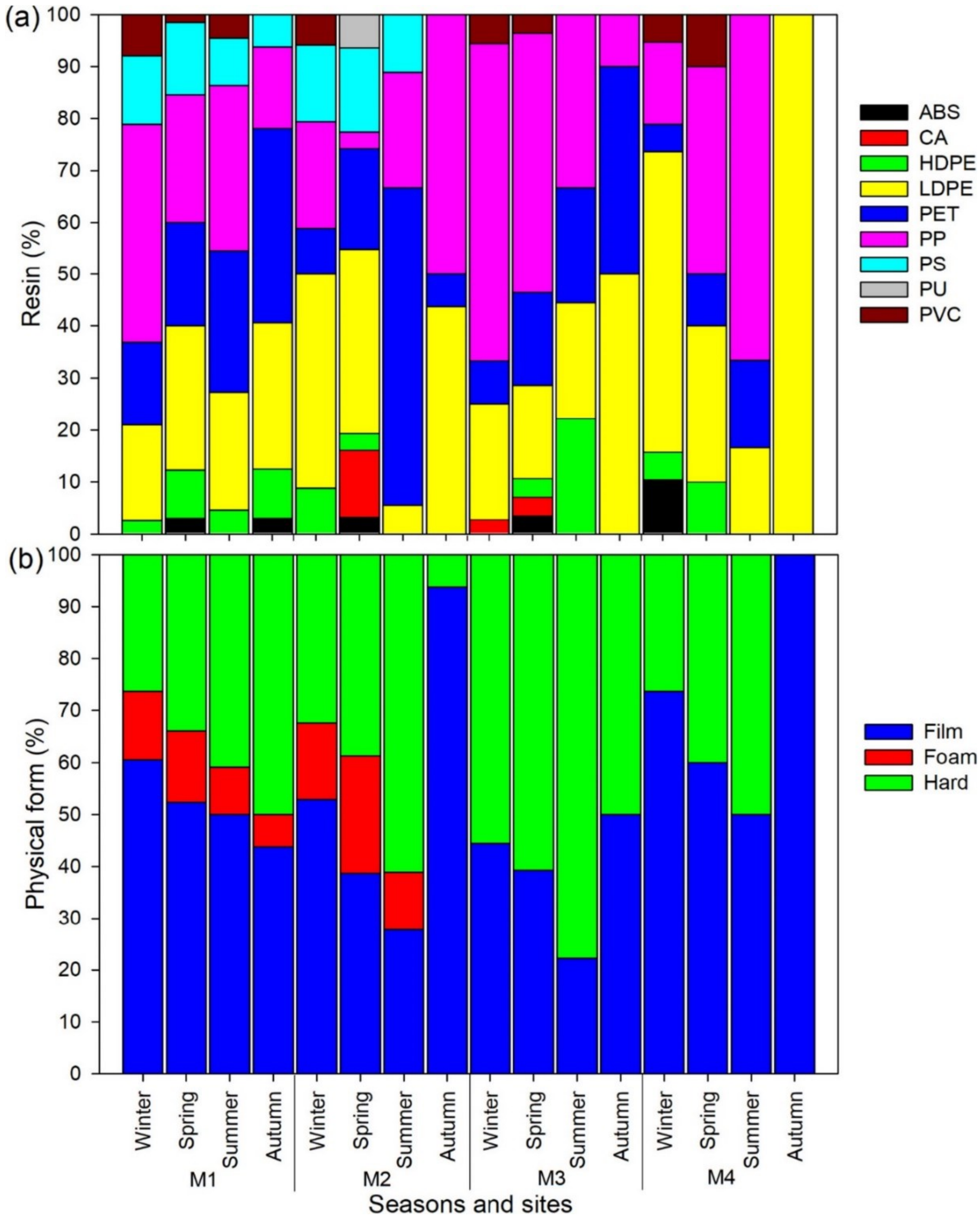

Figure 3.4. The macroplastic functional group (a) counts (%) of polymers and (b) macroplastic physical form counts (%) over a period of four seasons (i.e., winter, spring, summer, and autumn). Abbreviations: PP – polypropylene, PET – polyethylene terephthalate, PS –polystyrene, HDPE – high–density polyethylene, LDPE – low–density polyethylene, PVC – polyvinyl chloride, CA – cellulose acetate, ABS – acrylonitrile butadiene styrene, PU – polyurethane

3.4 Discussion

The study aimed to investigate the source, driving factors, type, and abundance of macroplastic debris within the Mvudi River Catchment, South Africa. I observed that there was a non-significant difference in macroplastic debris abundance across sites and seasons. I therefore reject our core hypothesis. The detected high PP polymer macroplastic debris abundance suggests that human activities such as waste disposal and the visitation of people to the river were high across all four seasons. Those activities increase the chances of macroplastic litter along the Mvudi River shoreline, while the meteorological factors such as wind and rain (Dalu *et al.,* 2019) will also have contributed to the distribution and abundance of macroplastic along the Mvudi River.

The distance of households from shorelines is another factor that can be considered for the non-correlation between household density and macro-plastic concentrations; at great distances (100m), it is unlikely that household density will have an impact on the accumulation of macroplastic debris near the river (Lee *et al*., 2015). People visiting the river directly contribute to litter, and it may be challenging to distinguish this from the litter that is washed to the shoreline (Kershaw *et al*., 2019). Moreover, additional environmental variables such as wind direction, river flow, and precipitation can also influence the distribution of macroplastics at small to large scales.

There was a variety of macroplastic functional group 'species' collected across all seasons and sites, mainly plastic litter associated with household and recreational activities, with plastic bags and food wrappers functional groups identified as the predominant plastic sources over the course of four seasons; this was indicated by the high trend of evenness across all the seasons in the current study which shows less frequent dominance of one type of macroplastic debris. The considerable differences indicated by the Shannon–Wiener index were related to seasonal changes in the number of plastic debris. The observed changes in total plastic item numbers for *α, β*, and y-diversity throughout the four seasons can be attributed to variations in deposition patterns caused by context-specific micro-geographical and environmental factors (Battisti *et al*., 2018). The higher diversity seen during the spring season suggested that there was a higher transition of plastic litter between seasons (Battisti *et al*., 2018).

Similar to this study, research on other river systems has found that plastic bags were the most dominant macroplastic collected (Pe *et al*., 2020). According to Jambeck *et al.* (2015), wind can transport plastic waste from poorly managed landfill sites and residential areas to waterbodies, where it eventually accumulates. However, we believe that, in the primary urban river of our study, the majority of macro-plastics accumulated directly from in-situ human activity, with climatic or hydrodynamic influences being less significant. Pe *et al*. (2020) suggested that most plastic bag comes from community economic activities such as markets, household waste, and recreation activities along the shoreline.

The identification of plastic polymer types is essential since it allows for inferences on the origin of plastic pollutants and further determines whether they originate from the breakdown of macroplastic components from nearby industrial or recreational activities (Veerasingam *et al*., 2016). The plastic polymer type results of this study showed that the most dominant polymers were PP and LPDE. Dalu *et al.* (2019), Maharana *et al.* (2020), and Blettler *et al*. (2017) also showed that the dominant polymer was PP. According to Claessens *et al.* (2011), PP is mostly used in the manufacturing of packaging applications such as bottles, beverage caps, bags, and other home appliances. Most of the PP polymer-type plastic was collected floating in the river during data collection (personal observation). In the current study, LPDE polymer was collected on film plastic-type materials such as plastic bags, soap, and furniture wrappers. Nakashima *et al*. (2012) also observed the high abundance of LPDE in their study. These polymer type macroplastics may later be washed to the nearest shoreline, suggesting that the distribution of polymers is also influenced by the availability of transport for a polymer and the climatic condition from the source area to another area (Erni-Cassola *et al*., 2019). The reason why LPDE plastics dominated was mostly due to their lightweight and buoyance, which makes them less likely to sink and more likely to be transported by water currents, thereby increasing visibility and prevalence in rivers (van Emmerik & Schwarz, 2020).

These plastics tend to dominate in many rivers of the world (e.g. Kurniawan and Imron (2019a, 2019b) in the Wonorejo River, Surabaya, Indonesia; Rowley *et al*. (2020) along the Thames River system, UK; and Parvin *et al*. (2022) in urban lakes and peripheral Rivers of Dhaka, Bangladesh). Furthermore, LDPE are resist-ant to tearing and breaking (i.e. exhibit durability), making them less susceptible to fragmentation in the fast-flowing environment of rivers compared to other plastics (Dilara & Briassoulis, 1998; Fotopoulou & Karapanagioti, 2019). While sunlight degradation breaks down some plastics, LDPE may only experience surface changes, leaving the core structure intact and persistent in the aquatic environment (Doğan, 2021). Lastly, their wide range of applications in a vast array of everyday items, including plastic bags, packaging, squeeze bottles, and agricultural films, can translate to a high probability of accidental or intentional release into aquatic ecosystems (Dilara & Briassoulis, 1998). Thus, understanding the reasons behind LDPE's dominance is crucial for addressing plastic pollution in rivers as it highlights the need for better waste management systems, improved recycling infrastructure for complex plastics, and a shift towards more sustainable packaging materials and consumer choices.

Film was the most dominant macroplastic physical form observed in this study, similar to the study conducted by Rohaningsih *et al.* (2022); this is attributed to the influence of the human activities that occur in the vicinity. On this study I suggest that film macroplastic are influenced by market related activities around Thohoyandou town. These are lightweight plastic forms that are unlikely to be transported long distances in water (Martí *et al*., 2017). Most of the film macroplastics collected in this study were made from the PP polymer. Film plastics are widely used because they are light in weight, slow to degrade, and reusable, while packaging bags are one of the most used plastic films as observed in this study. Film plastics such as black perforated film and white transparent and non-transparent plastic film are widely used in agricultural activities (Yan *et al*., 2016). Film plastics have a negative impact on aquatic environments since they can be ingested by organisms and cause physical and chemical effects (Dris, 2017). I found that the Mvudi River Catchment was dominated by film plastic pollution, which needs to be taken into consideration before those macroplastics are broken down by degradation and continue to pose a threat to aquatic organisms and the people who use water from the catchment.

3.5. Conclusion

The distribution of macroplastic debris based on the functional group, physical form, and polymer group was widespread and similar across sites and seasons, indicating that pollution intensity is consistent spatially in the study system and broad-scale management is needed. Macroplastics found in the Mvudi River are associated with human activities such as settlement, recreation, and dumping as well as economic activities such as markets. We suspect that the meteorological and hydrological factors played a major role in macroplastic accumulation due to the macroplastic debris that we collected floating in the Mvudi River, but these require further assessment. The diversity of macroplastic functional groups was significantly different between seasons and sites, with high diversity in winter and pollution levels elevated on the shoreline compared to mainstreams. Understanding seasonal variations in plastic loads and their drivers provides information on the sources and destiny of plastic, which can improve management methods for reducing this risk to the aquatic ecosystem.

CHAPTER FOUR: PRO–ENVIRONMENTAL BEHAVIOUR AND HUMAN PERCEPTIONS TOWARDS PLASTIC MANAGEMENT BY RURAL COMMUNITIES WITHIN A UNESCO SUBTROPICAL BIOSPHERE RESERVE

This chapter is currently under review:* *Mashamba R, *Dalu MTB, Cuthbert RN, Dondofema F and Dalu T. Pro–environmental behaviour and human perceptions towards plastic pollution by rural communities within a UNESCO subtropical biosphere reserve. Journal of Environmental Studies and Sciences.* ***Revision submitted***

4.1 Introduction

Plastic has been widely used to support the development of society throughout the 20th and 21st centuries (Geyer *et al.,* 2017; Cao *et al*., 2022). Plastic has become the most used packaging material because of its light weight, durability, and resistance to degradation (GESAMP, 2015). Since the 1950s, human demands have caused plastic production to increase, reaching about 359 million metric tons in 2018 worldwide (Plastics Europe, 2019). According to the year 2017 data, South Africa produced 2 742 970 tons of plastic products and around 1 350 000 tons of primary plastic (Olatayo *et al*., 2021). Approximately 79 % of plastic materials have ended up in landfills or the natural environment due to deliberate and unintentional human activities intentional (Geyer et al., 2017; Cao *et al*., 2022; Yardy *et al*., 2022).

These plastics persist in all environment types, breaking down into smaller plastic particles that could potentially pose risks to animals and humans (Cuthbert *et al*., 2019; Dalu *et al*., 2020; Yardy *et al*., 2022). Sizeable plastic debris can also block waterways, creating breeding sites for disease vectors and pests and releasing toxic chemicals that disrupt food webs (Dris, 2017). Thus, environmental plastic pollution is a global issue that warrants management and is a threat to environmental health (Dauvergne, 2018). The increase in plastic waste puts pressure on waste management activities, especially in developing countries, with several countries implementing policies such as banning plastic bags as a strategy aimed at reducing plastic waste, and also as a way of raising awareness (Xanthos and Walker, 2017; O'Brien and Thondhlana, 2019).

Environmentally responsible behaviours, environmentally appropriate behaviours, environmentally conscious behaviours, and pro–environmental behaviours (PEB) are some of the terms that researchers frequently use to describe actions that protect the environment (Lee *et al*., 2013). Pro–environmental behaviour has emerged as one of the strategies that can be used to solve the growing environmental issues in line with achieving sustainable development goals (O'Brien and Thondhlana, 2019; Dalu *et al*., 2020). The quality and health of the environment depend on human behaviour patterns towards the natural environment (Steg and Vlek, 2009). Schwart's norm activation theory (in the 1960s) argued that PEB comprises three variables: awareness of consequences, the ascription of responsibility, and personal norms (Sawitri *et al*., 2015). According to the norm activation theory, individual personal norms determine whether they would take action to stop adverse outcomes if they were aware of potential negative effects and assigned personal responsibility (Harland *et al*., 2007). This model, a theory of intervention behaviours, is only applicable when circumstances exist that an individual believes will have negative consequences for other people or other people and themselves (Sawitri *et al*., 2015). The norm activation model is useful in predicting PEB recycling and raising awareness towards plastic pollution (Oom *et al*., 2005; De Groot *et al*., 2013; Kautish *et al*., 2021). Perceived behaviour control is another theory that influences pro–environmental behaviours, it is described as a degree to which people believe they can accomplish a specific behaviour. It is one of the aspects that impact persons' intention and actions, along with attitude and subjective norms.

Perceived control is also linked to emotional well–being, stress coping, performance, and behavioural change (Xiao and Wong, 2020). Therefore, the key components for changing human behaviour towards the environment are environmental knowledge and attitudes (Dalu *et al*., 2020; Kautish *et al*., 2021), and, thus the current study aimed to assess and understand the pro–environmental behaviour, which is characterised as human behaviour that aimed at minimising the environmental impacts of one's action on the environment through raising awareness, education, and plastic reduction (Steg and Vlek, 2009) among local rural communities within the Vhembe Biosphere Reserve in South Africa. We aimed to understand whether the local community's connectedness to nature mediates their environmental concern impact and perceived consumer effectiveness on plastic consumption choice behaviour. Specifically, we hypothesized that the residents within the Vhembe Biosphere Reserve are not much aware of plastic pollution and its impacts due to it being rural and there won't be any waste recyclers present, and these areas will be associated with poor service leading to illegal plastic disposal and burning.

4.2 Methods

4.2.1 Ethical consideration

Human ethics was applied at the University of Mpumalanga. The respondents were told that they were allowed to withdraw at any time during the questionnaire when they no longer wanted to take part. Anonymity was ensured among the respondents, and everyone was treated with respect and confidentiality. The ethical clearance number is UMP/Dalu/1/2022.

4.2.2 Study area

The Vhembe Biosphere Reserve (VBR) was designated a biosphere reserve in 2009 and is in the northern part of the Limpopo Province, South Africa (Figure 4.1). It covers an area of ~30 457 km² and is one of the largest biosphere reserves in South Africa (UNESCO, 2021). The VBR supports a human population of more than 1.5 million, with 96 % of the population living in rural areas (VBR, 2021). The land tenure system within the VBR is distributed among state-owned land, local rural communities, and private ownership (Evans, 2017). Thus, the biosphere reserve aims to offer protection to 44 amphibians, 250 butterfly, 542 birds, 140 reptiles, and 152 mammal species, and sustainable development of the region (Evans, 2017), and sustainable development of the region (Evans, 2017). The study area was located at an altitude of 600–1000 m above sea level, with the two villages falling in the subtropical summer rainfall region. The study area receives a mean annual rainfall and maximum temperatures of 550 mm and 30–40 °C (September to March), respectively. The winters (i.e., May to August) are generally dry and cool, with most of the rains falling between December and March.

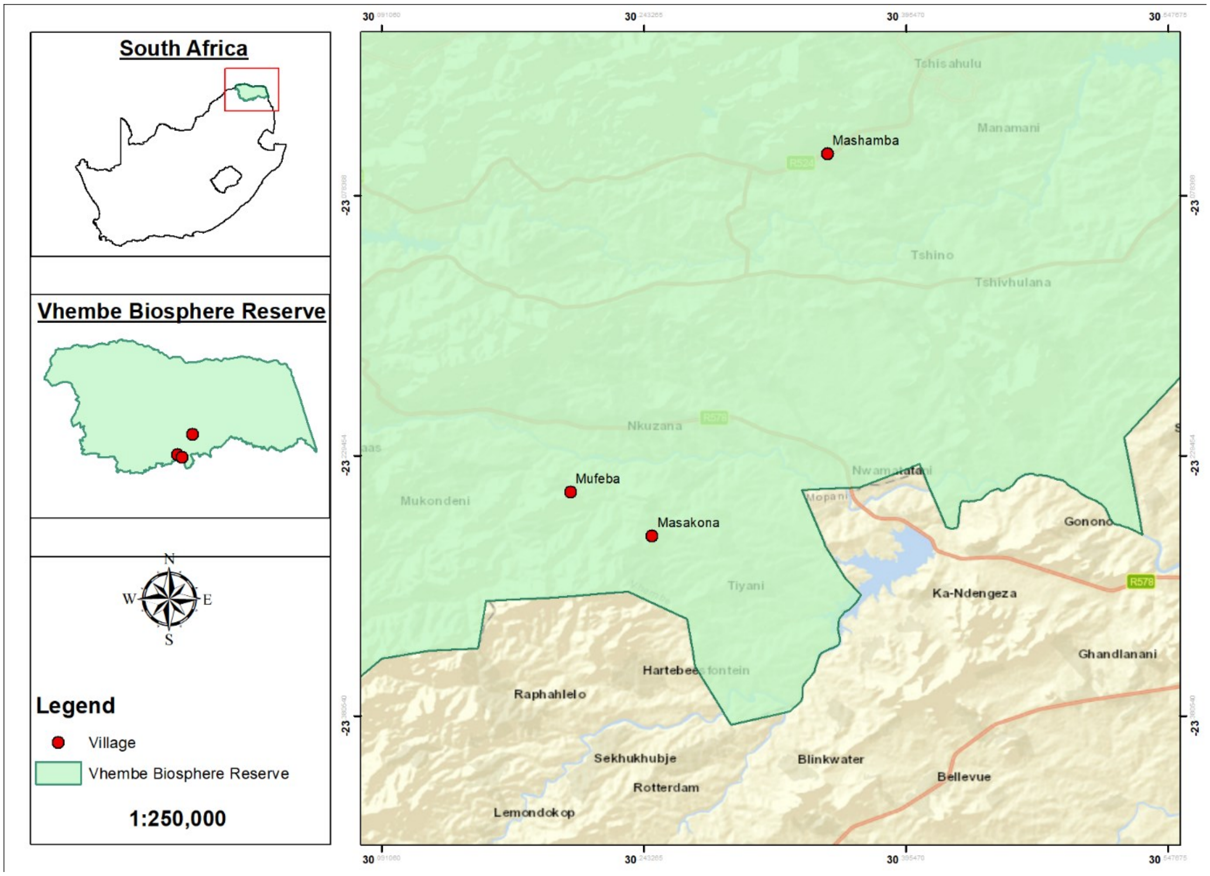

Figure 4.1. Vhembe Biosphere Reserve (VBR) map showing different villages where respondents were interviewed, Limpopo, South Africa.

Mufeba village has an area of 1.1 km², with a population of 833 (783.8 per km²) from 228 households, Mashamba village has a larger population of 6 348 (907.1 per km^2) distributed across 1 681 households (240.2 per km^2) and lastly, Masakona village had an area of 73.4 km², with a population of 7 033 (95.8 per km²) among 1 541 households. The key land uses are subsistence agriculture, human settlement, wood harvesting, and livestock farming within the villages (Sinthumule and Mashau, 2019). More than 66 % of households depend on natural resources for fuel, wood, and food in the reserve (Dalu *et al*., 2021). Natural resources are negatively impacted by population increase and dependence on the environment for energy and livelihood; changing climate is expected to worsen these pressures (Gumbo *et al*., 2022). The two main socio–economic sectors that support livelihoods in the reserve are agriculture and tourism (Gumbo *et al*., 2022).

4.2.3 Data collection

A questionnaire was used as method of data collection in the study. Semi–quantitative data were collected through the administration of 120 questionnaires between August and October 2022 in the Vhembe Biosphere Reserve, targeting local rural communities to assess individuals' perceptions about plastic pollution and, its impacts, as well as awareness towards plastic pollution reduction. Only one member of each family was asked to participate. Participant families were selected at random, and as a result, the bias in the study's participant selection was reduced. The study was conducted in Mufeba (n = 59), Mashamba (n = 25), and Masakona (n = 36), with the villages being randomly selected (Figure 4.1). Sections included in the questionnaire were perceptions about plastic use and its impacts, plastic use and management at the individual/household level, awareness and use of alternatives, and suggested solutions.

The questionnaire was the appropriate method to use as the information required for the sections/themes was brief and straightforward. The questionnaire made it possible for respondents to understand questions quickly, which made it possible to acquire the necessary standardised data. The questionnaire instructions were provided to the respondents, along with the purpose and study description. All respondents were granted a confidentiality agreement to ensure the anonymity of their responses. The respondents had access to the researcher's help with inquiries or misunderstandings. Although the survey was in English, some explanations were explained in the native language (i.e., TshiVenda, Tsonga) to enhance respondents' understanding. Survey questions were written as succinctly as possible to prevent respondents from losing interest and make them simple to understand.

4.2.4 Data analysis

Statistical Package for the Social Science (SPSS) version 25 and Microsoft Excel 2016 were used to capture and analyse the questionnaire survey data. Qualitative responses (i.e., in instances where individual respondents gave their opinion on a specific plastic topic) were summarised and recorded before the nominal answers were categorised and assigned numerical scores before any statistical analysis. All study data were tested for normality and homogeneity of variances. Since the data were found not to be normal, a non–parametric Spearman correlation was used to explore the relationships between sociodemographic variables (i.e., gender, age, education) and environmental consciousness behaviour (i.e., plastic preference, reuse, separate waste, waste disposal methods, knowledge) towards various socio–environmental explanatory variables (see Table 4.1) to plastic pollution.

4.3. Results

4.3.1. *Basic respondent information*

Regarding gender, most respondents were females (*n* = 69, 57.5 %) compared to males (*n* = 51, 42.5 %). The 20–29–year–old age group was the most dominant group of respondents (n = 62, 51.7 %), followed by the < 20 year–old (*n* = 34, 28.3 %), 30–39year–old (*n* = 16, 13.3 %), and 40 year–old (*n* = 8, 6.7 %) group (Table 4.1). About 50 % of the respondents were still studying at high school, college, and university, while respondents working for the government accounted for

13.3 % and those not working were 11.6 %. Other respondents indicated working in the private sector (10.0 %) and as domestic workers, (5.0 %) (Table 4.1).

Table 4.1. Sociodemographic variables information of participants

Variables	Number	Percentage (%)
Gender		
Female	69	57.5
Male	51	42.5
Age group		
>18–20	34	28.3
20-29	62	51.7
30-39	16	13.3
>40	8	6.7
Education level		
Secondary schooling (8-10)	29	24.2
Senior secondary (11-12)	29	24.2
Certificate and diploma	32	26.6
Bachelor's and/or Msc	30	25
Occupation		
Government employee	16	13.3
Service	4	3.3
Business owner	8	6.7
Domestic worker	6	5
Private sector employee	12	10
Student	60	50
Unemployed	14	11.6

4.3.2. *Perception of plastic use and its impacts*

Most respondents (n = 53; 44.2 %) indicated that they prefer using plastics because they are cheap compared to other packing materials. In comparison, other respondents (n = 34; 28.3 %) preferred using plastic products due to the price, weight, durability, availability, and lack of alternatives. The use of plastic products because of lack of alternative materials had the least respondents (n = 4; 3.3. %) (Figure 4.2). For respondents' perception about plastic recycling, approximately 90 % indicated "yes" that they recycle plastic, 2.0 % indicated "no", and 8.0 % indicated that they had "no idea/not sure" about plastic recycling.

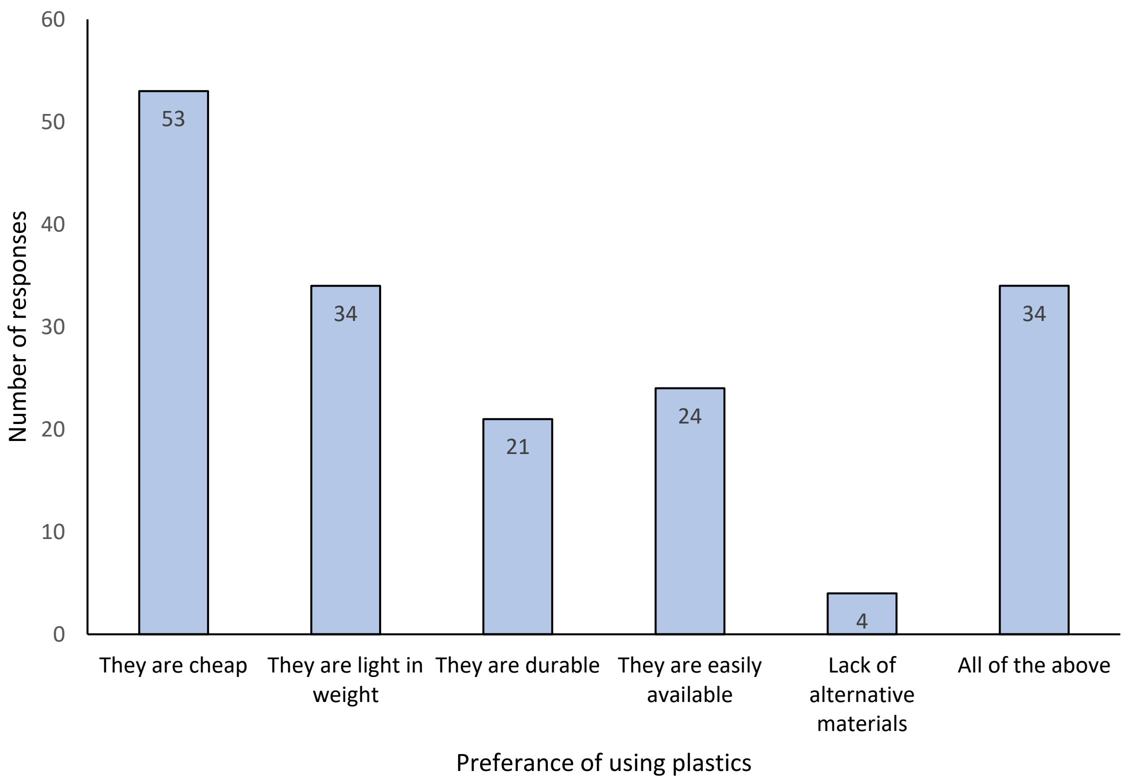

Figure 4. 2. Respondents' reasons as to why they prefer using plastics within their households or on an everyday basis based on mutually exclusive responses.

Regarding whether plastic waste is a problem for human health and the natural environment, about 80 % of the respondents indicated "yes", 12 % "no", and 8 % were unsure. Almost half of the respondents (n = 66; 55.0 %) indicated that there were aware of all the plastic problems (Figure 3). The problem which had fewest responses was "clogs drains, thus causing water logging in the city", with only 6 (5.0 %) responses (Figure 4.3). Most respondents indicated that the biosphere reserve was less polluted and better managed than the villages where they stayed (Figure 4.4).

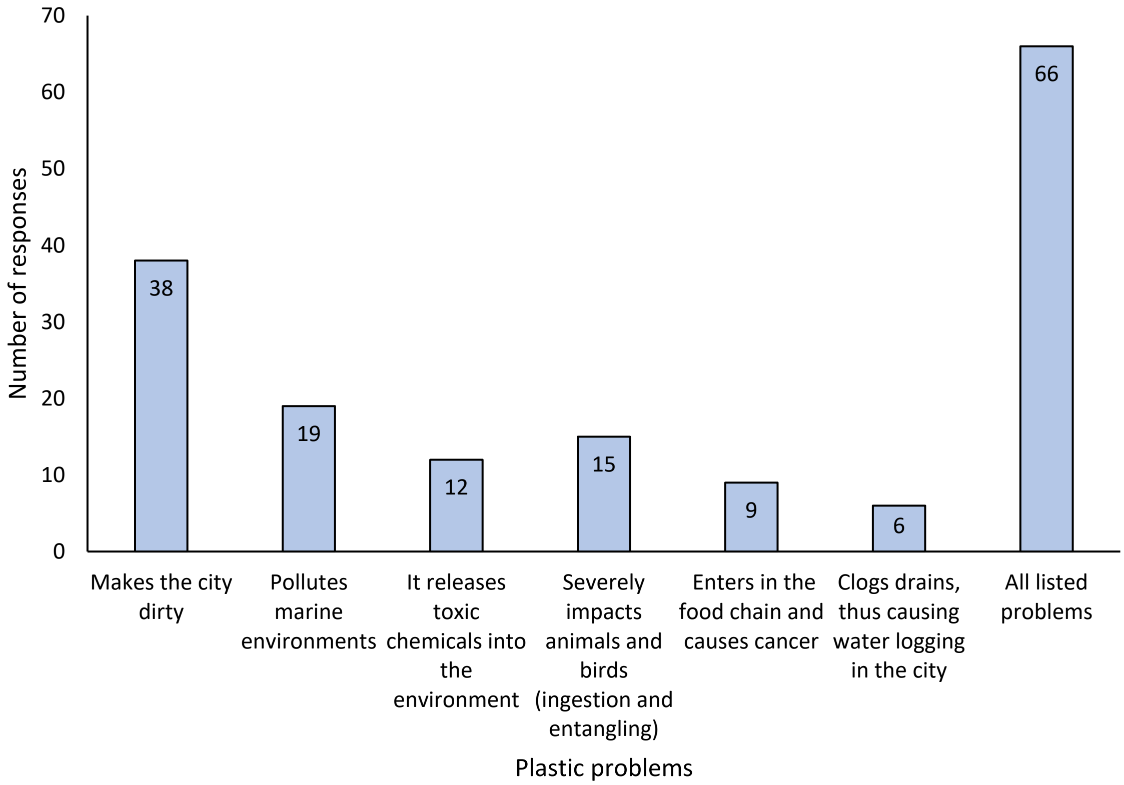

Figure 4.3. Number of responses concerning problems caused by plastics within the natural environment by respondents.

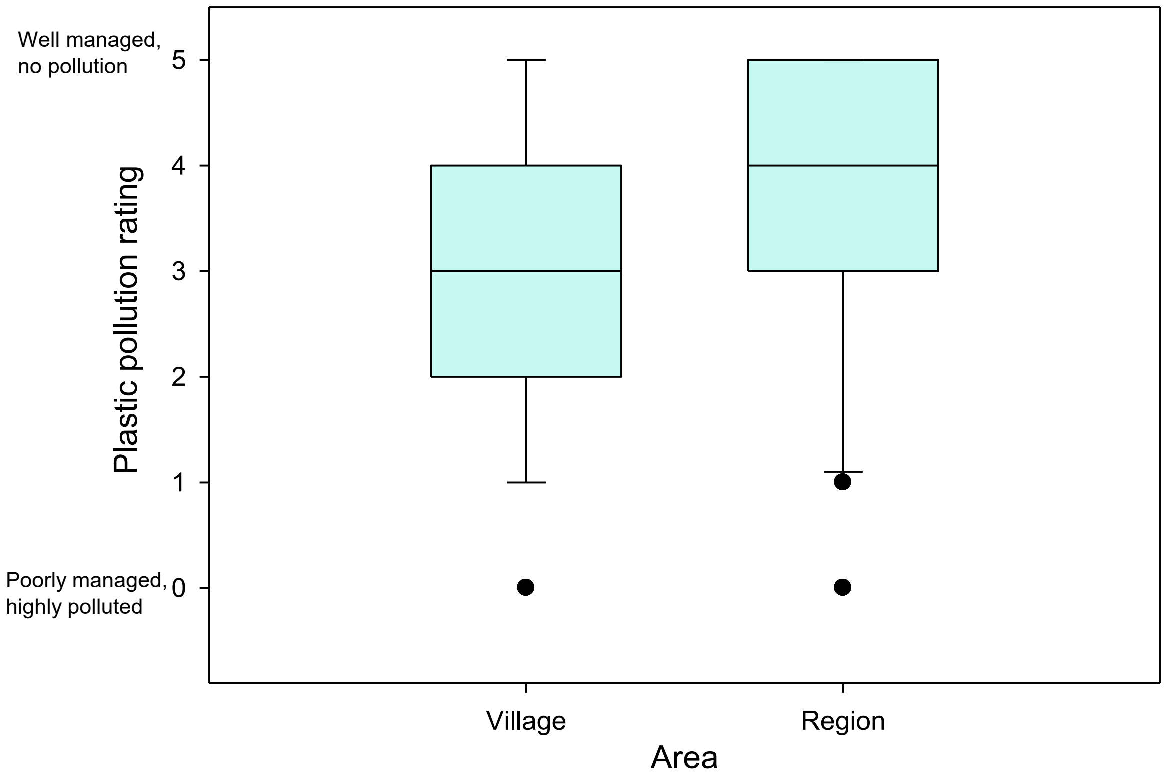

Figure 4.4. Boxplot showing the rating of plastic pollution within the village and region (i.e., Vhembe Biosphere Reserve) where the respondents are staying

4.3.3. *Plastic use and management at the individual/household level*

Plastic bags were the most used plastic products, as indicated by respondents (*n* = 65; 54.2 %), whereas 23.3 % (*n* = 28) of the respondents stated that they used a variety of plastic products (Figure 4.5). The least preferred plastic products were the disposable ones (*n* = 7; 5.8 %). If given a choice between paper and plastic bags, most respondents (53.0 %) indicated that they would prefer plastic bags, followed by 15.8 %, 11.7 %, and 19.2 % who indicated they would choose paper bags, cloth bags, and mixed/combination (i.e., plastic, cloth, paper), respectively. For the mixed/combination, most respondents (n = 17; 73.9 %) preferred plastic and paper bags, while the rest preferred plastic and cloth bags.

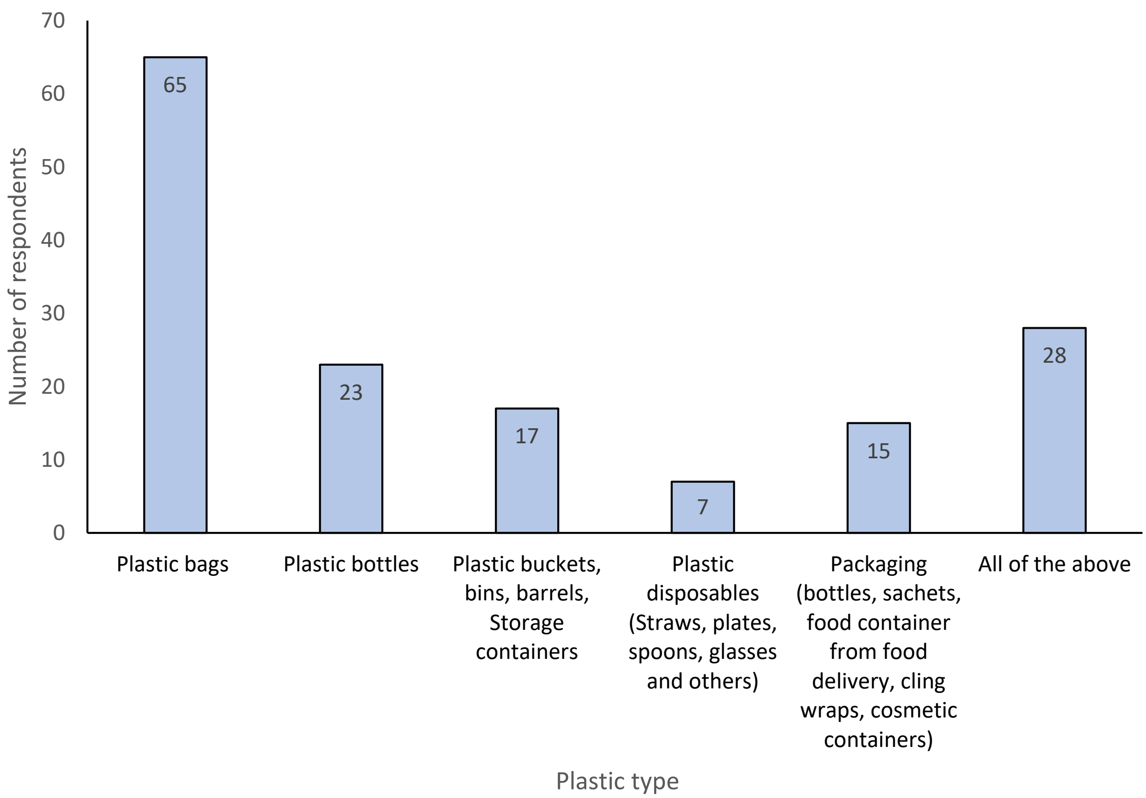

Figure 4. 5. The different types of plastic products used by respondents within the Vhembe Biosphere Reserve region.

About 38.0 % of respondents indicated that they carry their bags for shopping, 27.0 % did not carry any bags, and 35.0 % of respondents sometimes carried their bags to the shops, those who did not carry bags to the shops, about 94.0 % of respondents indicated that they usually forget. In comparison, 3.0 % indicated that they are not concerned with the type of bag they use for shopping, and the remaining 3.0 % indicated that they get plastic bags for free. When the respondents were asked if they bought plastic bags when offered by the shopkeeper, 68.0 % indicated that they always accepted. In comparison, 18.0 % refused if they had an alternate bag, and 14.0 % always refused plastic bags and then asked for paper/cloth bags.

Many respondents (50.0 %) indicated that their households generated less than 10 disposable plastic items per month. In comparison, 44.0 % of respondents indicated that their household generated less than 50 disposable plastic items, and the remaining 6.0 % indicated that their household generated more than 75 disposable plastic items per month. About 68.0 % of respondents indicated that they re–use plastic materials, 18.0 %, 10.0 %, and 5.0 % indicated that they do not re–use plastic, reuse plastic but not often, and rarely reuse, respectively. Based on the respondents who indicated that they re–use plastics, 51.0 % indicated that they reused 1–2 times the plastic material, while 36.0 % of respondents indicated that they re–use 2–5 times, with 13.0 % of the respondents indicating that they re–use the plastic materials until it is broken. For those who highlighted that they do not reuse plastic materials, about 55.0 %, 32.0 %, 9.0 % and 5.0 % of respondents indicated that they are not aware they can re–use, were not bothered, did not indicate a reason why they do not reuse, and disposing easy and better than reuse, respectively.

Respondents indicated that they reuse plastic bags for several reasons (Figure 4.6), with 49.2 % indicating that they re–use plastic bags for shopping. Regarding waste disposal, most respondents (54.2 %) highlighted that they did not separate biodegradable and non–biodegradable waste. About 14.2 % of the respondents indicated that they are aware of the need to separate waste, but they did not practice it.

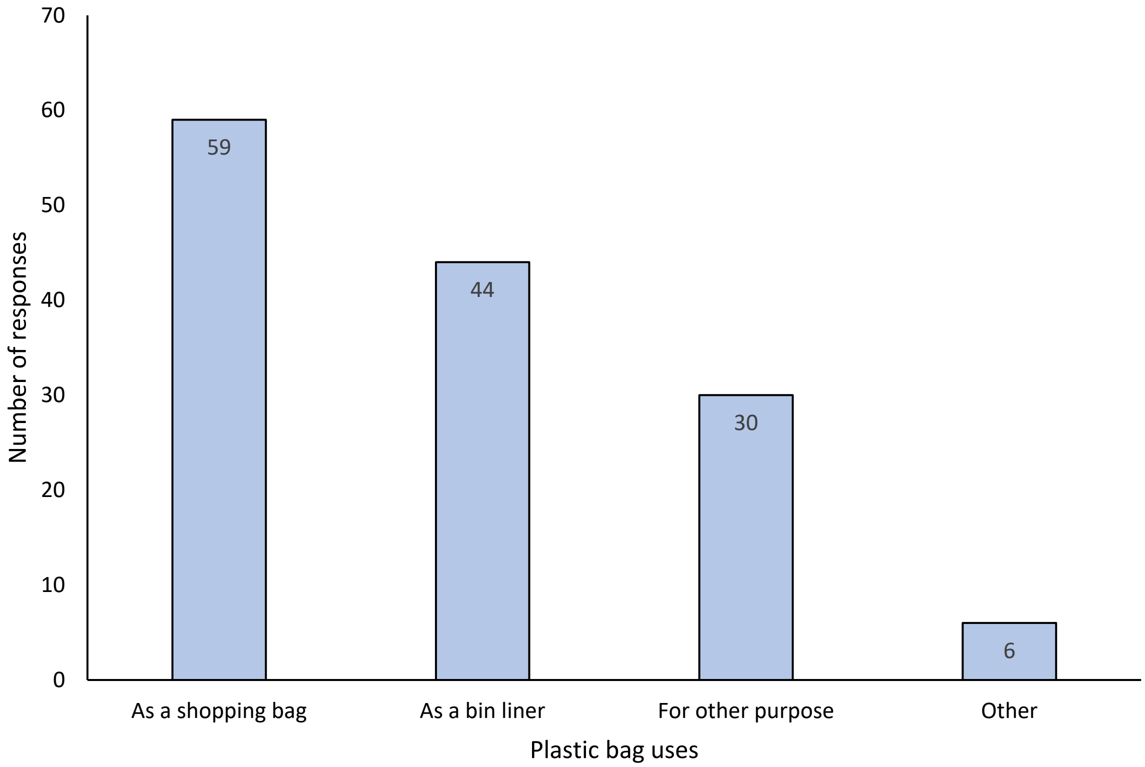

Figure 4.6. Respondents' reasons for re–plastic bags within their household in the Vhembe Biosphere Reserve villages

Regarding plastic waste disposal, 41.0 % of respondents indicated that they dispose of it through illegal open dumping. In comparison, 23.0 % was burnt, 18.0 % was handed over to waste collectors, and 23.0 % was mixed with other garbage collected by municipal garbage trucks. Approximately 40.0 % of respondents indicated no waste recyclers or waste for recycling collection where they lived, with 19.0 % and 16.0 % highlighting that waste recyclers came to collect recyclables and others said sometimes, respectively. Approximately 38.0 % of respondents were unsure about the approximate amounts of waste generated, and 35 % indicated that they were unsure of the approximate amounts of waste generated.

4.3.4. *Plastic awareness and use of alternatives*

Most respondents (52.5 %) had no knowledge of any government or non–governmental organisation awareness campaigns regarding reducing plastic waste, with 24.2 % being not sure of any such activities. The most common organisations raising awareness were the Universal Greening Organisation, Makhado Municipality, Tshikovha Greening Organisation, and Dziphathutshedzo Green Surfacing.

About 39.0 % of respondents indicated that they were aware of plastics and their associated impacts, with 30.0 % having no clue about plastic impacts. Respondents indicated that electronic media (i.e., television, radio) and social media (i.e., WhatsApp, Instagram, Facebook, YouTube) are the significant sources of information on plastic pollution, followed by print media (i.e., newspapers, magazines) (Figure 4.7a). Paper and cloth bags were one of the main alternatives to plastic bags used by respondents (Figure 4.7b). Edible cutlery made of organic products such as millet and other grains and metal (i.e., steel, copper, brass) cutlery were the least favoured by the respondents (Figure 4.7b). Most respondents (53.3 %) indicated that they were not aware of those alternatives, 31.7 % indicated that they were costly compared to plastic and 15.0 % respondents indicated that they were costly compared to plastic, indicated that those alternatives were not readily available compared to plastics.

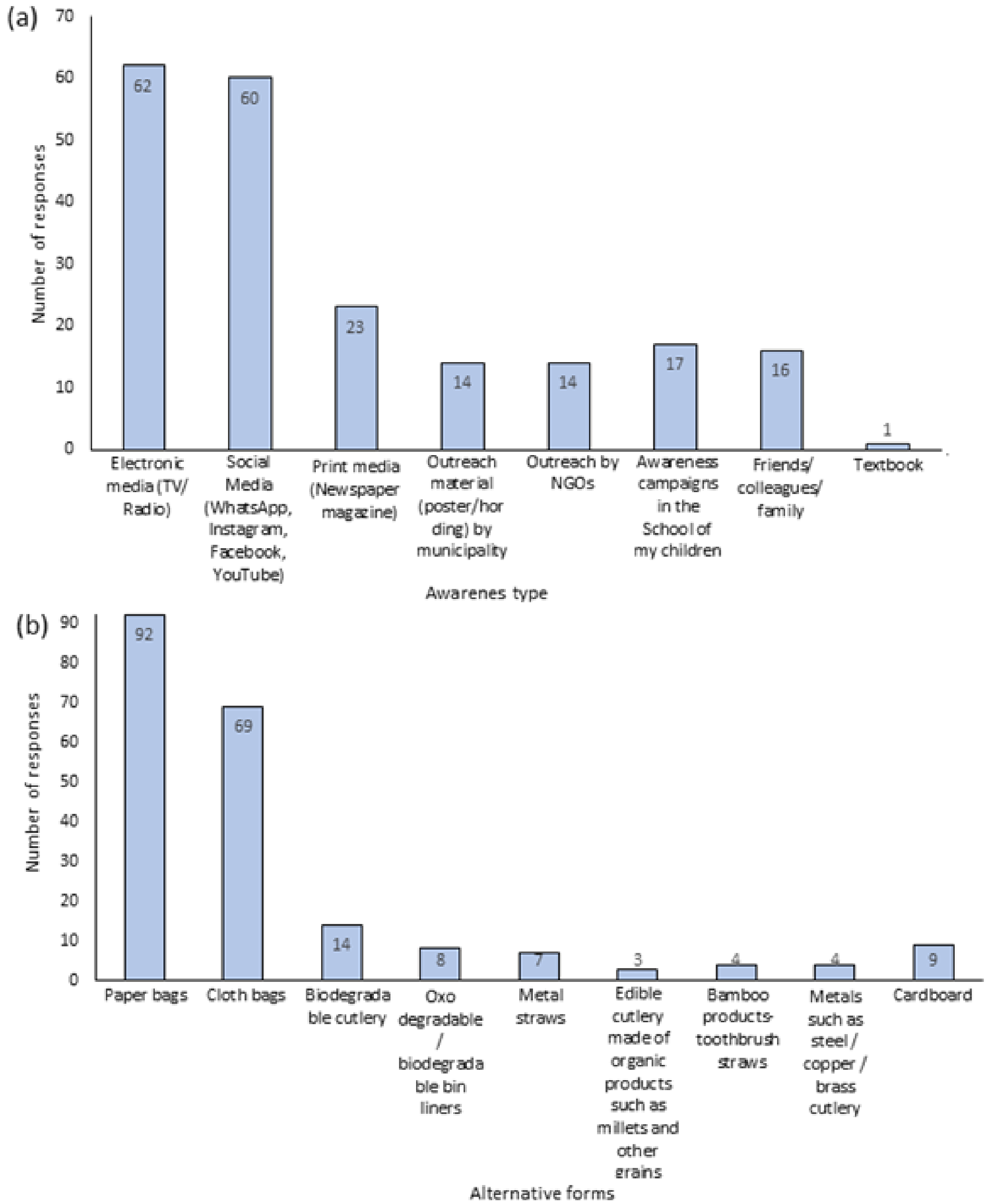

Figure 4.7. The (a) plastic pollution source of information and (b) alternate plastic types of responses from respondents within the Vhembe Biosphere Reserve

4.3.5. Suggested solution to reduce plastic use

Respondents were given pre–answers to choose from regarding whether increasing plastic bags prices is a good idea for reducing plastic use. Making users pay is one solution that can help reduce plastic bags. About 83.3 % of the respondents indicated that charging for plastic bags will reduce their use, whilst 10.8 % and 5.8 % indicated that it would not change behaviour, and others were not sure, respectively. Government regulations (response rate 59 %) were suggested to be one of the most effective ways of managing the region's plastic pollution. In comparison, individual actions, and efforts (response rate 20 %) and non–governmental organisation campaigns (21 %) were found to be the most preferred by the respondents in managing plastic pollution. Many respondents also suggested burning and recycling as the most favourable outcomes.

4.3.6. Relationship between environmental consciousness behaviour, population profiles and plastics

The results of the Spearman correlation assessing the relationship between respondents' population profiles and environmental consciousness behaviour and some selected explanatory variables are presented in Table 4.2, with most variables showing significant relationships. For example, a significantly ($p < 0.05$) positive relationship was observed for gender and separating plastic waste ($r = 0.19$) and the amount of plastic waste generated ($r = 0.21$). Age and education had several significant ($p < 0.05$) positive relationships with some of the explanatory variables, with education and plastic re–use times being negatively correlated ($r = –0.25$). For the environmental consciousness behaviour, most variables showed positive significant relationships (Table 4.2), with plastic reuse *vs* plastic re–use purpose ($r = –0.40$), separate waste *vs* plastic pollution waste – region ($r = –0.21$), plastic waste disposal *vs* plastic knowledge ($r = –0.20$), plastic waste disposal *vs* plastic waste recycling (r = –0.20) and plastic waste disposal *vs* awareness campaigns (r = –0.24) being weakly significantly ($p < 0.05$) correlated.

Table 4. 2. Relationship between sociodemographic variables and environmental consciousness behaviour towards various socio–environmental variables to plastic pollution. Significance levels: * $p < 0.05$, ** $p < 0.01$

	Sociodemographic variables			**Environmental consciousness behaviour**				
	Gender	**Age**	**Education**	**Plastic preference**	**Plastic re–use**	**Separate waste**	**Plastic waste disposal**	**Plastic knowledge**
Plastic preference	0.09	**0.26****	**0.36****					
Plastic re–use	0.03	0.05	0.01	–0.11				
Separate plastic waste	**0.19***	**0.30****	**0.39****	0.13	–0.07			
Plastic waste disposal	0.01	**0.18***	**0.19***	–0.04	–0.05	–0.11		
Plastic knowledge	–0.04	0.06	–0.06	0.07	–0.02	**0.27****	**–0.20***	
Plastic recycling	–0.05	**0.18***	0.01	0.17	**0.20***	–0.05	0.01	0.04
Plastic problem	–0.04	0.06	–0.16	0.02	**0.23***	–0.17	–0.03	–0.02
Charging for plastic bags	0.00	0.08	–0.14	–0.03	**0.24****	–0.10	0.01	–0.02
Plastic pollution rate – village	–0.13	–0.08	–0.11	–0.04	–0.03	–0.12	0.11	–0.06
Plastic pollution rate – region	0.13	–0.07	–0.13	–0.05	–0.01	**–0.21***	**0.21***	–0.13
Plastic bag type	0.10	**0.29****	0.14	**0.32****	0.16	–0.01	0.11	–0.04
Plastic bag carrying	0.00	–0.09	0.00	–0.01	0.16	0.09	–0.12	0.09
Willingness to accept plastic bag in shop	–0.01	–0.06	0.08	0.15	0.06	–0.09	–0.05	–0.05
Plastic waste generation quantity	0.06	0.04	0.14	–0.13	**0.21***	0.02	**0.21***	–0.09
Plastic re–use times	–0.09	–0.17	**–0.25****	–0.12	**0.30****	–0.18	–0.06	0.05
Plastic re–use purpose	0.01	**0.18***	0.14	**0.25****	**–0.40****	0.14	0.09	0.13
Plastic waste recycling	–0.04	–0.04	0.12	0.07	–0.03	**0.23***	**–0.20***	**0.29****
Plastic awareness campaigns	–0.03	–0.01	–0.01	0.03	0.00	0.09	**–0.24****	0.07

Plastic waste quantity generated	**0.21***	**0.18***	**0.19***	0.15	–0.05	**0.30****	–0.01	0.14
Best way to reduce plastic waste	0.05	0.01	**0.26****	0.03	0.16	0.09	0.06	0.06

4.4. Discussion

The main aim of this study was to assess the pro–environmental behaviour and human perceptions towards plastic pollution within selected villages of the Vhembe Biosphere Reserve, South Africa. Most of the respondents were females (57.5 %) rather than males (42.5 %), similar to Widayat *et al*. (2021), who had a similar gender balance, with more females (59.4 %) compared to males (40.6 %). Gender differences are an aspect that needs to be considered when assessing human behaviours and perceptions of plastic within the natural environment, with females more likely to accept the use of other alternative plastic forms than men (Madigele *et al*., 2017). However, I observed no significant relationship between plastic-type and gender, suggesting that gender was not significant in plastic type use within our study area. Furthermore, gender and the amount of plastic waste showed (r = 0.21) and the number of waste separations (r = 0.19) showed a positive significant relationship. I suggest that behaviours related to the management of plastic waste may be influenced by gender, with women possibly producing less plastic debris and separating it more frequently than men. This can be due to variations in cultural norms, individual beliefs about environmental stewardship, or variances in society duties and responsibility. Another aspect which needs to be taken into consideration in age difference and education, this study indicated that 50 % of respondents are young people who are still undertaking their studies. The results from socio-demographic variables and environmental consciousness behaviour showed several significant positive relationships with some explanatory variables, education was negatively correlated with plastic re-use times (r = -0.25). This implies that individuals with higher levels of education tend to re-use plastic items less frequently. Possible explanations could involve increased awareness of environmental issues among individuals with higher education, leading them to prioritize reducing plastic use rather than re-using plastic items.

According to Hartley *et al.* (2018) younger people are playing a vital role in sustainability and environmental problems, coming with solutions through the transmission of their knowledge, and promotion of sustainable behaviours compared to elders (Hartley *et al*., 2018). Most of the respondents from this study indicated that they are aware that plastic waste is an environmental and human health problem. Some of the problems indicated by respondents are that plastics make the area dirty, pollute the natural environment, and severely impact animals and birds. Respondents from the study conducted by Widayat *et al.* (2021) indicated that plastic damages aquatic ecosystems and impacts human organs such as the lungs, heart and skin.

Attitudes and norms have been identified as a critical driver of pro–environmental behaviour towards plastic pollution (e.g., O'Brien and Thondhlana, 2019; Dalu *et al*., 2020) and similar patterns were observed in the current study, where an individual's attitude towards the environment and the impact of plastic pollution significantly influenced their behaviour. Thus, it is important to nurture a positive attitude towards the environment and the importance of reducing plastic waste, which can lead or encourage individuals to engage in pro–environmental behaviour towards plastic pollution. According to Sawitri *et al*. (2015), the norm activation theory has argued that pro–environmental behaviour comprises three variables: awareness of consequences, the ascription of responsibility, and personal norms. One's consciousness of things such as plastics within the natural environment is indicated/raised by awareness (Savari *et al*., 2020). For example, in the context of pro– environment, an individual's awareness is needed to preserve the environment from plastic pollution and keeping the world free of pollution would affect that individual's attitude and behaviour. Personal norms form part of social norms, which have been internalised and now independently affect people's thoughts, and the general social conduct as individual and group norms influence it. Social norms can also shape pro–environmental behaviour towards plastic pollution and are referred to as the expectations and rules within a group or community (Hechter and Opp, 2001). When individuals perceive that pro–environmental behaviour is the social norm, they are thus likelier to engage in such behaviour. Our study observed that pro–environmental behaviour towards plastic pollution was not widely accepted and encouraged within a community. Individuals were less likely to adopt these social norm behaviours, although other village members raised awareness and shifted their behaviour towards being more pro-environmental.

In addition to attitudes and social norms, are other factors that can influence pro–environmental behaviour towards plastic pollution include access to recycling facilities, government policies, and education. Most of respondents from this study indicated that they did not have access to recycling facilities and believed that government policies can reduce plastic pollution but were not being followed. Access to recycling facilities can make it easier for individuals to dispose of plastic waste appropriately. In contrast, government policies such as plastic bag bans can encourage individuals to reduce their plastic consumption and find alternatives. Plastic bags are preferred as indicated by the respondents, whereby the largest shares of the respondents carried their bags for shopping, while those who do not carry their own bags indicated that they usually forget and accept paper bag always. Similarly, in a Malaysian study, about 60.0 % of the respondents indicated that they regularly forgot to carry their own bags for shopping (Zen *et al*., 2013). However, in the current study we found that more people were not favourable to using plastic bags compared to alternatives such as paper or cloth bags. Plastic products were preferred as they are cheap and Braun and Traore (2015) highlighted that convenience is another reason for plastic usage. Otsyina *et al*. (2018) further highlighted that people use plastic as it is easily available and very cheap compared to other bags. The individual's habit also becomes important when talking about plastic usage, with Romero *et al*. (2018) finding that using plastic in individuals' homes was just habitual.

The results from age groups indicate that there were many respondents between the age of 20–29, with 51.7 %, while Widayat *et al*. (2021) highlighted that the dominant age of respondents was between the age of 21 and 30 years (54.4 %). According to Widayat *et al*. (2021), the occupation of respondents is important as it tends to show the respondents social environment outside their home. Education can also play a significant role in promoting pro–environmental behaviour by increasing awareness of the impact of plastic pollution and how to reduce it, whereby over 50 % of respondents who participated in this study are still studying; hence, they had a better understanding of the impacts of plastic pollution and strategies that can help to reduce plastic pollution. The study found that >50.0 % of respondents are still students at school, universities, and/or college, similar to the study by Widayat *et al*. (2021) which indicated that 40 % of the respondents were still students. Young and more educated individuals possess more knowledge and are reliable sources of plastic pollution information than uneducated older individuals (Soares *et al*., 2021). Madigele *et al*. (2017) highlighted that more educated individuals demonstrated higher levels of plastic avoidance than less educated individuals because they were less inclined to pay for plastic bags, and more likely to join in a no plastic bag campaign.

Respondents from this study believed that charging for plastic will reduce plastic use, with charging for plastic being one of the most widespread policy instruments to reduce plastic usage. Several studies (e.g., Poortinga *et al*., 2013; Thomas *et al*., 2016; O'Brien and Thondhlana, 2019) examined the effectiveness of charging for plastic in changing consumer behaviour and acceptance and found that plastic bag usage actually decreased by about 40.0 % to 90.0 % depending on the area after implementing charging.

Most respondents are unaware of plastic waste separation from normal waste to send for re-cycling; hence they do not put it into practice. Arulnayagam (2020) found that public perception towards plastic pollution indicated that they were no data on whether individuals separated their garbage before collection. If the waste collection unit does separate the plastic waste, this will significantly reduce the pollution burden on the natural environment. According to Otsyina *et al*. (2018), open dumping and/or burning is reported to be a method of plastic disposal common in most developing regions, with respondents in the current study indicating that the most preferred method of plastic disposal is burning and open dumping. This behaviour is influenced by a lack of infrastructure, education, and unavailability of awareness campaigns to encourage behavioural changes (Otsyina *et al*., 2018). However, although the respondents indicated that electronic and social media are playing a vital role in spreading information about plastic pollution's impacts, this was being affected by the non-collection of waste due to a lack of infrastructure i.e., garbage trucks. However, the Wahid *et al*. (2020) study indicated that most of the respondents got most of their information about plastic pollution from formal classes at schools, colleges and/or universities.

It is critical to consider the study’s limitations. First, any research that relies on voluntary participants is subject to selection bias. The sample strategy may have resulted in increased engagement from those who are already more knowledgeable and aware of plastic pollution than non–participants. As perception research relies on self–report measures, it is possible that participants’ responses about the perceived impacts of plastic pollution, the frequency of pro–environmental behaviours, and their intentions to increase such behaviours were overstated due to a social desirability bias. Furthermore, due to sample characteristics, attention should be exercised when generalising the current study’s findings. Indeed, a sizable majority of the respondents were female, well educated, and of the young generation, which has previously been recognised as having a high pro–environmental views and practises in general (Soare *et al*., 2021). This study only focused on three villages, which might not give desired funding which can be used globally.

It is critical to consider the study’s limitations. First, any research that relies on voluntary participants is subject to selection bias. The sample strategy may have resulted in increased engagement from those who are already more knowledgeable and aware of plastic pollution than non–participants. As perception research relies on self–report measures, it is possible that participants’ responses about the perceived impacts of plastic pollution, the frequency of pro–environmental behaviours, and their intentions to increase such behaviours were overstated due to a social desirability bias. Furthermore, due to sample characteristics, attention should be exercised when generalising the current study’s findings. Indeed, a sizable majority of the respondents were female, well educated, and of the young generation, which has previously been recognised as having a high pro–environmental views and practises in general (Soare et al., 2021). This study only focused on three villages, which might not give desired funding which can be used globally.

Despite limitations on this study, the current study provides quantifiable information on public attitudes towards plastic pollution in a South African rural context, as well as practical and theoretical implications. The current study suggests that improving people's perceptions of the impacts brought by plastic pollution is likely to be associated with increased intentions of being more pro–environmental aware. At practical level, the findings of the study emphasise the significance of generating messaging and interventions to improve people's perceptions of the adverse impacts of plastic pollution. Furthermore, it emphasises the importance of adapting interventions to specific audiences and groups, particularly those who are old, with limited education. On a theoretical level, in a field were empirical research on individuals 'views on the problem of plastic pollution, its impacts, and influence on pro–environmental behaviour is still limited; the current study provides insight into how the people of the Vhembe Biosphere Reserve understand and respond to such a topic. Future studies should look more at representative samples, with a greater diversity in respondent's as well as a more equal gender distribution. Furthermore, it is critical to investigate the role of other psychological characteristics such as having knowledge of plastic pollution. This study only focused on three villages, future studies should include a large geological area.

4.5. Conclusions

Plastic pollution in the environment has been identified as a global problem that requires special attention and awareness from society. Thus, the results of this encourages re–usable shopping bags, and prominent media platforms need to be used to spread awareness of plastic pollution, encourage recycling, and increase plastic bag costs to deter their consumption. Additionally, respondents suggested that alternatives to plastics, including paper and cloth bags, should be provided at more affordable prices to encourage use. This might make it possible for consumption habits to switch from plastic to other alternatives. Van–Rensburg *et al.* (2020) suggested that consumers should be given financial incentives for reusable shopping bags. By providing incentives, people might change their behaviour and consume fewer plastics. Offering loyalty points or discounts on total purchases could also be effective incentives for utilising reusable shopping bags in stores. Most well–liked platforms mentioned in the study should be used to raise awareness of the environmental problems related to plastics. Overall, promoting a positive attitude towards the environment, encouraging social norms that promote pro–environmental behaviour, and providing access to resources and education can all contribute to reducing plastic pollution through pro–environmental behaviour. The availability of waste management facilities is a problem in communities within the Vhembe Biosphere Reserve since most of the population is living in rural areas; hence, the local government must develop strategies to accommodate communities without waste management facilities to reduce plastic pollution.

CHAPTER FIVE: GENERAL SYNTHESIS

5.1 General Introduction

This chapter brings together and combines the main findings from chapters this research investigation. This involves summarizing the main results, conclusions, and implications drawn from each section offering a thorough summary of the research's results.

5.2 General discussion

Plastic pollution is a rapidly growing environmental issue globally, which poses threats to trophic food chains and natural environments and has prompted governments and other organizations to come up with mitigation majors and ways to control it (Galgani *et al*., 2013). PEB has emerged as one of the strategies that can be used to solve the growing environmental issues in line with achieving sustainable development goals (O'Brien and Thondhlana, 2019). It is critical to understand PEB and strategies to promote them in relation to environmental problems (such as plastic pollution) where there is a consensus that human behaviour is the primary source (Muncke *et al*., 2020). In this study, we observed that the Mvudi River system was highly polluted during winter compared to the other season. Factors such as wind that transport plastic waste from poorly managed landfills, and residential areas approximate to the river and people visiting the river influences the accumulation of macroplastics in rivers (Jambeck *et al.* 2015).

Plastic pollution is made up of different organic polymers which are namely PET, PE, PVC, PP, PS, HDPE and LDPE (UN Environment, 2018). The identification of plastic polymer types is essential since it allows for an assumption on the origin of plastic pollutants and determines whether they originate from the breakdown of macroplastic components from nearby industrial or recreational activities (Veerasingam *et al*., 2016b). The results from this study indicate that plastic made of PS polymer were the most dominant than all other polymers which is the same to the study conducted by Maharana *et al.* (2019). Plastic bags were the dominate macroplastics waste observed on this study, Pe *et al*. (2020) suggested that most plastic bag comes from community economic activities such as markets, household waste, and recreation activities along the shoreline.

This study also investigated the pro-environmental behaviour/human perceptions towards macroplastic pollution, this section was achieved through administration of 120 questionnaires along the Vhembe Biosphere Reserve. The sociodemographic variables of participants were investigated. The results showed that they were many females than males' respondents, while the age of between 20-29 was dominant, the educational status of participants indicated that most of respondents are graduates, lastly the occupational status results of participants indicated about 50% of participants are still students, like the study conducted by Ahalya, (2020). This is because females are more involved in shopping and using plastic bags, hence they were more interested to participate.

In the current study most, respondents indicated that they are no waste collection facilities in their communities hence they use other methods of plastic disposal such as burning. I learned that the availability of facilities in the community can influence people's intentions and behaviour towards the plastic materials they use on a regular basis. Separate facilities for plastic and non-plastic waste can also assist to influence people behaviour as they utilise them daily (Widayat *et al*., 2021).

The findings of the research have implications for riverine ecosystem biodiversity integrity and environmental management. Specifically, they provide information on how to measure and analyse the abundance of macroplastics, which can help with the development of focused management plans that lessen the negative effects of plastic pollution on aquatic environments. Adaptive management strategies are informed by variations in the availability of plastic waste, which helps to prioritise treatments during periods of increased pollution.

Identifying significant quantities of macroplastic debris along shorelines indicates that clean-up campaigns and waste management strategies must be prioritised in order to reduce shoreline pollution. Observations of specific polymer abundances highlight the significance of customising management strategies to effectively target prevalent types of plastic debris. Lastly, the knowledge of the factors influencing pro-environmental behaviour informs educational campaigns aimed at fostering behaviours that reduce plastic pollution and mitigate its impact on biodiversity.

The current study suggests that investigating social perception on the impacts brought by plastic pollution is a first step of solving plastic pollution in the Vhembe Reserve Biosphere and it associated with the intentions of increasing PEB among participants. There is a need to conduct empirical environmental survey on individual individuals ‘views on the problem of plastic pollution, its impacts, and influence on pro–environmental behaviour since its still limited.

I recommend that an increase in public awareness and education initiatives to encourage pro-environmental behaviours like reducing back on the usage of single-use plastics, disposing of waste effectively, and assisting out with clean-up projects. Encouraging people to take initiative can support more extensive management initiatives.

There are limitations raised on this study. Any research that relies on voluntary participants is subject to selection bias. The sample strategy may have resulted in increased engagement from those who are already more knowledgeable and aware of plastic pollution than non–participants. As perception research relies on self–report measures, it is possible that participants' responses about the perceived impacts of plastic pollution, the frequency of pro–environmental behaviours, and their intentions to increase such behaviours were overstated due to a social desirability bias.

Future studies should look more into monitoring plastic pollution in riverine for an extended period of time in order to identify trends over time, variations in the seasons, and the effectiveness of management measures. Future studies should also look more at representative samples, with a greater diversity in respondent's as well as a more equal gender distribution. Furthermore, it is critical to investigate the role of other psychological characteristics such as having knowledge of plastic pollution.

5.3 Conclusion

Plastic pollution is environment problem which is ubiquitous and various policy measures have been implemented at local and international a level to manage and reduce it pollution. This study aimed at assessing the distribution of macroplastic debris based on the functional group, physical form, and polymer groups, which were found to be widespread and similar across sites and seasons. The diversity of macroplastic functional groups was significantly different between seasons and sites the overall results shows that macroplastics items in the Mvudi River are associated with human activities such as settlement, recreation, and dumping as well as economic activities such as markets. The driving factors associated with the distribution and accumulation of macroplastic along the Mvudi river from the source include meteorological and hydrological factors. Understanding seasonal variations in plastic loads and their drivers provides information on the sources and destiny of plastic, which can improve management methods for reducing this risk to the aquatic ecosystem. The PEB is one of the solutions to reduce plastic pollution, participants from the current study mentioned that they use plastic bags because they are easily available and very cheap compared to other bag materials. The use of media platforms to spread awareness is encouraged, recycling, increasing plastic bag cost and making cloth bag available at affordable price are some of the solutions to reduce the use of plastic bag. The availability of waste management facilities is a problem in communities within the Vhembe Biosphere Reserve. I recommend that the local municipalities must invest more on waste collection facilities and conduct awareness campaigns which will educate people more about the management of plastic and its impacts.

REFERENCES

Afroz, R., Rahman, A., Masud, M. M., & Akhtar, R., 2017. The knowledge, awareness, attitude and motivational analysis of plastic waste and household perspective in Malaysia. *Environmental Science and Pollution Research*, 24(3), 2304–2315.

Ahalya Arulnayagam., 2020. Public Perception towards Plastic Pollution in the Marine Ecosystems of Sri Lanka. *American Journal of Marine Science*,8(, 1), 6-13.

Arulnayagam, A., 2020. Public perception towards plastic pollution in the marine ecosystems of Sri Lanka. *American Journal of Marine Science*, 8(1), 6–13.

Avio, C.G., Gorbi, S. and Regoli, F., 2017. Plastics and microplastics in the oceans: from emerging pollutants to emerged threat. *Marine Environmental Research,* 128, 2-11.

Azhar, A. and Yang, K., 2019. Workplace and non-workplace pro-environmental behaviors: Empirical evidence from Florida city governments. *Public Administration Review*, *79*(3),399-410.

Baensch-Baltruschat, B., Brennholt, N., Kochleus, C., Reifferscheid, G. and Koschorreck, J., 2017. *Conference on Plastics in Freshwater Environments*.

Baini, M., Fossi, M.C., Galli, M., Caliani, I., Campani, T., Finoia, M.G. and Panti, C., 2018. Abundance and characterization of microplastics in the coastal waters of Tuscany (Italy): the application of the MSFD monitoring protocol in the Mediterranean Sea. *Marine Pollution Bulletin*, *133*,543-552.

Baldwin, A.K., Corsi, S.R. and Mason, S.A., 2016. Plastic debris in 29 Great Lakes tributaries: relations to watershed attributes and hydrology. *Environmental Science & Technology*, *50*(19), 10377-10385.

Bänsch-Baltruschat, B., Brennholt, N., Kochleus, C., Reifferscheid, G., Koschorreck, J., 2017. Conference on Plastics in Freshwater Environments. Report No. (UBA-FB) 002480/ ENG (Dokumentationen 05/2017).

Barnes, D.K., Galgani, F., Thompson, R.C. and Barlaz, M., 2009. Accumulation and fragmentation of plastic debris in global environments. *Philosophical Transactions of the Royal society B: Biological Sciences*, *364*(1526),1985-1998.

Bashir, N.H., 2013. Plastic problem in Africa. *Japanese Journal of Veterinary Research*. *61*(Supplement), S1-S11.

Battisti, C., Bazzichetto, M., Poeta, G., Pietrelli, L. and Acosta, A.T., 2017. Measuring non-biological diversity using commonly used metrics: Strengths, weaknesses and caveats for their application in beach litter management. *Journal of Coastal Conservation*, *21*,303-310.

Battisti, C., Malavasi, M. and Poeta, G., 2018. Applying diversity metrics to plastic litter 'communities': a first explorative and comparative analysis. *Rendiconti Lincei. Scienze Fisiche e Naturali*, 29, 811-815.

Beaman, J., Bergeron, C., Benson, R., Cook, A.M., Gallagher, K., Ho, K., Hoff, D. and Laessig, S., 2016. State of the Science White Paper. A Summary of Literature on the Chemical Toxicity of Plastics Pollution to Aquatic Life and Aquatic-Dependent Wildlife. *US Environmental Protection Agency*.

Beaman, R. J., & Bergeron, L., 2016. Geophysical evaluation of the sources and sinks of marine litter. *Marine Pollution Bulletin*, 110(1), 162-177.

Blettler, M.C., Ulla, M.A., Rabuffetti, A.P. and Garello, N., 2017. Plastic pollution in freshwater ecosystems: macro–, meso–, and microplastic debris in a floodplain lake. *Environmental Monitoring and Assessment,* 189, 1-13.

Braun, Y. A., & Traore, A. S. (2015). Plastic bags, pollution, and identity: Women and the gendering of globalization and environmental responsibility in Mali. *Gender & Society*, 29(6), 863–887.

Brennan, R. E., & Portman, M. E.,2017. Situating Arab Israeli artisanal fishermen's perceptions of marine litter in a socio–institutional and socio–cultural context. *Marine Pollution Bulletin.* 115(1–2), 240–251.

Brennholt, N., 2017. Macroplastic debris in marine environments: A review of methods used for monitoring and identification. *Environmental Science & Technology,* 51(12), 6734-6746.

Brennholt, N., Reifferscheid, G., Bänsch-Baltruschat, B., Breuninger, E. and Hatzky, S., 2017. Overview on plastics in European freshwater environments–Results of a survey. *In European Conference on Plastics in Freshwater Environments 21–22 June 2016 in Berlin*, 17

Brizga, J., Hubacek, K. and Feng, K., 2020. The unintended side effects of bioplastics: carbon, land, and water footprints. *One Earth*, *3*(1), 45-53.

Cable, R.N., Beletsky, D., Beletsky, R., Wigginton, K., Locke, B.W. and Duhaime, M.B., 2017. Distribution and Modeled Transport of Plastic Pollution in the Great Lakes, the World's Largest Freshwater Resource. *Frontiers in Environmental Science*,1–18.

Campana, I., Angeletti, D., Crosti, R., Di Miccoli, V. and Arcangeli, A., 2018. Seasonal patterns of floating macro-litter across the Western Mediterranean Sea: a potential threat for cetacean species. *Rendiconti Lincei. Scienze Fisiche e Naturali*, *29*, 453-467.

Caner, C., & Pascall, M. A., 2010. Consumer complaints and accidents related to food packaging. *Packaging Technology and Science*, 23(7), 413–422.

Canning-Clode, J., Sepúlveda, P., Almeida, S. and Monteiro, J., 2020. Will COVID-19 containment and treatment measures drive shifts in marine litter pollution?. *Frontiers in Marine Science*,691.

Cao, J., Yang, Q., Jiang, J., Dalu, T., Kadushkin, A., Singh, J., Fakhrullin, R., Wang, F., Cai, X. and Li, R., (2022). Coronas of micro/nano plastics: a key determinant in their risk assessments. *Particle and Fibre Toxicology*, 19(1), 55.

Carpenter, E., & Wolverton, S.,2017. Plastic litter in streams: The behavioral archaeology of a pervasive environmental problem. *Applied Geography*, 84, 93–101.

Cassola, G.E., Zadjelovic, V., Gibson, M.I. and Christie-Oleza, J.A., 2019. Distribution of plastic polymer types in the marine environment; A meta-analysis. *Journal of Hazardous Materials*, *369* ,691-698.

Chamas, A., Moon, H., Zheng, J., Qiu, Y., Tabassum, T., Jang, J.H., Abu-Omar, M., Scott, S.L. and Suh, S., 2020. Degradation rates of plastics in the environment. *ACS Sustainable Chemistry & Engineering*, *8*(9), 3494-3511.

Choudhary, K., Sangwan, K.S. and Goyal, D., 2019. Environment and economic impacts assessment of PET waste recycling with conventional and renewable sources of energy. *Procedia CIRP*, *80*, 422-427.

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

Collado, S., Staats, H. and Sancho, P., 2019. Normative influences on adolescents' self-reported pro-environmental behaviors: The role of parents and friends. *Environment and Behavior*. *51*(3), 288-314.

Corraini, N. R., de Souza de Lima, A., Bonetti, J., & Rangel–Buitrago, N., 2018. Troubles in the paradise: Litter and its scenic impact on the North Santa Catarina Island beaches, Brazil. *Marine Pollution Bulletin,* 131, 572–579.

Cuthbert, R.N., Al–Jaibachi, R., Dalu, T., Dick, J.T. and Callaghan, A., 2019. The influence of microplastics on trophic interaction strengths and oviposition preferences of dipterans. *Science of the Total Environment*, 651, 2420–2423.

Dalu, M.T., Cuthbert, R.N., Muhali, H., Chari, L.D., Manyani, A., Masunungure, C. and Dalu, T., 2020. Is awareness on plastic pollution being raised in schools? Understanding perceptions of primary and secondary school educators. *Sustainability*, *12*(17), 6775.

Dalu, M.T., Gunter, A.W., Makatu, M., Dowo, G.M., Dondofema, F. and Dalu, T., 2021. Contribution of natural forest products to rural livelihoods at Mavunde and Sambandou Villages, Vhembe Biosphere Reserve, South Africa. *Sustainability*, 13(8), 4252.

Dalu, T., Banda, T., Mutshekwa, T., Munyai, L.F. and Cuthbert, R.N., 2021. Effects of urbanisation and a wastewater treatment plant on microplastic densities along a subtropical river system. *Environmental Science and Pollution Research, 28*, 36102-36111.

Dalu, T., Malesa, B. and Cuthbert, R.N., 2019. Assessing factors driving the distribution and characteristics of shoreline macroplastics in a subtropical reservoir. *Science of the Total Environment,* 696, 133992.

Dauvergne, P., 2018. Why is the global governance of plastic failing the oceans? *Global Environmental Change,* 51, 22–31.

De Groot, J.I., Abrahamse, W., and Jones, K., 2013. Persuasive normative messages: The influence of injunctive and personal norms on using free plastic bags. Sustainability, 5(5), 1829–1844.

Derraik, J.G.B., 2002. The pollution of the marine environment by plastic debris: A review. *Marine Pollution Bulleti*, 842–852.

Driedger, A.G.J., Dürr, H.H., Mitchell, K. and Van Cappellen, P., 2015. Plastic debris in the Laurentian Great Lakes: A review. *Journal of Great Lakes Research*, 9–19.

Dris, R., 2017. First assessment of sources and fate of macro–and micro–plastics in urban hydrosystems: *Case of Paris megacity* (Doctoral dissertation, UPE, Université Paris–Est).

Eldesouky, A., & Mesías, F., 2014. An insight into the influence of packaging and presentation format on consumer purchasing attitudes towards cheese: A qualitative study. *Spanish Journal of Agricultural Research,* 12(2), 305–312.

European Bioplastics, 2019. Bioplastics: Facts and figures [WWW Document]. http://www.european–bioplastics.org/news/publications/ URL (accessed on the 20 July 2022)

Evans, S.W., 2017. An assessment of land cover change as a source of information for conservation planning in the Vhembe Biosphere Reserve. *Applied Geography*, *82*,35–47.

Faure, F., Demars, C., Wieser, O., Kunz, M., & De Alencastro, L. F., 2015. Plastic pollution in Swiss surface waters: Nature and concentrations, interaction with pollutants. *Environmental Chemistry*,12(5), 582–591.

Faure, F., Saini, C., Potter, G., Galgani, F., Alencastro, L.F. De and Hagmann, P., 2015. An evaluation of surface micro– and mesoplastic pollution in pelagic ecosystems of the Western Mediterranean Sea,.12190–12197.

Fischer I, Schmitt WF, Porth H, Allsopp MW, Vianello G.,2014. Poly (vinyl chloride). In; Ullmann's encyclopedia of industrial chemistry. Wiley, Germany

Fischer, E.K., Paglialonga, L., Czech, E. and Tamminga, M., 2016. Microplastic pollution in lakes and lake shoreline sediments – A case study on Lake Bolsena and Lake Chiusi (central Italy). *Environmental Pollution*, 213,648–657.

Ford, H.V., Jones, N.H., Davies, A.J., Godley, B.J., Jambeck, J.R., Napper, I.E., Suckling, C.C., Williams, G.J., Woodall, L.C. and Koldewey, H.J., 2022. The fundamental links between climate change and marine plastic pollution. *Science of the Total Environment,* 806, p.150392.

Galgani, F., Hanke, G., Werner, S., De Vrees, L., 2013. Marine litter within the European marine strategy framework directive. IC

Galgani, F., Hanke, G., Werner, S.D.V.L. and De Vrees, L., 2013. Marine litter within the European marine strategy framework directive. *ICES Journal of marine Science*, *70*(6), 1055-1064.

Gall, S. C., & Thompson, R.C., 2015. The impact of debris on marine life. *Marine Pollution Bulletin*, 92(1–2), 170–179.

GESAMP, 2016. Sources, fate and effects of microplastics in the marine environment: *part two of a global assessment. Reports and Studies GESAMP*.220.

GESAMP, 2019. Guidelines for the Monitoring and Assessment of Plastic Litter in the Ocean. Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection.

GESAMP., 2015. Sources, fate and effects of microplastics in the marine environment: a global assessment. In: Kershaw, P.J. (Ed.), (IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). Rep. Stud. GESAMP No. 90. 96.

Geyer, R., 2020. A brief history of plastics. *Mare plasticum-the plastic Sea: Combatting Plastic Pollution through Science and Art*, 31-47.

Geyer, R., Jambeck, J.R. and Law, K.L., 2017. Production, use, and fate of all plastics ever made. *Science advances*. *3*(7),e1700782.

Gumbo, A.D., Kapangaziwiri, E. and Mathivha, F.I., 2022. A Systematic Study Site Selection Protocol to Determine Environmental Flows in the Headwater Catchments of the Vhembe Biosphere Reserve. *International Journal of Environmental Research and Public Health,* 19(10), 6259.

Gumbo, A.D., Kapangaziwiri, E. and Mathivha, F.I., 2022. A Systematic Study Site Selection Protocol to Determine Environmental Flows in the Headwater Catchments of the Vhembe Biosphere Reserve. *International Journal of Environmental Research and Public Health*, *19*(10),6259.

Hamilton, L.A., Feit, S., Muffett, C., Kelso, M., 2019. Plastic & Climate: The Hidden Costs of a Plastic Planet. *Center of International Environmental Law.*

Hammami, M.B.A., Mohammed, E.Q., Hashem, A.M., Al-Khafaji, M.A., Alqahtani, F., Alzaabi, S. and Dash, N., 2017. Survey on awareness and attitudes of secondary school students regarding plastic pollution: implications for environmental education and public health in Sharjah city, UAE. *Environmental Science and Pollution Research*, *24*, 20626-20633.

Harland, P., Staats, H. and Wilke, H.A., 2007. Situational and personality factors as direct or personal norm mediated predictors of pro–environmental behavior: Questions derived from norm–activation theory. *Basic and Applied Social Psychology*, 29(4), 323–334.

Haseler, M., Schernewski, G., Balciunas, A. and Sabaliauskaite, V., 2018. Monitoring methods for large micro-and meso-litter and applications at Baltic beaches. *Journal of Coastal Conservation,* 22, 27-50.

Hechter, M., and Opp, K.D., 2001. Social Norms. Russell Sage Foundation, New York.

Heidbreder, L.M., Bablok, I., Drews, S. and Menzel, C., 2019. Tackling the plastic problem: A review on perceptions, behaviors, and interventions. *Science of the Total Environment*, *668*,1077–1093

Hoffman, M.J. and Hittinger, E., 2017. Inventory and transport of plastic debris in the Laurentian Great Lakes. *Marine Pollution Bulletin,* 115(1-2), 273-281.

Holland, E.R., Mallory, M.L. and Shutler, D., 2016. Plastics and other anthropogenic debris in freshwater birds from Canada. *Science of the Total Environment*, 251–258.

Honingh, D., 2018. Riverine debris: Interactions between waste and hydrodynamics: *Field Measurements and Laboratory Experiments for the Cikapundung River*, Bandung. (M.Sc. thesis). Delft University of Technology.

Jaiswal, K.K., Dutta, S., Banerjee, I., Pohrmen, C.B., Singh, R.K., Das, H.T., Dubey, S. and Kumar, V., 2022. Impact of aquatic microplastics and nanoplastics pollution on ecological systems and sustainable remediation strategies of biodegradation and photodegradation. *Science of The Total Environment,* 806,151358.

Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., Law, K.L., 2015. Plastic waste inputs from land into the ocean. *Science*, 347, 768–771

Katzenberger, T.D., 2015. Assessing the biological effects of exposure to microplastics in the three–spined stickleback (Gasterosteus aculeatus)(Linnaeus 1758) (Doctoral dissertation, University of York)

Kautish, P., Sharma, R., Mangla, S.K., Jabeen, F. and Awan, U., 2021. Understanding choice behavior towards plastic consumption: An emerging market investigation. *Resources, Conservation and Recycling,* 174, 105828.

Kawecki, D. and Nowack, B., 2019. Polymer-specific modeling of the environmental emissions of seven commodity plastics as macro-and microplastics. *Environmental Science & Technology*, *53*(16), 9664-9676.

Kazour, M., Terki, S., Rabhi, K., Jemaa, S., Khalaf, G. and Amara, R., 2019. Sources of microplastics pollution in the marine environment: Importance of wastewater treatment plant and coastal landfill. *Marine Pollution Bulletin*.*146*,608-618.

Koleff, P., Lennon, J.J. and Gaston, K.J., 2003. Are there latitudinal gradients in species turnover?. *Global Ecology and Biogeography*, *12*(6), 483-498.

Krishnakumar, S., Srinivasalu, S., Saravanan, P., Vidyasakar, A. and Magesh, N.S., 2018. A preliminary study on coastal debris in Nallathanni Island, Gulf of Mannar Biosphere Reserve, Southeast coast of India. *Marine Pollution Bulletin*, 131, 547-551.

Krüger, L., Casado-Coy, N., Valle, C., Ramos, M., Sánchez-Jerez, P., Gago, J., Carretero, O., Beltran-Sanahuja, A. and Sanz-Lazaro, C., 2020. Plastic debris accumulation in the seabed derived from coastal fish farming. *Environmental Pollution*, *257*,113336.

Lahens, L., Strady, E., Kieu–Le, T.C., Dris, R., Boukerma, K., Rinnert, E., Gasperi, J. and Tassin, B., 2018. Macroplastic and microplastic contamination assessment of a tropical river (Saigon River, Vietnam) transversed by a developing megacity. *Environmental Pollution,* 236,661–671.

Lambert, S., Sinclair, C. and Boxall, A., 2014. Occurrence, degradation, and effect of polymer–based materials in the environment. *In Reviews of Environmental Contamination and Toxicology*, 1–53.

Lange, F, Dewitte, S, 2019. Measuring pro–environmental behavior: Review and recommendations. *J Environtalm Psychology.*

Lebreton, L., & Andrady, A., 2019. Future scenarios of global plastic waste generation and disposal. *Palgrave Communications, 5(1),* 6.

Lebreton, L.C., Van Der Zwet, J., Damsteeg, J.W., Slat, B., Andrady, A. and Reisser, J., 2017. River plastic emissions to the world's oceans. *Nature Communications*. 8(1),15611.

Lechthaler, S., Dolny, R., Spelthahn, V., Pinnekamp, J. and Linnemann, V., 2020. Sampling concept for microplastics in combined sewage-affected freshwater and freshwater sediments. *Fundamental and Applied Limnology*,37-48.

Lee, J., Lee, J.S., Jang, Y.C., Hong, S.Y., Shim, W.J., Song, Y.K., Hong, S.H., Jang, M., Han, G.M., Kang, D. and Hong, S., 2015. Distribution and size relationships of plastic marine debris on beaches in South Korea. *Archives of Environmental Contamination and Toxicology* 69, 288-298.

Lee, T.H., Jan, F.H. and Yang, C.C., 2013. Conceptualizing and measuring environmentally responsible behaviors from the perspective of community-based tourists. *Tourism Management .36*,454-468.

Li, P., Wang, X., Su, M., Zou, X., Duan, L. and Zhang, H., 2021. Characteristics of plastic pollution in the environment: a review. *Bulletin of Environmental Contamination and Toxicology,* 107(4),577–584.

Lindh, H., Olsson, A., & Williams, H., 2016. Consumer Perceptions of Food Packaging: Contributing to or Counteracting Environmentally Sustainable Development? *Packaging Technology and Science,* 29(1), 3–23.

Lippiatt, S., Opfer, S. and Arthur, C., 2013. Marine debris monitoring and assessment: recommendations for monitoring debris trends in the marine environment.

Liu, E.K., He, W.Q. and Yan, C.R., 2014. 'White revolution'to 'white pollution'—agricultural plastic film mulch in China. *Environmental Research Letters*, *9*(9), 091001.

Löhr, A., Savelli, H., Beunen, R., Kalz, M., Ragas, A. and Van Belleghem, F., 2017. Solutions for global marine litter pollution. *Current Opinion in Environmental Sustainability*, 90–99.

Lundström, F.R. and Mårtensson, A., 2015. A study on quantifying micro plastic particles in ocean outside Costa Rican west coast. *The Journey of Plastic trough Oceans,* 30,59.

Lundström, K., & Mårtensson, L., 2015. Sources of microplastic pollution – A review. Swedish Environmental Protection Agency, 1-28.

Macali, A., Semenov, A., Venuti, V., Crupi, V., D'Amico, F., Rossi, B., Bergami, E., 2018. Episodic records of jellyfish ingestion of plastic items reveal a novel pathway for trophic transference of marine litter. *Scientific Reports*, 8(1), 6105.

Madigele, P. K., Mogomotsi, G. E. J., & Kolobe, M., 2017. Consumer willingness to pay for plastic bags levy and willingness to accept eco–friendly alternatives in Botswana. *Chinese Journal of Population Resources and Environment*, 15(3), 255–261.

Magurran, A., 2004. Measuring Biological Diversity. Blackwell, Malden

Maharana, D., Saha, M., Dar, J.Y., Rathore, C., Sreepada, R.A., Xu, X.R., Koongolla, J.B. and Li, H.X., 2020. Assessment of micro and macroplastics along the west coast of India: abundance, distribution, polymer type and toxicity. *Chemosphere,* 246,125708.

Malesa, B., 2018. Assessing the distribution and factors driving the occurrence extent of macroplastics around Mandeni reservoir.

Mapotse, T. A., & Mashiloane, T. K., 2017. Nurturing learners' awareness of littering through environmental campaigns: An action research approach. *Eurasia Journal of Mathematics, Science and Technology Education*, 13(10), 6909–6921.

Martí, E., Martin, C., Cózar, A. and Duarte, C.M., 2017. Low abundance of plastic fragments in the surface waters of the Red Sea. *Frontiers in Marine Science*, 4,333.

McIlgorm, A., Campbell, H. F., & Rule, M. J., 2011. The economic cost and control of marine debris damage in the Asia–Pacific region. *Ocean &Coastal Management, 54(9),* 643–651.

Meyer, A, 2015. Does education increase pro–environmental behavior? *Evidence from Europe*. 116,108–121.

Muncke, J., Andersson, A.M., Backhaus, T., Boucher, J.M., Carney Almroth, B., Castillo Castillo, A., Chevrier, J., Demeneix, B.A., Emmanuel, J.A., Fini, J.B. and Gee, D., 2020. Impacts of food contact chemicals on human health: a consensus statement. *Environmental Health*, *19*,1-12.

Muncke, J., Andersson, A.M., Backhaus, T., Boucher, J.M., Carney Almroth, B., Castillo Castillo, A., Chevrier, J., Demeneix, B.A., Emmanuel, J.A., Fini, J.B., Gee, D., Geueke, B., Groh, K., Heindel, J.J., Houlihan, J., Kassotis, C.D., Kwiatkowski, C.F., Lefferts, L.Y., Maffini, M.V., Scheringer, M., 2020. Impacts of food contact chemicals on human health: a consensus statement. *Environmental Health Global,* 19 (1), 25.

Nakashima, E., Isobe, A., Kako, S.I., Itai, T. and Takahashi, S., 2012. Quantification of toxic metals derived from macroplastic litter on Ookushi Beach, Japan. *Environmental Science & Technology,*46(18), 10099-10105.

Napper, I.E. and Thompson, R.C., 2019. Environmental deterioration of biodegradable, oxo-biodegradable, compostable, and conventional plastic carrier bags in the sea, soil, and open-air over a 3-year period. *Environmental Science & Technology*, *53*(9), 4775-4783.

Nazareth, M., Marques, M.R., Leite, M.C. and Castro, Í.B., 2019. Commercial plastics claiming biodegradable status: is this also accurate for marine environments?. *Journal of Hazardous Materials*, *366*,714-722.

Neo, E.R.K., Soo, G.C.Y., Tan, D.Z.L., Cady, K., Tong, K.T. and Low, J.S.C., 2021. Life cycle assessment of plastic waste end of life for India and Indonesia. *Resources, Conservation and Recycling*, 174, 105774.

Nicholson, J.W., 2006. The Chemistry of Polymers. *The Royal Society of Chemistry*, *Cambridge*

Nielsen, T.D., Hasselbalch, J., Holmberg, K. and Stripple, J., 2020. Politics and the plastic crisis: A review throughout the plastic life cycle. *Wiley Interdisciplinary Reviews: Energy and Environment*. *9*(1) 360.

O'Brien, J. and Thondhlana, G., 2019. Plastic bag use in South Africa: Perceptions, practices and potential intervention strategies. *Waste Management*, 84, 320–328.

Oom Do Valle P, Rebelo E, Reis E, &Menezes J., 2005. Combining behavioral theories to predict recycling involvement. *Environment and Behavior.* 37, 364–396.

Orset, C., Barret, N. and Lemaire, A., 2017. How consumers of plastic water bottles are responding to environmental policies?. *Waste Management*, *61*,13-27.

Ostle, C., Thompson, R.C., Broughton, D., Gregory, L., Wootton, M. and Johns, D.G., 2019. The rise in ocean plastics evidenced from a 60-year time series. *Nature Communications*, *10*(1),1622.

Otsyina, H. R., Nguhiu–Mwangi, J., Mogoa, E. G. M., Mbuthia, P. G., & Ogara, W. O., 2018. Knowledge, attitude, and practices on usage, disposal, and effect of plastic bags on sheep and goats. *Tropical Animal Health and Production*, 50(5), 997–1003.

Oturai, N.G., Pahl, S. and Syberg, K., 2022. How can we test plastic pollution perceptions and behavior? A feasibility study with Danish children participating in “the Mass Experiment”. *Science of The Total Environment*, 806,150914.

Paillé, P, Mejía–Morelos, J H, Marché–Paillé, A, Chen, C C, Chen, Y, 2016. Corporate greening, exchange process among co–workers, and ethics of care: An empirical study on the determinants of pro–environmental behaviors at coworkers–level. *J Bus Ethic,s*, 136(3),655–673.

Patrício Silva, A.L.; Prata, J.C.; Walker, T.R.; Duarte, A.C.; Ouyang, W.; Barcelò, D.; Rocha–Santos, T., 2020 Increased plastic pollution due to Covid–19 pandemic: Challenges and recommendations. *Chemical Engineering Journal*, *405*,126683.

Pe, E.O.L., Wardiatno, Y. and Mashar, A., 2020. Macroplastic distribution, abundance, and composition which flows to Cimandiri estuary, West Java. In *IOP Conference Series: Earth and Environmental Science,* 420(1), 012031.

Piehl, S., Leibner, A., Löder, M.G., Dris, R., Bogner, C. and Laforsch, C., 2018. Identification and quantification of macro-and microplastics on an agricultural farmland. *Scientific Reports*, 8(1),17950.

Plastics Europe Market Research Group (PEMRG)., 2017. Consultic Marketing & Industrieberatung ,. *Plastics – the Facts*.40

PlasticsEurope., 2019. Market data. https://www.plasticseurope.org/en/resources/ market–data. (accessed on 25 March 2023).

Poortinga, W., Whitmarsh, L., & Suffolk, C.,2013. The introduction of a single–use carrier bag charge in Wales : Attitude change and behavioural spillover effects. *Journal of Environmental Psychology,* 36, 240–247.

Ramsey, C.E. and Rickson, R.E., 1976. Environmental knowledge and attitudes. *The Journal of Environmental Education*, *8*(1), 10-18.

Ramulifho, P., Ndou, E., Thifhulufhelwi, R. and Dalu, T., 2019. Challenges to implementing an environmental flow regime in the Luvuvhu river catchment, South Africa. *International Journal of Environmental Research and Public health*, 16(19),3694.

Ramulifho, P.A., Foord, S.H. and Rivers–Moore, N.A., 2022. Structure and diversity of blackfly assemblages in the Luvuvhu River system, South Africa in response to changing environmental gradients. *Hydrobiologia*, 849(3), 711–723.

Rochman, C.M., Cook, A.–M. and Koelmans, A.A., 2016. Plastic debris and policy: Using current scientific understanding to invoke positive change. *Environmental Toxicology and Chemistry,* 1617–1626.

Rohaningsih, D., Henny, C., Suryono, T. and Santoso, A.B., 2022, July. Macroplastic abundance at Lake Singkarak riparian, West Sumatera. In *IOP Conference Series: Earth and Environmental Science*, 1062(1), 012025

Romero, C. B. A., Laroche, M., Aurup, G. M., & Ferraz, S. B., 2018. Ethnicity and acculturation of environmental attitudes and behaviors: A cross–cultural study with Brazilians in Canada. *Journal of Business Research*, 82, 300–309.

Romero, C.B.A., Laroche, M., Aurup, G.M., and Ferraz, S.B., 2018. Ethnicity and acculturation of environmental attitudes and behaviors: A cross–cultural study with Brazilians in Canada. *Journal of Business Research*, 82, 300–309.

Ryan, P.G., Moore, C.J., van Franeker, J.A. and Moloney, C.L., 2009. Monitoring the abundance of plastic debris in the marine environment. *Philosophical Transactions of the Royal Society B: Biological Sciences,*1999–2012

Ryberg, M.W., Hauschild, M.Z., Wang, F., Averous-Monnery, S. and Laurent, A., 2019. Global environmental losses of plastics across their value chains. *Resources, Conservation and Recycling*, *151*,104459.

Ryberg, M.W., Laurent, A., Hauschild, M., Tonda, E., Averous, S., Yan, C., Milà Canals, L., Wang, F., Savelli, H. and Hasegawa, K., 2018. Mapping of global plastics value chain and plastics losses to the environment. *With a Particular Focus on Marine Environment*.

Sanz-Lázaro, C., Casado-Coy, N. and Beltrán-Sanahuja, A., 2021. Biodegradable plastics can alter carbon and nitrogen cycles to a greater extent than conventional plastics in marine sediment. *Science of The Total Environment*, *756*, 143978.

SAPEA, 2019. *A Scientific Perspective on Microplastics in Nature and Society*.

Saraswathy K, Sumiani Y, Mohd F.R. F, Rusinah S., 2022, Plastic pollution in water ecosystems: A bibliometric analysis from 2000 to 2020. *Journal of Cleaner Production* ,313 (2021) ,127946

Savari, M., and Gharechaee, H., 2020. Application of the extended theory of planned behavior to predict Iranian farmers' intention for safe use of chemical fertilizers. *Journal of Cleaner Production,* 263, 121512.

Sawitri, D.R., Hadiyanto, H. and Hadi, S.P., 2015. Pro–environmental behavior from a socialcognitive theory perspective. *Procedia Environmental Sciences*, *23*, 27–33.

Sharp, A., Høj, S., & Wheeler, M., 2010. Proscription and its impact on anti–consumption behaviour and attitudes: The case of plastic bags. *Journal of Consumer Behaviour*, 9(6), 470–484.

Sherrington, C.; Hogg, D.; Darrah, C.; Hann, S., 2013. Exploring the Indirect Costs of Litter in Scotland; *Zero Waste Scotland: Stirling, UK*,. Available online:

https://www.eunomia.co.uk/reports–tools/exploring–indirect–costs–litter/ (accessed on 25 March 2023).

Silayoi, P., & Speece, M., 2004. Packaging and purchase decisions: An exploratory study on the impact of involvement level and time pressure. *British Food Journal*, 106(8), 607–628.

Sinthumule, N.I., and Mashau, M.L. 2019, Attitudes of local communities towards marula tree (*Sclerocarya birrea* subsp. *caffra*) conservation at the villages of Ha-Mashau and Ha-Mashamba in Limpopo Province, *South Africa. Resources*, 8, 22.

Soares, J., Miguel, I., Venâncio, C., Lopes, I. and Oliveira, M., 2021. On the path to minimize plastic pollution: The perceived importance of education and knowledge dissemination strategies. *Marine Pollution Bulletin*, *171*,112890.

Stefanini, R., Borghesi, G., Ronzano, A. and Vignali, G., 2021. Plastic or glass: a new environmental assessment with a marine litter indicator for the comparison of pasteurized milk bottles. *The International Journal of Life Cycle Assessment*, *26*,767-784.

Steg, L. and Vlek, C., 2009. Encouraging pro-environmental behaviour: An integrative review and research agenda. *Journal of Environmental Psychology*, *29*(3), 309-317.

Stergaard, S., & Hanssen, O. J. (2018). Wasting of Fresh–Packed Bread by Consumers Influence of Shopping Behavior, Storing, Handling, and Consumer Preferences. *Sustainability* (Switzerland), 10(7), 1–16.

Syberg, K., Hansen, S. F., Christensen, T. B., & Khan, F. R. (2018). Risk Perception of Plastic Pollution: Importance of Stakeholder Involvement and Citizen Science. In M. Wagner & S. Lambert (Eds.), *Handbook of Environmental Chemistry*, 58, 203– 221.

Synthia, I. J., & Kabir, S., 2015. An Investigation of Consumer Attitudes Towards New Varieties of Shopping Bags: Exploring Eco–Awareness and the Possibility of Behavior Change. *The Journal of Developing Areas*, 49(5), 183–196.

Thomas, G. O., Poortinga, W., & Sautkina, E., 2016. The Welsh Single–Use Carrier Bag Charge and behavioural spillover. *Journal of Environmental Psychology*, 47(2880), 126– 135.

Thompson, R.C., Moore, C.J., vom Saal, F.S. and Swan, S.H., 2009. Plastics, the environment and human health: current consensus and future trends. *Philosophical Transactions of the Royal Society B: Biological Sciences*.

Thushari, G. G. N., & Senevirathna, J. D. M., 2020. The Sources and Pathways of Microplastics to the Aquatic Environment. *Marine Pollution Bulletin*, 151, 110822.

Thushari, G.G.N. and Senevirathna, J.D.M., 2020. Plastic pollution in the marine environment. Heliyon, 6(8),e04709.

Tim van, E, and Anna S, 2020. Plastic debris in rivers: *Wiley Interdisciplinary Reviews; Water, 7(1),e1398*

Tudor, D. T., & Williams, A. T., 2003. Public Perception and Opinion of Visible Beach Aesthetic Pollution: The Utilisation of Photography. *Journal of Coastal Research,* 19(4), 1104–1115.

Turrell, W.R., 2020. Estimating a regional budget of marine plastic litter in order to advise on marine management measures. *Marine Pollution Bulletin*, *150*, 110725.

UNEP., 2018. Single Use Plastics: A Roadmap for Sustainability; United Nations Environment Programme (UNEP): Nairobi, Kenya.

UNESCO, 2021. Biosphere Reserves in Africa. Available online: https://en.unesco.org/biosphere/africa (accessed on 12 November 2022).

Valle, P.O.D., Rebelo, E., Reis, E. and Menezes, J., 2005. Combining behavioral theories to predict recycling involvement. *Environment and Behavior*, 37(3), 364-396.

Van Calcar, C.V. and van Emmerik, T.V., 2019. Abundance of plastic debris across European and Asian rivers. *Environmental Research Letters*, *14*(12), 124051.

Van Rensburg, M. L., Nkomo, S. L., & Dube, T., 2020. The ‘plastic waste era’; social perceptions towards single-use plastic consumption and impacts on the marine environment in Durban, South Africa. *Applied Geography*, 114, 102132.

VBR (Vhembe Biosphere Reserve), 2021. Available online: https://www.vhembebiosphere.org/ (accessed on 24 December 2022)

Veerasingam, S., Saha, M., Suneel, V., Vethamony, P., Rodrigues, A.C., Bhattacharya, S., Naik, B.G., 2016b. Characteristics, seasonal distribution and surface degradation features of microplastic pellets along the Goa coast, India. *Chemosphere*, 159, 496–505.

Vegter, A.C., Barletta, M., Beck, C., Borrero, J., Burton, H., Campbell, M.L., Costa, M.F., Eriksen, M., Eriksson, C., Estrades, A., Gilardi, K.V.K., Hardesty, B.D., Ivar do Sul, J.A., Lavers, J.L., Lazar, B., Lebreton, L., Nichols, W.J., Ribic, C.A., Ryan, P.G., Schuyler, Q.A., Smith, S.D.A., Takada, H., Townsend, K.A., Wabnitz, C.C.C., Wilcox, C., Young, L.C. and Hamann, M., 2014. Global research priorities to mitigate plastic pollution impacts on marine wildlife. *Endangered Species Research*, 25, 225–247.

Vicente–Molina, M A, Fernández–Sainz, A, Izagirre–Olaizola, J, 2018. Does gender make a difference in pro–environmental behavior? The case of the Basque Country University students. *J Clean Production,* 176,89–98.

Wagner, T. P., 2017. Reducing single–use plastic shopping bags in the USA. *Waste Management*, 70, 3–12.

Wahid, R.M., Purnamasari, E.D. and Fauzi, F., 2020. Environmental Education To Boost Pro–Environmental Behaviour In Reducing Plastics Consumption Among Students In Universitas Bina Darma Palembang. *EPRA International Journal of Multidisciplinary Resear*,20–32.

Wall R, Devine–Wright P, Mill GA., 2007. Comparing and combining theories to explain pro–environmental intentions: The case of commuting–mode choice. *Environment and Behavior*.39, 731–753.

Wan Yahaya, W.A.; Abd Hamid, I., 2020. Zero–Waste Campaign: Assessment on University Student's Behaviour, Awareness, and Impact on Plastic Products. *Malaysian Journal of Social Sciences and Humanities*,5, 24–29.

Wang, Q., Zhang, M. and Li, R., 2022. The COVID–19 pandemic reshapes the plastic pollution research. A comparative analysis of plastic pollution research before and during the pandemic. *Environmental Research*, 208, 112634.

Widayat, W., Praharjo, A., Putri, V.P., Andharini, S.N. and Masudin, I., 2021. Responsible consumer behavior: Driving factors of pro–environmental behavior toward post–consumption plastic packaging. *Sustainability*, *14*(1), 425.

Wikström, F., Williams, H., Verghese, K., & Clune, S., 2014. The influence of packaging attributes on consumer behaviour in food–packaging life cycle assessment studies – a neglected topic. *Journal of Cleaner Production,* 73, 100–108.

Windsor, F. M., Tilley, R. M., Tyler, C. R., & Ormerod, S. J., 2019. Microplastic ingestion by riverine macroinvertebrates. *Science of the Total Environment*, 646, 68–74

Wright, S., 2015. The potential for microplastics to cause harm in the marine environment,1–221.

Wyles, K. J., Pahl, S., Thomas, K., & Thompson, R. C., 2016. Factors That Can Undermine the Psychological Benefits of Coastal Environments: Exploring the Effect of Tidal State, Presence, and Type of Litter. *Environment and Behavior,* 48(9), 1095–1126.

Xanthos, D. and Walker, T.R., 2017. International policies to reduce plastic marine pollution from single-use plastics (plastic bags and microbeads): A review. *Marine Pollution Bulletin*, *118*(1-2),17-26.

Yan, C., He, W., Xue, Y., Liu, E. and Liu, Q., 2016. Application of biodegradable plastic film to reduce plastic film residual pollution in Chinese agriculture. *Sheng Wu Gong Cheng Xue Bao= Chinese journal of Biotechnology*, 32(6),748–760.

Yardy, L., Al–Jaibachi, R., and Callaghan, A., 2021. Microplastics in freshwater ecosystems with special reference to tropical systems; detection, impact, and management. In: Dalu, T., Tavengwa, N.T. (eds) Emerging Freshwater Pollutants: Analysis, Fate and Regulations. Elsevier, Cambridge.

Zen, I. S., Ahamad, R., & Omar, W., 2013. No plastic bag campaign day in Malaysia and the policy implication. *Environment, Development and Sustainability*, 15(5), 1259–1269.

Zhang, K., Shi, H., Peng, J., Wang, Y., Xiong, X., Wu, C. and Lam, P.K.S., 2018. Microplastic pollution in China's inland water systems: A review of findings, methods, characteristics, effects, and management. *Science of The Total Environment*, 1641– 1653.

Zhao, S., Zhu, L., Wang, T. and Li, D., 2014. Suspended microplastics in the surface water of the Yangtze Estuary System, China: first observations on occurrence, distribution. *Marine Pollution Bulletin*, *86*(1-2),562-568.

Zheng, J. and Suh, S., 2019. Strategies to reduce the global carbon footprint of plastics. *Nature Climate Change*, *9*(5),374-378.

Zou, J., Tang, Y., Qing, P., Li, H. and Razzaq, A., 2021. Donation or discount: Effect of promotion mode on green consumption behavior. *International Journal of Environmental Research and Public Health*, *18*(4), 1912.