TOWARDS DEVELOPING A RAPID CITIZEN SCIENCE-BASED MACROPLASTIC MONITORING PROTOCOL FOR RIVERS AND WETLANDS: A CASE STUDY OF THE UMSUNDUZI RIVER

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by

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EXECUTIVE SUMMARY

BACKGROUND

Macroplastic pollution in rivers and wetlands is a growing environmental issue that has significant impacts on wildlife, water quality, and human health. Plastic waste originating from households, industries and agricultural activities are carried by runoff into rivers and wetlands, where it accumulates and is transported downstream to the ocean. Not only can macroplastic in these ecosystems cause physical harm to wildlife, i.e. entanglement, plastic in rivers and wetlands have the potential to leach toxic chemicals that are harmful to aquatic life and can bioaccumulate in the food chain, affecting human health. To mitigate plastic pollution in rivers and wetlands, it is necessary to reduce the production and use of single-use plastic products and improve waste management practices, including pollution control, waste collection, and proper disposal.

In efforts to achieve the above, it is necessary to identify the sources, distribution pathways, accumulation zones, and impact of plastic pollution in rivers and wetlands to support evidence-based decision-making for plastic waste management. Riverine plastic monitoring is crucial for determining the extent and impact of plastic pollution in rivers and for developing effective strategies for plastic waste reduction and management. The data obtained from monitoring can also inform public awareness and education campaigns, as well as policy and legislative actions to reduce plastic pollution. Aquatic plastic monitoring can be achieved through various methods, including manual surveys, citizen science initiatives, and remote sensing techniques, but none have been formalised for a South African context yet.

AIMS

The main aims of the project were to:

1. Conduct an analytical review of current unautomated macroplastic monitoring approaches, protocols and recommendations locally and globally;
2. Develop a typology for profiling macroplastic in the uMsunduzi River (Pietermaritzburg);
3. Develop a citizen science-based macroplastic monitoring protocol for rivers;
4. Using the data generated from piloting the protocol, identify the potential sources/hotspots of the macroplastic entering the river and wetlands assessed and develop recommendations on mitigating this pollution;
5. Provide recommendations on the potential for valorisation of recovered plastics.

METHODOLOGY

Together with citizen scientists, a rapid macroplastic sampling protocol was created via an iterative process. The protocol involves an initial desktop site selection exercise, followed by an infield plastic collection activity along the edges and banks of rivers and instream as well as along the disturbed and undisturbed edges of wetlands. Following collection, the plastic is cleaned, classified using a macroplastic typology, and weighed. Total average weights were calculated, and a statistical test was performed to determine difference in plastic quantity for each site and sampling area. In order to compare the degree of disturbance at each site and to highlight potential sources at the sampling site, a field datasheet is utilised to record and rate current land use activities. This information was then used to prioritise areas of the river and wetlands for interventions.

Pilot sampling exercises occurred over a period of two years, considering the impact of high and low flow seasons on plastic transport and therefore accumulation. The objective of the study is to compare results from the high rainfall seasons (summer) against the results from the low rainfall seaons (winter).

RESULTS AND DISCUSSION

The development of a macroplastic sampling tool for rivers and wetlands emerged as a significant achievement resulting from collaborative efforts involving the project team and citizen scientists. This tool underwent pilot testing during four sampling events conducted in 2022 and 2023. The study documented noticeable seasonal variations in plastic accumulation within wetlands and rivers, predominantly influenced by changes in vegetation density triggered by periodic rainfall and seasonal precipitation fluctuations. During the summer, higher flow volumes, enhanced by increased rainfall, facilitated the collection and downstream transport of plastic debris. The dense riparian flora along river edges functioned as effective traps for macroplastic. Additionally, abundant wetland vegetation exacerbated plastic accumulation during the summer months. Notably, the heavily urbanized Site 4 in Lincoln Meade exhibited substantial plastic levels during both summer and winter, demonstrating statistical significance ($p < 0.05$). Furthermore, the tool revealed comparable levels of plastic contamination at the upstream sampling location Site 3, underscoring the similarity between Site 3 and Site 4 at New England Landfill. This alignment in plastic profiles suggests a potential connection between upstream land-based sources, such as illegal dumping or inadequate waste disposal, and the observed pollution downstream. The comparable patterns observed in both sites during the sampling periods reinforce the notion that upstream activities significantly contribute to downstream plastic pollution dynamics. This emphasizes the need for targeted interventions and proactive measures to address pollution levels of affected communities, offering a foundation for more focused and effective pollution mitigation strategies in these areas.

CONCLUSIONS

The comprehensive findings of the study explicitly identified Sites 3 and 4 as the most severely affected by macroplastic pollution, consistently producing the highest quantities of plastic throughout the study period. The primary objective of the research was to highlight pollution hotspots for targeted intervention and mitigation efforts, emphasizing the critical need for prioritizing these identified sites in the formulation of pollution management recommendations. High-density Polyethylene (HDPE), Low-density Polyethylene (LDPE), and Polypropylene (PP) emerged as the most prevalent plastic types, representing common household items such as detergent bottles, food containers, and plastic bags. The effectiveness of the macroplastic monitoring tool is evident in its capability to discern these household plastic types, facilitating the identification of pollution sources, predominantly attributed to households in this pilot study. Such insights will aid relevant authorities in developing impactful strategies, including awareness campaigns, community clean-ups, and the promotion of recycling activities aimed at reducing macroplastic pollution at its source. Moreover, the tool not only identifies macroplastic concerns but also proposes a systematic approach for continuous monitoring and evaluation of pollution trends and mitigation actions in the research area over an extended period, ensuring sustained efforts toward a cleaner and healthier environment.

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ABBREVIATIONS AND ACRONYMS

BPA	Bisphenol-A
DUCT	Duzi uMngeni Conservation Trust
EMM	eThekwini Metropolitan Municipality
EPA	Environmental Protection Agency
EPR	Extended Producer Responsibility
GDP	Gross Domestic Profit
HDPE	High-density Polyethylene
LDPE	Low-density Polyethylene
NGO	Non-government Organisation
PET	Polyethylene Terephthalate
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinyl Chloride
QDS	Quarter Degree Square
SALSA	Search, Appraisal, Synthesis, and Analysis Framework
SAPRO	South African Plastics Recycling Organisation
TDS	Total Disturbance Score
UNEP	United Nations Environmental Programme
WRC	Water Research Commission
WWF	World-Wide Fund for Nature

1. BACKGROUND

1.1 INTRODUCTION

Plastic pollution has emerged as a pressing environmental concern, primarily attributable to the escalating consumption of plastic products coupled with inadequate disposal mechanisms. The persistent nature of plastic compounds, taking hundreds of years to disintegrate, exacerbates the gravity of the issue and poses significant threats to ecosystems, wildlife, and human well-being (Geyer, Jambeck, and Law, 2017). As plastic waste infiltrates diverse environments, from terrestrial landscapes to rivers and oceans, its deleterious impacts are increasingly evident.

Plastic's slow disintegration makes it a persistent threat, contributing to its accumulation in natural ecosystems. Disturbingly, marine life often bears the brunt of this pollution, with plastics infiltrating ecosystems and adversely affecting various species. Studies have identified plastic residues in the stomachs of marine animals, underscoring the pervasive nature of plastic pollution (Laist, 1997). The consequences are dire, with compromised health and, in tragic instances, fatalities observed among affected marine organisms (Rochman et al., 2015).

Recognising the severity of the plastic pollution crisis, global entities such as the United Nations Environment Programme (UNEP) have sounded alarms, calling for immediate and concerted action (UNEP, 2018). Urgency is paramount, demanding a collective response from individuals, governments, and corporations to curtail plastic use and institute robust recycling and waste management practices. Individuals play a pivotal role in mitigating plastic pollution. By adopting conscientious consumption habits, such as minimising single-use plastic usage and embracing eco-friendly alternatives, individuals can contribute significantly to reducing plastic footprints. Corporations hold significant influence over consumer behaviour and environmental impact. Embracing sustainable packaging, implementing take-back programs, and investing in research for biodegradable alternatives are imperative steps that corporations can take to mitigate their plastic-related environmental footprint. Governments need to spearhead comprehensive policies and regulations to address plastic pollution. These may include incentivising sustainable practices, imposing restrictions on single-use plastics, and investing in effective waste management infrastructure. These steps, taken together, have the potential to pave the road for a real and coordinated solution to the plastic pollution crisis. The critical nature of the problem necessitates a multifaceted strategy incorporating individual behavioural adjustments, government legislation, and corporate accountability.

1.2 PROJECT AIMS

This study aims to develop a citizen science-based rapid macroplastic monitoring protocol for freshwater systems, rivers, and wetlands specifically, in South Africa using the UMsunduzi River and selected wetlands in central Pietermaritzburg as case study sites in an effort to bring the relative role players together to reduce the impact that plastic has on the natural environment. The plan is to sample different areas of the river and wetlands to determine the protocol's utility/sensitivity in prioritising systems and identifying waste streams and sources for management and mitigation activities. The objectives of the study are:

1. To conduct an analytical review of current unautomated macroplastic monitoring approaches, protocols and recommendations locally and globally;
2. Develop a typology for profiling macroplastics in the UMsunduzi River (Pietermaritzburg);
3. To develop a citizen science-based macroplastic monitoring protocol for rivers and wetlands by adapting / modifying / combining methods identified to be of value in the analytical review;
4. To use the data generated using the protocol to identify the potential sources of the macroplastics entering the river and wetlands assessed and develop recommendations on mitigating this pollution.
5. To provide recommendations on the potential for valorisation of the plastics recovered from the river system and wetlands assessed.

2. LITERATURE REVIEW

2.1 METHODOLOGY

The Search, Appraisal, Synthesis, and Analysis (SALSA) framework (Grant and Booth, 2009) was utilized to conduct a systematic search and review of pollution impacts on biodiversity with a focus on South Africa. The various steps of the SALSA framework (see Figure 1) enable a systematic, yet robust analysis of literature while minimizing the potential for bias. According to Grant and Booth (2009), the comprehensive search process and critical review which results from the adoption of the SALSA framework results in evidence-based synthesis. Using this search methodology relevant literature were identified, screened, and then reviewed to extract information on relevant policies, frameworks, guidelines, methods, case studies, etc. Popular articles and publications as well as public relations/educational material were included in the review.

Figure 1: Flow diagram of the SALSA framework (adapted from Gunnarsdottir et al., 2020)

The review was based on a literature search using Scopus, a database of abstracts and citations, which draws on a wide range of journal articles and secondary documents. The search was based on a set of keywords, timeframe, and symbols to avoid duplication of information. More specifically, the selection of the relevant keywords for the search was based on reducing false positives, and for this purpose Boolean search queries were used. Keywords were searched in title, abstract content, and indexed keywords in each primary study (see Table 1). Papers emerging from the Scopus search were interrogated and used as a starting point for the literature review.

Table 1: Search queries used and search results from the Scopus analysis which was used to guide the literature search.

Search Query	Date	Results
TITLE-ABSTRACT-KEYWORDS (river AND macroplastic)	2011-2022	97
TITLE-ABSTRACT-KEYWORDS ("citizen science" AND macroplastic AND method)	2011-2022	2
TITLE-ABSTRACT-KEYWORDS (macroplastic AND "south africa")	2011-2022	8
TITLE-ABSTRACT-KEYWORDS (river AND macroplastic AND "south africa")	2011-2022	4

Literature emerging from the Scopus search of the literature identified several papers focusing on plastic waste in the environment in South Africa but the majority focused microplastics, and/or the marine environment.

2.2 THE IMPACTS OF PLASTIC

Many studies across the world have been conducted as plastics have been an emerging environmental issue (Lebreton and Andrady, 2019; MacLeod et al., 2021). It has long been recognized that waste plastics in the environment have significant ecological and economic impacts, particularly in marine systems (Coe and Rogers, 1997). Plastic pollution in the river environment is an increasingly concerned issue due to the adverse effects it can cause (Schwarz et al., 2020) These effects include fauna mortality from ingestion or entanglement, property damage, reduced livelihoods for river-dependent people, increased risk of flooding due to clogging of urban drainage systems, and transport of plastics to the world's oceans (Honingh et al., 2020). Management of plastic pollution has become an international priority (Borrelle et al., 2017).

The UNEP describes plastic litter as a global ocean concern (UNEP, 2016). Since the 1950's, when large-scale production of plastics began, an increased proportion of solid waste in the ocean was found to have consisted of this material, representing up to 80% of marine litter found in surveys according to UNEP, 2016. This was a consequence of both land-based and sea-based anthropogenic activities. Plastic debris is mostly noticed on shorelines, where litter piles up due to current, wave and wind action, river outflows and by direct littering at the coast. Plastic can have severe and long-lasting impacts on the environment, the economy, human health, and society (Coe and Rogers, 1997). These impacts are unpacked in more detail below.

2.2.1 Environmental impacts

Plastics pose a threat to aquatic species through entanglement and ingestion. Furthermore, plastics have other harmful effects on the environment and can be differentiated into several categories, their severity based on an item's size and shape these categories also include leakage of toxic additives and accumulation of toxins, breakdown in microplastics and human livelihood. A study by Honingh (2020) states that in urban water systems, blockage of hydraulic infrastructure due to macroplastics lead to more severe and quicker water level increases compared to organic waste. Macroplastics are also considered to be a major contributor to microplastics production in the riverine environment as they break down after being exposed to ultraviolet light or mechanical forces in rivers (Weinstein et al., 2016. Plastic litter not only pose a threat to the health of our seas and coasts, but also to our economy and communities. For marine species in general, the main difficult biological interactions arising from contact with litter are associated with entanglement or ingestion. Plastic litter accounts for 92% of entanglement and ingestion cases and about 17% of all species involved are on the IUCN Red list of Threatened species (Schepis, 2016).

Entanglement occurs when the loops and openings of any type of waste entangle an animal's appendages or entrap it, which normally causes death by drowning, suffocation, or strangulation (Laist, 1997; Moore, 2008). Many different marine species are affected, including birds, turtles, mammals, fish, and crabs. It has gotten difficult to say which sites are most susceptible to this type of occurrence since the problem of marine litter has become global, entanglement can happen anywhere. Ingestion of plastics by animals can have various effects, varying in severity. A study by Gall and Thompson (2015) states these effects include starvation (due to gut obstruction), a false feeling of starvation, decreased fitness, behavioural changes, and impacted reproduction and growth.

Moreover, plastic that can contain potentially toxic contaminants that can travel up the food chain, especially when plastic ingestion is recorded in low trophic species like jellyfish (Macali et al., 2018). Gall and Thompson (2015) published an extensive review showing that 233 species of marine vertebrates were affected by ingestion, the limited studies on ingestion in rivers show ingestion rates up to 33% in the Goiana River, Brazil (Possatto et al., 2011).

A substantial fraction of marine plastic debris originates from land-based sources and rivers potentially act as a major transport pathway for all sizes of plastic debris (Schmidt et al. 2019). Schmidt et al. (2019) analysed a global compilation of data on plastic debris in the water column across a wide range of river sizes. Plastic debris loads, both microplastic (particles <5 mm) and macroplastic (particles >5 mm) are positively related to the mismanaged plastic waste (MMPW) generated in the river catchments (Schmidt et al. 2019). This relationship is nonlinear where large rivers with population-rich catchments delivering a disproportionately higher fraction of MMPW into the sea (Schmidt et al. 2019). The 10 top-ranked rivers transport 88-95% of the global load into the sea (Schmidt et al. 2019). Using MMPW as a predictor, Schmidt et al. (2019) calculated the global plastic debris inputs from rivers into the sea to range between 0.41 and 4 × 106 tons/year. Although there is some dispute around the number of rivers that account for 80-90% of ocean plastic, there is no dispute that the majority of ocean plastic comes from land and is deposited into the oceans via rivers (Burns and Boxall, 2018; Horton et al., 2017; Jambeck et al., 2015; Schmidt et al. 2019; Meijer et al., 2021).

2.2.2 Human health

Due to the degradation mechanism, macroplastics be prone to break down into smaller fragments until the size of micro and nanoplastics. Microplastics are seen in different food products such as honey, tap water, and sea salt (Kosuth *et al.*, 2018). Initial results from a study by Schwable *et al*. (2018) show the wide spread of microplastics in human stools. Human health, food security and food safety are jeopardized by plastics (Barboza *et al*., 2018) There is a direct impact on human livelihood, through economic losses and increased flood risk in urban areas due to the plastic litter in river systems.

2.2.3 Human health

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2.2.4 Economic impact

Plastic pollution not only affects the health of our communities, living things and ecosystems, but it also has a very significant economic impact. Plastic pollution significantly disrupts economic activities such as fishing and tourism, impedes transportation across rivers and threatens the availability of clean freshwater, endangering the livelihoods of the communities living next to and depending on the river (Emmerik *et al*., 2020). Impacts include lower land prices, reduced tourism, wasted resources, and clean-up costs as well as opportunity costs (Ritchie and Roser, 2018).

Property

Real estate prices also tend to be below average in areas with waste pollution problems (Corraini, 2018). Marine pollution also affects other economic activities such as shipping, fishing, aquaculture, and recreation. For example, the fishing industry pays a large amount of money each year to repair boats and equipment damaged by discarded fishing gear.

Tourism

The presence of plastic pollution on the coast can discourage visitors from tourist hotspots (Deloitte, 2019). This can lead to a loss of revenue for the tourism industry as the number of visitors decreases, especially in the presence of plastic waste during peak seasons. Tourism is an important industry for South Africa, estimated at R125 million and contributing 2.9% to South Africa's GDP (South Africa Tourism Board, 2017). Tourists are attracted to South Africa because of the more than 3000 km of coastline threatened by plastic pollution. For example, studies have shown that littering more than 10 large objects per metre of beach discourages 40% of foreign tourists and 60% of local tourists from returning to Cape Town (Balance *et al*., 2000) thus showing that plastic pollution can have a negative impact on people who depend on tourism for their livelihoods.

Clean-up

Governments, non-governmental organizations (NGOs), and related citizens also bear significant costs in conducting clean-up activities to eliminate waste (Deloitte, 2019). Most of this clean-up focuses on inhabited coasts, rivers, harbours, and marina, but ad hoc removal activities are also taking place in the terrestrial environment. Transportation costs and staff time are directly incurred in the form of government NGO funding. The direct cost of these activities can be high, and it will cost US$ 5.6 billion to US$ 15 billion to collect plastic debris floating in rivers, ports and marina and remove plastic from the beach in 2018 Deloitte, 2019).

Industry

Plastic pollution also threatens various industries in South Africa, such as the fishing sector. Studies have also shown that ingestion of microplastic fish can reduce the quality of fish stocks and catches (Thiele, 2021). To mitigate the risks, local governments spend a significant portion of their budgets on clean-up and illegal disposal of plastic pollution. Depending on the size and budget of the municipality, cleaning costs range from 1% to 26% of municipal operating costs for waste management (South African Environment Agency, 2018).

The World-Wide Fund for Nature (WWF) conducted a global assessment of the economic, societal, and environmental costs of plastic in 2021. This study found that the minimum lifetime cost of plastics imposed on South Africa in 2019 is approximately US$ 60.72 billion (WWF, 2021), which includes damage to livelihoods, industries, cost of clean-up, and human health.

2.3 TYPES OF PLASTIC

Plastics refer to a group of flexible synthetic materials that can be modelled into solid objects of different shapes and sizes (Geyer et al., 2017). In terms of shape, plastics can be in the form of pellets, fibres, films, or hard solid pieces. (Lahens et al., 2018). In terms of size, plastics are commonly defined as nanoplastic, microplastic and macroplastic, which are characterized by dimensions of 1 to 1000 nm, < 5 mm and > 5 mm, respectively (Emmerik et al., 2018). Macroplastic is commonly defined in distinction to microplastics as items with a diameter greater or equal to 5 mm. However, both size classifications are not internationally standardized. Regarding macroplastics, other definitions are also published. For example, Barnes (2009) defined plastics with a diameter >20 mm, the European Commission (2013) defined it as items >25 mm, while other studies define items >5 cm as macroplastics.

Literature by Law (2017) suggests that the first synthetic polymers were developed in the middle of the 19th century, marking the start of the "Plastic Era", and by the beginning of the 20th century, the manufacture of new plastic types. There has been an increasing demand for plastics, with a diversity of applications in industries from food packaging, civil construction products, auto motive and medical applications, as well as electrical and electronic components and its worldwide production is estimated to be approximately 322 million tons per year (Plastics Europe, 2016). Studies show that there are approximately fifty different basic types of polymers included in sixty thousand plastic formulations (Shashoua, 2008), the most common being high-density polyethylene (HDPE), low density polyethylene (LDPE), polyvinyl chloride (PVC), polystyrene (PS), polypropylene (PP), and polyethylene terephthalate (PET) (Li, et al., 2016; Plastics Europe, 2016). Plastics are long-lasting, which allows them to persist in the environment, where their degradation may take decades or even longer (Hammer et al., 2012; Hidalgo-Ruz, et al., 2012).

Plastic litter is categorized into different size classes to monitor and quantify possible impacts on biota. A study by Ryan (2019) suggests that, although different authorities propose subtly distinct size limits, plastic pollution can widely be divided into four classes which are micro, meso, macro and mega plastics (Barnes et al., 2009; GESAMP, 2016).

2.4 RECYCLABILITY OF PLASTIC

There are two types of plastics when it comes to recyclability: thermoset plastics and thermoplastics. Thermoplastics are plastics that can be re-melted and re-melded into new products, and hence, recycled. Moreover, thermoset plastics "contain polymers that cross-link to form an irreversible chemical bond," stating that no matter how much heat you apply, they cannot be re-melted into new material and thus non-recyclable. This article also states the importance of washing plastics as only clean plastics can be recycled and how recycled materials are in competition with virgin materials in the market, so quality is prioritized.

There are three main types of recycling, namely mechanical, energy and chemical recycling. Each type of recycling has various minor categories. Mechanical recycling is an open loop recycling, which means the recycled plastics serve a different purpose than where they were retrieved from (Ragaert,2017).

There is also a decrease in the quality of material caused by the degradation process as mechanical recycling methods generates a lower quality end product in comparison to virgin plastics (La Mantia, 2004). There is potential for closed-loop recycling as there are new ways of recycling plastics that are being developed in hopes of improving recyclability. Secondly, energy recycling consists of converting plastic into both thermal and electric energy by leveraging, through incineration, the heat power released by these materials in the form of fuel. Energy recycling is important due to its ability for diversifying the energetic matrix and optimizing the space available in heavily populated cities with little room for landfills. This solution is widely used in Europe and Japan but requires heavy investments and the engagement of public authorities since it is not financially sustainable. Energy recycling has been implemented a few times on the African continent, such as the energy-generation initiatives undertaken by eThekwini Metropolitan Municipality (EMM). Between 2002 and 2010, EMM opened landfill gas to energy sites at two of its landfills, namely Marianhill and Bisasar Landfills (Couth et al., 2011). These two facilities extract gas from the landfill (consisting of 50-60% Methane and 40-50% Carbon Dioxide with approximately 1% of impurities (SOx & NOx) (EMM, 2013). This gas is burned in 20-cylinder spark ignition engines which, in turn, drive a generator to produce electricity which is fed into the local electricity network. (EMM, 2013).

Lastly, chemical recycling (by dissolving the plastic in a solvent) and thermochemical recycling (pyrolysis) form part of the new methods for recycling plastics (Ragaert et al., 2017). Through the use of chemicals, plastics are reprocessed, and their chemical structure is changed so that they can be made into something else and re-used.

Despite the recyclability of certain plastics and ever-evolving technology that goes into recycling plastic, very little plastic actually gets recycled. The US Environmental Protection Agency (EPA) estimated that in 2018, just 8.7% of plastic waste produced by Americans gets recycled in the USA (EPA 2020). According to the South African Plastics Recycling Organisation (SAPRO), just 7.5% of South African households recycle (SAPRO, 2020). Further, SAPRO reported that the total plastic production in South Africa in 2019 was 1.8 million tons, while just 14% tons were collected for recycling in that year (SAPRO, 2020). While recycling efforts are increasing in South Africa, the amount of plastic waste being sent to landfill only decreased by 2% between 2018 and 2020 (SAPRO). As such, much of the plastic waste in South Africa does not get recycled and ends up in a landfill or in the environment.

2.5 EFFORTS TO MITIGATE PLASTIC POLLUTION

Plastic pollution is a serious problem in rivers around the world although the problem differs greatly between rivers and parts of the world. The main focus of the United Nations Environment Programme with regard to marine litter is nowadays on the reduction and prevention of litter entering the oceans (a good example are the litter traps that are being placed in rivers as well as clean-up actions at riverbanks). Monitoring the riverine environment for the presence of litter is therefore of utmost importance. Monitoring is needed to gather scientific knowledge on the amount, sources, transport and spread of litter and especially plastic litter in the environment (Ryan et al. 2009). The knowledge is a necessary part of assessing the extent and possible impact of riverine litter (Ryan et al. 2009).

Monitoring can be strictly defined as the repeated measurement of a characteristic of the environment, or a process, in order to detect a trend in space or time (UNEP, 2016). Monitoring rivers for the presence of plastic litter is a necessary part of assessing the extent and possible impact of river debris, devising possible mitigation methods to reduce inputs, and evaluating effectiveness of such measures. However, it is important to use consistent and reliable methods of sampling and sample characterisation (e.g. number, size, shape, mass, and type of material) to gain greatest benefit. Monitoring and assessment are essential steps towards addressing specific questions about plastic litter. They are needed to assess the state or level of pollution and provide objective information to design mitigation measures as well as to assess their effectiveness and promote adaptive management. But it is critical to understand the underlying policy concerns as this will help to determine the nature and extent of the approach. Since monitoring is goal dependent, the sampling strategies, protocols, and indicators used must be tailored to the specific questions being asked, which are often driven by policy considerations.

2.5.1 Macroplastic monitoring methods

Removing ocean plastic is difficult for many reasons: it is often far from the shore, it moves around in the swells/waves, or it can sink to the ocean floor (Cressey, 2016). Implementing ocean clean-up strategies requires an understanding and quantification of marine plastic sources, taking spatial and temporal variability into account (Lebreton *et al.,* 2017). Once plastic reaches the ocean, it is likely to stay there forever. As such, studies have examined the role that rivers play in the transport of plastic into rivers (Burns and Boxall, 2018; Horton *et al*., 2017; Jambeck *et al*., 2015; Schmidt *et al.* 2019; Meijer *et al.,* 2021). There is limited literature available on methods to monitor plastic pollution in freshwater environments but what could be sourced for the purposes of this review could be roughly divided into five different methods and approaches:

- Plastic tracking;
- Active sampling;
- Passive sampling;
- Visual observation; and
- Citizen science.

Trackers are normally used to study the travel paths and retention times of plastic litter in river systems. Plastic tracking has two main approaches: 1) actively tracking waste as it travels through the river system using a global positioning system (GPS), 2) release marked plastic items that can be recaptured by scientists, citizen scientists, or the general public before being registered. A study by Ivar do Sul *et al*. (2014) was conducted where they used painted plastic items to study the retention time of plastic litter in mangrove forests. This was done in two different seasons where plastic items with assorted colours were released and tracked for a couple of days, which showed that plastic bags are more easily retained than items such as bottles.

Active sampling by van Emmerik *et al*. (2019) of plastic litter is one of the easiest approaches to study riverine plastic pollution. Representative examples of active sampling methods include the use of nets deployed from boats or bridges, collecting waste on riverbanks and beaches, or taking sediment samples. Mass and size distribution, identification of items, degradation rates and classic composition can be studied through riverine plastic litter. Some studies have made use of small nets that can be stationed from bridges to collect plastic waste samples. The sizes of these nets usually range from 1m wide and 0.5m tall and can be easily used by one or two people. Applications of this method include the Cikapandung, Ciliwung, and Pesanggrahan rivers in Indonesia (Honingh, 2018; van Emmerik, Loozen *et al*., 2019), or Liedermann *et al*. (2018) who deployed a three-layered sampling net using a crane to sample plastic waste flowing at three depths in the Donau River in Europe.

An alternative to active sampling is passive sampling which can be performed by collecting and analysing waste that accumulates in infrastructure. In most rivers around the world, infrastructure already exists to concentrate, retain, and extract plastic litter in rivers. Several studies have collected riverine litter through floating barriers. For example, a study by Pikaar (2018) measured plastic composition using passive sampling utilizing riverine debris sampled from the Shoreliner litter trap (Tauw), located in the Lekhaven (port), Rotterdam. The Shoreliner passively collected riverine litter that accumulated in ports predominantly due to wind, tidal influences, and the flow of the river. This method has its own advantages and disadvantages, the advantage being the freedom of using infrastructure that is already in place that allows for litter analysis with no added investment in installing monitoring equipment and the drawback is that samples may not always be suited for answering specific research questions. Visual counting method is one of the most utilized methods (Castro-Jimenez *et al*., 2019; Crosti *et al*., 2018; Gonzalez-Fernandez *et al*., 2016, Gonzalez-Fernandez and Hanke, 2017; van Emmerik *et al*., 2018). For this method observes stand on bridges and count the amount of visible floating, and superficially sub-merged plastics for a particular duration.

The results can be used to quantify the plastic transport for the whole river at a given moment in time and its distribution over the river width. This method produces uniform data over time and space, a number of uncertainties are introduced through a possible observer-bias and the minimum size of the counted plastic because of bridge height and turbidity. A study conducted using this method on the Erasmusburg (bridge) in Rotterdam, Netherlands, on three consecutive days, from 23 to 25 October 2018, in a period classically characterized by low river discharge in the Rhine (Shabalova *et al*., 2003). Plastic observations were only done during ebb tide when the flow was directed toward the ocean. The river had a width of 500m, the bridge was sectioned into six segments, counting macroplastics at each segment in 20 minutes with three observers counting at the exact same time, resulting in the full width of the bridge being counted in 40 minutes. A day, three cross sections of the river were counted and were used to determine the total microplastic (particle size >5cm) flux in items per hour as well as its horizontal distribution.

Visual recording following the RIMMEL app methodology (Moss *et al.,* 2021) in unification with corresponding river sample collection in each river was undertaken at three monitoring locations on three major rivers near Port Elizabeth. The RIMMEL app is a European Commission supported, widely accepted data collection tool and was designed for global river plastic pollution data collection. The three rivers were selected as they provided an overview of the Port Elizabeth River conditions, from intensely industrialized, modified and polluted too relatively natural and undeveloped. The visual macroplastic monitoring methodology designed and previously pilot evaluated by EU JRC (Crosti *et al*., 2018; Gonzalez-Fernandes and Hanke, 2017; Gonzalez *et al*., 2016) was adopted for this research. At each location and during each monitoring period, one person visually monitored and recorded macroplastic moving down the river using the RIMMEL app, and a second person completed the same task using a paper version of the RIMMEL app. The two-visual plastic 'observers' worked separately and did not confer or support each other in the identification of the plastic samples. To undertake the visual assessment of macroplastic transported down the monitored rivers, the monitoring location upstream from the river mouth (with fluvial flow) was selected where a vantage point centred over the river was available (e. g., a bridge, preferably ≤10 m above the water surface). The visual monitoring point was specific to the location and aimed to provide an illustrative observation track for each river. The Swartkops River is also comparatively wide (110 m), but the bridge is ~4 m above the water surface and has a comparatively slow flow velocity (<0. 4 m/s). The observation track for the Swartkops River at the Colour Bridge of 15 m was selected.

2.6 CITIZENS IN SCIENCE

Citizen scientists are increasingly being used in the collection of field data, particularly with the use of digital tools (Silvertown, 2009; Bonney et al., 2014; de Sherbinin et al., 2019). The increased value of datasets can contribute to more efficient data entry methods in the field and advance research (Newman et al., 2012). Citizens' science-based data collection can be a cost-effective method while raising public awareness of this topic (Rambonnet et al., 2019). Freshwater waste monitoring using citizen scientists is a fast-growing approach to monitoring plastic waste in rivers and wetlands. It can be used to identify plastic sources and sinks, thereby optimizing resources spent on clean-up operations, and reducing the amount of plastic waste being deposited into the ocean.

Several citizen science data collection efforts have been adopted in the past years, as the plastic pollution issue is visual and well known to the greater masses of the public. Buytaert et al. (2014) suggest that although the nature of citizen science-based may not be the same as conventional data, it has been proven to be of exceptional value for riverine and marine plastic research. For rivers, several citizen science studies were performed on Chilean and German rivers. In both studies, schoolchildren were motivated to participate in sampling and quantifying plastics along riverbanks (Rech et al., 2015; Kiessling et al., 2019).

There is also continuous development of new citizen science data collection. Simple smartphone-based apps permit data collection of for example rainfall (Davids et al., 2019) and stream water level (Seibert et al., 2019). The CrowdWater app (Seibert et al., 2019) has recently been extended with a plastic measurement module for collecting more specific data on floating plastics in rivers and plastic on riverbanks. This protocol provides simplicity when compared to existing methods as it allows for more rapid assessments. For example, the OSPAR Beach Litter (OSPAR Commission, 2010) and River-OSPAR (Schone Rivieren, 2019) protocols use item category lists with more than 100 item categories. Also, they require a minimum sampling length of 100m. The Plastic Pirates Method (Kiessling et al., 2019) on the other hand is designed for data collection by school children. Floating plastic was measured on the Klang, which is one of Malaysia's main rivers and flows through the city of Kuala Lumpur. Field observations were made on the Jalan Tengku Kelana bridge in the city of Klang, an urbanized area approximately 18 km upstream of the river mouth. Measurements were taken every half-hour to an hour from 29 April to 4 May 2019, between 09:00 and 17:00. The CrowdWater app allows for crowd-based macroplastic observations everywhere around the world. Users can observe floating plastics in rivers and plastic on riverbanks. Observations include the number of observed plastic items, the composition, and information on for, e.g. the flow conditions. In South Africa, there is a lack of literature available on monitoring methods of macroplastics in rivers. Additionally, as a developing country, we also do not have access to plastic recycling equipment due to our financial status.

3. METHODOLOGY: EVOLUTION OF THE MACROPLASTIC SAMPLING PROTOCOL

The macroplastic sampling protocol underwent several iterations, each introducing modifications to enhance the effectiveness and feasibility of the sampling process. Modifications were introduced based on input from the project team, consultation with industry experts, and input from citizen scientists. The section below details the various changes to the microplastic sampling protocol throughout the project. The final (detailed) version is available in the accompanying technical sampling protocol report.

3.1 DESKTOP SITE SELECTION

Site selection is critical to this investigation since it affects the density and type of waste sampled (Tasseron et al., 2020). This section remained relatively unchanged. To commence infield sampling, a high-level desktop prioritisation is required to establish potential sampling regions. ArcGIS 10.8.2 was used to create a fishnet over the uMsunduzi study boundary, similar to the fishnet-based technique employed by Xu et al., (2017) using national landcover data. A fishnet is a feature class that has a grid of rectangular cells, similar to a quarter degree square (QDS) system. Each rectangle in the grid measured 250 hectares and had 20 rows and 20 columns.

Thereafter, a land use classification exercise was performed to identify areas that are prone to plastic pollution, using the assumption that:

1. More accumulation of plastics occurs on the inner and outer bends of a river than on a straight stretch of river (Corcoran et al., 2019);
2. Landuse activities closer, i.e. proximity, to the river may interact more frequently and may contribute to plastic pollution (Alam et al., 2019);
3. Wetlands and rivers act as plastic traps and transport mechanisms; and
4. Certain land use activities contribute more to pollution than others (i.e. formal residence vs informal residence) (Moss et al., 2021).

To highlight landcover activities that contribute to plastic pollution, the South African National Landcover 2020 was reclassified into the categories shown in Table 2 below. This method ensures that sample sites are chosen in a spatially representative manner. These landcover activities were then weighted 1-10 (1 = lowest plastic contributor and 10 = highest plastic contributor) for further analyses based on expert input from four waste management stakeholders (private consultant, non-profit organisation, university, government).

Table 2: Landcover classification and weighting

Landcover Type	Final Weighted Score
Landfill	9
Informal residential	9
Road	8
1:100-year flood line	7
Wetlands	7
Industry	7
Urban recreational	6
Formal residential	6
Commercial	6
Villages/small holdings	5

A pivot table was used to convert the total area for each land use per grid (n=58) to a percentage. The weights mentioned above were multiplied by these proportions and added together to yield a total grid score. The final sites are chosen at the discretion of the team leader (specified in Team composition), who should prioritise team safety and accessibility to the site. Furthermore, if a priority grid has wetlands that have been extensively modified/transformed to the point where they can no longer function as a wetland, or if a grid is largely riverine with little wetland area to sample, alternate grids can be chosen.

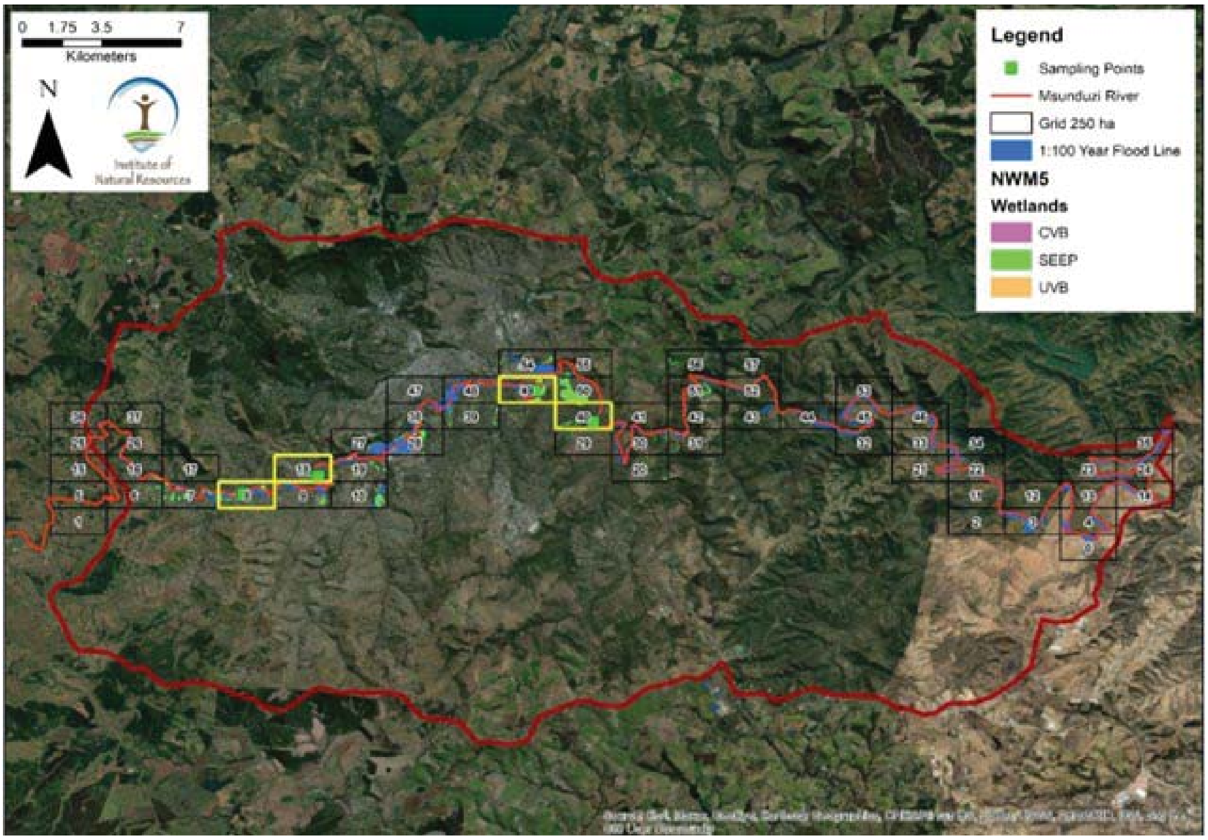

Figure 2: Output of the desktop site selection process within the uMsunduzi Catchment.

A disturbance profile was generated for each site using a combination of desktop and in-situ inspection (visual evaluation) of disturbances (following Govender et al., 2020). The intensity of the disturbances was determined using a typology and scoring system developed for estuaries by Govender et al., (2020). At each sample event, all sites will be scored. Human settlements, industrial activity, recreational parks, roads/access, and unlawful dumping are among the disruptions that will be considered. Each disturbance can carry a score between 0-4 (0 = absent, 1 = low, 2 = moderate, 3 = high and 4 = very high) and each site can be awarded a maximum of 20 (sum of all disturbances per site) and expressed as a total disturbance score (TDS).

3.2 RIVER SAMPLING

3.2.1 Team Composition

The citizen science method of monitoring macroplastic in rivers and wetlands should be carried out by one Team Leader, and at least three trained citizen scientists (roles and responsibilities defined in the technical sampling protocol report.. Teams should have one Visual Assessor and two Plastic Samplers. The Visual Assessor should be most familiar with the plastic categories described in the Plastic Typology and main land uses and activities, while the Plastic Samplers need only be familiar with the typology and sampling methods.

3.2.2 Visual Sampling

In the first iteration of the project, visual sampling involved a desktop exercise conducted by the project leader. However, this initial approach was deemed insufficient as it failed to provide detailed information regarding the surrounding area's land use. To address this limitation, the sampling method was revised in the second iteration. The project team incorporated a 12-minute stationary visual observation to be conducted in the field, complemented by the desktop exercise. By merging visual sampling and site characterization into a single step, the team could gather comprehensive data while simultaneously performing a 3 x 100-metre walk at the first sampling point. This change streamlined the process and eliminated the unproductive nature of stationary visual sampling, which struggled to identify plastic debris located more than 5 metres away.

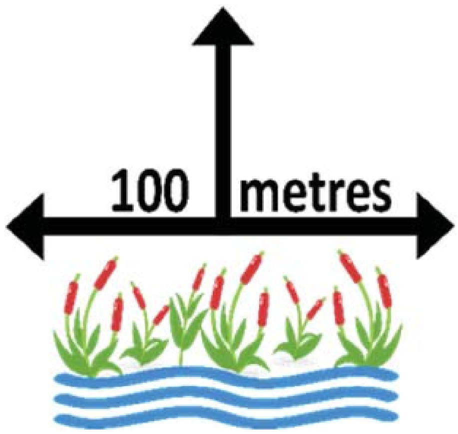

Figure 3: Visual sampling illustration.

3.2.3 Site Characterisation

In the initial iteration, site characterization involved a 5-minute walk-around followed by completing a site characterization form. Although this approach provided some valuable insights, it did not undergo any significant changes throughout the project's iterations. Hence, the sampling method for site characterization remained relatively consistent and reliable across the project's duration.

3.2.4 In-stream Sampling

The first iteration employed a single 5-minute sampling duration to collect plastic debris within the river. However, the project team recognized the need to increase statistical power by replicating the sampling process across three points at each site. Consequently, the second iteration introduced a change wherein in-stream sampling was conducted three times, with each sampling instance lasting 5 minutes. This alteration aimed to improve the robustness of data collection. However, upon subsequent analysis, it was discovered that the 5-minute duration did not yield significantly different results compared to a shorter duration. Hence, in the third iteration, the project team reduced the sampling time to 1 minute while still ensuring the absence of plastic debris in any of the samples. This adjustment effectively saved time without compromising the accuracy of the findings.

3.2.5 Edge Sampling

Initially, edge sampling involved a 1 x 5-metre scoop and a walk parallel to the river, with plastic debris in contact with the water collected. The first change made to this sampling method was moving the sampling points at least 1 metre away from the river's edge, prioritizing the safety of citizen scientists. Additionally, the team included sampling at the inner and outer bends of the river due to their hydrological significance. However, in practice, these modifications were found to be challenging to handle effectively. Consequently, in the third iteration, the edge sampling protocol was revised to three 5-metre samplings parallel to the river, disregarding vegetation, or bend location. This adjustment aimed to simplify the sampling process while still ensuring data collection along the river's edge.

Figure 4: Illustration of edge sampling.

3.2.6 Bank Sampling

Like edge sampling, bank sampling underwent modifications throughout the project iterations. The initial approach involved a 1 x 5-metre transect perpendicular to the river, but like edge sampling, safety concerns led to moving the sampling points away from the river's edge. Moreover, the inclusion of inner and outer bend sampling based on hydrological considerations was introduced. However, due to the practical challenges associated with these modifications, the project team decided to remove the inner and outer bend sampling from the protocol in the third iteration. Instead, bank sampling involved three 5-metre samplings perpendicular to the river, with points spaced 50-100 metres apart, irrespective of vegetation or bend. This change aimed to simplify the sampling process and improve its manageability.

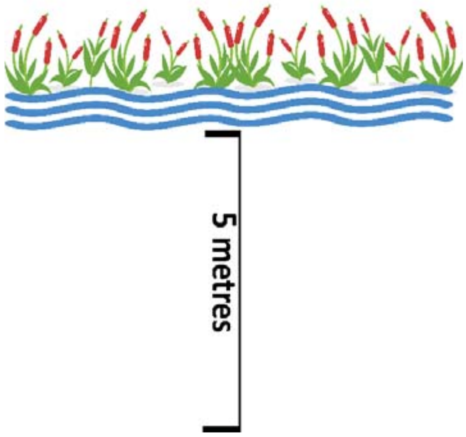

Figure 5: Illustration of bank sampling.

The modifications made to the sampling methods throughout the iterations of the plastic pollution research project in rivers reflect the project team's commitment to refining and enhancing data collection techniques. The changes implemented were driven by the need for more comprehensive characterization, increased statistical power, and practical considerations. By incorporating feedback from previous iterations, the project team successfully streamlined the sampling process while maintaining the integrity and accuracy of the collected data. These iterative improvements contribute to advancing our understanding of plastic pollution in rivers and support future research efforts in this critical environmental issue.

3.3 WETLAND SAMPLING

Initially, wetland sampling involved a visual assessment conducted as a desktop exercise by the project leader. However, this approach proved insufficient in providing detailed information about the surrounding area's land use, a crucial factor in understanding plastic pollution. As a result, the sampling method was revised in the second iteration. The project team combined visual sampling and site characterization into a single step, integrating both processes during a 3 x 100-metre walk at the first sampling point. This modification streamlined the process by eliminating the need for separate visual assessment and site characterization activities. Furthermore, it addressed the limitations of stationary visual sampling, which proved unproductive in identifying plastic debris located beyond 5 metres.

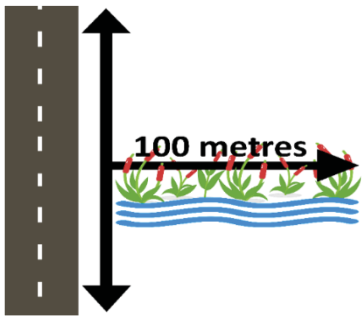

Figure 6: Illustration of wetland visual assessment.

Figure 7: Wetland path clearing and sampling in wetlands.

3.3.1 Site Characterization

Site characterization initially involved a 5-minute walk-around, followed by completing a site characterization form. This method provided valuable insights into the characteristics of the wetland but did not undergo significant changes throughout the iterations. Consequently, the site characterization sampling method remained relatively consistent and reliable throughout the project.

3.3.2 Edge Sampling

In the initial iteration, edge sampling included collecting samples within the wetland area. However, as the project progressed, the team decided to focus solely on sampling along the edges of the wetland. This change was motivated by safety concerns and the realization that plastic debris within the wetland was mostly trampled and submerged. The decision to exclude wetland sampling aimed to streamline the process and eliminate unnecessary and unsafe sampling practices. In the third iteration, the project team conducted 1 x 5-metre edge sampling, parallel to the wetland's edge. This adjustment enabled consistent sampling across different edge locations while ensuring the safety of the researchers. Throughout the project's iterations, the sampling method for edge sampling experienced a significant change in the number of sampling points. Initially, only one sampling point was chosen for edge sampling. However, in the third iteration, the number of sampling points was increased to three. This modification aimed to improve the statistical power of the data collected. By increasing the number of sampling points, the project team could gather more representative samples from different areas along the wetland's edge. This change enhanced the project's ability to draw accurate conclusions about plastic pollution in the wetland environment.

The iterative improvements were driven by the need for more comprehensive characterization, practical considerations, and increased statistical power. By integrating visual sampling and site characterization, streamlining the edge sampling process, and increasing the number of sampling points, the project team aimed to enhance the accuracy and efficiency of the sampling methods. These modifications contribute to advancing our understanding of plastic pollution in wetland environments and support future research efforts addressing this critical environmental concern.

3.4 IMPLEMENTING THE PILOT STUDY

Sampling teams were organised to implement the protocol at each site. Each team consisted of three citizen scientists and was supervised by one scientist (project team). The Figure 8 below illustrate the sampling efforts at each site.

Figure 8: Citizen scientists performing edge sampling at Site 1 – Edendale (29° 38' 50.71194" S, 30° 17' 33.648" E)

The following data was collected from the pilot study and recorded on the data sheet that was developed specifically for this project (Figure 9):

- Plastic data from transect sampling;
- Plastic data from instream sampling;
- Site characterisation data (including surrounding land use activities) from visual assessment.

Name:	
Date:	
Time:	
Site:	

Item	Composition	Properties	X
Soft drinks	Polyethylene Terephthalate (PET)	Clear, tough, barrier to moisture, can add colour	
Disposable water bottles			
Biscuit trays			
Salad dressing			
Salad domes			
Combs			
Rope			
Shopping bags	High-Density Polyethylene (HDPE)	Hard or semi flexible, waxy surface	
Freezer bags			
milk bottles			
Juice bottles			
Shampoo bottles			
Detergent bottles			
Crates			
Detergent containers			
Toys			
Cosmetic containers	Polyvinyl chloride (PVC)	Strong, tough, can be clear or colour can be added	
Electrical pipes			
Plumbing pipes			
Wall cladding			
Cling wrap	Low-density polyethylene	Strong, flexible, waxy surface, scratches easily	
Garbage bags			
Squeeze bottles			
Irrigation tubing			
Bottles	Polypropylene	Hard but flexible, waxy surface	
Ice cream tubs			
Chip bags			
Microwave dishes			
Garden furniture			
Kettles			
Lunch boxes			
Take-out containers			
Disposable cups and plates			
Disposable cutlery	Polystyrene	Clear, glassy, rigid	
CD Cases			
Meat trays	Expanded polystyrene	Foam	
Plastic food boxes			
Plastic CDs and DVDs	Other	Includes polycarbonate, polyctide, acrylic, acrylonitrile butadiene, styrene, fiberglass, and nylon	
Large water bottles with multiple-litre capacity			
Wigs, artificial hair			
Eyeglasses			
Lighting fixtures			

Name:	
Date:	
Time:	
Site:	

	Presence (mark with X)
Commerce	
Shopping centre	
Takeaway/Restaurants	
Informal traders	
Agriculture	
Subsistence	
Commercial	
Residential	
Township	
Sub urban	
City	
Rural/Village	
Religion & Recreation	
Sports	
Culture	
Religious activities	
Park	
Fishing	
Other	
Highway	
Tar road	
Dirt road	
Foot path	
Industry	
Illegal dumping	

Figure 9: Field data sheets used to record visual assessment data.

The plastic samples were then collected and transported back to the lab where a process of cleaning and sorting, as per the protocol guidelines, was undertaken (more detail on cleaning and sorting can be found in the technical sampling protocol report).

Figure 10: Citizen scientists at work cleaning and sorting plastic (29°37'1.17"S, 30°23'37.63"E)

The citizen scientists then proceeded to catalogue and weigh each plastic item, per site and recorded in a spreadsheet for further analysis (see Table 3 for reference).

Figure 11: Citizen scientists at weighing and sorting plastic in winter of 2023 (29°37'1.17"S, 30°23'37.63"E)

Table 3: Macroplastic data summary table

Site: 1/Team A													
Date02/08/22	RIVER										WETLAND		
Plastic type/category	Quantity	IN1	IN2	0	UEP1	UBP1	VEP2	UB2	VEP3	VBP3	WDE1	WDE2	WDE3
PET	n	0	0	0	1	1	0	1	0	0	4	0	0
	g	0	0	0	20	25	0	12	0	0	130	0	0
HDPE	n	0	0	0	6	7	23	0	11	14		6	13
	g	0	0	0	1.8465	5	245	0	31	75		21.59	50
PVC	n	0	0	0	0	0	0	0	0	0	0	0	0
	g	0	0	0	0	0	0	0	0	0	0	0	0
LDPE	n	0	0	1	11	35	33	10	5	15		13	22
	g	0	0	0.021	8.453	20	150	11.8346	59.499	6.6765		12.36	20
PP	n	0	0	0	3	10	3	7	10	0	0	20	18
	g	0	0	0	8.853	100	35	2.035	35.0615	0	0	85	50
PS	n	0	0	0	8	0	0	6	0	0	0		13
	g	0	0	0	7.6753	0	0	0.5881	0	0	0		19.1289
OTHER	n	0	0	0	0	0	3	0	1	3	0	5	4
	g	0	0	0	0	0	65	0	0.045	65	0	1.0366	0.075

IN - Instream
UEP - unvegetated edge point
UB - unvegetated bank point
VEP - vegetated edge point
VBP -vegetated bank point
WDE - wetland disturbed edge

3.5 PLASTIC TYPOLOGY

Aside from the monitoring procedure, another important project product is a freshwater plastic typology. This will be used in the laboratory to categorise macroplastic samples to highlight the most "problematic" plastic types in order to identify probable sources and hence better inform mitigation strategies.

The categories specified by the UNEP (2019) serve as the foundation for the plastic typology. The plastic typology described in Table 4 below was produced in collaboration with citizen scientists based on objects detected during an in-field training session held on July 14, 2022. The typology was refined after being challenged one-on-one by numerous specialists in the field of waste management. As a result of piloting the data collecting methods, the typology and accompanying data collection sheets have been improved to include a field sheet and a lab sorting sheet, rather than the previously proposed single plastic categorisation sheet.

Table 4: Plastic categories used to develop macroplastic typology for citizen science river and wetland monitoring.

CATEGORY	ITEMS	CHEMICAL COMPOSITION
1	Cooldrink bottles, Water bottles, Salad dressing bottles, Medicine bottles, Peanut butter bottles, Combs, Rope, Tote bags, Carpet	Polyethylene Terephthalate
2	Milk jugs, Juice containers, Grocery bags, Bin bags, Motor oil containers, Shampoo and conditioner bottles, Soap bottles, Detergent containers, Bleach containers, Toys	High-Density Polyethylene
3	Plumbing pipes, Tile, Shoes, Gutters	Polyvinyl chloride
4	Cling wrap, Sandwich bags, Squeezable bottles for condiments such as honey and mustard, Grocery bags, Frozen food bags, Flexible container lids	Low-density polyethylene
5	Disposable nappies, Tupperware, Kitchenware, Margarine tubs, Yogurt containers, Prescription bottles, Bottle caps, Take-out containers, Disposable cups, and plates	Polypropylene
6	Disposable coffee cups, Plastic food boxes, Packing foam	Polystyrene
7	Plastic CDs and DVDs, Large water bottles with multiple-litre capacity, medical storage containers, Eyeglasses, Lighting fixtures	(polycarbonate, polyctide, acrylic, acrylonitrile butadiene, styrene, fiberglass, and nylon)

3.6 STATISTICAL TEST

An Analysis of variance (ANOVA) was performed using IBM SPSS Statistics. AN ANOVA to determine significant difference between sites average total plastics. An ANOVA was also performed to determine significant different between sampling areas in summer and winter. The F-statistic and degrees of freedom (df) are key components of ANOVA results. A t-test was performed to compared significant differences between summer and winter on each sampling area.

4. RESULTS

The development of the protocol consisted of a series of pilot experiments at four sites along the Msunduzi River and four wetlands adjacent to the river, with each site being sampled twice in winter and twice in summer sampling events. This report contains the findings and comparison of the summer versus winter seasonal sampling. The present report contains the findings of the summer season sampling, conducted on the 5th December 2023, a follow-up on the winter season sampling that was conducted on the 12th June 2023.

4.1 SITE IDENTIFICATION

As described previously, a process was followed to identify four sampling sites [river sites (n = 4) and four wetlands (n = 4)]. Three grids with the highest scores (between 40-50) were selected and a fourth grid which resulted in a moderate score (between 30-40) to further test the effectiveness of the tool. Table 4 indicates the sites that have been selected, i.e. grid 8, 18, 49 and 40. If two consecutive grids are deemed a priority, the downstream most grid was selected, as was the case with grids 7 and 8.

Table 5: Study site selection.

Site name	Location	Coordinates
Site 1	Wadley Stadium – Edendale	29°38'46.42"S, 30°18'2.97"E
Site 2	Main access road – Ashdown	29°38'15.81"S, 30°20'7.45"E
Site 3	Downstream New England landfill	29°36'11.96"S, 30°25'21.32"E
Site 4	Housing estate – Lincoln Meade	29°37'5.34"S, 30°26'42.67"E

Site 1 is located in upper Edendale in the vicinity of Wadley Stadium (29°38'46.42"S, 30°18'2.97"E) and is characterised as an informal residential housing area. River accessibility was problematic; however, the team has no issues sampling the wetland located adjacent to the road. There is evidence of illegal dumping within and alongside the river and wetland.

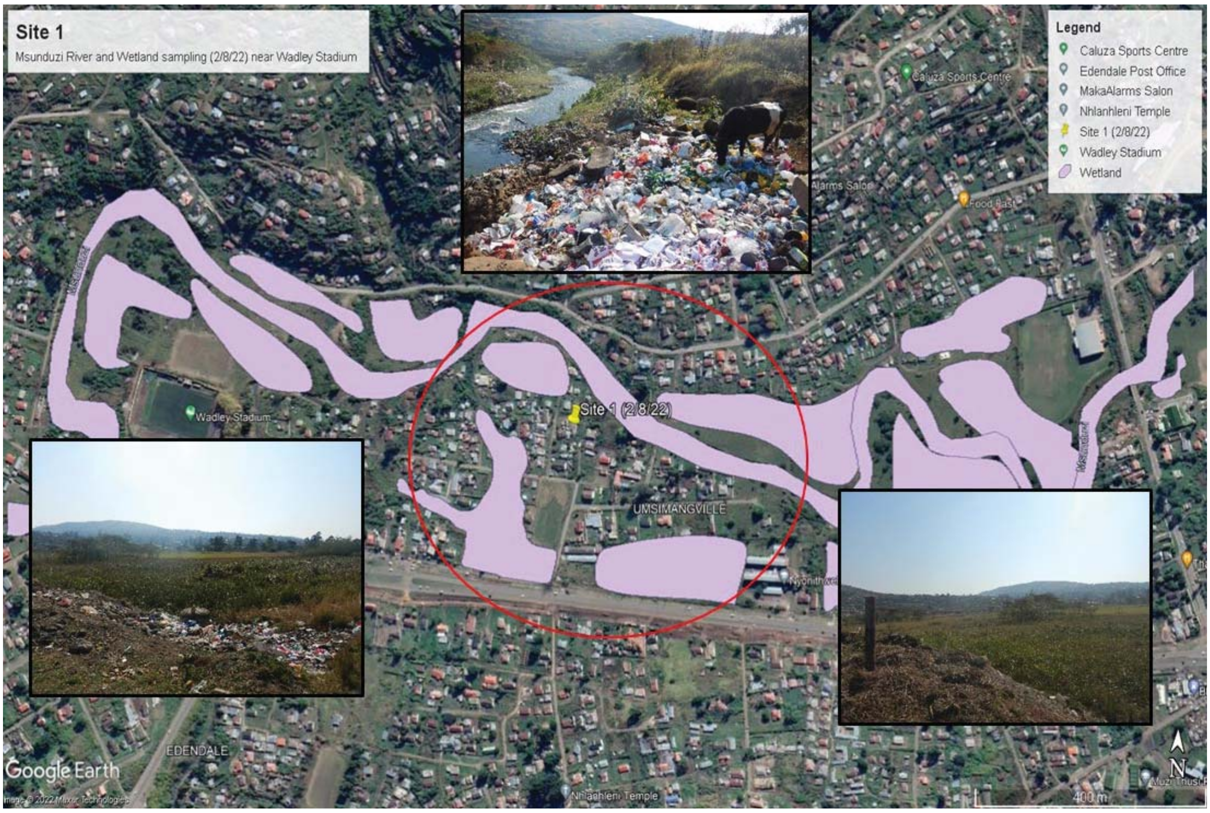

Figure 12: Site 1 - Wadley Stadium in Edendale (29°38'46.42"S, 30°18'2.97"E)

Site 2, downstream from Site 1 in Edendale is adjacent to a main access road to the residential area (29°38'15.81"S, 30°20'7.45"E). Here too, illegal dumping is noticeable issue along the riverbanks and foot paths.

Figure 13: Site 2 - Main access road to Ashdown (29°38'15.81"S, 30°20'7.45"E)

Site 3 is located downstream from the New England landfill in Hayfields (29°36'11.96"S, 30°25'21.32"E). The main concerns noted here is the fact that during high rainfall seasons, flood waters laden with plastic collected from the landfill are transported and deposited in the vicinity.

Figure 14: Site 3 - Downstream of the New England landfill at Darville WWTW (29°36'11.96"S, 30°25'21.32"E)

The last sampling Site 4 (29°37'5.34"S, 30°26'42.67"E), located downstream of a formal residential area in Lincoln Meade, was purposefully included as area with a moderate priority score, in attempts to illustrate the effectiveness of the desktop analysis through sampling both highly polluted versus moderately polluted areas. Access to the wetlands at this was restricted as most of the area is private property. In other areas, it appears that the National Wetland Map Five erroneously delineated riparian areas as wetlands. The wetland was at Site 4 was disregarded from the analysis as no other wetland in the close proximity was available for sampling.

Figure 15: Site 4 - Downstream of formal residential area below Lincoln Meade (29°37'5.34"S, 30°26'42.67"E)

The desktop process followed to select priority sites proved to be an effective. Ground truthing validated the excessive amounts of pollution at these sites. The biggest challenge, however, is the fact that sampling sites were confined to the upper reaches of the catchment and located next to each other, a consequence of landcover. All the sites are indeed priority areas, however their limited spatial variability across the catchment.

Outcomes from the land use disturbance assessment will at this point be used to further substantiate plastic hotspots. The visual assessment provided data on the land use and disturbance within a 1 km radius of the sampling sites. The TDS has been calculated and illustrated in the Table 6 below, showing the severity of the disturbances (high to low) impacting the river at that point.

Table 6: Total Disturbance Scores (TDS) based on visual observations of land use activities at each pilot site.

Land use	Site 1	Site 2	Site 3	Site 4
Human settlements	4	4	1	2
Industrial activities	0	0	4	0
Recreational parks	3	1	1	2
Roads/access	4	1	4	2
Illegal dumping	4	3	4	4
TDS	**15**	**9**	**14**	**10**

4.2 RIVERINE MACROPLASTIC ANALYSIS

Macroplastic samples were systematically collected from four different sites along the uMsunduzi River and its adjacent wetlands, employing a comprehensive sampling methodology that encompassed sampling along the riverbank, edge, and in the river (instream). The plastic quantities and typology detected at various sites are represented in the results below. As depicted in Figure 16, over the two-year study period, the findings reveal a consistent trend wherein summer seasons generally exhibited higher macroplastic accumulations compared to winter seasons. For Site 1, the data indicates a substantial difference between the summer season of 2022 and 2023, recording 785.6 g of plastic in summer 2022 in contrast to 276.72 g in summer 2023 ($t = 0.569; df = 4; p = 0.001$). Whereas no significant differences were observed for the winter season during 2022 and 2023, yielding 330.33 g and 199.67 g of plastic, respectively.

At Site 2, a total of 662.47 g of microplastic was observed during the summer and 360.19 g over the winter periods of 2023, showing a significant difference between plastic accumulated during these seasons ($p<0.05$). These results show a notable increase in microplastic accumulation from 2022, which reported 356.66 g and 157.33 g for the summer and winter sampling, accordingly ($t= 1.72, df=4; p=0.173$). Moreover, Site 3 witnessed a decline in the overall plastic accumulation from summer 2022 to 2023, with the data revealing a decrease from 828.67 g of plastic in 2022 to 341.16 g in 2023 ($t=2.05; df=4; p=0.0089$). Conversely, Site 3 also experienced a marginal increase of plastic during the winter sampling between 2022 and 2023, with the plastic quantity increasing from 405.37 g in 2022 to 514.13 g in 2023, with the t-test indicated a significant difference between the periods ($t=0.095; df=4=; p<0.05$).

There was no significant difference between summer and winter sampling of 2023 Site 4 ($p > 0.05$), with summer reporting 979.70 g plastic accumulation and winter observing 888.311 g. Additionally, there was no significant difference between summer and winter 2022 at Site 4 ($p > 0.05$), as summer recorded 324.67 g of plastic and winter recorded slightly more with 366.35 g of plastic in 2022. Nonetheless, a significant overall increase in total microplastic was observed at Site 4 between 2022 and 2023, reporting a total increase from 691.03 g in 2022 to 1 868,01 g in 2023 (both summer and winter).

Over a two-year study period, the predominant trend of higher macroplastic accumulation was observed across the sampling sites (except in Site 3 2023 and Site 4 2022) during summer season in comparison to the winter season. In 2022, the highest plastic quantities were recorded at sites 1 and 3, with a total macroplastic accumulation of 1116 g across both summer and winter sampling at Site 1 and 1234.04 g at Site 3. In 2023, sites 4 and 2 exhibited the highest plastic accumulation, with a total quantity of 1022.66 g at Site 2 and 1868.01 g at Site 4. ANOVA analysis revealed no significant difference in plastic quantities between sites during the summer of 2022 ($F=0.192; df=3,8; p=0.894$), and similarly, no significant difference between sites was observed in the year 2023 ($p>0.05$). Specifically, in 2023, there was no discernible variation in quantity between the sites ($F=0.257; df=3.8; p=0.074$).

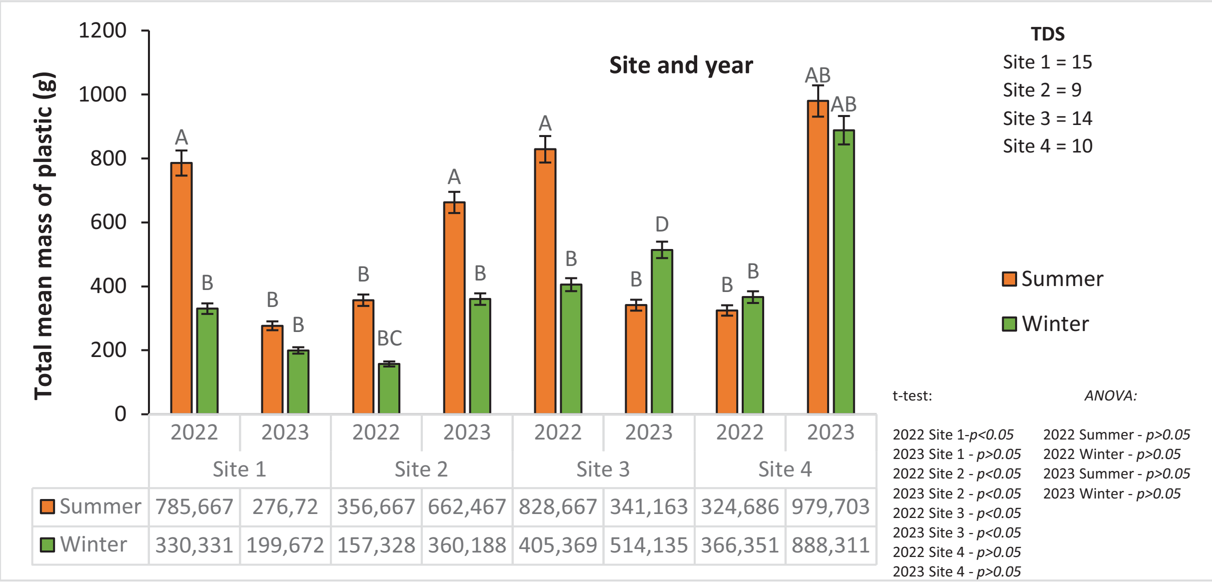

Figure 16: Average mass of plastic sampled at various sites along the uMsunduzi River for summer and winter of 2022-2023.

Figure 17 specifically focuses on the average mass of plastic accumulation at Site 1 across the different sampling areas, over the period of 2022 to 2023. In 2022, the bank sampling exhibited a plastic accumulation of 349 g during the summer and 107.71 g during the winter, with a significant difference observed ($p = 0.021$). Whereas the bank sampling reported a decrease in macroplastic accumulation in 2023, recording 143.71 g of plastic during summer and 60.90 g during the winter season. For the edge sampling, a higher overall quantity of plastic was observed in 2022 in comparison to 2023. In 2022, the edge sampling yielded a total of 436.67 g of plastic accumulation during the summer and 222.61 g during the winter season, with no significant difference reported between the seasons ($p > 0.05$) (Figure 19). In 2023, the edge sampling observed a slightly higher accumulation of plastic in the winter (138.76 g) in comparison to the summer sampling (133,01 g), revealing no significant difference. On the contrary, the instream sampling yielded zero accumulation of plastic for both summer and winter of 2022 and 2023, with an exception to winter 2023, which yielded a very low quantity of 0.007 g. ANOVA revealed no significant difference in the average quantity of plastic between the sampling areas for both summer and winter over two years ($p > 0.05$). However, the t-test demonstrated a significant difference in plastic quantity between summer and winter on the bank and the edge sampling ($p < 0.05$) of for Site 1.

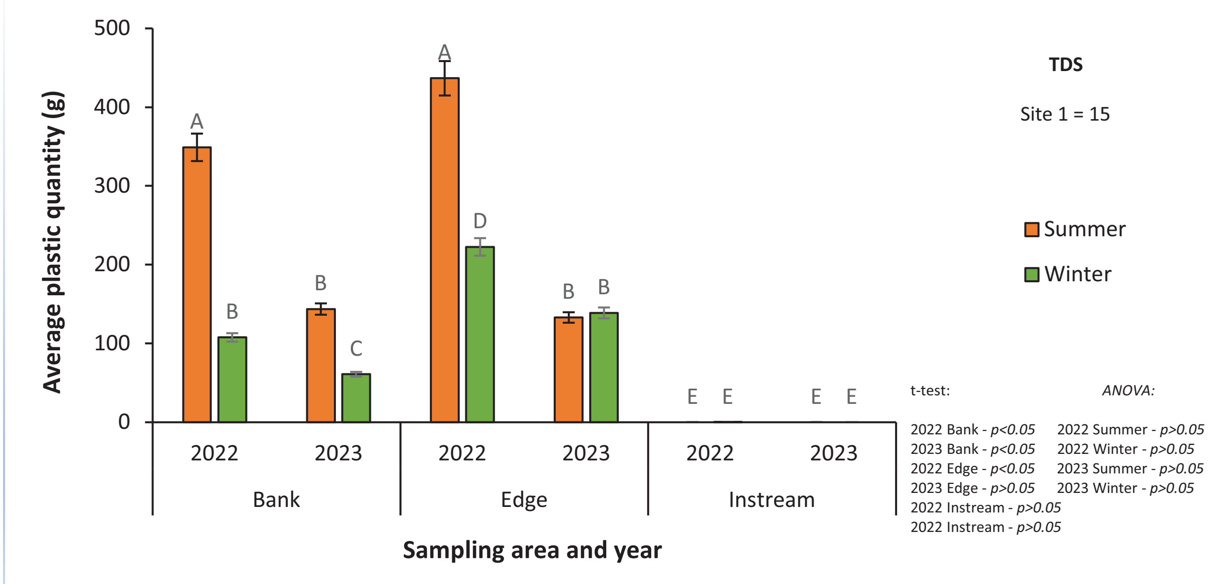

Figure 17: Average mass of plastic pollution in riverine area of Site 1 for summer and winter over a two-year period from 2022-2023, TDS = 15.

Figure 18 illustrates the average mass of plastic accumulation at Site 2 across the different sampling areas, over the period of 2022 to 2023. Notably, it was observed that the summer sampling events consistently recorded higher quantities of plastic compared to the winter season, across all sampling areas. Specifically, along the riverbank, the total plastic quantity in 2022 amounted to 166.67 g during summer and 45.96 g during winter. Whereas in 2023, the average accumulated plastic along the bank sampling increased, yielding 348.33 g in summer and 124.39 g during the winter sampling. Similarly, the summer sampling revealed greater plastic quantities for the edge sampling, reporting 190 g in summer 2022 in comparison to 111.37 g winter 2022 and 314.13 g in summer 2023 compared to 235.80 g winter 2023 (Figure 18). There was no significant difference between summer and winter plastic accumulation on the edge in the two years. Furthermore, ANOVA showed no significant difference in the quantity of plastic in summer and winter over the period of two years between the edge, bank, and stream ($F = 0.086; df = 3,8; p = 0.536$). Overall, the year 2023 recorder a higher accumulation of plastic for both bank and edge sampling. Lastly, the instream sampled recorded zero plastic quantities in both summer and winter seasons of 2022 and 2023.

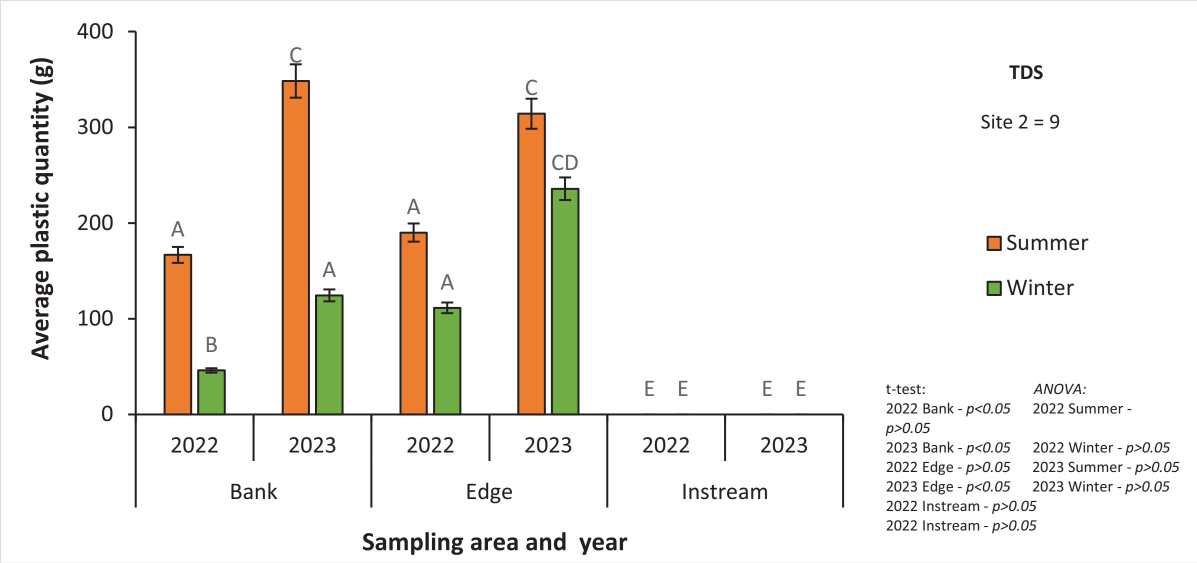

Figure 18: Average mass of plastic pollution in riverine area of Site 2 for summer and winter over a two-year period of 2022-2023, TDS = 9.

Figure 19 presents the average quantity of plastic collected at Site 3 over a two-year period of 2022-2023. In 2022, the bank sampling recorded 446.6 g in summer and 81.6 g in winter, exhibiting a significant difference according to the t-test. Whereas the bank sampling accumulated 183.21 g of plastic during summer and 278.02 g during winter of 2023. For the edge sampling, there was an accumulation of 323.7 g and 303 g in summer of 2022, with no significant difference observed. In 2023, the edge accumulated 157.94 g and 236.1 g during the summer and winter seasons, respectively (Figure 19). The decrease in plastic accumulated during the 2022 bank sampling at this site could be attributed to the steep gradient of the riverbank, limiting the project team's access. Safety concerns for citizen scientists further contributed to the restricted access to the river edge. Lastly, macroplastic accumulation for the instream sampling yielded zero plastic items. The ANOVA analysis indicated a significant difference in the quantity of plastic found between the bank, edge, and stream during the summer of 2022 ($p < 0.05$), but no significant difference during the winter period ($p = 0.2431$). The t-test revealed a significant difference in the quantity of plastic between summer and winter on the bank in 2022 ($p < 0.05$), emphasizing the importance of considering specific sampling locations and seasons when assessing macroplastic accumulation.

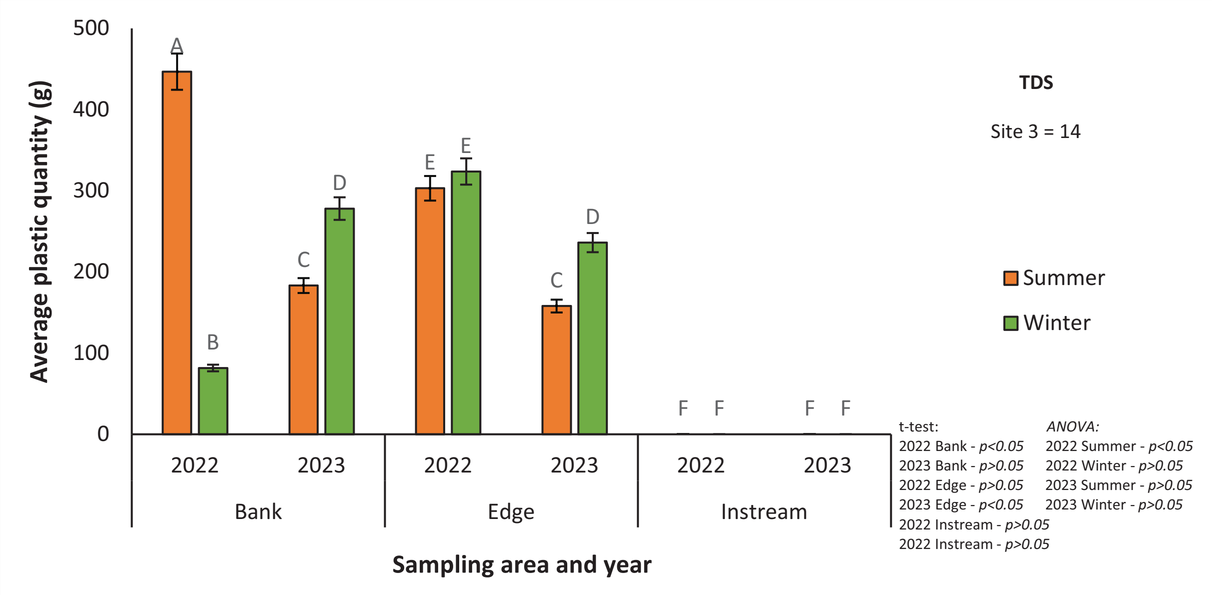

Figure 19: Average mass of plastic pollution in riverine area of Site 3 for summer and winter over a two-year period of 2022-2023, TDS = 14.

Figure 20 illustrates the plastic accumulation trend at Site 4, showcasing higher plastic quantities in summer compared to winter, both during 2022 and 2023. Along the riverbank, the plastic quantity reached 334.67 g in summer and 234.37 g in winter during 2022. A similar trend was observed during 2023 bank sampling, with the summer period accumulating 653.03 g of plastic in comparison to 470 g during the winter season. For the edge sampling, the plastic accumulation during 2022 amounted to 422.93 g in summer and 131.97 g in winter, while 2023 observed a decrease in plastic accumulation during both summer and winter, with 217.5 g and 59.75 g respectively (Figure 20). The instream sampling yielded zero accumulation of plastic for both summer and winter of 2022 and 2023.

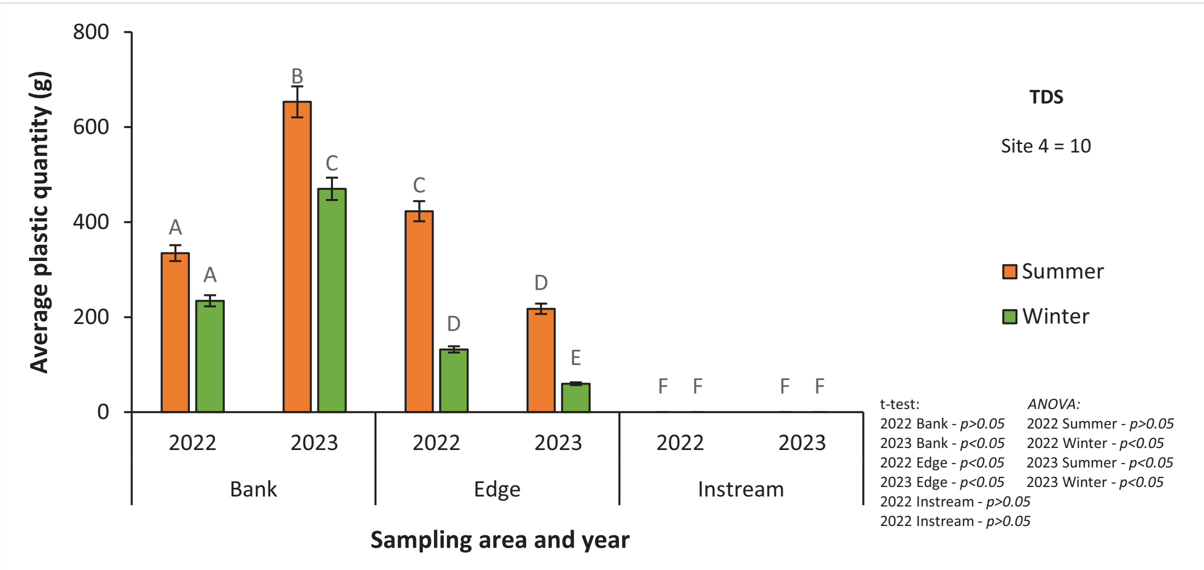

Figure 20: Average mass of plastic pollution in riverine area of Site 4 for summer and winter over a two-year period of 2022-2023, TDS =10.

Figure 21 and 22 present a comprehensive overview of the plastic typology determined during instream, edge, and bank sampling throughout the two-year period from 2022 to 2023 at Site 1 and Site 2, and Site 3 and Site 4. With reference to Figure 21, Site 1 observed LDPE as the most frequently occurring plastic obtained through the bank sampling during summer 2022, with a quantity of 550 g, followed by HDPE with an accumulation quantity of 282 g. However, in the summer 2023, the riverbank sampling produced less than 100 g of both LDPE and HDPE. In 2022, the contribution of the bank and edge sampling to macroplastic accumulation at Site 1 accounted for 33% and 41%, respectively (Figure 21). This contrasted with the percentages for 2023, where the bank and edge contributed 14% and 12%, respectively (Figure 21 - *top left*).

During winter, Site 1 accumulated 277. g and 158 g of LDPE plastic from the edge sampling for 2022 and 2023, respectively. During the winter 2022 season, PP amounted to 102.8 g of plastic accumulated from the bank sampling, while zero PP plastic was recorded during winter 2023. Furthermore, in winter 2022, Site 1 observed that 20% of plastic was accumulated from bank sampling and 42% from edge sampling (Figure 21). Meanwhile, during 2023, there was 12% and 26% plastic accumulated from bank and edge sampling, respectively (Figure 21 - *top right*).

At Site 2 during the summer sampling of 2023, PET (298 g on the bank), HDPE (247 g on the edge), and OTHER (196 g on the bank) emerged as the highest quantities of plastic. Notably, during the summer of 2022, Site 2 observed 16% of plastic accumulated from bank sampling and 19% from edge sampling. In contrast, the summer season of 2023 saw a shift, with 34% and 31% of total plastic accumulated from bank and edge sampling, respectively (see Figure 21 - *bottom left*).

In the winter period of 2023, OTHER dominated as the most prevalent plastic at Site 2, accumulating a mass of 466.58 g from edge sampling. Meanwhile, during the winter of 2022, LDPE and HDPE accounted for 123.62 g and 138.18 g, respectively, accumulated from edge sampling. Furthermore, the winter sampling of Site 2 in 2023 noted that edge sampling produced the highest plastic quantity at 46%, representing a significant increase from the 2022 edge sampling, which accounted for only 21% (Figure 21 – *bottom right*).

In summer, Site 3 exhibited a substantial quantity of HDPE, LDPE, PP and PET (Figure 22). HDPE reported the highest accumulation on the bank sampling at 535 g, followed by the edge at 300 g during the year 2022. Furthermore, LDPE accounted for 275 g and 310 g, from the bank and edge sampling of 2022, respectively (Figure 22). PP also contributed significantly, accumulating 210 g on the bank and 175 g on the edge sampling in 2022. In summer 2023, PP continued to demonstrate high accumulations, reaching 145 g from bank sampling and 183 g on the edge sampling (Figure 22). Furthermore, PET recorded notable quantities, with 175 g and 245 g accumulating on the bank and edge, respectively, in 2022. The summer 2022 period of Site 3 displayed a plastic accumulation of 38% and 33% on the bank and edge sampling, respectively. While the summer 2023 period observed lower quantities of 16% and 13% plastic from bank and edge, respectively (Figure 22 – *top left*).

During both winter periods of 2022-2023, Site 3 showed an accumulation of PET, HDPE, LDPE, PP, and PS. In 2023, the bank sampling accumulated a significant quantity of LDPE, reaching 355 g, while the edge sampling reported an accumulation of 268 g of LDPE plastic. Furthermore, both the bank and edge sampling of 2023 accumulated PP, measuring 175 g and 305 g, respectively. Whereas PS recorded 163.6 g from the bank sampling in 2023. The highest accumulation of HDPE was observed during the edge sampling of winter 2022, reporting a mass of 305 g. Furthermore, in winter 2022, Site 3 observed that only 9% of plastic was accumulated from bank sampling and 35 from edge sampling (Figure 22).

Meanwhile, during 2023, there was 30% and 26% plastic accumulated from bank and edge sampling, respectively (Figure 22 – *top right*).

During the summer of 2023, Site 4 exhibited substantial plastic accumulation of PET with 560 g and 435 g on the bank and edge, respectively. Furthermore, HDPE plastic reported notable quantities with 657 g of plastic from the bank during 2022 and 490 g on the bank sampling in 2023. PS and OTHER accumulated to 567.6 g from edge sampling in 2022, while OTHER reported 420 g of plastic from the bank sampling of 2023. The summer 2022 period of Site 4 displayed a plastic accumulation of 19% and 24% on the bank and edge sampling, respectively. While the summer 2023 period observed higher quantities of 38% and 19% plastic from bank and edge sampling, respectively (Figure 22 – *bottom left*).

In the winter of 2023, PET recorded the highest accumulations with 435 g from the bank sampling and 455 g on the edge sampling of Site 4 (Figure 22). Additionally, 307 g of HDPE was accumulated on the bank sampling during 2023. In 2022, LDPE recorded accumulations of 165 g and 270 g through the bank and edge sampling, accordingly. Furthermore, PS produced notably high accumulation from the bank sampling of 2023, measuring a mass of 405 g. Notably, during the winter of 2022, Site 4 observed 19% of plastic accumulated from bank sampling and only 11% from edge sampling. In contrast, the winter season of 2023 saw an increase, with 37% and 33% of total plastic accumulated from bank and edge sampling, respectively (see Figure 22 – *bottom right*).

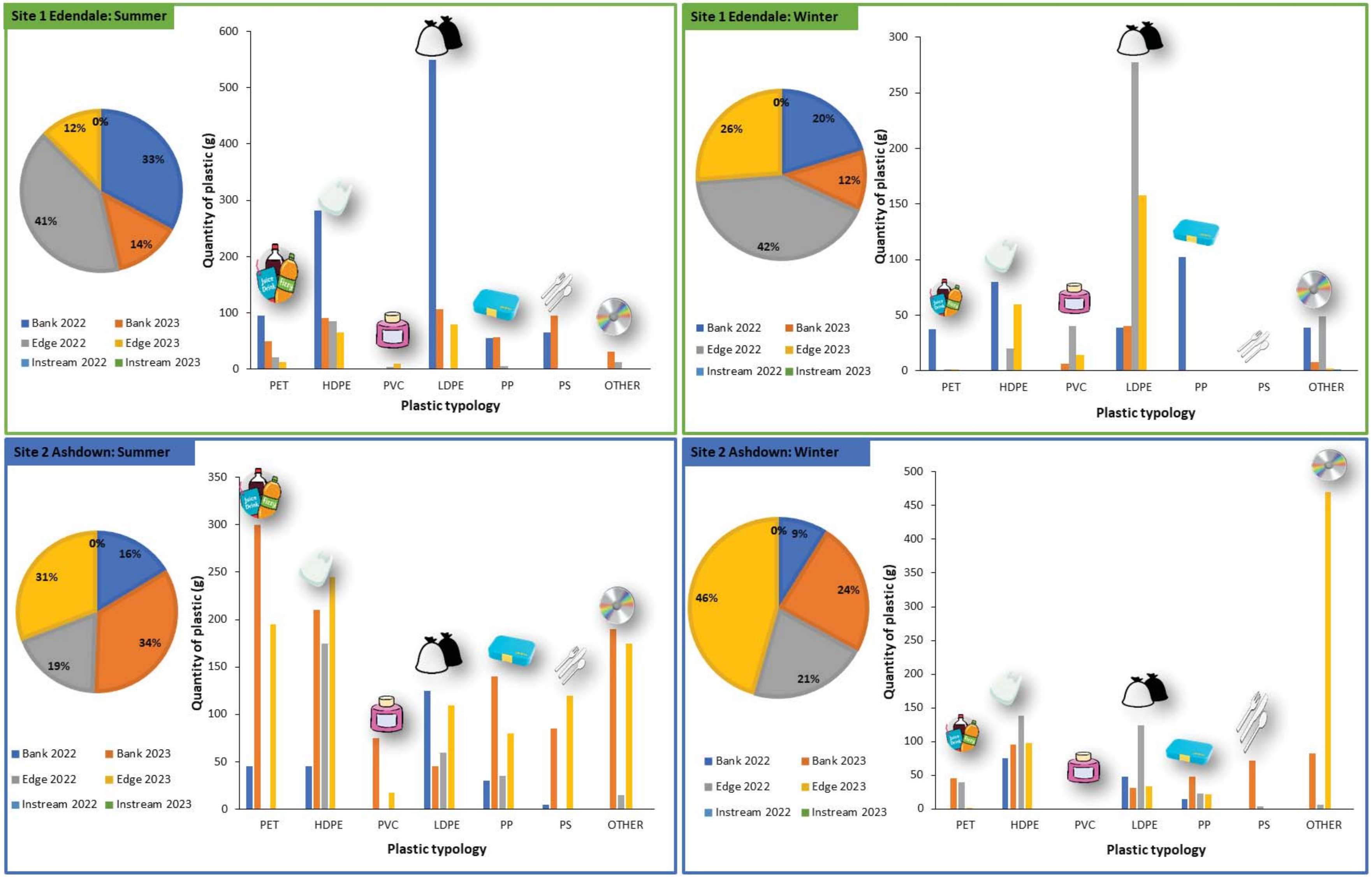

Figure 21: Site 1 and Site 2 total plastic typology determined instream, on the edge and bank of the uMsunduzi river during summer and winter.

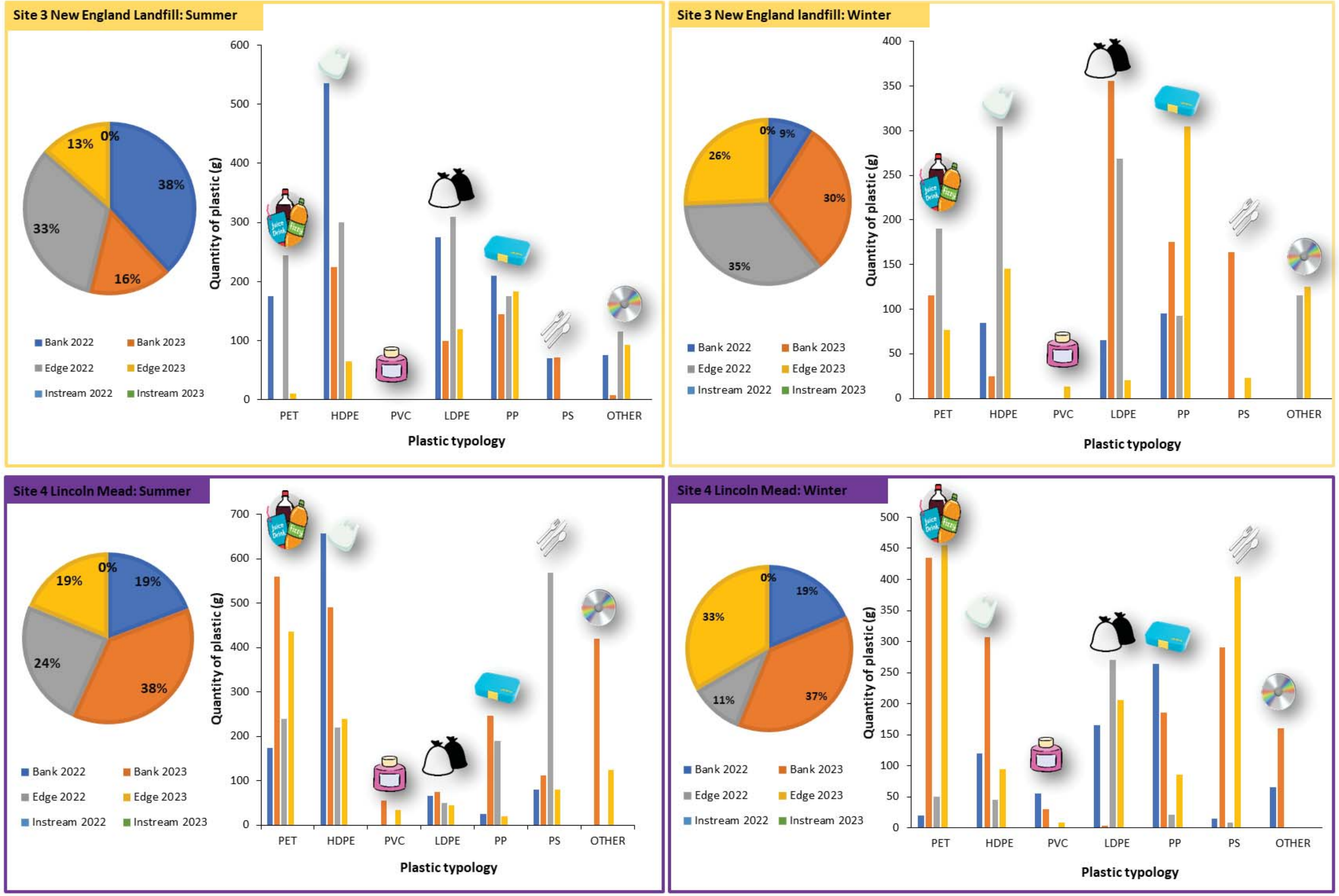

Figure 22: Site 3 and Site 4total plastic typology determined instream, on the edge and bank of the uMsunduzi river during summer and winter

4.3 WETLAND MACROPLASTIC ANALYSIS

In addition to the riverine sites, four adjacent wetland sites along the uMsunduzi River were also sampled for macroplastic accumulation. The plastic quantities and typology obtained from the different wetland sites are presented in the results below.

With reference to Figure 23, Site 1 exhibited the highest amount of plastic sampled in the wetland, registering a total of 387.6 g in summer (2022) and 235.46 g in winter (2023), as depicted in the figure. Site 2 recorded high quantities of plastic during the winter season of both 2022 and 2023, yielding 196.28 g and 114.63 g, respectively. Furthermore, Site 3 observed low accumulation of macroplastic in comparison to Site 1 and 2, reporting 50.9 g and 51 g during the summer and winter sampling of 2022, accordingly. While a significant difference was observed during the 2023 sampling with summer reported an increase of macroplastic to 101.87 g and winter recording a decrease in plastic accumulation to 6.33 g (Figure 23). An ANOVA comparing differences between sites revealed a significant variation in plastic found during both summer 2022 and 2023 ($F = 5.698; df = 3.8; p < 0.005$). During the winter period, there was also a significant difference in plastic accumulation across sites ($F = 4.723; df = 3,8; p < 0.05$). According to an independent t-test, there was a significant difference in plastic found during summer and winter at Site 2 and Site 3 in 2023 ($t = 0.159; df = 4; p < 0.05$). Furthermore, it must be noted that sampling was not conducted at Site 4 wetland due to restricted access to the site.

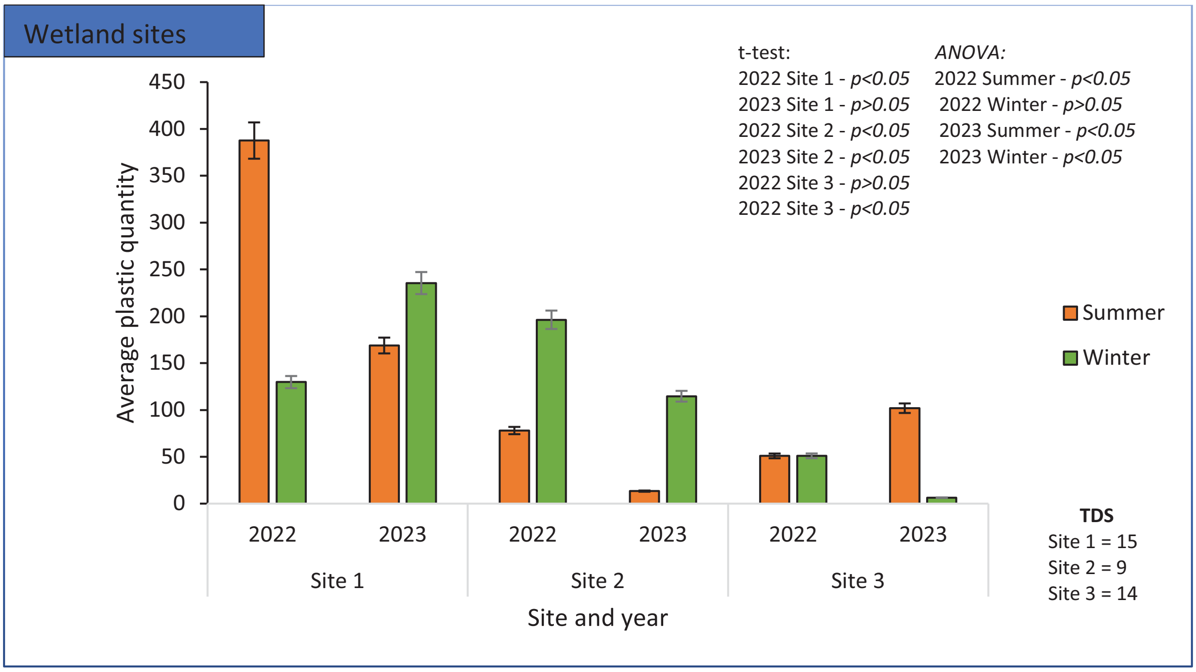

Figure 23: Average mass of plastic sampled at the four wetland sites along the uMsunduzi River for summer and winter of 2022-2023.

Figures 24 and 25 offer a comprehensive overview of the plastic typology observed across the four wetland sampling sites during the two-year period from 2022 to 2023. With reference to Figure 24, Site 1 (TDS = 15) stood out as the primary contributor, accumulating the highest amount of macroplastic during the summer of 2022, constituting 48% of the total plastic generated. Notably, HDPE, LDPE, PP, and OTHER were the most prevalent plastic typologies during this period, recording masses of 367.8 g, 340 g, 255 g, and 120 g, respectively. In the subsequent summer of 2023, Site 1 again recorded the highest accumulation of macroplastic, accounting for 21% of the total. The dominant plastic typologies during this period included LDPE (205 g), PP (105 g), and PS (82.3 g), which observed the largest quantities. Lastly, PET was consistently observed as the least prevalent plastic type, with less than 40 g of PET macroplastic across all sites in both 2022 and 2023.

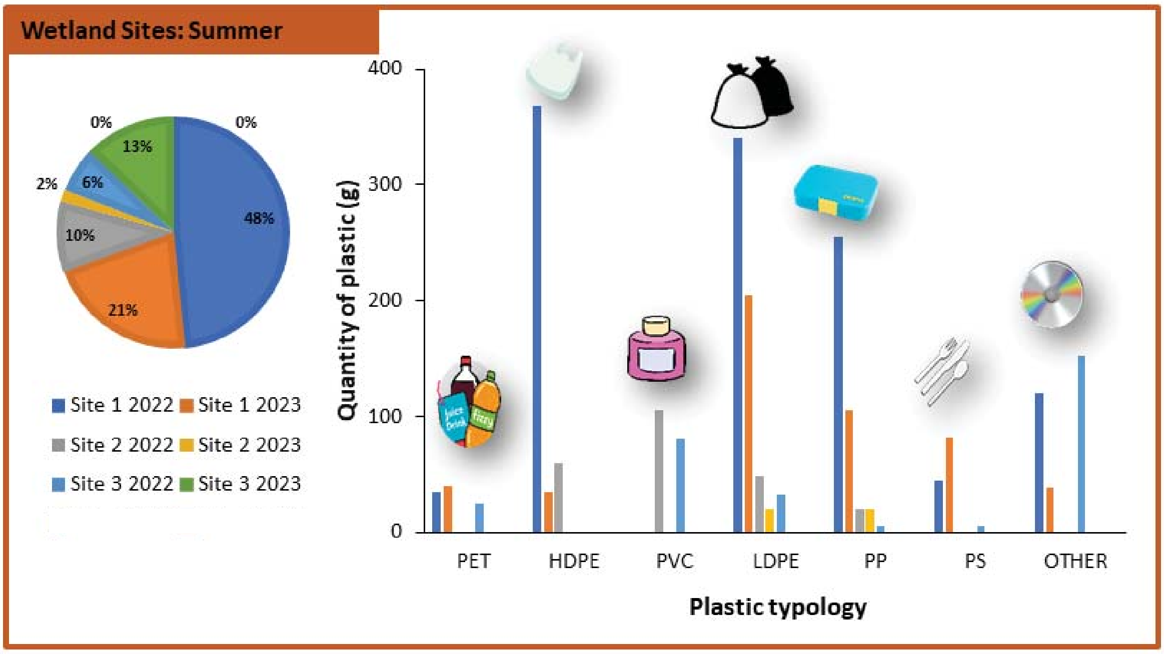

Figure 24: Wetland plastic typology in summer at Site 1, Site 2 and Site 3

As indicated in Figure 25, the wetland at Site 1 played a significant role in macroplastic accumulation during winter 2023, contributing to 32% of the total. The predominant plastic types observed were LDPE, HDPE, and OTHER, recording masses of 275 g, 175 g, and 175 g, respectively. Notably, these results marked a substantial increase from winter 2022 when Site 1 accounted for only 18% of the accumulated plastic. In addition, Wetland Site 2 (TDS = 9) emerged as a key contributor to macroplastic in winter 2023, representing 32% of the total plastic generated. LDPE and HDPE were the prominent types, registering the highest masses at 162.47 g and 130.7 g, respectively. It is noteworthy that PVC was not sampled throughout the two-year period, except for the winter of 2023 in Wetland Site 1, which reported 40 g of plastic.

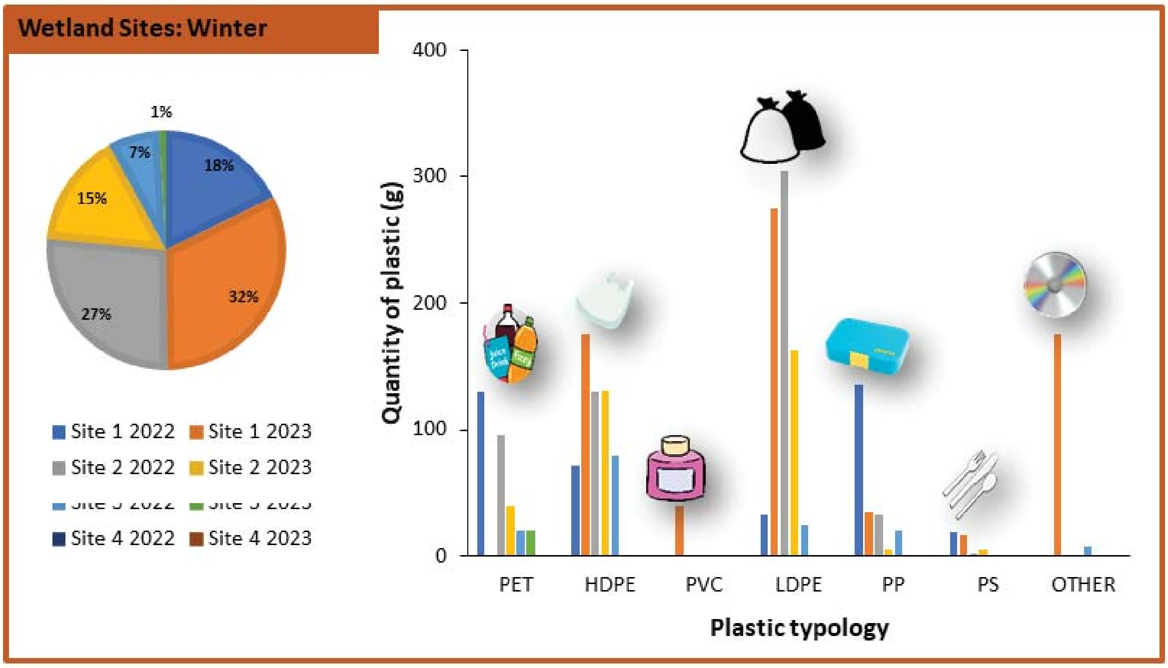

Figure 25: Wetland plastic typology in winter at Site 1, Site 2, and Site 3

4.3 SEASONAL VARIATION IN PLASTIC ACCUMULATION IN RIVERS AND WETLANDS

Seasonal fluctuations in the accumulation of plastic in rivers can be attributed to a diverse array of factors, including meteorological patterns, vegetation dynamics, human activity, and natural processes. In general, the findings of this study revealed a consistent trend of higher plastic accumulation during summer sampling events compared to winter periods. For instance, the urbanised area of Site 1 in Edendale demonstrated a statistically significant increase in plastic accumulation during summer compared to winter conditions ($p < 0.05$). Similarly, Site 3 located downstream of the New England Landfill, exhibited a higher plastic load during summer sampling events than during winter, emphasizing the influence of seasonal variations on plastic pollution dynamics in river ecosystems. Furthermore, the study identified Site 4 (TDS = 10) as the most heavily polluted site over the entire research period, closely followed by Site 3 (TDS = 14) and Site 1 (TDS = 15), underscoring the severity of plastic contamination in these specific locations.

In South Africa, summers are characterized by intense rainfall and storms, resulting in heightened flow rates and increased water volumes. Furthermore, the greater surface runoff can mobilize plastic wate from surrounding areas to nearby rivers and wetlands. This climatic phenomenon facilitates the introduction of plastic into rivers from surrounding areas, subsequently transporting it further downstream. Consequently, there is a notable increase in plastic accumulation during the rainy season. Moreover, the summer months witness the proliferation of thicker vegetation along riverbanks, enhancing the environments capacity to capture macroplastic. Conversely, the dry winter conditions, with reduced river flow, may see fewer plastic items in specific areas. Despite the drier weather, the potential for localized accumulation remains, particularly near points of human activity and improper waste disposal. Additionally, human activities, such as recreational use, tourism, and improper waste disposal during the summer holiday season, play a significant role in shaping seasonal variations, further highlighting the need for comprehensive studies to understand and address the multifaceted influences on plastic pollution in river ecosystems. Understanding the seasonal trends of plastic accumulation is crucial for designing effective pollution prevention and remediation measures. The tool has proven successful in identifying these patterns, enabling the development of strategies to enhance clean-up efforts during peak accumulation periods.

Furthermore, the wetland at Site 1 exhibited the highest concentration of plastic, with a greater abundance sampled during the summer compared to winter. Unfortunately, the wetland at Site 4 could not be sampled due to inaccessibility, while Sites 2 and 3 showed substantially lower plastic levels than Site 1. This disparity may be attributed to the heightened plastic pollution experienced by the wetland at Site 1, located in a heavily urbanized rural community grappling with issues of illegal dumping and inadequate waste disposal facilities. The comparatively lower plastic levels observed at Site 2 wetland can be explained by the fact that the site benefits from regular monitoring and cleaning by a local environmental non-profit organization, Duzi uMngeni Conservation Trust (DUCT). The application of the macroplastic monitoring tool in wetland environments has proven challenging due to access limitations and difficulties in distinguishing between disturbed and undisturbed wetland edges. Therefore, a more thoughtful approach is necessary to refine this component of the monitoring process.

4.4 WHERE DOES PLASTIC ACCUMULATE MOST FREQUENTLY?

The macroplastic monitoring tool serves as a valuable resource for identifying critical priority areas, contributing significantly to aquatic plastic pollution. The findings of this research observed the river band and edge as the most concerning areas of plastic accumulation. Various mechanisms, including but not limited to natural processes, can promote the accumulation of plastic debris along the edges and banks of rivers. Plastic is transported downstream by river currents, and when the flow is impeded or encounters obstacles such as vegetation, the plastic settles and accumulates along the edges. Additionally, wind also plays a role in transporting plastic waste to riverbanks. The primary cause of plastic accumulation on riverbanks is closely tied to human activities, including actions of littering, improper waste disposal, and illegal dumping.

The predominant location for plastic accumulation was along the edges of the river, observed consistently across Sites 1, 2, and 3. Interestingly, a comparable amount of plastic was closely followed on the riverbanks. The minimal distinction between the two suggests that both the vegetation along the river's edge and the banks act as effective physical barriers, trapping and accumulating plastic debris. Moreover, human activities, such as dumping or littering, are often concentrated near the riverbank, contributing to the localized accumulation of plastic debris along the river's edge. The findings of this study revealed that instream sampling yielded no results. This lack of findings is not attributed to the sampling method but potentially to the slow-flowing nature of the river during the times the samples were taken. Further exploration of this aspect of the tool is necessary to evaluate its viability, especially with the potential inclusion of flow monitoring.

4.5 MOST FREQUENTLY ACCUMULATING PLASTIC TYPES IN RIVERS AND WETLANDS

The findings of this study observed items such as plastic bottles, food containers, and packaging materials as most frequently encountered pollutants in river ecosystems. These plastics, often used briefly and then discarded, significantly contribute to river pollution. Among the noteworthy contributors are lightweight plastic bags, posing a substantial threat due to their ease of transport by wind and water, coupled with their persistent nature in the environment. Wrappers and other forms of packaging also emerge as prevalent sources of river plastic pollution, capable of fragmenting into smaller pieces over time. For example, Site 3 summer sampling revealed higher quantities of HDPE, LDPE, and PP plastic types during summer. LDPE, known for its persistence, was consistently more prevalent in both seasons, particularly along the bank transects. Meanwhile Site 4 exhibited elevated concentrations of HDPE and PS during the summer, with notable accumulations along the edge and bank. Whereas, in winter, high concentrations of PET, HDPE, and PS were recorded at this site. Illegal dumping, especially in proximity to rivers, has emerged as a significant source of pollution at Sites 1 and 2 in Edendale and Ashdown. The macroplastic monitoring tool has identified LDPE and HDPE plastics, commonly found in household waste, as problematic types in these areas. This information contributes to a targeted understanding of plastic pollution dynamics, enabling more effective mitigation strategies in regions affected by specific plastic types.

It's crucial to recognise that the typologies and quantities of plastic in rivers exhibit variability based on location, human activities, and environmental conditions. Effective site-specific measures are needed to address plastic pollution in rivers, including reducing the use of single-use plastics, enhancing waste management practices, and fostering public awareness regarding the detrimental impacts of plastic pollution. The macroplastic monitoring tool plays a pivotal role in identifying specific plastic types and gauging their prevalence in each area, contributing to informed strategies for pollution mitigation.

5. VALORISATION OPPORTUNITIES

The valorisation of the common household plastics found in this study, i.e. HDPE, LDPE, and PP, presents a unique opportunity for rural communities. Rather than viewing these plastics as waste, transforming them into valuable resources can contribute to environmental sustainability, economic empowerment, and community development. Leveraging these plastics for recycling or alternative utilization can contribute to minimizing environmental harm and fostering a circular economy. Initiatives such as community-based recycling programs, waste-to-energy conversion, or innovative upcycling projects could be explored as means of transforming these problematic plastics into valuable resources. Furthermore, with the identification of the potential source of pollution, municipalities can invest in initiatives and infrastructure that can minimize the influx of plastic into the environment and improve waste management, therefore enhancing local livelihoods. This project outlines specific initiatives aimed toward fostering a more circular plastic economy. The objective of valorisation in this context is twofold: to harness the potential of prevalent plastic types, promoting economic empowerment and income generation in rural areas, and simultaneously contribute to environmental conservation through heightened community awareness. The emphasis on circular practices not only addresses plastic pollution but also seeks to create a sustainable ecosystem where economic benefits align with environmental preservation, fostering a holistic and impactful approach to community development.

5.1 HARNESSING THE POTENTIAL OF PLASTIC

- Plastic Collection and Sorting Centres: The establishment of community-driven plastic collection and sorting centres can be a cornerstone for rural valorisation efforts. Engaging residents in the active collection and sorting of plastics facilitates the creation of a localized supply chain, contributing to subsequent processes.
- Plastic Shredding and Strategic investment in shredding machines capable of breaking down HDPE, LDPE, and PP into smaller particles is a pivotal step. These shredded plastics, in form of pellets, can then be repurposed for various applications, such as raw material for local enterprises or community projects, contributing to a circular and sustainable economy.
- Crafts and Artisanal Products: Empowering local artisans with the skills to transform plastic into crafts and products can be meaningful. For instance, activities like weaving rugs, crafting baskets, or creating art installations not only provide a source of income but also instil a sense of pride and creativity within the community, fostering a sustainable and artistic dimension to the valorisation process.

5.2 ECONOMIC EMPOWERMENT AND INCOME GENERATION

- Entrepreneurial Initiatives: Actively promote the establishment of small-scale enterprises dedicated to plastic recycling. This initiative could involve comprehensive training programs, equipping community members with essential skills in recycling, machine operation, and entrepreneurial leadership to initiate and manage their own ventures.

- Community-Owned Businesses: Advocate for the creation of community-owned businesses that oversee the entire recycling process, from collection to the production of final goods. By reinvesting profits into community development projects, these enterprises contribute to a sustainable cycle of economic growth, fostering self-reliance and resilience.
- Market Linkages: Facilitate strategic partnerships with local and regional markets to facilitate the sale of recycled plastic products. Establishing these linkages ensures a consistent demand for the community's products, creating a reliable and sustainable income stream that directly benefits the community.

5.3 ENVIRONMENTAL CONSERVATION AND COMMUNITY EDUCATION

- Environmental Education Programs: Implement comprehensive educational addressing the environmental impact of plastic pollution and promoting the benefits of recycling within the community. Foster a sense of environmental stewardship, encouraging responsible plastic use and disposal. Incorporating tools like the rapid macroplastic monitoring protocol in schools can serve as an initial step in raising awareness among community members.
- Eco-Friendly Building Materials: Explore the feasibility of utilizing recycled HDPE, LDPE, and PP in the creation of eco-friendly building materials. This exploration offers an eco-conscious alternative to traditional construction materials, contributing to sustainable infrastructure development within the community.
- Community Clean-up Initiatives: Integrate valorisation efforts with community clean-up initiatives. Actively involve residents in periodic clean-ups, not only as a means of sourcing additional plastic but also to strengthen the connection between plastic waste management and the overall well-being of the community.

The valorisation of common household plastics in rural communities represents a holistic approach to address both environmental and socio-economic challenges. By transforming plastics into valuable resources, these communities can achieve self-sufficiency, economic empowerment, and contribute to a cleaner, healthier environment. Through collaborative efforts and strategic initiatives, rural areas can unlock the hidden potential within the plastics that would otherwise be discarded, turning waste into wealth for the benefit of the entire community.

6. CONCLUSION AND RECOMMENDATIONS

The conclusions drawn from this study underscore the significance of prioritizing mitigation efforts in the most polluted areas, specifically Sites 4 and 3, as identified during the pilot phase. These locations emerged as major contributors to plastic pollution, necessitating focused attention in the formulation of recommendations aimed at addressing solid waste pollution. Remarkably, there is little variation in the quantities of plastic sampled at these downstream sites, indicating that the accumulation of plastic is synonymous with the flow of the river, leading downstream and eventually to the ocean. The prevalent presence of common household plastics, such as HDPE, LDPE, and PP, among the most frequently sampled forms, offers valuable insights into potential pollution sources. These findings pave the way for targeted interventions to address the primary contributors to plastic pollution in the studied river ecosystems. Furthermore, the observation that plastic tends to accumulate predominantly along the edges and banks of the river highlights the need for strategic measures focused on these specific areas to curtail plastic pollution effectively.

The identification of household plastics as significant contributors to the macroplastic hotspot at Site 4 suggests a connection to broader societal issues and the pervasive use of single-use plastics. Situated downstream from the New England Landfill, Site 4 experiences the natural downstream movement of plastic waste, leading to its heightened plastic accumulation. In addition, due to unusually high rainfall events during the sampling (flooding), it is not uncommon to expect that the accumulation of plastic would occur at the furthest point downstream. Furthermore, the site's exaggerated riverbends create zones of reduced water velocity, serving as natural traps for floating debris and contributing to the accumulation of plastics.

The substantial presence of plastic at Site 3 raises concerns about the municipal landfill located upstream. Landfills, often lacking proper containment measures such as liners and coverings, can become sources of plastic pollution when rainwater carries plastics into nearby waterways. Surface erosion in landfills, exacerbated by rainfall, leads to the transportation of loose plastic debris, microplastics, and contaminated soil into adjacent water bodies through stormwater runoff.

Furthermore, the erosive nature of rainfall over time contributes to the mechanical breakdown of larger plastic items, transforming them into smaller particles that disperse more easily downstream. To address the challenges at Site 3, it is recommended to investigate the lifespan of the landfill, considering the possibility of decommissioning the current site. In the short term, implementing more effective waste compaction measures can minimize the exposure of plastic to rainwater, reducing the potential for downstream transport. Additionally, the introduction of a vegetated buffer around the landfill is a valuable addition, as demonstrated in this study, where vegetation has shown the potential to trap a significant amount of plastic. This measure can function as a natural barrier, helping to mitigate the impact of plastic pollution originating from the landfill.

The comparison between summer and winter sampling results underscores that, overall, summer yielded a higher quantity of macroplastic accumulation. Elevated rainfall during summer intensifies runoff, increasing the potential for capturing macroplastic originating from the land. Additionally, increased flow volumes accelerate the downstream transport of macroplastic. To obtain a true reflection of the pollution that is occurring, it is advised that monitoring take place during seasons with considerable rainfall. The study recommends that communities situated downstream, particularly in rural areas, explore investments in community-based projects focused on recycling and environmental awareness. Such initiatives can contribute to mitigating the impact of plastic pollution on river and wetland ecosystems. Furthermore, future studies are encouraged to conduct a thorough examination of the macroplastic wetland monitoring component to develop a more practical method for ranking wetland hotspots, considering factors such as resource mapping and accessibility.

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