EFFECTS OF LAND USE PATTERNS ON MICROPLASTIC CONCENTRATION AND DISTRIBUTION IN RIVER RWIZI, MBARARA DISTRICT

BY

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DECLARATION

I, Kemigisha Mariam, declare that this dissertation represents my original work. To the best of my knowledge, it has not been submitted in whole or in part, to any University or institution of higher learning, for the purpose of obtaining an academic qualification.

Signature: ……………….…….… **Date:** ……………………….…..………

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APPROVAL

We confirm that the research titled “*Effects of Land Use Patterns on Microplastic concentration and Distribution in River Rwizi, Mbarara District*” was carried out by the student under our guidance, and this dissertation is submitted with our full approval.

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DEDICATION

This work is dedicated to my beloved family, whose love, cheer and encouragement have been my greatest strength.

"You are made for more than you can imagine, more than you have ever dreamed, and more than you have ever hoped." — Lisa Osteen Comes, You Are Made for More

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LIST OF ABBREVIATIONS AND ACRONYMS

FTIR	Fourier-Transform Infrared Spectroscopy
GIS	Geographical Information System
GPS	Global Positioning System
HDPE	High-Density Polyethylene
LDPE	Low-Density Polyethylene
MP	Microplastics
NaFIRRI	National Fisheries Resources Research Institute
NEMA	National Environment Management Authority
PE	Polyethylene
PES	Polyester
PET	Polyethylene Terephthalate
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinylchloride
UBOS	Uganda Bureau of Statistics
UNEP	United Nations Environment Programme

ABSTRACT

Microplastic pollution has become a pressing global environmental challenge, threatening aquatic ecosystems. In Mbarara District, growing industrial development, agricultural and urban activities, and poor waste management practices, contribute to the release of microplastics into River Rwizi. These plastic particles, typically less than 5 mm in size, largely originate from degradation of discarded plastics and can enter the food web through ingestion, biomagnification, and bioaccumulation. This research aimed to study the concentration, characteristics (colour, size, shape and polymer type), and distribution of microplastics in River Rwizi, with emphasis on the role of surrounding land use activities. Samples of water and sediments were obtained from nine purposively selected sites based on predominant land-use types, representing agricultural (upstream), urban/built up (midstream), and forested (downstream) land use types. Sample preparation involved sieving, drying, density separation, and filtration. Microplastics were then identified using stereomicroscopy and analyzed for polymer composition using FTIR spectroscopy. Land use mapping was conducted using Sentinel-2 satellite and supervised classification in ArcGIS, followed by ground truthing with a handheld GPS. Data analysis used IBM SPSS Version 29.0, while Pearson correlation and regression modeling were used to assess the influence of land use on microplastic concentrations. Results revealed that all samples collected contained microplastics. Concentrations in water samples ranged from 0.117 to 0.883 particles per liter, while sediments contained 0.012 to 0.132 particles/Kg. Built up and agricultural areas recorded higher concentrations of microplastics than forested areas. Fibers were the most common shape, most prevalent in built up land use, while blue particles were the most frequent colour. Most particles fell within 0.5–1.0 mm size range, suggesting they originated from larger plastic debris. Polyethylene and Polypropylene emerged as the dominant polymers identified across all land use categories. These findings demonstrate that land use patterns strongly influence microplastic pollution in River Rwizi. The study recommends improved waste management practices, promotion of alternatives to single-use plastic packaging materials, strengthening community awareness and policy interventions to reduce plastic pollution, and strengthening plastic recycling initiatives.

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Plastic pollution has emerged as one of the most pressing environmental challenges of our time, recently acknowledged as a severe ecological burden. Every year, numerous volumes of plastic waste enter into oceans and freshwater bodies, posing a significant risk for both humans and aquatic life (Galgani et al., 2019). Recognizing the urgency of this growing crisis, the United Nations declared “Beat Plastic Pollution” as the theme for World Environment Day 2023, emphasizing the global action against plastic pollution. Plastic products remain integral to modern society because they are affordable, durable, light weight, and have excellent oxygen/moisture barrier characteristics (Andrady & Neal, 2009). Consequently, production of plastics and usage have significantly increased globally, particularly for packaging (Andrady, 2011). However, poor plastic waste management and disposal methods, especially in Africa, have resulted in widespread environment contamination (Okeke et al., 2022).

Once discarded, in the environment, plastics slowly breakdown into fragments smaller than 5mm, commonly referred to as microplastics. These particles are particularly concerning because of their capability to be consumed by fish and other aquatic organisms, which allows them to accumulate in the food web, and ultimately pose risks to human health (Cole et al., 2013). Their small size also enables their long-distance transport to remote ecosystems (McMullen et al., 2024; Parolini et al., 2023). Microplastics are categorized as primary microplastics, which are intentionally manufactured (e.g., microbeads in cosmetics, plastic pellets, microfibers), and secondary microplastics, which originate from degradation of larger plastic debris through physical, chemical, and biological degradation processes (Muniv & Supanekar, 2024; Song et al., 2024). Improper plastic waste disposal accelerates the formation of secondary microplastics in environments like dumpsites, riverbanks, and beaches. Both types are not easily removed from water systems because of their tiny size and capability to adsorb toxic pollutants like heavy metals, pesticides, and industrial chemicals (Pan et al., 2023; Ziani et al., 2023). Ingestion of these pollutants can result in harmful effects like endocrine disruption and tissue damage in aquatic organisms. Beyond their biological impacts, microplastics can also alter water quality, thereby destabilizing river ecosystems and biodiversity (Witczak et al., 2024). Furthermore, as rivers transport these pollutants into lakes and oceans, they contribute to the broader marine plastic pollution crisis, with implications for marine organisms and ecosystems.

Globally, plastic manufacturing has been driven by the material’s affordability, durability, light weight, and excellent barrier properties, making plastics indispensable in sectors such as packaging, construction, automotive, agriculture, and healthcare (Pilapitiya & Ratnayake, 2024). This versatility has fueled rapid production growth, with over 390million metric tonnes manufactured each year (Geyer et al., 2017). However, this widespread use of single-use plastics and inadequate waste management systems has resulted in the accumulation of considerable volumes of discarded plastic materials. Once disposed off, these plastics frequently enter rivers, wetlands, and lakes, which act as natural pathways transporting these materials from terrestrial sources to marine ecosystems (Azevedo-Santos et al., 2021; Bexeitova et al., 2024). Rivers, in particular, collect inputs from urban runoff, wastewater discharges, agricultural activities, industrial effluents, and illegal dumping (Frei et al., 2019; Pakhomova et al., 2024). With increasing urbanization and industrialization, and without corresponding improvements in waste management infrastructure, the leakage of plastics into water bodies is accelerating. Once introduced into freshwater systems, these plastics undergo physical and chemical degradation, fragmenting into microplastic particles that can be transported across vast distances (Bexeitova et al., 2024).

The African continent, and particularly Sub-Saharan Africa, is increasingly vulnerable to microplastic pollution because of rapid urbanization, inadequate plastic waste management infrastructure, and poor enforcement of environmental laws (Moto et al., 2024; Yeboaa et al., 2025).

Land is a bridge between humans and natural ecosystems, and changes in land use influence their structure and function (Luan & Liu, 2022). Since human activities are the main source of microplastic production, land use changes inevitably have an impact on microplastic pollution (Wei et al., 2022). Recent research has started to investigate the relationship between land use and microplastic pollution (Klein et al., 2015) and (Barrows et al., 2018). For instance, Hao Y.L et al. (2022) studied how land use patterns affected and microplastic abundance in China’s Loess Plateau.

In Uganda, approximately 600 tons of plastic wastes are generated daily, but only 40% is collected, leaving the remaining 60% discarded in the environment (Muganga Eve, 2022). Poor plastic waste disposal practices, open dumping, and lack of effective recycling systems have worsened plastic pollution in both urban and rural settings. Studies conducted in Uganda, have highlighted the potential contamination of freshwater systems like River Mpanga (Nyakoojo et al., 2024), and Lake Victoria (Egessa et al., 2020), citing microplastics due to urban waste discharges, agricultural runoff, and industrial effluents. These findings emphasize the growing concern over freshwater systems as critical recipients and transporters of microplastics within Uganda’s catchment areas.

In southwestern Uganda, River Rwizi serves as a lifeline for over five million people across 12 districts, providing water for domestic, agricultural and commercial use. The river also supplies water to 264,425 residents of Mbarara City (UBOS, 2024). However, the river faces significant anthropogenic pressures, including urban runoff, wastewater discharge from households and industries, improper solid waste disposal, agricultural activities, sand mining, and wetland degradation. These land use activities make the river particularly susceptible to microplastic contamination, making the river a potential hotspot for pollution. Given its critical role in regional sustainability, protecting River Rwizi from pollution is essential for both environmental conservation and community wellbeing. However, there is no existing information about the level of microplastic pollution of River Rwizi. This research aimed at bridging this crucial knowledge gap, by assessing microplastic pollution in River Rwizi. Specifically, it provided data on the concentration, characteristics and distribution of microplastics in the river, while also analyzing how land use patterns influence their occurrence. The results are expected to provide valuable insights that can guide future mitigation and management efforts.

1.2 Statement of the Problem

River Rwizi is a vital freshwater source in Western Uganda, sustaining livelihoods, agriculture, and domestic water needs for communities in Mbarara and surrounding districts. Despite its importance, the river increasingly exposed to multiple threats pollution pressures, largely influenced by land use activities within its catchment such as expanding urban settlements, effluent discharge from industries, agricultural runoff, and poor solid waste management practices. Recent media reports (Daily Monitor, 2023; New Vision, 2021) have highlighted severe contamination of the river, with visible plastic litter accumulation in some stretches, indicating a growing pollution load that may accelerate the entry of microplastics into the river. Microplastics are a growing global concern due to their persistence in the environment and capacity to adsorb toxic and bio-accumulative compounds such as heavy metals and organic pollutants (Ashton et al., 2010; Koelmans et al., 2013a). Their minute size also makes them easily ingested by aquatic organisms, enabling them to move through the food chain, and creating potential health risks such as endocrine disruption, carcinogenicity, and immunotoxicity (Abbas et al., 2025). While research on a global scale has extensively documented microplastic pollution in freshwater ecosystems, only a limited number of studies have studied this issue in Uganda, such as Lake Victoria (Egessa et al., 2020), Nakivubo catchment in Kampala (Ocakacon et al., 2025), and River Mpanga in Fort portal (Nyakoojo et al., 2024). These studies confirm that microplastic contamination exists in Uganda's aquatic systems. However, microplastic pollution in River Rwizi remains undocumented. Given the river's ecological and socio-economic importance, this knowledge gap hinders effective mitigation and policy interventions. This research therefore aimed to assess the occurrence, concentration and distribution of microplastics in the Mbarara district section of River Rwizi, with particular attention to how land use activities influence their occurrence. By filling this gap, the research contributes not only to the natural body of knowledge on microplastic pollution in Uganda, but also provides critical evidence for policymakers, local communities, and conservation efforts dedicated to protecting River Rwizi and similar freshwater ecosystems.

1.3 Objectives of the study

1.3.1 General objective of the study

To assess the effects of land use patterns on microplastic concentration and distribution in River Rwizi, Mbarara District.

1.3.2 Specific objectives of the study

1. To determine the concentration of microplastics in water and sediment samples collected from selected points along the river Rwizi.
2. To analyze the characteristics (colour, shape, size, and Polymer type) of microplastics present in water and sediment samples collected from the selected locations along the river Rwizi.
3. To examine the influence of land use types such as agricultural, urban/built up, and forested on the distribution of microplastics in River Rwizi.

1.4 Null Hypotheses

1. There is no significant difference in microplastic concentrations among the various sampling points along the river Rwizi.

2. There is no significant difference in the characteristics (colour, shape, size, and polymer type) of microplastics found in water and sediment samples collected from different locations along River Rwizi.
3. There is no significant relationship between land use type and the concentration distribution of microplastics in river Rwizi.

1.5 Scope of the study

The scope of the study was as follows:

1.5.1 Geographical scope

The geographical scope of this study encompassed the river Rwizi in Western Uganda. The upper part situated in Mbarara District was the central focus of investigation, and the study area included the river itself, with any tributaries from surrounding land areas that contribute to the river's water flow and contamination potential. The study covered multiple points along the river's course in this area, to capture variations in microplastic pollution levels and characteristics. The study also considered the broader context of the influence of land use of microplastic pollution. It involved sampling at strategic locations that reflect various land use activities.

1.5.2 Content scope

The study examined microplastic concentrations, physical characteristics (size, colour, shape) and polymer composition, and distribution in river Rwizi, with emphasis on the role of surrounding land use patterns.

1.5.3 Time scope

This research was done from August, 2024 to December, 2024. This period covered sampling, laboratory analysis, and data analysis. Field sample collection was carried out in August, 2024 (9th to 11th), which was a dry month in Mbarara, with conditions to assess microplastic abundance during periods of low river discharge. Studying microplastics during low discharge conditions provides insights into how they accumulate under minimal hydrological disturbances.

1.6 Significance of the Study

The River Rwizi serves as a source of water for agricultural, domestic, and industrial uses, directly affecting the well-being of local communities. The fact that microplastics can carry harmful chemicals and other pollutants raises concern that they can be transferred to humans through drinking water and food intake.

Findings from this research will:

Provide baseline data on the presence and characteristics of microplastics in River Rwizi.

Help regulatory bodies such as the National Environment Management Authority (NEMA) and the Ministry of Water and Environment to design strategies for pollution control.

Contribute to public awareness about the dangers of plastic pollution and promote improved waste management practices.

Serve as a reference point for future academic studies on microplastic contamination in Ugandan freshwater systems.

CHAPTER TWO

LITERATURE REVIEW

2.1 Plastics production and disposal

The Uganda National Environment Act, 2019, describes Plastic as “a synthetic material made from a wide range of organic polymers such as polythene, that are molded into shape while soft and then set into a rigid or slightly elastic form”. Since the 1950s, global plastic production has grown from a few million tonnes to about 380 million tonnes by 2015 (Geyer et al., 2017). About 460 million metric tonnes were generated worldwide in 2019, while estimates suggest global plastics exceeded 500 million metric tons annually between 2023 and 2024, continuing an upward trajectory (OECD, 2022). A UNEP report (Intergovernmental negotiating committee, 2022) estimates that plastic production will triple by 2060. Increase in plastic production is as a result of population growth, affordability and convenience of plastics (Okunola A et al., 2019). This growth is also driven by the versatility of plastics, which comes from the synthetic polymers and chemical additives like plasticizers, stabilizers, fillers, colorants and flame retardants, which impart properties like flexibility and fire resistance (Intergovernmental Negotiating Committee, 2022). Plastics comprise a broad variety of synthetic polymeric materials that produce many different end products, as shown in the Table 2.1 below (Hanvey et al., 2017). Polyethylene, polystyrene, and polypropylene are the common forms of polymers detected within the environment (Leal et al., 2019).

Table 2.1: Common types of plastics and their main uses

Plastic (polymer)	Applications
PET/PETE	Food packaging, single-use drink containers, textile (synthetic fibers), tape, thermal insulation
HDPE	Bottle caps, milk crates, fuel tanks, plastic lumber
PVC	Inflatable products, plumbing pipes, watering hoses, protective coatings for electrical wires
LDPE	Shopping bags, beverage multipack holders, flexible clip-on covers
PP (expanded or nonexpanded)	Bottle covers, floor carpets, ropes
PS (expanded or nonexpanded)	Disposal cutlery, disposable food containers, dinnerware, and chilled storage crates.

Source: (Hanvey et al., 2017)

Despite their utility, the chemical additives in plastics contribute to their toxicity, while the polymers make them non-biodegradable, resulting in long-term environmental persistence. When discarded into the environment, plastics fragment into tinier fragments known as microplastics (Belmaker et al., 2024; Vincoff et al., 2024). With an estimated lifespan of 100 to 1,000 years (Barnes et al., 2009), plastics can persist in aquatic environments, thus adsorbing chemicals such as organic compounds, metals, and biofilms. In Uganda, common plastic waste disposal methods include open incineration, landfilling, and indiscriminate dumping along roadsides, drainage systems, and in the sewers (Okunola et al., 2019). These practices exacerbate the environmental burden of plastic waste.

2.2 Microplastics definition and sources

Microplastics, referred to as plastic particles under 5mm in size, have attracted global attention given their widespread distribution, persistence and potential environmental effects (Eerkes-Medrano et al., 2015; Koelmans et al., 2013b). Their persistence in the environment raises concern regarding the consequences on aquatic systems, and public health (Rochman et al., 2013). The inability of plastic particles to biodegrade makes them persist in various ecosystems, and gradually breaks down, creating a secondary source of microplastics, in addition to primary sources such as raw materials like pellets, beads, granules, and powders used in manufacturing personal care products (Andrady, 2011; Fendall & Sewell, 2009). Unlike typical environmental contaminants, microplastic exhibit a wide array of physical and chemical properties, like diversity in colour, chemical composition, shape, density and size, complicating their classification (Duis & Coors, 2016). Different authors have therefore given microplastics different definitions based on these properties. To address this complexity, Frias & Nash (2019) describe microplastics as "any water-insoluble, synthetic polymer-based structure or solid fragment, with regular or irregular shape, and size range (1μm-5mm), either of primary or secondary manufacturing origin".

2.3 Microplastic abundance in aquatic environments

Studies worldwide have confirmed microplastic pollution in fresh water bodies, including rivers, reservoirs and lakes. For instance, Horton et al. (2017) found microplastic particles in both sediments and water samples collected from of the tributaries of the River Thames in the United Kingdom, emphasizing the ubiquity of contamination. Similarly, Mani et al. (2015) demonstrated that rivers act as pathways, transporting microplastics from land sources to oceans and highlighting the interconnectedness of aquatic systems. Research done in Asia by Osorio et al. (2021) also confirmed microplastic particles in water and sediments at the mouths of five rivers flowing into Manila Bay. Beyond detection, several studies have quantified microplastics concentrations in aquatic environments, offering an understanding of their abundance, composition and distribution. For instance, X. Zhang et al. (2020) studied China's Yongjiang River, and reported levels ranging from 500 to 7,700 Particles/m^3 for water and 90 to 550 Particles/Kg in sediments, with polymers such as polypropylene, polythene and polystyrene dominating in various shapes and sizes. In Africa, microplastics have been discovered in surface water (257 to 1215 particles/m^3) and sediments (ranging from 688 to 3308 items/m^2) along the South African coast and in Lake Victoria (Biginagwa et al., 2016; Nel & Froneman, 2015). In Kenya, (Kosore et al., 2018) reported the presence of microplastics in coastal surface waters, with concentrations reaching 110 particles/m^3 These concentrations were linked to factors such as urban proximity, ecosystem size, population density, and waste management systems (Zhang et al., 2023). Similarly, Horton et al. (2017) documented averagely 703 particles/Kg in Thames River estuary sediments. Recent research on microplastics has highlighted their presence and distribution in various freshwater environments. Studies have documented microplastic particles in coastal and lakebed deposits from the northern part of Lake Victoria in Uganda and in fish within the Tanzanian portion of the lake Egessa et al., (2020); Biginagwa et al., (2016). Additional insights into microplastic contamination in Africa's freshwater environments have been provided by studies on tap water, rivers, and groundwater in Southern Africa (Verster et al., 2017), as well as investigations of river systems of Nigeria, as reported by (Akindele et al., 2019) and (Ebere et al., 2019). Collectively, these studies demonstrate the widespread prevalence of microplastic particles in aquatic environments across Africa, reinforcing the necessity for mitigation efforts.

2.4 Microplastic composition in aquatic environment

The composition of plastics, determined by the polymers used during their production, influences their performance and environmental behaviour (Andrady & Neal, 2009). According to Dris et al., (2018), polymers such as polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), and polystyrene (PS) influence microplastic buoyancy and durability. These polymers are also the most commonly reported in studies on aquatic microplastic contamination (Ballent et al., 2016; Song et al., 2014a). In African ecosystems, microplastics have been documented in coastal waters of Southern and East Africa, inland aquatic habitats like the African Great Lakes, and estuaries. For instance, Biginagwa et al. (2016) found polypropylene, polyethylene, polyurethane and silicone rubber polymers in 20% of Tilapia and Nile perch from Lake Victoria. These pollutants likely enter the aquatic systems through urban drainage channels and other pathways. Microplastics vary in size, colour and shape, depending on their origins. While pellets are commonly found around plastic production factories, scrubbers and microbeads are mostly found in factories and household wastewater. Domestic wastewater and industrial discharges are significant contributors to secondary microplastics in aquatic systems (Fendall & Sewell, 2009). Laundry of synthetic textiles also contributes to secondary microplastics, with polyester, acrylic, and polyamide being the primary polymers released. Studies have detected microplastics in freshwater ecosystems such as Lake Hovsgol in Mongolia and Lake Garda in Italy, as reported by (Free et al., 2014) and (Imhof et al., 2013).

2.5 Microplastic distribution in aquatic environments

Distribution of microplastic particles in aquatic environments depends on both of particle characteristics (size, density, and shape), and environmental conditions such as water currents, sedimentation and human activities (Ballent et al., 2012). The weight of microplastic particles significantly influences their vertical positioning within the water column, determining whether they are in benthic or pelagic transport systems (C. Li et al., 2025). Low density polymers like polypropylene and polyethylene float in surface layers, while high density polymers like polyvinyl chloride more likely sink and accumulate in bottom sediments (Ash et al., 2024). In addition, processes like biofouling, biomass accumulation, sedimentation and flocculation can increase particle density, causing microplastics to settle in sediments (Andrady, 2011).

Across aquatic environments, distribution of microplastics varies. In marine ecosystems, microplastics are found from coastal zones to deep-sea sediments, transported by ocean currents, tides, and wind-driven surface drift (Jolaosho et al., 2025). Freshwater systems such as rivers and lakes, act as major pathways for microplastic transportation from land sources to oceans, where hydrodynamics and land use patterns dictate their spatial accumulation (Mennekes & Nowack, 2023). Wetland ecosystems, including estuaries and marshes, serve as transitional zones where microplastics can become trapped within vegetation and sediment layers due to lower water velocities and filtering capacities of wetland plants (Camargo et al., 2022).

Spatially, human activities including wastewater/effluent discharges, storm water drains, agricultural runoff and urbanization, significantly impact microplastic distribution. Horton et al. (2017) revealed the interplay of land use activities and water flow patterns in shaping microplastic accumulation in urban river systems.

2.6 Land use activities and microplastic pollution

Land use practices such as agriculture and urbanisation, can transfer microplastics into aquatic ecosystem (Ye & Pei, 2023). In urban areas, activities such as improper solid waste disposal, industrial discharges, car tire wear, synthetic textile washing, construction activities, and runoff from impervious surfaces (e.g., roads, pavements, parking lots) are major contributors to microplastic pollution (Jahandari, 2023). X. Zhang et al. (2020) demonstrated that highly populated urban areas and industrial activities tend to release more microplastics into nearby rivers, primarily through stormwater drains, sewer overflows, and direct effluent discharges. Runoff from urban surfaces, which are largely impermeable, rapidly channels microplastic-laden debris into nearby water bodies, bypassing natural filtration mechanisms like soil infiltration.

In agricultural landscapes, microplastics are introduced through plastic mulch films, greenhouse covers, drip irrigation pipes, and controlled-release fertilizer coatings, which degrade over time, fragmenting into microplastics (Quilliam et al., 2023). Furthermore, biosolids from effluent treatment activities are often utilized as manure in agricultural areas, introducing microplastics into soils, that can reenter surface water during runoff events (Edo et al., 2020). Agricultural runoff can also be a source of microplastics, as highlighted by Olubusoye et al. (2024).

Research has further established links between microplastic pollution and anthropogenic activities. For example, Zbyszewski & Corcoran (2011) identified industrial activities as contributors to microplastic levels in Lake Huron, while Estahbanati & Fahrenfeld (2016) reported higher concentrations of microplastic particles downstream of effluent treatment facilities. Population density and impermeable surfaces within watersheds are also directly related to microplastic pollution (Baldwin et al., 2016; Huang et al., 2021). These factors often interact and amplify the effects of each other. For example, changes in land use can alter flow patterns and affect accumulation of microplastics in certain areas. Land use changes also influence hydrological dynamics; for example, urban expansion reduces infiltration, leading to higher runoff volumes that enhance microplastic transport, while agricultural land conversion may disrupt sediment retention capacity of riverbanks (Welde & Gebremariam, 2017).

The interplay between land use activities and hydrological processes was observed by Horton et al. (2017) during their study of microplastic distribution in urban river systems, who documented how urban river systems accumulate microplastics in areas with altered flow patterns caused by infrastructure development and land use modifications. The examination of land use activities is therefore essential to understanding the distribution of microplastics in Rivers. Previous research, as highlighted in this literature review, underscores the significance of these factors in shaping microplastic contamination in freshwater environments.

2.7 Impacts of Microplastic pollution on Human Health and Ecosystems

Microplastic pollution affects aquatic organisms and ecosystems through ingestion and contamination transport within the food web (Wright et al., 2013). Once ingested by aquatic organisms, these particles can obstruct the digestive tract, lower feeding efficiency, inflame intestinal tissues, and interfere with nutrient absorption. In addition, Rochman et al. (2013) demonstrated that microplastic particles can act as carriers for harmful substances including Persistent Organic Pollutants (POPs), heavy metals, and endocrine-disrupting chemicals (EDCs). Such pollutants, once attached to microplastic particles, may accumulate within the aquatic food chain and subsequently reach humans through bioaccumulation and biomagnification processes.

The tendency of microplastics to adsorb other contaminants onto their surfaces is affected by variables such as exposure time, pollutant concentration, and polymer type (Gomiero et al., 2018). When aquatic organisms ingest contaminated microplastics, they are exposed to harmful substances that can lead to oxidative stress, genotoxicity, endocrine disruption, immunotoxicity, and carcinogenic effects, as documented in studies on ragworms, mussels, and fish (Gomiero et al., 2018; Rochman et al., 2013b).

Furthermore, human consumption of seafood contaminated with microplastics can result in exposure to POPs, heavy metals (e.g., mercury, lead, cadmium), bisphenol A (BPA), phthalates, and other toxic additives, potentially leading to hormonal imbalances, neurotoxicity, immune system suppression, infertility, developmental disorders, and increased cancer risks (GESAMP, 2015).

Beyond individual organisms, microplastic pollution disrupts broader aquatic ecosystems. Microplastics alter sediment composition and water quality, affecting light penetration, oxygen diffusion, and nutrient cycling (Ali et al., 2024). Their accumulation in sediments can smother benthic habitats, diminishing the diversity and abundance of key species like macroinvertebrates, mollusks, and crustaceans, which play critical roles in ecosystem functioning (Zheng et al., 2025). Research by (Bryant et al., 2016), and (Zettler et al., 2013) further suggest that plastics in aquatic habitats act as surfaces that support microbial attachment and growth, including harmful pathogens, and invasive species, which could impact broader ecological populations. Recognizing the complex link between microplastics, pollutants, and aquatic life is key to understanding the broader ecological and public health hazards linked to plastic pollution. This underscores the need for concerted efforts to tackle microplastic contamination.

2.8 Synthesis of the literature review

Global research findings have shown the widespread occurrence of microplastics in rivers worldwide. Rivers act as conduits for microplastic transport, resulting in their accumulation in downstream areas, estuaries, and ultimately, the oceans. Studies as reviewed above, have found that microplastic concentrations vary depending on geographical location, with higher levels often observed in urbanized and industrialized regions. Common types of microplastics detected in rivers are fragments and fibers, originating from diverse origins like packaging products, textiles, and fishing equipment. Studies from around the world (UK, China, Philippines) and specifically within Africa (South Africa, Lake Victoria, Kenya, Nigeria) confirm that microplastics are ubiquitous contaminants. High concentrations have been detected in water columns, sediments and coastal zones. Their abundance is strongly associated with anthropogenic activities, population density, including urbanization, industrialization, and poor waste disposal. This literature review demonstrates the global prevalence of microplastic pollution in rivers and highlights the limited research conducted in Uganda. Existing research has largely concentrated on Lake Victoria, with some studies also documenting microplastics in River Mpanga and the Nakivubo catchment. The identified research gaps provide a basis for this study, which aimed to add to the knowledge of microplastic contamination in Ugandan river systems and its possible impact on both ecosystems and public health.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

Originating from the hills of Buhweju in western Uganda, River Rwizi is a 160Km long river, that traverses more than ten districts, including Sheema, Bushenyi, Buhweju, Mbarara, Ntungamo, Isingiro, Kibingo, Kiruhura, Lyantonde, and Rakai. The river ultimately drains into Lake Victoria through the interconnected Kooki lake system, which includes Lakes Mburo, Kachera, Nakivale, and Kijanebarola. While the River Rwizi catchment encompasses a vast area of over ten districts, this study focused specifically on its passage through Mbarara District. This focus was strategically chosen due to Mbarara City's status as the largest urban center in the catchment, where the largest population depends on the river for domestic supply, but also presents a major anthropogenic pressure point with concentrated anthropogenic pressure from high population density, industrial activity, poor waste management and extensive impervious surfaces. Choosing the district allowed for an investigation into the urban impact on microplastic pollution by comparing upstream (pre-urban), urban, and downstream (post-urban) sampling sites, while remaining logistically feasible within the scope of this research. Figure 3.1 below shows the map of the study area.

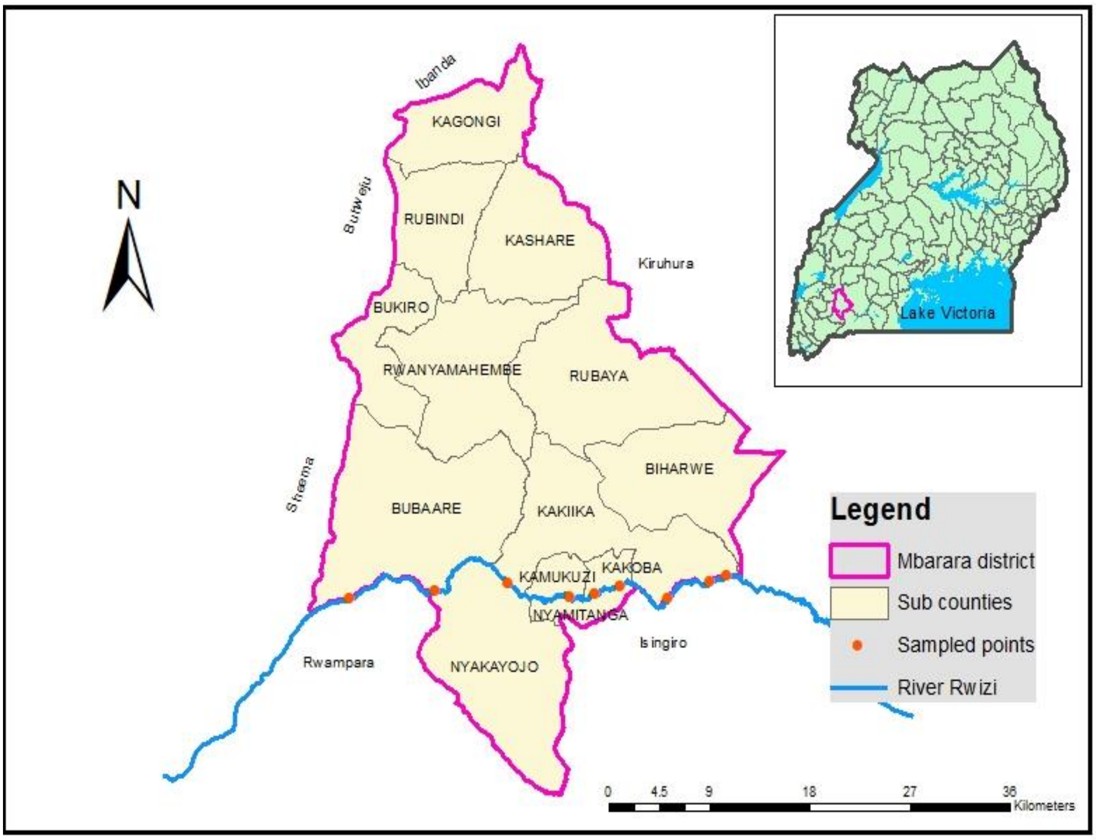


Figure 3.1: A Map showing the study area in Mbarara District

(Source: Researcher, 2024)

3.2 Research design

The study used a quantitative research design, employing field surveys, laboratory analyses, and GIS analysis. River Rwizi was purposively selected due to its vulnerability to plastic pollution from human activities in Mbarara District. To assess microplastic pollution, nine (9) sample collection points were strategically selected based on types of land use; that is urban, agricultural, and forested areas along the river from its entry into Mbarara district up to the exit of the district. This approach ensured diverse environmental contexts were represented.

3.3 Materials and equipment used

The materials and equipment that were used during this study include; Glass bottles, which were used to to securely keep water samples for transportation to the laboratory, Zipper bags for storage of sediment samples and transportation to the laboratory, Stainless steel bucket; used for collection of water samples from the river, Stainless steel spade; used for collection of sediment samples from the river, Stainless steel sieves (mesh size: 5mm for sediments and 63µm for water) for sieving the samples, ensuring that only the desired fractions were retained for analysis, Glass beakers; as containers for handling and processing samples in the laboratory, Vacuum filtration setup for filtering samples to concentrate microplastics onto filter papers for further analysis, Filter papers (0.45µm pore size, and 47 mm diameter); used to capture microplastics during filtration, Hydrogen peroxide (30% solution); used for digesting organic matter in samples, leaving microplastic particles for analysis, Sodium chloride (NaCl); used to create a high density solution for separating microplastic particles from sediments based on difference in densities, Glass stirring rods; used for mixing solutions and samples during sample preparation and processing, Tweezers were used to pick out microplastic particles for close examination, Petri dishes; used to hold and protect filter papers containing microplastics during sorting and analysis, Distilled water; for rinsing equipment, and preparing solutions, Gloves; work to avoid sample contamination and to protect the researcher during handling of chemicals, Aluminum foil for covering samples and worktops to prevent contamination during processing and storage, Microscope; used to visually inspect and identify microplastic particles by examining their physical features, and an FTIR equipment, which was used for identification and confirmation of the types of polymer of the microplastic particles through Fourier Transform Infrared Spectroscopy.

3.4 Selection of sampling sites

Nine sampling locations were selected to analyze microplastic concentrations, with site selection based on predominant land-use activities. Three locations were positioned upstream part of the river, representing agricultural farmlands. Three were situated midstream, covering urban built-up areas, with a mixture of commercial, residential, and industrial activities, while the remaining three sites were downstream, representing forested areas. Microplastic contamination was assessed through two environmental matrices (water and sediments) sampled at each of the nine sites. At each site, both water and sediments samples were collected on the same day, with water sampling carried out first to avoid disturbing and resuspending sediments. The sampling locations were strategically distributed to capture the dominant land-use types along the river's flow (upstream, midstream, and downstream). Site selection was further informed by preliminary field studies, secondary data sources such as topographic maps, and relevant literature from previous research. The final sampling points are shown in Table 3.1 below:

Table 3.1: Location and description of the sampling points

Catchment segment	Land use description (activities)	Assigned sampling ID	Location (Village)	GPS coordinates	
				Latitude	Longitude
Upstream	**Agricultural** - Crop gardens - Sparse residences - Cattle grazing and watering at the river - Animal farms - Sand mining - Domestic water sourcing at the river - Private tree plantations	A1	Kyamatete	-0.61972	30.470833
		A2	Karama II	-0.61467	30.539217
		A3	Bukindo	-0.6087	30.59885
Midstream	**Urban area** - Built up area - Commercial buildings - Industries - Residences - Institutions - Roads - Domestic water collection - Solid waste disposal	B1	Nyamitanga	-0.6187	30.647817
		B2	Kateete	-0.61683	30.668383
		B3	Kakooba	-0.61035	30.68875
Downstream	**Forested** - Tree cover (eucalyptus) - Timber cutting - Cattle grazing and watering at the river	F1	Kabaare IV	-0.6211	30.7131
		F2	Chani Forest Reserve	-0.60912	30.75395
		F3	Kyahi Forest Reserve	-0.60333	30.783617

(Source: Researcher, 2024)

3.4.1 Water sampling

A total of nine sampling sites were selected along the river, covering upstream, midstream, and downstream sections. From each section, three sites were chosen, and at every site, three replicates were collected to ensure statistical accuracy. This approach produced 27 samples in total (3 replicates × 3 sections × 3 sites). For each replicate, 20 liters of water were drawn using a 10-liter stainless steel bucket, amounting to 60 liters per sampling site. This method, adopted from Su et al. (2016) as a substitute for manta net, was chosen due to the nature of the water body, which made manta net sampling impractical. Manta nets require attachment to a moving boat, which was not feasible in this study. The collected water was filtered through a 63µm sieve, with particles larger than 5mm discarded. Residues retained on the sieve, presumed to contain microplastics between 63µm and 5mm size, were rinsed to obtain concentrates into pre-rinsed, labelled 250ml glass bottles using distilled water. Samples were kept in a cool box, shielded from light, and then transported to NaFIRRI - Jinja Laboratory for further analysis. The photographs in Figure 3.2 below show the water sample collection and sieving.

Sieving through the 63µm sieve

Rinsing for concentrates

Figure 3.2: Photographs showing water sample collection

3.4.2 Sediment sampling

Sediment collection was carried out using a stainless-steel spade. Onsite, the samples were sieved through a 5mm stainless steel mesh to remove coarse particles and stones. From each sampling location, approximately 400 grams of sediment were obtained. The sediment samples were transferred to pre-cleaned Zipper bags, sealed to prevent any loss or contamination, and labeled. Samples were kept in a cool box, protected from light, and transported to the NaFIRRI Laboratory in Jinja for further analysis. To ensure statistical reliability, three replicate samples were collected from every site, resulting in an overall total of 27 samples for this study. The photographs in Figure 3.3 below show the water sample collection and sieving.

Sediment sample collection Sediment sieving

Figure 3.3: Photographs showing sediment sample collection

3.4.3 Land use mapping and classification

The sentinel 2 images of 10m resolution were obtained from ESA (https://scihub.copernicus.eu/.) preprocessed and classified using the supervised classification method, applying the maximum likelihood algorithm in ArcGIS 10.8.2 software. The image classification accuracy of the land use was analyzed by use of the ground truth data combined with the digitized geographic coordinates from base maps (google earth, Environmental System Research Institute /ESRI and Bing) which were later exported to ArcGIS software to generate vector point layer. The Vector point layer was converted to raster, combined with corresponding land use/cover layers to make confused matrix. To calculate the accuracy of the producer, user and overall map, ground data was used for the columns; while the classified data was used for the rows using the formula indicted below.

Overall accuracy (proportional of correctly classified samples)

$$= \frac{(\text{total correct pixels})}{\text{Total pixels}} \ast 100$$

Producer's accuracy (Accuracy at the producer's perspective i.e., how well does the used model recognize the class types

$$= \frac{(\text{correct pixels from the reference class})}{\text{Total reference pixels}} \ast 100$$

User's accuracy (accuracy at the perspective of the map user i.e. the probability that the pixel predicted as e.g. water is actually water)

$$= \frac{(\text{correct pixels identified in the class field class map})}{\text{Total map pixels}} \ast 100$$ (Nasiri et al., 2022)

The overall classification accuracy attained for the land use/cover for this study was greater than 89% which is sufficient to proceed to the next analysis.

Figure 3.4 below presents the flow chart outlining the steps followed in generating the land use map for the study area.

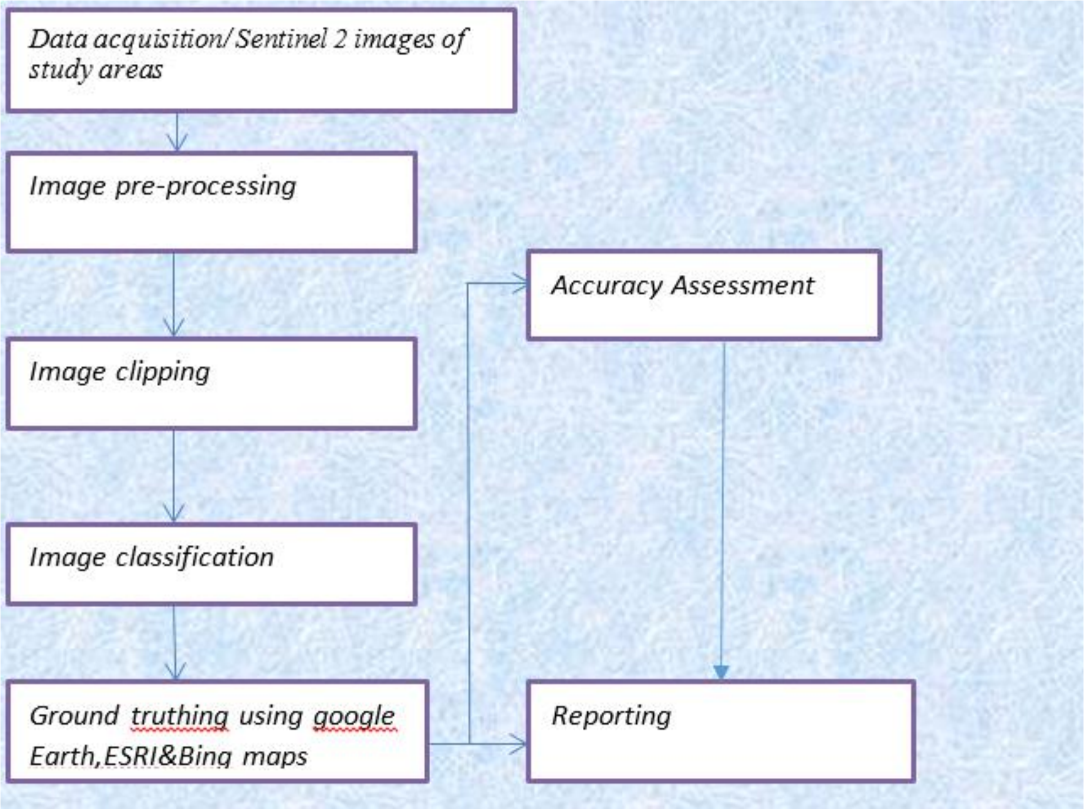


Figure 3.4: Flow chart of the process used to generate land use map of the study area

Land use classification

A handheld GPS receiver was utilized for ground verification to assess the three land-use/cover categories. During supervised classification of the study area, each category was quantified based on pixel counts in relation to the total site area. Land-use classifications were determined by area coverage and presented in both hectares and percentage. The three primary categories identified were Agricultural, Forested, and Built-up areas. The classification details are shown in Table 3.2 below.

Table 3.2: Land use type classification for the study area

Land use type	**Description**	**Area (ha)**	**Area (%)**
Agriculture	Regions primarily used for farming, including crop cultivation and livestock grazing. It also has sparse settlements.	93854	75.5
Urban/built up areas	Regions characterized by high population density, infrastructure, and human activity, including residential, industrial, and commercial areas.	16943	13.6
Forested	Natural or semi-natural landscapes dominated by trees and vegetation, with minimal human disturbance.	13478	10.8
Total		**124276**	**100.0**

(Source: Researcher, 2024)

Figure 3.5 below shows the land use map of the study area and the selected sampling sites.

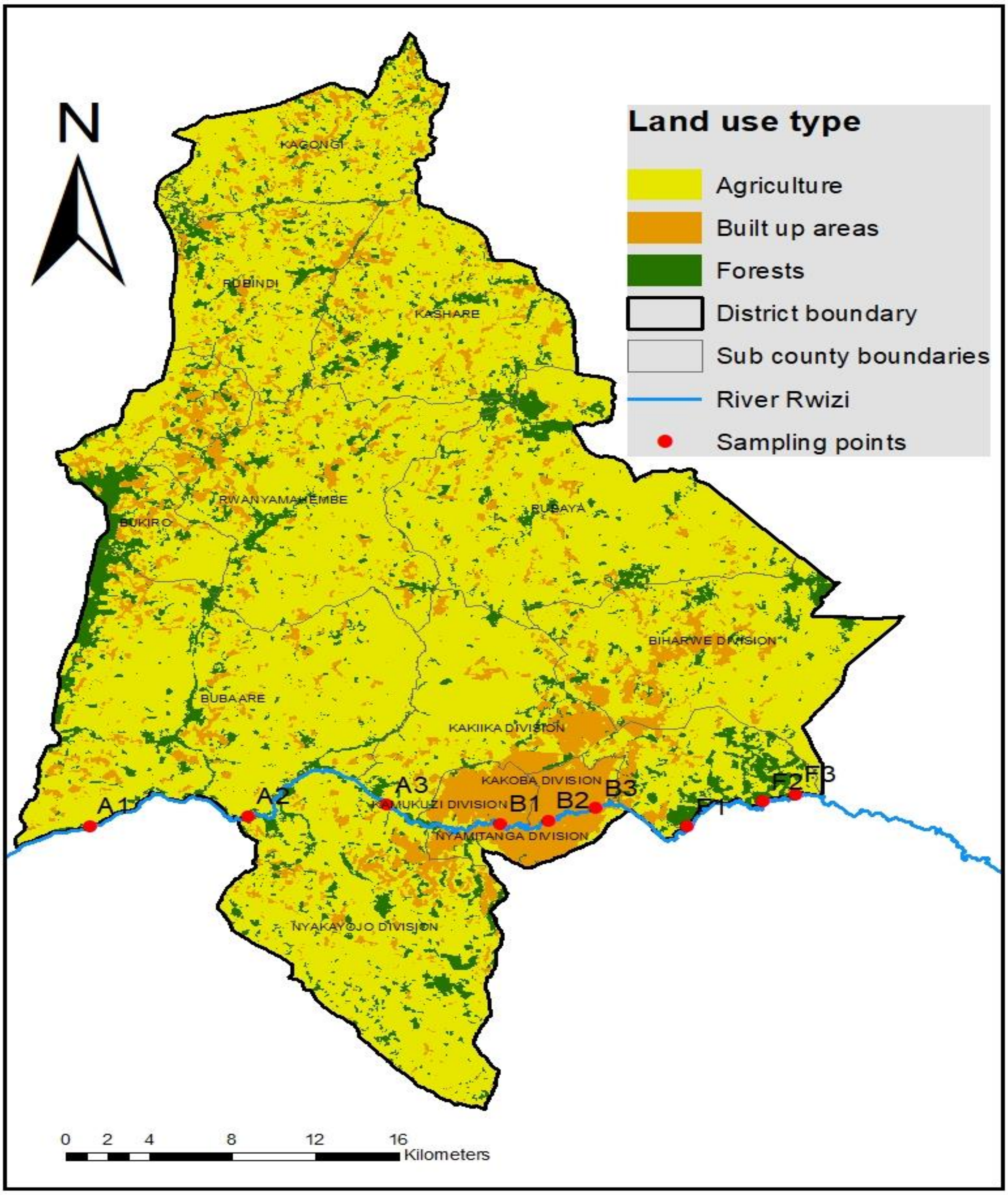


Figure 3.5: Land use map of the study area in Mbarara District

Source: Researcher, 2024

3.5 Sample preparation and Microplastics extraction

3.5.1 Water samples

Water samples were transferred into 500ml beakers and treated with 30% H_2O_2, with 0.05M of Fe (II) solution as a catalyst, to facilitate the breakdown of organic content (Masura, 2015). The treated mixture was then passed through a Whatman filter paper with pore size of 0.45 µm, and diameter of 47 mm. to prevent sample loss, the filtration device walls were rinsed several times using pre-filtered deionized water. The filter papers were then transferred into clean petri dishes, covered, air-dried, and stored in a contamination-free environment until microscopic analysis.

3.5.2 Sediment samples

In the laboratory, 400g of wet sediment samples were transferred to clean beakers and dried in the oven, heated to 90°C for at least 24 hours or until completely moisture-free. Working under a fume hood, 200g of the dried samples underwent wet peroxide oxidation using 20ml aliquots of 30% hydrogen peroxide (H_2O_2) and 20ml of 0.05M acidified iron (II) sulfate heptahydrate ($FeSO_4 \cdot 7H_2O$) as a catalyst. The catalyst was made by mixing 15g of $FeSO_4 \cdot 7H_2O$ in one liter of water, and adding 6ml of concentrated sulfuric acid (H_2SO_4) to enhance organic matter digestion (Masura, 2015). Additional 20ml aliquots of 30% hydrogen peroxide were introduced until no visible organic material remained.

Once digestion was complete, 6g of sodium chloride (NaCl) were added for every 20ml of the solution. This mixture was then stirred until NaCl fully dissolved, and then left in a density separator overnight to facilitate density-based separation (Masura, 2015). Sodium chloride solution with a density of 1.2 kg/L was preferred because of its non-toxic properties and affordability (Li et al., 2018). This process allowed microplastic particles to float while denser sediment particles settled. During separation, the suspension was shaken vigorously, and incubated until two distinct layers formed: the top layer containing particles of low density such as microplastics, and the bottom layer containing denser particles like clay. Microplastics particles were recovered from the top liquid layer and filtered using Whatman membrane filters of 0.45 µm pore size, and 47 mm diameter, cellulose nitrate, using glass Büchner funnels of Millipore brand, 250ml capacity, model xx1004704). The filters with the retained particles were carefully placed in petri dishes, covered, labeled, and air-dried in preparation for microscopic analysis.

3.6 Identification and quantification of Microplastics

Microplastics retained on the dry filters were analyzed using a Zeiss Stemi 508 stereomicroscope (manufactured by Carl Zeiss Microscopy GmBH, Germany), set at 50x magnification to assess their shape, color, and size. An AxioCam ERc5s Rev2 camera attached to the microscope was used for imaging. Every filter was meticulously examined, including the petri dish surface beneath it to ensure that all particles were accounted for. Microplastic concentrations were expressed as particle counts per liter for water and number of particles per kilogram for sediment samples. To distinguish plastics from non-plastic materials, the 'hot needle test' and 'break test' were applied, following methods described by Campbell et al. (2017) and Hendrickson et al. (2018). Microplastics were identified and measured based on specific criteria: 1) resistance to tearing with tweezers, 2) distinct coloration, and 3) absence of organic structures such as knots. Particles were then categorized by color, size, and shape, based on classification methods adapted from research by Free et al., (2014); Hidalgo-Ruz et al., (2012), as outlined in Table 3.3 below.

Table 3.3: Categorisation used for the studied microplastics

Characteristic	Categories
Shape	• Fibre/line (long, threadlike, straight) • Film (thin, flexible, transparent) • Fragment (rigid, uneven, sharp-edged) • Foam (light, porous, spongelike) • Pellet (solid, spherical, oval-shaped) • Sheet (flat, irregular, flexible)
Size	• Less than 0.5mm • 0.5mm to 1.0mm • 1.0mm to 5.0mm
Colour	• Blue • Black • Green • White/Transparent • Red • Yellow • Orange • Pink • Brown

(Source: Researcher, 2024)

3.7 FT-IR analysis for polymer type

The recovered microplastic particles were analyzed to determine their polymer composition using a Micro Fourier Transform Infrared (FT-IR) Spectrometer, following established methods (Hidalgo-Ruz et al., 2012). FT-IR is a widely applied technique that identifies polymers by detecting the unique vibrational frequencies of chemical bonds within a sample. These frequencies correspond to distinct polymer types and produce a spectrum with peaks indicative of specific bond vibrations. The generated spectrum is cross-referenced with a library containing spectra of known polymers for accurate identification (e.g., polyethylene, polypropylene, polystyrene, HDPE, LDPE, PVC). The analyses were conducted using the Attenuated Total Reflection (ATR) component on a diamond crystal of the AIM 9000 Automatic Infrared Microscope 9000, operated with LabSolutions IR software (Shimadzu Corporation, Japan). Every particle underwent 20 scans, at a resolution of 4/cm across a spectral range of 4000 to 400/cm. Before every analysis, a background scan was carried out. Polymers were identified by matching the raw sample's spectra against the software’s reference library, using a similarity threshold of ≥80% for confirmation (Y. K. Song et al., 2014b).

3.8 Quality control measures

To prevent plastic contamination during sample collection, only non-plastic tools such as steel sieves, stainless steel shovels, steel buckets, and glass sampling bottles were used, all of which were carefully rinsed with distilled water before being used.

All laboratory equipment used were meticulously cleaned, and the researcher used latex gloves and a cotton lab coat to minimize contamination. Samples were covered with aluminium foil during static processes to maintain their integrity.

To ensure no contamination was present, a filter membrane exposed in the laboratory for 24 hours showed no detectable microplastics. Additionally, after filtering 30-liters of distilled water under vacuum filtration, no plastic particles were observed.

3.9 Data Analysis

The data collected was entered and processed using IBM SPSS Software Version 29.0, which enabled systematic coding, organization, and input of variables for statistical analysis. Descriptive statistics were applied to generate frequencies and percentages of categorical variables, such as microplastic concentration, shapes, colours, sizes, and polymer types. To test for differences in microplastic concentrations across the sampling sites, Analysis of Variance (ANOVA) was used. In addition, Chi-square tests were used to examine associations between categorical variables, such as microplastic characteristics and specific land use categories. Pearson correlation analysis was performed to assess the strength and direction of associations between land use types (agricultural, urban/built up, forested) and microplastic concentration. Furthermore, regression analysis was performed to develop predictive models that estimate microplastic concentrations based on land use variables. A 5% significance threshold ($p < 0.05$) was applied to ensure statistical reliability meaningful interpretation of results.

The findings from the study were presented using a combination of maps, graphs, and tables for clarity. Spatial distribution maps were used to illustrate the concentration and spread of microplastics across various sampling points along River Rwizi, highlighting pollution hotspots and areas of significant microplastic accumulation. Bar graphs depicted the proportions of microplastics by size, shape, colour, and polymer category, while frequency tables were used to summarize categorical distributions across different land use types. The results of the regression analysis, including model equations, coefficients, and R-squared values, were presented in tabular form to demonstrate the predictive influence of land use variables on microplastic pollution levels. All figures and tables were clearly labeled and to ensure accurate interpretation.

3.10 Ethical considerations

The study was conducted in compliance with ethical guidelines governing environmental research, ensuring accuracy, transparency, and impartiality throughout the process. All data were collected, analyzed, and reported without manipulation or bias to ensure the integrity of the results. The study complied with established methodologies for microplastic identification and quantification to maintain scientific credibility. Efforts were made to minimize environmental disturbance during sample collection. All sampling activities followed best practices to avoid contamination and ensure the integrity of collected samples. Any waste generated during the research was managed and disposed of responsibly. This study made use of published literature and, where applicable, publicly available datasets. All secondary data sources used were properly cited to uphold academic integrity. Since no human participants or personal data were involved, formal ethical clearance from an institutional review board was not required.

CHAPTER FOUR

PRESENTATION OF RESULTS

4.1 Concentration of microplastics in water and sediment samples

4.1.1 Water samples

Microplastic particles were recovered in all the water samples collected for this study, in varying concentrations across the land use types (Figure 4.1 below). In agricultural areas, water samples exhibited relatively lower concentrations, ranging between 0.117 and 0.28 Particles/liter, averaging 0.194 ± 0.068 particles/liter. In contrast, urban areas showed significantly higher microplastic levels in water, with concentrations from 0.267 to 0.883 Particles/liter and an average of 0.528 ± 0.260 particles/liter. Forested areas displayed intermediate microplastic concentrations in water, ranging between 0.250 and 0.533 Particles/liter, and a mean of 0.428 ± 0.126 Particles/liter.

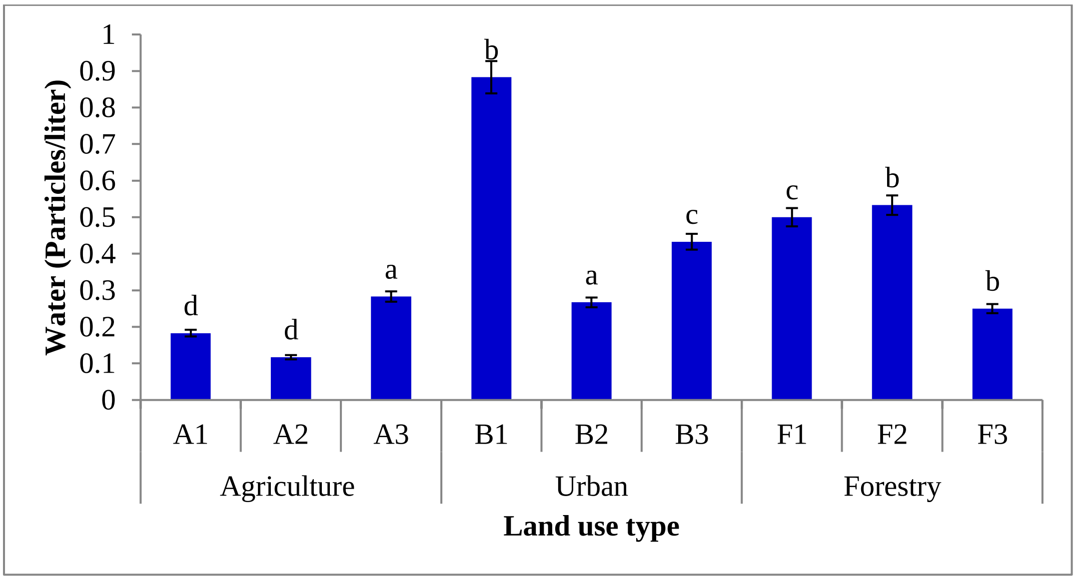


Figure 4.1: Microplastic concentrations in water samples

The ANOVA results (Table 4.1) below indicate a statistically significant difference in mean concentrations (particles per liter) among the groups analyzed (F = 620.894, p < 0.001). The high F-value shows that variation between the groups is much greater than variation within the groups, suggesting that land use type strongly influences microplastic concentrations.

Table 4.1: ANOVA for concentration of microplastics in water samples

		ANOVA **Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Abundance (P/L)	Between Groups	854.494	2	427.247	620.894	**0.000**
	Within Groups	140.376	204	.688		
	Total	994.870	206			

4.1.2 Sediment samples

Microplastic concentrations in sediments followed a similar trend but were generally lower than in water samples. In agricultural areas, sediment microplastic levels varied between from 0.012 and 0.03 Particles/kg dry weight, averaging 0.020 ± 0.007 Particles/kg dry weight. Sediments in urban areas exhibited higher concentrations, ranging from 0.050 to 0.132 Particles/kg dry weight, with a mean of 0.078 ± 0.038 Particles/kg dry weight. In forested areas, sediment microplastic levels were low, ranging from 0.025 to 0.042 Particles/kg dry weight. The bar graph in Figure 4.2 below shows the concentration of microplastics in sediment samples across all sampling points.

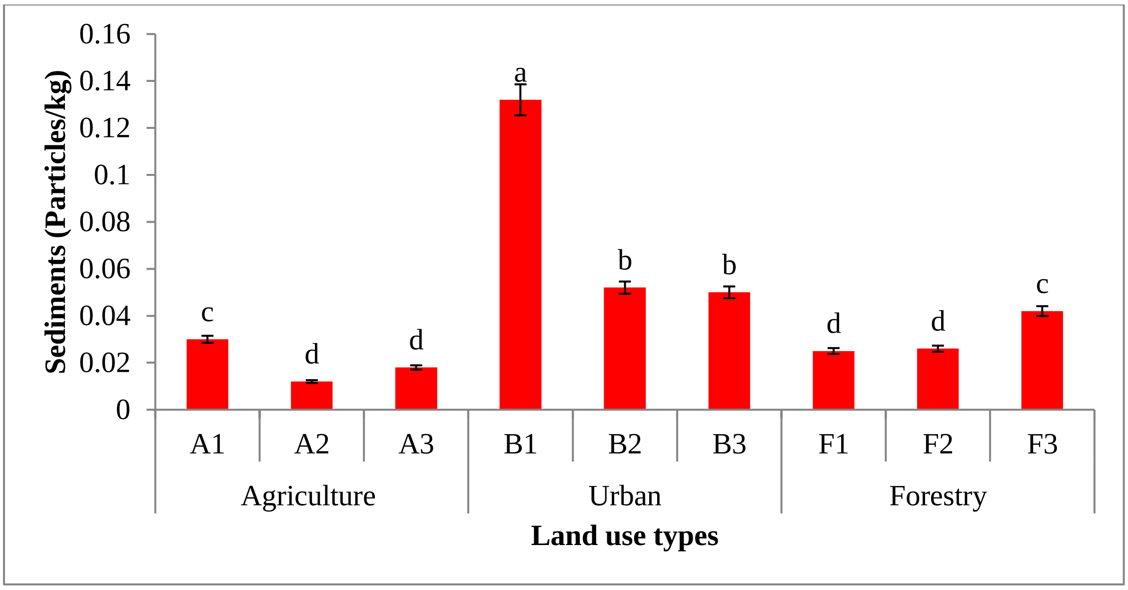


Figure 4.2: Concentration of microplastics in sediment samples

The ANOVA results (Table 4.2) reveal a statistically significant difference in mean abundance of microplastic particles per kilogram of dry weight among the groups compared (F = 689.347, p < 0.001). The large F-value indicates that variation between groups is substantially greater than variation within groups, suggesting that the grouping factor, such as sampling land use type, has a strong influence on microplastic abundance.

Table 4.2: ANOVA for concentration of microplastics in sediment samples

		ANOVA				
		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Abundance (Particles/kg dry wt)	Between Groups	949.452	2	474.726	689.347	**0.000***
	Within Groups	157.703	229	.689		
	Total	1107.155	231			

4.2 River Rwizi microplastic concentration comparison with other water bodies

A comparative analysis (Table 4.3) shows that River Rwizi records relatively low microplastic concentrations in both water (0.117–0.883 particles/liter) and sediments (0.012–0.132 particles/kg) compared to several other water bodies in Uganda and internationally. For example, Lake Victoria, despite being a large freshwater lake, has extremely low microplastic concentrations in water (0.00002–0.00219 particles/liter), but sediment concentrations are considerably higher (75–1,397 particles/kg), highlighting the tendency for microplastics to accumulate in sediments over time.

In contrast, the Nakivubo catchment in Uganda, which drains Kampala city, shows higher concentrations in water (1.569 ± 1.474 particles/liter during the dry season and 2.140 ± 3.670 particles/liter in the wet season), reflecting the impact of urban runoff and untreated wastewater discharges. Similarly, River Mpanga in Fort portal reports a high concentration in water (11.5 particles/liter), likely due to anthropogenic inputs.

Internationally, rivers such as the Yangtze River and Yongjiang River in China both exhibit elevated microplastic levels in water (8.407 and 0.5–7.7 particles/L, respectively) and sediments (84.9 and 90–550 particles/kg, respectively), largely driven by urban and industrial pollution pressures. The mouths of rivers draining into Manila Bay in the Philippines show an even higher values in water (1.58–57.67 particles/L) and sediment (386–1,357 particles/kg), reflecting intense coastal and urban pollution.

In comparison, River Rwizi's relatively low microplastic concentrations suggest that pollution sources are moderate and may be influenced by localized urbanization, agricultural activities, plastic littering and limited industrial discharges. While its microplastic levels are higher than those reported for Lake Victoria, they remain lower than those in heavily urbanized catchments such as Nakivubo and major Asian river systems. The minimal sediment concentrations observed in River Rwizi may be influenced by the river's hydrodynamics or sediment properties, which limit accumulation.

Overall, the comparative analysis demonstrates how land use, urbanization, and industrial activity strongly influence microplastic pollution. At present, River Rwizi shows moderate contamination, but continued monitoring is essential to prevent future increases.

Table 4.3: Comparison of microplastics concentration in River Rwizi with other studies

Study Area (Country)	Water (particles/L)	Sediments (particles/kg)	Reference
River Rwizi (Uganda)	0.117 – 0.883	0.012 – 0.132	**This study, 2025**
Lake Victoria (Uganda)	0.00002 – 0.00219	75 – 1,397	(Egessa et al., 2020)
Nakivubo Catchment (Uganda)	1.569±1.474(dry season) and 2.140 ± 3.670 (wet season)	-	(Ocakacon et al., 2025)
River Mpanga (Uganda)	11.5	-	(Nyakoojo et al., 2024)
Yangtze River (China)	8.407	84.9	(Ye & Pei, 2023)
Karnaphuli River Estuary (Bangladesh)	-	22.29 to 59.5	(Rakib et al., 2022)
Namibian River (Namibia)		13.2	(Faulstich et al., 2022)
Thames River (UK)	–	660	(Horton et al., 2017)
Yongjiang River (China)	0.5–7.7	90 to 550	(Zhang et al., 2020)
River mouths to Manila Bay (Philippines)	1.58 – 57.67	386 to 1,357	(Osorio et al., 2021)

4.3 Characteristics of microplastics present in water and sediment samples

4.3.1 Shape characteristics of microplastics present in water and sediments samples

4.3.1.1 Water samples

Microplastics identified were classified into three shapes, that is Fibre, Film and Fragment. Figure 4.3 shown below shows the percentage of microplastics by shape, in water samples across the three land use categories (Agricultural, Urban, and Forested). Fibers were the most prevalent shape of microplastics across all land use types, making up 92.8% of the total microplastics detected. They were especially highest prevalent in urban areas (95.8%), followed by forested (94.8%) sites, and slightly lower in agricultural areas (80.0%). Fragments accounted for (5.3%) from all the samples, and were more common in agricultural areas (14.3%) compared to urban (3.2%) and forest (3.9%). Films were the least common shape overall (1.9%), with slightly higher proportions in agricultural areas (5.7%).

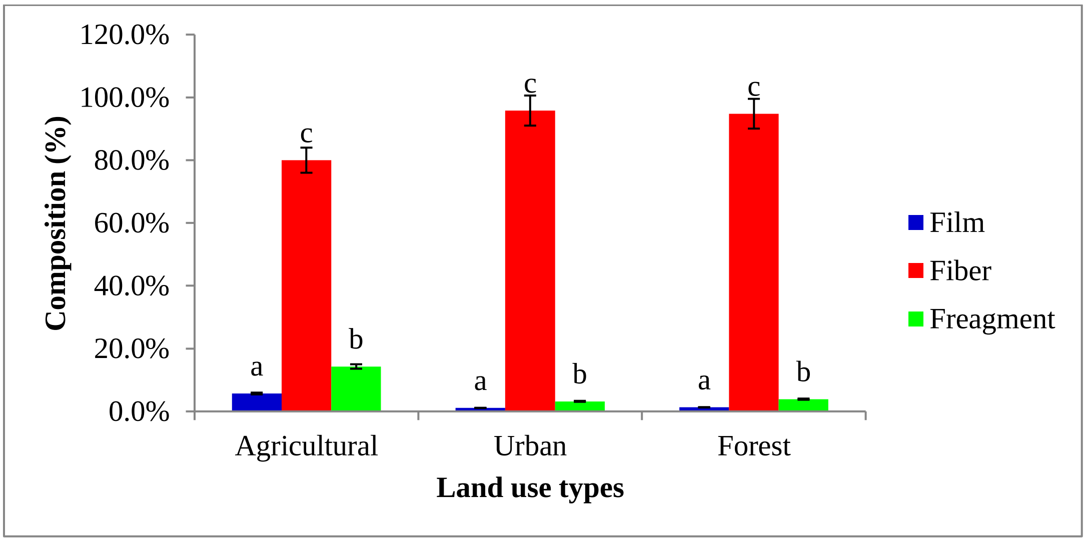


Figure 4.3: Percentage of microplastic shapes in water across the three land use types

4.3.1.2 Sediments

In sediment samples, fibers were the most common microplastic form, comprising 61.6% of all particles identified. They were particularly dominant in forested areas (87.5%), compared to agricultural (63.9%) and urban (50.7%) sites. Fragments were the second most prevalent form (20.3%), with a notably higher presence in urban sediments (26.4%) and agriculture (22.2%), while being minimal in forested sediments (3.6%). Films accounted for 18.1% of all sediment particles, more frequently observed in urban sites (22.9%) than in agricultural (13.9%) and forested (8.9%) areas. Figure 4.4 below presents the percentage distribution of microplastic shapes in sediment samples across the three land use types.

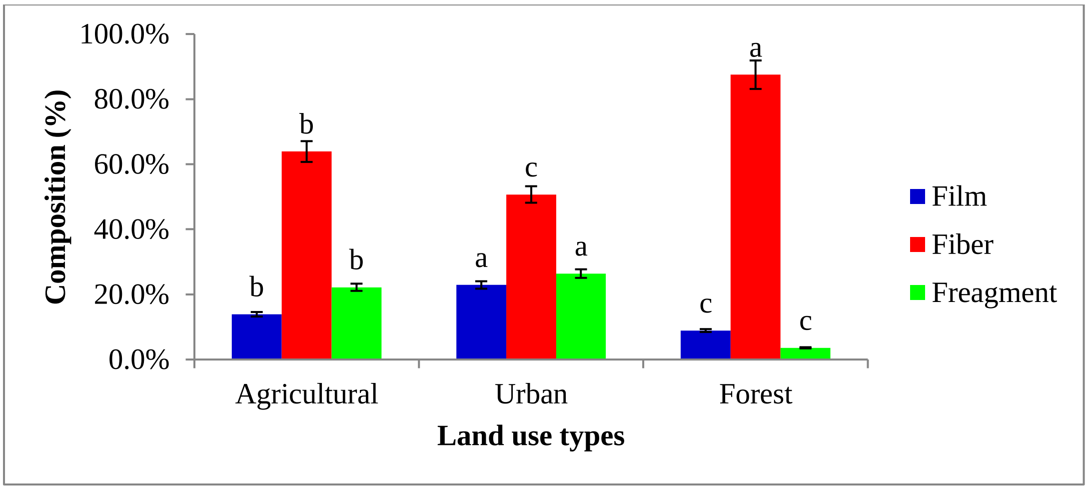


Figure 4.4: Percentage of microplastic shapes in sediments across the three land use types

4.3.1.3 Relationship between microplastic shape and the land use types in water and sediment samples

A Chi-square analysis indicated a statistically significant variation in the distribution of microplastic shapes across the land use types in sediments ($\chi^2 = 23.918$, $P = 0.000$). Similarly, for water samples, the test revealed a significant difference in microplastic shapes among land uses ($\chi^2 = 10.298$, $P = 0.036$) (Table 4.4).

Table 4.4: Relationship between microplastic shape and the land use types in sediments and water

		Land use type					
		Agricultural	**Urban**	**Forest**	**Total**	**χ^2**	**P – value**
		n (%)	n (%)	n (%)	n (%)		
Sediments	Film	5 (13.9)	32 (22.9)	5 (8.9)	42 (18.1)	**23.918**	**0.000***
	Fiber	23 (63.9)	71 (50.7)	49 (87.5)	143 (61.6)		
	Fragment	8 (22.2)	37 (26.4)	2 (3.6)	47 (20.3)		
		36	140	56	232		
Water	Film	2 (5.7)	1 (1.1)	1 (1.3)	4 (1.9)	**10.298**	**0.036***
	Fiber	28 (80.0)	91 (95.8)	73 (94.8)	192 (92.8)		
	Fragment	5 (14.3)	3 (3.2)	3 (3.9)	11 (5.3)		
		35	95	77	207		

4.3.2 Colour characteristics of microplastics present in sediments and water samples

4.3.2.1 Water

The Figure 4.5 below presents the percentage distribution of microplastic colors (White/Transparent, Blue, Yellow, Red, Green, pink, black, and Brown) across the three land use categories in water samples. Blue microplastics dominated overall, accounting for 49.8% of the total particles. It was most prevalent in forest waters (61.0%), compared to urban (42.1%) and agricultural (45.7%) sites. Red and green particles followed in frequency, accounting for 24.2% and 17.4% respectively. White/transparent particles were fewer in water (7.2%), particularly low in forest sites (2.6%) compared to agriculture (14.3%). Other colors such as yellow, brown, and black appeared rarely.

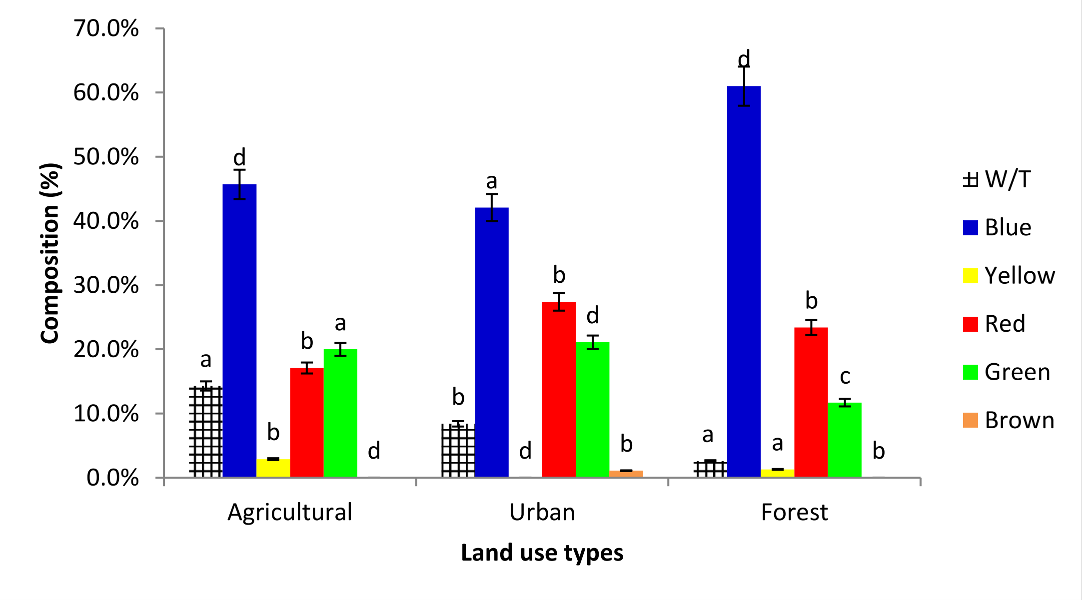


Figure 4.5: Percentage of microplastics in water by color across the three land use types

4.3.2.2 Sediments

As with the water samples, blue emerged as the most common colour in the sediment samples, which accounted for 47.0% of all sediment particles, with the highest occurrence in forested areas (53.6%), followed by urban (46.4%) and agricultural (38.9%) sites. White/transparent (W/T) particles made up 28.9% of the total, and were most common in urban sediments (30.7%), followed by agricultural (27.8%) and forest (25.0%). Other colors like red (14.7%), yellow (2.2%), green (3.4%), pink (1.7%), black (0.4%), and multicolor (1.7%) occurred in lower proportions. Notably, pink microplastics were only found in agricultural sediments, and multicolor particles were more prominent in forest sites (Figure 4.6).

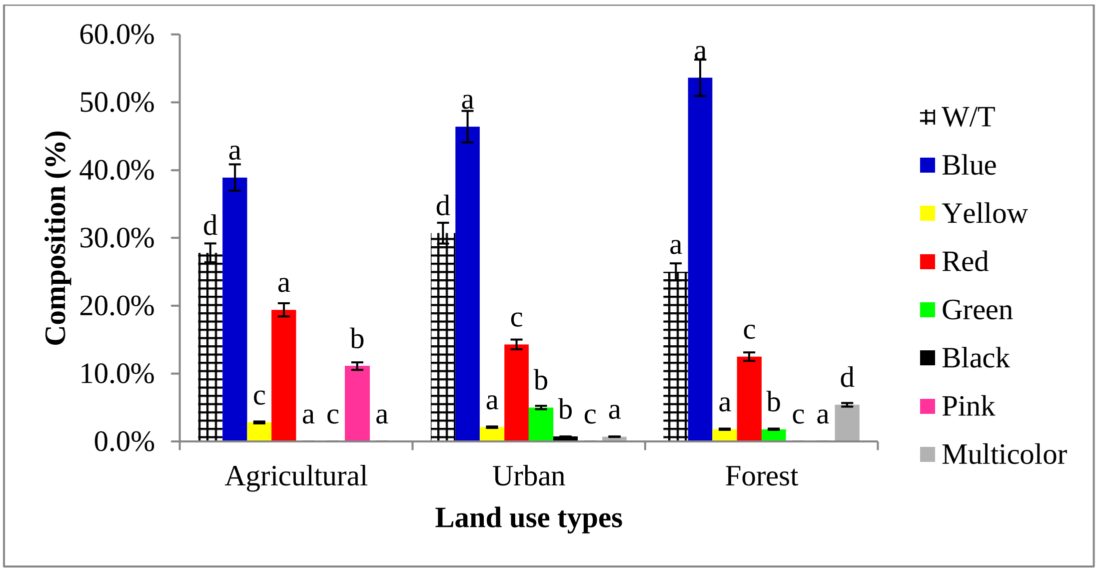


Figure 4.6: Percentage of microplastics in sediments by color across the three land use types

4.3.2.3 Relationship between microplastic color and the land use types in sediments and water

In sediment samples, the chi-square showed a statistically significant variation in microplastic colour across the land use types ($\chi^2 = 33.191$, P = 0.003). In contrast, the test for water samples did not indicate any significant difference in microplastic colour distribution across land use types ($\chi^2 = 15.001$, P = 0.132) (Table 4.5).

Table 4.5: Relationship between microplastic color and the land use types in sediments and water

		Land use type					
		Agricultural	**Urban**	**Forest**	**Total**	χ^2	**P – value**
		n (%)	n (%)	n (%)	n (%)		
Sediments	W/T	10 (27.8)	43 (30.7)	14 (25.0)	67 (28.9)	**33.191**	**0.003***
	Blue	14 (38.9)	65 (46.4)	30 (53.6)	109 (47.0)		
	Yellow	1 (2.8)	3 (2.1)	1 (1.8)	5 (2.2)		
	Red	7 (19.4)	20 (14.3)	7 (12.5)	34 (14.7)		
	Green	0 (0.0)	7 (5.0)	1 (1.8)	8 (3.4)		
	Black	0 (0.0)	1 (0.7)	0 (0.0)	1 (0.4)		
	Pink	4 (11.1)	0 (0.0)	0 (0.0)	4 (1.7)		
	Multicolor	0 (0.0)	1 (0.7)	3 (5.4)	4 (1.7)		
		36	140	56	232		
Water	W/T	5 (14.3)	8 (8.4)	2 (2.6)	15 (7.2)	15.001	0.132
	Blue	16 (45.7)	40 (42.1)	47 (61.0)	103 (49.8)		
	Yellow	1 (2.9)	0 (0.0)	1 (1.3)	2 (1.0)		
	Red	6 (17.1)	26 (27.4)	18 (23.4)	50 (24.2)		
	Green	7 (20.0)	20 (21.1)	9 (11.7)	36 (17.4)		
	Brown	0 (0.0)	1 (1.1)	0 (0.0)	1 (0.5)		
		35	95	77	207		

4.3.3 Size characteristics of microplastics present in water and sediments samples

4.3.3.1 Water samples

Figure 4.7 below shows the distribution of microplastic sizes in water samples across the three land use categories, with distinct patterns observed for each size range: less than 0.5 mm, 0.5 to 1.0mm, and 1.0 to 5.0mm. Overall, particles in the 0.5–1.0 mm range were the most prevalent, which constituted 43.0% of the total particles, followed by <0.5 mm particles at 41.1%, and 1.0–5.0 mm particles at 15.9%. Across land uses, agricultural waters had the highest proportion of <0.5 mm particles (54.3%), whereas forest and urban waters showed relatively similar distributions of small and medium-sized microplastics.

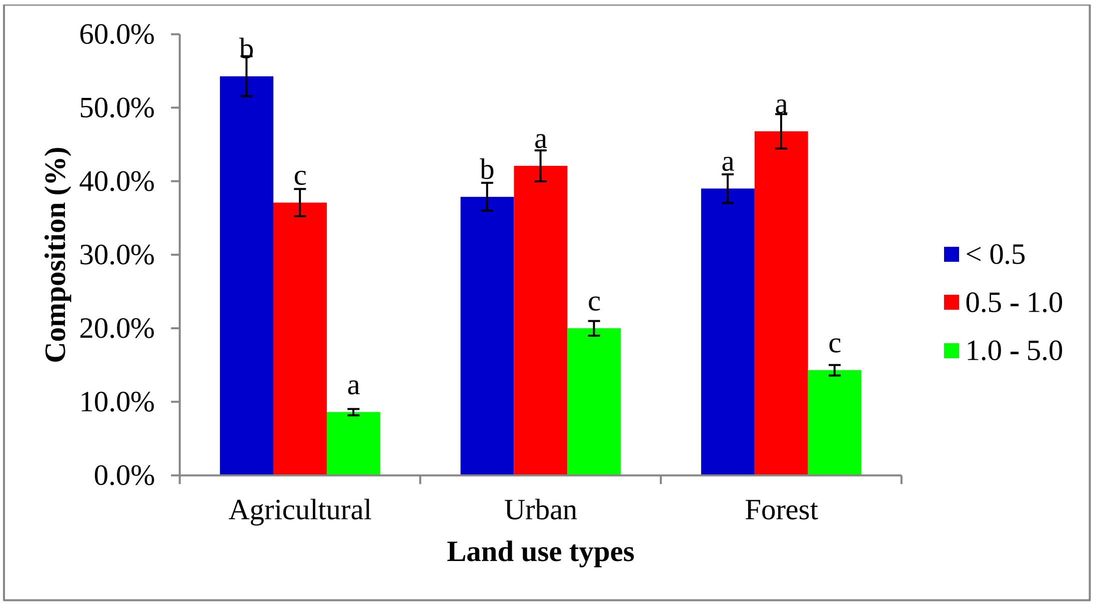


Figure 4.7: Percentage of microplastics in water by size across the three land use types

4.3.3.2 Sediments

Analysis sediment samples across agricultural, urban, and forest land uses showed that the microplastics in the 0.5–1.0 mm size range were the most common, accounting for 33.2% of total particles. This was followed closely by particles smaller than 0.5 mm at 39.2%, and particles between 1.0–5.0 mm at 27.6%. Some variation was noted across land use types such as a slightly higher percentage of <0.5 mm particles in urban sediments (41.4%) compared to agricultural (33.3%) and forest (37.5%) sites (Figure 4.8).

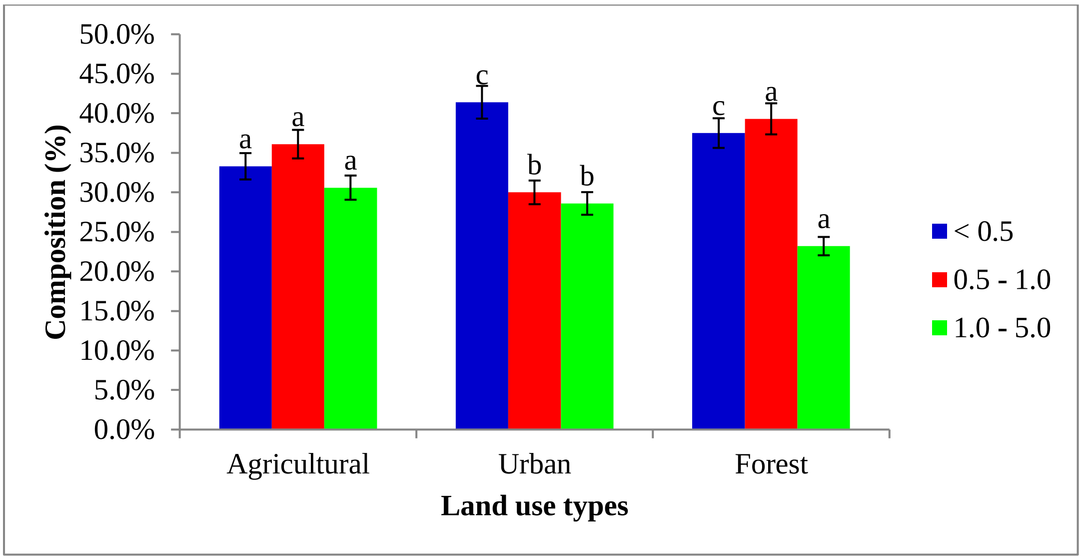


Figure 4.8: Percentage of microplastics in sediments by size across the three land use types

4.3.3.3 Relationship between microplastic size and the land use types in sediments and water

In sediment samples, the chi-square test yielded $\chi^2 = 2.295$ with a p-value of 0.693, showing that microplastic size distribution did not differ significantly across the land use types. Similarly, the chi-square test for water samples resulted in $\chi^2 = 4.661$ with a p-value of 0.324, confirming that size distribution was not statistically significantly different across agricultural, urban, and forest sites (Table 4.6).

Table 4.6: Relationship between microplastic size and the land use types in sediments and water

		Land use type					
		Agricultural	**Urban**	**Forest**	**Total**	**χ^2**	**P – value**
		n (%)	n (%)	n (%)	n (%)		
Sediments	< 0.5	12 (33.3)	58 (41.4)	21 (37.5)	91 (39.2)	2.295	0.693
	0.5 - 1.0	13 (36.1)	42 (30.0)	22 (39.3)	77 (33.2)		
	1.0 - 5.0	11 (30.6)	40 (28.6)	13 (23.2)	64 (27.6)		
		36	140	56	232		
Water	< 0.5	19 (54.3)	36 (37.9)	30 (39.0)	85 (41.1)	4.661	0.324
	0.5 - 1.0	13 (37.1)	40 (42.1)	36 (46.8)	89 (43.0)		
	1.0 - 5.0	3 (8.6)	19 (20.0)	11 (14.3)	33 (15.9)		
		35	95	77	207		

4.3.4 Polymer type characteristics of microplastics in water and sediment samples

4.3.4.1 Water samples

Identifying polymer composition helps trace the likely sources of plastics that have degraded or fragmented into microplastics. The recovered particles were analyzed using Fourier Transform Infrared (FT-IR) spectroscopy, and the resulting spectra (Appendix 1) were matched against a reference library of known polymers. The analysis identified three types of polymers: polyethylene (PE), polypropylene (PP), and high-density polyethylene (HDPE).

Water samples showed a more uniform distribution of microplastic types across land uses. PE remained the most abundant type overall (58.5%), with the highest proportion detected in agricultural sites (74.3%) compared to urban (55.8%) and forested sites (54.5%). PP was also widespread (37.2%), with similar proportions in forested (40.3%) and urban (38.9%) waters, but lower in agricultural waters (25.7%). HDPE was minimally present in water samples across all land uses (4.3%), appearing slightly only in urban and forested sites (Figure 4.9).

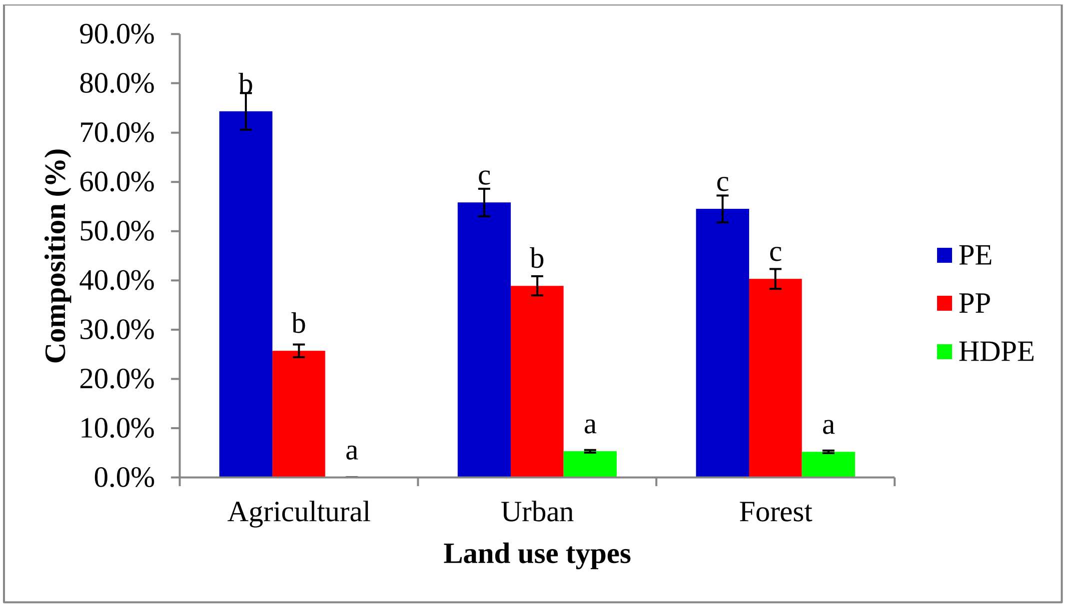


Figure 4.9: Percentage distribution of microplastic polymer types in water across the three land use types

4.3.4.2 Sediments

In the sediment samples, polyethylene (PE) emerged as the predominant polymer type across all land uses, accounting for 65.1% of total particles. Its highest proportion was observed in urban areas (71.4%), followed by agricultural areas (69.4%), and the lowest in forested areas (46.4%). Polypropylene (PP) was more prevalent in sediments from forested sites (44.6%) compared to urban (22.9%) and agricultural (30.6%) sites. High-density polyethylene (HDPE) was rare overall (5.6%), but present in urban (5.7%) and forested (8.9%) sediments, while absent from agricultural sediments entirely (Figure 4.10).

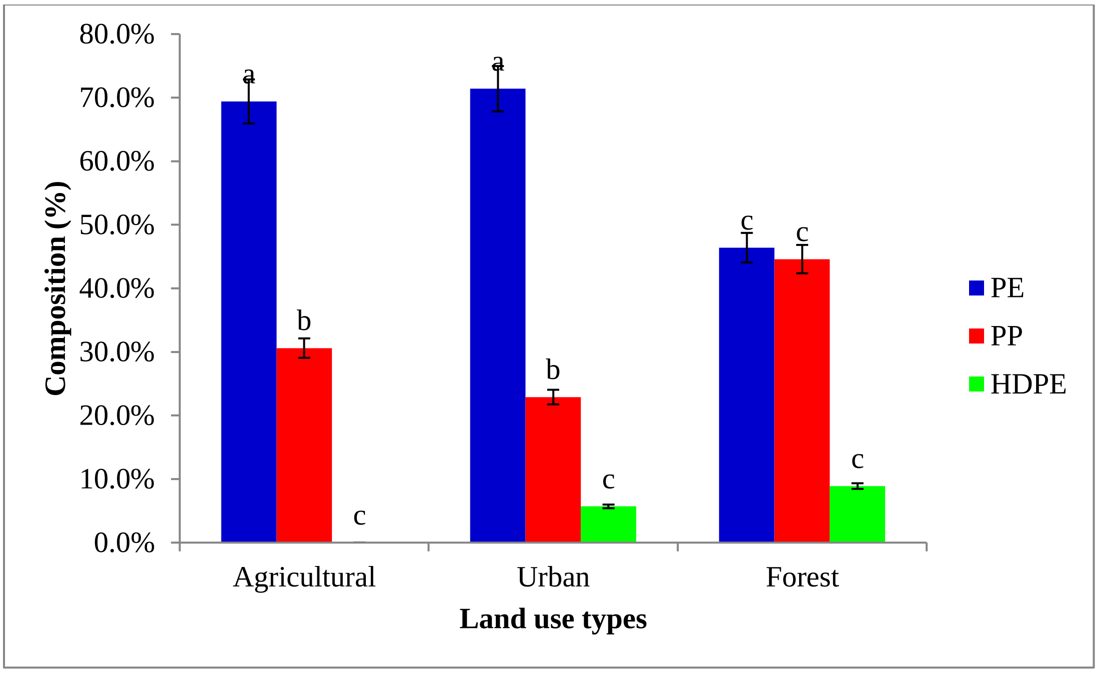


Figure 4.10: Percentage distribution of microplastic polymer types in sediments across the three land use types

4.3.4.3 Relationship between microplastic polymer type and the land use types in sediments and water

In sediment samples, the chi-square test showed a statistically significant variation in polymer type distribution across the three land use types ($\chi^2 = 13.590$, $P = 0.009$), indicating that land use strongly influenced the types of microplastics accumulating in river sediments. In contrast, the chi-square test for water samples indicated no significant differences in polymer composition among land use categories ($\chi^2 = 5.162$, $P = 0.271$) (Table 4.7).

Table 4.7: Relationship between microplastic polymer type and the land use types in sediments and water

		Land use type					
		Agricultural	**Urban**	**Forest**	**Total**	χ^2	**P – value**
		n (%)	n (%)	n (%)	n (%)		
Sediments	PE	25 (69.4)	100 (71.4)	26 (46.4)	151 (65.1)	**13.590**	**0.009***
	PP	11 (30.6)	32 (22.9)	25 (44.6)	68 (29.3)		
	HDPE	0 (0.0)	8 (5.7)	5 (8.9)	13 (5.6)		
		36	140	56	232		
Water	PE	26 (74.3)	53 (55.8)	42 (54.5)	121 (58.5)	5.162	0.271
	PP	9 (25.7)	37 (38.9)	31 (40.3)	77 (37.2)		
	HDPE	0 (0.0)	5 (5.3)	4 (5.2)	9 (4.3)		
		35	95	77	207		

4.4 Influence of land use activities on microplastic distribution and concentration

4.4.1 Water samples

In addition to measuring microplastic concentration and composition in aquatic ecosystems, understanding the environmental factors that may influence their distribution is also crucial. Pearson correlation analysis was used to evaluate the relationship between land use type and microplastic concentration in water samples, measured in particles per litre (P/L). Results demonstrated a very strong positive correlation, with a Pearson correlation coefficient (r) of 0.925. This implies that as land use intensity increases, from forest to agricultural to urban areas, microplastic concentrations increase correspondingly. The mean value for land use type was 2.20 (standard deviation = 0.709), while the mean microplastic concentration was 5.43 P/L with a standard deviation of 2.198. The correlation was statistically significant (p = 0.000), indicating that the relationship observed is highly unlikely to be due to chance. These findings suggest that land use practices are a major factor influencing microplastic pollution in aquatic environments, with more developed and human-modified areas contributing most (Table 4.8).

Table 4.8: Effect of land use activities on microplastic distribution and concentration s in water

	Mean	**Standard deviation**		**Land use type**	**abundance (P/L)**
Land use type	2.20	0.709	Pearson Correlation	1	**0.925***
			Sig. (2-tailed)		.000
			N	207	207
abundance (P/L)	5.43	2.198	Pearson Correlation	**0.925***	1
			Sig. (2-tailed)	0.000	
			N	207	207

Table 4.9 below demonstrates the regression model results, showing that land use type had a significant effect on microplastic concentration in water. The model fit is highly robust, with an R Square value of 0.855, showing that 85.5% of the variance in microplastic concentration could be explained by type of land use. The correlation coefficient (R = 0.925) indicates a very strong positive relationship between type of land use and microplastic concentration, further emphasizing the effect of land use on microplastic distribution.

Table 4.9: Regression model summary of land use influence on microplastic concentration in water

Model Summary									
Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**	**Change Statistics**				
					R Square Change	**F Change**	**df1**	**df2**	**Sig. F Change**
1	0.925[a]	0.855	0.855	0.838	0.855	1212.031	1	205	0.000
a. Predictors: (Constant), Land use type									

The spatial distribution of microplastic (MP) concentrations along River Rwizi is presented in Figure 4.11 below. The results reveal clear variations in microplastic concentrations across the sampling points, corresponding closely with dominant land use types. Microplastic concentrations were highest in urbanized areas, particularly Kakoba and Nyamitanga. These areas are characterized by dense settlements, commercial activities, and inadequate solid waste management, which contribute significantly to the discharge of plastics into the river. Moderate concentrations were observed in transitional zones influenced by both agricultural and peri-urban land uses. In contrast, the lowest concentrations were recorded in upstream and downstream sections of the river, which are dominated by agricultural and forested landscapes with relatively low population pressure.

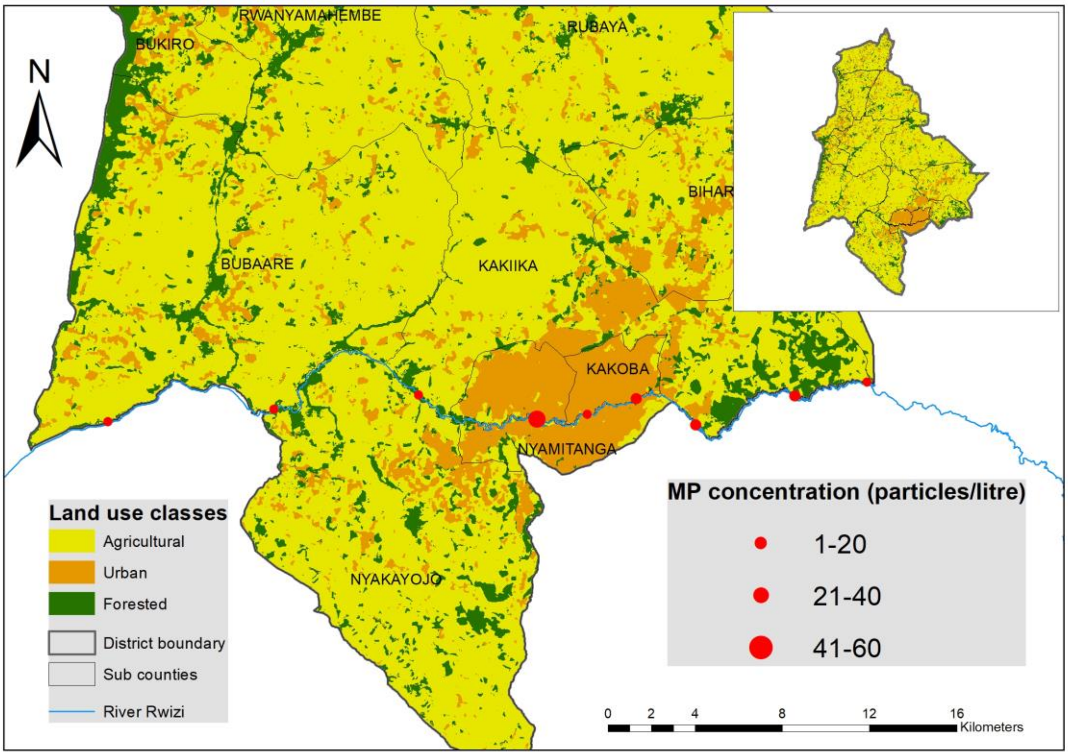


Figure 4.11: Map showing Spatial distribution of microplastics in water samples in different Land use types

4.4.2 Sediments

Pearson correlation analysis was used to examine the relationship between land use type and microplastic concentration in sediments (measured in particles per kilogram of dry weight). The results revealed a strong positive correlation between the two variables, with a Pearson correlation coefficient (r) of 0.923. This indicates that changes in land use type—such as transitions from forested areas to agricultural or urban settings—are strongly associated with increased microplastic abundance. The mean land use value was 2.09 with a standard deviation of 0.625, while the mean microplastic abundance was 5.06 particles/kg dry weight with a standard deviation of 2.189. The correlation was found to be statistically significant, with a p-value of 0.000 ($p < 0.05$), suggesting that the observed relationship is unlikely to have occurred by chance (Table 4.10).

Table 4.10: Effect of land use activities on microplastic distribution and concentration in sediments

	Mean	Standard deviation		Land use type	Abundance (Particles/kg dry wt)
Land use type	2.09	0.625	Pearson Correlation	1	**0.923***
			Sig. (2-tailed)		.000
			N	232	232
Abundance (Particles/kg dry wt)	5.06	2.189	Pearson Correlation	**0.923***	1
			Sig. (2-tailed)	.000	
			N	232	232

Table 4.11 below presents the regression model results, demonstrating that the type of land use had a significant impact on the sediment microplastic concentrations. The model fit is also highly robust, with an R Square value of 0.852, showing that 85.2% of the variance in microplastic concentration is attributable to type of land use. The correlation coefficient (R = 0.923) revealed a very strong positive relationship between type of land use and concentration of microplastics in sediments.

Table 4.11: Regression model summary of land use influence on sediment microplastic concentrations

Model Summary									
Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**	**Change Statistics**				
					R Square Change	**F Change**	**df1**	**df2**	**Sig. F Change**
1	0.923[a]	0.852	0.851	0.844	0.852	1322.620	1	230	0.000
a. Predictors: (Constant), Land use type									

The distribution of microplastic (MP) concentrations in riverbed sediments along River Rwizi is illustrated in Figure 4.12. The concentrations exhibit marked spatial variation that corresponds to surrounding land use patterns and intensity of human activity. The highest MP concentrations were recorded in sediments collected from the urban sub counties of Kakoba and Nyamitanga. These areas are characterized by dense urban settlements, roadside trading, and high levels of solid waste generation, which contribute to the deposition of plastics into the riverbed. The lowest concentrations occurred in the upstream and downstream rural stretches of the river where agricultural and forested land cover dominate. Overall, the results indicate that urban centres act as major sources of sediment-associated microplastics, while areas with relatively intact natural vegetation and low population density exhibit reduced contamination. This spatial pattern highlights the strong influence of urbanization and land use intensity in the accumulation of microplastics in river sediments.

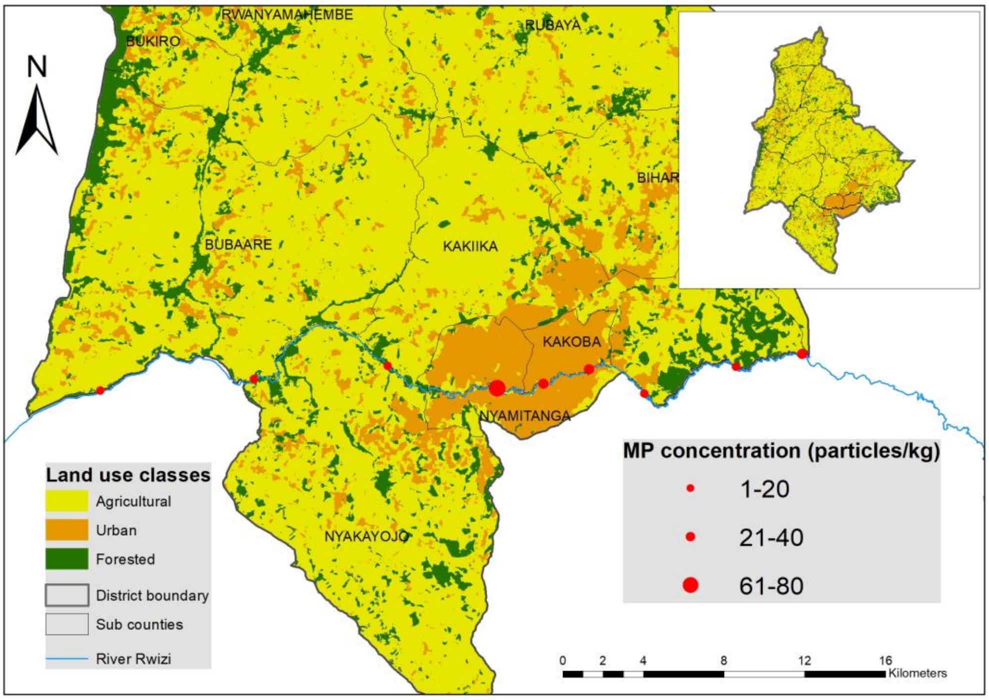


Figure 4.12: Map showing Spatial distribution of microplastics in sediment samples across different Land use types

CHAPTER FIVE

DISCUSSION OF RESULTS

5.1 Concentration of microplastics in water and sediment samples

The study revealed distinct variations in concentrations of microplastics across the different land-use categories. Urban areas recorded the highest level of concentration in both water and sediment samples, a trend linked to the intensity of human activities in these areas, associated with higher population density in urban areas, such as improper waste disposal practices, industrial activities and increased plastic usage and disposal. Macroplastic litter was seen in the riverbanks and comprised mainly of empty soft-drink plastic bottles, plastic (polythene) bags, plastic packaging materials, and PP bags among others. Storm water runoff from roads, sidewalks and open drains in these urban areas also transports plastics into the river. Agricultural areas had the lowest microplastic concentrations in both water and sediments, likely due to minimal plastic use and waste generation. Microplastics may also be retained in agricultural soils, reducing their transportation to the river. Forested areas displayed intermediate levels of microplastics in water, which may be due to the influence of upstream sources and atmospheric deposition. However, the relatively low sediment concentrations indicate minimal direct anthropogenic input, as forested areas generally have no significant industrial or domestic pollution sources.

The findings of this study are consistent with results reported in earlier research conducted by Stovall & Bratton (2022), who identified urban areas as hotspots for microplastic pollution in urban watersheds in Texas USA, due to poor waste management and industrialization. A study in Beijing China also observed a similar trend, where urban water bodies exhibited significantly higher microplastic concentrations than rural or natural areas (Niu et al., 2024). Ross et al. (2023) also reported that agricultural runoff contributes less to microplastic contamination compared to urban regions in a study conducted in Canada. These studies support the observed trends in microplastic concentration levels in River Rwizi across land-use types. However, some studies presented differing results. For example, in a study in China, B. Long et al. (2023) reported that agricultural areas could exhibit higher sediment microplastic levels because of extensive use of plastic in mulching, and irrigation pipes that degrade into microplastics. In another study done in Portugal, Leitão et al. (2023) found forestry areas with higher microplastic levels than urban zones due to deposition from atmospheric sources, particularly near industrial regions. In Bangladesh, Afrin et al. (2020) noted that urban areas with advanced waste management systems had lower microplastic concentrations, suggesting that the findings may vary based on regional management practices.

The findings have significant implications for strategies in environmental conservation and pollution control. Urban areas require targeted interventions such as improving waste management infrastructure, regulating industrial discharges, and minimizing plastic use to reduce microplastic contamination. In agricultural areas, policies encouraging use of biodegradable options and better runoff management can help mitigate microplastic pollution. For forestry areas, minimizing atmospheric deposition of microplastics and protecting natural water bodies can preserve ecosystem integrity.

5.2 Characteristics (colour, shape, size, and Polymer type) of microplastics present in water and sediment samples

5.2.1 Shape

The analysis showed that fibers were the most common shape of microplastics in both water and sediment samples across the three land-use categories (Agricultural, Urban, and Forest). Their dominance is likely linked to widespread use of textile, improper disposal of clothing, and washing of synthetic fabrics, which release fibers into water systems. Fragments were more common in urban sediments due to high levels of plastic use, degradation of discarded plastics, and mechanical breakdown of plastics during urban activities. The slightly higher presence of films in urban areas could be linked to the disposal of single-use plastics like packaging materials and bags, which degrade and settle in sediments through urban runoff and improper waste disposal.

The findings of this study are consistent with those reported by Fältström & Anderberg (2020) who observed fibers as the dominant shape of microplastics in urban water systems, primarily due to domestic and industrial wastewater discharge. Similarly, in Namibia, Faulstich et al. (2022) reported high fiber concentrations in sediments near agricultural and forested regions, citing atmospheric deposition and runoff as significant contributors. In another study in China, Qiang et al. (2023) also found fibers to be the most common microplastic shape in sediments, particularly in agricultural areas, attributing their presence to the degradation of plastic mulch and farming-related activities. The findings of this research also disagreed with other research findings. For example, Kadac-Czapska et al. (2023) reported that fragments were the most common microplastic shape in both water and sediments, suggesting packaging materials and litter breakdown as the key pollution sources. Additionally, in China, Z. Long et al. (2021) identified pellets as the dominant microplastic shape near industrial areas, linking their prevalence to industrial discharge.

These results highlight the pervasive nature of fiber-based microplastic pollution and underscore the urgent need for interventions tailored to different land-use categories. The dominance of fibers emphasizes the importance of improving textile waste management and promotion of biodegradable alternatives to synthetic fibers.

5.2.2 Colour

In water, blue microplastics were the most common across all categories, particularly in forest areas, while red and green microplastics were the second most frequent, with notable proportions in urban and agricultural areas. The dominance of blue microplastics in both water and sediments could be attributed to their origin from widely used products like fishing nets, ropes, and packaging materials that break down into smaller particles over time. Agricultural areas may accumulate red microplastics due to the use of plastics in farming equipment, mulch, and irrigation systems, which often contain colored plastics. Sediment samples from urban areas contained higher proportions of White/Transparent (W/T) microplastics, largely resulting from the degradation of clear or transparent plastic packaging bags and bottles, which are frequently disposed of improperly in urban areas.

Several studies support the study findings. For instance, in a study of Five river mouths of Manila Bay in the Philippines, Osorio et al. (2021) observed high prevalence of blue microplastic particles in water and sediment systems, linking them to fishing activities and degraded plastic materials. Ihenetu et al. (2024) reported a significant presence of W/T microplastics in urban environments, citing improper disposal of plastic waste as a key contributor. Ye et al. (2024) found that red microplastics were more common in agricultural soils, linked to the use of red-colored mulch films and farming equipment. Conversely, some studies provide different findings from those of this study. For instance, in China, Wang et al. (2022) found that green microplastics dominated in some coastal water systems in Coastal Waters of Zhanjiang Bay, attributing their prevalence to degraded green fishing gear. In another study in Beijing China, Niu et al. (2024) found black microplastics as the dominant color in sediments, attributing them to the breakdown of rubber and tire particles in urban runoff. The findings emphasize the need for targeted management of microplastic pollution based on land use. The prevalence of blue microplastics points to the importance of improving the management of discarded fishing gear and related waste in forested and agricultural areas.

5.2.3 Size

In water, smaller microplastics (<0.5 mm) were most prevalent in agricultural areas. Urban water systems exhibited a more even distribution across all size ranges, with a higher proportion of the medium-sized particles (measuring between 0.5–1.0 mm). In sediments, size distributions were more balanced across the three categories. Agricultural sediments exhibited highest prevalence of microplastics within the of 0.5mm to 1.0 mm size range. These findings can be explained by several factors. First, practices like the use of plastic mulching films and agricultural inputs such as fertilizers, contribute significantly to the dominance of smaller microplastics in agricultural water systems. Second, urban runoff introduces a diverse mix of microplastic sizes due to industrial and residential plastic waste, which undergoes rapid degradation from mechanical and chemical processes. Finally, natural degradation processes in forested environments are slower, resulting in the dominance of medium-sized microplastics. These processes are influenced by lower human activity and reduced environmental stressors, such as temperature fluctuations and pollution.

Several studies support the results the of this research. For example, Olubusoye et al. (2024) observed that microplastics smaller than 0.5 mm are prevalent in agricultural runoff, largely resulting from the breakdown of plastic mulch films and pesticide containers. Wang et al. (2022) in their research on Coastal Waters of Zhanjiang Bay in China, observed an even distribution of microplastic sizes in urban runoff, linking it to mixed sources such as industrial waste and household plastic. Similarly, Sharma (2023) found that forest ecosystems are dominated by medium-sized microplastics, likely due to slower degradation processes in areas with minimal anthropogenic disturbances. However, in contrast, some studies report different findings. For example, in their study in United Kingdom, Cusworth et al. (2024) found that larger microplastics (>1.0 mm) were more common in agricultural sediments, suggesting that the degradation of plastics in these areas occurs more slowly than anticipated. Niu et al. (2024) observed that larger microplastics dominated in urban water systems, attributed to the transportation of less-degraded plastics from industrial sources. In their study of the Mae Klong River in the upper Gulf of Thailand, Chaisanguansuk et al. (2023) found smaller microplastics of sizes <0.5 mm to be dominant in forest sediments, hypothesizing that microbial activity accelerates degradation in these environments.

The predominance of smaller microplastics in agricultural water and urban sediments underscores the importance of improving plastic use practices and disposal in these areas. Smaller microplastics pose greater risks to aquatic and terrestrial organisms due to their increased likelihood of being ingested and entering the food chain. Furthermore, the occurrence of microplastics in forest systems indicates that even relatively undisturbed environments are not exempt from pollution, underscoring the pervasive nature of microplastic contamination.

5.2.4 Polymer type

Polyethylene (PE) emerged as the dominant microplastic in both water and sediments, accounting for approximately 70–80% of the total composition. This finding can be linked to the extensive use of PE in agriculture (e.g., in mulching films and packaging), urban areas (e.g., in plastic bags and bottles), and even in forested areas (e.g., from packaging materials). Secondly, the higher durability of PE and PP compared to HDPE contributes to their higher prevalence, as they degrade more slowly and persist longer in the environment. Lastly, variations in land-use activities influence the distribution of these microplastics. Agricultural runoff is rich in PE due to farming materials, while urban runoff contains a mix of PE and PP from industrial and domestic sources. Forest areas, although less directly impacted by human activity, still exhibit microplastic contamination, likely due to proximity to agricultural or urban zones.

Several studies support the findings of the study. For instance, Yu et al. (2022) identified Polyethylene (PE) as the most dominant microplastic in agricultural soils and urban runoff, attributing this to its extensive use in farming and daily life. Similarly, in a study conducted in Serbia, Baloš et al. (2024) reported that PE were the common type in sediments from urban and agricultural areas, attributing its prevalence to extensive use in packaging materials and its slow degradation. In Korea, Bae & Yoo (2022) also reported that PP and PE dominated water and sediments in coastal environments, noting that HDPE was less common due to its density and specific usage patterns.

In contrast, other studies have produced different findings. For example, Sá et al. (2022), studying the Lis River in Portugal, reported that PP was more abundant than PE in water bodies near industrial zones, suggesting that localized factors may influence microplastic composition.in India, Ramakrishnan et al. (2024) reported higher concentrations of HDPE in sediments near urban areas, attributing this to improper disposal of construction materials. Sharma (2023) found no significant dominance of PE in forested areas, suggesting that microplastics in such regions are influenced more by long-range atmospheric transport than by direct human activities.

The findings underscore critical environmental management challenges. The predominance of PE reinforces the critical need to strengthen plastic waste management, particularly in agricultural and urban settings where its use is extensive. The presence of PP across all land-use types suggests that its widespread industrial and domestic usage must be regulated to reduce its environmental footprint. Despite its lower prevalence, HDPE's environmental risks should not be overlooked, as it may accumulate in areas not covered by this study.

5.3 **Influence of land use activities on distribution and concentration of microplastics**

The results of this study revealed a strong positive correlation between land-use types and microplastic concentrations in both water and sediments. The statistical significance supports the assertion that land use is a critical factor in microplastic pollution. The observed patterns can be explained by various factors associated with human activities and environmental processes in different land-use types. Urban areas, characterized by high population densities and industrial activities, generate significant amounts of microplastics because of factors like improper waste disposal and high plastic consumption. In contrast, agricultural areas, while less densely populated, contribute considerable microplastic pollution primarily from plastic materials used in farming, such as mulch films, fertilizers, and irrigation pipes, as well as residences. Forested areas, with fewer human interventions, generally exhibit lower microplastic concentrations, though these areas can still be contaminated through atmospheric deposition or waterborne transport of microplastics from adjacent land-use types. Runoff and erosion also significantly influence the distribution of microplastics. Water runoff from urban areas, where impervious surfaces like roads and pavements are prevalent, carries larger quantities of microplastics compared to agricultural areas, where runoff is typically linked to farming activities. Additionally, physical characteristics of sediments like particle sizes and organic content, influence the retention of microplastics. Practices like soil tilling in agriculture and construction in urban areas can disturb sediments and increase their capacity to trap microplastics, further explaining the higher concentrations observed in areas with such activities.

Numerous studies support the findings of this research. For instance, in a study done in Canada, Ross et al. (2023) found that urbanization significantly increases microplastic concentrations in water due to various factors related to increased human activity, waste generation, and altered land use. Urban areas are dominated by impermeable surfaces like roads, pavements, and rooftops, which limit water infiltration and accelerate runoff into nearby water bodies. This runoff carries microplastics from sources like tire wear, synthetic fibers, and plastic litter. Storm water systems and untreated or partially treated wastewater also serve as pathways for microplastics, especially during periods of heavy rains, when overflows discharge directly into the water bodies, which aligns with the observed trends in this study. Similarly, a study on River Ganga in India by Rajan et al. (2023) reported a positive relationship between urban development and concentrations of microplastics in river sediments, confirming the significant impact of urban activities in microplastic pollution. Olubusoye et al. (2024) also identified agricultural runoff as a major route through which microplastics enter water bodies, corroborating the findings observed in this study for agricultural areas. However, some studies present contrasting results. For instance, in a study done in the Melbourne Region of Victoria, Australia, Townsend et al. (2019) reported only a weak correlation between land use and microplastic concentrations in wetland sediments, indicating that atmospheric deposition might have a more substantial effect in remote areas, which contrasts with the strong correlation observed in this study. In a review paper titled "The Factors Influencing Microplastic Behaviour in Riverine Systems", Kumar et al. (2021) proposed that hydrodynamic factors, rather than land-use type, determine microplastic concentrations in sediments, challenging the findings of this study, where type of land-use was a significant factor. In a study conducted in Pristina City, Kosovo, Cakaj et al. (2023) also observed that microplastic concentrations in some forested areas were comparable to those in urban areas, likely due to long-range atmospheric transport, a finding that aligns with the observation that even forested areas can be vulnerable to microplastic contamination. This result of this study emphasize the influence of land-use activities on microplastic pollution, highlighting that urban and agricultural areas are the key sources of microplastic contamination in both water and sediments.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

6.1.1 Microplastic concentrations in water and sediment samples

Microplastic concentration levels were generally higher in water compared to sediments, indicating that many microplastics remain suspended due to their low density, continuous resuspension, and hydrodynamic movement. Water therefore serves as a transport pathway, while sediments act as long-term sinks for microplastics. However, disturbances in the river can remobilize microplastic particles from sediments back into the water, continuing the pollution cycle.

6.1.2 Characteristics (shape, colour, size, and Polymer type) of microplastics in water and sediment samples

Microplastic pollution varied in shape, colour, size, and type of polymer across the different land-use categories.

Shape: The prevalence of fibers in water indicates that they remain suspended for longer periods, while fragments and denser plastics are more likely to settle in sediments.

Colour: The predominance of blue microplastics across all land use types suggests that they likely originate from commonly used plastic products such as synthetic textiles, fishing gear, and plastic packaging. The variations in color distribution indicate that different sources contribute to microplastic pollution in different sections of the river. The presence of other colors, such as red and black, can be linked to deteriorating plastic materials from industrial and domestic wastes.

Size: The largest proportion of microplastics were within the of 0.5mm to1.0 mm size range, indicating that they primarily result from degradation of larger plastic debris rather than direct primary microplastic sources. This suggests ongoing degradation of mismanaged plastic waste within the river system. The presence of even smaller microplastics, though not dominant, raises concern regarding their potential for bioaccumulation and biomagnification in aquatic ecosystems.

Polymer type: the dominance of Polyethylene and Polypropylene suggests that these microplastics mainly originate from packaging materials, plastic bags, disposable containers, and bottle caps, which are widely used and frequently discarded in both rural and urban areas. The occurrence of these polymers of low density in both water and sediment samples highlight their persistence within the environment, and their potential for long distance movement within aquatic systems.

6.1.3 Influence of land use activities on distribution and load of micro plastics

Urban and agricultural areas recorded higher microplastic concentrations than forested areas, highlighting the influence of human activities on microplastic pollution. Urban sediments exhibited relatively higher concentrations, likely due to long-term deposition of microplastics from wastewater discharges and stormwater runoff. The findings confirm that land use activities have play a critical role in shaping the distribution and accumulation of microplastics in River Rwizi.

6.2 Recommendations

6.2.1 Microplastic concentrations in water and sediment samples

- Implement robust waste management systems, promote recycling, and regulate plastic usage in urban areas.
- Encourage the adoption of biodegradable packaging materials and manage runoff to reduce microplastic transport into the river.
- Develop policies to protect natural water sources and restore river buffer areas to lessen the entry of microplastics into the river.
- Raise awareness among stakeholders on the ecological impacts of microplastics.

6.2.2 Characteristics (colour, shape, size, and Polymer type) of microplastics present in water and sediment samples

- Promote use of alternative packaging materials in local communities. This includes shifting from single-use plastics to eco-friendly options such as reusable, compostable, or recyclable materials.
- Enforce strict regulations for plastic waste disposal, and promote recycling initiatives. Conduct public awareness campaigns on plastic waste management, focusing on the sources and impacts of microplastics.
- Encouraging responsible consumption and disposal practices, as well as reducing the use of plastic products, will reduce microplastic leakage into the environment.
- Regular monitoring programs should track pollution trends and evaluate the effectiveness of interventions to inform policy decisions.

6.2.3 Influence of land use activities on distribution and load of microplastics

- Urban areas should implement improved waste management systems, such as enhanced recycling programs, stricter regulations on plastic disposal, and public awareness campaigns. Local authorities should implement integrated land use management plans that incorporate environmental considerations.
- Proper zoning can prevent the encroachment of urban and agricultural activities along riverbanks. In agricultural areas, promoting sustainable farming practices such as reduction in use of plastic mulching and ensuring proper disposal of plastic materials (e.g., pesticide containers, plastic irrigation tubing) will help decrease the contribution of plastics to the river.
- Forest conservation efforts should be strengthened to maintain their protective function against pollution. Implementing river restoration programs, especially in areas impacted by urbanization and agriculture, would help restore natural filtration processes. Vegetated buffer zones and riparian restoration efforts should be prioritized to reduce microplastic inputs into the river system.

6.2.4 Recommendations for further research

This study analyzed microplastic concentrations in water and sediments of River Rwizi during August 2024. Further research should investigate how these concentrations change over time, particularly in relation to seasonal variations.

Further research is also recommended to examine the specific sources, pathways, and ecological impacts of microplastics, with an emphasis on size and colour variations.

REFERENCES

Abbas, G., Ahmed, U., & Ahmad, M. A. (2025). Impact of Microplastics on Human Health: Risks, Diseases, and Affected Body Systems. In *Microplastics* (Vol. 4, Issue 2). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/microplastics4020023

Afrin, S., Uddin, M. K., & Rahman, M. M. (2020). Microplastics contamination in the soil from Urban Landfill site, Dhaka, Bangladesh. *Heliyon*, *6*(11). https://doi.org/10.1016/j.heliyon.2020.e05572

Akindele, E. O., Ehlers, S. M., & Koop, J. H. E. (2019). First empirical study of freshwater microplastics in West Africa using gastropods from Nigeria as bioindicators. *Limnologica*, *78*. https://doi.org/10.1016/j.limno.2019.125708

Ali, S. S., Elsamahy, T., Al-Tohamy, R., & Sun, J. (2024). A critical review of microplastics in aquatic ecosystems: Degradation mechanisms and removing strategies. In *Environmental Science and Ecotechnology* (Vol. 21). Editorial Board, Research of Environmental Sciences. https://doi.org/10.1016/j.ese.2024.100427

Andrady, A. L. (2011). Microplastics in the marine environmentAndrady, A. L. (2011). Microplastics in the marine environment. Marine Pollution Bulletin, 62(8), 1596–1605. https://doi.org/10.1016/J.MARPOLBUL.2011.05.030. *Marine Pollution Bulletin*, *62*(8).

Andrady, A. L., & Neal, M. A. (2009). Applications and societal benefits of plastics. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1526), 1977–1984. https://doi.org/10.1098/rstb.2008.0304

Ash, S., Sharma, R., & Rabnawaz, M. (2024). Comparative Study of Polyethylene, Polypropylene, and Polyolefins Silyl Ether-Based Vitrimers. *Industrial and Engineering Chemistry Research*, *63*(51), 22287–22297. https://doi.org/10.1021/acs.iecr.4c04006

Ashton, K., Holmes, L., & Turner, A. (2010). Association of metals with plastic production pellets in the marine environment. *Marine Pollution Bulletin*, *60*(11), 2050–2055. https://doi.org/https://doi.org/10.1016/j.marpolbul.2010.07.014

Azevedo-Santos, V. M., Brito, M. F. G., Manoel, P. S., Perroca, J. F., Rodrigues-Filho, J. L., Paschoal, L. R. P., Gonçalves, G. R. L., Wolf, M. R., Blettler, M. C. M., Andrade, M. C., Nobile, A. B., Lima, F. P., Ruocco, A. M. C., Silva, C. V., Perbiche-Neves, G., Portinho, J. L., Giarrizzo, T., Arcifa, M. S., & Pelicice, F. M. (2021). Plastic pollution: A focus on freshwater biodiversity. In *Ambio* (Vol. 50, Issue 7, pp. 1313–1324). Springer Science and Business Media B.V. https://doi.org/10.1007/s13280-020-01496-5

Bae, S., & Yoo, K. (2022). Microplastic contamination and microbial colonization in coastal area of Busan City, Korea. *Frontiers in Marine Science*, *9*. https://doi.org/10.3389/fmars.2022.1030476

Baldwin, A. K., Corsi, S. R., & Mason, S. A. (2016). Plastic Debris in 29 Great Lakes Tributaries: Relations to Watershed Attributes and Hydrology. *Environmental Science & Technology*, *50*(19), 10377–10385. https://doi.org/10.1021/acs.est.6b02917

Ballent, A., Corcoran, P. L., Madden, O., Helm, P. A., & Longstaffe, F. J. (2016). Sources and sinks of microplastics in Canadian Lake Ontario nearshore, tributary and beach sediments. *Marine Pollution Bulletin*, *110*(1), 383–395. https://doi.org/https://doi.org/10.1016/j.marpolbul.2016.06.037

Ballent, A., Purser, A., de Jesus Mendes, P., Pando, S., & Thomsen, L. (2012). *Physical transport properties of marine microplastic pollution*. https://doi.org/10.5194/bgd-9-18755-2012

Baloš, M., Petrović, A., Tubić, A., Zeremski, T., Gvozdenac, S., Supić, D., & Bursić, V. (2024). Effects of Polyethylene Microplastics in Agricultural Soil on Eisenia fetida (Annelida: Oligochaeta) Behavior, Biomass, and Mortality. *Agriculture (Switzerland)*, *14*(4). https://doi.org/10.3390/agriculture14040578

Barnes, D. K. A., Galgani, F., Thompson, R. C., & Barlaz, M. (2009). Accumulation and fragmentation of plastic debris in global environments. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1526), 1985–1998. https://doi.org/10.1098/rstb.2008.0205

Barrows, A. P. W., Christiansen, K. S., Bode, E. T., & Hoellein, T. J. (2018). A watershed-scale, citizen science approach to quantifying microplastic concentration in a mixed land-use river. *Water Research*, *147*, 382–392. https://doi.org/10.1016/j.watres.2018.10.013

Belmaker, I., Anca, E. D., Rubin, L. P., Magen-Molho, H., Miodovnik, A., & van der Hal, N. (2024). Adverse health effects of exposure to plastic, microplastics and their additives: environmental, legal and policy implications for Israel.

Israel Journal of Health Policy Research, 13(1). https://doi.org/10.1186/s13584-024-00628-6

Bexeitova, K., Baimenov, A., Varol, E. A., Kudaibergenov, K., Zhantikeyev, U., Sailaukhanuly, Y., Toshtay, K., Tauanov, Z., Azat, S., & Berndtsson, R. (2024). Microplastics in freshwater systems: A review of classification, sources, and environmental impacts. In *Chemical Engineering Journal Advances* (Vol. 20). Elsevier B.V. https://doi.org/10.1016/j.ceja.2024.100649

Biginagwa, F. J., Mayoma, B. S., Shashoua, Y., Syberg, K., & Khan, F. R. (2016). First evidence of microplastics in the African Great Lakes: Recovery from Lake Victoria Nile perch and Nile tilapia. *Journal of Great Lakes Research*, *42*(1), 146–149. https://doi.org/https://doi.org/10.1016/j.jglr.2015.10.012

Bryant, J. A., Clemente, T. M., Viviani, D. A., Fong, A. A., Thomas, K. A., Kemp, P., Karl, D. M., White, A. E., & DeLong, E. F. (2016). Diversity and Activity of Communities Inhabiting Plastic Debris in the North Pacific Gyre. *MSystems*, *1*(3). https://doi.org/10.1128/msystems.00024-16

Cakaj, A., Lisiak-Zielińska, M., Drzewiecka, K., Budka, A., Borowiak, K., Drapikowska, M., Cakaj, A., Qorri, E., & Szkudlarz, P. (2023). Potential Impact of Urban Land Use on Microplastic Atmospheric Deposition: A Case Study in Pristina City, Kosovo. *Sustainability (Switzerland), 15*(23). https://doi.org/10.3390/su152316464

Camargo, A. L. G., Girard, P., Sanz-Lazaro, C., Silva, A. C. M., de Faria, É., Figueiredo, B. R. S., Caixeta, D. S., & Blettler, M. C. M. (2022). Microplastics in sediments of the Pantanal Wetlands, Brazil. *Frontiers in Environmental Science, 10*. https://doi.org/10.3389/fenvs.2022.1017480

Campbell, S. H., Williamson, P. R., & Hall, B. D. (2017). Microplastics in the gastrointestinal tracts of fish and the water from an urban prairie creek. *FACETS*, *2*(1), 395–409. https://doi.org/10.1139/facets-2017-0008

Chaisanguansuk, P., Phantuwongraj, S., Jirapinyakul, A., & Assawincharoenkij, T. (2023). Preliminary study on microplastic abundance in mangrove sediment cores at Mae Klong River, upper Gulf of Thailand. *Frontiers in Environmental Science, 11*. https://doi.org/10.3389/fenvs.2023.1134988

Cole, M., Lindeque, P., Fileman, E., Halsband, C., Goodhead, R., Moger, J., & Galloway, T. S. (2013). Microplastic Ingestion by Zooplankton. *Environmental Science & Technology*, *47*(12), 6646–6655. https://doi.org/10.1021/es400663f

Cusworth, S. J., Davies, W. J., McAinsh, M. R., Gregory, A. S., Storkey, J., & Stevens, C. J. (2024). Agricultural fertilisers contribute substantially to microplastic concentrations in UK soils. *Communications Earth and Environment*, *5*(1). https://doi.org/10.1038/s43247-023-01172-y

Daily Monitor. (2023, September 17). *Rwizi: A river on the brink of extinction*. Monitor Publications .

Dris, R., Imhof, H. K., Löder, M. G. J., Gasperi, J., Laforsch, C., & Tassin, B. (2018). Chapter 3 - Microplastic Contamination in Freshwater Systems: Methodological Challenges, Occurrence and Sources. In E. Y. Zeng (Ed.), *Microplastic Contamination in Aquatic Environments* (pp. 51–93). Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-12-813747-5.00003-5

Duis, K., & Coors, A. (2016). Microplastics in the aquatic and terrestrial environment: sources (with a specific focus on personal care products), fate and effects. In *Environmental Sciences Europe* (Vol. 28, Issue 1, pp. 1–25). Springer Verlag. https://doi.org/10.1186/s12302-015-0069-y

Ebere, E. C., Wirnkor, V. A., Ngozi, V. E., & Chukwuemeka, I. S. (2019). Macrodebris and microplastics pollution in Nigeria: First report on abundance, distribution and composition. *Environmental Health and Toxicology*, *34*(4). https://doi.org/10.5620/eaht.e2019012

Edo, C., González-Pleiter, M., Leganés, F., Fernández-Piñas, F., & Rosal, R. (2020). Fate of microplastics in wastewater treatment plants and their environmental dispersion with effluent and sludge. *Environmental Pollution*, *259*, 113837. https://doi.org/https://doi.org/10.1016/j.envpol.2019.113837

Eerkes-Medrano, D., Thompson, R. C., & Aldridge, D. C. (2015). Microplastics in freshwater systems: A review of the emerging threats, identification of knowledge gaps and prioritisation of research needs. In *Water Research* (Vol. 75, pp. 63–82). Elsevier Ltd. https://doi.org/10.1016/j.watres.2015.02.012

Egessa, R., Nankabirwa, A., Ocaya, H., & Pabire, W. G. (2020). Microplastic pollution in surface water of Lake Victoria. *Science of the Total Environment*, *741*. https://doi.org/10.1016/j.scitotenv.2020.140201

Estahbanati, S., & Fahrenfeld, N. L. (2016). Influence of wastewater treatment plant discharges on microplastic concentrations in surface water. *Chemosphere*, *162*, 277–284. https://doi.org/https://doi.org/10.1016/j.chemosphere.2016.07.083

Fältström, E., & Anderberg, S. (2020). *Towards control strategies for microplastics in urban water*. https://doi.org/10.1007/s11356-020-10064-z/Published

Faulstich, L., Prume, J. A., Arendt, R., Reinhardt-Imjela, Ch., Chifflard, P., & Schulte, A. (2022). Microplastics in Namibian river sediments – a first evaluation. *Microplastics and Nanoplastics*, *2*(1). https://doi.org/10.1186/s43591-022-00043-1

Fendall, L. S., & Sewell, M. A. (2009). Contributing to marine pollution by washing your face: Microplastics in facial cleansers. *Marine Pollution Bulletin*, *58*(8), 1225–1228. https://doi.org/10.1016/j.marpolbul.2009.04.025

Free, C. M., Jensen, O. P., Mason, S. A., Eriksen, M., Williamson, N. J., & Boldgiv, B. (2014). High-levels of microplastic pollution in a large, remote, mountain lake. *Marine Pollution Bulletin*, *85*(1), 156–163. https://doi.org/https://doi.org/10.1016/j.marpolbul.2014.06.001

Frei, S., Piehl, S., Gilfedder, B. S., Löder, M. G. J., Krutzke, J., Wilhelm, L., & Laforsch, C. (2019). Occurence of microplastics in the hyporheic zone of rivers. *Scientific Reports, 9*(1). https://doi.org/10.1038/s41598-019-51741-5

Frias, J. P. G. L., & Nash, R. (2019). Microplastics: Finding a consensus on the definition. *Marine Pollution Bulletin, 138,* 145–147. https://doi.org/https://doi.org/10.1016/j.marpolbul.2018.11.022

Galgani, L., Beiras, R., Galgani, F., Panti, C., & Borja, A. (2019). Editorial: “impacts of marine litter.” In *Frontiers in Marine Science* (Vol. 6, Issue APR). Frontiers Media S.A. https://doi.org/10.3389/fmars.2019.00208

GESAMP. (2015). *Science for Sustainable Oceans*. www.imo.org

Geyer, R., Jambeck, J. R., & Law, K. L. (2017). *Production, use, and fate of all plastics ever made*. https://www.science.org

Gomiero, A., Strafella, P., Pellini, G., Salvalaggio, V., & Fabi, G. (2018). Comparative effects of ingested PVC micro particles with and without adsorbed benzo(a)pyrene vs. spiked sediments on the cellular and sub cellular processes of the benthic organism Hediste diversicolor. *Frontiers in Marine Science*, *5*(APR). https://doi.org/10.3389/fmars.2018.00099

Hanvey, J. S., Lewis, P. J., Lavers, J. L., Crosbie, N. D., Pozo, K., & Clarke, B. O. (2017). A review of analytical techniques for quantifying microplastics in sediments. *Analytical Methods*, *9*(9), 1369–1383. https://doi.org/10.1039/C6AY02707E

Hao Y.L, Hu Y.X, Bai X.X, & Guo S.L. (2022). Abundances and Morphology Patterns of Microplastics Under Different land Use Types on the Loess Platueau. *Huan Jing Ke Xue*, *43*(9), 4748–4755.

Hendrickson, E., Minor, E. C., & Schreiner, K. (2018). Microplastic Abundance and Composition in Western Lake Superior As Determined via Microscopy, Pyr-GC/MS, and FTIR. *Environmental Science & Technology*, *52*(4), 1787–1796. https://doi.org/10.1021/acs.est.7b05829

Hidalgo-Ruz, V., Gutow, L., Thompson, R. C., & Thiel, M. (2012). Microplastics in the Marine Environment: A Review of the Methods Used for Identification and Quantification. *Environmental Science & Technology*, *46*(6), 3060–3075. https://doi.org/10.1021/es2031505

Horton, A. A., Svendsen, C., Williams, R. J., Spurgeon, D. J., & Lahive, E. (2017). Large microplastic particles in sediments of tributaries of the River Thames, UK – Abundance, sources and methods for effective quantification. *Marine Pollution Bulletin*, *114*(1), 218–226. https://doi.org/https://doi.org/10.1016/j.marpolbul.2016.09.004

Huang, D., Li, X., Ouyang, Z., Zhao, X., Wu, R., Zhang, C., Lin, C., Li, Y., & Guo, X. (2021). The occurrence and abundance of microplastics in surface water and sediment of the West River downstream, in the south of China. *Science of The Total Environment*, *756*, 143857. https://doi.org/https://doi.org/10.1016/j.scitotenv.2020.143857

Ihenetu, S. C., Enyoh, C. E., Wang, C., & Li, G. (2024). Sustainable Urbanization and Microplastic Management: Implications for Human Health and the Environment. In *Urban Science* (Vol. 8, Issue 4). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/urbansci8040252

Imhof, H. K., Ivleva, N. P., Schmid, J., Niessner, R., & Laforsch, C. (2013). Contamination of beach sediments of a subalpine lake with microplastic particles. In *Current Biology* (Vol. 23, Issue 19). Cell Press. https://doi.org/10.1016/j.cub.2013.09.001

Jahandari, A. (2023). Microplastics in the urban atmosphere: Sources, occurrences, distribution, and potential health implications. *Journal of Hazardous Materials Advances*, *12*. https://doi.org/10.1016/j.hazadv.2023.100346

Jolaosho, T. L., Rasaq, M. F., Omotoye, E. V., Araomo, O. V., Adekoya, O. S., Abolaji, O. Y., & Hungbo, J. J. (2025). Microplastics in freshwater and marine ecosystems: Occurrence, characterization, sources, distribution dynamics, fate, transport processes, potential mitigation strategies, and policy interventions. In *Ecotoxicology and Environmental Safety* (Vol. 294). Academic Press. https://doi.org/10.1016/j.ecoenv.2025.118036

Kadac-Czapska, K., Knez, E., Gierszewska, M., Olewnik-Kruszkowska, E., & Grembecka, M. (2023). Microplastics Derived from Food Packaging Waste—Their Origin and Health Risks. In *Materials* (Vol. 16, Issue 2). MDPI. https://doi.org/10.3390/ma16020674

Klein, S., Worch, E., & Knepper, T. P. (2015). Occurrence and spatial distribution of microplastics in river shore sediments of the rhine-main area in Germany. *Environmental Science and Technology*, *49*(10), 6070–6076. https://doi.org/10.1021/acs.est.5b00492

Koelmans, A. A., Besseling, E., Wegner, A., & Foekema, E. M. (2013a). Plastic as a Carrier of POPs to Aquatic Organisms: A Model Analysis. *Environmental Science & Technology*, *47*(14), 7812–7820. https://doi.org/10.1021/es401169n

Koelmans, A. A., Besseling, E., Wegner, A., & Foekema, E. M. (2013b). Plastic as a Carrier of POPs to Aquatic Organisms: A Model Analysis. *Environmental Science & Technology*, *47*(14), 7812–7820. https://doi.org/10.1021/es401169n

Kosore, C., Ojwang, L., Maghanga, J., Kamau, J., Kimeli, A., Omukoto, J., Ngisiag’e, N., Mwaluma, J., Ong’ada, H., Magori, C., & Ndirui, E. (2018). Occurrence and ingestion of microplastics by zooplankton in Kenya’s marine environment: first documented evidence. *African Journal of Marine Science*, *40*(3), 225–234. https://doi.org/10.2989/1814232X.2018.1492969

Kumar, R., Sharma, P., Verma, A., Jha, P. K., Singh, P., Gupta, P. K., Chandra, R., & Vara Prasad, P. V. (2021). Effect of physical characteristics and hydrodynamic conditions on transport and deposition of microplastics in riverine ecosystem. In *Water (Switzerland)* (Vol. 13, Issue 19). MDPI. https://doi.org/10.3390/w13192710

Leal Filho, W., Saari, U., Fedoruk, M., Iital, A., Moora, H., Klöga, M., & Voronova, V. (2019). An overview of the problems posed by plastic products and the role of extended producer responsibility in Europe. *Journal of Cleaner Production, 214*, 550–558. https://doi.org/https://doi.org/10.1016/j.jclepro.2018.12.256

Leitão, I. A., van Schaik, L., Ferreira, A. J. D., Alexandre, N., & Geissen, V. (2023). The spatial distribution of microplastics in topsoils of an urban environment - Coimbra city case-study. *Environmental Research, 218*. https://doi.org/10.1016/j.envres.2022.114961

Li, C., Zhu, L., Wang, X., & Li, D. (2025). Elucidating the distribution and characteristics of microplastics in water column of the northwestern South China Sea with a large-volume in situ filtration technology (plankton pump). *Frontiers in Marine Science, 12*. https://doi.org/10.3389/fmars.2025.1556592

Li, J., Liu, H., & Paul Chen, J. (2018). Microplastics in freshwater systems: A review on occurrence, environmental effects, and methods for microplastics detection. In *Water Research* (Vol. 137, pp. 362–374). Elsevier Ltd. https://doi.org/10.1016/j.watres.2017.12.056

Long, B., Li, F., Wang, K., Huang, Y., Yang, Y., & Xie, D. (2023). Impact of plastic film mulching on microplastic in farmland soils in Guangdong province, China. *Heliyon*, *9*(6). https://doi.org/10.1016/j.heliyon.2023.e16587

Long, Z., Wang, W., Yu, X., Lin, Z., & Chen, J. (2021). Heterogeneity and Contribution of Microplastics From Industrial and Domestic Sources in a Wastewater Treatment Plant in Xiamen, China. *Frontiers in Environmental Science*, *9*. https://doi.org/10.3389/fenvs.2021.770634

Luan, C., & Liu, R. (2022). A Comparative Study of Various Land Use and Land Cover Change Models to Predict Ecosystem Service Value. *International Journal of Environmental Research and Public Health*, *19*(24). https://doi.org/10.3390/ijerph192416484

Mani, T., Hauk, A., Walter, U., & Burkhardt-Holm, P. (2015). Microplastics profile along the Rhine River. *Scientific Reports, 5*. https://doi.org/10.1038/srep17988

Masura Julie, B. J. F. G. A. C. (2015). *Laboratory Methods for the Analysis of Microplastics in the Marine Environment: Recommendations for quantifying synthetic particles in waters and sediments*.

McMullen, K., Vargas, F. H., Calle, P., Alavarado-Cadena, O., Pakhomov, E. A., & Alava, J. J. (2024). Modelling microplastic bioaccumulation and biomagnification potential in the Galápagos penguin ecosystem using Ecopath and Ecosim (EwE) with Ecotracer. *PLoS ONE, 19*(1 January). https://doi.org/10.1371/journal.pone.0296788

Mennekes, D., & Nowack, B. (2023). Predicting microplastic masses in river networks with high spatial resolution at country level. *Nature Water*, *1*(6), 523–533. https://doi.org/10.1038/s44221-023-00090-9

Moto, E., Hossein, M., Bakari, R., Mateso, A. S., Selemani, J. R., Nkrumah, S., Ripanda, A., Rwiza, M. J., Nyanza, E. C., & Machunda, R. L. (2024). Ecological consequences of microplastic pollution in sub-Saharan Africa aquatic ecosystems: An implication to environmental health. In *HydroResearch* (Vol. 7, pp. 39–54). KeAi Communications Co. https://doi.org/10.1016/j.hydres.2023.11.003

Muganga Eve. (2022, February 5). *Uganda generates 600 tonnes of plastic waste daily - NEMA. Daily Monitor*. Monitor Publications.

Muniv, Y. S., & Supanekar, S. P. (2024). Microplastics: Classification, Sources, Characterisation, Fate, and Control Measures. *UTTAR PRADESH JOURNAL OF ZOOLOGY*, *45*(5), 136–144. https://doi.org/10.56557/upjoz/2024/v45i53939

Nasiri, V., Deljouei, A., Moradi, F., Sadeghi, S. M. M., & Borz, S. A. (2022). Land Use and Land Cover Mapping Using Sentinel-2, Landsat-8 Satellite Images, and Google Earth Engine: A Comparison of Two Composition Methods. *Remote Sensing*, *14*(9). https://doi.org/10.3390/rs14091977

Nayanathara Thathsarani Pilapitiya, P. G. C., & Ratnayake, A. S. (2024). The world of plastic waste: A review. In *Cleaner Materials* (Vol. 11). Elsevier Ltd. https://doi.org/10.1016/j.clema.2024.100220

Nel, H. A., & Froneman, P. W. (2015). A quantitative analysis of microplastic pollution along the south-eastern coastline of South Africa. *Marine Pollution Bulletin, 101*(1), 274–279. https://doi.org/https://doi.org/10.1016/j.marpolbul.2015.09.043

New Vision. (2021, February 28). *River Rwizi choking on plastic waste*. New Vision Uganda .

Niu, J., Xu, D., Wu, W., & Gao, B. (2024). Tracing microplastic sources in urban water bodies combining their diversity, fragmentation and stability. *Npj Clean Water, 7*(1). https://doi.org/10.1038/s41545-024-00329-2

Nyakoojo, C., Kabiswa, W., Najjuma, E., Matovu, P., & Ocaya, H. (2024). Potential of Heavy Metals and Microplastics Contamination in River Mpanga, Fort Portal, Kabarole District, Uganda. *Nature Environment and Pollution Technology, 23*(3), 1547–1557. https://doi.org/10.46488/NEPT.2024.v23i03.024

Ocakacon, S., Nyenje, P. M., Kalibbala, H. M., Kulabako, R. N., Nagawa, C. B., Omara, T., Kyarimpa, C., Lugasi, S. O., & Ssebugere, P. (2025). Spatiotemporal Dynamics of Microplastics in Nakivubo Catchment: Implications for the Pollution of Lake Victoria. *Microplastics*, *4*(2). https://doi.org/10.3390/microplastics4020021

OECD. (2022). *Global Plastics Outlook*. OECD. https://doi.org/10.1787/de747aef-en

Okeke, E. S., Olagbaju, O. A., Okoye, C. O., Addey, C. I., Chukwudozie, K. I., Okoro, J. O., Deme, G. G., Ewusi-Mensah, D., Igun, E., Ejeromedoghene, O., Odii, E. C., Oderinde, O., Iloh, V. C., & Abesa, S. (2022). Microplastic burden in Africa: A review of occurrence, impacts, and sustainability potential of bioplastics. In *Chemical Engineering Journal Advances* (Vol. 12). Elsevier B.V. https://doi.org/10.1016/j.ceja.2022.100402

Okunola A, A., Kehinde I, O., Oluwaseun, A., & Olufiropo E, A. (2019). Public and Environmental Health Effects of Plastic Wastes Disposal: A Review. *Journal of Toxicology and Risk Assessment*, *5*(2). https://doi.org/10.23937/2572-4061.1510021

Olubusoye, B. S., Cizdziel, J. V., Wontor, K., Heinen, E., Grandberry, T., Bennett, E. R., & Moore, M. T. (2024). Removal of microplastics from agricultural runoff using biochar: a column feasibility study. *Frontiers in Environmental Science, 12*. https://doi.org/10.3389/fenvs.2024.1388606

Osorio, E. D., Tanchuling, M. A. N., & Diola, M. B. L. D. (2021). Microplastics Occurrence in Surface Waters and Sediments in Five River Mouths of Manila Bay. *Frontiers in Environmental Science, 9*. https://doi.org/10.3389/fenvs.2021.719274

Pakhomova, S., Berezina, A., Zhdanov, I., & Yakushev, E. (2024). Microplastic fate in Arctic coastal waters: accumulation hotspots and role of rivers in Svalbard. *Frontiers in Marine Science*, *11*. https://doi.org/10.3389/fmars.2024.1392680

Pan, Y., Gao, S. H., Ge, C., Gao, Q., Huang, S., Kang, Y., Luo, G., Zhang, Z., Fan, L., Zhu, Y., & Wang, A. J. (2023). Removing microplastics from aquatic environments: A critical review. In *Environmental Science and Ecotechnology*

(Vol. 13). Editorial Board, Research of Environmental Sciences. https://doi.org/10.1016/j.ese.2022.100222

Parolini, M., Stucchi, M., Ambrosini, R., & Romano, A. (2023). A global perspective on microplastic bioaccumulation in marine organisms. *Ecological Indicators*, *149*. https://doi.org/10.1016/j.ecolind.2023.110179

Qiang, L., Hu, H., Li, G., Xu, J., Cheng, J., Wang, J., & Zhang, R. (2023). Plastic mulching, and occurrence, incorporation, degradation, and impacts of polyethylene microplastics in agroecosystems. In *Ecotoxicology and Environmental Safety* (Vol. 263). Academic Press. https://doi.org/10.1016/j.ecoenv.2023.115274

Quilliam, R. S., Pow, C. J., Shilla, D. J., Mwesiga, J. J., Shilla, D. A., & Woodford, L. (2023). Microplastics in agriculture – a potential novel mechanism for the delivery of human pathogens onto crops. *Frontiers in Plant Science*, *14*. https://doi.org/10.3389/fpls.2023.1152419

Rajan, K., Khudsar, F. A., & Kumar, R. (2023). Urbanization and population resources affect microplastic concentration in surface water of the River Ganga. *Journal of Hazardous Materials Advances*, *11*. https://doi.org/10.1016/j.hazadv.2023.100342

Rakib, M. R. J., Hossain, M. B., Kumar, R., Ullah, M. A., Al Nahian, S., Rima, N. N., Choudhury, T. R., Liba, S. I., Yu, J., Khandaker, M. U., Sulieman, A., & Sayed, M. M. (2022). Spatial distribution and risk assessments due to the microplastics pollution in sediments of Karnaphuli River Estuary, Bangladesh. *Scientific Reports*, *12*(1). https://doi.org/10.1038/s41598-022-12296-0

Ramakrishnan, D., Loganathan, S., Sathiyamoorthy, M., & Azamathulla, H. M. (2024). Microplastic pollution – a rising threat along an urban lake in the Vellore district of Tamil Nadu, India: abundance and risk exposure. *Water Quality Research Journal*. https://doi.org/10.2166/wqrj.2024.133

Rochman, C. M., Hoh, E., Kurobe, T., & Teh, S. J. (2013). Ingested plastic transfers hazardous chemicals to fish and induces hepatic stress. *Scientific Reports*, *3*. https://doi.org/10.1038/srep03263

Ross, M. S., Loutan, A., Groeneveld, T., Molenaar, D., Kroetch, K., Bujaczek, T., Kolter, S., Moon, S., Huynh, A., Khayam, R., Franczak, B. C., Camm, E., Arnold, V. I., & Ruecker, N. J. (2023). Estimated discharge of microplastics via urban stormwater during individual rain events. *Frontiers in Environmental Science, 11*. https://doi.org/10.3389/fenvs.2023.1090267

Sá, B., Pais, J., Antunes, J., Pequeno, J., Pires, A., & Sobral, P. (2022). Seasonal Abundance and Distribution Patterns of Microplastics in the Lis River, Portugal. *Sustainability (Switzerland)*, *14*(4). https://doi.org/10.3390/su14042255

Sharma, U. S. S. S. Su. S. H. P. G. R. K. R. N. K. A. S. S. S. J. N. (2023). APPRAISAL OF MICROPLASTICS IN FOREST ECOSYSTEM - SOURCES, MIGRATION AND MITIGATION. *Environmental Engineeering & Management Journal (EEMJ)*, *22*(8), 1361.

Song, J., Wang, C., & Li, G. (2024). Defining Primary and Secondary Microplastics: A Connotation Analysis. In *ACS ES and T Water* (Vol. 4, Issue 6, pp. 2330–

2332). American Chemical Society. https://doi.org/10 .1021/acsestwater .4c00316

Song, Y. K., Hong, S. H., Jang, M., Kang, J.-H., Kwon, O. Y., Han, G. M., & Shim, W. J. (2014a). Large Accumulation of Micro-sized Synthetic Polymer Particles in the Sea Surface Microlayer. *Environmental Science & Technology*, *48*(16), 9014–9021. https://doi.org/10.1021/es501757s

Song, Y. K., Hong, S. H., Jang, M., Kang, J.-H., Kwon, O. Y., Han, G. M., & Shim, W. J. (2014b). Large Accumulation of Micro-sized Synthetic Polymer Particles in the Sea Surface Microlayer. *Environmental Science & Technology*, *48*(16), 9014–9021. https://doi.org/10.1021/es501757s

Stovall, J. K., & Bratton, S. P. (2022). Microplastic Pollution in Surface Waters of Urban Watersheds in Central Texas, United States: A Comparison of Sites With and Without Treated Wastewater Effluent. *Frontiers in Analytical Science*, *2*. https://doi.org/10.3389/frans.2022.857694

Su, L., Xue, Y., Li, L., Yang, D., Kolandhasamy, P., Li, D., & Shi, H. (2016). Microplastics in Taihu Lake, China. *Environmental Pollution*, *216*, 711–719. https://doi.org/https://doi.org/10.1016/j.envpol.2016.06.036

Townsend, K. R., Lu, H.-C., Sharley, D. J., & Pettigrove, V. (2019). Associations between microplastic pollution and land use in urban wetland sediments. *Environmental Science and Pollution Research*, *26*(22), 22551–22561. https://doi.org/10.1007/s11356-019-04885-w

UBOS. (2024). *GOVERNMENT OF UGANDA NATIONAL POPULATION AND HOUSING CENSUS 2024 Final Report-Volume 1 (Main)*.

Verster, C., Minnaar, K., & Bouwman, H. (2017). Marine and freshwater microplastic research in South Africa. *Integrated Environmental Assessment and Management*, *13*(3), 533–535. https://doi.org/10.1002/ieam.1900

Vincoff, S., Schleupner, B., Santos, J., Morrison, M., Zhang, N., Dunphy-Daly, M. M., Eward, W. C., Armstrong, A. J., Diana, Z., & Somarelli, J. A. (2024). The Known and Unknown: Investigating the Carcinogenic Potential of Plastic Additives. *Environmental Science and Technology*, *58*(24), 10445–10457. https://doi.org/10.1021/acs.est.3c06840

Wang, S., Jian, Q., Zhang, P., Zhang, J., Zhao, L., Liu, D., & Kang, X. (2022). Tracing Land-Based Microplastic Sources in Coastal Waters of Zhanjiang Bay, China: Spatiotemporal Pattern, Composition, and Flux. *Frontiers in Marine Science*, *9*. https://doi.org/10.3389/fmars.2022.934707

Wei, Y., Ma, W., Xu, Q., Sun, C., Wang, X., & Gao, F. (2022). Microplastic Distribution and Influence Factor Analysis of Seawater and Surface Sediments in a Typical Bay With Diverse Functional Areas: A Case Study in Xincun Lagoon, China. *Frontiers in Environmental Science*, *10*. https://doi.org/10.3389/fenvs.2022.829942

Welde, K., & Gebremariam, B. (2017). Effect of land use land cover dynamics on hydrological response of watershed: Case study of Tekeze Dam watershed, northern Ethiopia. *International Soil and Water Conservation Research*, *5*(1), 1–16. https://doi.org/10.1016/j.iswcr.2017.03.002

Witczak, A., Przedpełska, L., Pokorska-Niewiada, K., & Cybulski, J. (2024). Microplastics as a Threat to Aquatic Ecosystems and Human Health. In *Toxics*

(Vol. 12, Issue 8). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/toxics12080571

Wright, S. L., Thompson, R. C., & Galloway, T. S. (2013). The physical impacts of microplastics on marine organisms: A review. *Environmental Pollution*, *178*, 483–492. https://doi.org/https://doi.org/10.1016/j.envpol.2013.02.031

Ye, C., Lin, J., Li, Z., Wang, G., & Li, Z. (2024). Characteristics of Microplastic Pollution in Agricultural Soils in Xiangtan, China. *Sustainability*, *16*(17), 7254. https://doi.org/10.3390/su16177254

Ye, S., & Pei, D. (2023). Relationships between microplastic pollution and land use in the Chongqing section of the Yangtze River. *Frontiers in Ecology and Evolution*, *11*. https://doi.org/10.3389/fevo.2023.1202562

Yeboaa, C., Tetteh, E. K., Chollom, M. N., & Rathilal, S. (2025). Sustainable Solutions for Plastic Waste Mitigation in Sub-Saharan Africa: Challenges and Future Perspectives Review. In *Polymers* (Vol. 17, Issue 11). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/polym17111521

Yu, H., Zhang, Y., Tan, W., & Zhang, Z. (2022). Microplastics as an Emerging Environmental Pollutant in Agricultural Soils: Effects on Ecosystems and Human Health. In *Frontiers in Environmental Science* (Vol. 10). Frontiers Media S.A. https://doi.org/10.3389/fenvs.2022.855292

Zbyszewski, M., & Corcoran, P. L. (2011). Distribution and Degradation of Fresh Water Plastic Particles Along the Beaches of Lake Huron, Canada. *Water, Air, & Soil Pollution*, *220*(1), 365–372. https://doi.org/10.1007/s11270-011-0760-6

Zettler, E. R., Mincer, T. J., & Amaral-Zettler, L. A. (2013). Life in the “plastisphere”: Microbial communities on plastic marine debris. *Environmental Science and Technology*, *47*(13), 7137–7146. https://doi.org/10.1021/es401288x

Zhang, X., Leng, Y., Liu, X., Huang, K., & Wang, J. (2020). Microplastics’ Pollution and Risk Assessment in an Urban River: A Case Study in the Yongjiang River, Nanning City, South China. *Exposure and Health*, *12*(2), 141–151. https://doi.org/10.1007/s12403-018-00296-3

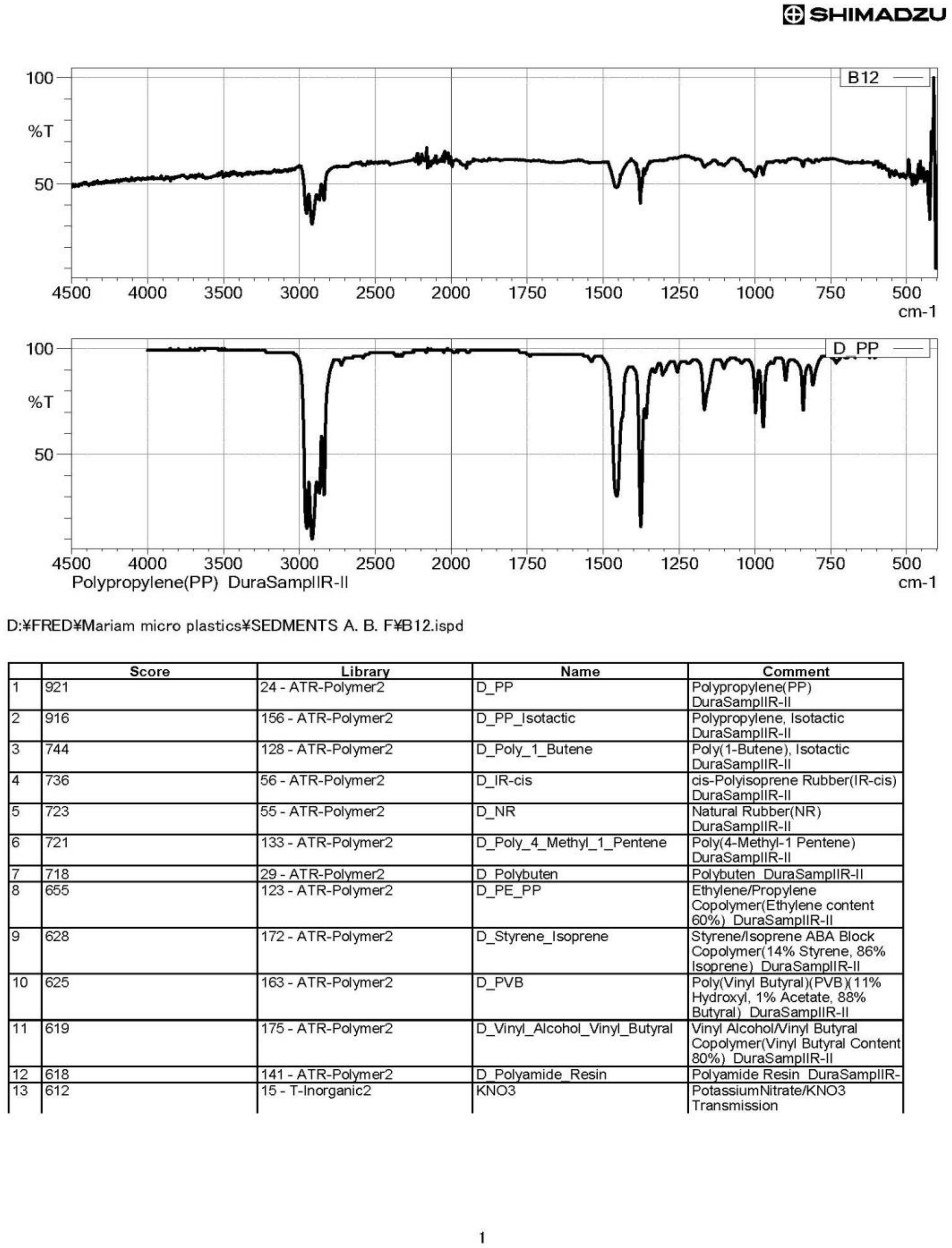
Zhang, Y., Xie, S., Wang, X., Akram, M. A., Hu, W., Dong, L., Sun, Y., Li, H., Degen, A. A., Xiong, J., Ran, J., & Deng, J. (2023). Concentrations and bioconcentration factors of leaf microelements in response to environmental gradients in drylands of China. *Frontiers in Plant Science*, *14*. https://doi.org/10.3389/fpls.2023.1143442

Zheng, F., Huang, Z., Chen, Z., Liu, J., Zhou, M., Ding, W., Guo, X., Chen, L., Wang, Z., & Xu, Y. (2025). Characterization of sediment contamination and benthic habitat response in mangrove ecosystems of Hainan Province. *Frontiers in Marine Science*, *12*. https://doi.org/10.3389/fmars.2025.1542864

Ziani, K., Ioniță-Mîndrican, C. B., Mititelu, M., Neacșu, S. M., Negrei, C., Moroșan, E., Drăgănescu, D., & Preda, O. T. (2023). Microplastics: A Real Global Threat for Environment and Food Safety: A State of the Art Review. In *Nutrients* (Vol. 15, Issue 3). MDPI. https://doi.org/10.3390/nu15030617

APPENDICES

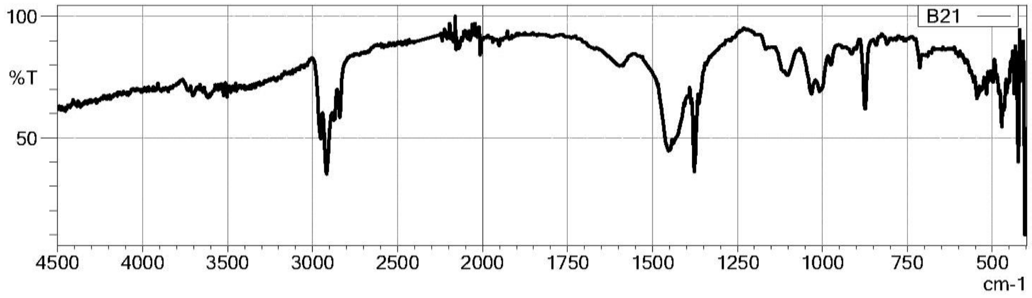
Appendix 1: FT-IR spectra obtained from chemical characterization of microplastics

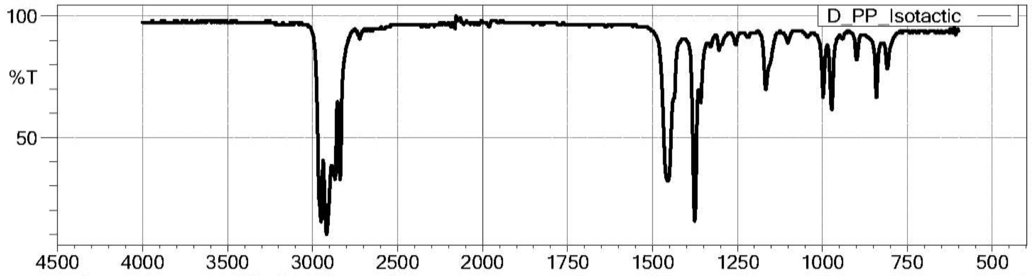


D:¥FRED¥Mariam micro plastics¥SEDMENTS A. B. F¥B12.ispd

	Score	Library	Name	Comment
1	921	24 - ATR-Polymer2	D_PP	Polypropylene(PP) DuraSamplIR-II
2	916	156 - ATR-Polymer2	D_PP_Isotactic	Polypropylene, Isotactic DuraSamplIR-II
3	744	128 - ATR-Polymer2	D_Poly_1_Butene	Poly(1-Butene), Isotactic DuraSamplIR-II
4	736	56 - ATR-Polymer2	D_IR-cis	cis-Polyisoprene Rubber(IR-cis) DuraSamplIR-II
5	723	55 - ATR-Polymer2	D_NR	Natural Rubber(NR) DuraSamplIR-II
6	721	133 - ATR-Polymer2	D_Poly_4_Methyl_1_Pentene	Poly(4-Methyl-1 Pentene) DuraSamplIR-II
7	718	29 - ATR-Polymer2	D_Polybuten	Polybuten DuraSamplIR-II
8	655	123 - ATR-Polymer2	D_PE_PP	Ethylene/Propylene Copolymer(Ethylene content 60%) DuraSamplIR-II
9	628	172 - ATR-Polymer2	D_Styrene_Isoprene	Styrene/Isoprene ABA Block Copolymer(14% Styrene, 86% Isoprene) DuraSamplIR-II
10	625	163 - ATR-Polymer2	D_PVB	Poly(Vinyl Butyral)(PVB)(11% Hydroxyl, 1% Acetate, 88% Butyral) DuraSamplIR-II
11	619	175 - ATR-Polymer2	D_Vinyl_Alcohol_Vinyl_Butyral	Vinyl Alcohol/Vinyl Butyral Copolymer(Vinyl Butyral Content 80%) DuraSamplIR-II
12	618	141 - ATR-Polymer2	D_Polyamide_Resin	Polyamide Resin DuraSamplIR-
13	612	15 - T-Inorganic2	KNO3	PotassiumNitrate/KNO3 Transmission

1



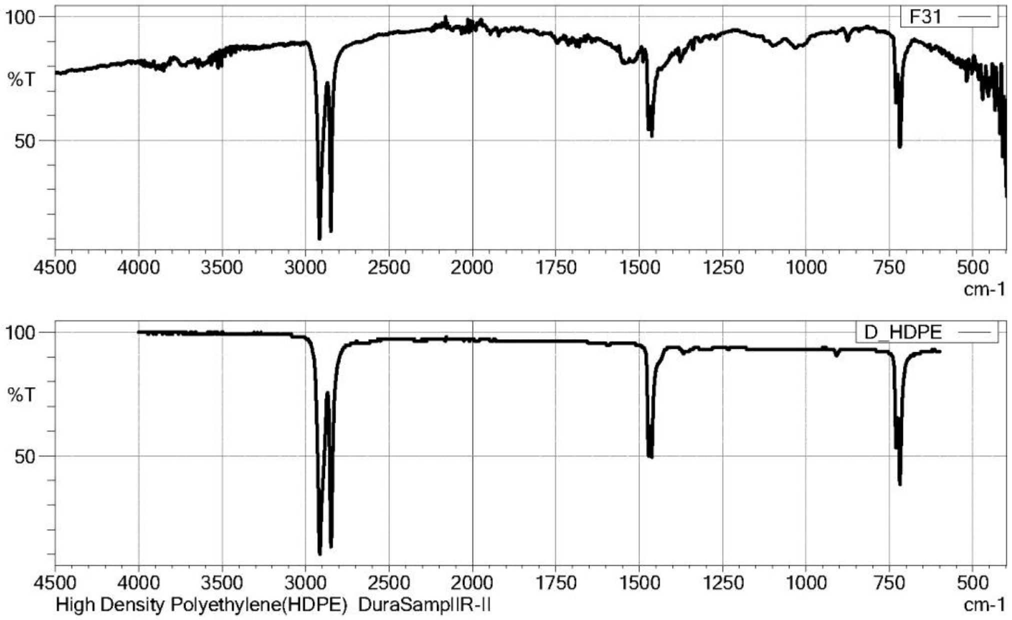


Polypropylene, Isotactic DuraSamplIR-II

D:¥FRED¥Mariam micro plastics¥SEDMENTS A. B. F¥B21.ispd

	Score	Library	Name	Comment
1	857	156 - ATR-Polymer2	D_PP_Isotactic	Polypropylene, Isotactic DuraSamplIR-II
2	856	24 - ATR-Polymer2	D_PP	Polypropylene(PP) DuraSamplIR-II
3	727	56 - ATR-Polymer2	D_IR-cis	cis-Polyisoprene Rubber(IR-cis) DuraSamplIR-II
4	722	55 - ATR-Polymer2	D_NR	Natural Rubber(NR) DuraSamplIR-II
5	711	128 - ATR-Polymer2	D_Poly_1_Butene	Poly(1-Butene), Isotactic DuraSamplIR-II
6	698	29 - ATR-Polymer2	D_Polybuten	Polybuten DuraSamplIR-II
7	669	7 - ATR-Inorganic2	D_CaCO3	Calcium Carbonate/CaCO3 DuraSamplIR
8	668	7 - T-Inorganic2	CaCO3	Calcium Carbonate/CaCO3 Transmission
9	661	123 - ATR-Polymer2	D_PE_PP	Ethylene/Propylene Copolymer(Ethylene content 60%) DuraSamplIR-II
10	658	133 - ATR-Polymer2	D_Poly_4_Methyl_1_Pentene	Poly(4-Methyl-1 Pentene) DuraSamplIR-II
11	653	57 - ATR-Polymer2	D_IR-trans	trans-Polyisoprene Rubber(IR-trans)
12	634	34 - ATR-Polymer2	D_PVC2	Polyvinylchloride(Soft PVC) DuraSamplIR-II
13	616	15 - T-Inorganic2	KNO3	PotassiumNitrate/KNO3 Transmission

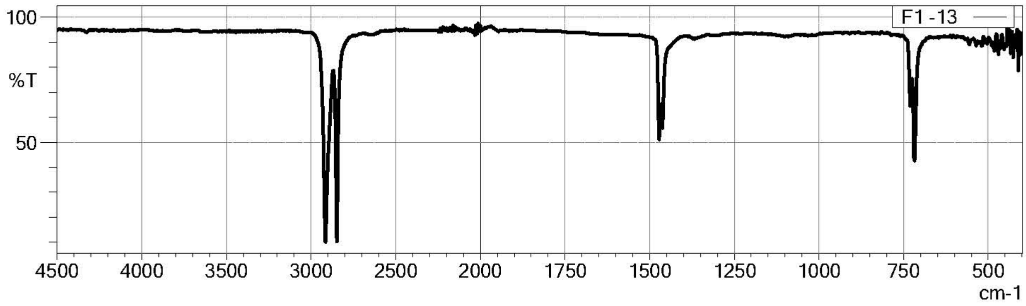
SHIMADZU

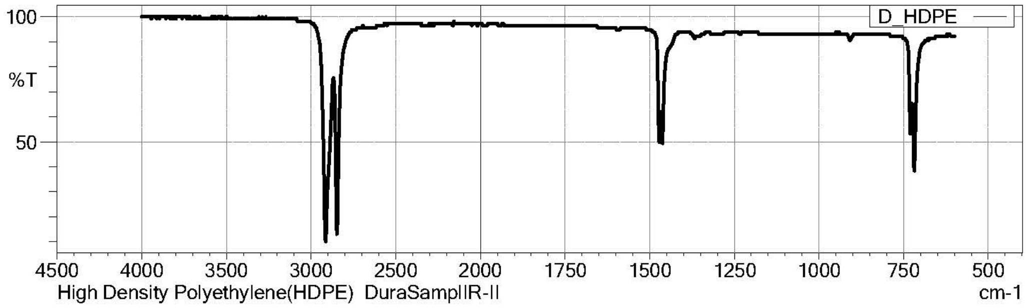


High Density Polyethylene(HDPE) DuraSamplIR-II

D:¥FRED¥Mariam micro plastics¥A3. F3 A1-1¥F3 1-3¥F3 1-3¥F31.ispd

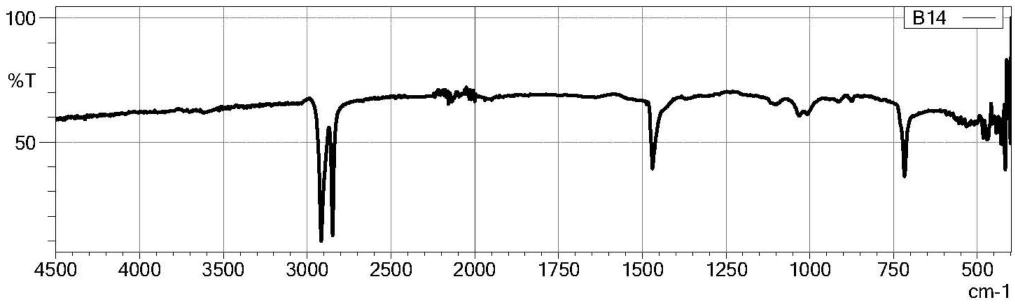
	Score	Library	Name	Comment
1	964	107 - ATR-Polymer2	D_HDPE	High Density Polyethylene(HDPE)
2	962	23 - ATR-Polymer2	D_PE	Polyethylene(PE) DuraSamplIR-
3	961	146 - ATR-Polymer2	D_Polyethylene_Oxidized	Polyethylene, Oxidized DuraSamplIR-II
4	948	4 - ATR-Polymer2	D_EAA	Ethylene Acrylic Acid(EAA) DuraSamplIR-II
5	919	100 - ATR-Polymer2	D_Ethylene_EthylAcrylate	Ethylene/Ethyl Acrylate Copolymer(Ethyl Acrylate content 18%) DuraSamplIR-II
6	908	123 - ATR-Polymer2	D_PE_PP	Ethylene/Propylene Copolymer(Ethylene content 60%) DuraSamplIR-II
7	878	221 - IRs ATR Reagent2	221	Cetyl Alcohol CH3(CH2)14CH2OH ATR/diamond molecular weight:242.44 powder
8	873	101 - ATR-Polymer2	D_EVA-1	Ethylene/Vinyl Acetate(EVA) Copolymer(Vinyl Acetate content 14%) DuraSamplIR-II
9	871	152 - ATR-Polymer2	D_Polyvinyl_Stearate	Poly(Vinyl Stearate) DuraSamplIR-II

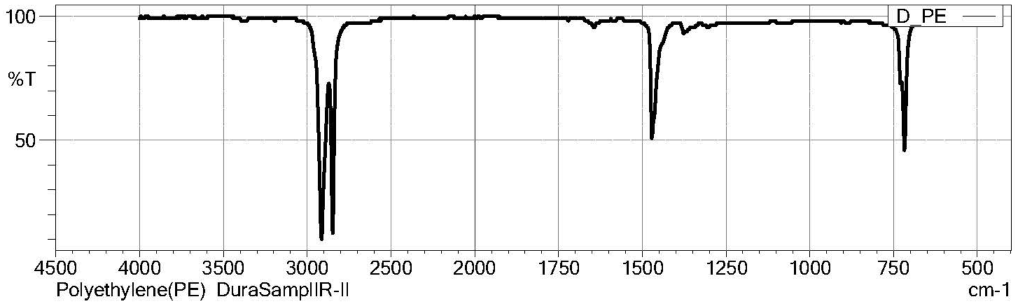




D:¥FRED¥Mariam micro plastics¥F1-1 TRANSPARENT PLASTIC BAG¥F1 -13.ispd

	Score	Library	Name	Comment
1	977	107 - ATR-Polymer2	D_HDPE	High Density Polyethylene(HDPE)
2	977	23 - ATR-Polymer2	D_PE	Polyethylene(PE) DuraSamplIR-
3	967	146 - ATR-Polymer2	D_Polyethylene_Oxidized	Polyethylene, Oxidized DuraSamplIR-II
4	958	4 - ATR-Polymer2	D_EAA	Ethylene Acrylic Acid(EAA) DuraSamplIR-II
5	927	100 - ATR-Polymer2	D_Ethylene_EthylAcrylate	Ethylene/Ethyl Acrylate Copolymer(Ethyl Acrylate content 18%) DuraSamplIR-II
6	911	221 - IRs ATR Reagent2	221	Cetyl Alcohol CH3(CH2)14CH2OH ATR/diamond molecular weight:242.44 powder
7	904	123 - ATR-Polymer2	D_PE_PP	Ethylene/Propylene Copolymer(Ethylene content 60%) DuraSamplIR-II
8	892	220 - IRs ATR Reagent2	220	1-Tetradecanol CH3(CH2)13OH ATR/diamond molecular weight:214.39 powder

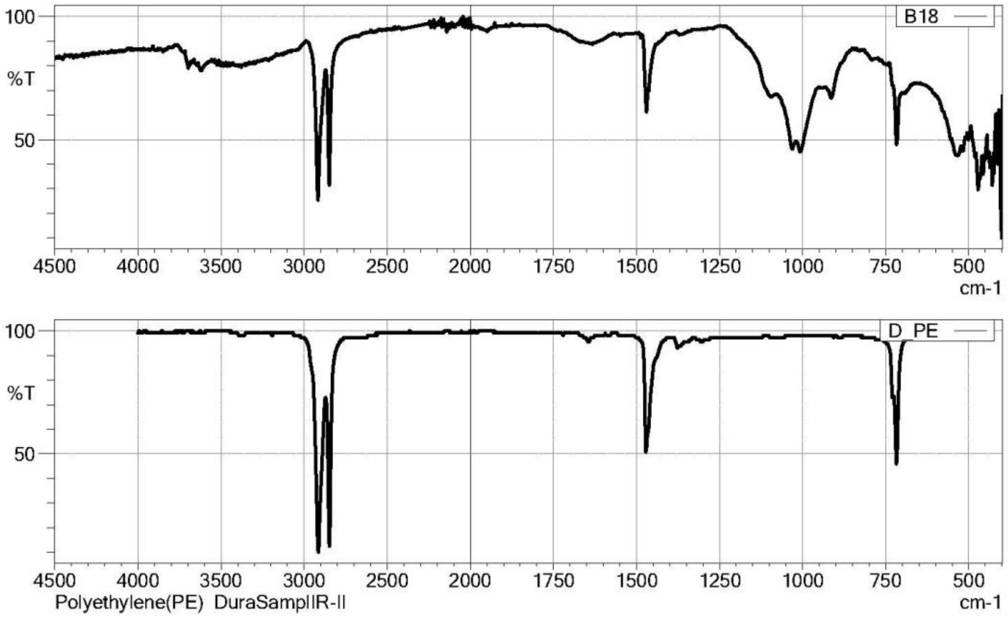




D:¥FRED¥Mariam micro plastics¥SEDMENTS A. B. F¥B14.ispd

	Score	Library	Name	Comment
1	963	23 - ATR-Polymer2	D_PE	Polyethylene(PE) DuraSamplIR-
2	943	146 - ATR-Polymer2	D_Polyethylene_Oxidized	Polyethylene, Oxidized DuraSamplIR-II
3	938	107 - ATR-Polymer2	D_HDPE	High Density Polyethylene(HDPE)
4	938	4 - ATR-Polymer2	D_EAA	Ethylene Acrylic Acid(EAA) DuraSamplIR-II
5	933	123 - ATR-Polymer2	D_PE_PP	Ethylene/Propylene Copolymer(Ethylene content 60%) DuraSamplIR-II
6	922	100 - ATR-Polymer2	D_Ethylene_EthylAcrylate	Ethylene/Ethyl Acrylate Copolymer(Ethyl Acrylate content 18%) DuraSamplIR-II
7	892	152 - ATR-Polymer2	D_Polyvinyl_Stearate	Poly(Vinyl Stearate) DuraSamplIR-II
8	880	101 - ATR-Polymer2	D_EVA-1	Ethylene/Vinyl Acetate(EVA) Copolymer(Vinyl Acetate content 14%) DuraSamplIR-II
9	873	99 - ATR-Polymer2	D_Ethylene_AcrylicAcid	Ethylene/Acrylic Acid Copolymer(Acrylic Acid content 20%) DuraSamplIR-II
10	870	102 - ATR-Polymer2	D_EVA-2	Ethylene/Vinyl Acetate(EVA) Copolymer(Vinyl Acetate content 18%) DuraSamplIR-II
11	844	141 - ATR-Polymer2	D_Polyamide_Resin	Polyamide Resin DuraSamplIR-

SHIMADZU



D:¥FRED¥Mariam micro plastics¥SEDMENTS A. B. F¥B18.ispd

	Score	Library	Name	Comment
1	934	23 - ATR-Polymer2	D_PE	Polyethylene(PE) DuraSamplIR-
2	919	146 - ATR-Polymer2	D_Polyethylene_Oxidized	Polyethylene, Oxidized DuraSamplIR-II
3	917	123 - ATR-Polymer2	D_PE_PP	Ethylene/Propylene Copolymer(Ethylene content 60%) DuraSamplIR-II
4	910	107 - ATR-Polymer2	D_HDPE	High Density Polyethylene(HDPE)
5	909	4 - ATR-Polymer2	D_EAA	Ethylene Acrylic Acid(EAA) DuraSamplIR-II
6	898	100 - ATR-Polymer2	D_Ethylene_EthylAcrylate	Ethylene/Ethyl Acrylate Copolymer(Ethyl Acrylate content 18%) DuraSamplIR-II
7	871	152 - ATR-Polymer2	D_Polyvinyl_Stearate	Poly(Vinyl Stearate) DuraSamplIR-II
8	858	101 - ATR-Polymer2	D_EVA-1	Ethylene/Vinyl Acetate(EVA) Copolymer(Vinyl Acetate content 14%) DuraSamplIR-II
9	853	99 - ATR-Polymer2	D_Ethylene_AcrylicAcid	Ethylene/Acrylic Acid Copolymer(Acrylic Acid content 20%) DuraSamplIR-II
10	851	102 - ATR-Polymer2	D_EVA-2	Ethylene/Vinyl Acetate(EVA) Copolymer(Vinyl Acetate content 18%) DuraSamplIR-II
11	833	141 - ATR-Polymer2	D_Polyamide_Resin	Polyamide Resin DuraSamplIR-
12	804	29 - ATR-Polymer2	D_Polybuten	Polybuten DuraSamplIR-II
13	802	35 - ATR-Polymer2	D_EVA	Ethylenevinylacetate(EVA) DuraSamplIR-II

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Appendix 2: Photographs showing the research activities

 Water sample collection	 Sediment sample collection
 In-field water sieving	 Sediment sieving
 Oven drying for sediment samples	 Water samples

Weighing dried sediments

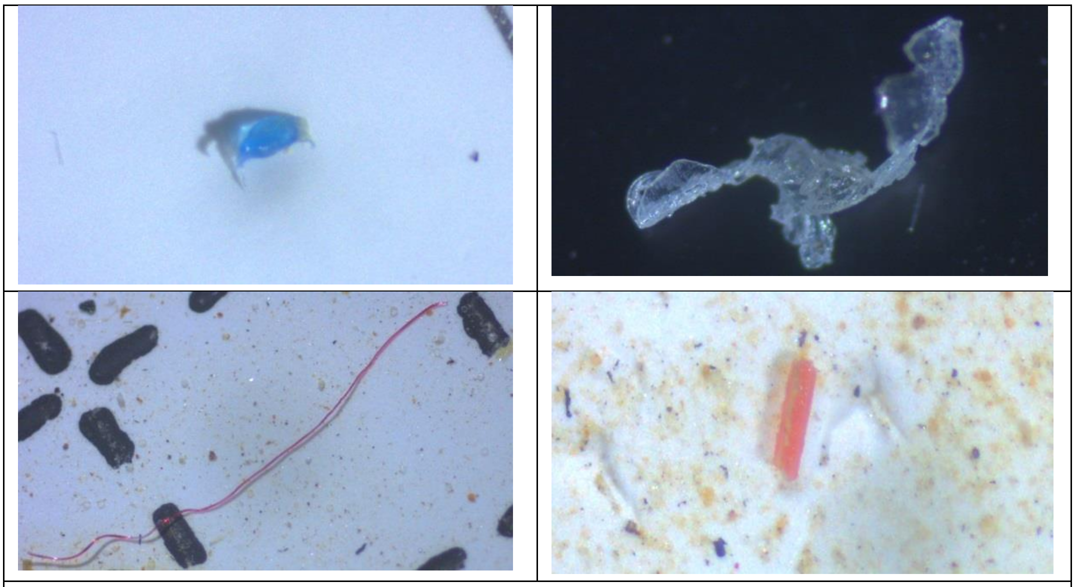
Digestion process

Density separation

Filtration

Microscopy

FTIR machine reading



Microplastic particles under the microscope

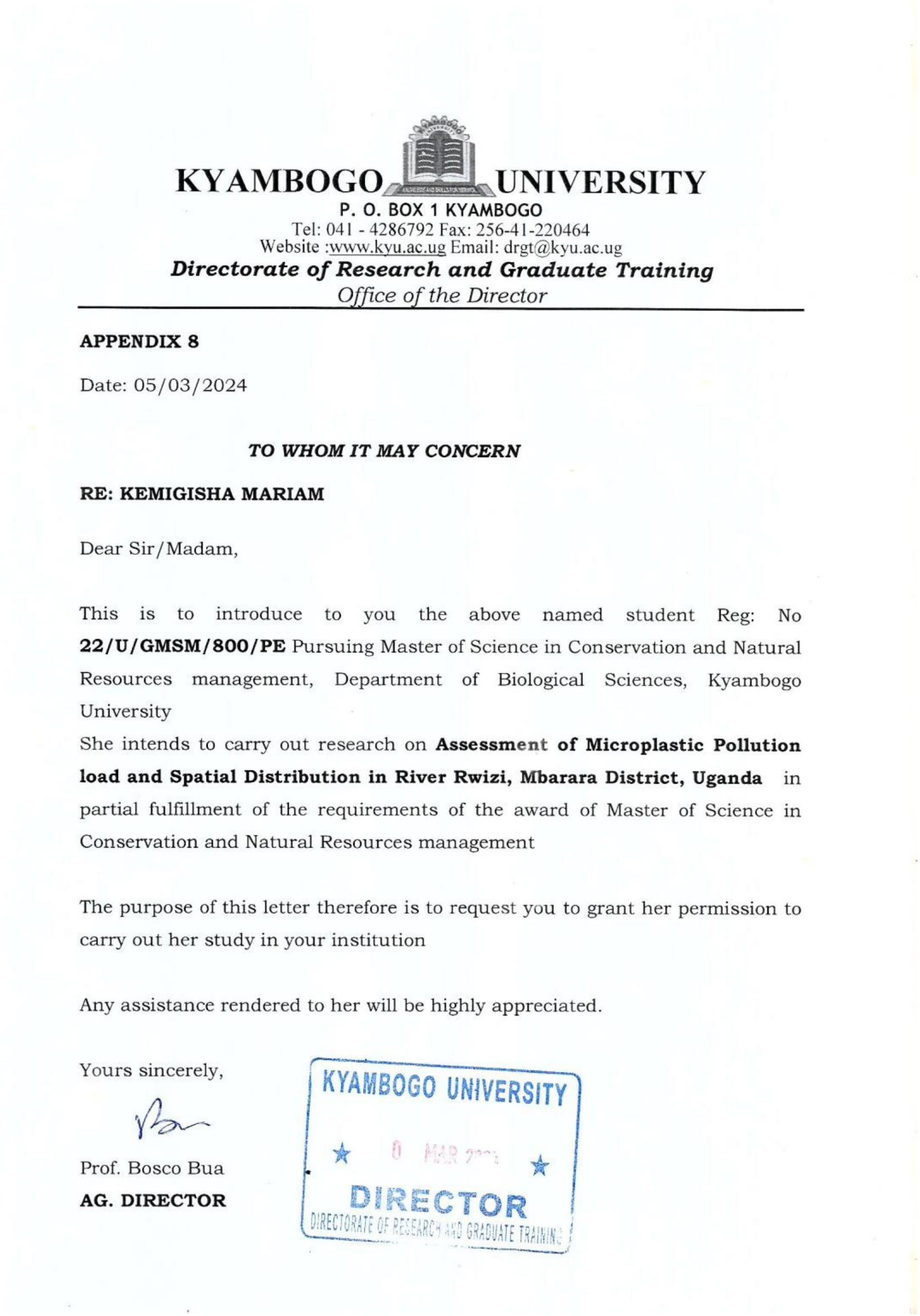
Visible Macroplastics within the river bank

Domestic water collection at the river

Cattle watering at the river

 Industrial land use	 Urban built area
 Agricultural area	 Forested area

Appendix 3: Introductory Letter



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Office of the Director

APPENDIX 8

Date: 05/03/2024

TO WHOM IT MAY CONCERN

RE: KEMIGISHA MARIAM

Dear Sir/Madam,

This is to introduce to you the above named student Reg: No **22/U/GMSM/800/PE** Pursuing Master of Science in Conservation and Natural Resources management, Department of Biological Sciences, Kyambogo University

She intends to carry out research on **Assessment of Microplastic Pollution load and Spatial Distribution in River Rwizi, Mbarara District, Uganda** in partial fulfillment of the requirements of the award of Master of Science in Conservation and Natural Resources management

The purpose of this letter therefore is to request you to grant her permission to carry out her study in your institution

Any assistance rendered to her will be highly appreciated.

Yours sincerely,

Prof. Bosco Bua
AG. DIRECTOR

KYAMBOGO UNIVERSITY
★ 0 MAR [illegible] ★
DIRECTOR
DIRECTORATE OF RESEARCH AND GRADUATE TRAINING