ASSESSMENT OF MICROPLASTICS IN SELECTED RIVERS, FISH, AND WASTEWATER FROM CAR WASH BAYS IN ARUA CITY

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A RESEARCH DISSERTATION SUBMITTED TO THE DEPARTMENT OF CHEMISTRY, FACULTY OF SCIENCE, IN PARTIAL FULFILMENT OF THE REQUIREMENTS LEADING TO THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN CHEMISTRY OF MUNI UNIVERSITY

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DECLARATION

I, DRAKU SYDNEY EMMANUEL, hereby declare that this research dissertation submitted to the Department of Chemistry, Muni University, is my original work. It has not been submitted previously, either in its entirety or in part, for a degree at this or any other institution.

DRAKU SYDNEY EMMANUEL

Signature.................................... Date......13|10|2025..................................

APPROVAL

This is to certify that the following research dissertation of **Draku Sydney Emmanuel**, entitled "ASSESSMENT OF MICROPLASTIC IN SELECTED RIVERS, FISH, AND WASTEWATER FROM CAR WASH BAYS IN ARUA CITY", has been developed under our supervision and is now ready for submission to the Department of Chemistry, Muni University, with our due approval.

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DEDICATION

This Dissertation is dedicated to my father, Rt. Rev Charles Collins Andaku, my mother, Mrs. Jane Andaku, my wife, Betty Agenrwoth Draku, and Mr. Sumile Noah, whose unwavering support, prayers, and encouragement have consistently provided strength throughout this academic journey.

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ACRONYMS

Acronym	**Full Meaning**
MPs	Microplastics
GIT	Gastrointestinal Tract
PVC	Polyvinyl Chloride
PE	Polyethylene
PP	Polypropylene
EVA	Ethylene-Vinyl Acetate
EAA	Ethylene-Acrylic Acid
EPC	Ethylene/Propylene Copolymer
EEA	Ethylene/Ethyl Acrylate
PS	Polystyrene
PET	Polyethylene terephthalate
ATR	Attenuated Total Reflectance
EDS	Energy-dispersive X-ray Spectroscopy
FTIR	Fourier Transform Infrared Spectroscopy
µFTIR	Micro Fourier Transform Infrared Spectroscopy
STEM	Scanning Transmission Electron Microscope
SEM	Scanning Electron Microscope
ANOVA	Analysis of Variance
NOAA	National Oceanic and Atmospheric Administration
UN SDGs	United Nations Sustainable Development Goals
NEMA	National Environment Management Authority
UNEP	United Nations Environment Programme
WHO	World Health Organisation

ABSTRACT

Microplastics (MPs) are increasingly recognised as critical pollutants in freshwater ecosystems, yet data from sub-Saharan urban settings remain limited. This study investigated the occurrence, distribution, and polymer composition of MPs in car wash effluents, receiving river water, and fish in Arua City, Uganda. Five (5) car wash bays and two rivers (Asa and Enyau) were purposively selected. Ten (10) litres of river water, one (1) litre of wastewater, and twenty (20) fish samples were collected and processed via filtration (300–0.45 µm), oxidative digestion, and polymer identification using micro–Fourier Transform Infrared Spectroscopy (µFTIR). One-way ANOVA results revealed significantly higher MP concentrations in bays employing jet washing and exhibiting prolonged wastewater retention (F = 133.98, $p < 0.05$). Fibres and fragments comprised >80% of particles, with dominant polymers being polyethylene (PE), polypropylene (PP), and ethylene-based copolymer (EPC). Mean MP levels in both rivers were observed to be in the same range, with spatial heterogeneity linked to local anthropogenic activity. Fish from River Asa showed the highest MP loads, positively correlated with body length (r = 0.714, $p = 0.000$). Findings position car wash facilities as major sources of microplastics, calling for targeted regulatory and infrastructural interventions, alongside public awareness campaigns and further research to mitigate microplastic pollution in Arua City.

CHAPTER ONE: INTRODUCTION

1.1 Background

Since the early 1900s, over 8300 million metric tons (Mt) of virgin plastic materials have been produced, and most of this has ended up in landfills or the environment as plastic debris (Werbowski et al., 2021), resulting from the mismanagement of waste (Geyer et al., 2024). In 2022 alone, worldwide plastic production was approximately 400.3 million tons, with annual production consistently exceeding 359 million tons (Nayanathara Thathsarani Pilapitiya & Ratnayake, 2024). Unfortunately, only 9% of these plastics are recycled, 12% are incinerated, and 79% accumulate in landfills (Geyer et al., 2024). Among these are plastic debris less than five millimetres (mm) in length, referred to as microplastics (MPs) (Werbowski et al., 2021). MPs result from the breakdown of large plastic items, or are intentionally manufactured at a microscopic scale (Filella, 2015).

Microplastic pollution has emerged as a serious environmental issue worldwide, putting pressure on ecosystems and raising concerns for human health (Roy et al., 2022). This is because they are persistent, mainly as a result of slow degradation rates (Ragu Prasath et al., 2025). They can easily bind with other organic contaminants, which only increases the concern (Y. Hu et al., 2019). They have spread across various environments, from freshwater systems to oceans, because of their mobility and persistence(Roy et al., 2022). This could potentially lead to adverse effects on aquatic life and ecosystems (Schell et al., 2020; Roy et al., 2022). Research has shown that the increased accumulation of MPs in aquatic environments can easily lead to exposure of aquatic organisms to plastic waste particles (Sun et al., 2019).

According to Werbowski et al. (2021), apart from poor waste management, MPs can enter the environment through many different channels, including road runoff (Piñon-Colin et al., 2020), agricultural runoff (Grbić et al., 2020), atmosphere (Luo et al., 2019), industrial wastewater (Zhou et al., 2020), and treated wastewater effluent (Mason et al., 2016). MPs that are in road runoff mainly come from tyre wear, brakes, car paints, and road markings, which can be transported into waterways and ecosystems as tiny fragments when the road surface erodes (Tamis et al., 2021). Qiu et al. (2020) documented that urban areas are one of the primary sources of MPs due to the high density of human activity. These MPs can enter the urban rivers and streams before they eventually find their way into mainstream or bigger rivers (Luo et al., 2019).

A lot of research has been done on the sources and pathways of microplastics (Browne, 2015). However, there is still a critical gap in our understanding concerning the contribution of commercial car wash activities to this environmental challenge. Commercial car wash operations discharge large volumes of wastewater into the environment. This water may contain various pollutants (Ghaly et al., 2021), potentially including microplastics (Dris et al., 2015). Research in other regions has reported that the microplastic pollution originating from roadways and urban runoff is notable (Werbowski et al., 2021; Tamis et al., 2021). Commercial car washes may release microplastics into the environment, coming from car tyres, brake systems, and paint (Tamis et al., 2021; An et al., 2020). These MPs show a unique threat because they can be readily removed from plastic surfaces during car washing procedures.

According to Wagner et al. (2014) Rivers play a key role as transport routes for microplastics from urban regions to larger aquatic systems like lakes and oceans. In Arua City, streams and rivers are at a high risk of microplastic pollution because of urban runoff. This includes the discharge of untreated or partially treated wastewater from commercial car wash bays. These water bodies are important to the local environment by supporting a variety of aquatic life and also serving as a source of water for both domestic and agricultural use by the locals. Therefore, the presence of microplastics in these rivers not only puts fish and other aquatic life at risk (Bhan et al., 2025), but it also raises concerns for human health through the contamination of water resources (Issac & Kandasubramanian, 2021; Thornton Hampton et al., 2022).

Fish are an important element within aquatic ecosystems. They can easily be affected by microplastic pollution in the aquatic environment (Pothiraj et al., 2023). This is because they can take in microplastics either directly from the water or indirectly when they feed on smaller organisms that have already ingested them (Mamun et al., 2023). Microplastics, once ingested, may injure internal organs, interfere with normal feeding, or even introduce harmful chemicals into fish tissues (Mallik et al., 2021). This is of notable concern given that fish form an important component of local diets in Arua City and beyond. If they carry microplastics, then there could be serious consequences for both food safety and human health. Therefore, assessing the microplastic contamination in fish is important for understanding potential threats to consumers and for developing strategies to reduce such effects.

In Uganda, there has been limited research done to investigate the presence and levels of microplastics in wastewater discharged by commercial car wash facilities. As a result, major gaps have been left in assessing the risks posed by these pollutants to the aquatic ecosystem. Therefore, this study addresses this knowledge gap by investigating the presence of microplastics in commercial car wash wastewater, surrounding rivers, and fish from the water bodies of Arua City, which is a fast-growing urban centre in northwestern Uganda that has experienced a steady increase in vehicle numbers and the expansion of commercial car wash facilities. Therefore, there is an urgent need to investigate how these activities contribute to microplastic pollution.

1.2 Problem statement

In Arua City, Untreated Wastewater from car wash facilities is routinely discharged into nearby streams and rivers, potentially introducing microplastics into the surrounding environment. Despite growing concerns of microplastic contamination globally, the degree to which untreated wastewater discharged by these facilities contributes to this problem in Arua has not been examined.

While official safe exposure thresholds for microplastics are still unknown, laboratory studies in fish and simulated human studies have revealed that ingested microplastics can cause intestinal and liver malfunction (Jovanović, 2017; Jin et al., 2019; Rubio et al., 2020; Kang et al., 2021). Moreover, the World Health Organisation (WHO, 2019) report stressed the need for more research to be done on exposure to microplastics through various pathways, including contaminated water bodies. Therefore, investigation of microplastic pollution in Arua is essential for filling the knowledge gap and forming strategies that protect the aquatic life and public health.

1.3 General objective

To assess the contribution of commercial car wash wastewater to microplastic contamination in fish and receiving water bodies in Arua City.

1.4 Specific objectives

i. To assess car wash operational practices that may influence microplastic generation and discharge into nearby water bodies.
ii. To characterise microplastics in fish, river water, and wastewater samples from car wash facilities in Arua.
iii. To determine the polymer composition of microplastics in the samples.

1.5 Significance of the study

This study has determined the concentrations and polymer compositions of microplastics in wastewater from car wash bays, nearby rivers, and fish from those rivers in Arua City. The data could be used by the relevant government agencies, such as the National Environment Management Authority, stakeholders in the plastic industry, and city authorities in developing practical measures to control pollution and promote safer washing practices within the Car wash industry.

1.6 Justification

Microplastic pollution is now recognised as a global threat, but its sources and impacts vary from one setting to another. In Arua City in particular, filling this gap is important because many households depend on these rivers for fishing and domestic water. Evidence from this work will not only support local management strategies but can also be compared with findings from other African cities facing similar challenges (Arora et al., 2023).

In addition, the study contributes to international efforts on plastic pollution reduction and speaks directly to the Sustainable Development Goals (UN SDGs), especially Goal 6, which seeks to ensure safe, clean, and sustainable management of water for everyone, and Goal 14 on the conservation of aquatic ecosystems. Unlike many global reports, however, this study provides city-level data that can provide guidance for immediate action in Uganda.

1.7 Scope of the study

This study was carried out in Arua City, northwestern Uganda, from February to April 2025. It focused on five commercial car wash facilities that were selected through purposive sampling. The research also included the two main rivers, Asa and Enyau, as well as three commonly consumed fish species from these rivers: Tilapia (*Oreochromis niloticus*), Rohu (*Labeo rohita*), and Mudfish (*Clarias gariepinus*), which serve as relevant indicators of both environmental and human exposure to microplastics.

CHAPTER TWO: LITERATURE REVIEW

2.1 Classification of microplastics

In this study, microplastics are grouped according to their shape, polymer composition, and origin. This approach is useful for source identification, their transport, and nature throughout the environment. This will help in assessing their possible effects on both ecosystems and human health (A. Rani, 2024).

2.1.1 Classification by shape

Microplastics occur in many different forms. Cole et al. (2011) describes them as appearing mainly as fibres, fragments, films, pellets, and beads. Fibres are thin, thread-like particles from synthetic textiles and fishing nets. Fragments, meanwhile, are irregular pieces that usually form from the breakdown of bigger plastic materials like bottles and packaging materials (Andrady, 2011). Films are degraded plastic bags and sheets that are commonly found in surface waters and shorelines (Osorio et al., 2021). Pellets are little plastic resin balls that can enter the environment during shipping or manufacturing as a result of spills (Cole et al., 2011). Beads are spherical particles that are commonly used in personal care products and industrial applications (Singh & Mishra, 2023). Andrady (2011), in their study highlighted the presence of microbeads in marine environments due to their use in exfoliating products.

2.1.2 Classification by polymer type

Microplastics can also be differentiated based on the type of polymers used for manufacturing them. Research has shown that polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), and polyethylene terephthalate (PET) make up the most common polymer types (Hidalgo-Ruz et al., 2012; Chubarenko et al., 2016). Each of these polymer types has unique physical and chemical properties that affect its environmental behaviour and degradation (Kaundal & Singh, 2025). These polymers are associated with plastic materials that are commonly used in our everyday lives. For example, PE is commonly used for making packaging materials (Tajeddin & Arabkhedri, 2020). It is the most commonly identified polymer in aquatic environments (Hidalgo-Ruz et al., 2012). PP is light, making it buoyant and often floats on the water surface where it is detected (Eriksen et al., 2013). These MPs are associated with bottle caps, straws, and other plastic consumer goods (Alsabri et al., 2022). PS, commonly used in the manufacture of food containers and packaging materials (Carr et al., 2016). Carr et al. (2016) has found them very common in coastal sediments. PET, which is often used in the manufacture of beverage containers and synthetic fibres, has also been detected in aquatic environments (Zhang et al., 2021). Although PVC MPs are rare in the aquatic environment, they can be a toxicity threat (Chubarenko et al., 2016). It is commonly used in the manufacture of pipes and medical equipment (Edo et al., 2024).

2.1.3 Classification based on origin

Microplastics originate from many different sources, which can be both terrestrial and marine (Osman et al., 2023). Terrestrial sources include urban runoff, wastewater treatment plants, industrial discharges, and farming (Ragu Prasath et al., 2025). In the marine environment, fishing, shipping, and aquaculture are major contributors to microplastic pollution (Osman et al., 2023). Jambeck et al. (2015) estimated that millions of tons of plastic waste flow into the oceans every year from land-based sources. This shows the close connection between human activities on land and the growing marine pollution.

2.2 Physical and chemical characteristics of microplastics

The physical and chemical properties of MPs are important to determine their environmental behaviour and their associated dangers to living organisms (K. Hu et al., 2022). These properties influence how the particles are being transported, their persistence, and also how they interact with other contaminants, as well as organisms, once they are released into the environment (Rushdi et al., 2023).

Table 2. 1 Physicochemical characteristics of microplastics

Characteristic	**Implications**	**Reference**
Size Distribution	Smaller particles tend to be more mobile, more bioavailable, and more challenging to remove.	Saad et al. (2024)
Shape	Fibres and fragments dominate in multiple freshwater systems. Shape influences aggregation and transport.	Fox et al. (2024)
Colour	Colour may affect ingestion by organisms (recognition), solar heating/photo-degradation, and visibility in environmental monitoring.	Saad et al. (2024)
Polymer Type	Different polymers have different densities, degradation rates, pollutant sorption capacities, and impacts on fate and risk.	Saad et al. (2024)
Intrinsic Properties (crystallinity, molecular weight, hydrophilicity, and backbone structure)	These properties affect how MPs break down, how long they persist, how pollutants adhere, and how biofilms form.	Conradie et al. (2022); Salehi et al. (2024)
Surface Texture / Weathering	Roughness enhances surface area for adsorption; weathered MPs may sink or aggregate faster.	Saad et al. (2024)

2.3 Microplastics in car wash effluents

Commercial and residential car wash facilities are said to be a notable source of urban water pollution through the discharge of their wastewater (Monney et al., 2020). The wastewater from these facilities contains a wide range of pollutants like detergents, surfactants, heavy metals, hydrocarbons, and it could contain microplastics (Edward et al., 2022). These pollutants can seriously affect aquatic environments (Edward et al., 2022). These MPs can come from the different cleaning processes, like the use of detergents, soaps, and waxes (Rai et al., 2020). Additionally, they could still also come from vehicle debris, and fabric used (Rai et al., 2020).

Urban runoff, including waste from commercial vehicle washes, has become an emerging route through which microplastics contaminate the aquatic environment (Aryal et al., 2010). However, the contribution of car wash wastewater to microplastic pollution in the aquatic environments has not been well researched, especially in developing nations. These facilities can be able to release wastewater containing microplastics, which come from vehicle tear and wear, cleaning products, and other various sources (Tamis et al., 2021). If not properly managed, Car wash effluents can transport a notable amount of microplastics into natural water bodies (Kye et al., 2023).

2.4 Mechanisms of microplastic release

Microplastics are generated and released through three main processes during car washing. These are physical abrasion, chemical degradation, and water flow (Choi et al., 2022; Sun et al., 2022). These processes work together to loosen and remove plastic particles from vehicle surfaces and equipment. The result is that the microplastics are then carried into wastewater, contributing to environmental pollution.

2.4.1 Mechanical action

The physical forces that are involved in car washing, such as scrubbing, brushing, and high-pressure rinsing, create friction that can dislodge microplastics from vehicle surfaces. Guangmin Liu et al. (2023) observed a similar occurrence in the laundry process, where microfibers from synthetic textiles were released during washing as a result of repeated agitation. In car washing, the same principle applies: friction and pressure gradually wear down plastic surfaces, like plastic trims, paint coatings, bumpers, and rubber linings. Over time, this repeated mechanical stress causes these materials to degrade and fragment into microplastics, contributing to environmental contamination.

2.4.2 Chemical factors

Cleaning products that are used in car washing, like detergents, degreasers, wax removers, and polishes, can interact with plastic surfaces, breaking their chemical bonds, resulting in the release of MPs (Dalla Fontana et al., 2020). These agents usually contain acids, bases, or surfactants that break down the molecular structure of plastics (Q. Lin et al., 2023). Repeated exposure makes the plastics more prone to fragmentation, hence increasing microplastic pollution.

2.4.3 Water flow dynamics

During car washing, flowing water, especially from jet washing and canon spray method at varying pressures and angles, creates turbulence strong enough to dislodge microplastics from vehicle surfaces. This water can loosen particles already weakened by mechanical abrasion or chemical degradation. Additionally, it can resuspend particles already settled on the washing bay floor, drainage channels, or surrounding surfaces. This increases their release into the environment.

2.5 Microplastics in aquatic environments

Recent studies have shown a widespread occurrence of MPs in marine environments (Pal et al., 2025). Ross et al. (2021) for instance, documented that the extensive microplastic contamination in deep-sea sediments, including isolated regions of the Arctic Ocean, is influenced by Atlantic sources. This means that the particles can move a long way. Microplastics have been discovered in several marine environments, ranging from surface waters to deep-sea sediments (Thushari & Senevirathna, 2020). According to Wright et al. (2013) these particles can be ingested by a wide range of aquatic organisms, including fish, which can result in physical and toxicological effects. Microplastics have been found in coastal sediments, surface waters, and marine life around the coasts of Africa. Research in the Mediterranean Sea off the coast of Egypt reported microplastic levels of up to 600 particles /m^{-3} (Saad & Alamin, 2024).

Although much of the study on microplastics has been done mainly on marine environments, freshwater systems are also at risk (Jolaosho et al., 2025). For instance, studies have demonstrated that rivers and lakes can serve as channels for microplastics to reach the ocean (Yuan et al., 2022; Wagner et al., 2014). Mani et al. (2015) in their study found microplastics in the Rhine River. The findings indicate notable contamination in freshwater systems. Studies in the Nile River and Lake Victoria have also revealed significant concentrations of microplastics (Khan et al., 2020; Egessa et al., 2020; Saad & Alamin, 2024). For instance, research in Lake Victoria found microplastic abundance between 2834 and 329,167 particles/km^2, with the highest concentrations near urban areas (Egessa et al., 2020).

2.6 Sources and pathways of microplastics into the environment

Waldschläger et al. (2020) defines sources as the place, product, or action that generates MPs, and entry paths as the particles' way (conduit) from the source into the environment.

2.6.1 Sources

Microplastics are generally divided into primary and secondary, depending on how they are formed (Tirkey & Upadhyay, 2021). Primary microplastics are deliberately manufactured as small plastic particles for direct use in many products and processes (Song et al., 2024). They include microbeads that are commonly added to cosmetics, toothpaste, and exfoliating scrubs for their abrasive properties (Xanthos & Walker, 2017). In addition, microplastics used in industrial applications such as sandblasting, polishing, or cleaning can also serve as major primary sources when residues are washed away and eventually enter waterways (Boucher & Friot, 2017).

Secondary microplastics are obtained from the breakdown of larger plastic debris as a result of physical, chemical, and biological processes (Song et al., 2024). According to Andrady (2011), weathering processes such as UV radiation, mechanical abrasion, and biodegradation break down larger plastic items like bottles, bags, and fishing nets into smaller particles. Synthetic fibres from clothing that are released during washing and can pass through wastewater treatment systems into aquatic environments (Napper &

Thompson, 2016). Each wash can release hundreds of thousands of microfibers (Boucher & Friot, 2017).

2.6.2 Pathways

Wastewater treatment plants (WWTPs) have been identified as one of the major pathways through which microplastics enter aquatic systems (Hajji et al., 2023; Maleka et al., 2025). Although treatment processes are done at these facilities, a notable amount of microplastics can still bypass these systems and end up in rivers, lakes, and oceans (Carr et al., 2016). This is because of their small size, which prevents them from being captured by conventional treatment plants (Carr et al., 2016; Lei et al., 2017). For instance, Hajji et al. (2023) found concentrations of 188 microplastic particles per litre (MPs/L) in the influent and 50 MPs/L in the effluent of wastewater treatment plants along the Moroccan Atlantic coast. Similarly Maleka et al. (2025) reported microplastic abundance in the influent of the wastewater treatment plant of up to 142 MPs/L and in the effluent of up to 89 MPs/L in South Africa.

Another major pathway through which microplastics are transported into aquatic environments is the stormwater runoff (Sewwandi et al., 2024). Runoffs from urban areas, roadways, and agricultural lands can carry MPs derived from a wide range of sources into water bodies (Sewwandi et al., 2024). This pathway is particularly associated with particles obtained from tyre wear and atmospheric deposition, which are common in urban areas (Ziajahromi et al., 2023; Liu et al., 2019). Additionally, runoffs from construction sites can also carry microplastics that are derived from building materials and plastic sheeting (Besseling et al., 2017). In case of an agricultural setting, the use of plastic mulch and other agricultural plastics can contribute to microplastic runoff especially when it rains (Steinmetz et al., 2016).

Recent studies in Africa have shown that stormwater contains significant concentrations of MPs that can find their way into the water bodies. For example Ocakacon et al. (2025) reported MPs abundance of up to 1.57 particles/L in the dry season and 2.14 particles/L in the wet season along the Nakivubo catchment in Uganda. This channel drains Urban waste and stormwater into Lake Victoria (Ocakacon et al., 2025). In a similar study in South Africa, Ariefdien et al. (2024) also reported concentrations of up to 0.15 MPs/ L in stormwater outlet pipes during the wet season. The findings of these two studies show higher contamination occurring during the wet season. Globally, MP abundance in stormwater ranges between 0.4 to 191 MPs/L (van Leeuwen et al., 2019). This shows that African stormwater pollution can be minimal to moderate in various urban systems, depending on the local sources, hydrology, and how samples are prepared.

Y. Liu et al. (2025) documented that Microplastics can also be transported through the atmosphere, and after which they are deposited into aquatic and terrestrial environments. This process can transport low-density fibres originating from textiles, and also fine particles from road dust (Allen et al., 2019). According to Allen et al. (2019) ocean waves and bubbles can also break down plastic debris into microplastics. This causes the particles to be aerosolised and carried by atmospheric currents dust (Allen et al., 2019). Factories and industrial processes emit particles, including microplastic particles, into the air, which are then carried by wind and deposited in aquatic environments (Prata et al., 2020).

According to Rochman et al. (2016) microplastics can be directly discharged into the aquatic environment through different maritime activities, like the loss of fishing gear during fishing and littering from ships during transportation. In a Similar way, plastic equipment and feedbags that are used in aquaculture can degrade over time and directly enter water bodies (de Sá et al., 2018).

The use of sewage sludge as fertiliser on farms adds microplastics to the soil (Ramage et al., 2025). These sewage fertilisers contain microplastics that have bypassed treatment from the WWTP (Lei et al., 2017) . They can eventually be carried by surface runoff into the aquatic environments (Horton et al., 2017). Similarly, the use of fertilisers that are coated with plastic polymers can also introduce microplastics into the soil (Yang et al., 2021). The MPs can later be washed into water bodies by surface runoff when it rains (Yang et al., 2021). According to Steinmetz et al. (2016) plastic greenhouse coverings result can degrade into microplastic residues that eventually are carried away by surface runoff.

2.7 Microplastic contamination in fish

According to Garcia et al. (2020), the widespread presence of microplastics in aquatic environments poses a very big risk to aquatic organisms. This is especially true for fish, due to their feeding habits (Garcia et al., 2020). A study by Rochman et al. (2016) has documented that microplastics not only cause physical harm, like blocking the digestive tract of fish, but can also act as carriers for toxic chemicals due to their ability to adsorb other pollutants. The presence of microplastics in fish raises serious concerns about the possible transfer to humans, because fish are a major food source for many communities (Lu et al., 2021).

2.8 Extraction of microplastics

It is very important to extract microplastics from environmental samples before analysing them. This lets researchers separate these particles from complex matrices like water, sediment, or biological tissues for identification and quantification. Various protocols have been developed to extract microplastics from different environmental matrices.

2.8.1 Filtration

Filtration is a technique that is used to separate a solid phase from a liquid phase, using filters of a desired pore size (M. Rani et al., 2023). This method has been employed at many stages of sample processing, like after density separation or chemical digestion, and also at the start of the sample preparation (Lusher et al., 2020). Traditionally, filtration procedures involve the use of vacuum or membrane filtration, in which the membranes are made of Alumina, ceramics, and polycarbonate (Li et al., 2019; Lusher et al., 2020). Recent studies have employed the use of glass fibre, cellulose acetate, and cellulose nitrate as the most common filter membranes in MP analysis (Arenas-Lago et al., 2023). The choice of filter material (e.g., stainless steel, nylon, glass fibre) and pore size (commonly 0.45 μm to 5 mm) is important to ensure that MPs are efficiently captured and at the same time to minimise contamination (Masura et al., 2015).

2.8.2 Digestion

According to Lavoy & Crossman (2021), the organic matter in water and fish tissue samples can interfere with the identification of microplastics using the microscope. This, therefore, requires the use of digestion techniques to remove the organic material (Lavoy & Crossman, 2021). The most common methods that have been reported in literature include oxidative digestion using hydrogen peroxide (H_2O_2) and enzymatic digestion using proteases (Sridhar et al., 2022). These processes, among others, help to isolate microplastics from biological matrices (Mercogliano et al., 2021).

Table 2. 2 Summary of digestion protocols for microplastic isolation

Protocol	**Conditions**	**Pros**	**Cons**	**References**
Enzymatic digestion	Sequential enzymes (proteinase K, cellulase, amylase, lipase), 37–50 °C, hours–days	High efficiency in removing organic matter; gentle on polymers; preserves integrity for FTIR/Raman	Costly; time-consuming; multiple steps required	Löder et al., (2017); Pfeiffer & Fischer (2020)
Alkaline (KOH, NaOH) digestion	10% KOH or NaOH, 40–60 °C, 24–48 h	Cheap; effective for proteins and tissues; simple to apply	May damage sensitive polymers at high temperature/ concentration; less effective on polysaccharides	Karami et al. (2017)
Oxidative (H_2O_2 / Fenton)	30% $H_2O_2 + Fe^{2+}$, ambient–50 °C, hours	Fast; effective for organic-rich samples (sludge, wastewater)	Risk of altering PA, PET if too harsh; needs careful pH control; safety issues (heat/foam)	Tagg et al. (2017).
Acid (HNO_3, H_2SO_4)	Concentrated acids, elevated Temperature	Very strong digestion; rapid removal of organics	High polymer destruction risk; alters many polymers	Pfeiffer & Fischer (2020)

Protocol	Conditions	Pros	Cons	References
Hybrid (e.g., Fenton + Enzymes)	Fenton pre-treatment followed by enzymatic digestion	Balances speed and gentleness; effective on complex matrices	Expensive; labour-intensive; multi-step workflow	Tagg et al. (2017)

2.8.3 Density separation

Density separation is a major technique in microplastic analysis. It works on the principle that depends on the difference in density between microplastics and the solution (Debraj & Lavanya, 2023). This method is widely used to isolate microplastics that are denser than water from environmental samples because they tend to settle down. The method involves the use of a saturated salt solution, such as sodium chloride (NaCl), sodium iodide (NaI), or zinc chloride ($ZnCl_2$), to create a medium in which microplastics, which generally have lower densities, can float, while denser materials sink (Sridhar et al., 2022). The choice of salt used depends on the targeted polymers, environmental safety concerns, and the cost of the salt (Schütze et al., 2022).

2.9 Instrumental analysis of microplastics

Instrumental analysis is one of the most significant parts of microplastic investigations. The major goal of this step is to accurately identify and describe microplastics. It is classified into microscopic and spectroscopic techniques that provide information about the physical and chemical properties of microplastics. The properties identified include the types of polymers, the size, the shape, and the chemical makeup.

2.9.1 Microscopy

Microscopy is a method that is primarily used for identifying and determining the abundance of microplastics (Huang et al., 2023). It allows for the initial categorisation of microplastics according to their size, morphology, and colour (Kalaronis et al., 2022). Stereomicroscopy and polarised light microscopy are the two most popular microscopic techniques used in many studies (Kalaronis et al., 2022). However, these techniques have limitations as they cannot provide a specific chemical composition of the plastics

(Nandikes et al., 2024). These techniques can also lead to overestimation or underestimation, depending on their resolution, sample preparation, and the skill of the operator (Nandikes et al., 2024).

2.9.2 Fourier Transform Infrared (FTIR) Spectroscopy

Fourier Transform Infrared (FTIR) spectroscopy is one of the most reliable techniques used to determine polymer compositions that make up microplastic samples (Andoh et al., 2024). The method relies on how a material absorbs infrared light at different wavelengths, which then produces a pattern that depends on its chemical structure (Andoh et al., 2024). Each polymer interacts with infrared light in its own distinct way, and the resulting spectrum serves as a kind of fingerprint that can be matched to known reference materials whose absorption spectra are installed in the instrument (Corami et al., 2020).

When the particles that are to be analysed are very small, researchers often turn to the Attenuated Total Reflectance (ATR) version of FTIR (Circelli et al., 2024). This approach is easy and efficient since it requires little to no sample preparation, and it can handle irregularly shaped particles with ease (Circelli et al., 2024). The ability of FTIR to reveal polymer composition quickly and accurately has made it a standard method in microplastic research.

2.9.3 Raman spectroscopy

Raman spectroscopy offers another option for the chemical identity of microplastics, complementing the information obtained through FTIR (Araujo et al., 2018). Rather than measuring light absorption, Raman works by examining how a beam of monochromatic light scatters when it hits the surface of a particle. The wavelength shifts that occur during this process give information about the molecule’s vibrational structure, making it possible to identify specific polymers (Araujo et al., 2018).

One of the key advantages of Raman spectroscopy offers over FTIR is its ability to detect colorants and additives in plastics. Nonetheless, fluorescence interference can occasionally obscure the spectral signals, making interpretation more challenging (Araujo et al., 2018). Even with this limitation, Raman’s fine spatial resolution allows scientists to examine extremely small particles, sometimes just a few micrometres in size, making it especially useful when dealing with micro- and nano plastic contamination (Xu et al., 2019).

2.9.4 Scanning Electron Microscopy (SEM)

SEM is a non-destructive analytical method in microplastic studies, with more than basic optical microscopy, because of its high resolution down to 1 nm (Adelugba & Emenike, 2024). Although SEM has higher magnification and better imaging, the images cannot be used in colour and chemical composition analysis (Shim et al., 2017). SEM, whenever it is coupled with energy-dispersive X-ray Spectroscopy (EDS), provides detailed surface morphology and elemental composition of microplastics, and provides an understanding of the degradation process (Shi et al., 2022).

2.10 Microplastic pollution in Uganda

Urbanisation and industrial activities in Uganda have led to higher levels of MP pollution in bodies of water (Egessa et al., 2020). A study by Egessa et al. (2020) showed notable amounts of MPs detected in fish and in Lake Victoria, mainly of secondary origin, which is a threat to the water quality and the fisheries industry at the lake. However, research on microplastic pollution from car wash effluents is still limited.

This study aims to fill existing knowledge gaps by thoroughly evaluating microplastic contamination in car wash wastewater, river water, and fish in Arua City. Focusing on this specific area provides localised information on the sources and effects of microplastic pollution. The findings could help deepen the overall understanding of microplastic pollution and also help guide local policies and actions to address this growing environmental challenge.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Study area

This study was conducted in Arua City, a fast-growing City bordering the Democratic Republic of Congo and South Sudan, with growing car wash activities that discharge untreated wastewater into nearby water bodies. The study focused on five car wash stations selected through purposive sampling. The selection criteria included logistical considerations such as budgetary constraints, ease of access, the willingness of facility managers to cooperate, and operational similarities among the sites. A key inclusion criterion was that the selected car wash stations must directly or indirectly discharge wastewater into Rivers Enyau or Asa. Notably, all selected car wash stations are situated at a higher topographic elevation than the rivers, which facilitates the downhill flow of wastewater (Appendix A)

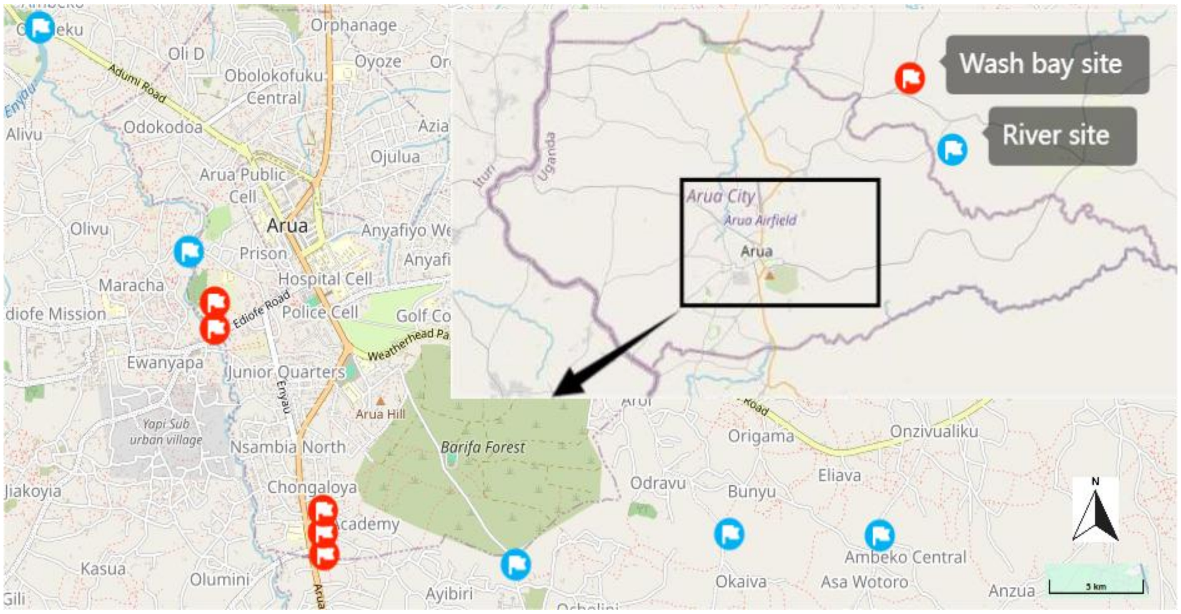

Figure 3. 1: Map showing the study area. Adapted from OpenStreetMap**.**

3.2 Assessment of car wash operational practices

To assess operational practices influencing microplastic discharge, a structured questionnaire was administered to thirty (30) participants from five purposively selected car wash bays (A–E) in Arua City (appendix G). The question consisted of both closed and open-ended formats and was pre-tested to ensure clarity and relevance. Interviews were also conducted in the local language for accurate responses and meaningful engagement. All responses were analysed descriptively alongside the questionnaire data. The findings were used to interpret the observed levels of microplastics and to identify key operational factors contributing to microplastic pollution.

3.3 Chemicals and reagents

The study used analytical grade chemicals (sulfuric acid, 30% hydrogen peroxide, 10 % potassium hydroxide, zinc chloride, 70% ethanol, and distilled water) and one prepared reagent (0.05 M Iron(II) sulphate solution).

3.4 Apparatus and equipment

The primary apparatus included stainless-steel sieves (measuring 8 cm in diameter and 2 cm in depth, with mesh sizes of 300 μm, 80 μm, and 32 μm), a glass microfilter membrane with a pore size of 0.45 μm and a 47 mm diameter, glass Petri dishes, a filtration apparatus with a vacuum pump, squirt bottles, 500-mL glass beakers, watch glasses, standard forceps, glass Petri dishes, and an analytical balance with 0.1 mg precision. Additional instruments used comprised magnetic stirrers, a stereo microscope, a micro FTIR, and laboratory hot plates.

3.5 Sample collection

Each car wash station was sampled twice (2 sampling campaigns) to account for variability and ensure precision of the results, and samples were collected during the dry season. One litre of discharged wastewater was collected using glass sampling cups from each of the sampling sites. All sampling equipment was cleaned with filtered distilled water before use to prevent contamination. Wastewater was then transferred into glass bottles that had been previously cleaned and covered with aluminium foil. The sample bottles were then wiped externally with lint-free paper towels, labelled with the sample name and date, and stored in a cool box. They were later transported on the same day to Muni University laboratory.

River water samples were collected at three spatially distinct sites. The sites were named proximal (near the point of wastewater discharge), intermediate (midstream), and distal (very far from the point of wastewater discharge) to ensure representativeness across the hydrological gradient. Each site along the river was sampled twice to account for temporal variability. This approach followed a modified version of the stacked sieve methodology, which was adapted from Gheorghe et al. (2024). At each of the sites, ten (10 L) litres of river water were collected using a clean metal can and passed sequentially through a custom-built stacked sieve system with mesh sizes of 300 µm, 80 µm, 32 µm, and 11 µm in the field. The sieves were labelled by sampling site and mesh size, then placed in a cool box to maintain sample quality during transport. All samples were taken to Muni University laboratory on the same day for further processing.

In total, twenty (20) fish samples were collected, which comprised 8 Tilapia (*Oreochromis niloticus*), 8 Mud fish (*Clarias gariepinus*), with 4 from each river, and 4 Rohu (*Labeo rohita*), collected exclusively from River Enyau, where the species is locally consumed but is not present in River Asa. This approach ensured ecological representativeness and was influenced by species availability, ethical, and logistical constraints. All the fish were captured from accessible sites along Rivers Asa and Enyau by hand and the hook-and-line method, with earthworms serving as bait. Following capture, all fish were individually wrapped in aluminium foil, labelled, stored in a cool box, and promptly transported to Muni University laboratory for analysis.

3.6 Sample preparation

Microplastics from the water matrix were isolated using a modified version of the NOAA protocol developed by Masura et al. (2015). Waste water samples from car wash bays were poured through a stacked sieve arrangement (300 µm above 32 µm). Sample containers were rinsed with distilled water to transfer residual solids. The filtrate was vacuum filtered using a 0.45 µm glass microfiber filter membrane. Materials retained on the 300 µm and 32 µm were collected in clean glass beakers by washing using filtered distilled water and labelled, while the filter membrane was sealed in glass petri dishes and labelled, awaiting microscopic analysis. Samples from the river were collected from the sieves into clean glass beakers by washing using filtered distilled water and clearly labelled by date and site.

To digest organic matter, 20 mL of 0.05 M Iron(II) sulphate solution and 20 mL of 30% hydrogen peroxide were added to the beakers. The mixture stood for 5 minutes before magnetic stirring commenced. The beaker was covered with aluminium foil and left for 24 hours. An additional 30% hydrogen peroxide was added as needed until visible organic material was eliminated. A $ZnCl_2$ solution (1.5 g/cm^3) was prepared and added to the digested sample to increase density. The mixture was stirred, loosely covered, and allowed to settle for 24 hours. Floating solids were collected on a 0.45 µm glass microfiber filter membrane in a vacuum filtration and left to air dry for at least 72 hours under aluminium foil.

Microplastics from fish tissues were extracted following the procedure outlined by Karami et al., (2016). Fish were rinsed with filtered distilled water to remove surface contaminants and weighed individually. This was followed by dissection to isolate gastrointestinal tracts (GITs), as these are the primary sites for microplastic ingestion and accumulation. The GITs were weighed and placed in labelled glass beakers covered with aluminium foil to prevent air-borne contamination

A 10% KOH solution (100 g KOH in 1 L distilled water) was added to the tissues at 10 mL per gram of tissue, sealed, and incubated at 40°C for 48 hours. Post-incubation, the supernatant was filtered through a grade one Whatman glass microfiber filter membrane (0.45 µm pore size) using a vacuum filtration system. The filtered membranes were air-dried while loosely covered with aluminium foil for at least 72 hours and later placed in labelled petri dishes for microscopic analysis. The remaining tissues were immersed in $ZnCl_2$ solution (1.5 g/cm^3), stirred using a magnetic stirrer for 10 minutes, and allowed to settle for 24 hours. The suspended solids were then filtered through a Whatman glass microfiber filter membrane of 0.45 µm. Filters were air-dried and stored in Petri dishes for further analysis.

3.7 Characterization of microplastics

All processed samples, including wastewater, river water, and fish tissue, were examined using a ZEISS Scanning Transmission Electron Microscope (STEM) 508. The microscope was operated at varying magnifications to enable the identification, quantification, and classification of microplastics based on shape (e.g., fibres, fragments, films, beads), colour, surface texture, and particle size. High-resolution images were captured for documentation purposes and to support the morphological interpretation of the microplastics. This imaging approach provided visual confirmation of particle characteristics and enhanced the accuracy of microplastic assessment across all sample types.

3.8 Determination of polymer composition

A μFTIR instrument was used to confirm polymer types by matching the measured infrared absorption spectrum to a spectral reference library of known polymer types. Each filter was imaged using a built-in camera and scanned in five defined regions using a 25-μm aperture, 16 cm^{-1} resolution, and two co-added scans. Spectral images from each region were integrated to form a false-colour composite map indicating plastic types and spatial distribution (Tagg et al., 2015).

3.9 Statistical analysis

Data analysis was performed using Microsoft Excel (Microsoft Corporation, Redmond, WA, USA) and Minitab 22 (Minitab, LLC, State College, PA, USA). Descriptive statistics were done to gain initial insights into concentration patterns within the dataset. While Parametric tests, like one-way ANOVA, were used to assess differences in the average number of microplastics across different groups, such as sampling locations. Correlation analysis was also performed to determine how microplastic load was related to specific biological factors, such as fish length and gastrointestinal tract weight. Appropriate graphs, like bar charts, were plotted in Microsoft Excel to visualise the data.

3.10 Quality assurance

All apparatuses were thoroughly cleaned with distilled water and alcohol before use and immediately covered with glass or aluminium foil to prevent contamination. In the laboratory, cotton lab coats and latex gloves were worn throughout all procedures. In addition, only high-purity reagents and pre-filtered solutions were used in all analytical steps.

Procedural blanks were also done at every stage to monitor and account for potential contamination. During filtration, distilled water was filtered as a negative control to detect any contamination from air or equipment. For chemical digestion, the digesting solution was added to distilled water to identify possible microplastic introduction from reagents.

Similarly, during density separation, the salt solution was combined with distilled water to assess contamination originating from the separation medium. All blanks were processed in parallel with actual samples under identical laboratory conditions, ensuring the reliability and integrity of the microplastic data obtained

3.11 Ethical considerations

Permission for sample collection was obtained from Arua City's Department of Environment and Natural Resources. Informed consent was obtained from all car wash station owners or managers. Confidentiality was maintained, and all environmental and community interactions were conducted responsibly. To ensure transparency, locals dependent on the rivers were engaged before sampling, while the fish were handled humanely.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Operational practices at the car wash facilities.

Table 4. 1 Operational characteristics and potential microplastic sources at selected car wash bays in Arua City

Car Wash Bay	No. of days	Average Vehicles Washed/Day	SD	Washing Method	Wastewater Retention	Potential Microplastic Sources
A	5	32.4	4.0	Manual hand washing	Low	Vehicle debris, blue and white buckets, plastic water bottles, synthetic fabric, brushes, and packaging
B	5	28.0	5.5	Manual hand washing	Very low	Vehicle debris, blue and white buckets, plastic water bottles, synthetic fabric, brushes, and packaging
C	5	43.4	2.7	Jet wash and manual hand washing	High	Vehicle debris, blue and white buckets, blue plastic chairs, plastic bottles, fabric, brushes, and packaging
D	5	40.0	4.5	Jet wash and manual hand washing	High	Vehicle debris, blue and white buckets, blue plastic chairs, plastic bottles, fabric, brushes, and packaging
E	5	38.0	2.1	Jet wash and manual hand washing	Low	Vehicle debris, red jerricans, white buckets, blue plastic chairs, plastic bottles, fabric, brushes, and packaging

The average number of vehicles washed each day was different among the five car wash bays after five consecutive days. Bay C had the highest daily average of about 43.4 vehicles. This was followed closely by bay D with 40.0, while bay B had the lowest at 28.0. Bays C and D used both jet washing and hand washing, and also had higher wastewater retention compared to the others. In contrast, bays A and B depended entirely on manual washing and retained very little wastewater.

Across all the bays, there were many plastic-based materials in use. These included buckets, chairs, bottles, synthetic fabrics, and packaging. Each of these items serves as a possible source of microplastics. The bays with jet washing systems and longer water retention, like C and D, are more likely to build up microplastics because of the stronger water pressure and longer exposure time of plastics to water. On the other hand, bay B, with very low retention, means that wastewater, along with any microplastics, is quickly released into the environment.

4.2 Characterisation of microplastics

This section presents the identification and description of microplastics. Shapes, colours, and abundance in water and fish samples collected were analysed. These features provided an understanding to the nature and potential sources of microplastic pollution in the study area.

4.2.1 Characterisation of microplastics in wastewater from car wash bays

Table 4. 2 Microplastic concentration (particles/L) per sampling campaign and average counts by shape in wastewater from car wash bays

Wash bays	**Sampling campaign**				**Shapes**						
	1	**2**	**Mean**	**SD**	**Fragments**	**Fibers**	**Beads**	**Filaments**	**Pellets**	**Films**	**Foams**
A	25	17	21.0	5.7	6.5	5.0	2.5	1.0	4.0	2.0	0.0
B	18	15	16.5	2.1	5.0	5.5	1.5	1.5	0.5	2.5	0.0
C	83	91	87.0	5.7	9.5	45.5	27.0	1.5	0.0	3.5	0.0
D	86	90	88.0	2.8	10.0	17.5	28.5	10.5	4.5	15.5	1.5
E	57	62	59.5	3.5	20.5	23.5	2.5	0.5	9.0	1.5	2.0

Bays C and D recorded the highest average microplastic concentrations, at 87 and 88 particles per litre (particle/L), respectively, whereas bays A and B showed the lowest averages, of 21 and 16.5 particles/L (Table 4.2). These differences are primarily attributed to the car washing methods used and the capacity of each site to retain wastewater before discharge. The higher levels of microplastics in bays C and D could be attributed to pressure hose and manual washing methods (Table 4.1) employed in these bays, which increase surface abrasion intensity. According to Grbić et al. (2020), mechanical abrasion often acts by wearing surfaces down through friction and pressure, combined with physical or chemical processes. This accelerates plastic surface deterioration and enhances microplastic release. This explains the high levels of microplastic detachment observed at these bays, where vehicle surfaces and plastic cleaning tools are subjected to repeated high-pressure contact.

In addition to the washing techniques, the high frequency of vehicle traffic and inadequate drainage systems at bays C and D contribute to water stagnation (appendix F). Prolonged water retention promotes the accumulation of suspended particles before discharge into the environment. Wang et al. (2022) noted that microplastic levels in urban runoff can reach up to 8,580 particles/L. It was linked to densely serviced areas with poor water management.

Conversely, bays A and B use only manual washing and discharge wastewater immediately. This reduces both abrasion and particle retention time. This limits the wear on plastic materials and the overall release of microplastics. Although bay E uses both washing methods, its contamination level remains lower than in C and D due to fewer vehicles washed and more efficient drainage, which restricts microplastic build-up.

One-way ANOVA confirmed significant differences in microplastic concentrations among the five wash bays (F = 133.98, $p < 0.05$) (appendix D). Tukey's pairwise comparison test further grouped the bays D and C. This was due to their similarly high contamination levels. While bays A and B formed a separate group with significantly lower levels. Bay E, with an average of 59.5 particles/L, was intermediate. This result was statistically different from both high and low groups. These variations reinforce the influence of car wash operations. In Particular, washing methods, wastewater retention, and vehicle volume played the biggest role.

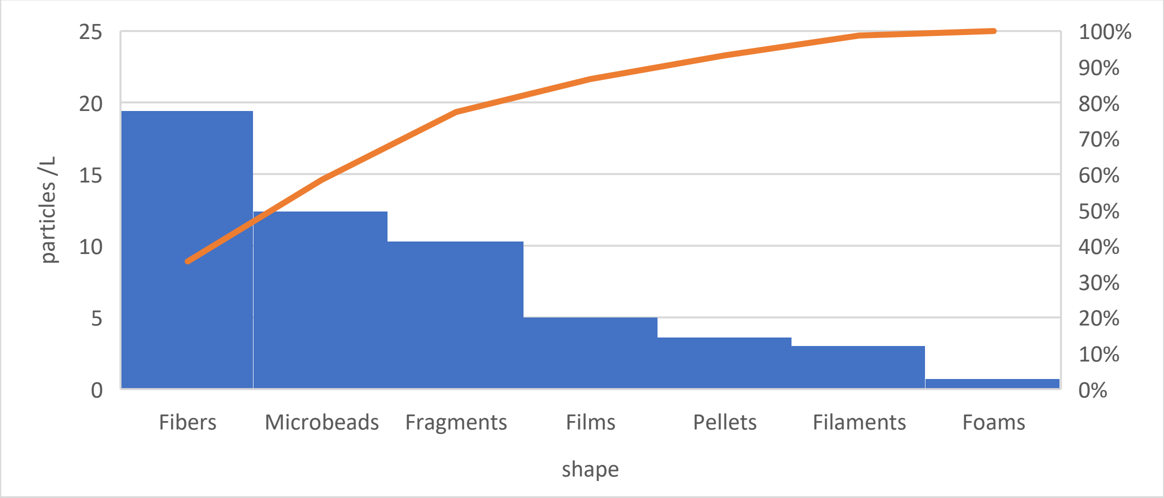

Figure 4. 1: Average abundance of microplastics shapes in waste water from car wash bays

Fibres, microbeads, and fragments were the dominant shapes. This was identified across all car wash bays. They collectively account for over 80% of the total microplastics per litre. Fibres were likely shed from synthetic cleaning cloths and brush bristles. Microbeads likely originated from car waxes, polishes, and soaps. Fragments were attributed to the physical degradation of vehicle parts. In particular, bumpers, as well as worn-out plastic tools used at these facilities.

The predominance of these shapes aligns with wastewater studies from other urban settings. Similar studies identified fibres and fragments as dominant microplastics (Ziajahromi et al., 2020; Treilles et al., 2021; Kwarciak-Kozłowska & Madeła, 2025). Their frequent occurrence points to mechanical and chemical wear. This is associated with intensive car washing practices.

Other shapes, such as films, filaments, pellets, and foams, were also identified, though they appeared in smaller amounts. The films likely came from torn plastic packaging and disposable wraps, while filaments may have resulted from the wearing down of synthetic towels and cleaning brushes. Pellets and foams probably originated from the breakdown of plastic containers, insulation materials, or even vehicle seat cushions used within the car wash bays (Gan et al., 2023). Although less common, these forms add to the overall diversity of microplastic pollution and point to the wide range of materials contributing to it during car washing activities. Their presence highlights how complex and varied the generation of microplastics can be in commercial vehicle cleaning environments. Similar findings were reported by Boni et al. (2022) and Smyth et al. (2021), who also observed films in runoff from urban areas, further supports the trends seen in this study.

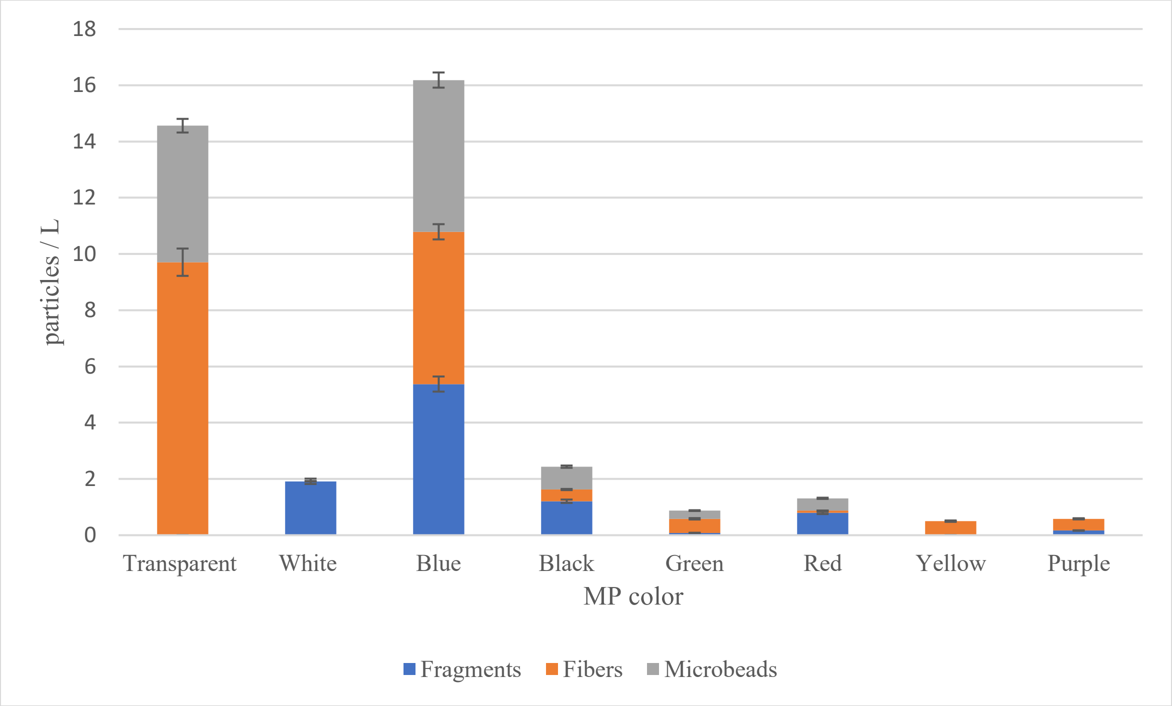

Figure 4. 2: Colour distribution of MPs from car wash bays

Colour analysis showed that blue and transparent microplastics were the most common across all car wash bays. These colours appeared in several particle types, such as fragments, fibres, and microbeads, and were especially abundant in bays with more intense mechanical washing. Their dominance likely reflects the kinds of plastic materials most frequently used at these sites.

In Bays A and B, the blue particles were likely shed from plastic buckets and detergent packaging often used during cleaning. The transparent fibres may have come from synthetic cloths and brush bristles. Likewise, in Bays C, D, and E, the blue and transparent particles were probably from the gradual wear of plastic tools and equipment used (appendix F). These explanations provide possible links between microplastic colours and their potential sources. However, without detailed source apportionment studies, these reasons remain speculative. Therefore, future research should include a quantitative determination of how different materials and washing practices contribute to microplastic pollution.

4.2.2 Characterisation of microplastics in river waters

Table 4. 3 Microplastic concentrations and shapes in water from rivers Enyau and Asa

Sample Area	**Sample Position**	**MPs /L**	**Shape**					
			Fragments	**Fibers**	**Filaments**	**Beads**	**Films**	**Foams**
River Enyau	P (Distal)	3.7	1.3	2.4	0.0	0.0	0.0	0.0
	R (intermediate)	2.8	0.2	2.1	0.2	0.1	0.1	0.1
	Q (proximal)	3.5	1.7	1.8	0.0	0.0	0.0	0.0
	Average	**3.330**	**1.067**	**2.100**	**0.067**	**0.033**	**0.033**	**0.033**
River Asa	X (Distal)	4.9	0.0	4.9	0.0	0.0	0.0	0.0
	Y (intermediate)	1.3	0.2	0.7	0.4	0.0	0.0	0.0
	Z (proximal)	3.1	1.3	0.8	0.2	0.4	0.3	0.1
	Average	**3.100**	**0.500**	**2.133**	**0.200**	**0.133**	**0.100**	**0.033**

Analysis of river water samples showed similar average microplastic concentrations in River Enyau (3.33 particles/L) and River Asa (3.10 particles/L). While the overall averages were comparable, noticeable spatial variation existed within each river. In both river systems, the number of microplastics followed a clear pattern: downstream (distal) sites consistently showed the highest concentrations, upstream (proximal) sites had moderate levels, while the midstream areas recorded the lowest amounts. This pattern likely reflects hydrodynamic effects. The slower flow in distal areas allows microplastics to settle and accumulate. on the other hand, faster flows in mid-stream regions promote dilution and downstream transport.

These observations are consistent with McCormick et al. (2016), who found elevated microplastic concentrations downstream of wastewater treatment plant outflows. In comparison, Kunz et al. (2023) reported much lower levels of 0.2298 particles/L in the Old Han River. Shikwambana et al. (2024) recorded 11–50 particles/L in South Africa's

Olifants River. These values are higher than those in Rivers Asa and Enyau. The regional and global comparisons demonstrate the variations in freshwater pollution. This has mainly been due to both human activity and hydrological conditions.

A one-way ANOVA showed no significant difference in microplastic concentrations between the two rivers ($F = 0.05$, $p = 0.839$) (Appendix D). Although River Asa displayed a higher standard deviation (1.80) than River Enyau (0.473). This implies that contamination levels varied more widely from one site to another along Asa. This uneven pattern likely reflects local human activities along the river. These include laundry, car washing, and waste dumping. These activities differ in intensity along different sections of the river. The paired sample t-test also supported this finding, showing no statistically significant difference in the average microplastic concentrations between the two rivers at the 95% confidence level (Appendix D).

This kind of uneven distribution of microplastics along the River Asa is similar to patterns seen in studies around the world. For example, McCormick et al. (2016) carried out a large meta-analysis of 862 water samples from 29 countries and found that microplastic concentrations varied widely. Much of this variation was linked to the closeness of the sampling sites to urban areas, wastewater outlets, and other localized human activities.

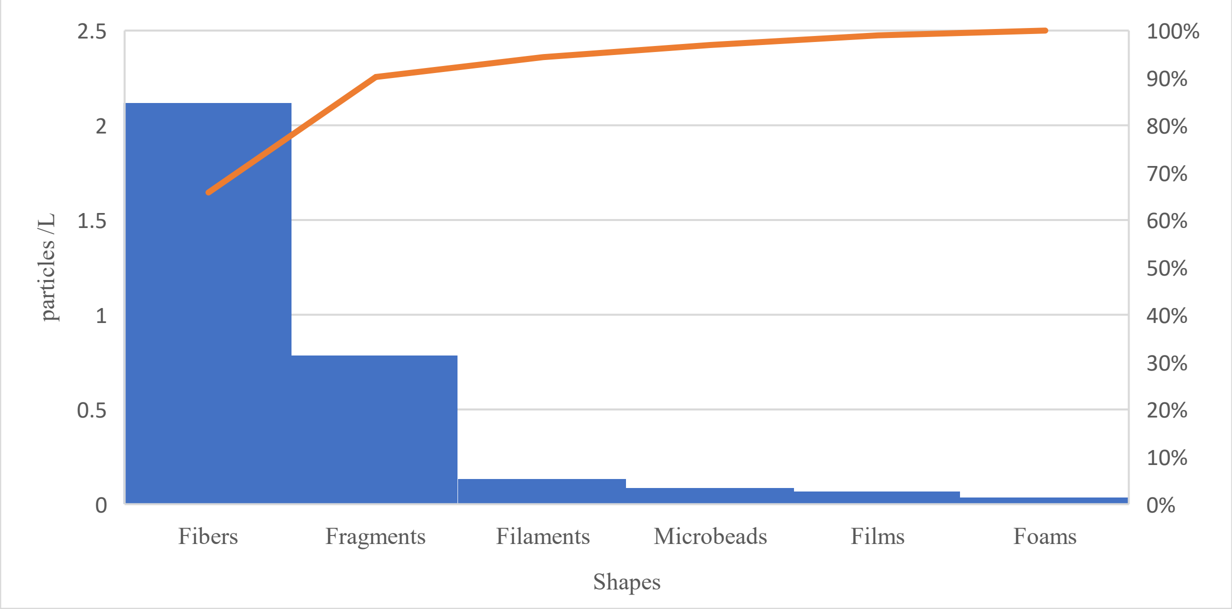

Figure 4. 3 Average abundance of microplastics shapes in water from rivers Enyau and Asa

Fibers and fragments were the dominant shapes of microplastics in both rivers. These accounted for over 80% of the total microplastics in the rivers. it is consistent with the profiles found in upstream car wash bays. Blue and transparent fibres were particularly dominant. These findings are similar to those of Nyakoojo et al. (2024), who documented fibre and fragment dominance in River Mpanga due to anthropogenic input.

The current results also mirror global patterns. These shapes consistently characterise riverine microplastic contamination. For instance, Shimul et al. (2023) documented fragments and fibres as the most commonly found shapes in the Karnaphuli River in Bangladesh. This was associated with industrial discharge and urban runoff. In the Sundarbans mangrove river system, Ahmed et al. (2025) found that fragments and fibres were most common. This was linked to port activities and organic matter content.

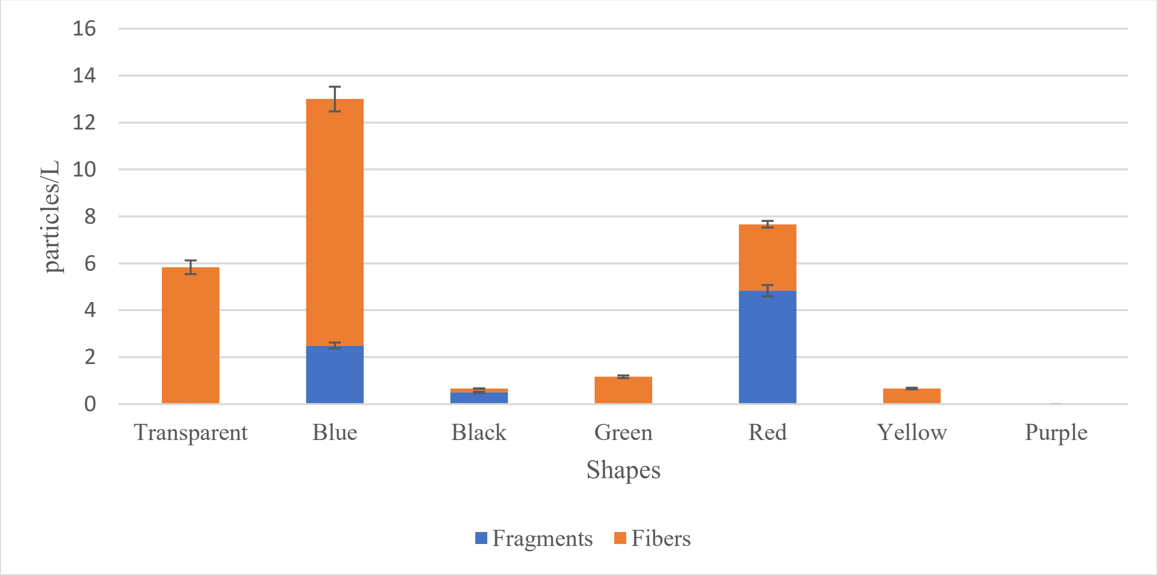

Figure 4. 4*:* Colour distribution of MPs in water from rivers Enyau and Asa**.**

Blue fragments and fibres were the dominant microplastics observed in both rivers. This resembles the colour profiles recorded in the upstream car wash bays. Transparent fibres were also commonly detected in river samples. This was also consistent with their presence in wash bay effluents. This strong visual consistency reinforces the connection between car wash discharge and downstream microplastic contamination, supporting the argument for wash bays as significant point sources of riverine plastic pollution.

There was a frequent occurrence of red fragments and fibres in both river systems. This suggests the presence of additional microplastic sources beyond the wash bays. These red particles were relatively less prominent in the wash bay effluents. It indicates possible entry through surface runoff, informal waste disposal, or plastic erosion from the surrounding catchment area. Their distribution highlights the complex and multi-source nature of microplastic pollution in urban freshwater systems.

4.2.3 Characterisation of microplastic contamination in fish

Table 4. 4 Microplastic concentrations in fish from rivers Enyau and Asa

Sample area	Fish Type	Weight of fish (g)	length(cm)	weight of GITs (g)	Plastic Count	Plastics /1000g of GITs
River Enyau	Mud fish	558.9	46.0	97.1	41	422.24
	Mud fish	1571.7	61.4	150.1	45	299.80
	Mud fish	905.2	68.0	103.7	89	858.24
	Mud fish	711.3	45.3	61.4	30	488.60
	Rohu Fish	287.3	29.0	22.1	41	1855.20
	Rohu Fish	298.4	30.0	30.8	16	519.48
	Rohu Fish	252.1	28.2	18.3	33	1803.28
	Rohu Fish	246.7	27.8	25.6	6	234.38
	Tilapia	123.5	17.2	17.5	12	685.71
	Tilapia	140.1	18.5	19.8	15	757.58
	Tilapia	155.8	20.0	20.5	17	259.27
	Tilapia	152.4	16.8	15.0	11	733.33
River Asa	Mud fish	82.5	27.5	7.3	37	5068.49
	Mud fish	97.2	25.0	7.8	30	4477.61
	Mud fish	60.3	28.1	6.7	24	3582.09
	Mud fish	43.0	20.0	5.7	12	2105.26
	Tilapia	36.4	13.0	6.2	33	5322.58
	Tilapia	33.5	12.9	5.5	42	7636.36
	Tilapia	24.1	9.8	4.7	10	2127.66
	Tilapia	14.6	10.9	2.8	22	7857.14

Microplastic contamination in fish from Arua City’s aquatic systems revealed marked spatial disparities. Fish from River Asa carry significantly higher microplastic loads (mean = 4,772 particles/1,000 g tissue) than those from River Enyau (mean = 743 particles/1,000 g tissue). Comparing similar fish types and sample size in both rivers, the mean microplastic load in fish in river Enyau (563.1 particles/ 1,000g tissue) was still low compared to that in river Asa (4,772 particles/ 1000g tissue). This difference was statistically significant (F = 37.90, $p < 0.001$) and (F = 29.11, $p < 0.001$) (appendix D), respectively. This reflects the influence of localized pollution dynamics. The causes are likely urban runoff, car wash wastewater, and unregulated waste disposal. The higher microplastic levels in the River Asa suggest greater human impact.

Within the broader Nile Basin, Nile tilapia from Khartoum, Sudan, showed a lower average of 72 ± 62 particles/1000g of GIT (Saad & Alamin, 2024). In the same way, a study in Cairo reported microplastics in over 75% of Nile fish, with fibres and films as the dominant forms (Khan et al., 2020). Despite their nature, these Nile River values remain considerably below the levels detected in Arua. This suggests a more intense contamination scenario in Uganda's urban freshwater systems.

Freshwater fish around the world show varying levels of microplastic contamination, which has been attributed to local environmental conditions and human activities. For example, a study in Dhanmondi Lake, Dhaka, found very high amounts of microplastics in fish of up to 4,880 particles per 1,000 g of gastrointestinal tract content in fish (Mercy et al., 2023). The high levels recorded in the River Asa lie within this global range. This suggests that Arua's freshwater systems are among the more heavily polluted urban waterways. In both River Asa (appendix D) and Dhanmondi Lake, Tilapia showed particularly high microplastic loads. This implies that this species may be more exposed or susceptible in polluted freshwater habitats. However, the differences among Tilapia, Mudfish, and Rohu were not statistically significant ($p = 0.395$) (Appendix D). This suggests that the variation observed was not enough to conclude that one species accumulates more microplastics than the others.

Species-wise, Felicitas et al. (2025) reported an average of 3.2 ± 1.0 particles per Fish in Tilapia from Lake Tugno and 1.7 ± 0.33 particles per Fish in Lake Panlabuhan. When these results were compared to the current, River Asa recorded a higher average microplastic count of 5.7 ± 1.3 particles per Fish, while River Enyau recorded a lower average of 0.7 ± 0.03 particles per Fish. The observed values ranged from 0.69 particles per Fish in River Enyau to a maximum of 7.86 particles per Fish in River Asa. Merga et al. (2020)

reported a median microplastic count of 4 particles per fish (range: 1–29) in benthic species (*Clarias gariepinus*), commonly referred to as mud fish, during their investigation of microplastics in the gastrointestinal tracts (GIT) of fish from African lakes. In contrast, the current study recorded a significantly higher median microplastic count in the same type of fish of 33.5 particles per fish (range: 12–89) for the same species.

Rashid et al. (2025) conducted a 90-day feeding trial where Rohu (*Labeo rohita*) were given diets containing up to 2.5% polystyrene microplastics. The study did not account for the exact number of microplastics in the fish's gastrointestinal tract. However, the researchers observed clear physiological changes, pointing to notable accumulation (Rashid et al., 2025) . In contrast, the current study looked at wild fish and recorded an average of 1,103 microplastic particles per 1,000 g of gastrointestinal tissue in Rohu. Unlike earlier work that relied on indirect measures, this study provides direct, measurable evidence of substantial microplastic ingestion in Rohu fish species. Therefore, the findings in this current study show that environmental exposure to polluted waters plays a bigger role in determining microplastic load in fish than differences in the species' biology or physiology.

Even though more studies are revealing how common microplastics have become in water and food, scientists still know very little about how they affect human health. According to the European Food Safety Authority (EFSA, 2016), there isn't enough information about how micro- and nano plastics move through or impact the human body to clearly assess any health risks from eating them. Likewise, the United Nations Environment Programme (UNEP, 2021) noted that the possible health effects of microplastics are still poorly understood, and there are currently no established safe limits for human exposure.

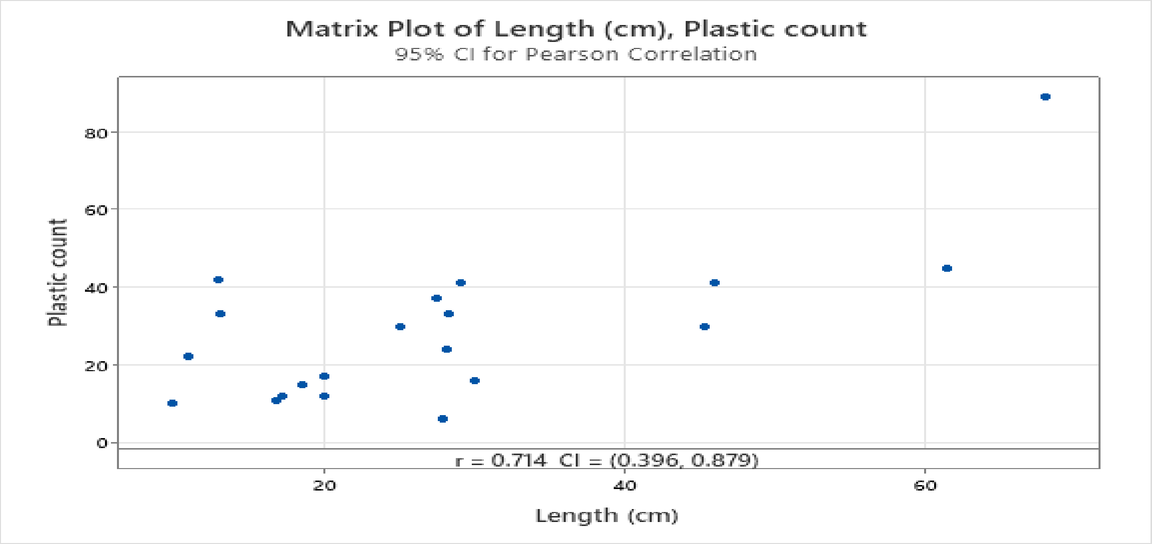

Figure 4. 5: Matrix plot showing a high correlation between fish length and Microplastic count

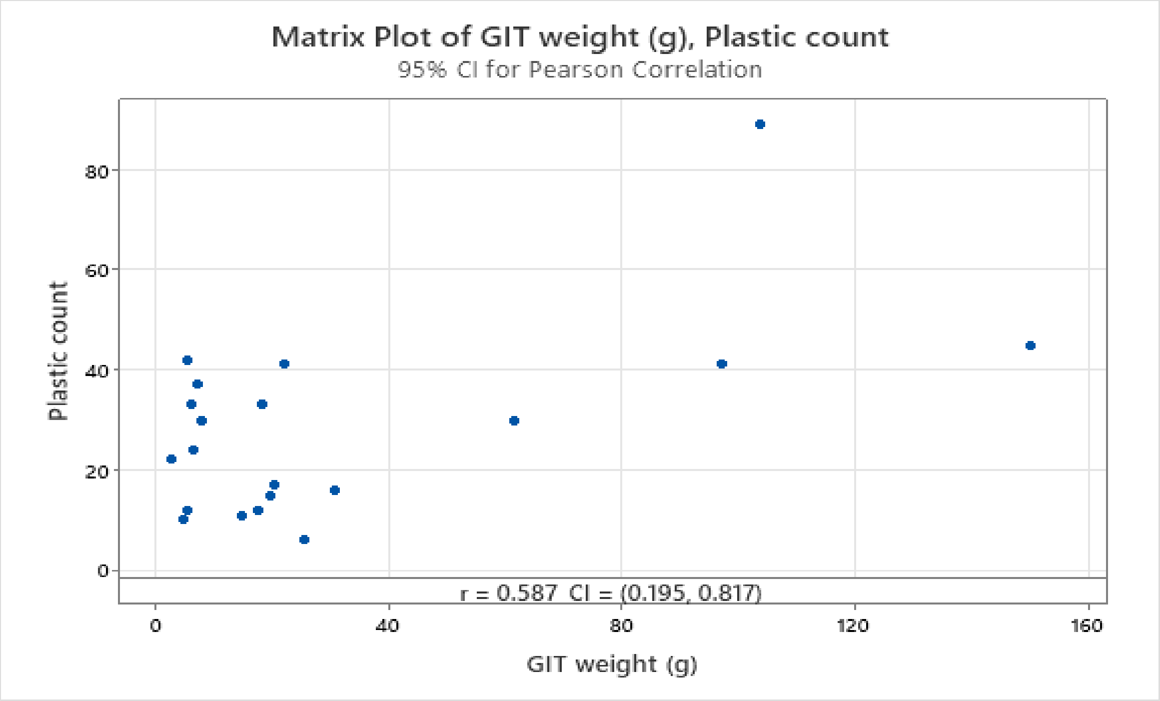

Figure 4. 6: Matrix plot showing a moderate correlation between GIT weight and microplastic count.

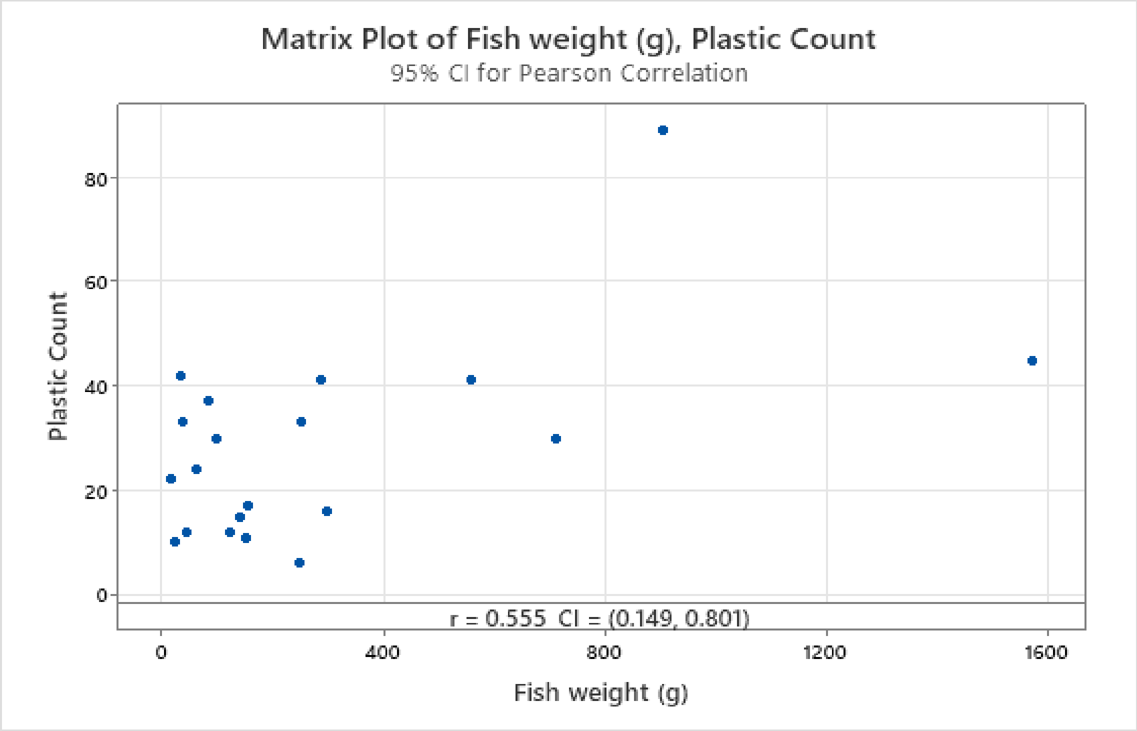

Figure 4. 7*:* Matrix plot showing a moderate correlation between fish weight and microplastic count.

Correlation analysis showed a high positive relationship between fish length and microplastic load (see Figure 4.5), suggesting that longer fish tend to ingest or retain more microplastics. A moderate but statistically significant correlation was also observed between gastrointestinal tract (GIT) weight and microplastic load, as well as fish weight and microplastic load (see Figures 4.6 and 4.7, respectively, and Table D 1 in Appendix D), indicating a possible link between digestive capacity and ingestion volume. These findings align well with previous studies, which reported that larger or longer fish species accumulate higher microplastic burdens (Khan et al., 2020; Nawar et al., 2023; Wootton et al., 2021). This is due to longer exposure periods, broader feeding ranges, and greater ingestion capacity.

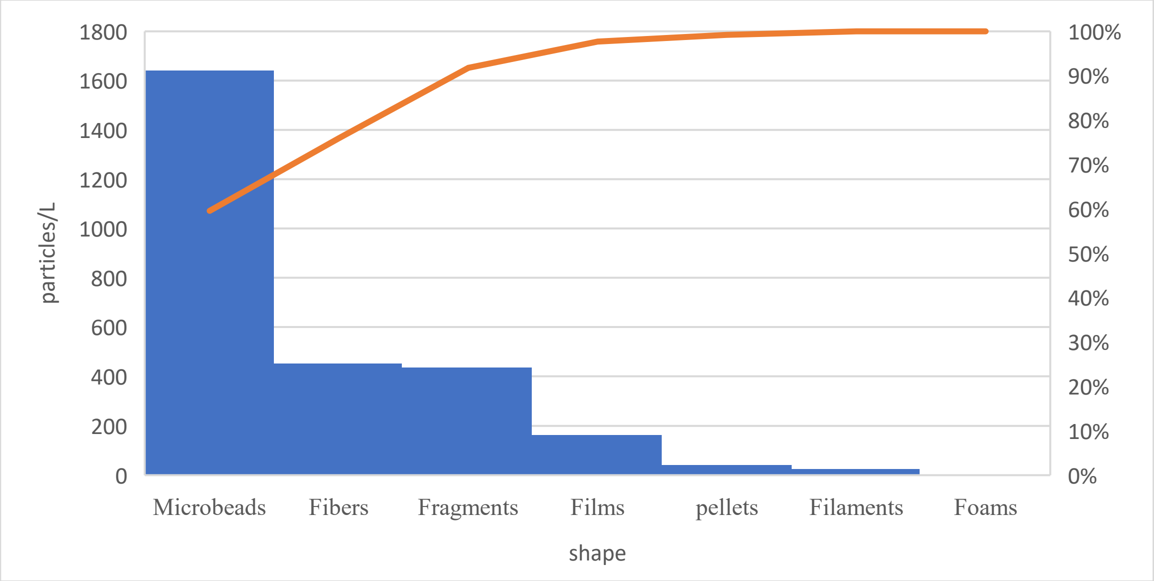

Figure 4. 8*:* Average abundance of microplastics shapes in fish from rivers Enyau and Asa

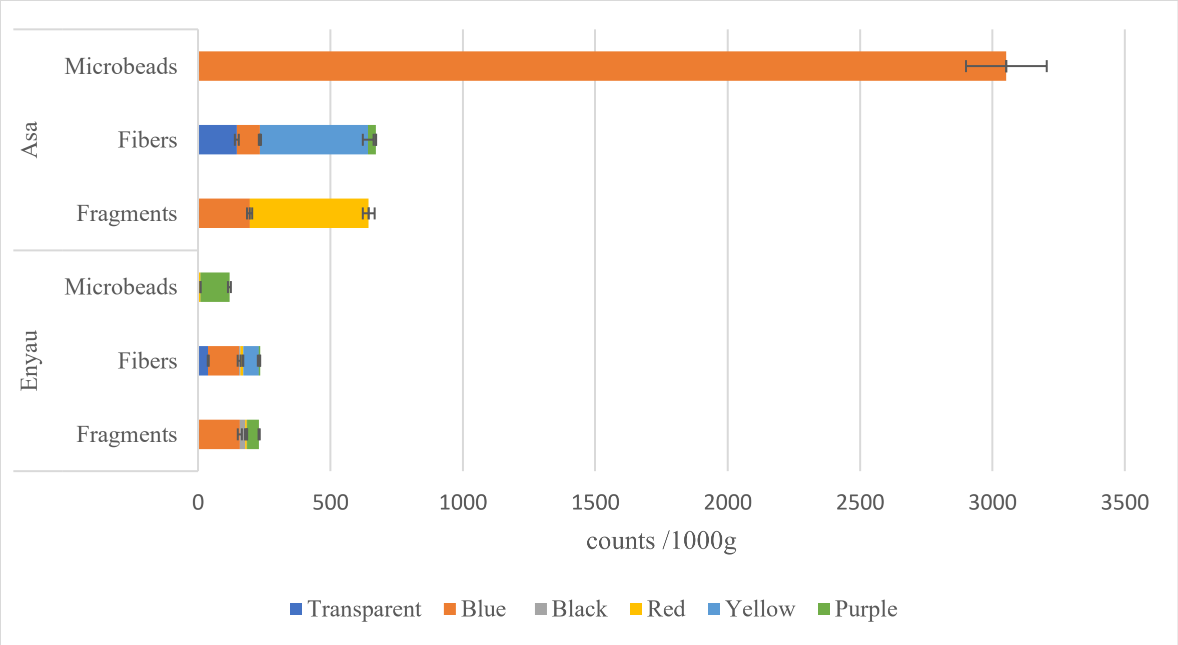

Figure 4. 9*:* Colour distribution of MPs in fish from rivers Enyau and Asa

Microbeads, fibres, and fragments were the most common types of microplastics found in fish tissues. These make up over 90% of the total MPs in fish. High levels of microbeads, especially in fish from River Asa, can be linked to high concentrations of MPs in bays C and D that flow into River Asa. The presence of fibres and fragments in large amounts aligns with the patterns seen in river water and car wash bay samples.

Fish collected from the River Asa had much higher levels of microplastic contamination than those from the River Enyau. This is likely because of heavy localised human activities along the River Asa. In Addition, the fish from the river Asa were collected at the distal position, which had recorded higher microplastic concentrations. Blue microbeads were especially abundant, exceeding 3,000 particles per 1,000 grams of tissue. This has been linked to the heavy exposure of the fish to plastic-containing car care products, which could have come from the upstream wash bays (C and D). Additionally, bioaccumulation of these microbeads in fish can contribute to the high concentration that was observed. The study also found a significant presence of yellow fibres that may be linked to oxidation and breakdown of older plastic materials. The large number of red fragments in the fish closely matches what was found in the river water. This suggests a possible shared source of contamination.

On the other hand, fish taken from the River Enyau had fewer microplastics, where blue fibres and fragments were the most common types observed. The relatively low levels of microplastics observed were mainly attributed to the fish's feeding habits and the sampling location along the river. The fish were specifically collected at the intermediate position, where microplastic contamination was low. Additionally, washing bays A and B, which had employed simpler, mostly manual washing methods, also discharge into the river. The bays are associated with low microplastic contamination levels. The prevalence of blue fragments and fibres in these fish reflects the pattern seen in wastewater from those bays (appendix B).

These findings further show that car wash wastewater can contribute to microplastic pollution in aquatic life. The fact that similar types, shapes, and colours of plastics were found in samples from the wash bays, river water, and fish tissues suggests that regular washing activities in urban areas are directly adding microplastics to the river environment.

Lin et al. (2023) discovered that most of the microplastics that were found in fish were fibres and fragments, where blue and black appeared the most. Similarly, Timaná Morales et al. (2025) also observed that fibres and fragments were the main types of MPs present, where blue, black, and transparent particles were the most common colours. These results are related to the findings of this study, where fibres and fragments made up the largest share of microplastics, with blue particles being the most frequently seen in all fish samples.

4.3 Determination of polymer composition of microplastics in wastewater, river water, and fish samples

Microplastics from car wash wastewater, river water, and fish tissues were examined for their polymer composition. Using µFTIR, the samples were matched against known polymer signatures, allowing precise identification of their material composition.

The most commonly found plastics were Ethylene/Propylene Copolymer (EPC, around 60% ethylene), Polyethylene (PE), and Polypropylene (PP). These types appeared in nearly all samples, indicating they are the main contributors to microplastic pollution in the area. Their detection in both water and fish tissues highlights how these plastics travel through the environment, moving from human activities into aquatic life.

Figure 4.10 shows the infrared spectra of a microplastic particle (upper graph) from car wash bay A, next to a reference spectrum of an ethylene/propylene copolymer with around 60% ethylene (lower graph). In the mid-infrared range (4000–500 cm^{-1}), the sample shows a number of clear absorption bands. The peaks around 2915 and 2848 cm^{-1} are the most important and are caused by the stretching vibrations of methylene ($–CH_2–$) groups that are not symmetrical. There are also extra absorption features at about 1456 and 1377 cm^{-1} that correspond to the bending vibrations of methyl ($–CH_3$) groups. Smaller bands near 720 cm^{-1} exhibit CH_2 rocking, a phenomenon typically associated with polyethylene chains. When these signals are compared to the reference spectrum, they are very similar, which means that the substance is an ethylene/propylene copolymer.

The detection of EPC in Arua City is particularly noteworthy. This polymer, which is widely used in automotive seals, construction adhesives, and flexible packaging (Begum et al., 2020), has not been widely reported in regional studies. Its appearance in all matrices points to the role of urban vehicular activity and infrastructure as significant contributors to microplastic contamination. Because of the durability and resistance of EPC to environmental degradation, it is especially persistent once released into the aquatic systems. PE and PP, on the other hand, are more common and widely recognized plastics. They are found in everyday items such as packaging films, plastic containers, detergent bottles, and synthetic textiles. The finding of these polymers in all matrices in this study suggests that everyday consumer products are a likely source.

Similar observations have been made in other regions. In Ghana's Densu River, for instance, Polyethylene (PE) and Polypropylene (PP) were the most commonly found plastics (Prabhu et al., 2022). There were present in both the river water and in fish species such as *Chrysichthys nigrodigitatus* and *Sarotherodon melanotheron* (Prabhu et al., 2022). These plastics were present throughout the river, from stagnant pools to swiftly flowing stretches, illustrating how pervasive and long-lasting PE and PP contamination can be. These findings suggest that these polymers are a persistent part of the river ecosystem (Prabhu et al., 2022). They affect both the water itself and the organisms that inhabit it (Peters & Bratton, 2016; Prabhu et al., 2022).

The finding of similar polymers in water and in fish shows that these plastics are present in the aquatic environment and are also accessible to aquatic life. This is because they are light and buoyant, making them float and remain suspended in water. As such, they are easily ingested by organisms as they feed. Observing them across different parts of the ecosystem highlights how plastic pollution moves between sources, water, and living organisms, showing the close link between contamination and ecological exposure.

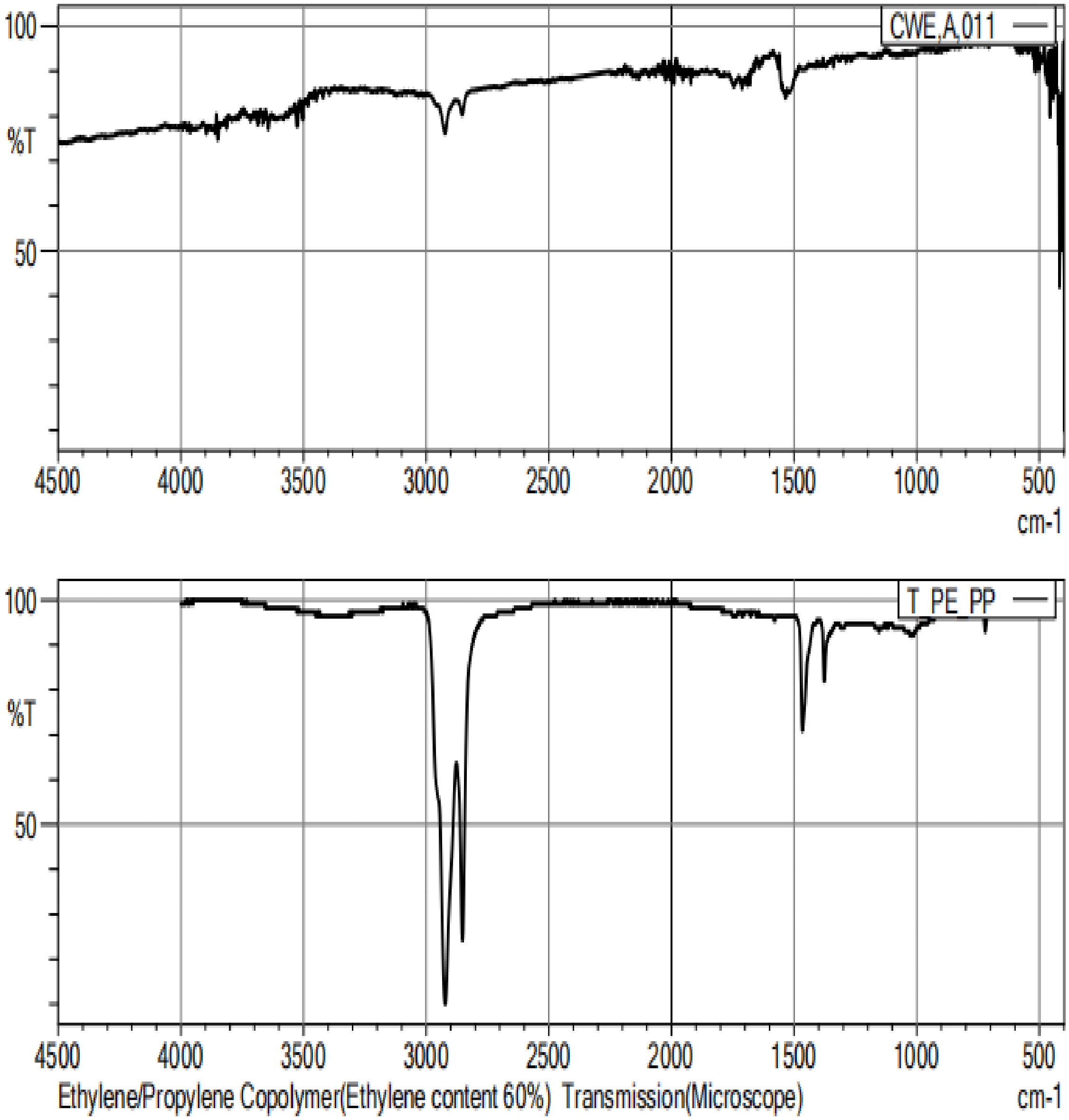

Figure 4. 10*:* FTIR spectrum of microplastics from car wash bay wastewater

FTIR spectra of microplastics that have been isolated from both fish and river water samples are presented in Appendix C, as the spectral profiles were largely similar across all samples, indicating the presence of similar polymer types.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The findings of this study confirm that car wash bays are notable sources of microplastic pollution. Bays that utilize jet washing and exhibit poor wastewater retention, particularly bays C and D, recorded the highest microplastic concentrations. This emphasises the role of washing technique and drainage design on pollutant loads.

Rivers Enyau and Asa, receiving wastewater from upstream bays, were found to be contaminated with microplastics. Fragments and fibres dominated the particle types. The distal sampling points had the highest accumulation due to reduced flow velocity and increased settling. These spatial patterns suggest that there is downstream accumulation driven by hydrodynamic factors.

The ingestion of microplastics by fish suggests a direct route of exposure from the environment to aquatic organisms. Microplastics were identified in the gastrointestinal tissues of fish. This suggests uptake through feeding, and it raises concerns for food safety and ecosystem health in communities surrounding the studied rivers.

FTIR analysis revealed consistent polymer composition across all matrices, wastewater, river water, and fish tissue. The top matching polymers were polyethylene (PE), polypropylene (PP), and ethylene-based copolymer (EPC). This similar chemical signature across all matrices confirms a common source of contamination likely linked to urban car washing activities.

The study also demonstrates that human activity directly shapes microplastic characteristics, including their shape, colour, and polymer type. For instance, the dominance of red fragments in River Asa and fish was hypothesized to have come from the use of red jerricans at bay E. Similarly, the prevalence of blue fibres and fragments was hypothesized to have come from commonly used car wash items, plastic buckets, brushes, and uniforms.

5.2 Recommendations

Based on the findings of this study, a number of strategic recommendations have been proposed that could help to mitigate microplastics pollution in Arua city coming from urban car wash activities. They are organised into thematic areas to guide public engagement, policy formulation, and future research, all aimed at promoting sustainable environmental practices.

5.2.1 Public awareness and capacity building

There is an urgent need for the Arua City Council and the National Environment Management Authority (NEMA) to consider developing new guidelines for wastewater management. The facilities should be required to adopt effective, low-cost treatment techniques, like installing filtration traps or rain gardens at car wash stations, to reduce direct discharge into rivers. These interventions would contribute to supporting long-term environmental protection efforts in urban centres.

5.2.2 Policy and regulation

Arua City Council and the National Environment Management Authority (NEMA) should urgently consider developing guidelines for wastewater management requiring these facilities to adopt low-cost treatment technologies, like installing filtration traps or rain gardens at car wash stations to reduce direct discharge into rivers. These interventions would contribute to supporting long-term environmental protection efforts in urban centres.

5.2.3 Further research

Future studies should establish the specific operational practices that contribute most to microplastic release for tailored interventions. Sampling across different seasons should be considered to capture seasonal variations in microplastic pollution across all the matrices, as well as investigating the ecological and human health risks associated with detected microplastic levels, considering the fact that the rivers studied contain fish consumed by the locals. These efforts will contribute to a more comprehensive risk assessment framework.

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APPENDIX

Appendix A: Sampling Sites

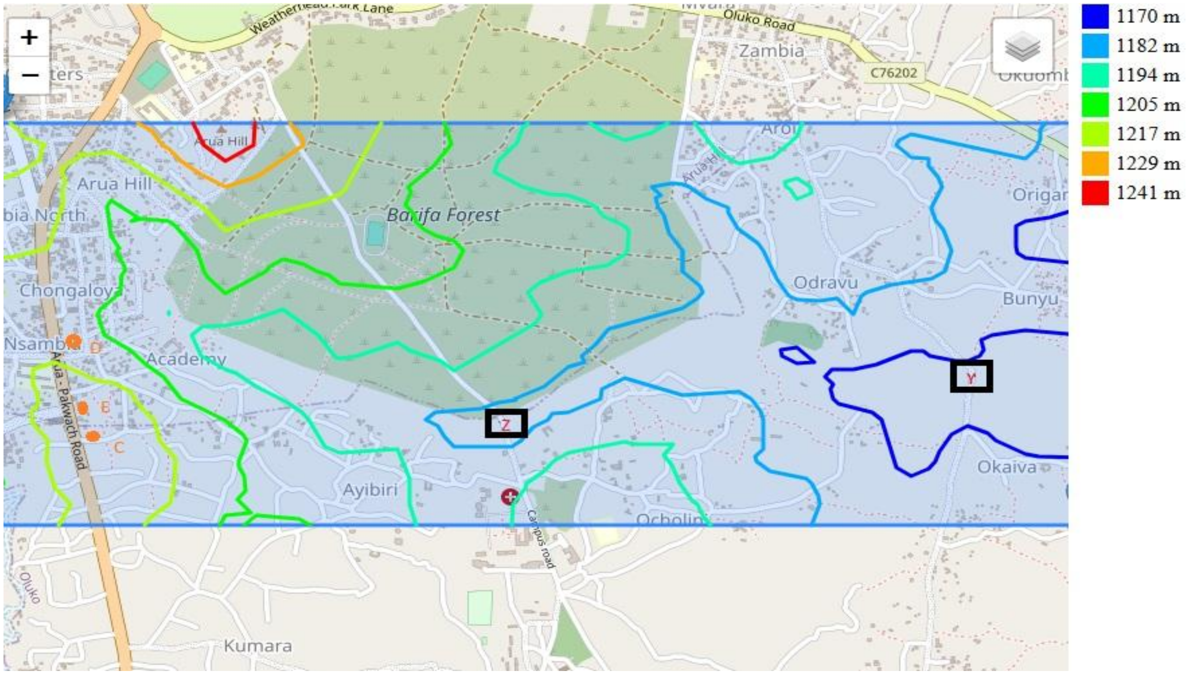


Figure A 1: A topographic map of Arua City illustrating the gradient flow of wastewater from car wash bays C, D, and E into River Asa, with sampling points Z and Y positioned along the river.

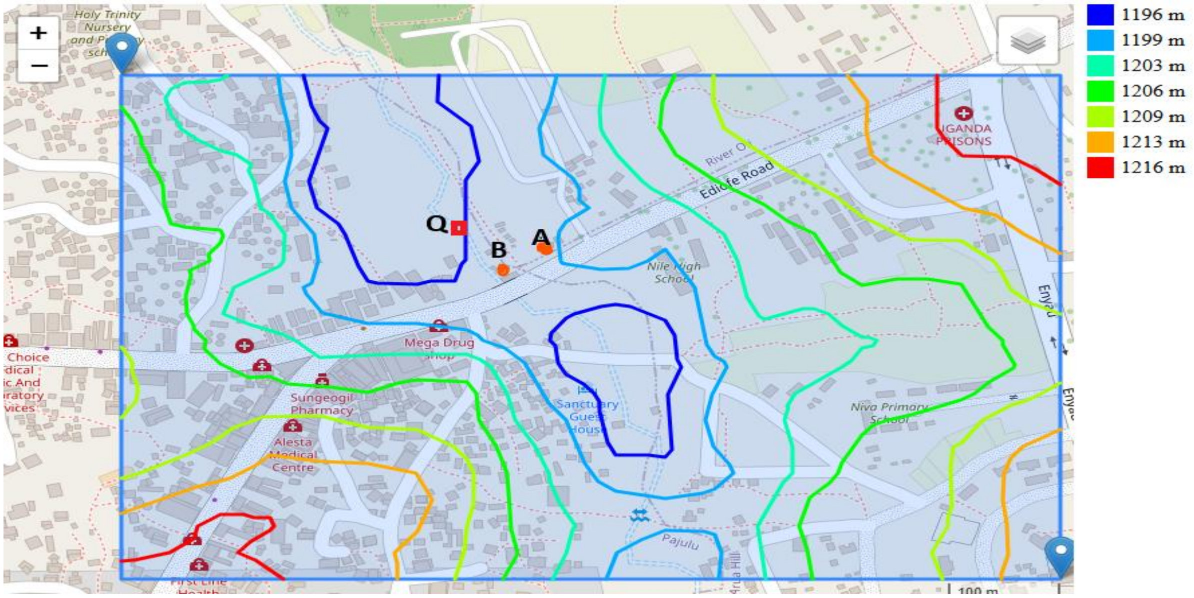


Figure A 2: A topographic map of Arua City illustrating the gradient flow of wastewater from car wash bays A and B into River Enyau, with sampling point Q located along the river.

Appendix B: Characterization of microplastics by shape and colour

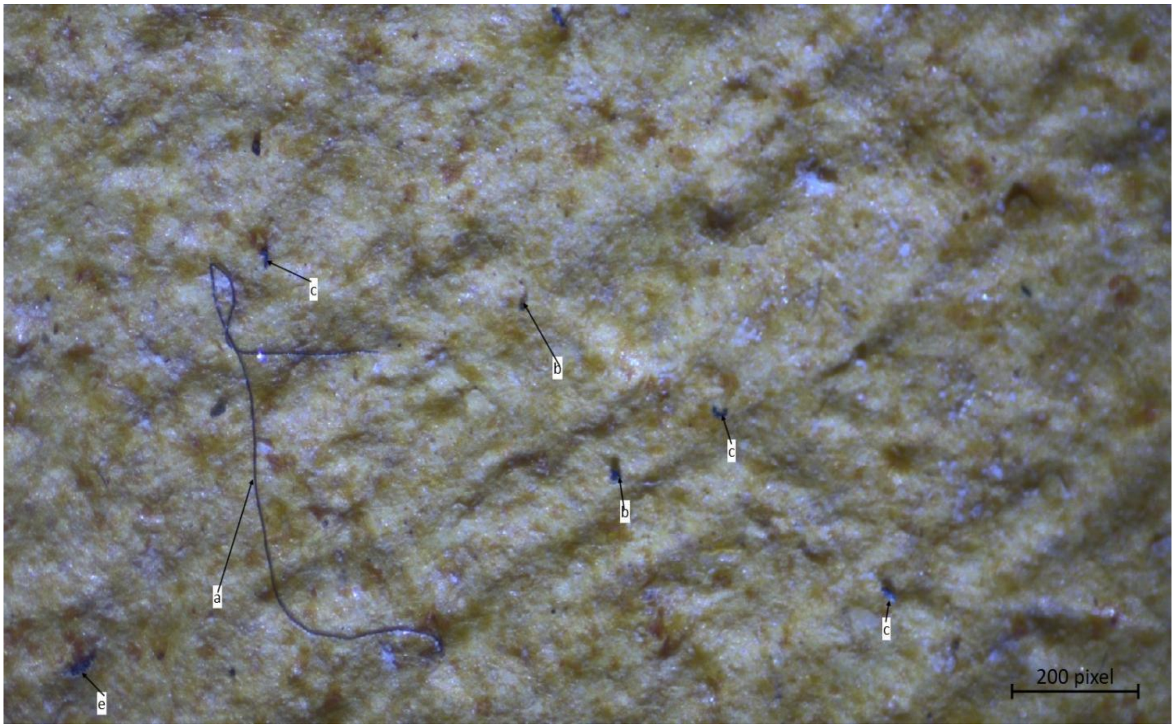


Figure B 1: STEM images showing a blue fibre (a) and a blue fragment (b) isolated from the car wash wastewater sample A.

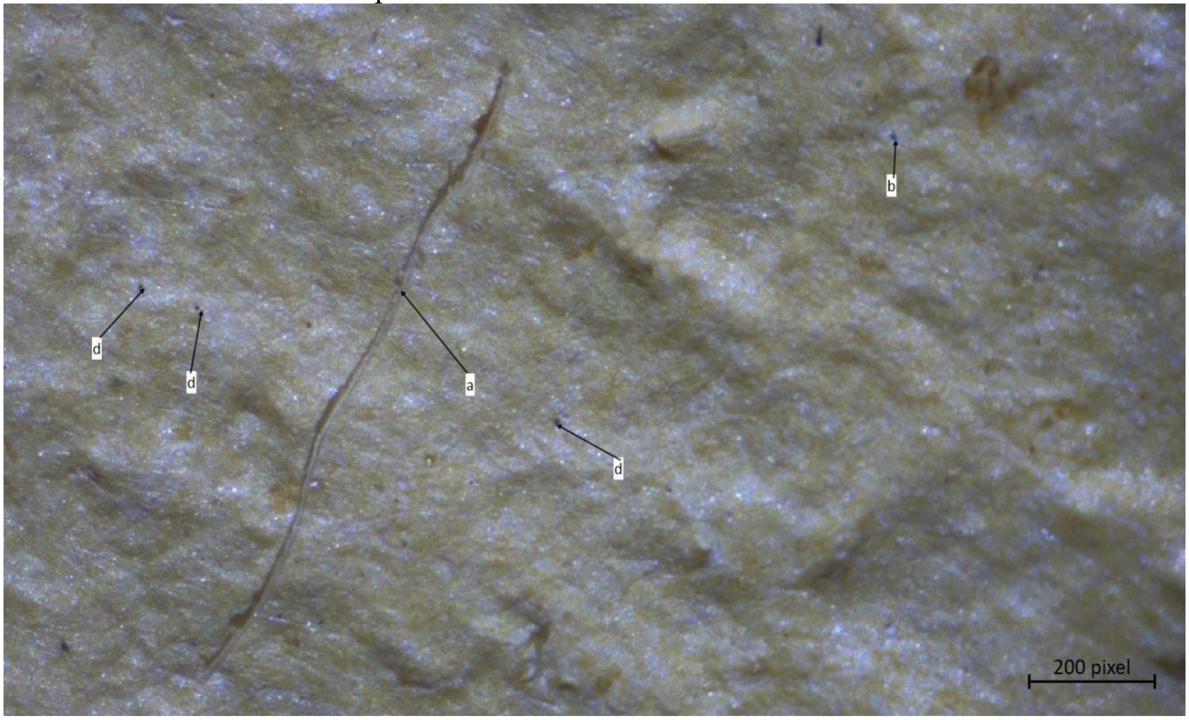


Figure B 2*:* STEM image of a transparent fibre (a) extracted from River Enyau.

Appendix C: FTIR spectral Outputs

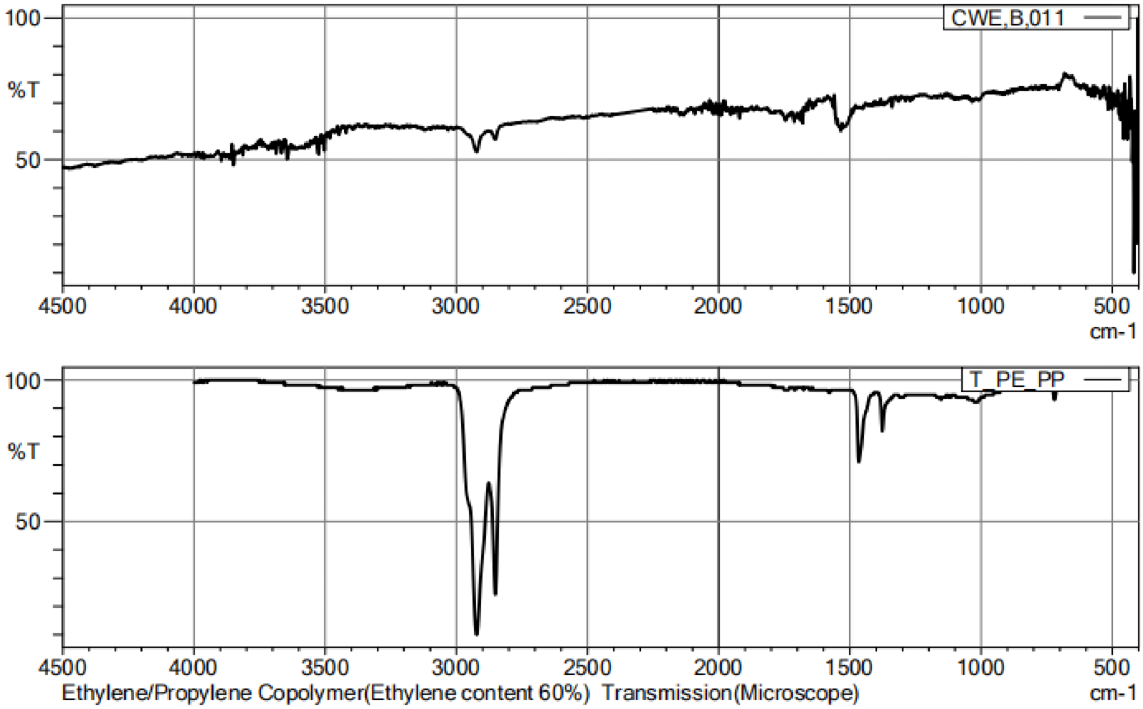


Figure C 1: FTIR spectrum of microplastics isolated from River water sample from Enyau, showing identified polymer compositions.

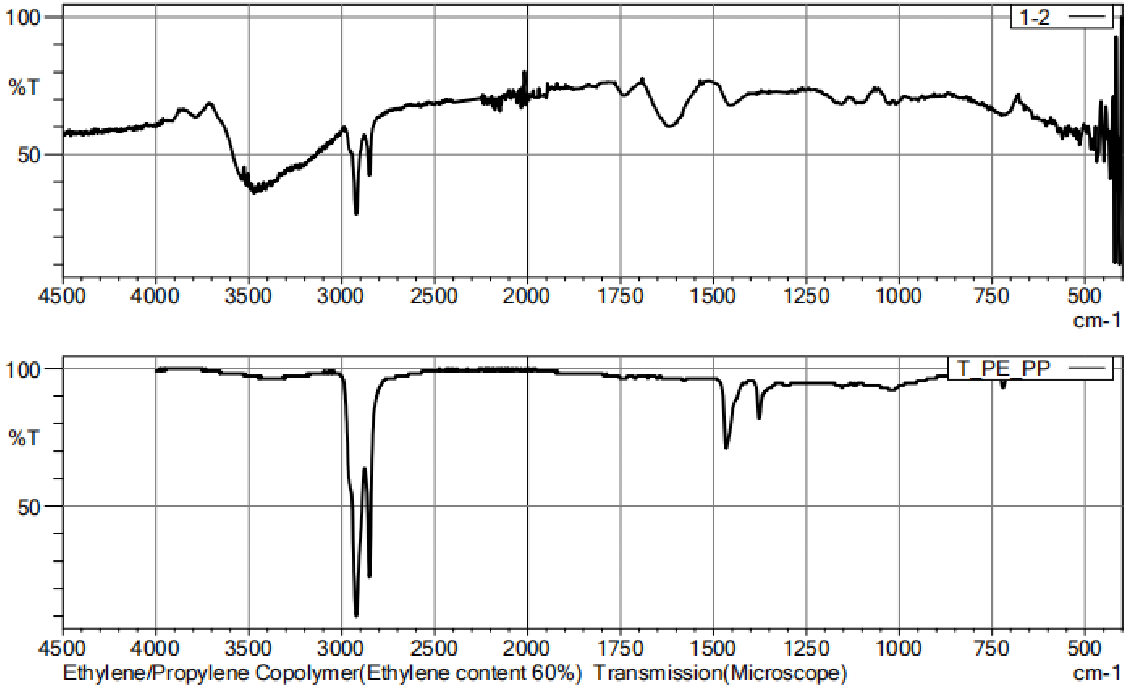


Figure C 2*:* FTIR spectrum of microplastics isolated from River water sample from Enyau, showing identified polymer compositions.

Appendix D: Statistical analysis outputs

Table D 1*:* Correlation coefficients between microplastic load and fish Length, total weight, and GIT weight.

Variable Compared with Plastic Count	Correlation (r)	95% CI	P-Value	Strength of Association
Fish Weight	0.555	(0.149, 0.801)	0.011	Moderate, significant
GIT Weight	0.587	(0.195, 0.817)	0.007	Moderate, slightly higher than Fish Weight
Length of Fish	0.714	(0.396, 0.879)	0.000	High, most significant

Table D 2*:* One-Way ANOVA summary for microplastic concentrations across the car wash bays

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	4	9539.40	2384.85	133.98	<0.001
Error	5	89.00	17.80		
Total	9	9628.40			

Table D 3 Tukey pairwise comparisons grouping car wash bays by microplastic concentration

Factor	N	Mean	Grouping		
D	2	88.00	A		
C	2	87.00	A		
E	2	59.50		B	
A	2	21.00			C
B	2	16.50			C

Table D 4 One-Way ANOVA summary for microplastic contamination in River Asa and River Enyau

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	1	0.08167	0.08167	0.05	0.839
Error	4	6.92667	1.73167		
Total	5	7.00833			

Table D 5 Paired sample t-test results comparing mean microplastic concentrations between River Asa and River Enyau,

T-Value	P-Value	StDev	95% CI for µ difference
-0.30	0.794	1.358	(-3.606, 3.139)

Table D 6 One-Way ANOVA summary for microplastic contamination across all sampled fish from River Asa and River Enyau.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	1	77919812	77919812	37.90	<0.001
Error	18	37005013	2055834		
Total	19	114924825			

Table D 7 One-way ANOVA summary for microplastic contamination in fish from River Asa and River Enyau, using similar fish types and equal sample sizes.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	1	70864492	70864492	29.11	<0.001
Error	14	34076252	2434018		
Total	15	104940744			

Table D 8 Mean microplastic count per 1000 g of gastrointestinal tissue by fish species

Factor	N	Mean	StDev	95% CI
Tilapia	8	3172	3252	(1336, 5009)
Mud fish	8	2163	1958	(327, 3999)
Rohu fish	4	1103	847	(-1494, 3700)

Table D 9 One-Way ANOVA summary for microplastic count per 1000 g of gastrointestinal tissue by fish species.

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Factor	2	11910562	5955281	0.98	0.395
Error	17	103014263	6059663		
Total	19	114924825			

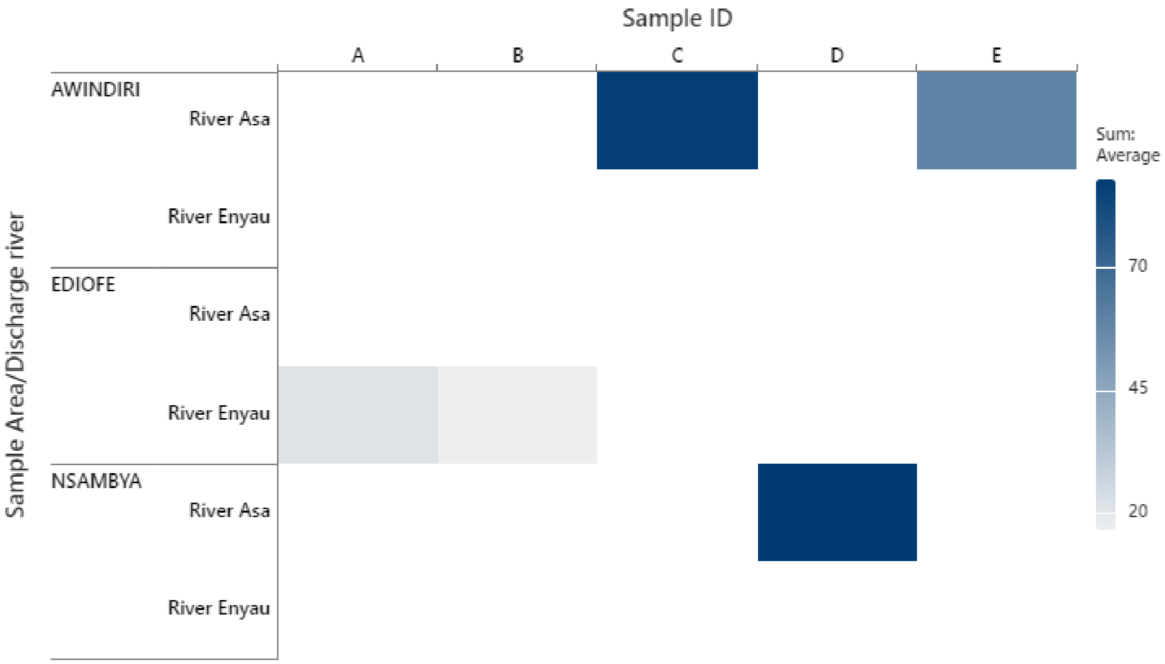


Figure D 1*:* Heat map indicating microplastic concentration levels across sampled locations in Arua City.

Appendix E: Photographic documentation of sampling and laboratory procedures.

Figure E 1: Tilapia and mudfish samples collected from River Asa (left), and Rohu fish specimen from River Enyau (right).

Figure E 2*:* River water sampling at a downstream site in River Asa (left), laboratory filtration using a vacuum filtration unit (Right).

Figure E 3*:* Dissection of fish to isolate gastrointestinal tracts (left) and incubation of GITs during organic matter digestion using Fenton reagent (right).

Appendix F: Photos of potential microplastic sources from car wash bays

Figure F 1: Common items at Bay E likely contributing to red, blue, and transparent fragment microplastics.

Figure F 2: Common items at the car wash bay D likely contributing to microplastic fibres (left and centre) and plastic films (right).

Figure F 3*:* Wastewater accumulation that facilitates microplastic settling and concentration at wash bay D.

Appendix G: Questionnaire

Microplastic Pollution from Car Wash Bays

INTRODUCTION

Dear Participant,

My name is **Draku Sydney Emmanuel**, a Master of Science in Chemistry student at **Muni University**. I am conducting research for my dissertation titled: *“Assessment of Microplastics in Selected Rivers, Fish, and Waste Water from Car Wash Bays in Arua City.”*

Part of the study involves understanding factors that may influence microplastic contamination in car wash bays. This questionnaire is designed to collect information from car wash operators and workers to help identify those factors. Your responses will support and complement the laboratory findings.

Participation is voluntary, and all information will be kept confidential and used only for academic purposes. Your honest input is greatly appreciated. Thank you for your time and contribution.

Section A: Background Information

1. Name of Car Wash Facility: ______________________________________

2. Respondent's Role (e.g., Owner, Operator, Worker): ____________________

3. How long have you worked at this facility? _________________________

4. Approximate number of vehicles washed per day: _____________________

5. Average amount of water used per day (in litres): ____________________

Section B: Factors Influencing Microplastic Abundance

1. Type of Detergent and Cleaning Agents

6. What types of detergents or cleaning products do you commonly use?

☐ Powdered detergent
☐ Liquid soap
☐ Industrial car shampoo
☐ Degreasers
☐ Other (please specify): ____________________

7. Are any of these products labelled as biodegradable or environmentally friendly?

☐ Yes ☐ No ☐ Not sure

8. Do you notice residue (e.g., beads, particles) from detergents after use?

☐ Often ☐ Sometimes ☐ Never

2. Vehicle Type and Condition

9. What types of vehicles are mostly washed here? (Select all that apply)

☐ Private cars ☐ Taxis ☐ Trucks/Lorries ☐ Motorcycles ☐ Other: ____________

10. How often do you encounter vehicles with damaged or peeling paint and plastic trims?

☐ Frequently ☐ Occasionally ☐ Rarely

3. Washing Method

11. What is the primary method used to wash vehicles?

☐ Manual hand-wash with cloth/sponge
☐ Pressure hose
☐ Foam cannon/sprayer
☐ Combination

12. What kind of brushes or cloths do you use?

☐ Cotton cloth ☐ Microfiber cloth ☐ Sponge ☐ Plastic-bristled brush ☐ Other: ____________

4. Source of Water

13. What is your main source of water?

☐ Tap/municipal water ☐ Borehole ☐ Rainwater ☐ Recycled/greywater ☐ Other: ____________

14. Do you treat or filter the water before use?

☐ Yes ☐ No

5. Type of Debris on Vehicles

15. What types of dirt/debris do vehicles typically come in with?

☐ Road dust ☐ Mud ☐ Plant debris ☐ Oil/grease ☐ Rubber/tire particles

6. Frequency and Duration of Washing

16. How frequently are vehicles washed at this facility?

☐ Daily ☐ Several times a week ☐ Weekly

17. On average, how long does it take to wash one vehicle?

☐ Less than 15 minutes ☐ 15–30 minutes ☐ More than 30 minutes

7. Volume and Operational Scale

18. During peak days, how many vehicles do you handle? ________________

19. Do you use any form of water recycling or drainage filtration?

☐ Yes ☐ No ☐ Not sure

Section C: Perceptions and Practices

20. Are you aware of microplastic pollution and its environmental impact?

☐ Yes ☐ No

21. Have you ever received training on sustainable or environmentally friendly car wash practices?

☐ Yes ☐ No

22. What measures (if any) do you take to reduce pollution in your effluent water?

____

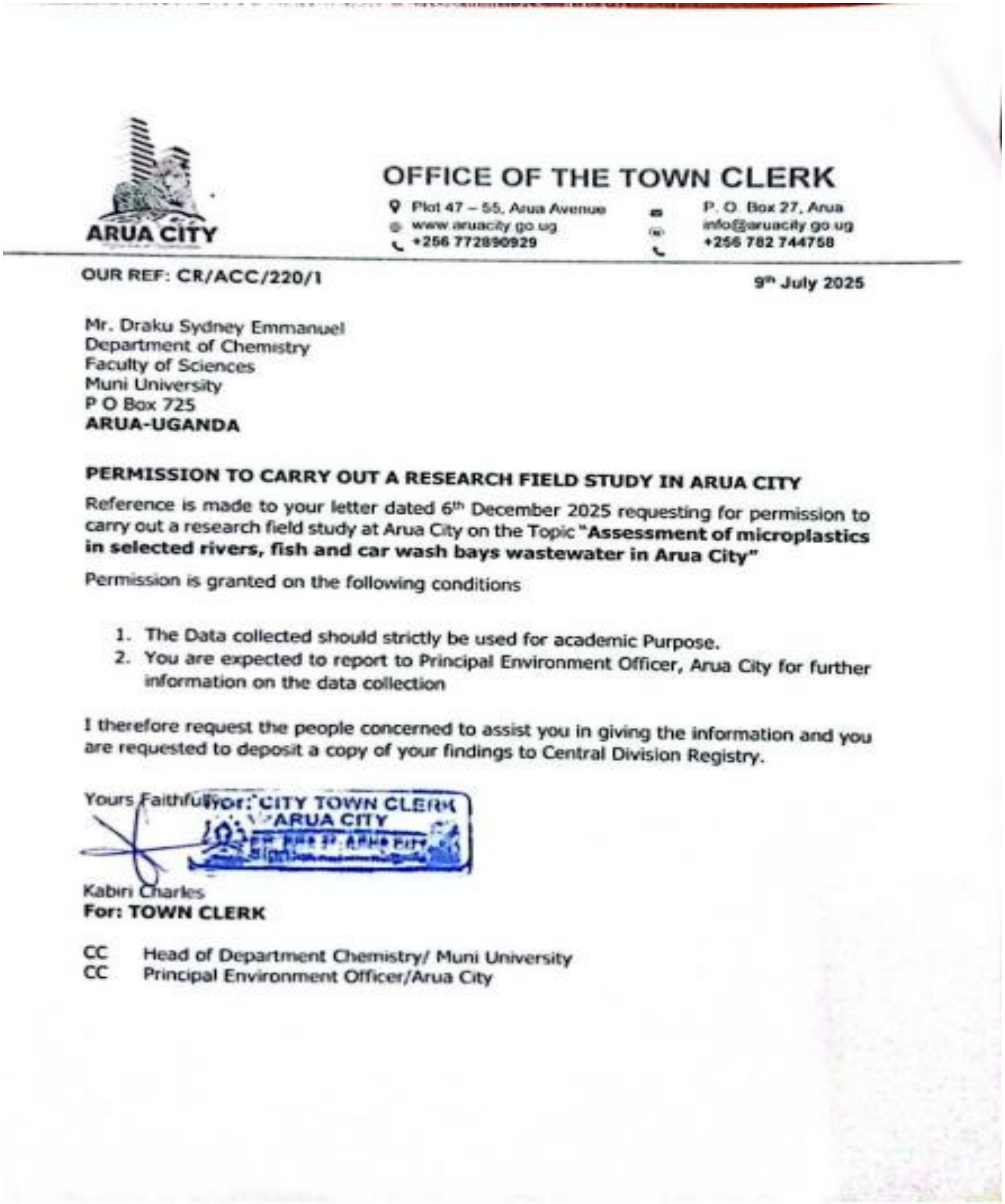
23. In your opinion, what are the main contributors to plastic particles in your wastewater?

____

24. What are the common colours of plastic materials or tools used in your car wash bay?
(Select all that apply)

☐ Blue
☐ Red
☐ White/Clear
☐ Black
☐ Yellow
☐ Green
☐ Other: ______________

Appendix H: Clearance



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OUR REF: CR/ACC/220/1

9th July 2025

Mr. Draku Sydney Emmanuel
Department of Chemistry
Faculty of Sciences
Muni University
P O Box 725
ARUA-UGANDA

PERMISSION TO CARRY OUT A RESEARCH FIELD STUDY IN ARUA CITY

Reference is made to your letter dated 6th December 2025 requesting for permission to carry out a research field study at Arua City on the Topic **"Assessment of microplastics in selected rivers, fish and car wash bays wastewater in Arua City"**

Permission is granted on the following conditions

1. The Data collected should strictly be used for academic Purpose.
2. You are expected to report to Principal Environment Officer, Arua City for further information on the data collection

I therefore request the people concerned to assist you in giving the information and you are requested to deposit a copy of your findings to Central Division Registry.

Yours Faithfully

For: CITY TOWN CLERK
ARUA CITY
[illegible]

Kabiri Charles
For: TOWN CLERK

CC Head of Department Chemistry/ Muni University
CC Principal Environment Officer/Arua City