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Spatio-Temporal Variation of Microplastic Along a Rural to Urban Transition in a Tropical River in Selangor Malaysia

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ABSTRACT

It is acknowledged that microplastic contamination is a worldwide problem that jeopardise both human and environmental health. Rapid industrial and urbanisation in many tropical nations, along with weak ecological regulation, may lead to an upward trend in microplastics entering rivers; yet there is a shortage of fundamental data on contamination levels. The purpose of this study was to catalogue the physical features of microplastics found in the Klang River and to examine their characteristics in relation to the river basin in the Malacca Strait. It was selected for its commercial, residential, and industrial regions, which are situated along its length. The study also measured the water quality parameters, including DO, pH, salinity, turbidity, and FTIR analysis. A total of 171 microplastic pieces were obtained from the six stations. Microplastics have been discovered in many shapes and sizes, including films, fibres, and fragments. The FTIR analysis revealed that the microplastics most found were HDPE, LDPE, polypropylene, and polyamide/nylon. The findings indicate that the Klang River is heavily polluted with microplastics. The outcomes enable future research to further the investigations of microplastics along the Klang River as it is one of the main water sources in Peninsular Malaysia and provide new insights into understanding of microplastics.

Keywords: Microplastic; Klang River; water; FTIR

INTRODUCTION

Plastics are extensively produced and utilized worldwide, but insufficient waste management systems have led to significant threats to both marine and terrestrial ecosystems. Plastics degrade into microplastics, defined as particles smaller than 5mm, through physical, chemical, and biological processes. Over time, microplastics have become a global environmental concern due to their pervasive distribution, often transported by rivers into oceans, where they accumulate and persist. Despite their widespread presence, the ecotoxicological impacts of microplastics remain inadequately understood. Consequently, various approaches have been developed to investigate their occurrence and ecological effects in marine environments (Burns, & Boxall, 2018; Ma et al. 2020; Kaur et al. 2022).

Anthropogenic activities, both on land and in the ocean, have resulted in the extensive dispersion of microplastic debris into many environmental compartments, primarily through water, which after that accumulates in rivers. (Cordova 2021; Cordova et al. 2022). Indeed, rivers exhibit foreseeable trends when the origin of pollution is linked to commercial and human developments (Chakraborty 2021). Additionally, agricultural activities such as the transformation of treated sludge into soil or plastic munching have been identified as another cause of plastic contamination in rivers. The speeds at which microplastics settle from water columns are affected by factors such as their inherent density, the possibility of biofilm buildup, and the predominant water currents (Kumar et al. 2021; Wang et al. 2021; Jiang et al. 2024).

Although significant efforts have been made to dispose of waste through landfilling or recycling, a substantial quantity of plastic debris continues to enter the aquatic environment. Given an insufficient grasp of the situation, it is now one of the most sensitive and disputed environmental problems with increasing attention worldwide. Under certain conditions, such as UV light, hydrolysis, or mechanical forces, plastic waste has been observed to break down into small particles (Zhang et al. 2021; Dimassi et al. 2022). Following degradation, the plastic undergoes alterations in its physical characteristics, including discolouration, decreased tensile strength and elasticity, ultimately becoming fragile and prone to breaking. The particles created by this process are known as microplastics.

However, fewer studies of microplastic distribution, especially in Malaysia, have been conducted in freshwater, which makes data retrieval a difficult task. Moreover, there is a lack of understanding of the contribution of microplastics in freshwater to the ocean. Thus, it is essential to determine and forecast the distribution of microplastics in rivers and how the distribution affects the microplastics in oceans. This research aims to (i) identify the physical characteristics of microplastics in the Klang River, (ii) to determine the spatial distribution pattern in the Klang River and its river basin in Malacca Strait and finally (iii) to investigate the contribution of microplastics into the Malacca Strait through Klang River.

The research is divided into three stages: Stage 1 involves the identification of the sampling location due to its characteristics; Stage 2 requires the extraction of microplastics with the identification of physical properties; and Stage 3 includes the spatial distribution pattern of microplastics. The findings have a major impact as it considers the possible routes of microplastic dissemination by examining the river flows and ocean currents in Malaysia. This will be a crucial tool for assisting researchers worldwide in tracking the locations of microplastics so that their potential futures can be predicted for future reference.

CLASSIFICATION OF MICROPLASTICS

Subsequently, microplastics were divided into primary and secondary categories based on the means of manufacturing and intended uses (Steensgaard et al. 2017; Hale, et al. 2020). Primary microplastics are principally designed to suit their intended use, such as microbeads, pellets, and fibres. Conversely, secondary microplastics refer to tiny plastic particles that undergo fragmentation through various processes, including both abiotic and biotic degradation. The materials can be distinguished based on their morphology. Primary microplastics are spheres (beads, granules, and pellets), while the latter are fibres (lines and filaments), fragments, films, and foams.

Increasingly, primary microplastics are being employed as air-blasting agents and as drug delivery systems in medicine, particularly in facial cleansers and beauty products. The research undertaken indicates that microplastic "scrubbers" have superseded natural ingredients like oats, powdered almonds, and pumice. The popularity of plastic-containing exfoliating cleansers has grown substantially since the formulation of microplastic scrubbers for cosmetics in the 1980s (Rani, 2022). The polymers, commonly designated as "micro-exfoliates" or "microbeads," could exhibit differences in size, shape, and composition that depend on the particular product. A groundbreaking study conducted revealed a substantial quantity of microplastics exhibiting irregular shapes within a distinct cosmetic product (Foshtomi et al. 2019; Alex et al. 2024). The microplastics had an average diameter of less than 0.5 mm and a mean size not exceeding 0.1 mm. These types of microplastics are commonly found in household or residency areas. Besides, primary microplastics were specifically designed for application in air blasting procedures. This method involves blasting motors, machinery, and boat hulls with melamine, acrylic, or polyester microplastic removers to eliminate paint and rust effectively. Long-term use of these scrubbers can cause them to shrink and lose some of their cutting efficiency, which can lead to exposure to heavy metals like lead, cadmium, and chromium, hence possessing environmental threats (Paluchamy et al. 2021).

Disintegration of larger plastic debris in the water and on land results in the formation of small plastic fragments called secondary microplastics (Ezeala et al. 2023). This degradation could result in the separation of additives intended to enhance durability and resistance to corrosion from the polymers. Contrarily, plastic waste on beaches will break down more quickly due to the high oxygen content and direct solar exposure, eventually becoming brittle, developing fractures, and "yellowing" (Quang et al. 2023). The structural integrity of these polymers is compromised by wave action, abrasion, and turbulence, making them more susceptible to fragmentation and ultimately leading to microplastics pollution in our oceans (Vivekanand et al. 2021; Issac& Kandasubramanian 2021).

SEPARATION OF MICROPLASTICS

Microplastics primarily consist of polypropylene (PP), polyethylene (PE), and polystyrene (PS), which have a density lower than freshwater and are thus more prone to floating. At the same time, microplastic polymers like PVC, nylon, and PET have a density that is much higher than that of freshwater, making them the most prone to sinking. The conventional classifications of microplastics polymer types found globally, along with their densities relative to freshwater (1.00 g/cm3) and usual applications, are displayed in Table 1.

Microplastics are recognised as an emerging contaminant in aquatic environments, being predominantly transported by rivers to various oceans and freshwater systems from terrestrial sources. The low density of microplastics causes them to float in the water column upon entering a body of water, where they are carried downstream by currents (Ng et al. 2018; An et al. 2020).

TABLE 1. Conventional categories of microplastic polymers, their densities compared to freshwater (1.00 g/cm3), and common uses. In freshwater, objects with a density of less than 1.00 g/cm3 float on the surface

Plastic Polymer	Density (g/cm^3)	Applications
Polyethylene (PE)	0.91 – 0.94	Packaging, containers
Polypropylene (PP)	0.83 – 0.85	Fishing gear, industrial, electrical, automotive
Polystyrene (PS)	1.05	Packaging
Poly (vinyl chloride) (PVC)	1.38	Household goods, general
Poly (ethylene terephthalate) (PET)	1.37	Textile, industrial, electrical
Polyamide / nylon (PA)	1.13	Clothing, fishing gear
Cellulose acetate / cellophane (CA)	1.29	Wrapping, film

Based on past investigations of plastic pollutant abundance in river ecosystems, recent modelling studies have estimated that globally, rivers discharge annually about 1.2-2.4 million tonnes of floating plastic pollutants from inland areas to oceans (Vivekanand et al. 2021). Under the influence of changed flow rates, microplastics can be mobilised by water flow or remain where they settle if there are interactions with sediment clays. Nevertheless, detailed studies on the dispersal of different microplastic types and the movement behavior of floating microplastics under certain hydrodynamic conditions in river environments are scarce. It is vital to understand the connection between the movement of floating microplastics and its characteristics to give enhanced new knowledge to society.

TABLE 2. Sampling stations and their land use

Sampling Point	Station Name	Latitude	Longitude	River Section	Description of Land Usage
Station 01	Jeti Pengkalan Batu	3.047629	101.443199	Downstream	Recreational Area
Station 02	Jeti Sg. Udang	3.045609	101.411499	Downstream	Jetty/Residential Area
Station 03	Jeti Bagan Hailam	3.003278	101.388016	Downstream	Jetty/Residential Area
Station 04	Laguna Park	2.946550	101.358582	Downstream	Recreational/Residential
Station 05	Kg Sg. Kembong	2.914267	101.323975	Downstream	Fishing Area
Station 06	Pantai Acheh	2.885151	101.284477	Downstream	Tourism/Fishing

MATERIALS AND METHOD

STUDY LOCATION

The Klang Gates Dam is the source of the 120-kilometer-long Klang River. After descending into the Straits of Malacca, it continues its south-westward course past Kuala Lumpur until turning westward along Puchong Drops. The upper basin is linked to two significant streams. In the heart of Kuala Lumpur, the rivers Gombak and Batu converge to form the Klang River. In general, the Klang River can be divided into three sections. The first section is upstream and has a steep gradient. The second section is in the middle, between the confluence with the Gombak River and a point about 10 km downstream of the Puchong. At this point, the river's slope changes from steep to lower and gently descends towards the river mouth. Nevertheless, the downstream of the Klang River is the primary focus of study areas for this research. Following this, as indicated in Table 2, a total of six (6) sampling places were identified: Jeti Pengkalan Batu, Jeti Sg Udang, Jeti Bagan Hailam, Laguna Park, Kg Sg Kembong, and Pantai Acheh.

COLLECTION, CHARACTERISTIC OF MICROPLASTIC AND HYDROGEOLOGY OF RIVER

The microplastics that are determined consist of polyethylene (PE), polypropylene (PP), polyamide (PA), and polyethylene terephthalate (PET). Meanwhile, the hydrogeological properties such as water density, wind, velocity and area are obtained from the Department of Drainage (DID). The microplastics have be sampled at the selected sampling point by using Manta nets. The properties of microplastics were sorted based on the density, shape, size (e.g., fiber, particle, fragment), adsorption of chemicals and biofouling. The microplastics are expressed as total microplastics per unit of sample (1 Liter, in water sample).

FIGURE 1. Sampling location of Klang River

RESULTS AND DISCUSSION

IDENTIFICATION OF MICROPLASTIC PARTICLES

A total of 16 microplastic (MP) samples (Table 3) were subjected to Fourier Transform Infrared (FTIR) spectroscopy to identify their polymer composition. These samples, randomly selected from six stations along the Klang River, were categorized into four morphological groups: fragments, films, fibers, and pellets. The classification provides insights into the sources and environmental behavior of microplastics within the study area.

The analysis revealed that the dominant types of microplastics were fragments and films, with polypropylene (PP) being the most frequently identified polymer, followed by high-density polyethylene (HDPE), low-density polyethylene (LDPE), and polyamide (PA/nylon). These findings align with global trends, as PP and HDPE are widely used due to their durability, low cost, and diverse applications, particularly in the packaging and consumer goods industries (Kumar et al. 2011). Fragments, primarily composed of HDPE and PP, suggest significant contributions from improperly managed waste streams and the breakdown of larger plastic items. Station 01 (Jeti Pengkalan Batu), which is in close proximity to urban and industrial zones, likely acts as a major source of these fragments. This site's urban setting is characterized by high human activity, commercial operations, and possible illegal waste disposal, all of which could exacerbate the introduction of HDPE and PP microplastics into the river system (Lange & Wyser, 2003).

The presence of LDPE fragments at Station 04 (Laguna Park) highlights the input of lightweight and flexible plastics, which are often associated with single-use items like plastic bags, wraps, and thin packaging films. These materials are commonly discarded in residential and recreational areas, and their low density allows them to float and be transported downstream by river currents (Attaran et al. 2017). Additionally, Laguna Park's dual land use for residential and leisure purposes likely generates considerable amounts of household and recreational waste, further contributing to the abundance of LDPE microplastics.

LDPE, unlike HDPE, is less rigid and more prone to photodegradation when exposed to sunlight. This suggests that LDPE fragments found at Station 04 may have undergone significant environmental weathering, leading to their breakdown into secondary microplastics. The identification of such fragments underscores the role of surface weathering, mechanical abrasion, and UV-induced photodegradation in the formation of microplastics, particularly in areas where human activities are prominent (Cheng et al. 2021). The detection of these polymers points to gaps in waste management practices in the region, highlighting the need for interventions to reduce the prevalence of single-use plastics and improve recycling and disposal systems (Van Hau 2024; Cornago et al. 2021).

This spatial distribution of HDPE, PP, and LDPE fragments provides insights into the anthropogenic pressures along the Klang River. The findings emphasize the impact of urbanization and industrial activities in upstream regions and the subsequent transportation of microplastics to downstream areas. Furthermore, the persistence of these polymers in aquatic environments due to their slow degradation rates raises concerns about their long-term ecological impacts, including their potential ingestion by aquatic organisms and eventual entry into the food web (Suedel et al., 1994; Carbery et al. 2018). These observations call for stricter enforcement of waste management policies, public education campaigns to reduce plastic use, and enhanced research to explore the environmental fate of these materials (Wang et al. 2019).

Films were predominantly composed of polypropylene (PP), accounting for over 60% of the samples analyzed. PP's widespread use in flexible packaging materials, disposable containers, and other consumer products makes it a common contributor to plastic pollution in aquatic environments. Its abundance at Stations 01 and 04 underscores the influence of human activities such as improper waste disposal and agricultural runoff. These stations are characterized by urban and mixed land use, where packaging materials and other single-use plastics are often discarded improperly, leading to their entry into the Klang River system. Additionally, PP's low density (0.83–0.85 g/cm³) enables it to float, enhancing its transport by river currents and increasing its spatial distribution in downstream areas (Habumugisha et al. 2024).

The repeated detection of PP films at these stations may also highlight the polymer's resistance to environmental degradation. Unlike other materials, PP is highly durable and less susceptible to photodegradation and mechanical breakdown, allowing it to persist in aquatic ecosystems for extended periods (Seltenrich, 2015). This durability raises concerns about the long-term environmental impacts of PP films, as they can accumulate in sediments or remain suspended in the water column, where they are accessible to aquatic organisms.

One sample of high-density polyethylene (HDPE) film was found at Station 01, likely originating from plastic bags, industrial wraps, or agricultural materials. HDPE is widely used in industrial and domestic applications due to its strength and versatility, but its mismanagement contributes significantly to environmental pollution (Wright et al. 2013). Its detection at Station 01 highlights the impact of industrial activities and urban waste streams on microplastic pollution. While HDPE shares PP's resistance to degradation, its slightly higher density (0.91–0.94 g/cm³) makes it less likely to float indefinitely, suggesting that its presence in surface waters may result from recent discharges or disturbance of previously settled plastics.

The findings also suggest that PP and HDPE films might serve as pathways for the adsorption of organic pollutants and heavy metals, given their hydrophobic surfaces and high surface-area-to-volume ratios (Wright et al. 2013). This dual role as pollutants and carriers of other toxic substances exacerbates their ecological impacts, particularly in regions where aquatic organisms may mistake them for food. The persistence and widespread occurrence of these films in the Klang River call for stricter management practices, including the regulation of single-use plastics and the implementation of targeted cleanup initiatives.

Comparisons with global studies reveal that PP and HDPE films are among the most prevalent forms of microplastics in freshwater systems, reflecting a universal challenge in addressing plastic waste (Heidbreder et al. 2019). Their role as dominant microplastic types underscores the need for a global strategy to minimize plastic waste and mitigate its environmental impacts through improved waste management infrastructure and public awareness campaigns.

Fibers, composed of polyamide (PA), were found exclusively at Station 04, which may be attributed to contributions from fishing nets, ropes, or textile-derived microplastics. These findings align with previous studies that identify PA as a common polymer in fishing and industrial applications due to its high tensile strength, abrasion resistance, and elasticity (Ding et al. 2022). The mixed land use of Laguna Park, encompassing recreational and residential areas, likely exacerbates the introduction of PA fibers into the river through discarded fishing gear, clothing fibers shed during washing, or runoff from nearby human activities. Additionally, residential waste containing textiles or improperly disposed of nylon products may serve as a source of these fibers (Neri et al. 2023).

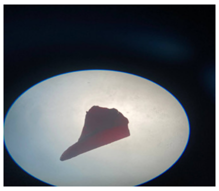
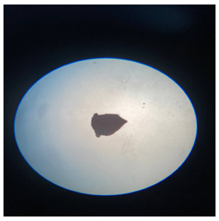
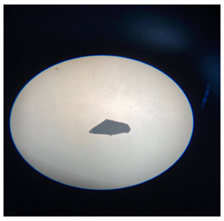
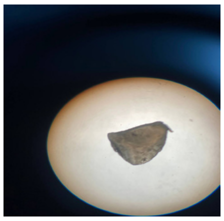
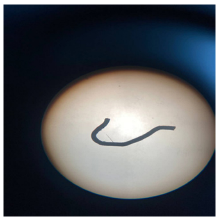
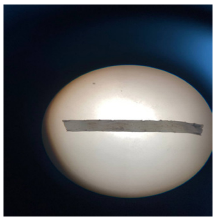
Polyamide's higher density (1.13 g/cm³) compared to other polymers like polyethylene (PE) or polypropylene (PP) is a significant factor in its localized occurrence. Unlike lower-density polymers, which are buoyant and easily transported downstream, PA fibers tend to sink or remain suspended in slower-moving sections of the river (Kooi et al., 2018). The river's hydrodynamics at Station 04, characterized by lower flow velocities and possible sedimentation zones, could facilitate the retention and accumulation of denser polymers such as PA. This finding is consistent with studies showing that hydrodynamic conditions significantly influence the transport, settling, and spatial distribution of microplastics in aquatic systems (Dey et al. 2024).

Furthermore, the identification of PA fibers highlights the potential role of washing machine effluents as a source of microplastics. During domestic laundering, synthetic textiles release fibers into wastewater, which may enter rivers due to insufficient filtration in wastewater treatment plants (Vinh, 2024). PA's presence at Station 04 suggests the influence of untreated or partially treated effluents in areas with high residential density.

The localized distribution of PA fibers raises ecological concerns, as these materials are prone to biofouling and ingestion by aquatic organisms. Studies have shown that fibers, regardless of their density, can pose a higher ingestion risk compared to other microplastic forms due to their elongated shape, which mimics natural food sources like algae or organic detritus (Tuuri & Leterme 2023). Once ingested, PA fibers can lead to physical blockages, reduced feeding efficiency, or exposure to adsorbed pollutants, with cascading effects throughout the food web (Koelmans et al. 2022). Moreover, PA's chemical stability ensures its persistence in aquatic environments, amplifying its long-term impact on ecosystem health.

These findings emphasize the need for targeted management strategies to address fiber pollution, particularly in urbanized and mixed-use regions like Laguna Park. Improved filtration technologies in wastewater treatment plants and public education on responsible disposal of fishing and textile waste could significantly reduce the input of PA fibers into freshwater systems. Further research is required to investigate the ecological impacts of PA fibers on local biota, particularly their ingestion by fish and invertebrates, and their potential role in pollutant transport.

TABLE 3. MPs type and station it was found

No	Image	Type	Found at station
01		High Density Polyethylene (Fragment)	Station 01
02		Low Density Polyethylene (Fragment)	Station 04
03		Polypropylene (Fragment)	Station 01
04		Polypropylene (Fragment)	Station 01
05		Polyamide/Nylon (Fragment)	Station 02
06		Polypropylene (Film)	Station 02

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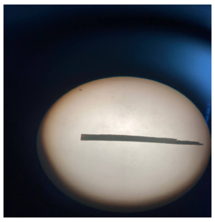
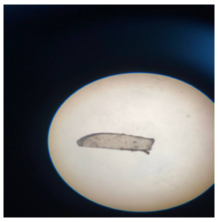
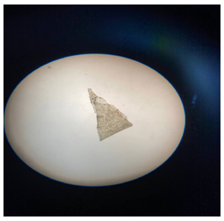
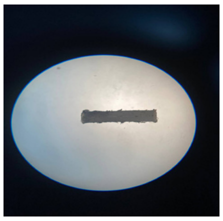
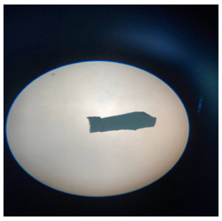
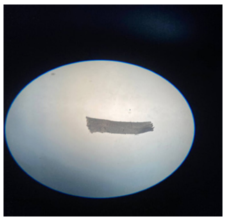
07		Polypropylene (Film)	Station 04
08		High Density Polyethylene (Film)	Station 01
09		Polypropylene (Film)	Station 04
10		Polypropylene (Film)	Station 01
11		Polypropylene (Film)	Station 04
12		Polypropylene (Film)	Station 04
13		Polypropylene (Film)	Station 04

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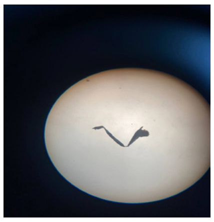
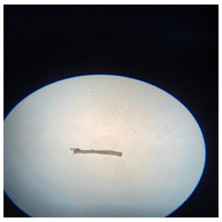
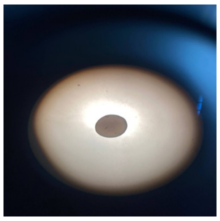
14		Polypropylene (Film)	Station 04
15		Polyamide/Nylon (Fibre)	Station 04
16		Polypropylene (Pellet)	Station 02

One pellet composed of polypropylene (PP) was identified at Station 02 (Jeti Sungai Udang), which likely originated from raw material spills or industrial processes. These pellets, also known as "nurdles," are categorized as primary microplastics because they are directly manufactured as raw materials for plastic production. Nurdles are widely used in the plastic manufacturing industry and are often transported in bulk, making them highly susceptible to accidental spillage during production, handling, or shipping (Yokota et al. 2017). Their presence at Station 02 underscores the potential influence of nearby industrial zones, where inadequate handling practices and accidental releases into the environment may contribute to their entry into the river system.

PP pellets, due to their low density (0.83–0.85 g/cm^3), float on water surfaces and are readily transported by currents, increasing their dispersion in aquatic environments (Drago et al., 2020). However, their small size and spherical shape make them particularly hazardous, as they are easily ingested by marine organisms that mistake them for food (Tuuri & Leterme, 2023). This ingestion can lead to physical harm, such as blockages in the digestive systems of aquatic fauna, and chemical toxicity due to the adsorption of persistent organic pollutants (POPs) onto the pellet surfaces (Okoye et al. 2022). These harmful effects can ultimately result in reduced reproductive success and population declines.

The identification of a single PP pellet at Station 02 may also indicate local sources, such as small-scale plastic industries or improper waste disposal practices within the area. Jeti Sungai Udang's proximity to industrial and residential zones further supports the likelihood of these pellets being introduced into the river from unregulated waste streams or as runoff during rainfall. Studies have shown that industrial regions are often hotspots for primary microplastic contamination, with pellets being among the most frequently reported types (Okereafor et al. 2020).

The environmental persistence of PP pellets adds to their impact, as their resistance to biodegradation allows them to remain in ecosystems for extended periods. Additionally, their mobility in water systems contributes to their widespread distribution, with potential for these materials to reach marine environments such as the Malacca Strait. This highlights the need for stricter industrial regulations and improved handling practices to minimize pellet spills. Awareness campaigns targeting industrial stakeholders, alongside innovations in containment systems during pellet transport, could play a crucial role in reducing the prevalence of these primary microplastics in aquatic systems.

These findings are consistent with global studies that identify PP and PE as the most commonly detected microplastics in freshwater systems, owing to their extensive use in packaging, durability, and resistance to degradation (Elgarahy et al. 2021; Huang et al. 2021). The dominance of fragments and films underscores the secondary formation of microplastics from larger plastic debris, likely accelerated by weathering and mechanical forces during river transport. The presence of PA/nylon reflects the influence of fishing activities and textile waste, emphasizing the need for targeted interventions in these sectors to mitigate microplastic pollution.

This study highlights the interplay between polymer types, morphology, and environmental conditions in determining the fate and transport of microplastics. The FTIR results provide a detailed understanding of the sources and characteristics of microplastics in the Klang River, offering a foundation for further research on their ecological and human health implications. Future studies should focus on quantifying the adsorption of pollutants on these microplastics and their ingestion by aquatic organisms to assess their biotoxicity and contribution to trophic transfer in freshwater ecosystems.

IN-SITU WATER QUALITY

The in-situ water quality of the Klang River was assessed at six stations: Laguna Park, Kg Sungai Kembong, Jeti Bagan Hailam, Jeti Sungai Udang, Pantai Acheh, and Jeti Pengkalan Batu. Using a multi-prop Horiba device, key parameters, including turbidity, salinity, pH, dissolved oxygen (DO), and temperature, were measured to evaluate the environmental conditions affecting microplastic distribution. Figure 2 illustrates the results of the in-situ water quality tests, revealing notable trends in these parameters as the sampling progressed downstream.

The salinity, temperature, and pH readings exhibited a clear upward trend moving downstream, which is indicative of increasing tidal influence, estuarine mixing, and anthropogenic inputs. These findings are consistent with studies in other tropical river systems, where proximity to the river mouth and interaction with marine environments typically result in elevated salinity and temperature levels due to seawater intrusion and reduced freshwater dilution (Agboola & Benson, 2021; Zeb et al. 2024). The progressive increase in salinity downstream likely reflects the tidal influence from the Malacca Strait, where saltwater intrusion becomes more pronounced. This is particularly relevant in tropical regions with a monsoonal climate, where tidal fluctuations and seasonal flows further exacerbate salinity variations (Karbalaei et al. 2018)

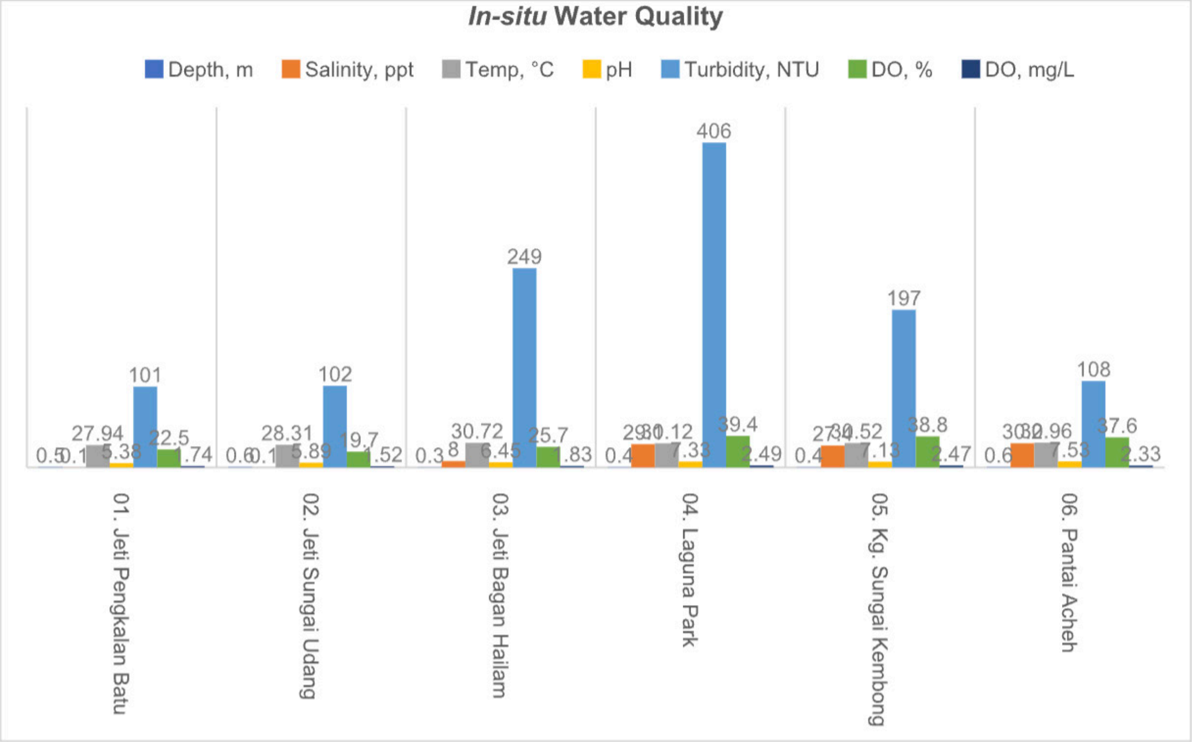


FIGURE 2. Reading for in-situ water quality

Similarly, the observed rise in pH downstream can be attributed to a combination of tidal mixing, the decomposition of organic matter, and potential chemical discharges from industrial and residential activities along the riverbanks (Schwarz et al. 2019). Additionally, the breakdown of organic material releases carbonates and other compounds that alter the chemical composition of the water, further contributing to pH elevation. Anthropogenic inputs, such as untreated wastewater from residential areas and industrial effluents, may also introduce alkaline substances, exacerbating pH changes. This aligns with findings from urban river studies, where industrial activities significantly influence downstream water chemistry (Ghosh et al. 2016).

The relationship between pH and microplastic dynamics is particularly significant in the context of the Klang River. Variations in pH can influence the degradation and fragmentation of microplastics, altering their size, density, and surface characteristics. For instance, higher pH levels can accelerate hydrolytic degradation of certain polymers, such as polyethylene terephthalate (PET) and polyamide (nylon), making them more susceptible to fragmentation (Priya et al. 2022). Conversely, pH-induced changes in polymer density can affect the buoyancy and transport of microplastics, influencing their spatial distribution along the river and their potential to settle in sedimentary zones (Zhang, 2017). Furthermore, shifts in pH may impact the adsorption behavior of pollutants, such as heavy metals and hydrophobic organic compounds, onto microplastic surfaces, altering their role as carriers of contaminants within the ecosystem (Ballent et al. 2012).

The implications of these findings underscore the complex interactions between water chemistry and microplastic behavior. Understanding the influence of salinity, temperature, and pH on microplastic transport and degradation is critical for predicting their fate and ecological impacts in riverine and estuarine environments. Targeted monitoring and mitigation strategies, such as regulating industrial discharges and improving wastewater treatment, are essential to managing the dual challenges of water quality degradation and microplastic pollution in systems like the Klang River.

The highest turbidity level was recorded at Laguna Park, a location characterized by mixed residential and leisure land use. Elevated turbidity levels in this area may be attributed to several contributing factors, including soil erosion, surface runoff from nearby construction sites, and sediment disturbances caused by recreational activities such as boating or fishing. These anthropogenic influences are well-documented in studies of urban rivers globally, where urbanization and poorly managed land-use practices significantly increase sediment loads in aquatic systems (Kumar et al. 2021).

Turbidity plays a crucial role in river ecosystems, as it not only reduces water clarity and visual appeal but also has broader ecological and environmental implications. High turbidity levels can hinder photosynthesis by blocking sunlight penetration, thereby reducing oxygen production by aquatic plants and algae (Gao et al. 2020). This can lead to a cascade of effects, including decreased oxygen availability for aquatic organisms, altered food web dynamics, and reduced habitat quality. The implications for microplastic behavior are also significant. High turbidity increases the concentration of suspended particles, which may facilitate the aggregation of microplastics with organic matter, clay, or other particulates. Such aggregation can alter the buoyancy and transport dynamics of microplastics, potentially leading to their sedimentation in slower-moving sections of the river (Lin et al. 2024).

The sedimentation of microplastics aggregated with suspended solids may explain why certain types of microplastics, such as fibers and fragments, are often found in areas with elevated turbidity. This process not only affects the spatial distribution of microplastics but also has implications for their long-term persistence in aquatic environments. Once settled, microplastics may become part of the benthic environment, where they could interact with sediment-dwelling organisms or be resuspended during high-flow events (Li et al. 2023). Additionally, the aggregation of microplastics with organic material may enhance their role as vectors for pollutants. Hydrophobic contaminants, such as polycyclic aromatic hydrocarbons (PAHs) and heavy metals, are known to adsorb onto microplastic surfaces, and their transport and bioavailability could be influenced by turbidity-driven aggregation and deposition processes (Gao et al. 2020).

The turbidity recorded at Laguna Park highlights the importance of land use and human activities in influencing water quality and microplastic dynamics. Effective land management practices, such as controlling soil erosion, implementing sediment traps at construction sites, and regulating recreational activities, are critical to mitigating turbidity and its associated impacts. Future research should focus on understanding the interaction between turbidity, microplastic aggregation, and pollutant transport in freshwater systems, particularly in regions experiencing rapid urbanization and increasing plastic waste generation.

Dissolved oxygen (DO) levels varied across the stations, with lower levels observed at sites with higher turbidity. This inverse relationship is well-documented in freshwater ecosystems, as elevated turbidity reduces light penetration, thereby impairing photosynthesis in aquatic plants and algae, which are primary oxygen producers (Kumar et al. 2021). The suspended particles causing turbidity, such as sediments and organic matter, can also create additional oxygen demand during their decomposition. This process, known as biochemical oxygen demand (BOD), further depletes DO levels, particularly in areas with high organic pollution or sediment influx (Samal et al. 2024).

The recorded DO levels at sites with high turbidity, such as Laguna Park, indicate localized environmental stress that could have far-reaching implications for aquatic ecosystems. Low DO levels, often referred to as hypoxic conditions, can reduce the metabolic efficiency and survival rates of aquatic organisms, particularly fish and invertebrates. Hypoxia also alters the behavior of microplastics in the aquatic environment. Studies have shown that under low oxygen conditions, microbial communities involved in biofilm formation on microplastics may change, potentially affecting the adsorption and desorption of pollutants such as heavy metals and hydrophobic organic compounds on the plastic surfaces (Chau et al. 2023).

Moreover, the reduced metabolic activity of aquatic organisms in low-DO environments may impair their ability to ingest or process microplastics. For instance, filter-feeding species, which play a critical role in the uptake and redistribution of microplastics, may be less effective in hypoxic conditions (Cable et al. 2017). This could lead to increased persistence of microplastics in the water column, altering their spatial distribution and potential ecological impacts. Additionally, low DO levels can exacerbate the release of pollutants adsorbed onto microplastic surfaces, as hypoxic conditions may cause desorption of heavy metals, increasing their bioavailability and toxicity to aquatic organisms (Hale et al. 2020).

The interplay between turbidity, DO levels, and microplastic dynamics highlights the complex interactions within freshwater ecosystems. Elevated turbidity not only affects light availability and oxygen production but also influences the physical and chemical properties of microplastics, potentially altering their role as pollutant carriers and their bioavailability to aquatic organisms. Addressing these challenges requires integrated management approaches, including reducing turbidity through erosion control, improving wastewater treatment to minimize organic loads, and restoring aquatic vegetation to enhance oxygen production. Long-term monitoring of DO levels and turbidity, coupled with microplastic assessments, can provide valuable insights into the health of freshwater systems and inform strategies to mitigate the impacts of microplastics and associated pollutants.

Collectively, these findings revealed notable trends in turbidity, salinity, pH, and dissolved oxygen (DO), highlighting the influence of tidal mixing, anthropogenic inputs, and environmental conditions on microplastic behavior. Salinity, temperature, and pH increased downstream due to seawater intrusion and tidal mixing, with industrial and residential discharges further elevating pH levels, which can influence the fragmentation and buoyancy of microplastics (Turner, 2020). Turbidity was highest at Laguna Park, driven by construction runoff, soil erosion, and recreational activities, facilitating microplastic aggregation with suspended particles, potentially leading to sedimentation and enhanced pollutant adsorption (Rangel-Buitrago et al. 2024). DO levels were inversely correlated with turbidity, as elevated suspended solids reduced light penetration and photosynthesis, creating hypoxic conditions that impaired aquatic organisms' ability to process microplastics and increased pollutant desorption from microplastic surfaces (Chanda et al. 2024). These findings underscore the interconnected impacts of water quality degradation and microplastic pollution, highlighting the need for improved wastewater treatment, erosion control, and long-term monitoring strategies to protect freshwater ecosystems (Wang et al. 2023).

VELOCITY FLOW METER RESULT

The velocity flow meter readings across the six stations of the Klang River (Table 4) demonstrate an upward trend, with the river flow increasing from 0.595 m/s at Station 01 (Jeti Pengkalan Batu) to 0.968 m/s at Station 06 (Pantai Acheh). This progression reflects the river's natural downstream gradient, where increasing discharge volumes from tributaries and tidal effects near the Malacca Strait amplify flow velocity. The transition from upland to lowland sections is characterized by changes in river morphology, such as widening channels and reduced sediment loads, which decrease flow resistance and facilitate faster water movement (Zhou et al. 2020).

TABLE 4. Flowmeter Reading

Station	River flow (m/sec)
01. Jeti Pengkalan Batu	0.595
02. Jeti Sungai Udang	0.568
03. Jeti Bagan Hailam	0.408
04. Laguna Park	0.675
05. Kg. Sungai Kembong	0.701
06. Pantai Acheh	0.968

This rise in flow velocity has important implications for sediment transport and pollutant dynamics. Higher flow velocities downstream enhance the river's capacity to suspend and transport fine particles and microplastics, particularly low-density polymers such as polypropylene (PP) and polyethylene (PE). These microplastics, which tend to remain buoyant, can be carried over long distances, increasing their distribution in downstream areas (Kooi et al., 2018; Eerkes-Medrano et al., 2015). Conversely, denser microplastics like polyamide (nylon) and polyethylene terephthalate (PET) are more likely to settle in upstream or midstream sections where flow velocities are lower. This hydrodynamic sorting plays a critical role in determining the spatial distribution of microplastics along river systems.

Additionally, increasing downstream velocities can enhance the mechanical breakdown of larger plastic debris into smaller microplastics, a process driven by turbulent flow and physical abrasion against sediments and channel structures. This fragmentation contributes to secondary microplastic generation, increasing the diversity and abundance of microplastic particles downstream (Raju et al. 2018). The observed velocity gradient also has ecological implications, as faster flows may reduce sedimentation rates in certain areas, influencing habitat availability for benthic organisms and altering pollutant deposition patterns (Feng et al. 2023). These dynamics highlight the interconnected roles of hydrology and river morphology in shaping pollutant and microplastic transport, emphasizing the need for integrated river management strategies.

The implications of increasing flow velocity are critical for understanding the transport and behavior of microplastics in river systems. Higher flow velocities downstream enhance the river's ability to suspend and transport lightweight microplastics, such as polyethylene (PE) and polypropylene (PP), which have low densities and tend to float or remain suspended in the water column (Uzun et al. 2022). These polymers are highly mobile and can travel significant distances before depositing in calmer zones or entering marine environments. The increased kinetic energy in downstream areas not only facilitates their movement but may also prevent these particles from settling, thereby extending their ecological footprint and exacerbating pollution in estuarine and coastal areas.

Conversely, denser microplastics, such as polyamide (nylon) and polyethylene terephthalate (PET), are more likely to settle in slower-flowing upstream sections where flow velocities and shear stresses are insufficient to maintain suspension. These denser materials, with specific gravities greater than that of freshwater, are prone to accumulate in sediments or become trapped in deposition zones created by complex channel morphology or vegetation (Molazadeh et al. 2023). This hydrodynamic sorting phenomenon creates distinct spatial distribution patterns of microplastics within river systems, with lighter particles dominating downstream reaches and heavier particles aggregating upstream or in depositional zones.

This dynamic has significant ecological and environmental implications. Downstream areas, which often exhibit higher flow velocities, may serve as hotspots for microplastic accumulation due to hydrodynamic sorting and tidal influences. These regions can also act as convergence zones for microplastics and other pollutants, increasing the likelihood of bioaccumulation and trophic transfer within aquatic food webs (Möhlenkamp et al., 2018). Additionally, the interaction between flow velocity and microplastic transport affects their role as pollutant carriers. Lightweight microplastics can adsorb hydrophobic organic contaminants (HOCs) during their prolonged suspension, potentially increasing the bioavailability and toxicity of these pollutants in downstream or estuarine ecosystems (Kooi et al. 2017). The transport of microplastics under varying flow conditions underscores the importance of hydrodynamic studies in predicting their fate and developing targeted mitigation strategies to address their ecological impacts.

The findings underscore the role of hydrodynamics in shaping microplastic transport pathways and deposition zones. Faster flow velocities downstream may also enhance the mechanical fragmentation of larger plastic debris, contributing to the formation of secondary microplastics. Additionally, flow velocity variations influence sediment transport and erosion processes, which can indirectly affect microplastic deposition and resuspension. Understanding these relationships is critical for predicting microplastic behavior in riverine systems and developing targeted mitigation strategies to reduce their environmental impact (Meyer, 2008).

QUANTIFICATION AND IDENTIFICATION OF MICROPLASTICS

The quantification and identification of microplastics (MPs) from the Klang River revealed a total of 171 particles across six sampling stations, with the highest concentration recorded at Station 04 (Laguna Park), which accounted for 81 particles (Figure 4). This significant abundance at Laguna Park underscores the influence of mixed residential and leisure land use, where anthropogenic activities such as improper waste disposal, recreational boating, and surface runoff from nearby urban areas likely act as primary contributors to microplastic pollution. Recreational activities, particularly those involving water-based leisure, are often linked to the direct introduction of plastics into river systems, while urban runoff can carry a variety of microplastic sources, including fibers from textiles, fragments from degraded plastics, and pellets from industrial areas (Zhu et al. 2016).

The abundance of microplastics at Laguna Park also reflects the inadequate management of plastic waste in densely populated or recreational zones. Research on urban rivers has consistently shown that land use significantly determines the spatial distribution of microplastics, with higher densities observed in areas with high population density, recreational activities, and industrial outputs (Darabi et al. 2021). In such areas, improper disposal practices and inadequate waste management infrastructure exacerbate the introduction of plastics into aquatic systems. Furthermore, the runoff during rainfall events can transport microplastics from streets, landfills, and industrial sites into the river, amplifying the local pollution load (Mirzaei Aminiyan et al. 2018). This trend emphasizes the need for interventions targeting waste management and community awareness to address microplastic pollution at its source.

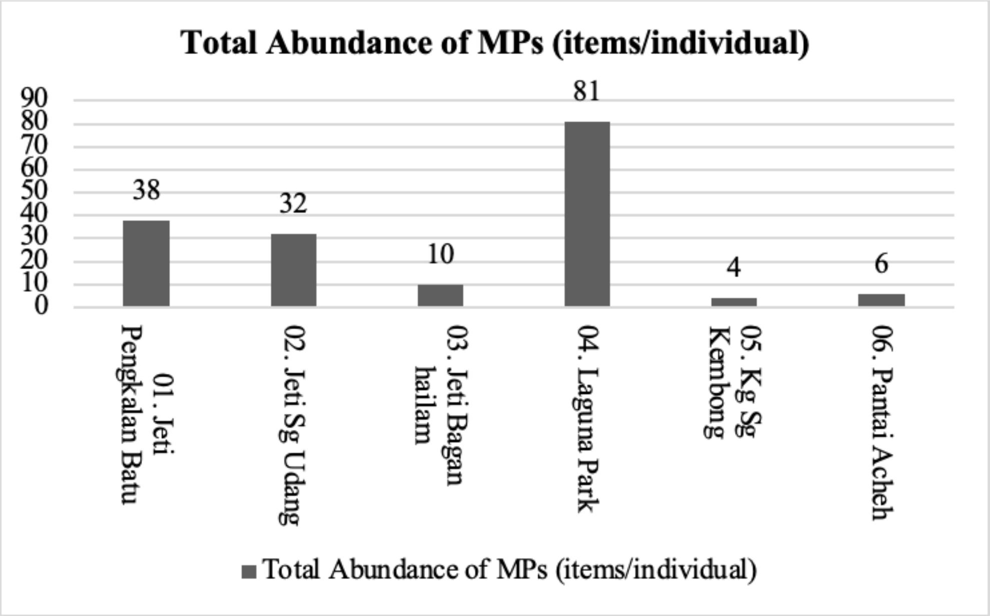


FIGURE 4. Graph total abundance of microplastics

Laguna Park's location within a hydrodynamically active section of the river also contributes to the observed microplastic concentration. The combination of slower flow velocities and increased sedimentation in recreational and urbanized zones provides ideal conditions for the accumulation of both floating and settling microplastics. High levels of activity and proximity to pollutant sources in this area create a pollution hotspot, which is concerning given the potential impacts on local aquatic ecosystems. Microplastics in such environments can interact with organic matter and pollutants, forming aggregates that may alter their buoyancy, transport patterns, and potential ecological risks (Liu et al. 2019). These findings highlight the importance of targeted policy measures, such as installing waste traps, promoting sustainable practices in recreational areas, and enhancing waste management infrastructure in urban river catchments.

Station 01 (Jeti Pengkalan Batu) and Station 02 (Jeti Sungai Udang) exhibited relatively high concentrations of microplastics, with 38 and 32 particles, respectively. These stations, situated in upstream regions with significant residential and light industrial activity, highlight the influence of municipal and industrial waste on microplastic pollution. Residential areas contribute to microplastics through improper disposal of single-use plastics, synthetic fibers shed during laundry, and general urban runoff, while light industrial zones are potential sources of raw plastic pellets, fragments from manufacturing processes, and degraded industrial packaging materials (Rogers et al., 2023). Runoff during rainfall events may exacerbate these contributions, transporting microplastics from impervious surfaces and waste disposal sites into the river system.

In contrast, Station 03 (Jeti Bagan Hailam), located in a less urbanized area, recorded a much lower count of 10 particles. This suggests that microplastic abundance is closely tied to population density, land use intensity, and waste management practices. Lower human activity in rural or less developed regions typically corresponds with reduced plastic waste generation and a lower likelihood of microplastics entering aquatic environments (Hurley et al. 2023). The disparity in microplastic counts between urbanized upstream stations and less developed areas like Station 03 underscores the critical role of land use and human activity in determining the spatial distribution of microplastics in freshwater systems.

Stations 05 (Kg. Sungai Kembong) and 06 (Pantai Acheh) recorded the lowest microplastic counts, with 4 and 6 particles, respectively. These stations, located further downstream, are characterized by reduced anthropogenic activity and higher flow velocities, which likely facilitate the transport of microplastics toward downstream or estuarine regions rather than allowing accumulation. The increased flow velocity reduces sedimentation rates, preventing heavier microplastic particles from settling and instead propelling them further downstream (Chen et al. 2021). This trend aligns with studies highlighting those hydrodynamic conditions, including flow velocity and turbulence, play a significant role in microplastic transport and deposition patterns. These findings emphasize the need for integrated approaches that address both waste management in high-density urban areas and the downstream impacts of hydrodynamic forces on microplastic distribution.

The results highlight the complex interplay between land use, hydrodynamic conditions, and pollution sources in influencing microplastic distribution. The high abundance at Laguna Park emphasizes the need for targeted mitigation strategies, such as improving waste management systems, installing litter traps, and promoting public awareness to reduce plastic waste generation. Furthermore, the findings underscore the importance of monitoring microplastic pollution in urban rivers, as these systems act as conduits for microplastics entering marine environments, with significant ecological and environmental implications (Abd Karim et al. 2023).

COLOUR

The analysis of microplastic particles retrieved from the Klang River identified eight distinct colors: black, blue, green, pink, purple, red, white, and yellow. Among these, white microplastics were the most abundant, accounting for 79 particles, followed by black (24 particles), red (22 particles), blue (20 particles), green (19 particles), yellow (4 particles), pink (2 particles), and purple (1 particle) (Figure 5). The prevalence of white-colored microplastics likely reflects their origin from commonly used single-use plastics, such as packaging materials, plastic bags, food containers, and disposable cutlery. These items are often made from polypropylene (PP), polyethylene (PE), and polystyrene (PS), which are typically manufactured in white or transparent forms for aesthetic and practical purposes, such as better visibility of contents (Phuong et al. 2022). Over time, these materials degrade due to UV exposure, mechanical abrasion, and environmental conditions, fragmenting into smaller pieces that contribute significantly to the microplastic load in aquatic environments.

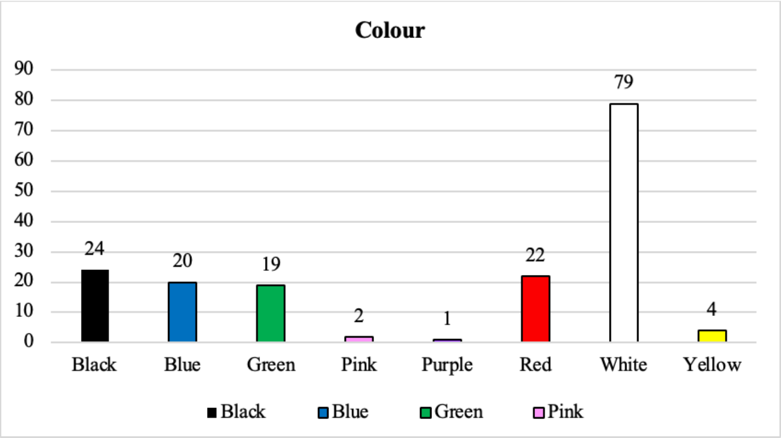


FIGURE 5. Abundant of MPs coloured particles found at Klang River

The second most common color, black, is commonly associated with industrial and urban sources such as tire wear particles, construction debris, and fragments from electronic and automotive components (Raju et al. 2023). Black microplastics are often composed of denser polymers such as polyamide (nylon) and acrylonitrile butadiene styrene (ABS), which are frequently used in durable products and construction materials. Their abundance in urban rivers, like the Klang River, highlights the impact of vehicle emissions, road runoff, and construction activities on microplastic pollution (Alfonso et al. 2021). Similarly, red microplastics, the third most abundant color, are often derived from fishing gear, ropes, and textiles, which are commonly dyed red to enhance visibility in aquatic environments, particularly in commercial fishing and recreational water-based activities (Zhang et al. 2021).

The presence of brightly colored particles such as blue, green, yellow, and red has significant ecological implications. These colors are more likely to be ingested by aquatic organisms because they resemble natural prey items, such as algae or plankton (Kraus et al. 2014). In particular, brightly colored plastics are often mistaken for food by fish, crustaceans, and birds, leading to physical blockages, malnutrition, or exposure to adsorbed pollutants. Furthermore, darker-colored particles, such as black, have been shown to adsorb higher levels of hydrophobic organic pollutants (HOCs) like polycyclic aromatic hydrocarbons (PAHs) and heavy metals due to their higher surface area and longer environmental persistence (Soliman et al. 2022). This dual role as a physical hazard and a vector for chemical contaminants emphasizes the need for strategies to reduce the input of colored microplastics into freshwater systems and mitigate their environmental impact.

The abundance of black microplastic particles in the Klang River likely reflects significant contributions from tire wear particles, vehicle emissions, and industrial materials such as plastic piping, construction debris, and fragments from automotive components. Tire wear particles, composed of synthetic rubber and various polymer additives, are a well-documented source of black microplastics in urban environments. These particles are generated during vehicle braking and road friction, entering waterways through stormwater runoff or wind transport (Galgani et al. 2024). Additionally, black microplastics may originate from industrial sites where plastic components, such as pipes and cables, degrade over time or during improper disposal processes. These particles often accumulate in urban rivers due to their proximity to roads, industrial areas, and construction sites, underscoring the strong link between human activity and black microplastic pollution.

Red and blue microplastics, which are also prominent in the Klang River, are commonly derived from synthetic fibers, fishing gear, and decorative items. Synthetic fibers released during domestic laundry are a major source of microplastics in aquatic systems, with textiles often dyed in vibrant colors such as blue and red to cater to consumer preferences (Zhao et al. 2024). Fishing gear, including ropes, nets, and buoys, is another significant contributor, particularly in rivers that support recreational or commercial fishing activities. These materials are often manufactured in highly visible colors like red and blue to enhance functionality and ease of identification in water (Iqba et al. 2024). The presence of such microplastics in the Klang River highlights the influence of both domestic and recreational activities on the distribution of these colored particles.

The green and yellow microplastics observed in the Klang River are likely attributed to agricultural plastics, consumer packaging, and synthetic dyes used in various products. Green plastics are often associated with agricultural mulch films, greenhouse covers, and packaging materials used in food and beverage industries. Yellow microplastics, on the other hand, could originate from plastic wrappers, bottles, and other items that incorporate synthetic pigments for branding and product differentiation (Tong et al. 2022). Both colors also appear in industrial applications, where plastics are dyed to meet specific functional or aesthetic requirements. These diverse sources highlight the multifaceted pathways through which microplastics enter aquatic systems, emphasizing the importance of sector-specific waste management strategies to mitigate their environmental impact (Brebu, 2020).

The variation in color among microplastics has significant implications for their ecological interactions and environmental behavior, influencing both their ingestion by aquatic organisms and their role as carriers of pollutants. Brightly colored microplastics, such as red, yellow, and green, are particularly problematic because they resemble natural food sources like algae, plankton, or fish eggs. Many aquatic organisms, including fish, crustaceans, and birds, have been observed to mistakenly ingest these particles due to their vibrant hues, which mimic prey items. This ingestion can result in physical blockages in the digestive system, reduced nutrient absorption, and even starvation (Mishra et al. 2022). Studies have shown that brightly colored microplastics are disproportionately ingested compared to less conspicuous particles, highlighting the heightened ecological risk they pose (Worm et al. 2017).

Darker microplastics, such as black and blue, pose an additional environmental threat due to their propensity to adsorb hydrophobic pollutants, including heavy metals, polycyclic aromatic hydrocarbons (PAHs), and persistent organic pollutants (POPs). These particles typically have larger surface areas and more prolonged exposure to organic matter in sediment-rich environments, enhancing their ability to act as carriers of toxic substances (Zeb et al., 2024). When these contaminated particles are ingested by aquatic organisms, the pollutants can desorb in the acidic conditions of the digestive tract, leading to bioaccumulation and potential biomagnification in food webs (José & Jordao, 2022). This dual role of darker microplastics as physical hazards and vectors for chemical contaminants underscores their complex impact on freshwater ecosystems.

These findings emphasize the urgent need for targeted mitigation strategies to address the sources and distribution of colored microplastics in aquatic systems. Effective measures could include improving waste management systems to prevent microplastic entry into water bodies, promoting the use of less toxic and biodegradable pigments in plastic manufacturing, and implementing education campaigns to reduce plastic waste at the source. Furthermore, policies aimed at controlling industrial discharges and runoff can help reduce the input of both brightly and darkly colored microplastics into freshwater systems. Long-term monitoring programs are also essential to track the ecological impacts of microplastic color variation and to inform adaptive management strategies aimed at mitigating their environmental risks (Li et al. 2020).

FTIR ANALYSIS

The Fourier-transform infrared (FTIR) analysis of microplastic samples collected from the downstream Klang River provided detailed insights into the chemical composition and types of microplastics present in the aquatic environment. The analysis identified fibers, fragments, films, and pellets as the most prevalent microplastic types. These particles primarily originated

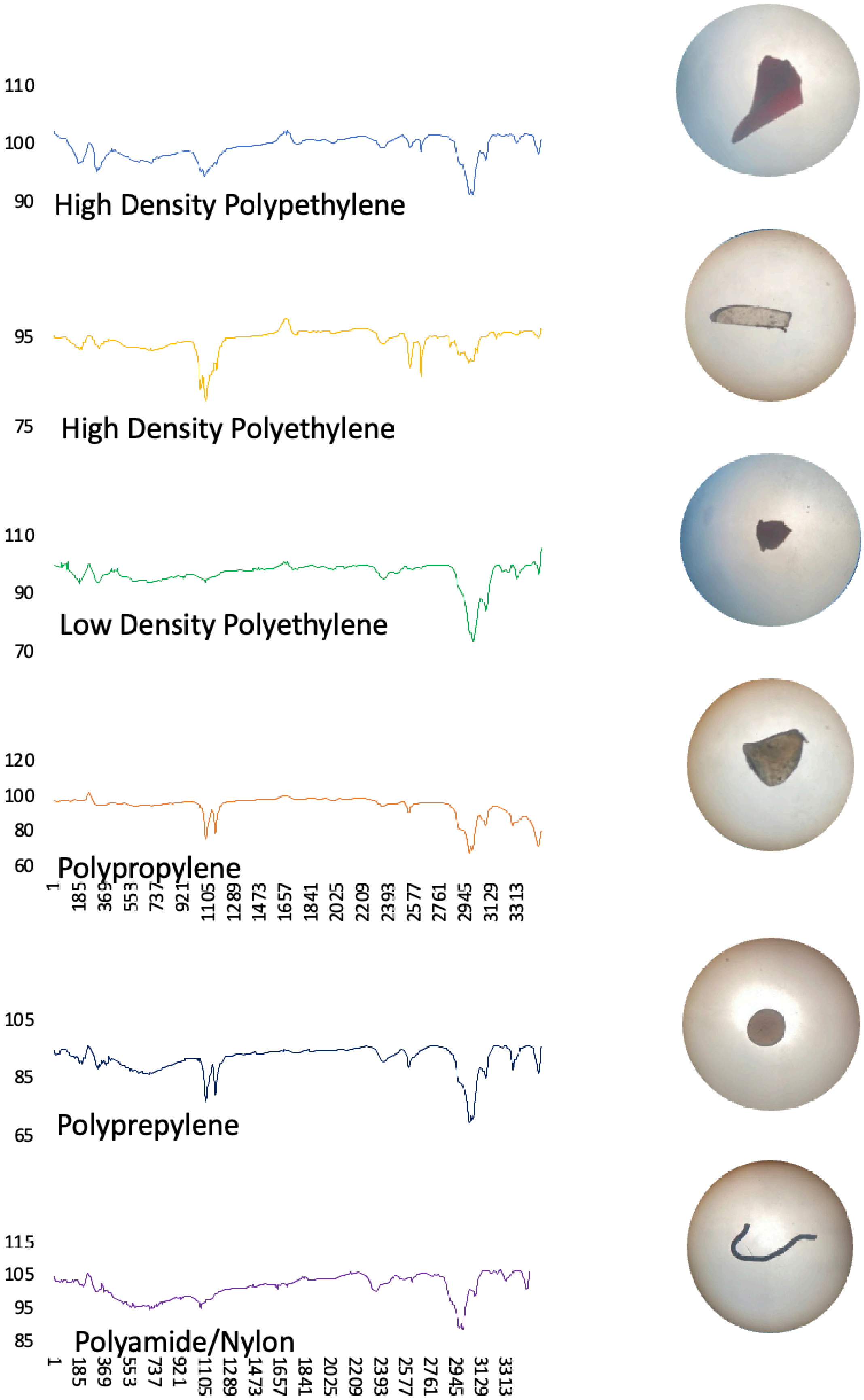


FIGURE 6. FTIR and microscope images of microplastics found in downstream Klang River

from the weathering of larger plastic objects, such as discarded packaging materials, fishing nets, and industrial debris, which degrade under the influence of UV radiation, mechanical abrasion, and microbial activity (Abbasi et al. 2021).

The FTIR spectra revealed that the dominant polymers in the samples were polyethylene (PE), polypropylene (PP), and polyamide (nylon). These materials are commonly found in consumer goods, industrial packaging, and fishing gear, highlighting their widespread use and potential as major contributors to microplastic pollution (Li et al. 2020). The color analysis of the microplastic samples showed white particles as the most dominant (79 particles), followed by black (24 particles), red (22 particles), and blue (20 particles). White particles are likely derived from single-use plastics and disposable containers, while black particles are attributed to tire wear, vehicle emissions, and construction materials. Red and blue particles often originate from synthetic fibers, fishing gear, and industrial materials dyed for aesthetic or functional purposes (Conesa, 2022; Foshtom et al. 2019).

The results also highlighted the various pathways through which microplastics enter the aquatic environment, including direct urban runoff, wind-driven deposition, and atmospheric dispersion from vehicle exhaust and tire wear. These pathways illustrate the multifaceted sources of microplastic pollution in river systems, influenced by both urban and industrial activities (Abbasi et al. 2021). The FTIR findings underscore the anthropogenic origins of these microplastics and the role of environmental conditions in their degradation and transport.

The identification of polymers such as PE, PP, and nylon raises concerns about the bioavailability of these particles to aquatic organisms, particularly zooplankton and fish, which can mistake them for food. Ingestion of microplastics may lead to physical blockages, reduced nutrient absorption, and bioaccumulation of toxic pollutants such as heavy metals and polycyclic aromatic hydrocarbons (PAHs) adsorbed onto the plastic surfaces (Feng et al. 2022). These findings highlight the urgent need for mitigation strategies to address microplastic pollution, including improving waste management systems and implementing policies to reduce plastic waste generation.

CONCLUSION

The study of microplastics in the Klang River revealed significant findings regarding their types, sources, and environmental impacts. The most prevalent microplastic types identified were fibers, fragments, films, and pellets, primarily originating from the weathering of larger plastic objects, such as packaging materials, fishing nets, and industrial debris. Environmental factors, including UV radiation, mechanical abrasion, and microbial activity, were identified as key contributors to the fragmentation process. FTIR analysis confirmed the dominance of polymers like polyethylene (PE), polypropylene (PP), and polyamide (nylon), which are commonly used in consumer goods, packaging, and fishing gear. The presence of microplastics in the river was linked to various pathways, including urban runoff, wind-driven deposition, and atmospheric dispersion, highlighting the multifaceted sources of pollution.

The study also revealed that microplastics exhibited diverse color profiles, with white being the most dominant, followed by black, red, and blue particles. These colors are indicative of their origins, with white microplastics primarily derived from single-use plastics, while black particles were associated with tire wear, construction materials, and automotive components. Red and blue particles likely originated from synthetic fibers, fishing gear, and industrial materials. Brightly colored microplastics were found to pose a higher ingestion risk to aquatic organisms due to their resemblance to natural food sources like algae and plankton. In contrast, darker particles, such as black and blue, had a higher affinity for adsorbing hydrophobic pollutants, including heavy metals and polycyclic aromatic hydrocarbons (PAHs), increasing their ecological and toxicological risks.

To address the environmental threats posed by microplastics, targeted mitigation strategies are crucial. Improved waste management systems should be prioritized to prevent plastic leakage into river systems, including better regulation of industrial discharges and enforcement of anti-littering policies. Public awareness campaigns are necessary to educate communities about the impacts of microplastic pollution and encourage responsible plastic use and disposal. Additionally, promoting the use of biodegradable materials and reducing the production of single-use plastics can help minimize microplastic generation. At a scientific level, further research is needed to evaluate the long-term impacts of microplastic ingestion on aquatic organisms and human health, particularly focusing on bioaccumulation and trophic transfer of adsorbed pollutants. Collaborative efforts among policymakers, researchers, and industries are essential to develop sustainable solutions for mitigating microplastic pollution in freshwater ecosystems.

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DECLARATION OF COMPETING INTEREST

None.

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