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RESEARCH ARTICLE

Understanding the Extent of Microplastic Pollution in Penang's River: A Baseline Study on Abundance and Distribution of Microplastic and Water Quality Parameters

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Abstract Microplastics are particles that can be found in various environments including aquatic soil and air. Presently, a lack of research exists concerning microplastic investigation in the northern peninsular of Malaysia. The objective of this study is to investigate the presence of microplastics in Pinang River and Kerian River and to correlate the microplastics presence with several in situ parameters. A water sample was taken, and the parameters measured were temperature, pH, dissolved oxygen (DO), conductivity (CDC) and turbidity (TUR). This study served as a baseline setting for subsequent microplastics research at Pinang River and Kerian River. The microplastics abundance in Kerian River was higher than microplastics abundance in Pinang River. Additionally, Microplastics fragment shaped dominates the other shape of microplastics. Polycarbonate and Nylon also were identified through ATR-FTIR analysis.

Keywords: Microplastics pollution, baseline study, river water quality parameter, anthropogenic activities, Penang's River.

Introduction

Rivers are known as vital elements in the natural environment and play a crucial role in fostering ecological, economic, and social well-being by serving as biodiversity hotspots that support a diverse range of aquatic and terrestrial species [5, 44, 49]. Rivers also have been serving as primary sources of freshwater for drinking, agriculture, and industrial activity. Moreover, rivers also play a vital role in generating electricity through the dam and hydroelectric facility located by the river [42]. They also provide critical ecosystem services such as flood regulation, sediment transport, and nutrient cycling [1, 54]. However, the acceleration of development of a country may have posed direct and indirect risk to the environment. During the past decades, manufacturing and use of plastics has been growing to unforeseen levels [47]. The prevalence of plastics in our daily lives can be due to their remarkable properties such as lightweight, waterproof, durable, flexible and cost effective [38]. Consequently, plastics have been invaluable in industries ranging from packaging to construction, improving accessibility and affordability for billions of people [40]. However, the prevalence of plastic consumption in our daily lives, along with ineffective waste management practices has taken toll on our environment and has begun to be discussed all around the world [45]. Mass production of plastics began around 1950s, the infiltration of this durable, versatile material has rapidly appeared as the largest element of marine debris with other worldwide key issues severely threaten the biodiversity of aquatic ecosystem

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[51]. According to the United Nations Environment Programme (UNEP), around 8 million tons of plastic waste enter the oceans each year, impacting marine life and ecosystems [50].

Most plastic particles found in the environment which are smaller than 5 mm are recognized as microplastics. This particle can be found in any environment including aquatic, soil and air. Based on Cole *et al*., [12] and Herzke *et al.,* [19], primary microplastics are initially produced as industrial pellets that are utilized as precursors in the production of bigger plastics products that are used in variety of industry and domestic products. Farrell & Nelson, [15] stated that secondary microplastics formed from the fragmentation of plastics through deterioration processes such as photo-oxidation or mechanical degradation. Additionally, plastic wastes could be undergone deep weathering and transferred into the river through surface runoff long transport distance may contribute their degradation in river [20]. There is substantial evidence that shows microplastics ingestion can cause severe physical and physiological effects such as growth and reproduction reduction [14]. Moreover, microplastics is easily contaminated hence act as a medium of toxic chemicals resulting from its own origin or the surrounding environment and it will eventually enter the food chain and have a harmful impact on human health [26]. A study by Tien *et al*., [48] demonstrated that microplastics can accumulate hazardous chemicals like polychlorinated biphenyls (PCBs), which are known to be carcinogenic and can affect human and animal health.

Malaysia is well known as one of the four developing countries within the Southeast Asian region beside Singapore, Philippines and Indonesia that produces a tremendous 0.5 - 1.9 kg/capita/day of municipal solid wastes (MSW) with plastic wastes contributing to an estimated 25% of the overall composition [2]. Consequently, Malaysia has been appointed as one of the top plastics generators in Southeast Asian [28]. There are a few environmental studies and data relating to the abundance and distribution of plastic and microplastic pollution in Malaysian freshwater such as the Dungun, Baram, Cherating, and Klang rivers [11, 39, 57, 60]. However, no studies have been conducted in the northern region. With the lack of studies on microplastics abundance and distribution, this study will provide a preliminary assessment of the microplastics abundance and surface water quality in the Pinang and Kerian rivers of Pulau Pinang as well as baseline data for future microplastic pollution research, particularly on the abundance and distribution of microplastics in Malaysia's northern region and Southeast Asian.

Materials and Methods

Water samples were collected in June 2023 during the inter-monsoonal period at six sampling stations at Pinang River, Balik Pulau and six sampling stations at Kerian River, Nibong Tebal which parts of northern Peninsular Malaysia. Both rivers are in Penang state of Malaysia. Balik Pulau is a precinct on Penang Island meanwhile Nibong Tebal is located on the mainland. Both rivers flow through coastal areas of Penang. The Kerian River, which has a total length of 104 km, rises in the Bintang Range and runs southwest towards the Malacca Straits near the town of Nibong Tebal. Nibong Tebal is a base for some manufacturing industries that are located near the Kerian River. The related industries include metal machining, rubber industry, paper industry and furniture industry [4]. The area all along Kerian River is also surrounded by sugarcane, rice, and palm tree plantations. Along the Kerian River basin, land uses such as forested regions, paddy fields, palm oil plantations, orchards, and settlement areas are distributed [4]. Each river was appointed with six sampling points, as illustrated in Figures 1 and 2, and Table 1 provides the coordinates for all these sampling points with description. In Akhtar *et al*., [4] studies, 4 sampling points were taken as reference for Kerian River. Pinang River originated from Laksamana Hill and Tiger Hill Reserve. Most of the tributaries of the Pinang River receive wastewater from anthropogenic activities such as aquaculture, agriculture and domestic [16]. Wastewater from aquaculture ponds agriculture activities is discharged directly into the river without treatment [32]. The estuary holds significant importance for the local community as most of them are fishing. It serves as their primary location for fishing, collecting clams, and snails. Additionally, the Pinang River estuary also serves as the secondary gateway to the entrance of the Penang National Park [25, 32]. The Pinang River has numerous tributaries that eventually converge and merge at the estuary's end. SP1 through SP3 constitutes a common watercourse. Meanwhile, SP4 also serves as a tributary of the Pinang River, converging at SP5 and SP6, although it does not share the same watercourse as SP1 through SP3. All four checkpoints were selected based on their accessibility and, most importantly, their origin from the Pinang River, culminating in their convergence at SP5 and SP6.

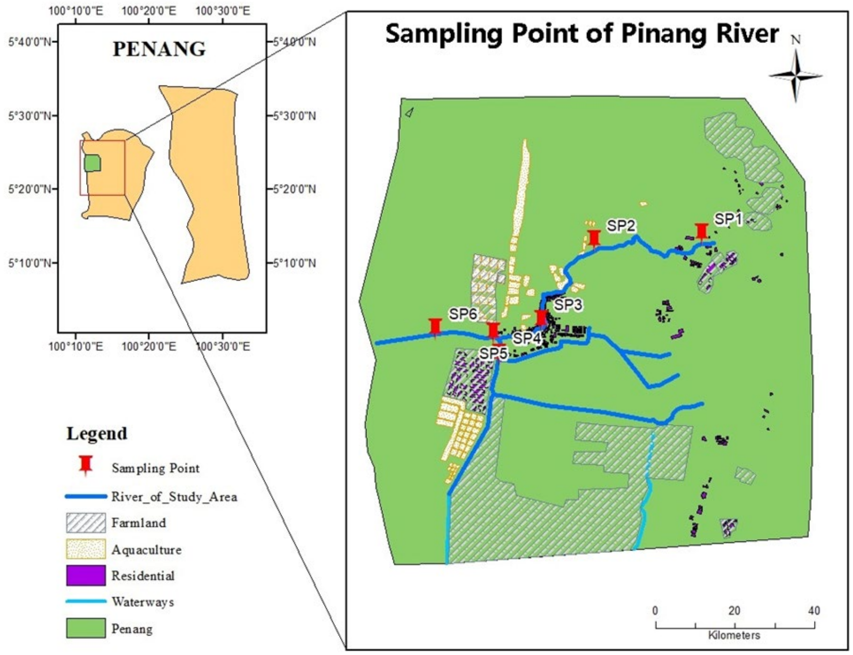

Figure 1. Sampling point at Pinang River

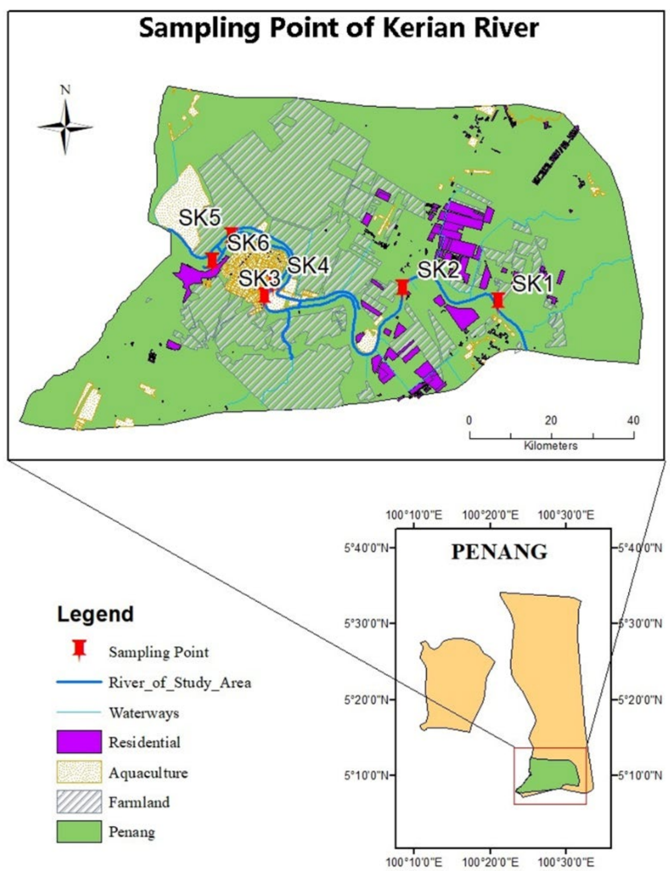

Figure 2. Sampling point at Kerian River

Table 1. Coordinate of sampling point

Station	Latitude	Longitude	Description
SP 1	5°23'59.4"N	100°12'46.9"E	Sungai Pinang, Balik Pulau
SP2	5°23'56.9"N	100°12'15.5"E	Sungai Pinang, Balik Pulau
SP 3	5°23'35.5"N	100°12'00.5"E	Sungai Pinang, Balik Pulau
SP 4	5°23'31.8"N	100°11'45.3"E	Sungai Pinang, Balik Pulau
SP 5	5°23'33.5"N	100°11'28.4"E	Sungai Pinang, Balik Pulau
SP 6	5°23'25.8"N	100°11'47.0"E	Sungai Pinang, Balik Pulau
SK 1	5° 9'26.26"N	100°29'44.03"E	Sungai Kerian, Nibong Tebal
SK 2	5° 9'38.75"N	100°28'28.55"E	Sungai Kerian, Nibong Tebal
SK 3	5° 9'31.30"N	100°26'37.85"E	Sungai Kerian, Nibong Tebal
SK 4	5° 9'41.71"N	100°26'44.62"E	Sungai Kerian, Nibong Tebal
SK 5	5°10'20.05"	100°26'11.11"E	Sungai Kerian, Nibong Tebal
SK 6	5° 9'59.62"N	100°25'55.70"E	Sungai Kerian, Nibong Tebal

Methodology

Measurement of parameters for temperature, pH, dissolved oxygen (DO), Electrical Conductivity (EC) and turbidity were done in situ at each sampling station. Figure 3 shows the procedure from water sampling until microplastics analysis. Water samples were collected at each sampling station starting from middle stream to downstream. A 5-litre steel bucket was used to collect water samples from the water surface [11, 37, 57, 63]. Forty L from the water surface was sieved through 3 layers of mesh filter with different pore size started from bigger size of pore size at top and smaller at bottom to discard big particle from the water surface [48]. The smallest filter at the bottom was rinsed using distilled water to get the particles into the 500 mL amber glass bottle. The step was repeated to get 3 samples for each sampling station. The water sample was stored in a cool box. At the laboratory, each of the water samples was treated with 10 mL of 30% H_2O_2 for 7 days in room temperature to remove organic compounds. Then GF/B filter paper was used to filter the water sample and leave it for 3 days in a closed petri dish. The dried filter paper was examined using Nikon Eclipse E200 to quantify the number of microplastics based on its shapes. The remaining on the filter paper was scraped and was stored in glass bottle. All analysis samples were in powder form and were analysed using ATR-FTIR (Attenuated Total Reflectance-Fourier Transform Infrared Spectroscopy) to identify the functional groups of polymers.

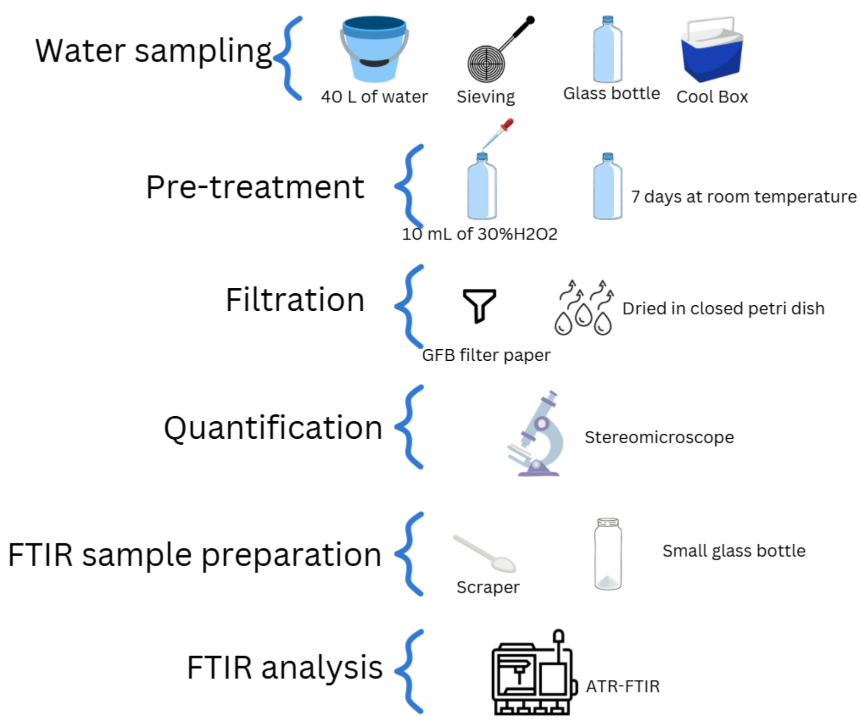

Figure 3. Procedure for examining microplastics in surface water samples

After filtration of water samples using GF/B filter paper and the filter paper was dried. The remaining on the filter paper was examined using stereomicroscope. Figure 4 shows there were 5 shapes of microplastics that were found that can be identified on the filter paper including sheet, fiber, film, fragment and pellet/bead referring to the shape from Wu *et al.*, [55] studies. This characteristic can be utilized to identify the possible origin. There were many types of polymers used in various industries as their versatile properties and application. Polyethylene (PE), polypropylene (PP), Polyvinyl Chloride (PVC), Polystyrene (PS), Polycarbonate (PC) and others were commonly used depending on application. Different polymers have distinct physical properties, and the shape of microplastics can change depending on factors such as manufacturing method, environmental conditions, and period of degradation [31]. Microplastic fragments, filaments, and fibers, for example, can reveal information about the type of polymer from which they are made [9, 23]. Polyethylene and polypropylene, for example, are typically seen as pieces and fibers, other than polyester and nylon may appear as filaments [13, 30]. However, identifying a polymer's precise functional group merely based on its physical appearance might be difficult. Advanced analytical techniques are frequently required to determine the functional group of a polymer with greater accuracy.

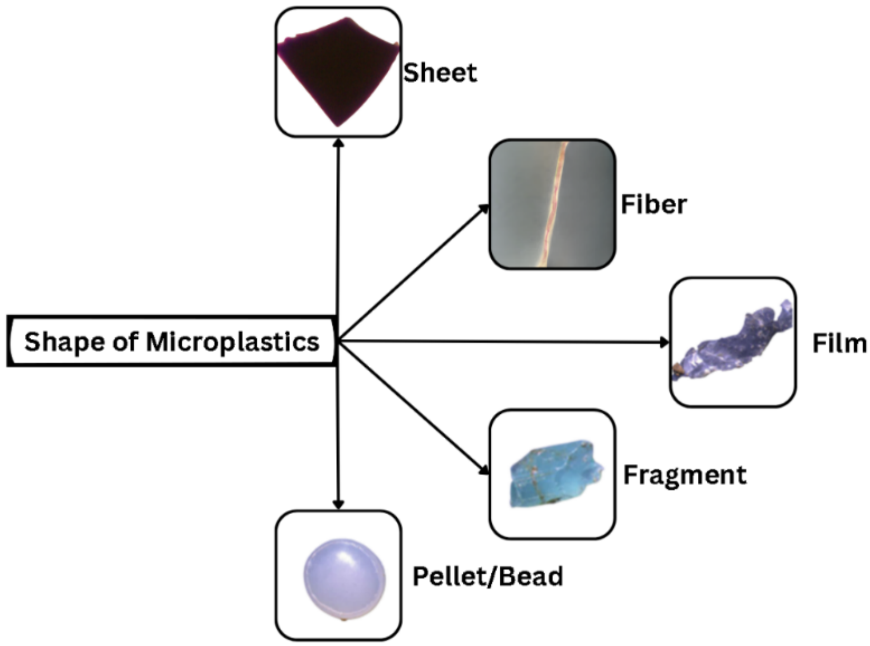

Figure 4. Shape of microplastic found in Pinang River and Kerian River

From the observations and quantification using stereomicroscope, abundance of fragment shaped microplastic in Kerian River was dominant with 44.84% than others shape shown in Figure 5. Meanwhile in Pinang River, abundance of fiber shaped microplastics was dominant with 39.06% than others. Overall, the abundance of fragment shaped microplastic was dominant with 37.89% in total for both rivers. Additionally, the film shaped microplastic were in insignificant amount of number with 7.37%. This finding aligns with other studies conducted in similar riverine environments, where fragment-shaped microplastics often predominate due to the breakdown of larger plastic debris from both domestic and industrial source as a preliminary study, Polycarbonate and Nylon were identified through ATR-FTIR analysis, providing an initial insight into the types of microplastics present in the sampled waters. These materials are commonly used in various consumer products, indicating that local human activities, such as improper disposal of plastic goods and effluents from manufacturing processes, significantly contribute to microplastic pollution. Polycarbonate is often used in the production of electronic components, water bottles, and eyewear, while Nylon is extensively utilized in textiles and fishing nets, suggesting a link to both urban and rural sources of pollution [33]. This initial identification indicates further investigation is necessary to comprehensively characterize the full spectrum of microplastics, understand their potential ecological impact, and ascertain the specific sources of Polycarbonate and Nylon, which may be linked to anthropogenic activities in the surrounding areas. For instance, understanding the degradation rates and transport mechanisms of these polymers can provide valuable information on their persistence in the aquatic environment and their potential to cause harm to aquatic organisms. Studies from Foley *et al*. [17] shown that different types of microplastics can affect organisms in various ways, from physical blockages in the digestive systems of fish and invertebrates to the leaching of harmful chemicals.

In the next study, there is potential to explore and identify other functional polymer groups, contributing to a more comprehensive understanding of the microplastic composition in the Pinang and Kerian Rivers. Future research should also include seasonal variations in microplastic abundance and composition to understand how factors such as monsoons or dry seasons might influence the distribution and concentration of microplastics. Additionally, investigating the interaction of microplastics with other pollutants, such as heavy metals or organic contaminants, can reveal complex ecological impacts and help in formulating effective mitigation strategies. The ecological implications of microplastic pollution are profound, affecting not just the aquatic life directly, but also the human populations that rely on these water bodies for drinking water, food, and recreation [6, 21]. Understanding the pathways and fate of microplastics in river systems can inform policies and regulations aimed at reducing plastic pollution at its source.

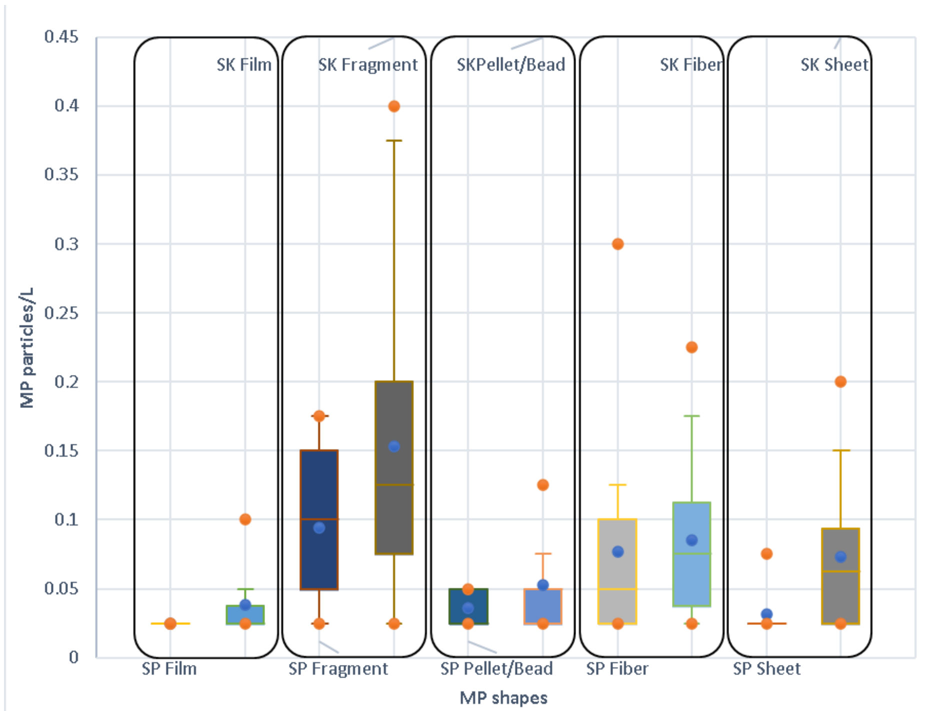

Figure 5. Comparison of Microplastics Concentration in Pinang and Kerian River using Box and Whisker Plot

Figure 6 shows the distribution of water quality parameters were recorded. The highest turbidity average was recorded at Pinang River. The main factor of pollution at both rivers were agricultural activities, domestic waste from residential areas and aquaculture activities [34]. Agricultural runoff typically contains a mix of pesticides, herbicides, and fertilizers, all of which can significantly degrade water quality. Domestic waste contributes organic matter and pathogens, while aquaculture activities introduce excess nutrients and chemicals used in fish farming operations [24]. High usage of fertilizer in the agriculture activities near to river leached and flow into the river water system, increasing the ammonia content in the river water [8]. Elevated ammonia levels can be toxic to aquatic life, leading to decreased biodiversity and disruptions in the aquatic food web [62]. This condition also promotes algal blooms, which further deplete oxygen levels when the algae decompose [53]. Fishing and shrimp catching at the river also causing the high turbidity in the river. Turbidity, which measures the cloudiness of water, can hinder photosynthesis in aquatic plants and affect the habitat of fish and other organisms [36]. High turbidity is often associated with increased levels of suspended solids and pollutants, which can have far-reaching impacts on the river ecosystem. Pinang River also have the highest dissolved oxygen average recorded during the in situ. Dissolved oxygen is crucial for the survival of fish and other aquatic organisms. The high DO levels in Pinang River suggest that, despite high turbidity, there might be sufficient aeration or photosynthetic activity occurring within the water body. However, fluctuations in DO levels can indicate pollution events or changes in water quality over time. This is because of concentration of DO is caused by elements such as the presence of organic pollution, water temperature, river flow and the river assimilative capacity [10, 18, 52]. Organic pollution typically results from the decomposition of organic matter, which can consume oxygen and lead to hypoxic conditions [29]. The river's flow rate and temperature also play significant roles in determining DO levels; faster flowing, cooler water tends to hold more oxygen.

Pinang River also have the highest conductivity average than Kerian River. It is because the downstream of the river is close by and connected directly to estuary. Conductivity, which measures the water's ability to conduct electrical current, is influenced by the presence of dissolved salts and other inorganic chemicals. The proximity of Pinang River to the estuary means that tidal influences and saltwater intrusion contribute to higher conductivity levels. High conductivity levels can indicate the presence of various dissolved ions, which might originate from natural sources, agricultural runoff, or industrial discharges [56]. Monitoring conductivity alongside other parameters like pH and nutrient concentrations provides a comprehensive picture of water quality and the potential impacts on the aquatic ecosystem. The relationship between these water quality parameters and microplastic pollution is also worth noting. For instance, high turbidity can facilitate the aggregation and transport of microplastics, while variations in dissolved oxygen and conductivity might influence the distribution and degradation of microplastic particles. Therefore, understanding these interactions is crucial for developing effective management and mitigation strategies to address both microplastic and conventional pollutants in river systems.

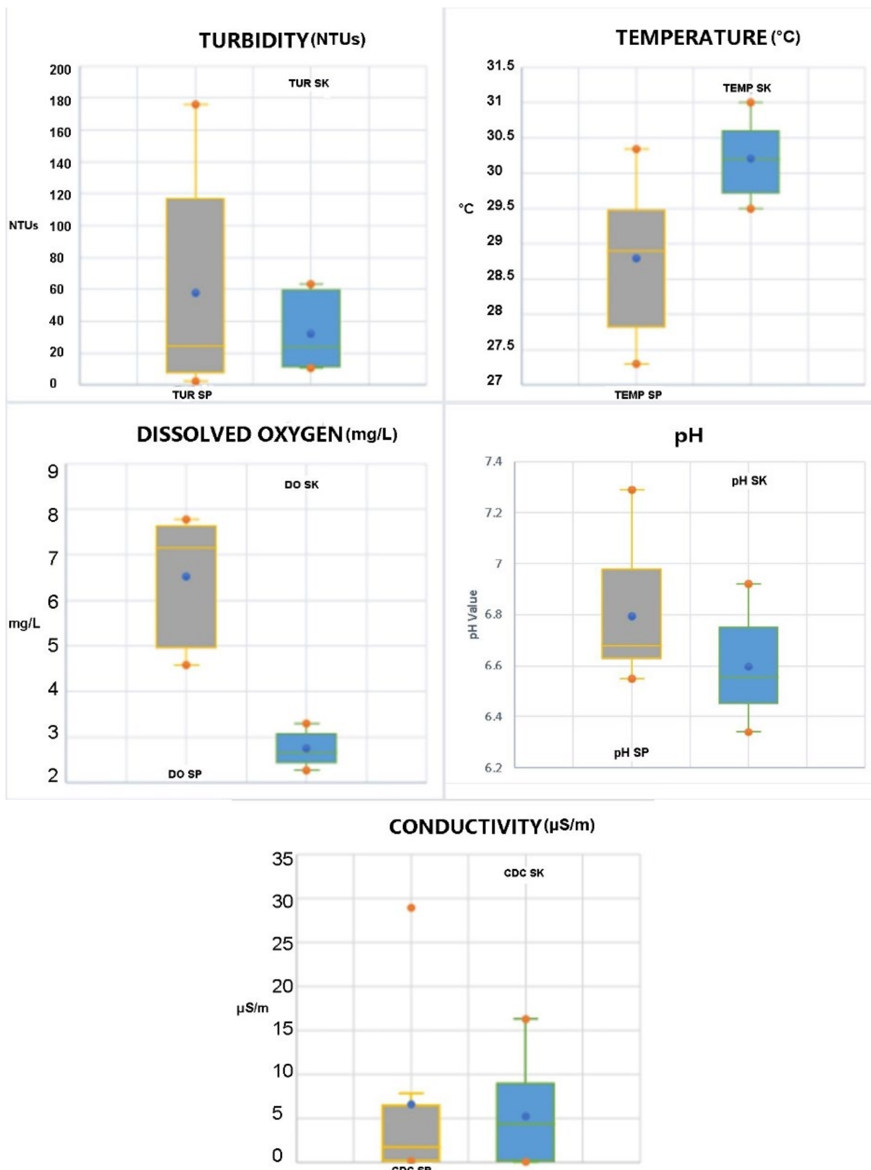

Figure 6. Parameter in Penang River and Kerian River

The presence and distribution of microplastics in aquatic environments are subject to the influence of various water quality parameters. Turbidity levels, for instance, can indicate heightened microplastic concentrations as microplastics can attach to suspended particles, increasing the overall turbidity. Elevated turbidity may also suggest a higher likelihood of microplastics being transported along with other particulate matter, potentially dispersing them throughout the water column and into different environmental compartments while temperature affects both microplastic degradation and transport [22, 41, 43, 58]. Higher temperatures can accelerate the breakdown of certain plastics, leading to the formation of smaller microplastic particles. Additionally, temperature variations can influence the density and buoyancy of microplastics, affecting their vertical and horizontal distribution in the water [64]. pH, on the other hand, plays a role in plastic stability and potential degradation, and with more acidic or alkaline conditions potentially enhancing the chemical breakdown of plastics [7, 65]. This can result in the release of toxic additives and monomers into the water, further impacting aquatic life. The interaction of pH with microplastics also affects their surface properties, which can influence their aggregation and interaction with other pollutants.

Shifts in conductivity may signal variations in ion concentrations, which can affect the adsorption of metals and other contaminants onto microplastic surfaces. High conductivity levels might indicate the presence of salts and other dissolved substances that could interact with microplastics, potentially altering their chemical properties and environmental fate. Moreover, DO levels contribute to microbial activity, impacting microplastic breakdown and the overall health of aquatic ecosystems [46]. Microbial communities can colonize microplastic surfaces, forming biofilms that facilitate the degradation of plastics through biodegradation processes [35, 61]. However, low DO levels can impair these microbial activities, reducing the efficiency of microplastic breakdown and leading to their prolonged persistence in the environment [27, 59].

Although these parameters are not direct measures of microplastics, they function as indicators of the environmental conditions affecting microplastics' presence and behavior. For instance, understanding how seasonal changes in water quality parameters influence microplastic distribution can help in predicting periods of higher microplastic concentrations. This knowledge is crucial for implementing timely mitigation measures and for improving the design of monitoring programs.

Conclusion

In conclusion, this study indicates the ubiquitous presence of microplastics in the Kerian and Pinang Rivers, shedding light on the significant impact of land use activities on microplastic pollution. The elevated abundance of fragment-shaped microplastics, particularly in the Kerian River, highlights the pervasive nature of plastic fragmentation in riverine environments, driven by a combination of domestic, industrial, and agricultural sources. The identification of polymers such as Polycarbonate and Nylon through ATR-FTIR analysis suggests a diverse array of plastic materials contributing to contamination, emphasizing the need for comprehensive characterization to discern the full spectrum of microplastics and their ecological implications. Moreover, the correlation between microplastic abundance and water quality parameters underscores the intricate interplay between environmental factors and microplastic distribution, with turbidity, conductivity, dissolved oxygen, temperature, and pH influencing microplastic behaviour and fate in aquatic ecosystems.

Furthermore, the study emphasizes the urgent need for continued investigation into microplastic pollution in the Kerian and Pinang Rivers, particularly to elucidate seasonal variations in abundance and composition. By expanding the scope of research to include other functional polymer groups, researchers can deepen their understanding of microplastic diversity and sources, laying the groundwork for more effective mitigation strategies. Additionally, exploring the interaction of microplastics with other pollutants, such as heavy metals and organic contaminants, promises insights into complex ecological impacts and informs targeted interventions to safeguard both aquatic life and human populations reliant on river ecosystems for sustenance and recreation. Ultimately, integrating knowledge of water quality parameters with microplastic research enables a holistic approach to river management, facilitating the development of evidence-based policies to mitigate plastic pollution at its source and preserve the health and integrity of freshwater ecosystems for future generations.

In conclusion, this study underscores the pressing need for interdisciplinary collaboration and holistic approaches to address the multifaceted challenges posed by microplastic pollution in riverine environments. By elucidating the spatial distribution, composition, and ecological implications of microplastics in the Kerian and Pinang Rivers, researchers contribute valuable insights into the complex dynamics of plastic contamination and its interaction with environmental variables. Moreover, by leveraging advances in analytical techniques and integrating findings from water quality monitoring, researchers can develop comprehensive strategies to mitigate microplastic pollution, safeguarding both aquatic ecosystems and human well-being. As such, continued research efforts are imperative to unravel the intricate web of factors shaping microplastic pollution and to inform targeted interventions aimed at preserving the integrity and resilience of freshwater ecosystems in the face of mounting anthropogenic pressures.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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