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Characterization of microplastics in the water and sediment of Baram River estuary, Borneo Island

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ABSTRACT

The Baram River is one of the largest rivers in Sarawak, where many large industries, such as plywood, sawmills, shipyards, interisland ports, and other wood-based industries are located along the river.

Microplastic contamination has become a widespread and growing concern worldwide because of the small sizes of microplastics and their presence in seafood such as fish, squid, scallop, crabs, shrimp, and mussels. In this study, microplastics were found in all sampling stations. Out of the 4017 microplastics found in the water and sediment, microplastics fragment accounted for 67.8% of total microplastics, followed by fiber, film, pellet, and foam. Five microplastic polymer types were detected by ATR-FTIR, including polyethylene (PE), polyester (PET) fibers, silicon polymer, nitrile, and polystyrene (PS). The most common microplastics size range in Baram River was 0.3–1 mm, with blue as the highly abundant color.

Water contamination is a serious environmental concern caused by anthropogenic activities. The rapid development of industrial and agricultural activities resulted in the high production of harmful pollutants such as organic pollutants, synthetic dyes, microplastics, and heavy metals. (Hadibarata et al., 2012; Hii, 2021; Kristanti et al., 2012; Lai, 2021; Tang, 2021). As a result of increased plastic manufacturing, disposal, and anthropogenic activities, plastic waste has become a widespread and growing concern worldwide. Plastic waste is often categorized based on its size as follows: macroplastic (> 20 mm), mesoplastic (5–20 mm), and microplastic (< 5 mm). Microplastics, in particular, are dispersive and have recently gained scientific and public attention because of their harmful effects on the water ecosystem, agriculture, and other human impacts (Oliveria et al., 2013). The prevalence of microplastics in the environment has been a major issue since the early 1970s. However, there has been increasing awareness in the last few years that contributed to the discovery of geographical spread, accumulation, and ecological impact of microplastic contamination. Microplastics are abundantly found in oceans, rivers, lakes, mangroves, air, snow, polar sea ice, and aquatic organisms (Tang, 2021).

In addition, microplastic debris can be categorized based on shape (spheres, beads, pellets, foams, fibers, fragments, films, flakes), color, polymer type, and size (Doyle et al., 2011). Owing to their small size and widespread distribution, microplastics threaten marine species – as they are often mistaken for food because of their size similar to that of the prey. Furthermore, microplastics are found in seafood such as fish, squid, scallop, crabs, shrimp, and mussels (Browne et al., 2011; Cole et al., 2015; Setala et al., 2014). Despite the lack of information with regard to the ecotoxicological impacts of microplastics, this pollution remains a global environmental concern. Accumulated microplastics in aquatic animals' bodies might be transferred to human by the trophic transfer effect (Van Cauwenberghe et al., 2013). Studies have shown that zooplankton, the most abundant organism on earth, can ingest different types and sizes of microplastics. Consequently, the growth and

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reproduction of zooplankton are compromised because microplastics cannot be digested, and hence, agglomerate in their digestive system, thereby changing their intracellular activity. Moreover, as zooplanktons link two trophic levels, microplastics that can migrate up the food chain pose a risk to other aquatic organisms (Cole et al., 2011; Tang, 2021).

Malaysia is one of the largest plastic producers in Southeast Asia that generates a massive 0.5–1.9 kg/capita/day of municipal solid wastes (MSW), where 25% comprise plastic wastes (Aja and Al-Kayiem, 2014; Amin et al., 2020). However, studies on microplastic contamination are scarce in the local setting; existing data are primarily obtained from Peninsular Malaysia, where the focus is on coastal and beach areas, with limited studies of rivers or freshwater systems (Auta et al., 2017; Khalik et al., 2018; Fauziah et al., 2015; Amin et al., 2020; Sarijan et al., 2018; Hwi et al., 2020). Furthermore, only one study has reported the occurrence and distribution of microplastics in East Malaysia (Noik and Tuah, 2015). Therefore, this research aimed to study the abundance and distribution of microplastics in the water and sediments of the Baram estuaries, Sarawak, Malaysia. Moreover, microplastic abundance in the Baram estuary was compared with that of Malaysia and other worldwide locations. The Baram River is one of the largest rivers in Sarawak, located in the Borneo Islands, and originated from the Kelabit Highland. Many large industries, such as plywood, sawmills, shipyards, interisland ports, and other wood-based industries, are located along the Baram estuary. The river is approximately 980 km long, and it is estimated that the river catchment area is located between 113°58′23.3″E–115°36′02.8″E longitude and 2°42′34.8"N–4°35′03.8"N latitude of approximately 22,800 km^2. The rainfall intensity in the river basin varies from 2500 to 4000 mm/year. However, the average annual discharge of fresh water and sediments into the South China Sea is estimated to be approximately 1590 m^3/s of fresh water and 24 million tonnes of sediments (Sandal, 1996; Straub and Mohrig, 2009). Nonetheless, comprehensive data on microplastic contamination in the Baram River are not presently available.

The microplastics sampling procedures involved the collection of water and sediment samples twice from five locations from September to October 2020. The map of sampling locations is shown in Fig. 1. A total of 10 L (per sample) of surface water (0–20 cm depth) was collected in stainless steel buckets. Then, the water samples were sieved with stainless steel mesh (0.3–5 mm) to trap the microplastics. To date, filtering remains a popular method to remove microplastics from water samples, using sieves that vary in pore size or mesh size. More microplastics are identified when the pore or mesh size is smaller. Subsequently, sediment samples (400 g) were collected using an Ekman Grab sampler and refrigerated before analysis. Later, the sediment was dried in an oven overnight at 65 °C, and a 20 μm mesh stainless steel sieve was used to trap microplastics. First, the separation was conducted by adding 300 ml of aqueous lithium metatungstate (1.62 g/cm^3) to float out the microplastic particles from the soil sediments (He et al., 2020). The second separation was conducted by adding iron and hydrogen peroxide solution to the samples to eliminate the organic matter. Plastic debris was unaffected by the wet peroxide oxidation (WPO) procedure (Masura et al., 2015). Density separation was then conducted by adding NaCl solution to both water and sediment samples to remove inorganic matter from microplastics. Visual inspection of any precipitated microplastics was carried out using forceps, and the remaining liquid solution was sieved through a 0.3 mm stainless steel mesh. The filtered microplastics were then placed on a clean petri dish to characterize their shape, size, and color through a stereomicroscope equipped with a high-resolution camera at 40× magnification. Next, the collected microplastics were analyzed using the Agilent ATR-FTIR spectroscopy to identify functional groups. The spectrum recorded was in the mid-range; 4000–700 cm^{1} using 20 scans/s at 0.25 cm^{1} resolution for each analysis (Cincinelli et al., 2017). The analysis was performed in triplicate and the spectrum recorded was also compared to previous studies. Subsequently, a simple regression analysis was conducted to determine significant relationships between the microplastic concentration in the water and sediment, expressed as (mg/L) and (mg/g). Characteristics of the microplastic samples were recorded, including amount, color (yellow, green, white, red, blue, black, and transparent/no color), shape (fiber, pellet, fragment, film, foam), size (0.3–1 mm, 1–2 mm, 2–3 mm, 3–4 mm, and 4–5 mm), and polymer composition (polyethylene, polyester, fibers, silicon polymer, nitrile, and polystyrene).

In this study, microplastics were found in all sampling stations. A total of 1289 particles were identified in the water samples, while 2727 particles were detected in the sediment samples (Fig. 2). The mass fraction of microplastics in the water samples ranged from 0.55± 0.071

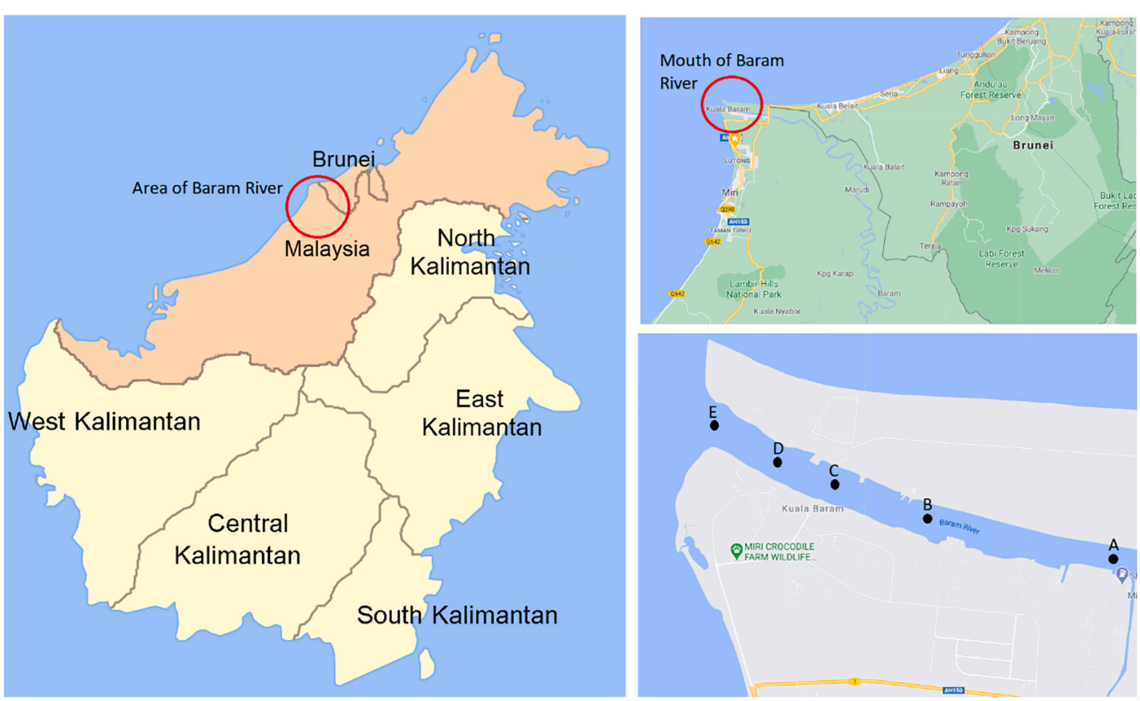

Fig. 1. Map of sampling location in Baram river estuaries.

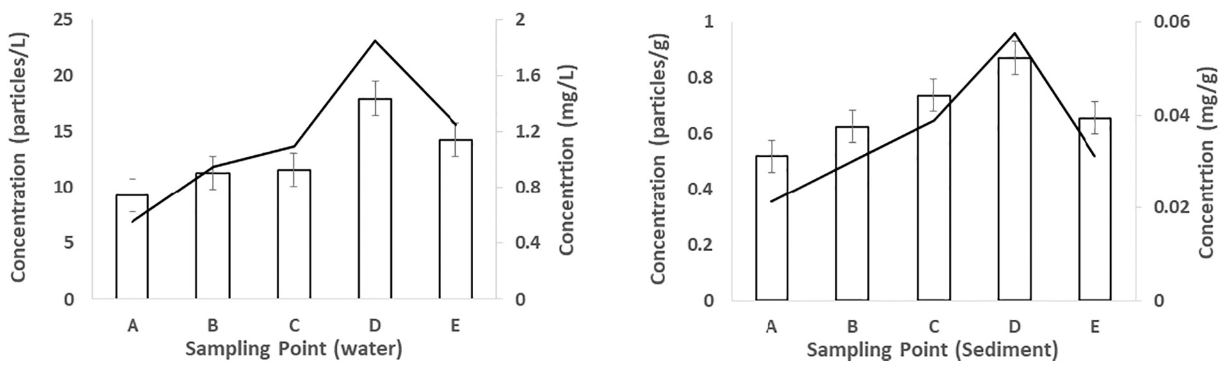

Fig. 2. Microplastic abundance in water and sediment samples.

to 1.85 ± 1.48 mg/L or from 9.3 ± 1.27 to 18 ±1.41 particles/L. In the case of sediments, the mass fraction of microplastics ranged from 0.021 ± 0.002 to 0.057 ± 0.039 mg/g, or from 0.52± 0.005 to 0.87 ± 0.025 particles/L. Station D (SD) recorded the highest abundance of microplastics in water (18 ±1.41 particles/L or 1.85 ± 1.48 mg/L) and sediment (0.87 ± 0.025 particles/L or 0.057 ± 0.039 mg/g), while station A (SA) had the least microplastics in water (9.3 ±1.27 particles/L or 0.55 ± 0.07 mg/L) and sediment (0.52 ± 0.001 particles/L or 0.021 ± 0.001 mg/g). The abundance and distribution of microplastics at all sampling points were mainly caused by various anthropogenic activities such as illegal waste disposal and fishing. However, the accumulation of microplastics in the lower estuary was because of its proximity to the heavy industrial factories such as interisland ports, plywood, sawmills, shipyards, and other wood-based industries. Furthermore, fishing activities and domestic wastewater were also major contributors to the high concentration of microplastics in the lower estuary of Baram River. These findings aligned with previous studies, which stated that the estuary is a complex environment where tidal movement leads to the accumulation of plastic garbage from both the river and the sea. Furthermore, the estuary has been identified as the main location for evaluating riverine microplastic discharges into the sea (Schmidt et al., 2017). Besides, the higher microplastic abundance corresponded with the accessibility of the river shore to anthropogenic activities such as commercial, industrial, and residential areas (Wang et al., 2018). A moderate correlation was observed between the concentration of microplastics in the water ($R^2 = 0.5865$) and sediment ($R^2 = 0.3026$). Moreover, the abundance of microplastics in the sediment was higher at all sampling points compared to the water samples. According to previous studies, the lighter plastic debris remained on the top of the water column, while heavier plastic debris sinked directly to the riverbed (Tibbetts et al., 2018). Table 1 shows the shape composition of microplastics at each site. Out of the 4017 microplastics found in the water and sediment, the fragmented shape accounted for 67.8% of total microplastics, followed by fiber (18,7%), film (8.4%), pellet (3.0%), and foam (2.0%). Liu et al. (2019) also reported that fragmented microplastic was commonly found in the river owing to the deterioration and degradation of larger plastic products. Fiber-shaped microplastic was produced during the manufacturing of synthetic clothing, ropes, fishing lines, and other fabric products. The pellet- and film-shaped microplastics were usually generated from the ornaments of clothing, plastic bags, food packaging, and other synthetic fabric materials (Sang et al., 2021). Furthermore, foam-shaped microplastic was mainly generated from polystyrene packaging boxes and floral foam plastics (Trestrail et al., 2020). The proportion of the microplastic shapes – fragments, pellets, and foams – in the riverbank sediments were higher compared to the water samples, while the proportion of fiber and film shapes were higher in the water samples. The fragments, pellets, and foam forms have a higher density, lower specific surface area, and unique surface structure, which results in these microplastic items to accumulate more frequently in sediments than in surface water (Campanale et al., 2020).

A wide array of colors were detected for microplastics in the Baram River estuary. Fig. 3 shows that the dominant microplastic color in water samples was blue, accounting for 34.4% of the total microplastics, followed by black (28.8%), transparent/no color (18.1%), red (8.4%), green (6.6%) and yellow (3.3%). In the case of sediment samples, among the 2727 plastic items identified, blue-colored plastics were the most commonly observed (30.3%), followed by black (24.2%), transparent (23.7%), yellow (8%), red (7.8%), and green (6.1%). The distribution of microplastic colors within the Baram River estuary is quite indistinguishable from various other published data of freshwater and marine environments, globally and in Malaysia (Hidalgo-Ruz et al., 2012; Campanale et al., 2020; Hwi et al., 2020; Khalik et al., 2018). Therefore, the various plastic colors may indicate the origin of the plastic materials, although color separation may not provide further verification. For example, blue and black are the standard colors in fishery-related materials and activities. In addition, bright- or light-colored microplastics within the water environment were often ingested by aquatic species (Boerger et al., 2010). Fig. 4 illustrates the dimensional composition of microplastics from the Baram River estuary. The smallest particle (0.3–1 mm) was predominant in the water samples, accounting for 36.8% of the total microplastic particles, followed by 1–2 mm (25.7%), 2–3 mm (18.6%), 3–4 mm (11.6%), and 4–5 mm (7.4%). Similarly, the most abundant microplastics detected in sediment samples at all sites were also 0.3–1 mm (30.9%), followed by 1–2 mm (26.0%), 2–3 mm (19.5%), 3–4 mm (13.5%), and 4–5 mm (10.2%). These results are in agreement with previous studies which reported that microplastics with

Table 1
Microplastics type percentage in water and sediment samples.

Plastic shape	Water					Sediment					Total	%
	SA	SB	SC	SD	SE	SA	SB	SC	SD	SE		
Fiber	42	48	49	76	59	74	93	109	101	102	753	18.7%
Pellet	0	2	1	4	2	15	20	31	26	19	120	3.0%
Fragments	123	150	153	235	185	290	350	395	480	364	2725	67.8%
Film	20	26	26	39	34	26	26	47	66	28	338	8.4%
Foam	1	0	2	6	6	10	12	8	23	12	80	2.0%
Total	186	226	231	360	286	415	501	590	696	525	4016	100.0
%	4.63%	5.63%	5.75%	8.96%	7.12%	10.33%	12.48%	14.69%	17.33%	13.07%	100.00	

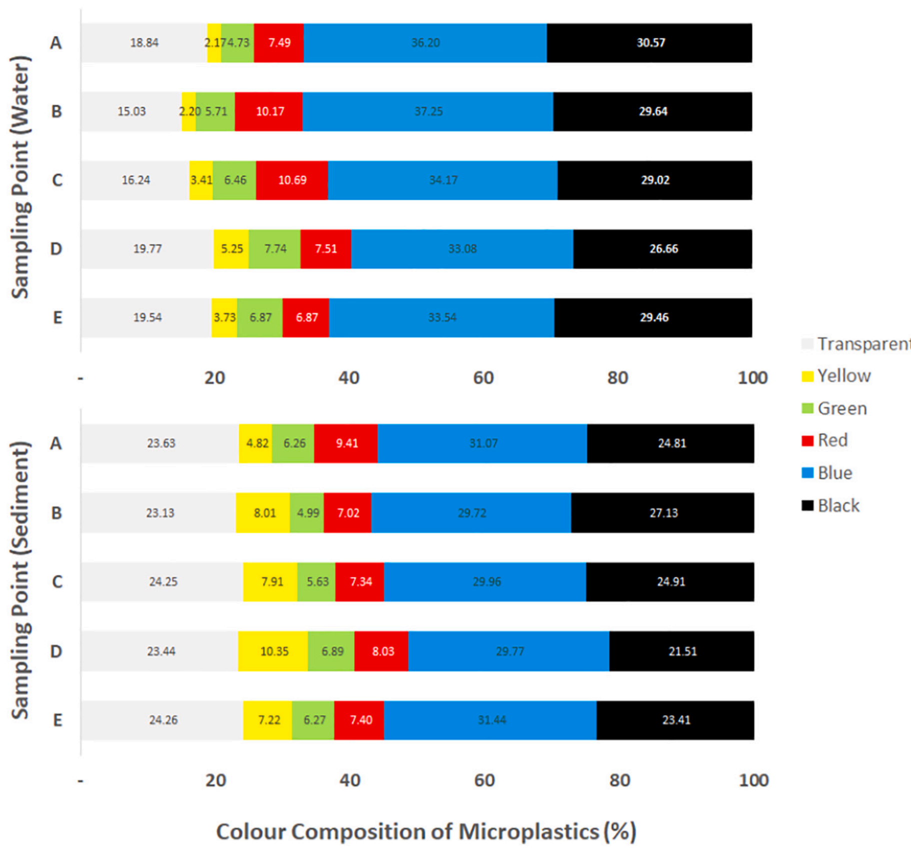

Fig. 3. Color composition of microplastics from water and sediment samples.

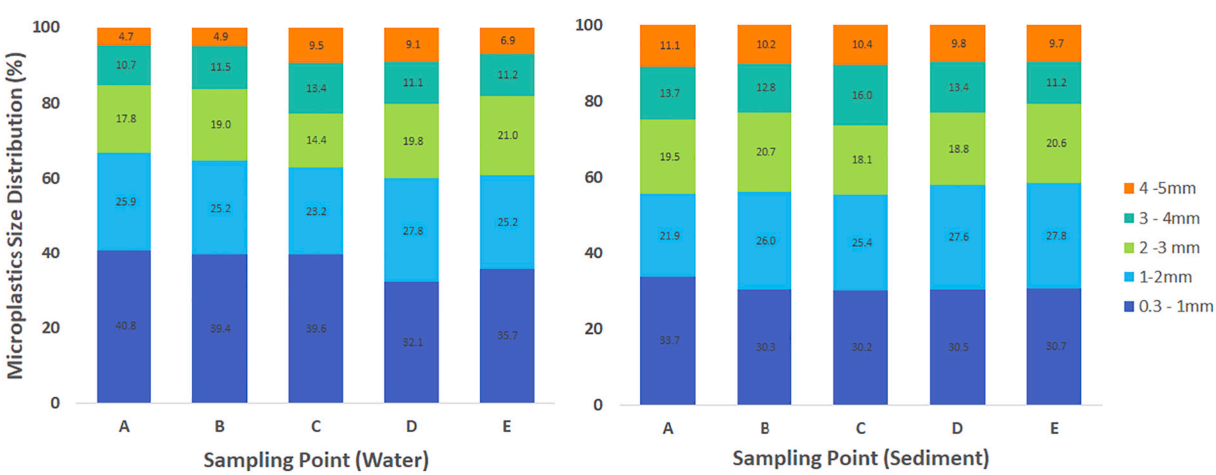

Fig. 4. Microplastic size distribution of water and sediment samples.

a particle size of <2 mm are commonly found in the aquatic environment; this is because of the degradation and fragmentation of microplastics and reflects the pollutant distribution along the water column (Avio et al., 2017; Campanale et al., 2020). Besides, the higher abundance of small-sized microplastics in the aquatic ecosystem increases the risk of ingestion by aquatic species because their size makes them indistinguishable from other microorganisms, such as planktons (Su et al., 2019).

Fig. 5 demonstrates the polymer composition of microplastics in the Baram River estuary. Five microplastic polymer types were detected; including polyethylene (PE), polyester (PET) fibers, silicon polymer, nitrile, and polystyrene (PS). The main absorption bands of detected polymers were as follows: 1) PE: the main absorption bands were shown at band 2919 cm^{-1} (CH_2 asymmetric stretching), 2851 cm^{-1} (CH_2 symmetric stretching), 1473 cm^{-1} (bending deformation), 1377 cm^{-1} (CH_3 symmetric deformation), 1176 cm^{-1} (Wagging deformation), and 731–720 cm^{-1} (Rocking deformation); 2) PET: the absorption bands of C—H symmetric stretch observed at 3052 cm^{-1}, with additional bands appeared around 1733 cm^{-1} (C=O stretching of the carboxylic acid group), 1451 cm^{-1} and 1324 cm^{-1} (stretching of the C—O group and wagging vibrational modes of ethylene glycol segment), and 1126 cm^{-1} (Terephthalate group $OOCC_6H_4$-COO); 3) silicon: the absorption bands of CH_3 asymmetric stretching were observed at 2960 cm^{-1}, 1430 cm^{-1} (C—H bending), 1385 cm^{-1} and 1370 cm^{-1} (Si-alkoxy compounds), and

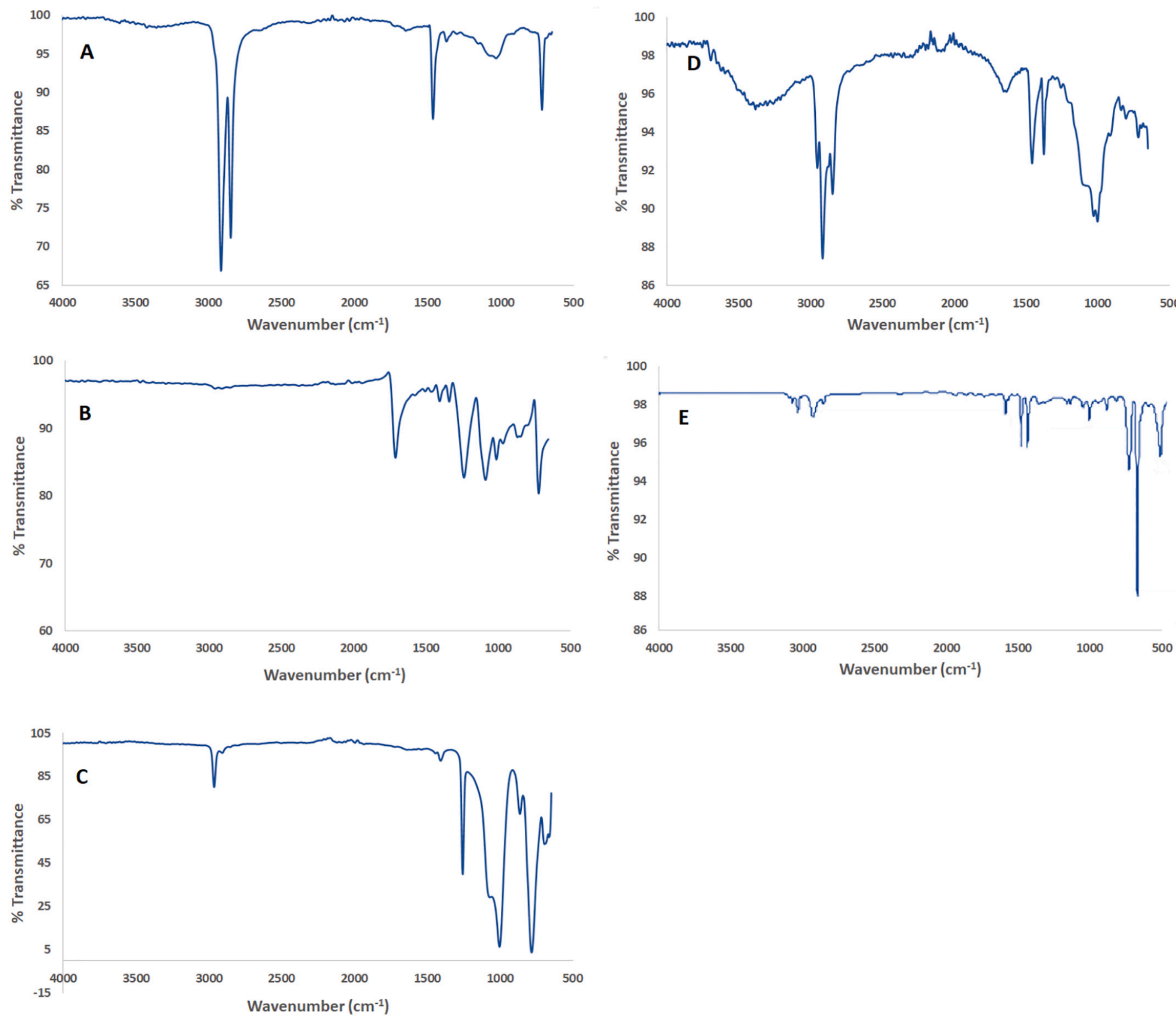

Fig. 5. ATR-FTIR spectrum transmittance of the polymers presents within the water and sediment samples: (a) Polyethylene; (b) Polyester fibers; (c) Silicon Polymer; (d) Nitrile; and (e) Polystyrene.

1050–1010 cm^{-1} (Disilymethylene band); 4) nitrile: the main absorption were at 2855 cm^{-1} (CH_2 symmetric stretching), 2231 cm^{-1} (CN stretching), 1620 cm^{-1} (C═C stretching), 1462 cm^{-1} and 1340 cm^{-1} (CH_2 bending), and 972 cm^{-1} (C—H symmetrical bending); and 5) PS: the absorption bands of C—H aromatic stretching were observed at 3020 cm^{-1}, 2850 cm^{-1} (CH stretching), 1612 cm^{-1} and 1489 cm^{-1} (Aromatic ring stretching), 1432 cm^{-1} (CH_2 bending), and 705 cm^{-1} (Aromatic CH out-of-plane bending).

PE has been reported as the most used plastic material in Malaysia (48%), followed by PET (13%) and polystyrene (10%). Most PE wastes originated from foils, bottles, and cords from tires (Ahmad et al., 2017). PE is also commonly found in disposable plastic bags and food packaging bags, which are used by billions of people daily. PET polymers are frequently applied in the production of clothing, textiles, and wool products (Wang et al., 2018). It was suggested that the source of PET in the Baram River originated from the domestic waste of villages located upstream. Furthermore, silicon was frequently used as plastic materials owing to its flexibility, malleability, clarity, and water resistance, while nitrile was considered as synthetic rubber that was produced through the combination of butadiene and acrylonitrile (Agrawal et al., 2015).

The nitrile polymer in the Baram River was suspected to originate from various industries such as plywood, resin, and wood product. Previously, nitrile has been reported to be commonly used within the chemical, medical, pharmaceutical, automotive, and aeronautical industries as it is resistant to oil, fuel, and other corrosive chemicals (Utrera-Barrios et al., 2020). Polystyrene is another popular polymer used in food packaging or laboratory and is found in water environments and aquatic organisms (Gambardella et al., 2017). Therefore, in Malaysia, considering that most food packages are made of fragile polystyrene (Ahmad et al., 2017), it is not surprising that most local rivers are polluted with this microplastic, including the Baram River. Thus, it can be concluded that the mishandling of plastic wastes and lack of public awareness are the main contributors to the microplastic contamination in the Malaysian rivers.

The abundance and distribution of microplastics in some Malaysian rivers and different locations of the world are detailed in Table 2. The Baram River estuary recorded lower microplastic abundance and distribution compared to Dungun River (Terengganu), Skudai River (Johor), Terbrau River (Johor), Santubong Beach (Kuching), and Trombol Beach (Kuching). Moreover, Kuantan Port (Pahang) and Kuala

Table 2
The abundance and distribution of microplastics in some rivers of Malaysia and different parts of the world.

Location	Sample	Sampling technique	Abundance	Reference
Baram River, Malaysia	Surface water and sediment	Scoop 10 L of water using water scooper and sieved through 5 mm and 0.3 mm stainless steel sieve Scoop 400 g of riverbank sediments using a steel scooper and sieved through 5 mm and 0.3 mm stainless steel sieve	Water: 0.55± 0.0707 to 1.85 ± 1.4849 mg/L or 9.3 ± 1.2728 to 18 ±1.4142 items/L Sediment: 0.02125 ± 0.0018 to 0.0575 ± 0.0389 mg/g or 0.5188± 0.0053 to 0.87 ± 0.0247 items/g	This study
Dungun River, Terengganu, Malaysia	Surface Water	Scoop 400 L surface water with a depth of 20 cm using a 20 L Flameer stainless steel bucket	177.1 ± 80 item/L	Hwi et al., 2020
Skudai River, Johor, Malaysia	Sediment	Sediment collection using a box corer (Wildco)	200± 80 particles per kg	Sarijan et al., 2018
Tebrau River, Johor, Malaysia	Sediment	5.7 L calibrated steel sampler and 20 μm serial filtration net	680 ± 140 particles per kg	Sarijan et al., 2018
Kuala Nerus Beach, Terengganu, Malaysia		5.7 L calibrated steel sampler and 20 μm serial filtration net	0.13–0.69 particles per kg	Khalik et al., 2018
Kuantan Port, Pahang, Malaysia	Surface water	Scoop sediments until a depth of 2 cm using stainless steel spoon and sieved through 1 mm mesh	0.14–0.15 particles per kg	Khalik et al., 2018
Santubong Beach, Sarawak, Malaysia	Sediment	Scoop sediments until a depth of 2 cm using stainless steel spoon and sieved through 1 mm mesh	0.0358 ± 0.062 particles per g	Noik and Tuah, 2015
Trombol Beach, Sarawak, Malaysia	Sediment	Sediment collection using a box corer (Wildco)	1.7343 ± 2.173 particles per g	Noik and Tuah, 2015
Rhine River, Germany	Sediment	Not indicated	21.8–932 mg/kg	Klien et al., 2015
Brisbane River, Australia	Sediment	Scoop sediment samples with a Ponar-stainless steel grab sampler at a depth of 0–3 cm	0.18–129.20 mg/kg	He et al., 2020
Nan Lake, China	Rainwater pipelines	Collect 8 L water samples using a stainless-steel graduated bucket	2.75 ± 0.76 to 19.04 ± 2.96 items/L	Sang et al., 2021
Gallatin River, USA	Surface water	Grab sampling approach used by collecting 1 L of surface water using stainless steel sample bottles	0–67.5 items/L	Barrows et al., 2018
Amazon River, Brazil	Sediment	Sediment samples were collected using a van Veen sampler with a depth of 5–10 cm	417–8178 items/kg	Gerolin et al., 2020

Nerus Beach (Terengganu) had lower abundance and distribution of microplastics than the Baram River (Ibrahim et al., 2017; Sarijan et al., 2018; Khalik et al., 2018; Noik and Tuah, 2015). Globally, Baram River had fared better than Rhine River (Germany), Brisbane River (Australia), Nan Lake (China), Gallatin River (USA), and Amazon River (Brazil) (Klien et al., 2015; He et al., 2020; Sang et al., 2021; Barrows et al., 2018; Gerolin et al., 2020). Despite its higher starting range of microplastic abundance – than some rivers such as the Brisbane River, Han Lake, and Gallatin River – Baram River had a relatively lower ending range, which places it last in microplastic contamination.

The findings in this study reflected the abundance and distribution of plastic debris within the freshwater environment of East Malaysia. Malaysia lacks studies regarding microplastics—because it is not considered a significant pollution threat compared to other pollutants, such as heavy metals and crude oil. Marine debris is believed to be generated by anthropogenic activities. Therefore, it is crucial to assess the potential hazards of microplastics on the aquatic environment, including the identification of microplastic stockpiling dynamics and remobilization in riverbeds. These studies will provide a clearer view and understanding with regard to microplastic pollution and ensure the well-being of the ecosystem.

CRediT authorship contribution statement

Wei Sheng Choong: Investigation, Data curation, Writing-original draft. **Tony Hadibarata:** Supervision, Funding acquisition, Methodology, Writing-original draft, Resources. **Adhi Yuniarto:** Formal analysis, Resources, Review & editing. **Kuok Ho Daniel Tang:** Supervision, Methodology. **Faizuan Abdullah:** Visualization, Writing - Review & Editing. **Muhammad Syafrudin:** Writing - Review & Editing, Software. **Dunia A. Al Farraj:** Funding acquisition; Writing - Review & Editing, Visualization. **Amal M. Al-Mohaimeed:** Writing - Review & Editing, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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