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# Assessment of Microplastics in the Surface Water of Mengkabong and Salut Rivers of Sabah, Malaysia

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## ABSTRACT

Microplastics in river water are a global risk to aquatic ecosystems due to their longevity in the environment, causing toxicity, ingestion by organisms, and bioaccumulation. However, knowledge and research on microplastic pollution are still scarce in Sabah, Malaysia, as no studies have been carried out before. Hence, this study aimed (1) to determine the occurrence of microplastics in the surface water of the Mengkabong and Salut Rivers in Sabah and (2) to assess the spatial variability in the concentration and characteristics of microplastics within these rivers. Microplastics were extracted, counted, and characterized for their shape, colour, size, and polymer. An independent t-test was used to compare microplastic abundance and characteristics between the two rivers, whereas Hierarchical cluster analysis was used to group the eight stations based on similarities in microplastics. This study detected microplastics at all stations, with a significantly higher concentration ($p < 0.05$) of microplastic in the Salut River (4.78±2.43 items/L) compared to those in the Mengkabong River (1.63±0.87 items/L). Fibre was the most abundant microplastic shape in both Mengkabong (78%) and Salut (57%), likely sourced from textile washing, fishing, and aquaculture activities in the vicinity. Transparent microplastics were prevalent in Mengkabong (30%), while black microplastics dominated in Salut (42%). Size distribution exhibited the opposite trend, with 74% larger-sized microplastics in Mengkabong but 63% smaller-sized microplastics in Salut. Polymer analysis revealed rayon (68%) dominance in Mengkabong, while polyethylene (34%) and rayon (33%) in Salut. Spatial heterogeneity of microplastics was evident through cluster analysis, categorizing stations into clean, moderately polluted, and polluted. Stations adjacent to areas with fewer land-based activities were clean with a low microplastics count, while areas with intense developments, residential, and fishing activities were polluted with high microplastic counts. This study underscores the presence of microplastics in Sabah's rivers, serving as a foundational reference for future research. It is also imperative to conduct regular monitoring of microplastics in the rivers of Sabah since it is anticipated that microplastics contamination will escalate in the coming years globally.

Keywords: Fibre, microplastics, rayon, Sabah, tidal rivers



## INTRODUCTION

Increasing plastic pollution particularly microplastics has been a serious worrying issue since the past decade (Henderson & Green, 2020; Issac & Kandasubramanian, 2021; Li *et al.,* 2023). Pittura *et al*. (2022) defined microplastics as microscopic sized of plastic particles smaller than 5 mm in sizes from two manufacturing origins; primary and secondary. Primary microplastics refer to plastic particles that are intentionally manufactured to be microscopic in size, such as microbeads found in skincare products. On the other hand, secondary microplastics are plastic particles that are formed through the degradation and fragmentation processes of larger plastic materials (Hocking, 2022). The surge of demand in usage of plastics products results in their excessive production, if are not managed properly leads to indiscriminate disposal into the environment (Fauziah *et al*., 2015). Additionally, the characteristics of plastics such as slow degradation period along with intense fragmentations of plastics into microscopic size rendered them as the most problematic persistent pollutant in the environment (Multisanti *et al*., 2022).

Approximately 6,000 to 1.5 million tons of microplastics are transported to the ocean annually via rivers (D'Avignon *et al*., 2022). It highlights the importance of rivers as primary channels for the transportation of plastic debris from terrestrial environments to the marine ecosystem. Anthropogenic activities, including aquaculture and fishing activities, the direct disposal of plastic trash, and industrial discharges into rivers, were identified as significant contributors to the escalation of microplastics pollution in river ecosystems (Choong *et al*., 2021; Primus & Azman, 2022). The transportation and deposition of microplastics in river ecosystems are influenced by various factors, including the presence of nearby sources, land use patterns, river flow dynamics, hydraulic conditions, and the terrain of the surrounding area. Additionally, the characteristics of the microplastic particles play a role in their movement and distribution within rivers (Lin *et al.,* 2018; Idrus *et al.,* 2022).

The rapid pace of new constructions and infrastructural changes in Sabah have greatly affected the general lifestyle of its residents, leading to the mismanagement of plastic garbage (Dusim, 2021). Despite having awareness of increasing plastic and microplastic pollution, the knowledge and research of microplastic pollution in Sabah however is still scarce. The majority of microplastic study conducted in Malaysian river waters has been concentrated on the regions of Peninsular and Sarawak. Seven studies were conducted in Peninsular Malaysia; Skudai River and Tebrau River in Johor (Sarijan *et al*., 2018), Cherating River in Pahang (Pariatamby *et al*., 2020), Dungun River in Terengganu (Hwi *et al*., 2020), Klang River Estuary (Zaki *et al*., 2021), Langat Rivers (Suardy *et al*., 2020) in Selangor, Melayu River in Johor (Primus & Azman, 2022), and three rivers in East Malaysia; Kuching Rivers (Johnson *et al*., 2020), Miri River Estuary (Liong *et al*., 2021), and Baram River Estuary (Choong *et al*., 2021) in Sarawak. The lack of documented works pertaining to research on microplastics in the river waters of Sabah accelerates the need of conducting this study.

Recognizing the substantial reliance of local communities on rivers and coastal areas for vital resources such as water, sustenance, and other basic necessities in their daily lives and endeavours, it becomes imperative to assess the rising issue of microplastic pollution as a key indicator of river water quality in Sabah. The rivers in the Tuaran District, which originate from the headwaters of the Crocker Range Mountain and flow westward towards the South China Sea in Sabah, have played an important part in supplying fish and water for industrial, agricultural, and residential purposes in both the Tuaran and Kota Kinabalu Districts (Montoi *et al*., 2017). On the other hand, these river systems are important conduits for transporting pollutants such as microplastics from nearby inland sources into the marine environment (Liu *et al.*, 2021). The distribution and fate of microplastics in these rivers could be influenced by velocity changes and tidal influx (Choong et al., 2021; Jendanklang et al., 2023).

Conducting a study into the occurrence of microplastic within the rivers of Tuaran is a preliminary endeavour aimed at expanding our knowledge of microplastic pollution in the region of Sabah. Knowing the microplastic status of these rivers allows further mitigation efforts by relevant agencies to monitor and reduce their presence in the environment along with promoting more further extensive research on this research area. Therefore, the objectives of this study were primarily to determine the occurrence of microplastics in the waters of Mengkabong and Salut Rivers in Tuaran, Sabah, and to assess the spatial variability in the concentration and characteristics of microplastics within these rivers.

## MATERIALS AND METHODS

### Study Area and Sampling Stations

Tuaran District is located in the west coast division of Sabah, having a tropical humid climate with an average rainfall of 2,800 mm. The annual average population growth rate for Tuaran is 2.8%, with a current total population of 135.7 thousand people recorded residing latest in 2020 by the Department of Statistics of Malaysia (2022). Rivers from the Tuaran District were selected in this study as they are one of the most important rivers in Sabah for fishing and aquaculture activities. Moreover, the expansion of adjacent Kota Kinabalu and Sepanggar Towns pressurised the urbanisation of the Tuaran District from its increasing developments. Two tidal rivers were selected for this study namely Mengkabong River, situated adjacent to Tanjung Badak, and Salut River, located close to Kuala Karambunai. A total of eight sampling stations were selected, with each river having four sampling stations with approximately 2 km apart. Samplings were conducted during the period of high tide on 16th of February 2023 at Mengkabong River and on 15th of March 2023 at Salut River. Figure 1 shows the map of study area with sampling stations while Table 1 shows their sampling details.

**Water Sample Collection**

Bulk sample of 30 L of surface water was collected using a stainless-steel bucket and sieved using a 10 µm stainless sieve on field in a boat (Huang *et al.,* 2020). Retained materials were transferred into capped glass bottles using distilled water. All water samples were taken in triplicates for each station. All collected samples were taken to the Institute of Tropical Biology and Conservation (ITBC), Universiti Malaysia Sabah (UMS) for further laboratory analysis.

**Sample Analysis**

*Microplastics Extraction*

Microplastics were extracted from water samples by density separation method following Lin *et al.* (2018). Prior to microplastics extraction, organic matter in water samples were first digested using wet peroxide oxidation. Approximately 150 ml of 35% hydrogen peroxide ($H_2O_2$) were added to the glass bottles and incubated in incubator at 65 °C for 24 hours to aid in complete breakdown of organic matter. Digested samples were then sieved and rinsed with distilled water before pouring the residuals into 100 ml glass beakers using salt solution, 5 M of sodium chloride (NaCl). The salt solution was further added until the beaker’s mouth and covered loosely with aluminium foil.

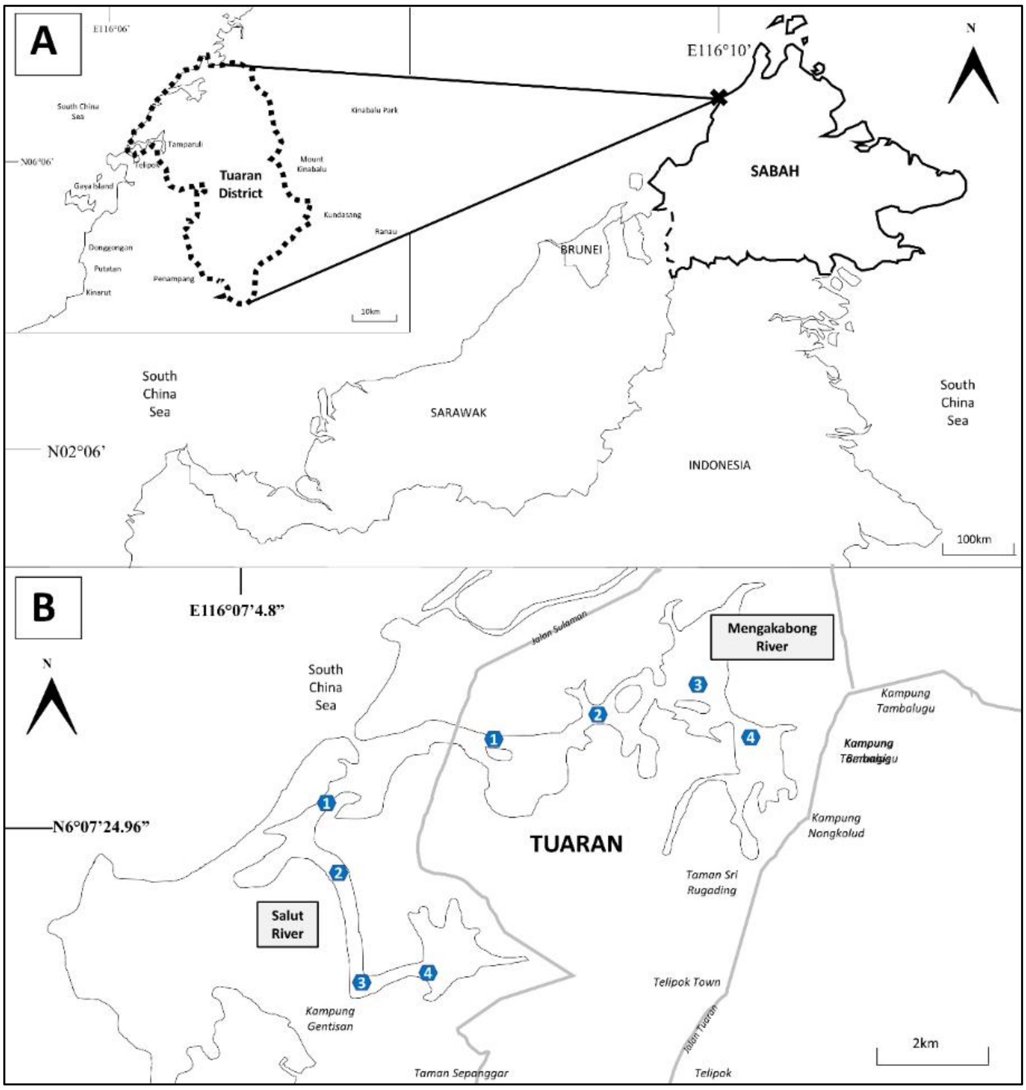


**Figure 1.** Map A: The map of study area of Mengkabong and Salut Rivers at Tuaran District of Sabah. Map B: Detailed sampling stations were indicated with blue circle and number for the stations

**Table 1.** Description of sampling stations and sampling regime

| River | Station | Depth (m) | Coordinates | Time | Observation |
|---|---|---|---|---|---|
| Mengkabong River (16-02-2023) | Station 1 (S1) | 6.5 | 06°08'27.2"N 116°09'42.0" E | 9.20 am | Downstream near Mengkabong Bridge |
| | Station 2 (S2) | 15 | 06°08'41.2"N 116°10'43"E | 1.00 pm | Clear, surrounded by mangroves |
| | Station 3 (S3) | 3 | 06°08'52.1"N 116°11'46.1" E | 11.58 am | Below village houses |
| | Station 4 (S4) | 2 | 06°08'32.2"N 116°12'18.9" E | 10.50 am | Upstream near to village houses, aquaculture and fishing activities. Observed waste dump near shore and floating plastic wrappers and bottles |
| Salut River (15-3-2023) | Station 1 (S1) | 3.17 | 06°04.037' N 116°09.025'E | 10.10 am | Located downstream at Kampung Batangan, nearby to Trombong bay |
| | Station 2 (S2) | 3 | 06°7'04.2"N 116°08'07.4"E | 1.30 pm | Located near to a fishing jetty and a construction area |
| | Station 3 (S3) | 2.6 | 06°5'59.5"N 116°8'19.3"E | 12.21 pm | Located near to residential flats |
| | Station 4 (S4) | 2 | 06°06'0.4"N 116°8'59.9"E | 11.28 am | Located at the upstream boundary of the mangroves |

The solution was allowed to settle overnight where the supernatant of the solution was then pump filtered through a 1.2 µm pore size glass microfiber filter (Whatman GF/C) the following day. The filter paper was placed in a clean glass petri dish and allowed to air dry before microscope examination. This process was repeated three times. Blank samples were prepared with distilled water and allowed to go through similar process as samples for quality control. To minimise external microplastics contamination from surrounding, only glass and stainless-steel equipment were used throughout microplastics extraction and examination in laboratory. Additionally, all equipment was rinsed with distilled water prior any microplastics analysis.

*Microplastics Examination and Identification*

In this study, microplastics were classified as plastic particles ranging from 10 µm to 5 mm in size. The size was further classified into two categories: small microplastics (SMP) that ranged from 10 µm to 1 mm, and large microplastics (LMP), which ranged from 1 mm to 5 mm. Microplastics were examined for visual identification, sorting, and counting process under a stereo microscope (Leica EZ24). Microplastics observed were sorted and classified according to shapes (fibre, filament, foam, fragment, pellet, and film) following Singh *et al.* (2022) and colours (black, blue, red, white, yellow, transparent) following Peng *et al.* (2017) as described in Table 2. All colours were noted based on the surface colour dominancy, with the exception of transparent, which was noted based on the colour of the patches (if any) to minimize overestimation of transparent microplastic due to discolouration. Polymer types were identified by using micro-FTIR (Nicolet iN10 MX) scanned with a spectral range of 4000-1200 $cm^{-1}$ in the ALS Technichem Laboratory, Malaysia. The spectrum obtained were compared with available libraries on established database on polymers type with quality matching more than 80%. Only one replicate at each station was conducted for polymer type analysis.

## Data Analysis

All data obtained during microplastics examination were recorded in concentration units of items/L. Prior to statistical analysis, all parameters were checked for outliers using boxplots, tested for normality using the Shapiro-Wilk's test, and examined for equality of variances using Levene's test. Normality and Levene's tests showed that the data was normally distributed and had equal variances ($p>0.05$). Therefore, a parametric test, the independent t-test, was used. Independent t-test was carried out to compare if there was any significant difference in microplastics concentration and characteristics between Mengkabong and Salut Rivers at $p$ value < 0.05. Next, Hierarchical cluster analysis was used to investigate the grouping of sampling stations based on the similarities of microplastics concentration and characteristics of shape, colour and size of microplastics. Ward's method using Euclidean distances as a measure of similarity and Z-score standardization of variables was used in this analysis. Output of the analysis was presented in a dendrogram with the cluster's number and linkage distances less than 60% was considered statistically significant. All statistical analysis was carried out using Statistical Software for Social Sciences (SPSS Version 25).

**Table 2.** Categories used in description and identification of microplastics

| Characteristic | Categories | Description | References |
|---|---|---|---|
| Shape | Fibre | A very thin threadlike straight structure | Singh *et al.* (2022) |
| | Filament | A thicker and harder straight structure | |
| | Foam | A sponge-like lightweight structure | |
| | Fragment | An irregular edge of hard structures | |
| | Pellet | A round spherical hard structure | |
| | Film | A thin layer plan of flimsy structure | |
| Colour | Black | Black, transparent black, grey and white-striped black | Peng *et al.* (2017) |
| | Blue | Deep blue, light blue, deep green, light green | |
| | Red | Red, purple, pink | |
| | White | Opaque white, silver | |
| | Yellow | Yellow, brown, orange | |
| | Transparent | Colourless | |

## RESULTS

### Microplastics Occurrence and Characteristics

Microplastics were present in all Mengkabong and Salut Rivers stations (Figure 2). The abundance of microplastics in Salut River water (4.78 ± 2.43 items/L) were three times higher than in Mengkabong River water (1.63 ± 0.87 items/L). Station 4 of Mengkabong River and Station 1 of Salut River waters recorded the highest number of microplastics, accounting 2.7 items/L and 6.5 items/L, respectively. The concentration of microplastics in the waters of the Mengkabong River displayed a decreasing pattern as it moved from the upstream station (Station 4) to the downstream station (Station 1). Conversely, the concentration of microplastics in the waters of the Salut River exhibited an opposite trend, increasing as it moved from upstream to downstream.

Both large size microplastics (LMP) and small size microplastics (SMP) were found in this study (Figure 3). Mengkabong River recorded 74% of LMP and the Salut River recorded 63% of SMP from their total counts. This pattern was similarly found in each respective individual station of the rivers, as depicted in Figure 4. Microplastics shapes observed in both rivers were fibre, film, fragment, and foam, as shown in Figure 5. There were no pellet or filament observed in any stations. Fibre was the most abundant shape in both Mengkabong River (78%) and Salut River (57%) (Figure 6). Microplastics colours in Mengkabong and Salut Rivers waters were black, blue, red, yellow, white and transparent (Figure 7). In Mengkabong, transparent (30%), blue (26%) and black (24%) microplastics were dominant. Meanwhile in Salut, black (42%) and yellow (30%) microplastics were dominant (Figure 8). Microplastics polymers detected in Mengkabong River were rayon (68%) and polytetrafluoroethylene (PTFE) (25%). Meanwhile Salut River recorded high percentages of polyethylene (PE) (34%), rayon (33%), ethylene propylene diene monomer (EPDM) (21%) and polyethylene terephthalate (PET) (9%) as shown in Figure 9.

### Spatial Variation of Microplastic Composition in Rivers

The results of independent t-test show that Salut River had significantly higher total microplastics (3.16 items/L, $p$ value ≤ 0.05), foam (0.02 mg/L, $p$ value = 0.04) and SMP (2.58 items/L, $p$ value = 0.02) than in Mengkabong River (Table 3). Microplastics showed spatial heterogeneity in the Mengkabong and Salut Rivers where the

Hierarchical cluster analysis test grouped the eight stations into four different clusters according to the abundance and characteristic of microplastics (Figure 10). In general, the river stations were clustered based on three categories where it goes from clean, moderate to most microplastic polluted rivers as it goes down from Clusters 1 to 4. Stations 1, 2, and 3 of Mengkabong River and Station 4 of Salut River were clustered together as Cluster 1. This cluster was the indicative of minimal microplastic pollution, with microplastics counts less than 1.9 items/L. These stations were also grouped together as they are shared the same similarities of clean surroundings. Cluster 2 indicates a moderate level of microplastic pollution, as evidenced at Station 2 of Mengkabong River, which documented high fibres (84%). Clusters 3 and 4 encompassed the remaining stations along the Salut River, that exhibit high microplastics counts (> 5.3 items/L) but distinct microplastics compositions. Both of these two stations were situated in close proximity to residential areas along the Salut River. Lastly, Station 2 of Salut River stands alone in cluster 4 because it had the highest percentage of fibre (80%), and large sized microplastics (51%). Additionally, the percentage of black colour (68%) microplastics were also higher than other stations.

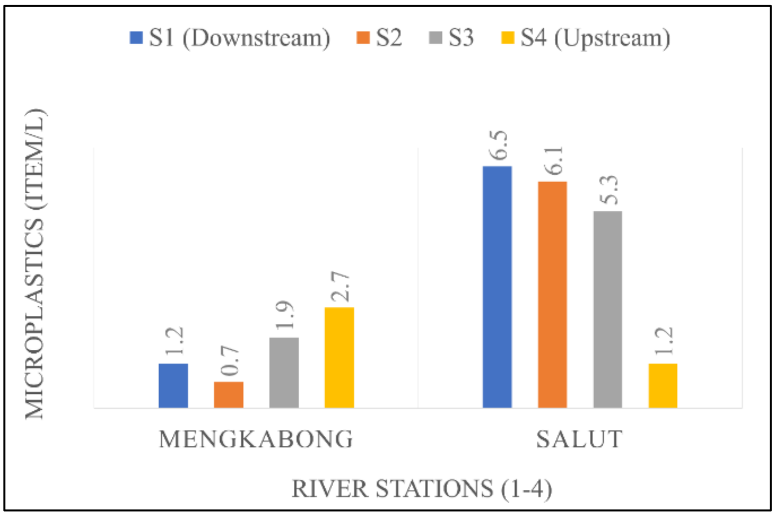


**Figure 2.** Microplastic concentration (items/L) in Mengkabong and Salut Rivers from downstream (S1) to upstream (S4) direction

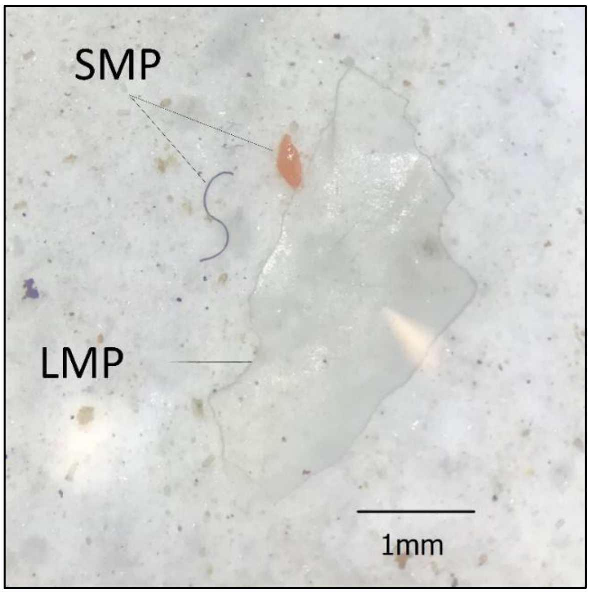


**Figure 3.** The difference between small sized microplastics (SMP) and large sized microplastics (LMP) observed in Mengkabong and Salut Rivers

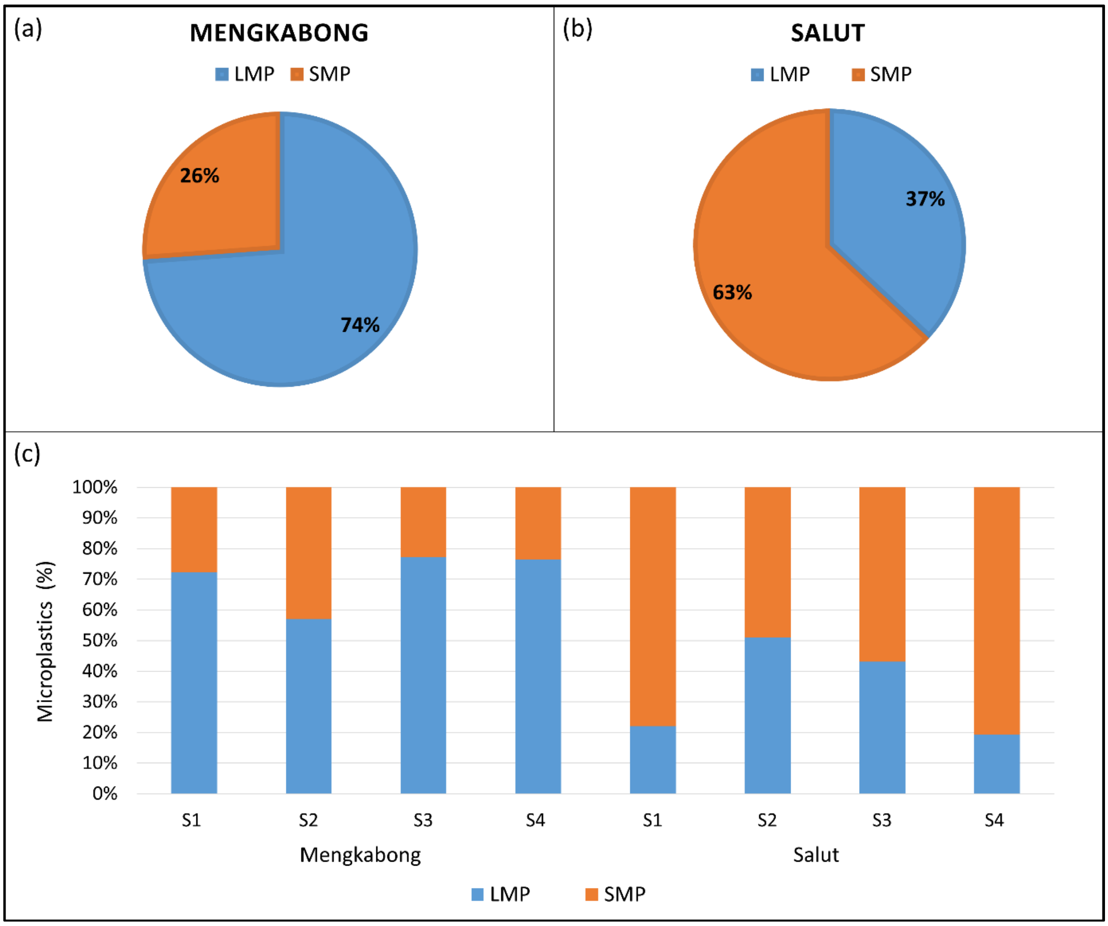


**Figure 4.** Composition of microplastics size observed in (a) Mengkabong River, (b) Salut River, and (c) individual stations of Mengkabong and Salut Rivers

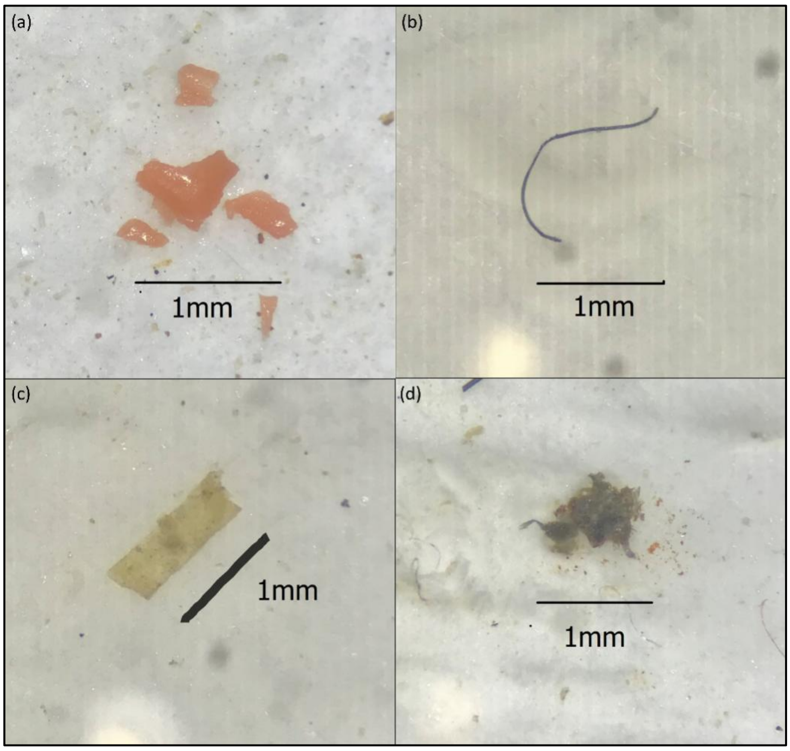


**Figure 5.** Examples of microplastics shape observed in Mengkabong and Salut Rivers waters, namely (a) fragment, (b) fibre, (c) film, and (d) foam

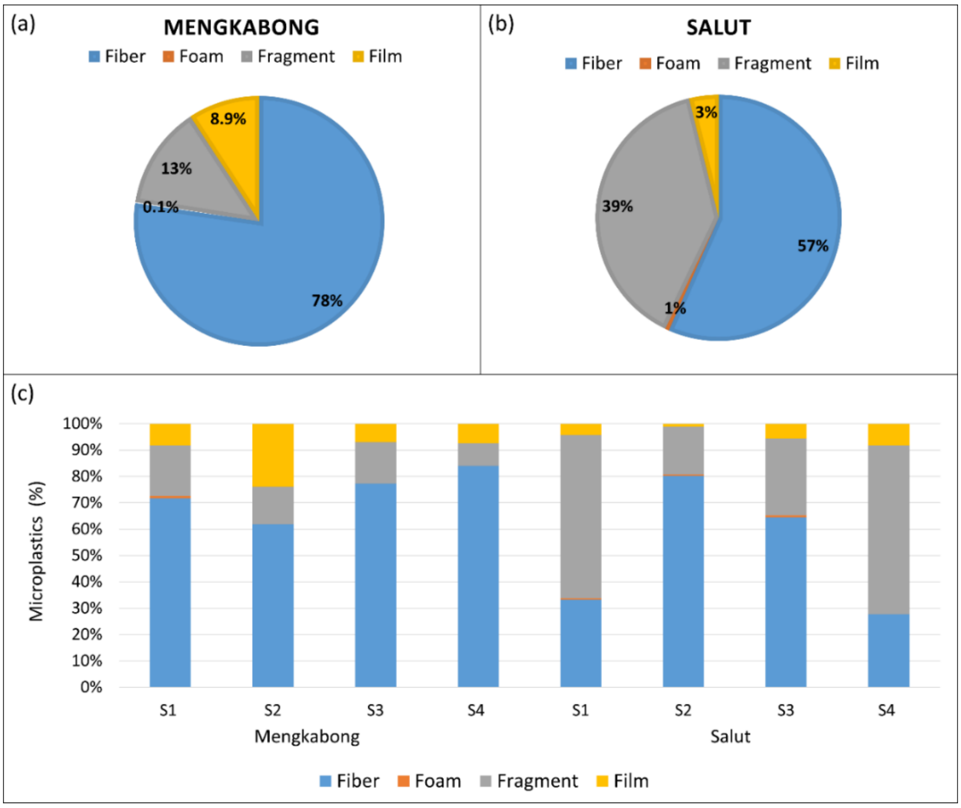


**Figure 6.** Composition of microplastics shapes observed in (a) Mengkabong River, (b) Salut River, and (c) individual stations of Mengkabong and Salut Rivers

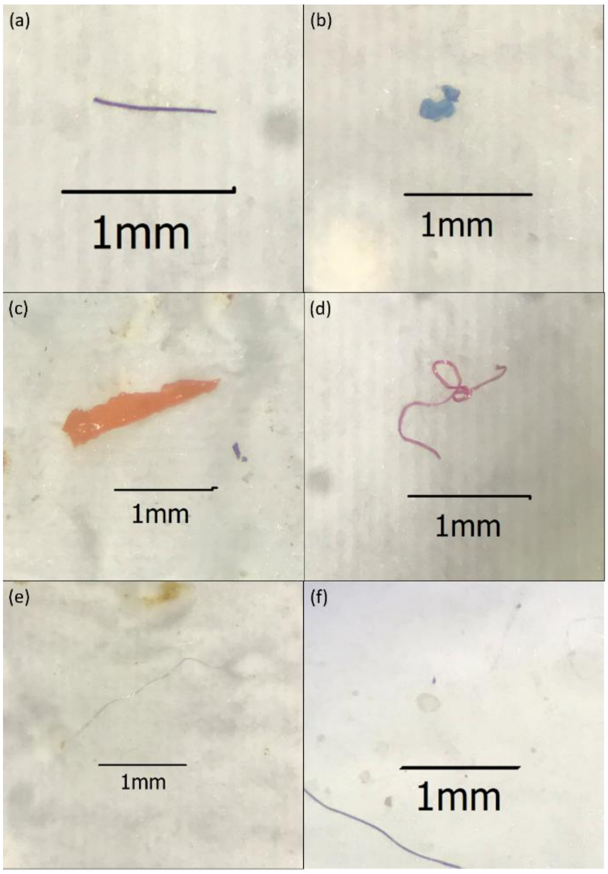


**Figure 7.** Examples of microplastics colour observed in Mengkabong and Salut River based on dominant colour categories; (a) black, (b) blue, (c) yellow, (d) red, (e) transparent, and (f) white

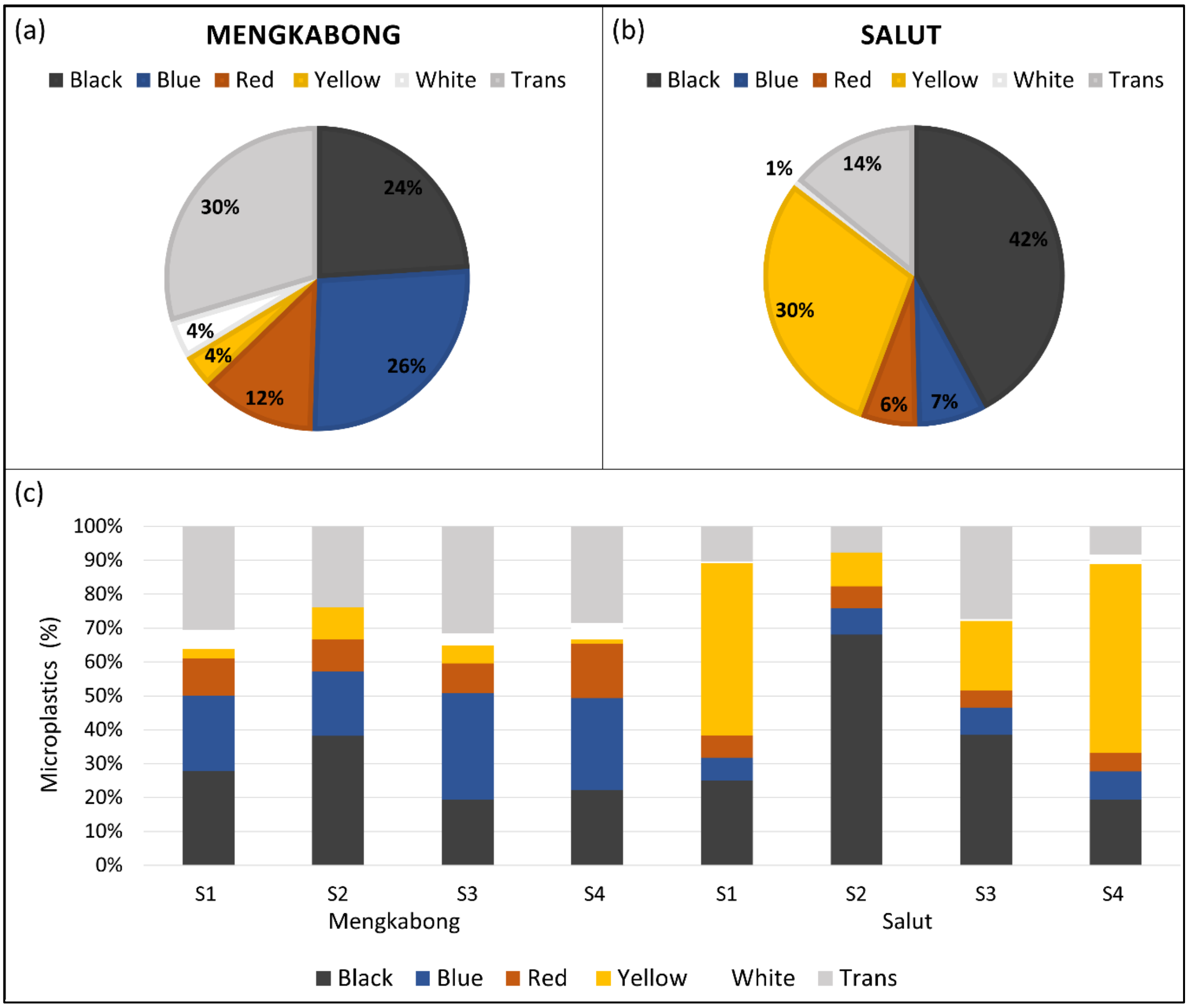


**Figure 8.** Composition of microplastics colours observed in (a) Mengkabong River, (b) Salut River, and (c) individual stations of Mengkabong and Salut Rivers

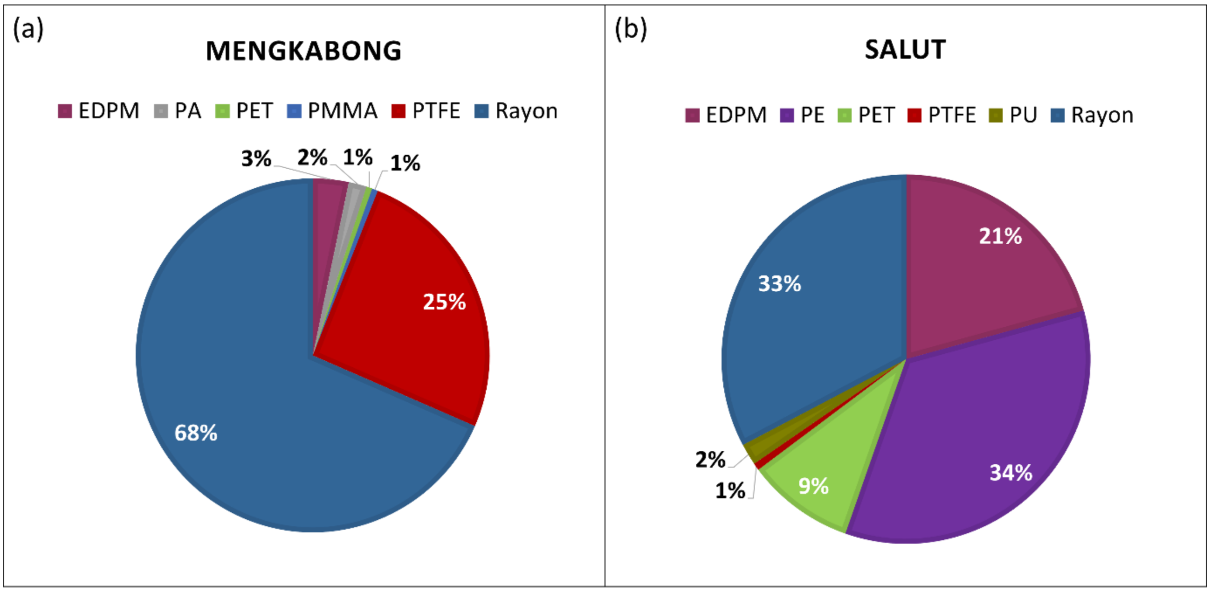


**Figure 9.** Composition of microplastics polymer type analysed by micro-FTIR in (a) Mengkabong River (b) and Salut River

**Table 3.** Mean difference of microplastics concentration and characteristics between the Mengkabong and Salut Rivers

| Parameters | | Mengkabong | Salut | Mean difference | *p* value |
|---|---|---|---|---|---|
| Total microplastics (items/L) | | 1.63 ± 0.87 | 4.78 ± 2.43 | -3.16 | **0.05** |
| Shape | Fibre | 1.26 ± 0.78 | 2.71 ± 1.93 | -1.45 | 0.21 |
| | Foam | 0.003 ± 0.01 | 0.03 ± 0.02 | -0.02 | **0.04** |
| | Fragment | 0.22 ± 0.08 | 1.87 ± 1.48 | -1.65 | 0.11 |
| | Film | 0.15 ± 0.04 | 0.18 ± 0.12 | -0.03 | 0.62 |
| Colour | Black | 0.39 ± 0.14 | 2.01 ± 1.61 | -1.63 | 0.09 |
| | Blue | 0.43 ± 0.28 | 0.36 ± 0.17 | 0.08 | 0.67 |
| | Red | 0.20 ± 0.16 | 0.29 ± 0.16 | -0.09 | 0.46 |
| | Yellow | 0.06 ± 0.03 | 1.42 ± 1.27 | -1.36 | 0.12 |
| | White | 0.07 ± 0.05 | 0.03 ± 0.02 | 0.04 | 0.19 |
| | Transparent | 0.48 ± 0.26 | 0.68 ± 0.58 | -0.19 | 0.57 |
| Size | LMP | 1.20 ± 1.0.72 | 1.77 ± 1.22 | -0.57 | 0.46 |
| | SMP | 0.43 ± 0.15 | 3.01 ± 1.67 | -2.58 | **0.02** |

Positive value of mean difference indicates parameter studied was higher in the Mengkabong River whereas negative value indicates parameter studied was higher in Salut River. The significant difference in mean was indicated in bold, $p$ value ≤ 0.05.

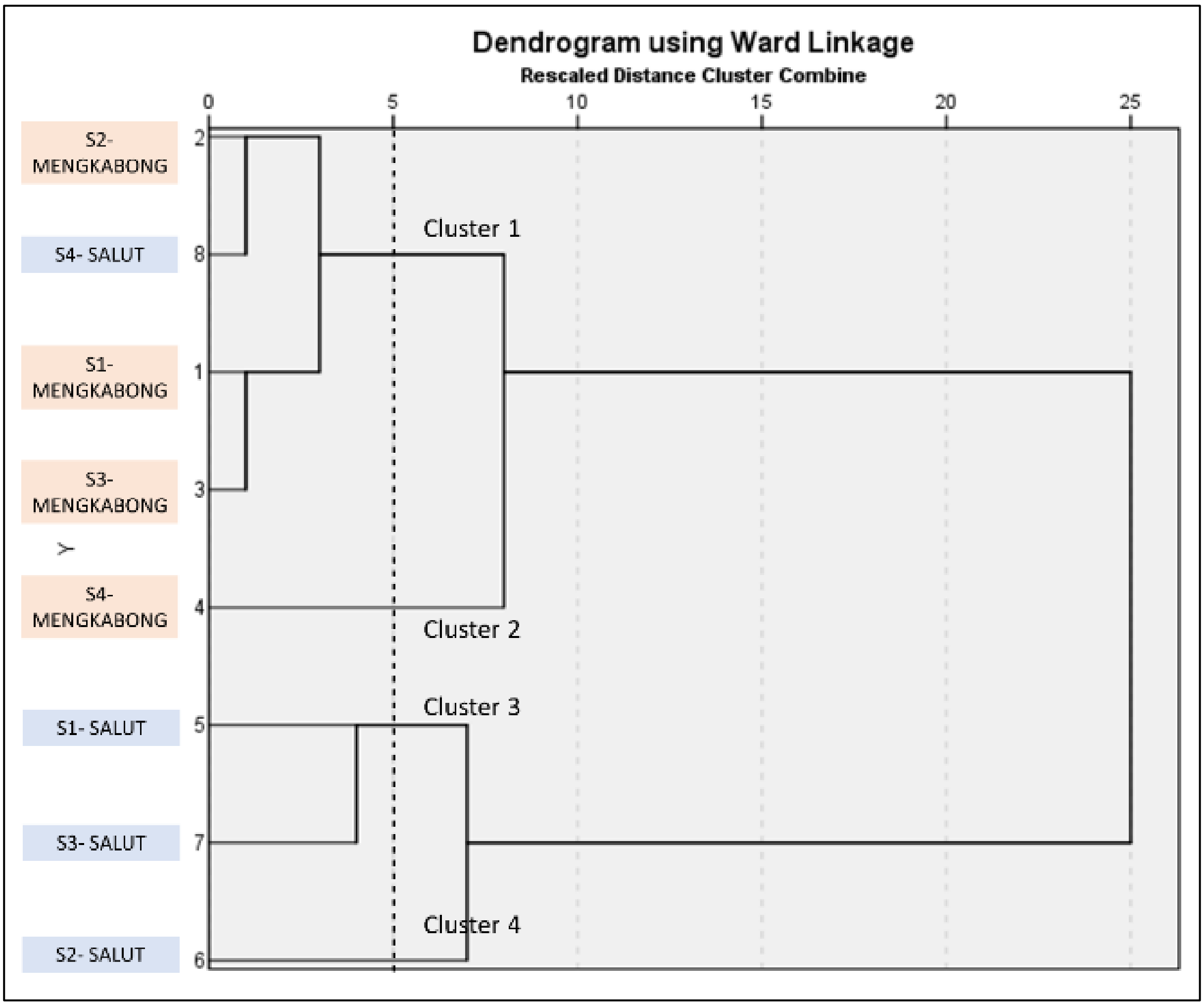


**Figure 10.** Clustering of the eight sampling stations of Mengkabong and Salut Rivers based on the similarities of microplastics concentration and characteristics. Red box on the left indicates stations in Mengkabong River and blue box for stations in Salut River.

## DISCUSSION

### Microplastic Pollution Status in Mengkabong and Salut Rivers

Microplastics have been documented to contaminate aquatic ecosystems worldwide, and the present study reveals that Sabah is no exception. Microplastics were found in both Mengkabong and Salut Rivers in the present study but in different level of pollution status. Microplastic in Salut River was significantly higher ($p$ value $\leq$ 0.05) compared to Mengkabong River. In addition, cluster analysis demonstrated that most stations in the Mengkabong River were grouped in the Cluster 1 indicative of minimal microplastic pollution whereas stations in Salut River were grouped into clusters indicative of moderate and high counts of microplastics. One of the main factors that affecting the pollution level is the adjacent land use. Salut River is more urbanised with developments compared to Mengkabong River leading to higher microplastics counts coming possibly from land-based activities such as increased residential, more notable industrial presence, and recreational developments compared to Mengkabong River. Salut River is also smaller and shallower than Mengkabong River thus, contributing to more concentrated microplastics influx per chance due to a reduced dilution (De Arbeloa & Marzadri, 2024). The observed trend of decreasing microplastic concentrations downstream in the Mengkabong River, contrasted with increasing counts downstream in the Salut River, can be attributed to the intensity of the land uses adjacent to the sampling stations. The substantial land utilization in the vicinity of the stations could serve as a notable origin of microplastics entering the nearby river waters. The closer the river with area of intense activities, the more pronounced the occurrence of microplastic in that specific waterway (Idrus *et al.,* 2022).

Given the lack of international or national regulations pertaining to microplastics pollution standards, this study undertook a comparison of microplastic in relation to similar studies conducted in tidal rivers or estuaries (Table 4). Overall, Mengkabong River in the present study recorded as the least polluted with microplastics while the microplastics count in Salut River waters were comparatively higher than rivers in Selangor (*Zaki et al.,* 2021) and Johor (Primus and Azman, 2022) but less polluted than rivers in Sarawak (Choong *et al*., 2021; Liong *et al.,* 2021), Vietnam and Thailand (Babel *et al.,* 2022). The relatively lower levels of microplastics in the current study can be ascribed to the existence of mangrove forests in the Salut and Mengkabong Rivers. Similarly, Zaki *et al*. (2021) demonstrated that lower microplastic count was observed at area covered with forests and mangroves with less anthropogenic activities at that vicinity. Primus and Azman (2022) also attributed the lower microplastics count at Melayu River, Johor, as that particular area was preserved for eco-tourism activities and surrounded by mangroves forest. Mangrove forest could act as a natural physical barrier that traps, captures and retains microplastics by filtration process of mangrove sediment and roots system and thus, prevents microplastics entry into the river waters from plastic waste released from adjacent land.

The low microplastics counts in the present study also attributable to a lower intensity of anthropogenic activity as compared to a more urbanized river. The Saigon River in Thailand and the Miri River Estuary in Sarawak, for instance, were loaded with high microplastics due to their urban setting and the extensive land utilization for residential purposes, commercial activities, aquaculture and fishing operations that contributes to source of microplastics (Liong *et al*., 2021: Babel *et al*., 2022). High microplastics presence in river waters in these urbanised areas were reported to be sourced from intense residential activities through everyday plastic use and disposal practices (Hwi *et al.,* 2020), industrial processes through manufacturing and wastewater discharge (Choong *et al.,* 2021), while fishing activities contributed through the degradation and fragmentations of plastic-based fishing equipment (Johnson *et al.,* 2020).

### Microplastics Characteristics and Their Potential Entry Sources

All microplastics in both present rivers were of secondary microplastics from the fragmentations of larger plastics as no pellets were recorded. It was observed that domestic wastes consisting plastics were piled up nearby the village houses while plastic bottles, wrappers and large fragments were seen floating in those river waters during sampling. Long exposure to direct sunlight and sufficient oxygen could lead to microcracking and embrittlement of surface plastic leads to fragmentations of these larger plastics into small sized microplastics following physical, chemical and biological processes (Qaisrani *et al.,* 2020). The initiated UV-induced photo-oxidation then continues with autocatalytic degradation, which reduces the polymer's molecular weight and weakens its structural integrity to more smaller fragmentations easily (Andrady, 2011). The elevated concentrations of SMP across all stations in the Salut River also may indicate a pronounced fragmentation process, leading to an increased abundance in the smaller size microplastics range (He *et al.,* 2020).

**Table 4.** Comparison of the microplastics concentration (Items/L) in river waters

| Location | Concentration (items/L) | Remarks | Reference |
|---|---|---|---|
| Mengkabong River, Sabah | 1.63 ± 0.87 | Surrounded mainly with mangrove forests with less anthropogenic activities except at village houses that has fishing activities. | ***Present study*** |
| Klang River Estuary, Selangor | 2.5 ± 2.00 | Urban areas of industrial, residential and fishing and ecosystem of mangrove forests. | Zaki *et al.* (2021) |
| Melayu River, Johor | 3.0 ± 0.00 | Reserved river for eco-tourism activities. Residential and fishing area surrounded by mangrove forests. | Primus and Azman (2022) |
| Salut River, Sabah | 4.78 ± 2.43 | Surrounded by anthropogenic activities along river such as villages, residential and fishing. | ***Present study*** |
| Miri River Estuary, Sarawak | 12.34 ± 1.54 | Upstream surface water runoff end point while residential, agricultural and industrial activities at river banks. Improper waste disposal: Vast plastic wastes of bags, bottles, containers reported in terrestrial environment. | Liong *et al. (*2021) |
| Baram River Estuary, Sarawak | 13.65 ± 4.65 | Illegal waste disposal with anthropogenic activities of fishing. Lower estuary comprises of large wood production industries and interisland ports and shipyards. | Choong *et al.* (2021) |
| Saigon River, Vietnam | 42.00 ± 5.00 | Low population density of new residential area and agriculture activities but has canal water influence that carries sewages. | Babel *et al.* (2022) |
| Chao Phraya River, Thailand | 48.00 ± 8.00 | Extensive urban area for industrial, aquaculture, fishing and residential activities. | Babel *et al.* (2022) |

The diverse and distinct characteristics of microplastics found in different stations are inherently linked to their respective sources, from which these pollutants originated. The highest abundance of fibres observed in both Mengkabong and Salut Rivers were hypothesized to originate from the fishing and aquaculture activities. Aquaculture activities of mussels and oysters were carried out in river waters at upstream (Station 4) of Mengkabong River while there was a fishing jetty at Station 2 of Salut River. Fishing equipment, such as fishing ropes, lines, and nets, are composed of fibres that could be released into rivers as a result of their breakdown during fishing operations (Zaki *et al*., 2021). Besides, the prevalence of fibres may also be contributed from the release of synthetic fibres from the domestic wastewater discharge that sips through filtration into watercourses (Chen *et al.*, 2021).

The occurrence of a substantial quantity of fibre has also been documented in previous studies such as the Melayu River in Johor (Primus & Azaman, 2022) and Cherating River in Pahang (Pariatamby *et al*., 2020). The lower density and high surface area to volume area of fibres compared to other microplastics shapes allows them to remain floating on surface water. Therefore, fibres tend to accumulate and become more prevalent in aquatic environments (Choong *et al.,* 2021). Contradictorily, the percentage of fragment was greater than fibre at Stations 1 and 4 in Salut River, due to the substantial fragmentation of plastics derived from domestic garbage coming from nearby housing villages (Zaki *et al*., 2021). Additionally, the elevated presence of foam in the waters of the Salut River may be traced back to the foam shape plastic used for furniture and mattresses, shoe soles and car seats from these domestic households, as supported by the polyurethane (PU) that found in the Salut River (Liong *et al.,* 2021).

Microplastics in river waters display a diverse array of colours, providing valuable insights into their transportation and sources. The observed colours of microplastics play a crucial role in deciphering their origin and subsequent transport mechanisms within aquatic ecosystems. The prevalence of transparent, blue and black colours in this study may stem from fishing activities, as fibres from fishing nets and lines exhibit the same colours. Corroboratively, there was a notable abundance of fibre in this study potentially sourced from the similar fishing activities. This emphasizes that the colours observed can serve as a secondary confirmation of the microplastics' origin after initially discerning the source based on microplastic shapes. Likewise, other research studies have recorded that colour assisted in determining the origin of microplastics whereby in their investigations, the transparent (Wang *et al.,* 2017; Hwi *et al.,* 2020), blue (Primus & Azman, 2022) and black (Liu *et al.,* 2021) colours were also identified as fibres sourced from fishing activities.

The present study revealed that rayon was the most abundant polymer type in the Mengkabong River, accounting for 68% of the total polymer types, and the second most abundant polymer type in the Salut River (33%). Rayon is semi-synthetic cellulose-based polymer fibres from artificial clothing, textiles manufacturing, bedding, linens and fishing nets supports those fibres possibly released from household clothing washing and fishing activities. Hwi *et al.* (2020) mentioned that if the particular rayon was material from the natural fibre, there would be an assignment band at 1,735 $cm^{-1}$ corresponding to C=O stretching of an ester. Notably, this peak was absent in the rayon spectrum (Figure 11) therefore verified that the they were not natural fibre and were an actual plastic derived polymer. Natural rayon is from animal and plants and is not considered as plastic. Man-made fibres chemically synthesised through the polymerization of plastic materials unlike the non-natural fibre rayon. A high percentage of PTFE microplastics (25%) was also found in the Mengkabong River. This polymer type of microplastics is commonly used in non-stick coatings for cookware and labware, implying that microplastics are soured from the domestic waste. Also, the fact that polyamide (PA) microplastics, which are commonly used in textiles, fishing lines, and nets, were found in the Mengkabong River lends credence to the idea that the fibres came from fishing or textiles (Zaki *et al.,* 2021).

In contrast, PE (32%) was the most abundant in the Salut River, and when combined with PET (9%) yields the highest percentage (41%) of plastic polymer type found in Salut River waters. PE are often used in manufacturing products such as packaging like plastic bags and films, containers for plastic bottles, pipes and plumbing components, toys and household items (Ezeudu *et al*., 2024). Similarly, PET is commonly utilized for more rigid packaging and containers, in addition to the application as polyester fibres used for clothing and textiles (Choong *et al.,* 2021). Additionally, EPDM, which is commonly used for automotive parts such as seals, roofing materials, and construction manufacturing (Liong *et al.,* 2021) was also abundant (21%) in Salut River. The presence of these polymer type microplastics suggests a possible origin from household appliances and construction materials from residential flats and a construction site spotted in Salut River.

**The Potential Ecological Impacts of Microplastic to Aquatic Ecosystems**

The occurrence of microplastics in the Mengkabong and Salut Rivers can pose an environmental hazard and health risk to the aquatic organisms inhabiting the rivers' ecosystem. The widespread dispersion of these microplastics makes their removal from the rivers challenging due to their small size properties. The microplastics in river waters can be transported to the ocean by currents (D'Avignon *et al.,* 2022) or deposited into river bottom (He *et al.,* 2019). The transportation of microplastics in river waters varies among rivers as it is greatly influenced by the hydrological features such as the overall topography, water flow and velocity as well as hydraulic parameters like depth and width of that particular river (Choong *et al.,* 2021). The present study is a preliminary endeavour with a one-time sampling in these rivers, hence, further studies on temporal and tidal variations of microplastics abundance in rivers should be conducted to better understanding the dynamic of microplastics in the rivers for better management plan.

The next alarming issue is that aquatic organisms such as fish (Primus & Azaman, 2022), zooplanktons (Amin e*t al.,* 2020) and invertebrates (Fachruddin *et al.*, 2020) can inadvertently ingest microplastics and mistake them for food. Both Mengkabong and Salut Rivers had the highest fibre which can be mistakenly ingested by these organisms that favours fibres shape microplastics due to the resemblances to their diet. For instance, Yasaka *et al.* (2022) discovered ingestion of fibres by two fish species, *Barbonymus altus* and *Laides longibarbis* were due to their threadlike resemblance of food to worms or zooplanktons. Numerous other studies have also shown that fibre is the highest microplastics shape extracted from fish (Lim *et al.,* 2023; Matupang *et al.,* 2023). Similarly, a study in the Bohai Sea, China, interestingly found microplastics being ingested by zooplankton were predominately blue fibres, likely due to the specific composition of microplastics in the area (Zheng *et al.,* 2020).

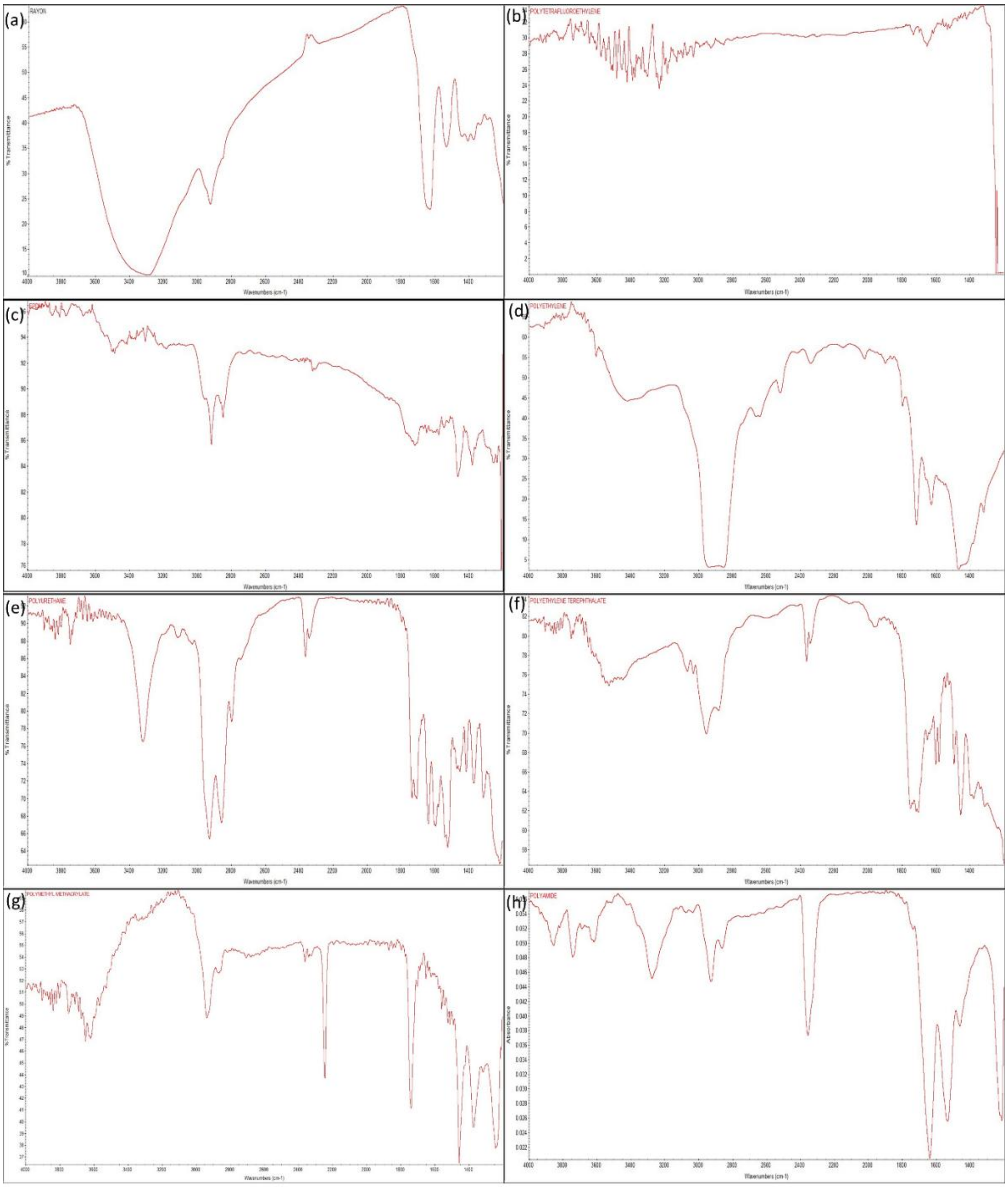


**Figure 11.** Micro-FTIR spectrum of polymer type (a) rayon, (b) polytetrafluoroethylene (PTFE), (c) ethylene propylene diene monomer (EPDM), (d) polyethylene (PE), (e) polyurethane (PU), (f) polyethylene terephthalate (PET), (g) polymethylmethacrylate (PMMA), and (h) polyamide (PA).

In addition to microplastic shape, studies have shown that microplastics smaller than 1 mm are frequently ingested by fish (Bianchi *et al*., 2020; Primus & Azman, 2022; Arshad *et al*., 2023), as well as by zooplanktons (Zheng *et al*, 2020) and invertebrates like mussels (Li *et al*., 2021). Consequently, the presence of a high number of small-sized microplastics in the water column of the Salut River may expose these organisms to a higher risk of ingestion. The presence of high numbers of transparent, blue and white microplastics in Mengkabong River waters and black and yellow microplastics in Salut River might be another risk factor to specific aquatic organisms that resembles their food preferences (Xiong *et al.,* 2019; Okamoto *et al.,* 2022).

The deposited microplastics in the benthic realm poses ingestion risk to benthic invertebrates too (Bertoli *et al*, 2022). Microplastic contamination levels in grazers and filter-feeders were found to be three to five times greater than in predators and omnivores with highest microplastics count recorded in bivalves followed by gastropods, polychaete, amphipods, and actinia in Terra Nova Bay (Sfriso *et al*., 2020). Although aquatic invertebrates capable of ingesting microplastics, invertebrate like mussel can expel 81-85% of the ingested microplastics through bio deposits (pseudofeces) within six days of depuration (Fernandez & Albentosa, 2019).

Lastly, both rivers in Sabah examined in this study showed a higher percentage of rayon in water. The rayon identified in this study was found to be synthetic fibres, and consequently, their effects on river waters are akin to those of fibre-shaped microplastics. Different polymer type of microplastics can pose different toxicity level to aquatic organisms based on their chemical structures and compositions (Laila *et al.,* 2020). Given all the potential risks of ingestion and toxicity, this study serves as a starting point to accelerate more research on the potential ecological impact of microplastic on native aquatic species in Sabah waters since microplastics were found in the present study.

## CONCLUSION

The present study demonstrated that the Mengkabong and Salut Rivers, located in Sabah, exhibits a low level of microplastics pollution. The microplastic concentrations in Salut River were significantly higher than Mengkabong River, which can be attributed to the greater level of development observed in the Salut River area. The microplastics found in both rivers were from the secondary microplastics and consisted primarily fibre, fragment, foam and film. The sources of microplastics in these rivers are mainly from domestic, fishing, and aquaculture activities. Microplastics showed spatial heterogeneity in the Mengkabong and Salut Rivers where the adjacent anthropogenic activities and land uses influence the abundance and characteristics of microplastics in rivers. Despite the low level of microplastic pollution, regular monitoring is necessary to evaluate the long-term pollution status of rivers and the potential ecological impacts of microplastics on aquatic organisms. This study can serve as a reference and a starting point to accelerate further research on microplastic pollution in Sabah rivers since there is confirmed presence of microplastics influx in the studied rivers.

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