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Research Article

Occurrence of Macro- and Microplastics on Pasir Pandak Beach, Sarawak, Malaysia

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Abstract

Pasir Pandak Beach is close to human settlements, resorts, and food stalls. It becomes a place for gathering of beachgoers especially during weekend. As a result, the beach became polluted with rubbish, particularly plastics (e.g., macro- and micro-plastics). Hence, this study was done to determine the occurrence of macro- and micro-plastics on the Pasir Pandak Beach, Kuching, Sarawak, Malaysia. Transect quadrat was used during the samples collection on the beach. The samples were then undergone the wet peroxide oxidation, filtering and classifying under dissecting microscope. Macroplastics were isolated for ATR-FTIR and SEM analyses, while microplastics were separated according to their sizes, colors, and types. Approximately 101.70 items/m² of macro-plastics and 1084 items/m² of micro-plastics were found in this study. Clean Coast Index (CCI) was also estimated and the calculated CCI value obtained was >20, which indicated as extremely dirty beach. Fragments of carpet/canvas/mat and hardware crate/item were the most abundance macroplastics found, followed by plastic ropes/fishing lines and bottle caps. HDPE, PES, PP, and PS were the main identified polymers. Fibers, filaments, fragments, and foams were identified for micro- and macro-plastics. Microplastics with smaller sizes of 0.25-0.50 mm were available abundantly and they comprise 63.47 % of the total microplastics found. Clear/white, black, and blue were the main colors for microplastics. SEM images presented that those adhering particles, grooves, pits, fractures, and flakes were the common patterns of degradation. No relationship was apparent between macro- and micro-plastics at each station. The abundance of macro- and micro-plastics showed that they were mainly controlled by the land-based input. As Pasir Pandak beach is busy with local communities and beachgoers, the presence of macro- and micro-plastics on the beach posing a severe threat for marine environment, thus further studies on the behavior of this emerging pollutant from beach to the seas are necessary.

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1. Introduction

Pasir Pandak is a fishermen village located at the Kuching District which has a beach facing the South China Sea. Pasir Pandak Beach is very close to human settlement and also a tourist area. Beach littering is one of the main problems leading to aquatic environmental issues such as threat to aquatic organisms and destroying their natural habitats and also reducing the beach esthetical value. Plastics, in many sizes, are the most abundant litters that can be easily spotted on this beach. Many beach cleaning programs were conducted for almost every month on this beach, but the problem was still occurring. Improper waste management and littering activities are believed to be the source of this problem.

According to IUCN (2021), the visible impacts of plastics debris are ingestion, suffocation, and entanglement of marine species such as seabirds, fish, turtles and even whales, which left them to die due to starvation and injuries. Beaches in Malaysia are under marine debris (particularly plastics) pollution threat but has received less attention in the past. This issue has affected the tourism industry badly. The fish-landing beaches have also severely suffered from the negative impacts of the plastics too (Fauziah et al., 2021). Wilson and Verlis (2017) obtained a number of plastics on the tourism beaches in Australia especially nearby the Great Barrier Reef. The distribution of plastics on these beaches were influenced by the current and wind patterns, and these plastic debris mainly were from the commercial fishing and shipping, recreational boat, and fishing activities. Indonesia has also suffered the impacts of plastic debris such as on the beach aesthetic, microbial assemblages, biodiversity ecosystems, economy, and human health (Purba et al., 2019). Entanglement of turtles, baleen whales, toothed whales, dolphins, and dugongs were observed in several coastal areas of Indonesia due to the plastic ropes and ghost fishing.

Plastics on the beach can be defined based on their sizes: macro-, meso-, and micro-plastics. Macroplastics are plastic debris that have sizes more than 20 mm (Noik and Tuah, 2015; Wahyuningsih et al., 2018; Napper and Thompson, 2019) or 25 mm (Lee et al., 2013; Blettler et al., 2017; Bancin et al., 2019), and easy to spot due to their clear visibility, hence, easy to remove (Jeyasanta et al., 2020). Macroplastics can be broken down into small fractions due to various factors, such as, the weathering and UV radiation processes (Wagner et al., 2014). This fraction is called mesoplastics and microplastics. The plastic fractions that have sizes between 5 and 20 mm are classified as mesoplastics.

Microplastics are generally defined as plastics that have a smaller size range of less than 5 mm, usually buried inside the sand/sediment. These plastics (macro-, meso- and microplastics) become a persistent environmental threat when they enter the aquatic ecosystems, such as marine, especially the microplastics. Numerous studies were reported animals that have ingested or been entangled in microplastics, such as, zooplankton (Frias et al., 2014; Cole et al., 2013), fish (Jovanovic, 2017; Lusher et al., 2013; Foekema et al., 2013), seabirds (Tanaka et al., 2013), marine mammals (Lusher et al., 2015), and turtles (Santos et al., 2015; de Carvalho et al., 2015).

Plastic debris are often easily seen on the beach, especially if the beach is close to a settlement area. Most beaches in Sarawak, Malaysia, are located in rural or sub-urban areas, and have poor waste disposal systems. Research on plastic debris on the beaches in Malaysia is in the growing stage, such as, at the Santubong and Trombol beaches in Kuching (Noik and Tuah, 2015), Seberang Takir and Batu Burok beaches of Kuala Terengganu (Fauziah et al., 2015), Teluk Kemang and Pasir Panjang beaches of Port Dickson (Khairunnisa et al., 2012), Sebatik Island, Sabah (Estim and Sudirman, 2017), Strait of Johor (Matsuguma et al., 2017), Penang Island (Vin et al., 2020), Penarik, Pengkalan Atap, Rantau Abang and Ma' Daerah beaches of Terengganu (Hamza et al., 2020), Kuala Perlis (Lee et al., 2020) and Setiu Wetland, Terengganu (Ibrahim et al., 2021).

Despite the global and transboundary problem caused by the plastic debris, only a handful of studies have been conducted on the occurrence of macro- and micro-plastics on the beaches facing the South China Sea, especially from the Malaysia Borneo (e.g., Sarawak and Sabah) (Harris et al., 2021). Previous studies conducted on Pasir Pandak beach were concerning on marine debris (Mobilik et al., 2014; 2016), which were not specifically focus on small size plastic debris (i.e., macro-, micro-plastics). Hence, this study can be used as a baseline for future reference of macro- and micro-plastics on the sub-urban beach dataset.

Therefore, the objective of this study was to determine the occurrence of macro- and micro-plastics on the Pasir Pandak beach in Sarawak, Malaysia.

2. Materials and Methods

2.1 Study Area

This study was carried out on 8th December 2018. Pasir Pandak Beach, Sarawak is located in a sub-urban area about 25 km from the Kuching City



Figure 1. The sampling site at Pasir Pandak beach, Sarawak. S1-S8 were the sampling locations. Each station was separated about 100 m. S7 and S8: closed to human settlements, rocky shore, and some mangrove trees; S1-S3 are related to the resort and tourism; S4-S6: near to food stalls and se Inset: The study sites were plotted on the Malaysia’s map with the blue sign. (Map: Google Earth)

approximate beach length of 1.2 km and 50 m width (Mobilik *et al.*, 2014), connected with the Salak River and the Santubong River mouths. The samples of plastics were collected along the Pasir Pandak beach which divided into eight sampling stations (Figure 1) and their coordinates were recorded starting from 1° 41’ 30” N, 110° 18’ 31” E and end at 1° 41’ 45” N, 110° 18’ 31” E (Table 1). Each sampling station was separated with an approximate of 100 m and three spatial replications with a distance of 10 m were determined within high tide water level area (Figure 2).

2.2 Method Samples Collection and Analysis of Macroplastics

The plastic debris were collected from the sampling sites were classified as macro- (>25 mm), meso- (5mm to 25 mm), and micro- (< 5mm) plastics, based on their size ranges. However, mesoplastic was not found during our sampling, therefore, it was excluded in our study. Line transects according to Lippiatt *et al.* (2013) were used, where the transect area was kept at 1000 m² with fixed length of 100 m and breadth of 10 m (Figure 2) as reported in Noik and Tuah (2015) and marked with a GPS receiver (GPSMAP® 62 series). Macroplastic samples were taken from six sampling quadrats of 50 x 50 cm that were positioned along the line of the macro

debris transects. The researchers recorded the data along the transect lines and collected all visible macro-plastics in an individual stainless-steel bucket and were brought back to the laboratory. In the laboratory, the collected samples were sorted, washed, dried, weighed, counted, and classified sequentially into categories based on their functional (Lippiatt *et al.*, 2013), such as, plastic bottles, food wrappers, and ropes; morphology and physical appearance (Idrus *et al.*, 2022), and color.

The macroplastic samples were recorded as number of item per m² (items/m²). The occurrence of macroplastic items (number of items/m²) was estimated by using the method of Lippiatt *et al.* (2013) (Equation 1):

$$c = \frac{n}{w \times l} \quad (\text{Eq. 1})$$

Where, *c* is the occurrence of debris items (no. of debris items/m²); *n* is the number of macro-plastic items observed; *w* is the transect width (m) and *l* is the transect length (m).

2.3 Collection and Analysis of Microplastic Samples

Microplastics were collected from the high

tide line of the macroplastic transects by 50 x 50 cm quadrats. Once the quadrat location was confirmed, surface sand sediment was collected in every quadrat, and were placed in Duran glass bottles. The sand was sieved through a 5 mm mesh stainless steel sieve (Lee et al., 2015), and the particles that passed through the sieve were washed to remove the adhering sand. Then, all particles that passing through the sieve were collected (with size <5 mm). In the laboratory, approximately 50 g of sand samples was treated with wet peroxide oxidation by using ~30 mL of 30 % H₂O₂ at the 75 °C for 30 minutes, to degrade labile organic matter (Hendrickson et al., 2018). Once the reaction was visually effervescing, the samples were cooled to room temperature to let the reaction subside. Then, the samples were visually assessed for the presence of further organic material. If organic material persisted, another 20 mL of 30 % H₂O₂ was added with subsequent heating (30 min, 75°C), and this step was repeated until all organic material disappeared (Masura et al., 2015). After the oxidation was completed and cooled at room temperature, the supernatant water was then filtered with a Millipore vacuum pump, onto Bioflow (~0.4 mm pore: diameter of 47 mm), in order to recover floating plastic debris (Frias et al., 2016) and were placed in individual glass Petri dish with lid. The filters were observed under a dissecting microscope at 10 – 40x magnification and photographed (Motic digital stereo microscope).

The microplastics were classified into different size groups, based on their individual morphology and their physical appearance (Idrus et al., 2022): microplastics were classified as fibers, filaments, foams, and fragments. Fiber has a slender-shaped, long, and fibrous

line; filament is defined as thin thread-like structure; foam has a light and soft feature; and fragment is described as hard and jagged piece resulted from degraded plastic items (Idrus et al., 2022). Microplastic color was also recorded based on the dominant colors.

2.4 Verification of Plastic Fragments using ATR-FTIR and SEM Analyses

The polymers of the macroplastic samples were identified by using the ATR-FTIR (Thermo Scientific). Spectra ranges were set at 4000 – 400 cm⁻¹. The resulting spectra were directly compared with the available reference library databases (Hummel Polymer Library spectra). Microplastics were not accounted for the ATR-FTIR analysis in this study due to the size limitation. Morphology of macroplastics of more than 5000 μm were also observed using the SEM (JOEL) to identify the surface textures.

2.5 Quality Control Procedure

Background of samples contamination were minimizing during the sampling and laboratory works by keeping the glass sample containers closed, avoiding of using fibers clothing and preventing of using the plastic containers to store the samples. The stereo microscope room was always cleaned prior to sample analysis. Glass Petri dishes were used to keep the filters until the FTIR analysis or the SEM analysis. Other surrounding factors such as less people were allowed to enter the laboratory during the analysis were done. All windows and doors were kept closed too during the analysis to avoid contamination from the air.

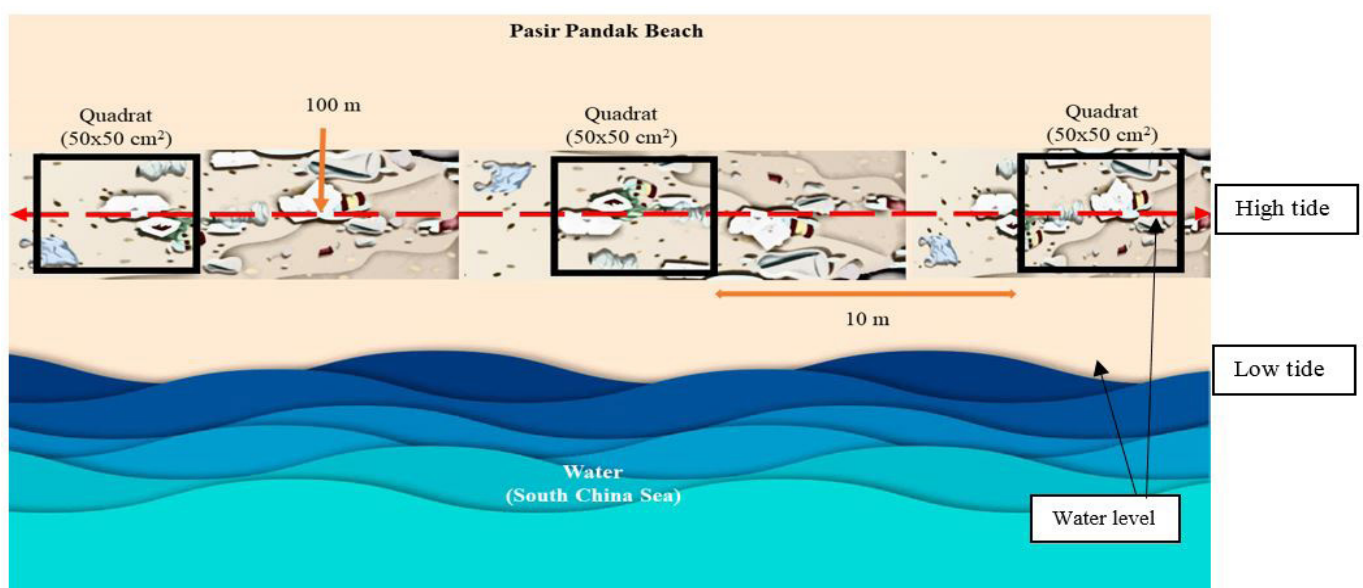


Figure 2. Samples collections were conducted in three replicates (R1-R3) were determined within high tide water level area. Each sampling station was separated by 100 m.

Table 1. Coordinates of the sampling stations

| Station | Longitude (N) | Latitude (E) |
|---------|---------------|--------------|
| 1 | 1° 41' 30" | 110° 18' 10" |
| 2 | 1° 41' 32" | 110° 18' 13" |
| 3 | 1° 41' 34" | 110° 18' 17" |
| 4 | 1° 41' 36" | 110° 18' 21" |
| 5 | 1° 41' 38" | 110° 18' 24" |
| 6 | 1° 41' 40" | 110° 18' 27" |
| 7 | 1° 41' 42" | 110° 18' 29" |
| 8 | 1° 41' 45" | 110° 18' 31" |

2.6 Beach Cleanliness Index

Assessment of the beach cleanliness was done by applying the Clean Coast Index (CCI) calculation in this study (Alkalay *et al.*, 2007; Jeyasanta *et al.*, 2020) as shown in Equation 2:

$$CCI = CM \times K \quad (\text{Eq. 2})$$

Where, *CM* is the density of macro-plastics (items/m²); and *K* is a constant that is equal to 20 (Jeyasanta *et al.*, 2020). The *K* value was set to 20, referring to the Mediterranean context (Portman and Brennan, 2017). The beach cleanliness was classified from 'clean' to 'extremely dirty' according to the scale provided. The CCI scale will follow this value: 0 – 2 indicates very clean beach, 2 – 5 is clean beach, 5 – 10 means moderately clean, 10 – 20 is dirty beach and if > 20 indicates the extremely dirty beach.

2.7 Statistical Analysis

One-way analysis of variance (ANOVA) was done to determine the differences among individual sampling stations in the occurrence of macro- and micro-plastics. The significant level was set to $p = 0.05$. It was hypothesized that majority of the microplastics on this beach came from the macroplastics degradation. Therefore, a linear regression analysis was also conducted to test the significant correlation among the macro- and micro-plastics. All statistical analyses were performed in SPSS v.20 (SPSS Inc., Chicago, IL, USA).

3. Results and Discussion

3.1 Macroplastics

The number of macroplastics obtained in this study were in a range of 40 - 1470 items/100 m² (Table 2), following this trend: Station 8 > Station 7 > Station

4 > Station 5 > Station 6 > Station 3 > Station 2 = Station 1. There was a significant difference in the number of macroplastics ($p < 0.05$) among the study locations. Stations 7 and 8 were very close to the villagers' residential area and has a rocky shore with some mangrove trees. Hence, it is easy to trap marine litters (particularly plastics) during tides (high and low tides). Moreover, these stations were also the minor fish landing area and the fishermen's route to the sea from their village. Many human activities were spotted close to these areas such as boat and fishing net repairing, and fish landing activities, which litters the beach with pieces of fishing ropes (12.75 %) and plastic bag (2.03 %). Nonetheless, the pieces of the fishing nylon and PE ropes may also possibly come from the abandoned or lost fishing net from the sea, since about 10 % of the beach littering were expected to come from the sea (Ryberg *et al.*, 2019; Lechthaler *et al.*, 2020). In the previous research by Mobilik *et al.* (2014), they suggested that about ~30 % debris that they found were from the sea. However, their works were not only focused on the plastic debris, but include all marine debris such as metal, glass, wood, and rubber. During our sampling, we spotted a house renovation work was carried out nearby Station 7 and located very close to the beach too, hence, there was no surprise that we found a lot of hardware crates/items (15.70 %) and pieces of plastic canvas/carpet/mat (13.03 %). Overflow of plastic carpet/canvas/mat pieces (1.26 %) and the hardware crates/items (1.54 %) were also spotted at Stations 5 and 6.

According to Lechthaler *et al.* (2020), around 75 % of the macroplastics that entered the coastal areas are via the land-based entry such as the littering (e.g., general littering, littering by tourists and event activities), industrial activity (e.g., construction and demolition work, agricultural and other industries), improper waste disposal and landfills. There is a possibility that plastic debris on this beach originated via the rivers nearby (e.g., from the Salak River and Santubong River). Fok and Cheung (2015) in their study found that plastics obtained on the Hong Kong beaches came from the nearby river, Pearl River. Plastic debris from rivers can be transported towards the sea by the turbulent river flow and flood events (Lebreton *et al.*, 2017). Stations 5-8 witness more anthropogenic activities other than fisheries, such as the dumping of household wastes. Fragments of dishwashing/detergent bottles (6.87 %) and diapers (6.45 %) were dominant in these sites. Other items such as straws (4.63%), drinking bottles (2.80%), shampoo/shower gel bottles (0.28%), toothpaste/ointment packets (0.28%), medicine bottles (0.84%), and fabrics (0.28%) were also observed. In Stations 4 and 5, the macroplastics obtained in these sites were related

to the local food and beverage stalls that contributed of the drinking bottle caps (7.85%), icebox fragments (3.50%), food containers (3.08%), food wrappers (0.70%) and straws (0.42%). Meanwhile at Stations 1-3, on our field observation, these sites seemed to have the least anthropogenic contamination of the plastic debris on the beach, probably because they are located nearby the family park resort, which has a frequent beach clean-up by the management of the resort. Macroplastics that were found at Stations 1-3 were mostly from the visitors that came for picnics, such as, plastic bags (0.85%), drinking water bottle caps (0.56%), baby diaper fragments (0.56%), food wrappers (0.28%), and shampoo/shower gel bottles (0.14%). Approximately 2.10% of waste was polystyrene foam food.

The percentages of the macroplastic ranges from 1.40 % (at Stations 1 and 2) to 51.51 % (at Station 8) (Figure 3). These values were lower than obtained by Zhao et al. (2015) (~75 %) on the six tourism beaches around the South China Sea. Fauziah et al. (2015) also found ~73 % macroplastics compared to other sizes of

plastic debris on Batu Buruk, Seberang Takir, Tanjung Aru, and Teluk Likas beaches that faces the South China Sea. Other studies such as by Topçu et al. (2013) along the sandy beaches of the Turkish Western Black Sea reported values of 0.085 to 5.058 items/m². Our values were also higher than Jeyasanta et al. (2020) which recorded a range of 0.138 – 0.616 items/m² macroplastics on the Tuticorin beaches, India. Macroplastics that recorded in Kuala Perlis (0.00167 – 0.00402 items/m²) and selected beached at the Penang Island (~0.05 to ~1.5 items/m²) were also lower (Lee et al., 2020) than our values. However, our values were considered low compared to Maharana et al. (2020) which recorded around 21.6–195 items/m² on the beaches along the Maharashtra coast, India, and with Manullang (2019) that recorded around 0.722 to 68.8 items/m² at the Ambon Bay, Indonesia.

Due to the high amount of macroplastics on the Pasir Pandak beach, CCI was used to assess the level of cleanliness of this beach. The calculated CCI value obtained was >20, which indicated as extremely dirty

Table 2. Macroplastic items based on their function recorded at every sampling station (transect area = 100 m²)

| No. | Macroplastic items found | Number of macroplastic items observed | | | | | | | |
|-----|------------------------------|---------------------------------------|----|----|-----|----|----|-----|-----|
| | | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 |
| 1 | Plastic bag | 24 | | | | | 16 | 32 | 26 |
| 2 | Drinking bottle | | | | | | | 12 | 68 |
| 3 | Carpet/canvas/mat | | 12 | 8 | | 12 | 24 | 112 | 260 |
| 4 | Shampoo/shower gel bottle | | 4 | | | | 8 | | |
| 5 | Toothpaste/ointment packet | | | | | | | 8 | |
| 6 | Plastic lighter | | | | 28 | | | | |
| 7 | Plastic rope/fishing line | | | | 12 | | | 196 | 156 |
| 8 | Bottle cap | 16 | | | 224 | | | | 84 |
| 9 | Food container | | | | 24 | 64 | | 28 | 116 |
| 10 | Medicine bottle | | | | | 8 | | 16 | |
| 11 | Detergent/dishwashing bottle | | | | | 32 | | 24 | 140 |
| 12 | Pen/pen cap | | | | | 24 | | | |
| 13 | Icebox | | | | 20 | 80 | | | |
| 14 | Food wrapper | | 8 | | | 20 | | 24 | 20 |
| 15 | Diaper | | 16 | | | | 84 | 16 | 84 |
| 16 | Hardware crate/item | | | | 4 | | 44 | 20 | 380 |
| 17 | Fabric | | | | | 4 | | | 4 |
| 18 | Straw | | | | | 12 | | | 132 |
| 19 | Disposal foam container | | | 60 | | 4 | | | |

beach. The highest CCI value is at Station 8 (CCI=1030) followed by Station 7 (CCI=342), Station 4 (CCI=219), Station 5 (CCI=182), Station 6 (CCI=123), Station 3 (CCI=48) and Stations 1 and 2 (CCI=28). The highest CCI value was obtained for the stations that located close to the human settlement area (Station 8). This high CCI value is similar to the values shown by [Jeyasanta et al. \(2020\)](#), in the selected beaches of the Southeast India ([Vlachogianni, 2019](#)) and in some Mediterranean beaches.

The most abundant polymer found was HDPE (51.04%), followed by polyester (PES) (21.30 %), and polypropylene (PP) (17.80%) ([Figure 4](#)). Polystyrene (PS) (5.75 %), polyamide (PA) (3.08 %), and LDPE (2.73 %) were the least abundant polymers found along this beach. PES, PE, PP, and PS are the most frequently found polymers on this beach ([Figure 5](#)). These results are similar with [Noik and Tuah \(2015\)](#) findings on Trombol and Santubong beaches in Kuching, Sarawak. Plastic polymer degradation processes work in tandem with abiotic and biotic processes ([Chamas et al., 2020](#)). Plastics degradation occurred through physical degradation and chemical degradation. Long exposure to heat and

waves can induce chemical changes in plastic polymers causing the loss of their original properties by reaction with oxygen, free radicals, the formation of oxidation products, and carbon dioxide. The polymer properties have deteriorated gradually as the polymeric chain breaks the plastic's size into smaller particles ([Oliveira et al., 2020](#)) and faded their original colors. Bacteria and fungi can colonize the degraded polymer surface and polymer enzymatic reaction can occur through hydrolysis, which creates biofilms ([Yuan et al., 2020](#)). Biofilms lead to the plastic further damage, loss of stability; rendering it fragile, and water can eventually penetrate the polymer, resulting in decomposition ([Yuan et al., 2020](#)). Plastics are widely known to have a slow degradation process in the environment ([Chitaka and von Blottnitz, 2019](#); [Maurya et al., 2020](#)), but the findings obtained by [Weinstein et al. \(2016\)](#) showed that the degradation process of plastics polymers (e.g., HDPE, PS, and PP) are faster in the subtropical coastal area, as quick as 8 weeks. This degradation process also causes a reduction in the weight of the plastics, it was suggested that this weight loss was the result of microplastic particles release ([Weinstein et al., 2016](#)).

The macroplastic found were in the shape of fragment (88%), foam (6.8%) and fiber (4.9%), that existed in several colors, such as blue (31 %), white (14 %), yellow (13 %), clear (11 %), green (10 %), brown (6 %), purple (6 %), grey (4 %), red (3 %), pink (3 %), and orange (1 %) ([Figure 6](#)). Clear plastics seemed to be due to the breakdown process where the plastic wastes were exposed to the UV radiation and mechanical stress caused by the wave movement at the beach ([Lechthaler et al., 2020](#)). [Duncan et al. \(2021\)](#) reported that clear (36 %), white (36 %), green (16 %), and blue (16 %) were the dominant colors found in turtle stomachs from the Pacific Ocean regions, with the most common polymers identified were PE (58 %) and PP (20.2 %). These ingested plastics were usually found as hard fragments (52 %), filaments (52 %), and plastic sheet (38 %) with sizes from about 5 mm to approximately 220 mm.

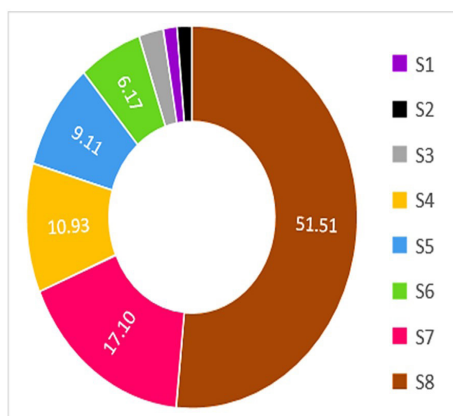


Figure 3. Concentration of macroplastics at the sampling stations (S=station) in percentage (%). S1-S3 were recorded the minimum amount of macroplastics with S1=S2=1.40 % and S3=2.38 %.

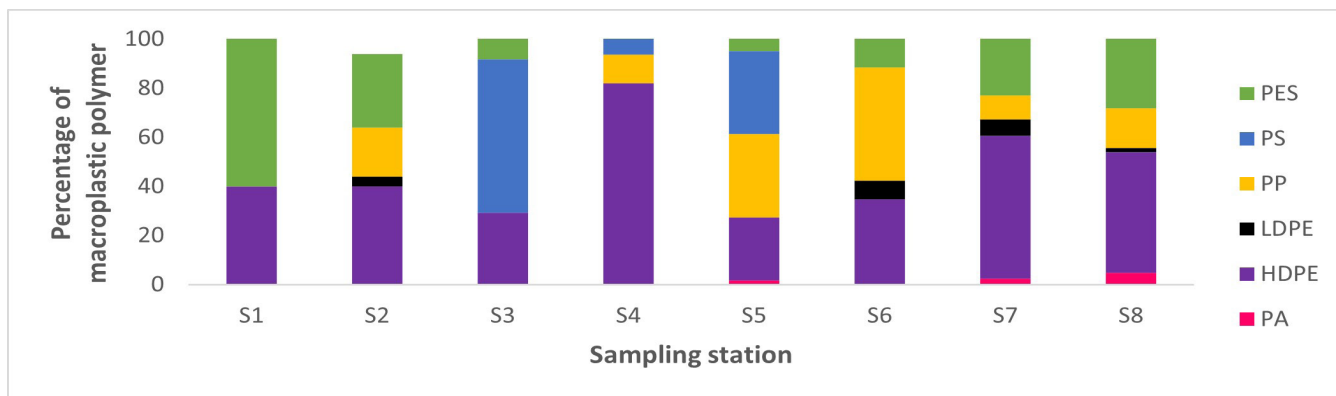


Figure 4. The polymer distribution (%) of the macroplastic at each sampling station.

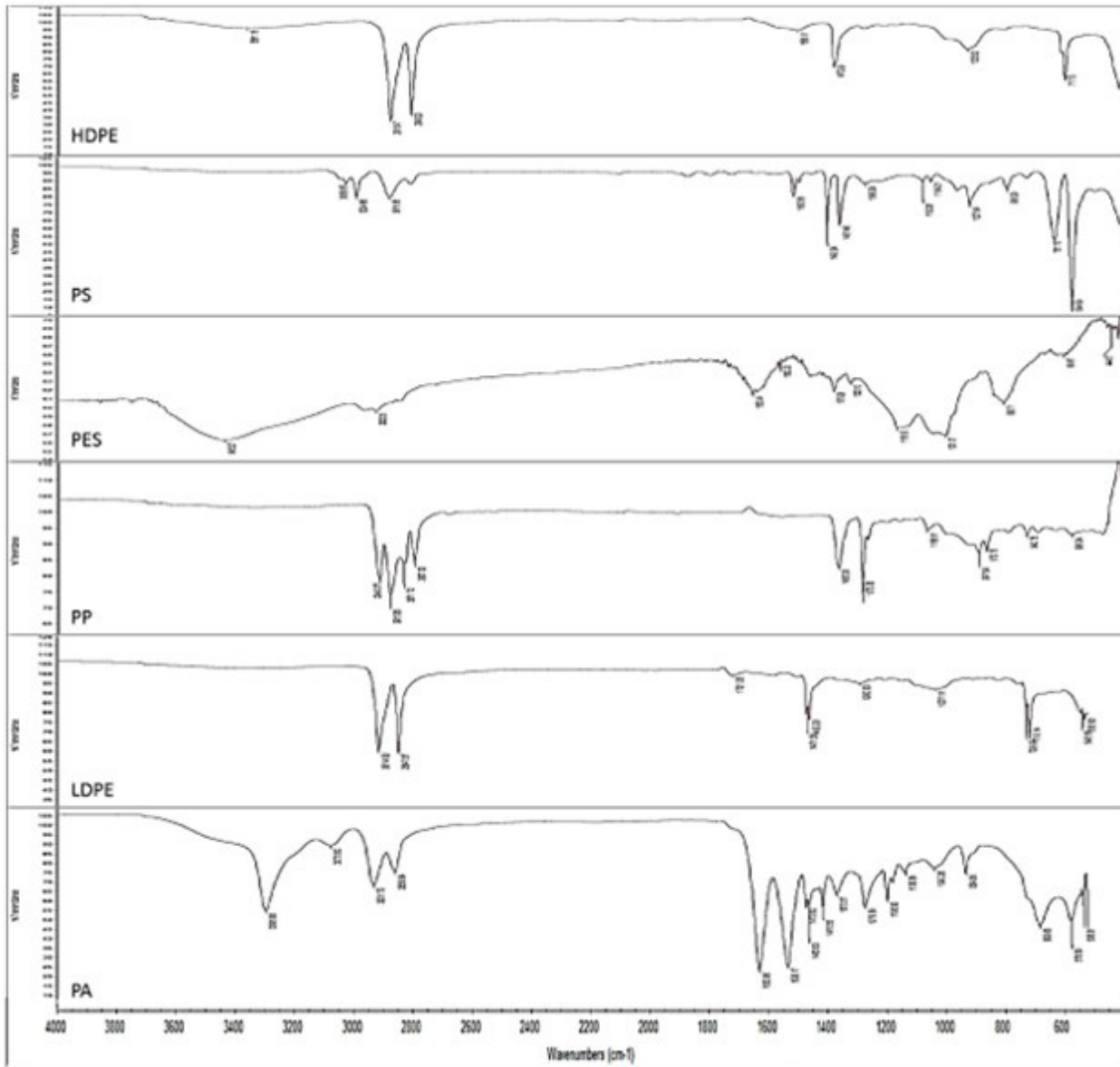


Figure 5. Examples of FT-IR spectra for pieces of HDPE, PS, PES, PP, LDPE, and PA for the macroplastics in this study.

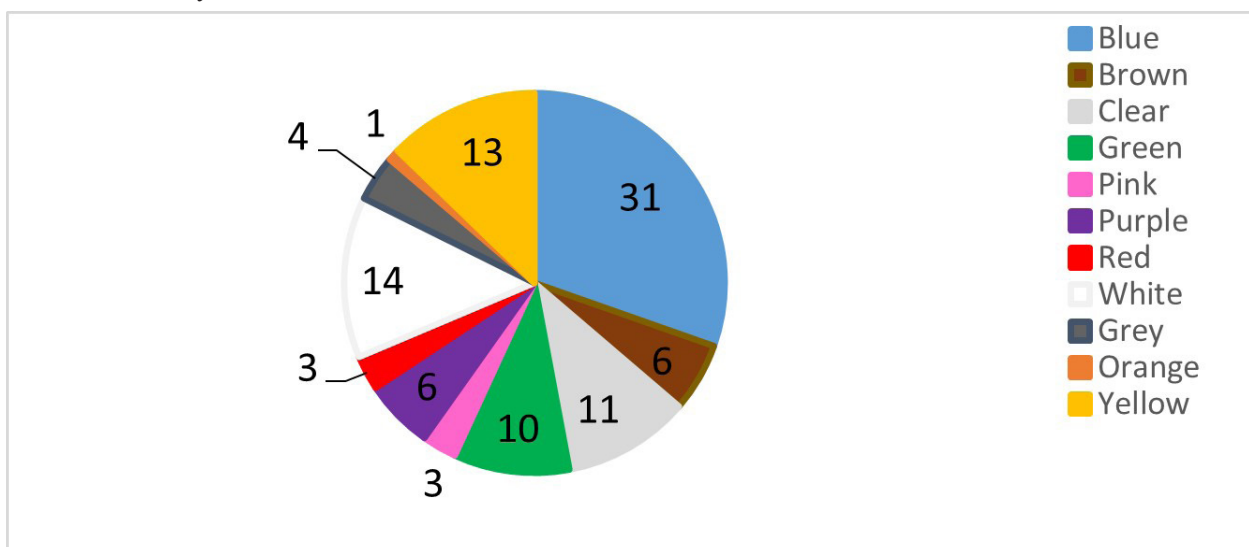


Figure 6. The colors of macroplastic obtained in this study. Values are in percentage (%).

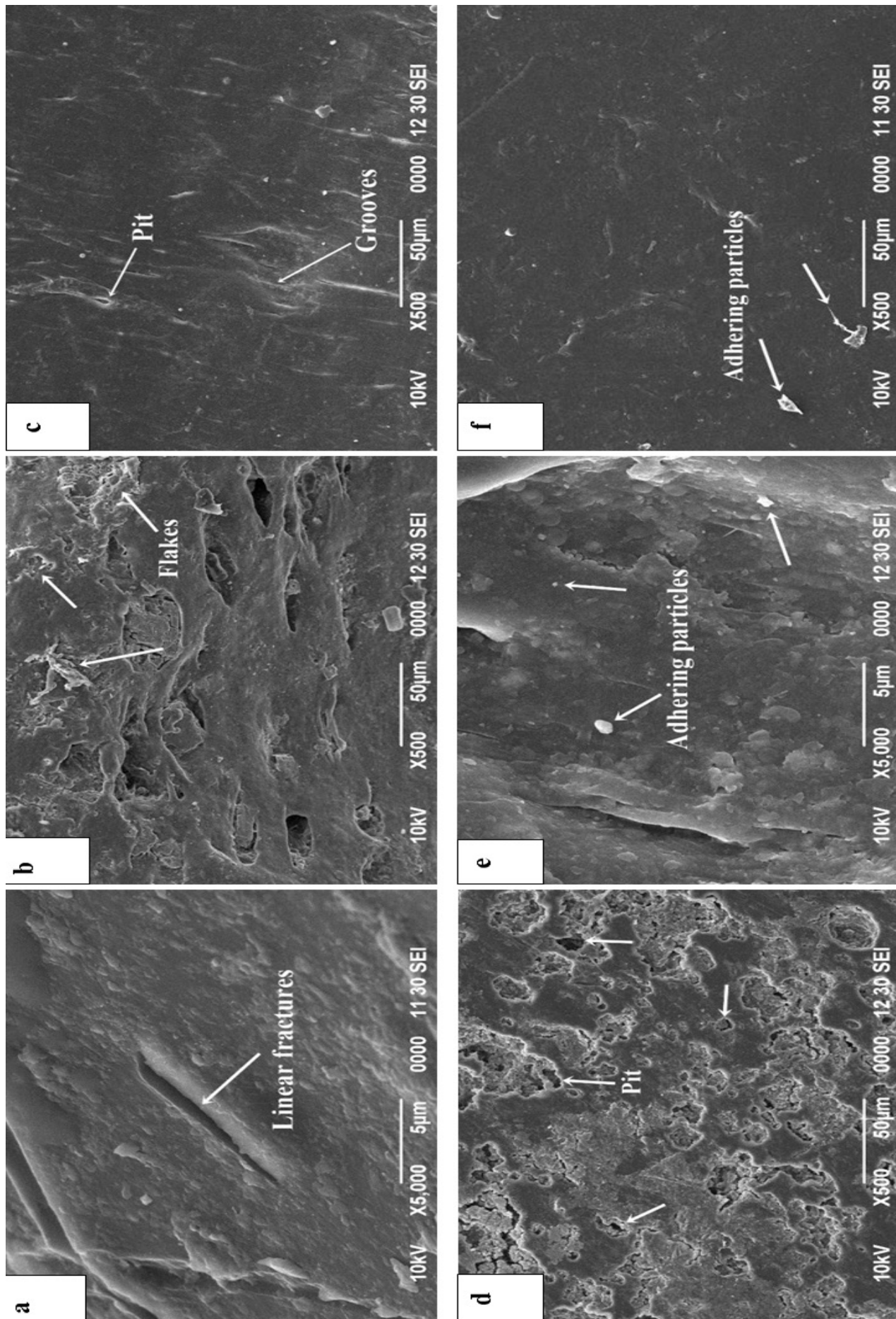


Figure 7 (a-f). Scanning electron microscope (SEM) images on the surface topography of the macroplastic particles on Pasir Pandak Beach that had shown the breakdown processes due to the weathering and other external forces yielding microplastics on the beach. (a) linear fractures on fragment, (b) flakes on fragment, (c) pit and grooves on fiber, (d) pit on foam, (e) adhering particles on fragment, (f) adhering particles on fiber.

Table 3. Data of the microplastics in term of concentrations (items/m²), shape and size (mm)

| Sampling Station | Conc. (items/m ²) | Shape | Size, mm (and it's percentage) |
|------------------|-------------------------------|--|--|
| S1 | 132 | Fiber (87.88%), filament (12.12%) | 0.05 (9.09%), 0.25 (27.27%), 0.50 (30.3%), 1.00 (15.15%), 5.00 (18.18%) |
| S2 | 76 | Fiber (42.10%), filament (57.90%) | 0.05 (10.52%), 0.25 (36.85%), 0.50 (36.85%), 1.00 (5.26%), 5.00 (10.52%) |
| S3 | 328 | Fiber (21.95%), filament (78.05%) | 0.05 (35.37%), 0.25 (51.23%), 0.50 (7.32%), 1.00 (6.10%) |
| S4 | 144 | Fiber (44.44%), filament (36.11%), Foam (19.44%) | 0.05 (2.78%), 0.25 (36.11%), 0.50 (36.12%), 1.00 (25%) |
| S5 | 108 | Fiber (51.85%), filament (37.04%), fragment (11.11%) | 0.05 (7.40%), 0.25 (37.04%), 0.50 (25.93%), 1.00 (22.21%), 5.00 (7.40%) |
| S6 | 132 | Fiber (43.75%), filament (46.88%), Fragment (9.38%) | 0.05 (12.50%), 0.25 (25.01%), 0.50 (34.40%), 1.00 (21.89%), 5.00 (9.38%) |
| S7 | 60 | Fiber (20%), filament (26.67%), fragment (53.33%) | 0.05 (13.34%), 0.25 (46.66%), 0.50 (20%), 1.00 (26.67%) |
| S8 | 104 | Fiber (23.08%), filament (26.92%), Fragment (50%) | 0.05 (7.69%), 0.25 (26.92%), 0.5 (38.46%), 1.00 (15.39%), 5.00 (15.39%) |

The SEM images of the macroplastics show that the breakdown process has happened, proven by the evidence of the presence of numerous fractures, grooves, flakes, and pits (Figure 7). Linear fractures were formed during grain-grain impacts and saltation, meanwhile grooves created from sand grains dragging across plastic surfaces (Schwarz *et al.*, 2019) or also known as stress corrosion process. This occurred when a critical strain is exceeded and caused fine cracks on the surface, known as crazing. Crazing would transform into micro-cracks due to fiber breakage and spread to a critical size where the catastrophic failure occurred and eventually developed a fracture (Figures 7a and 7b). High exposure to liquid would cause plasticization (swelling of a polymer). Grooves which were long and narrow hollows or sometimes curved were developed from sand grains dragging across plastic surfaces (Schwarz *et al.*, 2019; Zbyszewski *et al.*, 2014). Dissolution caused pits to occur while the plastic fragments were floating on the water surface or while resting on the beach (Figures

7c and 7d). Adhering particles indicated in Figures 7e and 7f were influenced by chemical beach weathering by lodging or gluing fragments onto the surface of the plastics. These features were commonly associated with oxidation textures.

3.2 Microplastics

Microplastics varied from 60 to 328 items/m². The highest concentration of microplastic was found at Station 3 and the lowest was at Station 7 (Table 3). There were statistical differences among all sampling stations in the values of microplastic concentrations ($p < 0.05$). These results were lower than the reported microplastic particles (~1620 particles) found at the North African beaches (Tata *et al.*, 2020) and the data from Seberang Takir beach, Terengganu (Fauziah *et al.*, 2015) that observed approximately 1000 items/m².

Sizes of the microplastic were grouped into 5 sizes: <0.05 mm, <0.25mm, <0.50mm, <1.00mm, and

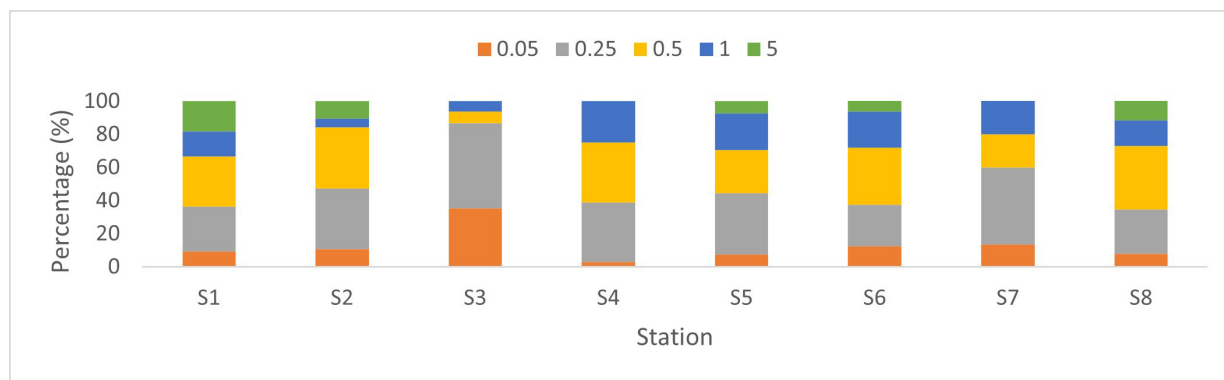


Figure 8. Composition of microplastic sizes (<0.05, <0.25, <0.50, <1.00, and <5.00 mm) at different sampling stations.

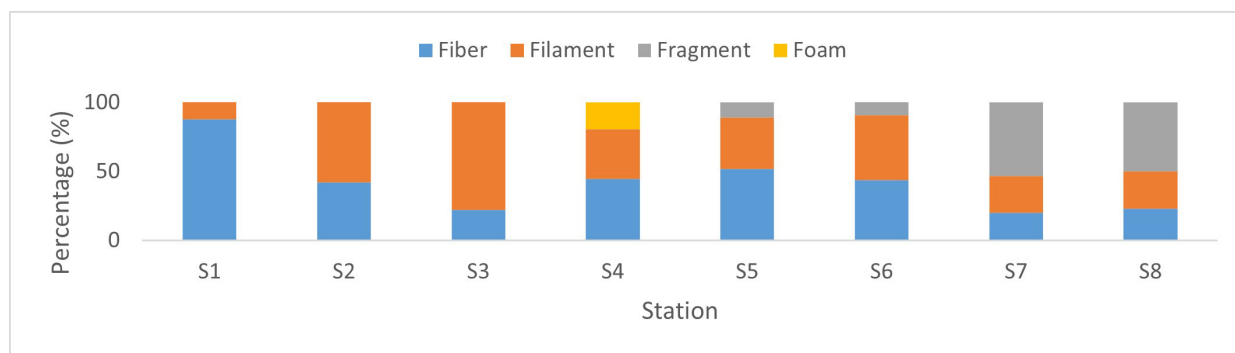


Figure 9. Shapes of microplastics found at all sampling stations.

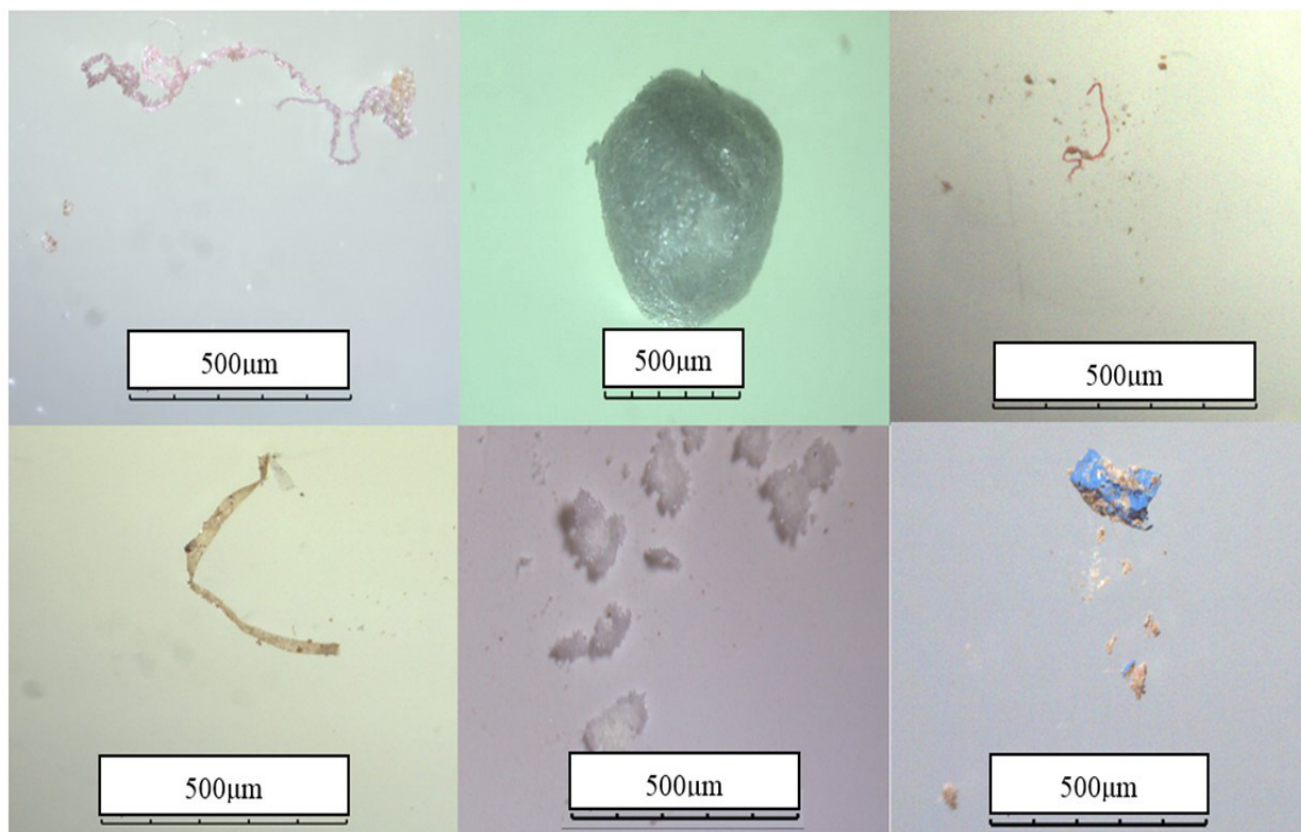


Figure 10. Examples of microplastics shapes found on Pasir Pandak Beach. a: fiber, b and e: foams, c: filament, d: film, f: fragment.

<5.00mm (Figure 8). They were varied in shapes (Figures 9 and Figure 10), and colors (Figure 11). Microplastics with sizes between 0.25 mm and 0.50 mm were available abundantly at all stations, and they comprise 63.47 % of the total microplastics estimated from the shoreline sediments. Small size of microplastics can be eaten by fish. For example, De Witte et al. (2022) found that fishes caught in the North Sea contained granules, films, fibers, and irregular microplastics with sizes from 0.123 mm to 2.37 mm in the gastrointestinal tracts. Our results are in line with those of Jeyasanta et al. (2020) who observed approximately 60 % of the similar sizes at the beaches of Tuticorin, India. Cai et al. (2018) reported that 92 % of their microplastic particles were in a range of 0.02 and 0.3 mm, and only 8 % of the microplastic particles were in bigger sizes (0.3 – 5.0 mm) in the South China Sea. Meanwhile, Noik and Tuah (2015) and Fauziah et al. (2015) found more microplastic particles with sizes 1 to 5 mm in the sediment of selected Malaysian beaches. A recent study at beaches of the South China Sea (Chai et al., 2022) reported that about 85 % of their microplastics have sizes below 1.00 mm.

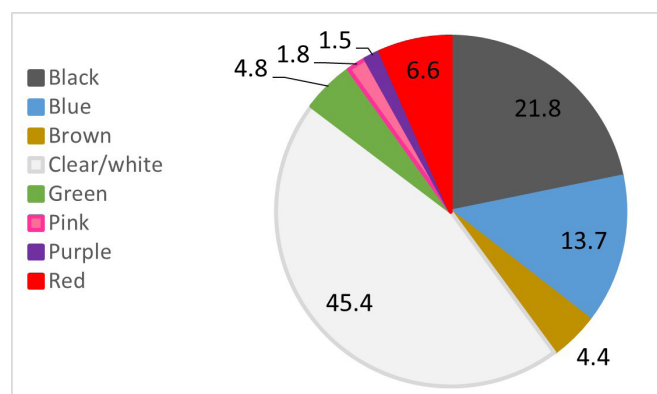


Figure 11. Colors of microplastics obtained in this study in percentage (%).

Fibers, filaments, fragments, and foams were the shapes of microplastic particles that were observed in this study (Figures 9 and Figure 10). Fibers (41.88%) were the most abundant microplastics obtained in this study, followed by filaments (40.21 %), fragments (15.48 %) and foams (2.43 %). Several studies, such as by Cai et al. (2018); Tata et al. (2020); and Masiá et al. (2021) also reported fibers as their main microplastic particles found in their studies. It has also been found that fibers can be ingested by some zooplankton in the northern South China Sea (Cai et al., 2018), usually in smaller size (< 0.2 mm) (Sun et al., 2017). Then, this ingested microplastics can be transferred and biomagnified in the foodweb (Erni-Cassola et al., 2017). Ibrahim et al. (2017) found that fish like Asian sea bass (*Lates calcarifer*) had ingested fiber and fragment mi-

croplastics in cage-cultured and natural environment at Setiu Wetlands. Susanti et al. (2022) reported film (2 – 21 particles/fish) and fiber (15 – 26 particles/fish) in the gastrointestinal tracts of *Lutjanus vitta*. Microplastic particles that ingested by the aquatic organisms are not digested as there are no enzymatic pathways available for the synthetic polymer breakdown (Coyle et al., 2020). Instead, those microplastic particles will accumulate in body tissues such as hepatopancreas and ovaries of organisms such as mussels and crabs (Coyle et al., 2020).

Most of these microplastics were lightweight and thus, could float at the surface of the seawater. Surface seawater is the most productive zone and the smaller sizes of microplastics would pose a severe ecological risk (Cai et al., 2018). Furthermore, these floating microplastics can be denser than the seawater and eventually sink to the seafloor due to the biofouling process (Coyle et al., 2020), and this process can occur in days or weeks. One of the main sources of fibers and filaments was from the degradation of larger plastics with combination of several effects such as UV, heat, waves, biological activity, and oxygen demand (Andrady, 2017; Tata et al., 2020; Coyle et al., 2020). Plastic degradation usually occurred in the marine environment as all conditions are favorable to high rates of photodegradation (Coyle et al., 2020). These microplastic particles might also enter coastal area from the wastewater of domestic discharges. Masiá et al. (2021) did not rule out the possibility of fiber ingress from airborne pollution via wind blowing due to its lightweight nature, as this idea was also supported by Cai et al. (2017) and Liu et al. (2019) studies. Jeyasanta et al. (2020) believed that fishing gear and sewage dumping are also other vital sources of fibers, filaments, fragments, and foams to the beach.

Microplastics existed in several different colors (Figure 11). The most frequent colors observed in all sampling location was the transparent (clear) or off-white (45.4 %), followed by black (21.8 %), blue (13.7 %), red (6.6 %), green (4.8 %), brown (4.4 %), pink (1.8 %), and purple (1.5 %), and this result was in agreement with other studies (Jeyasanta et al., 2020; Tata et al., 2020). Pradit et al. (2020) and Martí et al. (2020) were also found that white and clear/colorless plastics (43 %, Pradit et al., 2020; and 47 %, Martí et al., 2020) as the most abundant microplastic colors on the beach sediments, with suggestion that this discoloration is due to the longer exposure time to sunlight. Susanti et al. (2022) also found out that transparent (clear) (57.3 %), blue (26.4 %), black (10 %) and red (6.4 %) in *L. vitta* samples from the Jakarta Bay. Several crab species such as *Portunus pelagicus*, *P. trituberculatus*, *P. arma-*

tus, and *Carcinus maenas* contained microplastics with transparent, white, black, grey, blue-green, yellow, and mostly were fibers, with a few of fragments (Yi *et al.*, 2021). Crabs are susceptible to microplastics ingestion due to their burrowing activities and feeding behavior.

3.3 Correlation Analysis

An average of 101.70 items/m² macroplastics and 1084 items/m² microplastics were observed in this study from the beach sediments. The abundant of microplastics were approximately 10 times more than the amount of macroplastics. The simple linear regression was applied to determine a relationship between the number of macroplastics and microplastics and the results show $R^2 = 0.0791$ ($p < 0.05$). The regression shows that the concentration of macroplastics does not influence the amount of microplastics on this particular beach. The land-based macroplastic inputs may be contributed to the abundance of the microplastics on this beach, but it seemed that more microplastics sources came from the sea-based, as suggested by Mobilik *et al.* (2014). Floating materials at the sea, including plastics, can be transported to the faraway places from its sources. Cai *et al.* (2018) had also reported that approximately 2000 particles/m³ were found in the surface seawater of the South China Sea, which has a direct access to our study sites. Moreover, the macroplastics from the land-based may have been removed due to the wind-blowing, buried in the sand, degradation process into smaller sizes, and the beach clean-ups.

4. Conclusion

Macroplastics (101.70 items/m²) and microplastics (1084 items/m²) were found in all stations of Pasir Pandak Beach. Macroplastic are mostly found close to the human activities by the nearby villagers, including house renovation, beachgoers, and fishing activities. This contributed to >20 amount of the CCI, which indicated as extremely dirty beach. Our study also highlighted the existence of huge amount of smaller microplastics (<0.50 mm) on this beach. However, there is no correlation between the macroplastics and microplastics, perhaps due to the removal of the visible macroplastics by the regular beach clean-up activities. As Pasir Pandak beach is busy with local communities and beachgoers, the presence of macro- and micro-plastics on the beach posing a severe threat for marine environment, thus further studies on the behavior of this emerging pollutant from beach to the seas are necessary.

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Authors' Contributions

All authors have contributed to the final manuscript. The contribution of each author is as follows, Farah Akmal Idrus; collected the data, drafted the original manuscript, critical revision the article, conceptualization, methodology, wrote the original draft, reviewed, and editing, funding acquisition, and supervision; Nur Sakinah Roslan: Data curation, formal analysis, investigation; Mohd Nasarudin Harith: Funding acquisition, writing review, and editing. All authors discussed the results and contributed to the final manuscript.

Conflict of Interest

The authors declare that they have no competing interests.

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