A First Survey on the Abundance of Plastics Fragments and Particles on Two Sandy Beaches in Kuching, Sarawak, Malaysia

V James Noik[1] and P Mohd Tuah
Department of Environmental Science, Faculty of Science and Natural Resources, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia.

E-mail: victorjms8007@gmail.com, pmdtuah@ums.edu.my

Abstract. Plastic fragments and particles as an emerging environmental contaminant and pollutant are gaining scientific attention in the recent decades due to the potential threats on biota. This study aims to elucidate the presence, abundance and temporal change of plastic fragments and particles from two selected beaches, namely Santubong and Trombol in Kuching on two sampling times. Morphological and polymer identification assessment on the recovered plastics was also conducted. Overall comparison statistical analysis revealed that the abundance of plastic fragments/debris on both of sampling stations were insignificantly different ($p>0.05$). Likewise, statistical analysis on the temporal changes on the abundance yielded no significant difference for most of the sampling sites on each respective station, except STB-S2. Morphological studies revealed physical features of plastic fragments and debris were diverse in shapes, sizes, colors and surface fatigues. FTIR fingerprinting analysis shows that polypropylene and polyethylene were the dominant plastic polymers debris on both beaches.

1. Introduction

Ever since its discovery, man-made polymers of various types can be easily found virtually in any industrial materials and consumer products today thanks to its desirable performance. Commonly known as 'plastics' in layman's term, this man-made polymers are physically durable (i.e. tough, flexible, long-lasting), chemically and thermally stable, lightweight and can be easily molded into various shapes and sizes while addition of colour dyes improves visual attractiveness and functions of the end-products. With our 'addiction' to plastics and highly dependent on it economically, the high demand which led to lower production cost have seen our modern society reaching the so-called 'Plastic Age' due to the unprecedented amount of plastics that we produce, use and dispose [1].

By and large, plastics are designed either as a single- or extended-use product that eventually end up in the waste stream where it may be recycled or disposed off into solid waste treatment facilities. Apparently in most cases, irresponsible littering and indiscriminate dumping of solid wastes has made plastics unnaturally available ubiquitously in the environment. The adverse impacts exerted on the

[1] To whom any correspondence should be addressed.

ecosystem and marine wildlife by this synthetic anthropogenic debris is multitude [2] – [5]. Human health too is not spared by the potential dangers of plastics debris [6].

Disposed or littered plastics are commonly thought to resist physical and chemical breakdowns. This however is partially true as some plastics actually degrades albeit at a very slow rate depending on its type and chemical composition when left exposed to Nature's elements [7], [8]. Degraded plastics are fragile, discoloured and dull, brittle, flaky, powdery and fragmented in small tiny pieces or particles called microplastics in which it become an environmental contaminant [9]. The term microplastics itself is not uniformly defined by various authors, for example [9] – [12], but generally are plastics fragments and/or particles that range in the size of few millimeters to sub-millimeters (i.e. micrometers). For the sake of clarity, this paper will refer particles in the size of 1 to <5 mm as microplastics while those that measures between 5 to <20 mm are small fragments or meso-plastics and > 20 mm are large fragments or macroplastics [13] – [15].

The abundance of microplastics and plastic fragments in the environment are difficult to estimate largely due to spatial and temporal challenges and the heterogeneity of plastic debris [16], as well as the lack of standard sampling and analysis methods [17], [18], let alone monitoring them. Hence, the environmental risks and biological hazards of the contaminants are yet to be fully understood. Nevertheless, a number of studies e.g. [19] – [28] had shed some lights on the potential ill-effects and its roles on both environment and biota.

This paper presents the first ever findings of the abundance of micro-, meso and macro- plastics from two selected estuarine beaches in Kuching, located at Kampung Santubong (1°43.164'N, 110°19.165'E WGS84) and Kampung Trombol (1°42.191'N, 110°11.635'E WGS84) respectively. Kampung Santubong is situated about 30 km from Kuching City while the latter is about 35 km. Located at the river mouth of Santubong River, Kampung Santubong was once a well-known fishing village/town and public beach facing both the river and South China Sea. The inhabitants enjoy basic public amenities such as schools, treated water, electricity, well-maintained tar-sealed road and scheduled municipal solid waste collections. Kampung Trombol is located at the vicinity of Telaga Air town in Matang District. The population are sparse with roughly a couple dozen of household, mostly involve in coastal agriculture (i.e. coconut and small holdings of oil palm plantation). The village is connected from the main road via makeshift tar-sealed road and electricity supply is just recent. Treated water is not available at the time of sampling and is yet to receive scheduled solid waste collection services. The beach of Kampung Trombol faces South China Sea and its coastline stretches to the river mouth of Sibu River which flows through Telaga Air town. Unlike the beach of Kampung Santubong, the beach of Kampung Trombol is unknown to public hence low human activities. The objectives of this study were: 1) To estimate the spatial and temporal abundance of types and sizes of microplastics/plastic fragments, and 2) To assess the morphological features of the collected microplastics/plastic fragments.

2. Materials and Methods

2.1. Sampling station, sample collection and sample handling

Beach sampling works were carried out at Santubong (STB) and Trombol (TRB) stations in November 2013 and a revisit in August 2014. Sand samples were collected from three sampling sites (designated as S1, S2 and S3 respectively) on each station that was randomly selected. The sites were 100 m apart from each other, with a 50 m transect length along the strandline in each site. Sampling quadrats (20x20 cm) were placed 10 m apart within the site and marked with a handheld GPS receiver (Garmin GPSMap 60C) along the upper and lower strandline.

Sands were collected using a cleaned stainless steel scoop at a depth of 2 cm from the surface and transferred into a cleaned sanitized glass bottle with air tight cap. The bottles were then wrapped with aluminum foils and put into a cool box for transportation. All sampling activities were done during low tide.

Sampling precautionary measures were adhered for sample quality control and assurance to minimize any undesired contamination: Cotton fabric clothes were worn throughout sampling activities, the body of sample collector was opposite facing in relative to wind direction, and a field blank of washed and cleaned sand was used.

2.2. Recovery of plastic fragments/particles

Recoveries of plastics micro- meso- and macro-plastics were done at the Environmental Chemistry Research Laboratory, Faculty of Science and Natural Resources, Universiti Malaysia Sabah (UMS). All sand samples were dried in a drying oven at 40 °C until constant weight. Dried sands were then sieved through a 1 mm mesh size stainless steel sieve. Plastics fragments/particles that were retained by the sieve were visually pre-sorted to remove any unwanted coarse organic matter. The pre-sorted fragments/particles were then further visually sorted and identified from organic matters of similar size under a compound stereoscope for coarse fragments and microscopes for small particles, and subsequently measured for weights and size. All recovered plastics fragments were stored in a cleaned sanitized glass bottle container and kept in an auto-controlled drybox.

On the other hand, plastics fragments/debris that escaped the 1 mm sieve together with bulk of the sand were separated using a low-cost fluidized density separation system (FDSS) (Figure 1).

The FDSS used in this experiment was adopted and modified based on the system developed by [29], [30] and [31] by utilizing available laboratory glassware. Concentrated NaCl solution (ρ=1.2 g·cm^{-3}) was prepared by dissolving a pure sea salt (food grade) in distilled water and subsequently filtered using Whatman filter paper No. 1. The solution was then poured into the glass column (I) until about 50% full. Sieved sand was then gently transferred into the glass column using clean metal spatula via a glass funnel. Sand and other particles denser than the solution will precipitate towards the bottom of the column, while those that are less dense will buoyed on the upper layer of the liquid column.

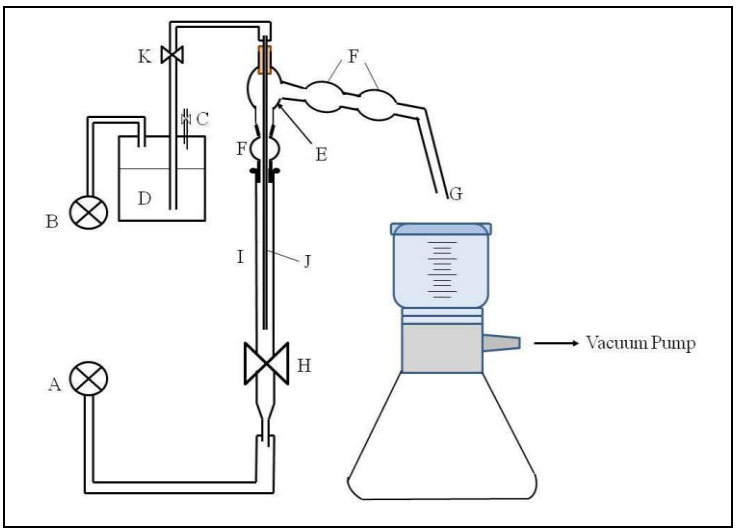

Figure 1. The set-up of the Fluidised Density Separation System (FDSS): **A** – Air Pump A, **B** – Air Pump B, **C** – Pressure release valve, **D** – NaCl solution reservoir, **E** – Overflow exit junction, **F** – Bulbous traps, **G** – Outfall, **H** – Air valve, **I** – Glass column, **J** – Glass pipette, **K** – Outflow valve.

Air Pump A (flow rate: 4 L·min^{-1}) was then switched on and the air valve (H) is slowly opened, resulting in streams of air bubble in a controlled manner purging through the liquid column agitating the gravitated sand and buoying particles. This fluidisation of the column mixture was allowed to run for 10 minutes after which shutting sequence was then initiated beginning with the closure of the air valve (H) followed by the air pump. The mixture solution was then left for 30 minutes to allow dense particles gravitate, resulting a clear liquid supernatant. In some samples where silt and colloidal matter content are high, the gravitation was left overnight for complete settlement.

Pump B (flow rate: 3.5 $L \cdot min^{-1}$) was then activated to pressurize the NaCl solution reservoir (D), forcing the solution into the column via a submerged glass pipette (J) for 2 minutes. The addition of solution causes an increase of the mixture's volume in the column until it overflows at the exit junction (E). Any sand grains or dense particles were retained at the bulbous trap (F). The overflow brought along flotsam and suspended solids in the column and get collected in the vacuum filter funnel. Shutting down sequence was initiated after 2 minutes beginning with the pump then closure of outflow valve (K) to prevent any possible backflow of the solution into the reservoir. The air release valve (C) was then quickly open to equalize the reservoir's internal pressure with that of atmospheric pressure.

Collected flotsam and suspended particles together with the saline solution were then vacuum filtered through a glass microfiber filter (Whatman Grade GF/B), whereas the filtered NaCl solution is transferred into the reservoir for reuse. The trapped flotsam and suspended particles on the glass microfiber filter were then rinse with distilled water and vacuum filter several times to remove residues of NaCl. The flotsam particles along with the microfiber filter were then dried in a drying oven for 40 °C until constant weight.

2.3. Removal of biogenics

Dried flotsam particles adhered to the glass microfiber filters were subjected to acid treatment for the removal of any biogenic matters present. The glass microfiber filters were then placed in a petri dish. Concentrated analytical grade hydrochloric acid (HCl) 37% v/v (Merck, Germany) and nitric acid (HNO_3) of 65% v/v (Merck, Germany) was then pipetted on the flotsams until saturated and left for 10 minutes. The glass microfiber filter was then gently lift up using a metal forceps and nozzle spray with NaCl solution to wash off any particles into the petri dish. The contained acidic saline solution in the petri dish was then gently poured into a beaker to collect any floating particles which was subsequently vacuum filtered and washed with distilled water for several times. The filter papers were then let dry in a drying oven at 40 °C for 2-days to affix any plastics particles on it.

2.4. Characteristics observation

Recovered plastics fragments/particles were observed under an inverted light microscope for physical features such as shapes and fatigues. Plastic particles that are loosely fixed on the filter paper were gently scrapped with a spatula onto a microscope slide and affixed firmly by sandwiching it with another slide and observed under normal light microscope. All microscopic images were captured using a 8 megapixels camera attached to the ocular lens. Images were enhanced using PhotoScape 3.6.3 photo editing software.

2.5. Fourier-Transform Infrared (FTIR) identification of plastic types

Mesoplastics with the size of 15 mm and above from all three sampling sites of each station were pooled together and randomly sampled for plastic type identification. A total of 100 samples (n=100) from STB and 132 samples (n=132) from TRB station were selected for identification. Samples were cut to a size of 10 mm and washed with distilled water to remove any dirt and residues. The samples were then placed and firmly clamped on the ZnSe crystal plate holder of the MIRacle™ Single-Reflection Horizontal attenuated total reflectance (ATR) accessory (PIKE Technologies, USA) installed on the Perkin-Elmer (Model: Spectrum 100) FTIR spectrometer. The samples were then scanned in the range of 4000 – 650 cm^{-1} wavenumber. Output from the scans in the form of spectrum peaks expressed as %T, were compared with established online polymer spectra databases and libraries.

2.6. Statistical analysis

Obtained data from the measured weight were statistically analysed using SPSS ver. 13.0 for descriptive statistics (Mean±SD). Comparison of temporal changes within station were analyzed using one-way ANOVA, while comparison between stations were analyzed using two-way ANOVA with

confidence level of 95% (significant difference, $p<0.05$) whereby values from the latter's analysis were assessed with Tukey's honesty significant difference (HSD) post-hoc test.

3. Results

3.1. Weight and size classification of recovered plastic fragments and particles

A total of 60 sand samples were collected from Kuching, with 30 samples each from Santubong and Trombol beach in November 2013 and August 2014 respectively. Weight can be use as a subjective indicator on the amount of plastics debris present on the sampling site since most of them were found in various sizes and shapes. Generally, STB recorded a mean±SD weight of 0.0358±0.062 g (November 2013) and 0.4108±0.610 g (August 2014), while the mean weight of sampled plastic fragments debris was 1.7343±2.173 g (November 2013) and 1.5419±2.291 g (August 2014). Table 1 shows the mean weight of plastic fragments and particles collected from both sampling stations at two different sampling times. Results from statistical comparison using one-way ANOVA between weights of paired same strandline with the respective sampling time showed that there were no significant difference ($p>0.05$) of fragments/particles collected, except for the upper strandline of STB-S2 which shows significant increase of the debris of interest.

The mean weight of sampled plastics from sites of both stations within the same month was compared using multivariate analysis (MANOVA). The analysis outcome indicate that there were no significant different, $F(4,54)=0.181$, $p=0.947$ i.e. $p>0.05$. Comparison of the August 2014 mean weight also yielded no significant difference, $F(4,54)=0.398$, $p=0.809$. Tukey's HSD post-hoc test affirmed that both the mean weight was insignificant different $p=0.73$ for the former month and $p=0.231$ for the latter's, respectively. It is however worthy to note that some of the collected individual fragment pieces were too light to be measured by analytical balance, hence the number of debris does not reflect by the weight in Table 1. Hence, both visual judgment from site sampling and laboratory sorting observation presented a more objective abundance.

Table 1. Mean weight of pooled plastics fragments/particles recovered from the respective sampling stations.

	Weight, g (Mean ±SD)			
	November 2013		**August 2014**	
Station, Site	**Lower Strandline (n=15)**	**Upper Strandline (n=15)**	**Lower Strandline (n=15)**	**Upper Strandline (n=15)**
STB-S1	0.0018 ±0.003	0.0496 ±0.031	0.0009 ±0.001	0.1794 ±0.223
STB-S2	0.0140 ±0.002	0.0963 ±0.110[a]	0.1883 ±0.419	1.2710 ±0.922[b]
STB-S3	Nil	0.0659 ±0.068	Nil	0.8254 ±0.885
TRB-S1	0.0049 ±0.011	4.0075 ±1.995	0.0273 ±0.033	3.3028 ±2.451
TRB-S2	0.0011 ±0.002	3.5698 ±2.569	Nil	3.6672 ±3.288
TRB-S3	0.0008 ±0.002	2.8219 ±0.491	Nil	3.2544 ±1.507

Superscript letters denotes significant difference ($p<0.05$).
Nil denotes no plastic found or recovered.

Table 2 shows the size of plastics recovered with apparently mesoplastics and macroplastics were the dominant size on the sampling stations particularly at the upper strandline.

Table 2. Size classification of recovered plastic fragments from upper and lower strandlines of the respective sampling stations.

. Sampling period	Class (Size, mm)	Station			
		ΣSTB (1, 2, 3)		ΣTRB (1, 2, 3)	
		Lower Strandline	Upper Strandline	Lower Strandline	Upper Strandline
November 2013	Microplastics				
	1 – 5	4	10	1	9
	Mesoplastics				
	6 – 10	1	11	2	18
	11 – 15	2	18	1	27
	16 – 20	2	17	0	38
	Macroplastics				
	> 20	0	25	2	37
Total:		**9**	**81**	**6**	**129**
August 2014	Microplastics				
	1 – 4	1	8	0	7
	Mesoplastics				
	5 – 10	0	10	0	3
	11 – 15	2	17	2	25
	16 – 20	4	22	1	37
	Macroplastics				
	> 20	2	23	2	28
Total:		**9**	**80**	**5**	**100**

3.3. Plastic polymer identification

Plastic fragments and particles were pooled together irrespective of strandline and the sampling month. Figure 2 shows the abundance of various plastic types identified using FTIR. Polypropylene (PP), polyethylene (PE), polyethylene terephthalate (PET) and polystyrene (PS) were the plastics identified and present most commonly on both beaches. PP and PE constitute the highest abundance on both beaches: 28.0% and 31.0% respectively on STB station while 37.12% and 30.30% respectively on TRB station. PP, PE, PET and PS are commonly found in a wide range of industrial and consumer products. Other types of polymers found and accounted for were nylon and polyurethane.

3.2. Observation of recovered plastics fragments and particles

Figure 3 shows some of the plastic debris and fragments that were recovered from STB and TBR sampling stations. Fragments were in the form of various shapes and sieze. Most of the fragments exhibit degraded form such as discoloration, torn, shrinked, fragmented, flaky, powdery, and fragile. Microscopic observations revealed that surfaces morphology of some plastics were cracked (Figure 4). Generally, most of the plastic fragments do not have any association with heavy industrial materials but of household as observed during site samplings. Items include broken kitchen and bathroom wares, motor oil containers, personal care and toiletries, children toys and derelict fishing gears and storage boxes.

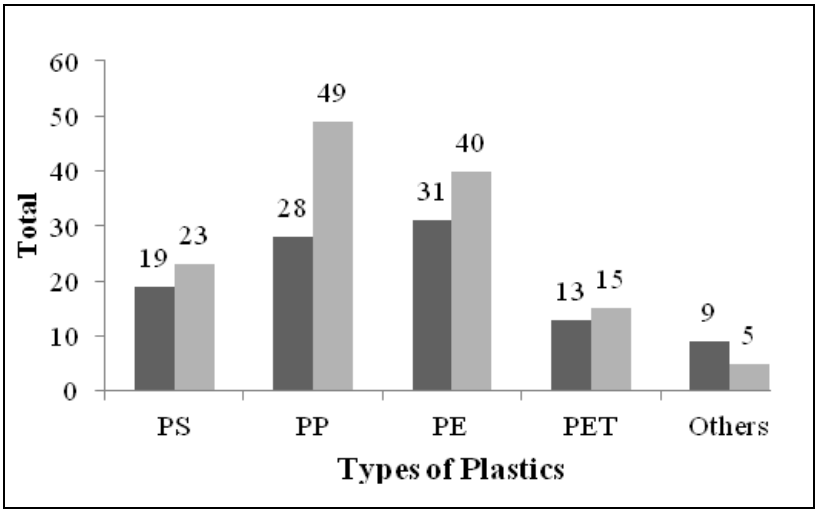

Figure 2. Total number of plastic fragments and debris pooled from Santubong (■) and Trombol (■) stations identified through FTIR analysis.

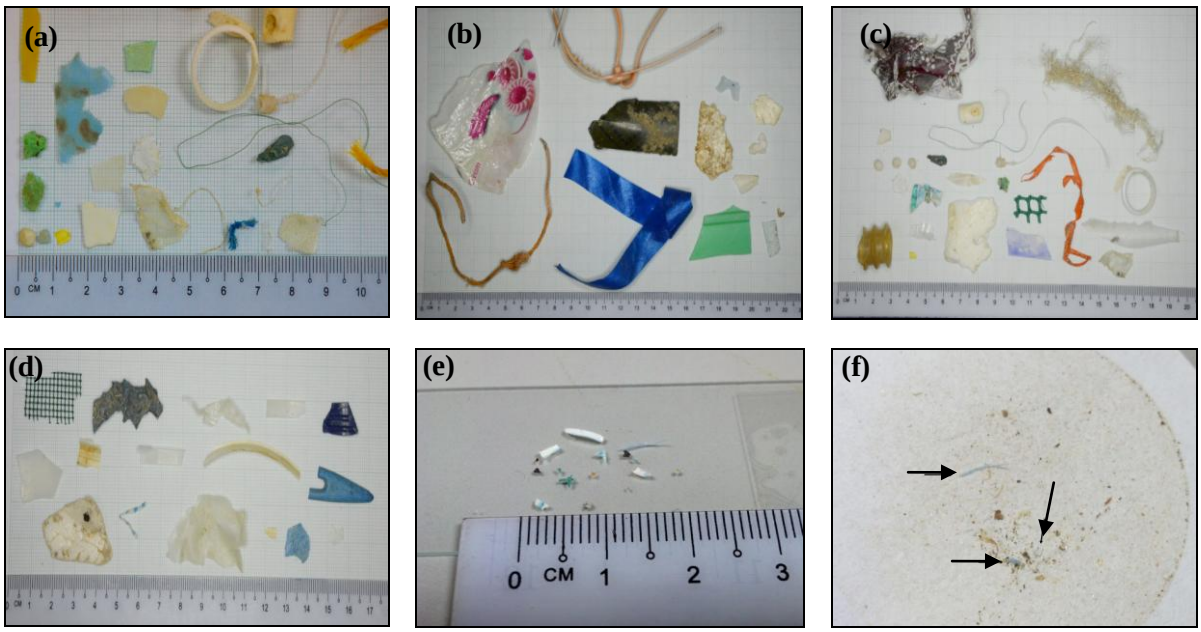

Figure 3. Some of the macro- and mesoplastics that were recovered from the 1 mm sieve, **(a)** – **(d)**; microplastic particles recovered via FDSS on a slide, **(c)**; colored microplastic indicated with arrowheads affixed on a filter paper after drying, **(d)**.

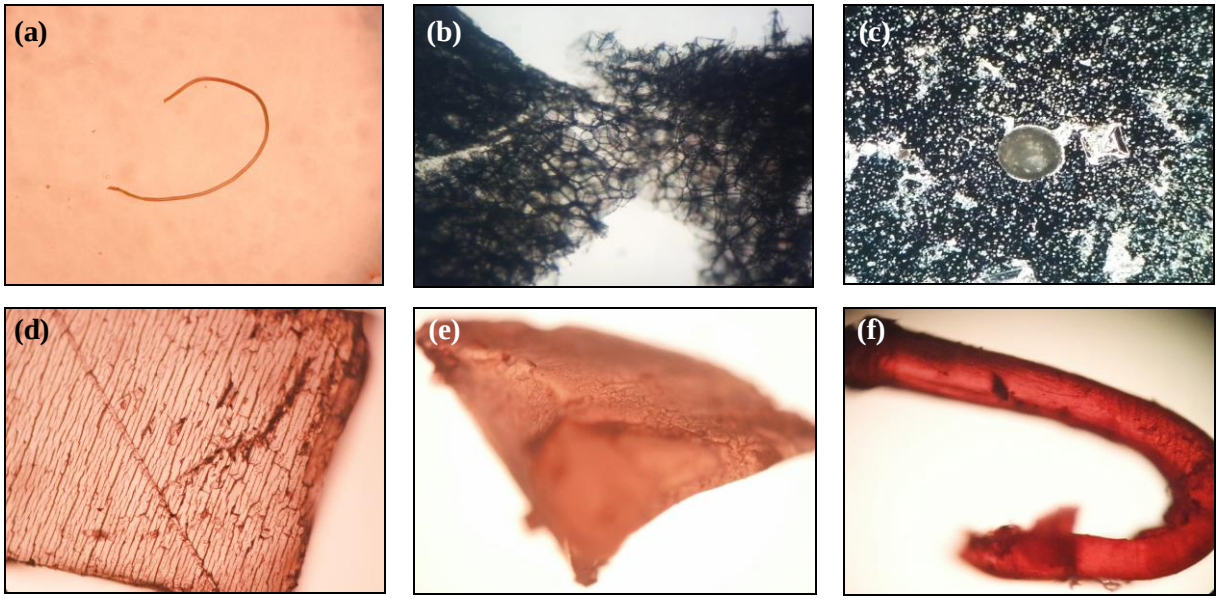

Figure 4. Microplastics viewed under light microscope. A strain of polymer, possibly a polyethylene fiber (100x mag.), **(a)**; Degraded polystyrene Styrofoam (100x mag.), **(b)**; A possible microbead with a salt crystal on its right (50x mag.), **(c)**; Cracked surface of polyethylene plastic (100x mag.), **(d)** and **(e)**; A fragment of possibly nylon debris (100x mag.), **(f)**.

4. Discussion

The present of plastic debris in the environment is not uncommon ever since humans have been using the polymer products for many years. Human factors are widely attributed to the sore sights of plastic being distributed and deposited in the environment. Most of the plastic were translocated to a great distance by wind, water and animals. Seas, oceans gyres, islands, beaches and rivers are the most common depository sites for these man-made polymers. Lagoons and estuarines are not even spared from the present plastic particles [32]. Besides marine environment, plastics are also invading freshwater ecosystem [33], [34]. With most of those ecosystems are biologically diverse, the present of plastics debris could potentially have great impacts on the well-being and safety of the animals inhabitants. What makes it even more of a concern is that those plastic debris gradually degraded over-time, making pieces of fragment present even far greater in numbers than the debris itself. This translates to greater translocation distance and into the food chain at the same time leaching out its additives compounds, plasticizers and adsorbing-desorbing hazardous chemicals along its way to the potential victim [35] – [40].

The results obtained from the present study shows that plastic particles present on the beaches of Santubong and Trombol. Most of the plastics particles were found on the upper strandline compared to the lower strandline. The upper strandline is the highest tide level on a beach nearest to land. Most debris and flotsams are washed to the uppermost strandline during the highest tide incident, leaving them there as when tide recede. Plastic debris might also be washed to the shore during storm events. Apart from being washed ashore by tides and rough seas, inhabitants in Santubong and Trombol and nearby locations might have explicitly disposed their household trash at the beach during high tide thinking that it would be drifted to the sea during tide recede. Observation of debris during site sampling found that most solid wastes stranded on the beach were not of industrial type. Additionally, both Santubong and Trombol are located at a river mouth hence high possibilities that those plastics have translocated from other populated places located upstream of the river. Plastics debris that were found on the lower strandline were mostly either partially embedded in the sedimented sand, got entangled on rocks or stranded tree branches, or stranded from fast receding tide.

The present findings also showed that there were slight decreasing in the total number of collected plastic debris on two sampling occasions. This can be explained from the weather/climate standpoint [41]. November is a wet month for Malaysia. Frequent heavy and prolonged downpour during the monsoon season in urban areas washes down plastic litters into storm drains that subsequently flow into rivers and seas. The incident of high tide during rainy months led to some locations experiencing flood. The receding floods brought along any flotsams and debris down to the sea and concentrated. The next tide might possibly transport the debris to beaches. Higher cloud coverage and cooler ambient temperatures during monsoon months, plastic debris experience slow onset degradation. The low present of humans and seaside animals on beach might also explain the high number of plastics at the shores during the wetter months. The incoming plastics debris from the sea were not being disturbed by humans nor animals, causing the amount of plastic debris increase.

The dry months in Malaysia normally begins in March until September or October. The dry and bright conditions favour degradation of plastics [9], [42]. Dry and windy seaside also causes some of the lighter plastics were blown away, and dry sand blown by wind burying the plastic debris underneath it. Some coastal plants, particularly those that creep on the sand, do not grow well during the wetter months but dry months. Their growth over some degraded plastics debris causes it hidden, and it grows denser, the roots began to push those plastics into the sand embedding them inside. The present of animals such as birds might have mistaken plastics debris for food, picking them up and translocate them elsewhere, while some littoral organisms such as shore crabs and insects might have translocate or ingested small fragmented plastics [43].

Microscopic observation on the recovered microplastic reveals its shapes and surface properties. Most plastics debris and particles recovered in this study were of degraded condition, hence the diverse shapes and sizes signifying that they were fragments of a larger item [44]. Spherical particles were of exception as it exhibit uneven surface. Some microplastics exhibit rough and cracked surface. The irregular surface with depressions and crevices provide higher surface area for biological, as well as chemical interaction due to the exposed polarity of the surface [45]. Microplastics of the polystyrene origin generally exhibit a ‘foam’ and ‘hollow’ character, making them lightweight less dense.

A combination of acids HNO_3 and HCl were employed to digest biogenic matter. Although both acids satisfactorily digested microscopic shells, spores, plankton and soft tissues present leaving residues to precipitate and easily remove any plastic debris later, the mixture however failed to digest small plant matter due to the present of fiber cellulose and lignin. Several published experiments demonstrated the effectiveness of hydrogen peroxide (H_2O_2) and to some extent hydrofluoric acid (HF), the strong oxidizing properties of both acids may affect plastic particles that are susceptible to acid corrosion and possibly digest it.

5. Conclusion

Plastic debris in the form of particles and fragments are getting more attention as an environmental contaminant and pollutant due to its hazardous potentials. The roles and fates of this emerging pollutant and contaminant are yet to be fully understood due to the nature of this debris and the challenges to sample, isolate and to quantify them. Thus far, only rough estimated from studies conducted in many places give us the idea on the abundance of this debris in the environment, as well as analyses on its chemical attributes.

This paper presents the first ever finding on the abundance of plastic particles on the shores of Santubong and Trombol in Kuching, Sarawak, Malaysia. The results from this study show that plastic particles were present in abundance on the selected sampling stations, with TBR had the significantly higher abundance of debris compared to STB. Analyzed data also showed that temporal fluctuations of plastic fragments were not significant for the sampling months. FTIR analysis showed that PE and PP were the dominant plastic types on both sampling stations, while morphological observations found that plastic fragments and particles exhibit diverse physical features.

This study also demonstrated the ability of FDSS to recover plastic particles. The use of saline solution to recover most plastic particles of lower density was satisfactory and at lower cost but was

unable to recover higher density plastic particles. Heavier density salts such as sodium iodide (NaI) or sodium polytungstate (SPT) is recommended for full recovery however its price is a drawback for small scale research [17], [29], [46], [47].

The present of plastic debris mirrors the possibility of living organisms in the estuarine may face adverse threats in the long-term. It also signifies the condition of waste management in Kuching and the mentality of its inhabitants as a whole with regards to solid waste disposal especially plastic littering which need to be addressed.

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