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Qualitative Analysis of Plastic Debris on Beaches of Brunei Darussalam

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ABSTRACT: Plastic debris is one of the major environmental concerns for the coastal area of Brunei Darussalam. It reduces the aesthetic appeals of the beaches in the country. The current study investigates marine debris on six different beaches of Brunei Darussalam along the South China Sea. Plastic was found the most abundant among whole debris by number (90.02%) and by weight (39.12%). It was classified by size (micro (<5 mm), meso (5-20 mm), macro (21-100), and mega (>100 mm)), colour (transparent, coloured, white and black). Fourier Transform Infrared Spectroscopy (FT-IR) was used to investigate the types of plastics and additives present in it. Statistical analysis using Minitab 17 and Kruskal-Wallis test was performed for comparison of data at different study sites. All major types of plastics were found in different forms with varying quantities from which toxic chemicals may leach out during degradation. The highest abundance by the number of plastic debris was found on Muara beach with a mean value 74.428 $n/m^2 \pm 34.33\ n/m^2$, while the lowest abundance was found on Lumut beach 53 $n/m^2 \pm 20.9\ n/m^2$. The study shows beaches used for recreational facilities are likely to have more debris as compared to other beaches.

Keywords: Plastic debris; Abundance; Qualitative analysis; FTIR spectroscopy; Beaches; Brunei Darussalam.

INTRODUCTION

The conservation of the marine environment became a challenge of the current century due to the presence of persistent materials in the environment. Plastic is used in different forms from daily life materials to ships and planes. It ultimately reaches the oceans in various forms by both point and non-point sources. Its use increased after 1950s, and now it is one of the most favourite products due to many characteristics such as long life, light weight, abundance, cheap price, corrosion-resistant, reshapable, and many others

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(Barnes et al., 2009). Hardesty et al., (2015) stated that these above-mentioned characteristics of plastics make it harmful for marine environment. Initially, its positive aspects were focused, while adverse effects were not seriously concerned (Thompson et al., 2009). Harper & Fowler (1987) reported the impacts of plastic on the ecosystem for the first time. Recently physical, chemical, economic, social and environmental adverse impacts of plastics are widely documented by many researchers (Balestri et al. 2017; van Truong and BeiPing 2019). It has many adverse effects on beaches and coasts (Barboza et al., 2018). It is not only visible debris, but seafloor is also getting polluted by the regular addition of plastic debris into the sea (Barboza et al. 2018).

Many researchers are conducting research in exploring the sources, fate, and impacts of plastic debris on aquatic lives (Hardesty et al., 2015). Rapidly developing countries such as China and India discharge the largest quantities of plastic into the world's oceans along its coastal zones. Therefore, a considerable amount of such plastic debris comes from continental sources entering the marine environment mainly through rivers (Lebreton et al., 2017).

Different species were reported to be affected by plastic debris directly in many ways, including entanglement and ingestion (Bellas et al., 2016; Bessa et al., 2018). Toxic chemicals such as persistent organic pollutants (POPs) in plastic material are added for better performance (Johns et al., 2015). For example, phthalates used as plasticizers have endocrine disrupting effects (Mylchreest et al., 1999). Di-(2-ethylhexyl) phthalate (DEHP) is generally used as plasticizer in PVC and have endocrine, cardiotoxic, neural and hepatotoxic impacts (Rowdhwal & Chen, 2018). Similarly, di-butyl phthalate (DBP) is being used in cosmetics as fixative, which is toxic (Johns et al., 2015). Apart from non-biodegradable debris, there are few pieces of evidences of the threat of biodegradable debris for the environment (Balestri et al., 2017). It is obvious that plastic debris is ultimately has disrupting impacts for humans when they enter to the human body (Bang et al., 2012). However, more comprehensive studies are required to get a clear picture of the problem.

It has many economic impacts on coastal cities and countries, including a decrease in fishing, high clean-up costs, and many more (Newman et al., 2015). Recreational activities are greatly affected by marine plastic debris, as cleanliness and scenic beauty attract beach users (Gianluca, 2016). It is estimated that plastic takes hundreds of thousands of years to decompose depending upon its type, ingredients and weather conditions; however the exact degradation time of plastic material is still unknown. Microplastics are greatly documented as serious threats for food security (Abbasi et al., 2018; Karami et al., 2017). Both floating and sea-floor persistent debris are equally harmful, causing suffocation, ingestion, and navigation problems (Bellas et al., 2016). Many types of microplastics found in sea animals show a clear threat to human health (Renzi et al., 2018). These possess a serious threat to human food security, food safety and health (Abassi et al., 2018; Karami et al., 2017; Renzi et al., 2018; Barboza et al., 2018). It requires timely management otherwise, 99.8% of the species would be digesting plastic by 2050 (Perkins, 2015).

A qualitative and quantitative study of plastic and other persistent material is of utmost concern for marine pollution (Qaisrani et al., 2018, 2019; van Truong & BeiPing, 2019). The study of sources, transport and accumulation of debris in many coastal areas around the globe are still very limited, while no such study prior to this study has been done along the 161 km long coastal area of Brunei Darussalam. In the current research, a pioneer attempt was made to investigate the potential sources and impacts of debris accumulation on the beaches of Brunei Darussalam. This research focuses on selection of six beaches at different locations and classified into three groups having recreational, riverine estuaries, and sea-based effects (Poeta et al., 2016). The beaches along the coast of South China Sea were selected to quantify the amount of plastic debris and carry out qualitative analysis. The current study was conducted in May 2016 and March 2017 for one week (dry season) on each beach to identify plastic debris through qualitative analysis which considers shape, size and chemical characteristics. The study was conducted during dry season as the preliminary study noticed more debris are accumulated on the beaches during the dry season due to the increased number of visitors.

MATERIALS AND METHODS

Data for debris characteristics along Brunei coast was not available prior to this study; hence the selection of hotspots for the current study was very important. Brunei Darussalam being a tropical country, very rich in biodiversity, and well known for its pristine rain forests, has its unique importance in the region particularly in relation to eco-tourism. It has some historical places such as water villages (Kampong Ayer) located on Brunei River and Istana Nurul Iman Palace (The Palace of the light of Faith) which attract not only local visitors, but also foreigners (Tiquio et al., 2017). Water villages have a history of more than one thousand years. The white sandy beaches with lush green vegetation cover along its shore are other attractions for tourists visiting the country. There are more than ten beaches of different sizes along the coastal stretch. Six stretches of beaches were selected for current study (Fig. 1), with details mentioned in Table 1, keeping in view the sources of debris i.e., land-based or sea-based (OSPAR, 2010).

Table 1. Details of study sites along Brunei coast

Group	Beaches	Coordinates	Area selected (m^2)	Sampling dates
A (Recreational)	Maura	05°02.284N, 115° 04.645E, 05°02.298N, 115° 04.648E, 05°02.278N, 115° 04.586E, 05°02.294N, 115° 04.589E	110×30	May 6-12, 2016
	Tungku	04°58.376N, 114° 52.374E, 04°58.362N, 114° 52.383E, 04°58.341N, 114° 52.324E, 04°58.358N, 114° 52.324E	110×30	May 6-12, 2016
B (Near River mouth)	Lumut	04°40.211N, 114° 27.364E, 04°40.187N, 114° 27.312E, 04°40.227N, 114° 27.354E, 04°40.199N, 114° 27.304E	110×25	May 20-26, 2016
	Seri Kenangan	04°08.171N, 114° 37.922E, 04°08.185N, 114° 37.912E, 04°08.145N, 114° 37.045E, 04°08.145N, 114° 37.869E	110×27	May 20-26, 2016
C (Little known activity)	Meragang	05°02.439N, 115° 02.603E, 05°02.451N, 115° 02.601E, 05°02.470N, 115° 02.657E, 05°02.456N, 115° 02.661E	110×25	March 1-7, 2017
	Tanjung Batu	05°02.325N, 115° 03.747E, 05°02.325N, 115°03.747E, 05°02.301N, 115° 03.805E, 05°02.290N, 115°03.795E	110×25	March 1-7, 2017

These six sites were categorized into three groups called A (Muara and Tungku), B (Lumut and Seri Kenangan) and C (Meragang and Tanjung Batu). The samples were collected on a daily basis for seven days on each site in consistent with other research studies (Zhao et al., 2015). The difference in width is due to the location of sites depending upon the distance from natural vegetation at the bank. The beaches in group 'A' have recreational activities throughout the year, although generally extensive visitors are seen on beaches during weekends. The beaches in group 'B' are affected by rivers, as these are located on rivers estuaries. Hence a relation of storm water with debris input to the sea can be made from these sites. The beaches in group 'C' have sea-based debris as direct human contact to these sites was very rare. There are no restrictions on the accessibility of the beaches for recreational or other activities, as a result, some beaches like Muara and Tungku are quite popular for frequent visitors.

The surveys were conducted on sites in group A on May 6-12, 2016, group B on May 20-26, 2016 and group C on March 1-7, 2017 shown in Table 1. The area on sites was measured and cleaned one day before samples collection. Each visible artificial debris was collected within selected transects; however, the materials buried under the sandy beach or beyond the defined area were not considered. The sampling on beaches under groups A and B was done after equal intervals of time (i.e. 24 hours) while under group C was done one hour after high tides. These samples were collected in labelled plastic bags and shifted to the laboratory for further classification. The process flow chart is shown in Figure 2.

Fig. 1. Study sites (beaches) along the coast of Brunei Darussalam (A1: Muara, A2: Tungku, B1: Lumut, B2: Seri Kenangan, C1: Meargang and C2: Tanjung Batu)

Fig. 2. Flow chart of the process

The collected debris was washed well to remove the salt, sand, and the adhesive materials on surface. It was completely dried in sunlight, counted and its weight was checked by digital weight balance at the water resources engineering laboratory, Universiti Teknologi Brunei. In initial classification, overall debris was taken into consideration and classified into seven classes called plastic, metal, glass, rubber, lumber and miscellaneous (Kumar et al. 2016). However, focus was on plastics due to its abundance.

The size of plastic material was further classified into four groups micro (<5 mm), meso (5-20 mm), macro (21-100) and mega (>100 mm) by using callipers. Plastic was further categorized on the basis of colour e.g. transparent, translucent and black (Zhao et al., 2015). The density on each site was noted and concentration was calculated using following equation;

$$C= n/ A$$

Here 'C' represents concentration, 'n' number of debris and 'A' denotes the area of the measured site.

The chemical characterization of plastic material found in different form was of keen concern. Chemical analysis of plastic debris was done at INHART lab at International Islamic University of Malaysia (IIUM) by using FTIR spectroscopy technique (iS50 FT-IR) for 14 selected samples. Spectra were compared with available database at central laboratory and chemical structures to find the chemical composition (additives) of different products. Also, the health risks of these additives were analysed based on their leaching out behaviour because of degradation shown in Table 4.

Statistical analysis was done to check the abundance of debris on beaches with different sources. Non-parametric Kruskil-Wallis test was used to compare the data. Mean values and standard deviations were calculated to check the variations.

RESULTS And Discussions

Overall, plastic debris found on all six beaches was 2958 items with a weight of 73.03 kg shown in Table 2 . By number, there is no significant difference of plastics on all sites; however, by weight Muara beach is the most affected site because plastics with larger sizes were found on this beach due to throwing behaviour of litter illegally near or on the beach. Percent abundance by number and weight for all beaches are shown in Figure 1 and Figure 2 respectively.

Plastics in different forms were found on all sites classified by size and colour shown in Table 3.

By size macro plastics are the most abundant 55.65% by number and 73.54% by weight followed by mega 24.95% (19.35%), meso 13.96% (4.55%) and micro 5.44% (2.56%) which can be seen in Table 3. By colour the most abundant portion found was transparent 35.83% by number with weight 44.94% followed by white 31.27% (24.95%), coloured 30.63% (21.19%) and black 2.27% (8.97%) shown in Table 3.

Fourteen (14) representative samples were used for investigation of chemical composition. The FTIR spectra for these samples can be seen in Figure 3. The results show that all major types of plastics in different forms were present on all beaches. Poly vinyl chloride was found more harmful due to its loosely bound phthalates leaching out behavior as a result of photo-degradation causing endocrine disrupture in marine organisms (Ma et al., 2020).

Table 2. Details of plastic debris collected during the study from each beach

S.No.	Group	Beaches	Plastic debris			
			No. of items (count)	Count (%)	Weight (kg)	Weight (%)
1	A	M	521	18	36.66	50
2		T	479	16	14.38	20
3	B	L	371	13	5.16	7
4		SK	504	17	10.04	14
5	C	Mg	568	19	3.93	5
6		TB	515	17	2.85	4
	Total		2958	100	73.03	100

Table 3. Plastic debris classification by size and colour

Beach		Size (mm)				Colour			
		Micro	Meso	Macro	Mega	Transparent	Coloured	White	Black
Muara	Count	11	24	336	150	206	170	129	16
	Weight	0.21	0.35	16.50	5	11.05	4.70	6.20	1.19
Tungku	Count	42	65	241	131	183	188	95	13
	Weight	0.70	1.01	8	2.25	7.10	4.70	2.15	2.05
Lumut	Count	38	21	260	52	154	118	93	6
	Weight	0.45	0.45	10.20	0.53	3.93	1.95	2.31	0.87
Seri Kenangan	Count	46	52	320	86	202	156	124	22
	Weight	0.50	0.99	15.90	0.60	8	2.60	5.90	2.20
Meragang	Count	5	106	281	176	182	131	249	6
	Weight	0.001	0.23	0.573	3.56	1.57	0.91	1.005	0.09
Tanjung Batu	Count	19	145	208	143	133	143	235	4
	Weight	0.004	0.27	2.2	2.1	0.97	0.52	0.55	0.07
Total	Count	161	413	1646	738	1060	906	925	67
	Weight	1.86	3.30	53.38	14.04	32.62	15.38	18.11	6.47

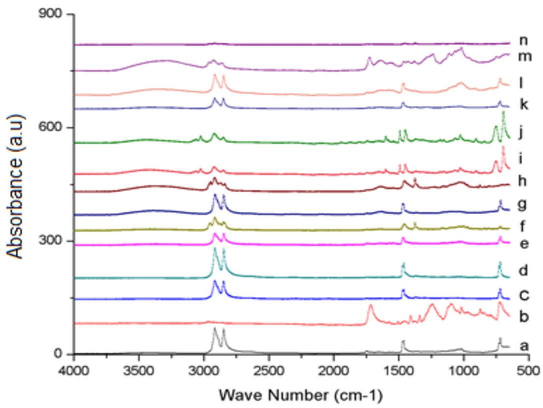
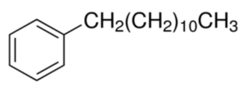


Fig. 3 FTIR spectra of the plastics collected in this study (a: Shampoo bottle (plastic), b: Water bottle c: Polyethylene bag, d: Engine oil container, e: Bottle lid, f: Rope, g: Fishing net, h: PET strap, i: Styrofoam (Cooler box) , j: Styrofoam (Food container), k: PVC pipe , l: Drinks cans, m: Shoe (sleeper), n: Plastic chair piece)

Absorbance shows the intensity (absorbed radiations) and wavenumber gives information about the additives present in these samples. The shape and size of plastic debris found was heterogeneous. Food containers (transparent and Styrofoam) were found abundantly followed by polyethylene bags. Strong chemical bonding makes the degradation of plastics difficult; however, degradation occurs under chemical weathering and mechanical currents in marine environment depending upon the type and composition of material. Monomers may behave as inert under normal conditions, but polymers do not in terms of health and environmental impacts. Ultraviolet (UV) light starts photo-oxidative degradation in polypropylene (PP), polyethylene (PE), high density polyethylene (HDPE), low density polyethylene (LDPE) etc. Once degradation starts, it will convert into autocatalytic degradation as long as oxygen is available.

FTIR spectra results for sample "shampoo bottle" show the presence of 1-phenyldodecane with chemical structure as below.



The comparison of FTIR spectrum for sample "water bottle" with laboratory database search matches 100% with "polyester" showing no contaminants. Sample "polythene bag" majorly contains "polyethylene" which undergoes photo degradation on beaches. It causes suffocation to aquatic organisms if these living organisms indulge with larger pieces.

FTIR spectrum with library search indicates that sample "engine oil container" has Tritriacontane which is higher n-alkane with chemical formula $C_{33}H_{68}$. Its accumulation causes skin and eyes irritation in humans and animals. Sample "bottle lid" is majorly polypropylene with some indications of "Polypropylene, Atactic" and "polypropylene, isotactic". It is generally categorized as low to medium toxic chemicals; however, it oxidizes by ultraviolet radiations at higher temperatures. Under severe conditions, it increases the CO level, which causes lethal effects (Purohit and Orzel 1988). Sample "rope" is majorly Polypropylene + poly (ethylene:propylene). Polyethylene contain "isomeric acyclic alkenes" which are loosely bound and leach out during photo-degradation (Sojáka et al., 2006). Sample "fishing net" mainly has low density polyethylene (LDPE), which has entanglement effects for sea users and sea animals including turtles, sea birds and many more while chemically polyethylene is categorised as non-toxic (Bang et al., 2012).

Spectra for sample "PET strap" match with Polypropylene and Polyethylene. During manufacturing of Polyethylene terephthalate (PET), a metalloid element "Antimony" is used in the form of antimony trioxide (Sb_2O_3) which causes health problems after degradation. Although it has low health concerns, but needs care in water bottles and food packaging materials, especially dealing at higher temperatures (Li at al., 2018). Apart from recycling, landfill and incineration; recently research shows bacterial degradation of PET (Yoshida et al., 2016). Biodegradation is one of the attractive choices for polymer decomposition, but still not famous on commercial scale (Webb et al., 2013).

FTIR spectra for samples "Styrofoam (cooler box)" and "Styrofoam (food container)" give indications of presence of polystyrene which is non-biodegradable and its acidification potential impacts on environment are reported in literature (Zabaniotou and Kassidi 2003). Spectrum for sample "PVC pipe" matches in library search with Polyvinyl chloride (PVC). PVC is available in different products used for garden hoses, electrical pipes, automobile seat covers and many more (Ma et al. 2020). Flexible PVC products are of main concern due to phthalates concentration, which is added to increase its flexibility during manufacturing. Di-ethylhexyl phthalate (DEHP), di-isononylphhalate (DINP), butylbenzyl phthalate (BBP) and di-isodecyl phthalate (DIDP) are extensively used as additives which are persistent and can degrade chemically and biologically in the presence of oxygen and finally enter the food chain. These are soluble in fat and expose to human body through food chain very easily, having endocrine disrupting and hormones effects (Rowdhwal, S., & Chen, J. 2018).

IR Spectrum for sample "drinks can" matched with Polyethylene terephthalate. It is safe under normal temperature and used as drink bottle (i.e. fruit juice), but antimony leaches out when goes under higher temperature conditions. Antimony and antimonide both are dangerous and cause many health problems including eyes, lungs, stomach, urine, liver skin problems depending upon concentration and contact time (Li et al. 2018). Whereas sample "shoe piece (sleeper)" has some indications of "Chrysocolla" from database search, which is copper-based mineral and will become part of soil on beaches after degradation. The effects of copper on aquatic organisms are lethal if inhaled in higher concentration. Copper inhalation affects gills ability in fishes to move salts regularly inside the body (Padrilah et al. 2018). IR spectrum results for sample "plastic chair piece" matched with polypropylene, which degrades under higher temperature conditions by increasing carbon monoxide and decreasing oxygen.

Statistical analysis shows that there was no significant difference in debris density on each beach, which indicates equal risk on all beaches. Kruskal-Wallis test was used to check the variation in existence of debris on each studied beach. In Table 5 "N" value is 14 which shows the summation for number of sampling days in each group. Each group contains two beaches and every beach was studied for 7 consecutive days. Here $P > 0.05$ which shows no significant difference in abundance on beaches under each group.

Table 4. Details of representative samples and their health hazards adopted from Li et al. 2016

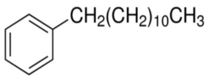
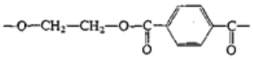
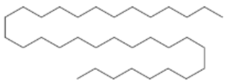
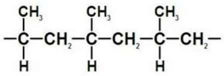
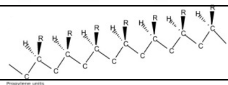
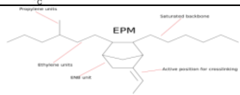
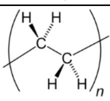
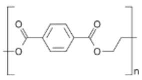
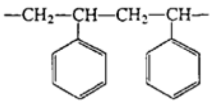
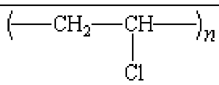
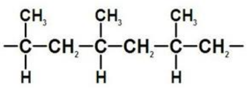
Sample code	Product	Chemical Name	Chemical Structure/Formula	Effects
A	 Shampoo bottle	High density polyethylene		It disturbs human cells as a result of released estrogenic chemicals. Also, affects reproductive system, endocrine, lungs and have carcinogenic impacts
B	 Water bottle	Poly(ethylene terephthlate) (PET)		It is a potential human carcinogen. Causes nausea, vomiting, and diarrhoea, eyes and respiratory problems
C	 Plastic bag	Polyethylene	$(—CH_2—CH_2—)_n$	Suffocation, ingestion
D	 Engine oil container	Tritriacontane		Not so hazardous
E	 Bottle lid	Polypropylene		Affects developmental and reproductive system, interference with thyroid hormone
		Polypropylene, isotactic		
F	 Rope	Ethylene propylene rubber		Entanglement
G	 Fishing net	Low density polyethylene		Entanglement
H	 PETstrap	Polyethylene terephthalate		Antimony releases at higher temperature and causes eye, lungs and skin problems
I	 Styrofoam (Cooler box)	Polystyrene		Affects eyes, nose and throat. Estrogen receptors binding, Carcinogen and can form DNA adducts
J	 Styrofoam (Food container)			
K	 PVC pipe	Poly vinyl chloride		Genetic problems lead to cancer, vision failure, mimics estrogen, interferes with testosterone, sperm motility, deafness, vision failure
L	 Drinks cans	High-density polyethylene	$—CH_2—CH_2—CH_2—CH_2—$	It disturbs human cells as a result of released estrogenic chemicals. Also, affects reproductive system, endocrine, lungs and have carcinogenic impacts Also, reproductive damages and adverse impacts on thyroid hormones
M	 Shoe (sleeper)	Contains copper-based mineral "Chrysocolla"	$(Cu,Al)_2H_2Si_2O_5(OH)_4 \cdot nH_2O$	Ingestion, Lethal effects if inhaled in higher concentration, skin allergies
N	 Plastic chair piece	High-density polyethylene		Effects reproductive system after photo degradation at higher temperatures

Table 5. Kruskal-Wallis test for plastic debris on beaches under group A, B and C

a) **Kruskal-Wallis Test on Plastic**

	N	Median	Ave Rank	Z
A	14	68.00	22.4	0.32
B	14	57.00	18.5	-1.12
C	14	64.50	23.6	0.80
Overall	42		21.5	

H = 1.33 DF = 2 P = 0.514

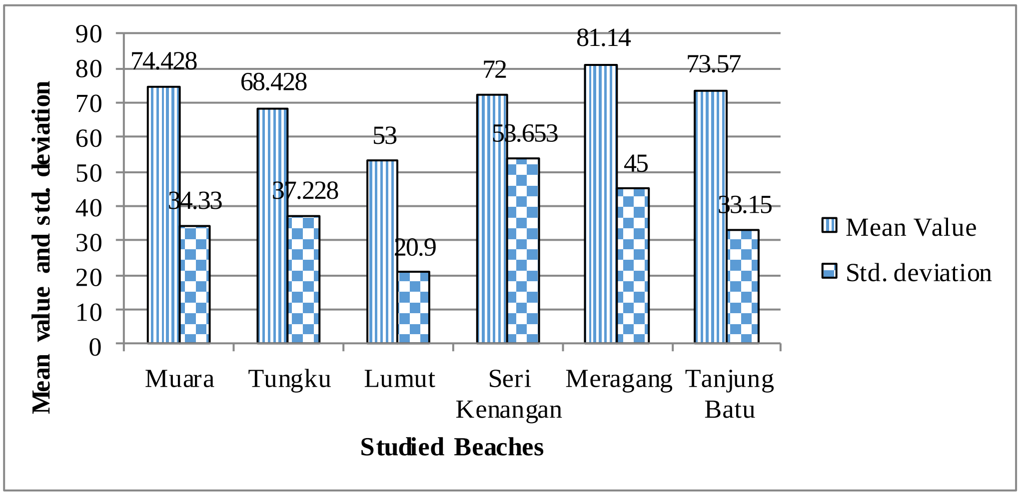


Fig. 4. Mean value and standard deviation of plastic debris by number on each beach

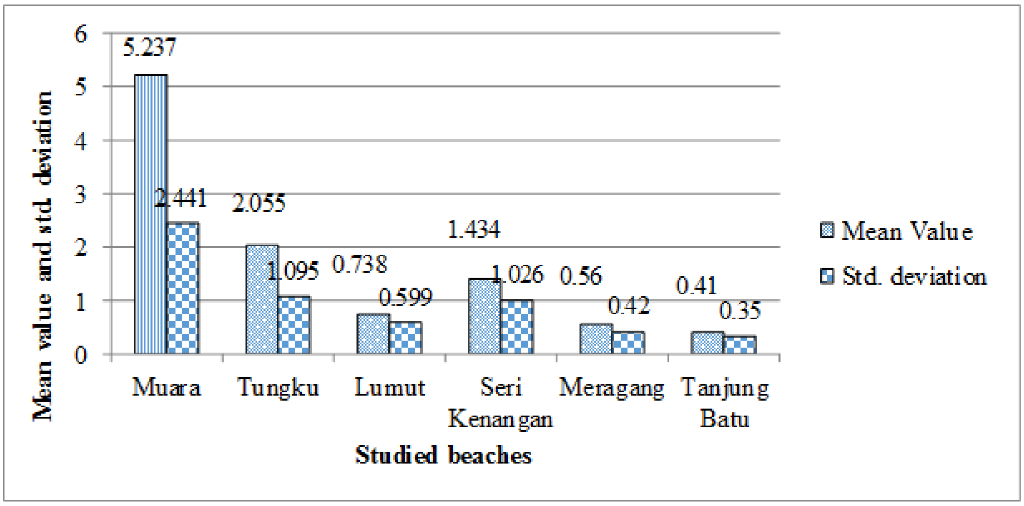


Fig. 5. Mean value and standard deviation of plastic debris by weight on each beach

The highest abundance by number of plastic debris was found on Muara beach with mean value 74.428 n/m^2 ± 34.33 n/m^2, while the lowest abundance was found on Lumut beach 53 n/m^2 ± 20.9 n/m^2 which can be observed in Figure 4. On the other hand, highest abundance by weight was found on Muara beach 5.237 kg/m^2 ± 2.441 kg/m^2 and lowest was on Tanjung Batu beach 0.41 kg/m^2 ± 0.35 kg/m^2 shown in Figure 5.

CONCLUSIONS

The plastic in different forms comprises of significant parts of marine debris along the Brunei coast. Even the remote areas having no direct human contact are also affected. Due to the high photo-degradation rate, plastic pollution is the major challenge for a sustainable coastal environment in Brunei Darussalam, like other parts of the world. The awareness from school children to beach users and boaters can greatly be helpful in the long run. The existing plastic debris on beaches needs much attention to be removed as early as possible. Legislation, its forceful implementation, and treaties with regional countries might be effective tools as well. The problem can greatly be solved with simultaneous multi-dimensional actions, which are more favourable for a long-term solution. Mechanical sifters along the coast of Brunei Darussalam are recommended, as these sifters give the best results on sandy sites. Bacterial degradation of plastics might be a reasonable solution; however, more research is required in this regard. The plastic collectors and water wheel are recommended for Brunei bay and Kampong Ayer areas to get rid of floating plastic debris before reaching the sea. More research on the plastic debris along the coast might be more beneficial for management actions. The use of user-friendly mobile App “marine debris tracker” developed by NOAA and South East Atlantic Marine Debris Initiative could be a positive step towards quick response and solution.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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