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Physical Assessment of Marine Debris Along the Coast of Brunei Darussalam

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***Abstract*--Debris along coastlines is a global issue as it affects ecosystem, human health, tourism and economy; thus, requires more attention from town planners, policy makers and researchers. Various studies have been conducted around the world to identify and quantify the debris, its sources and mitigation strategies; however, it is a pioneer study of its kind in Brunei Darussalam. The current study involves selection of different beaches, debris collection and its physical analysis. Brunei Darussalam has 161 km long coast along South China Sea and the debris was collected from four different beaches in the month of May considering different sources related to anthropogenic, riverine and sea-based activities. The selected areas for study were 110x30 m^2 and collected samples were categorized by number, weight, size and colour. By number, large amount of plastic (91.46%) was found on all four beaches followed by miscellaneous materials. As, the most abundant type of debris was plastic, hence it was further classified on the basis of size and colour. Most of the materials found on these beaches were the result from land based human activities, but the contribution of debris through the waterways is also significant.**

***Key words*-- Brunei Darussalam; Debris classification; Marine debris; Plastic pollution; Sea beaches**

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I. INTRODUCTION

Marine debris is "any persistent solid material that is manufactured or processed and directly or indirectly, intentionally or unintentionally, disposed of or abandoned into the marine environment of great lakes" [1]. Mainly plastic waste is found in coastal zones all over the world [2]. It adversely effects marine environment and human life[3]. In another report it is stated that more than 90% of litter on beaches is plastic [4]. Urbanization and rapid industrialization along the coastal areas make the situation more worse in many areas of the world [5]. Initially no serious attention was paid on negative impacts of plastic material [6]; however it became a serious problem as more research was carried out on its potential health impacts both on aquatic and human lives directly or indirectly[7] [8] [9]. Many factors including low cost, durability, light weight, easy availability and others made plastic a popular and extensively used product. With increase in population and their growing demands, the quantity of plastic material is increased rapidly with time [10].The annual production of plastic has been increased 200-fold from 1950 to 2014 [11]. Another research reports that during 2010, 4.8 to 12.7 million metric tons of plastic reached the oceans around the globe [12]. Some researchers described that about 5.25 trillion plastic particles are floating in world's oceans/water [12]. The floating debris not only represents unpleasant views but also have significant adverse impact on ecosystem, human health, tourism and economy[13] [14] [15] [16]. More or less all marine environment users are affected by debris to some extent including boats, divers, ship propellers and many more. Entanglement and ingestion by animals and birds are very common consequences observed all over the world [11]. Entanglement may cause serious issues for sea animals (sea turtles, fishes, birds, mammals), divers, choking of impellers of ships and many more [17]. Aquatic animals ingest this product as food by mistake where suffocation and internal injuries are resulted [18]. Sea turtles are affected particularly as they consider floating and light synthetic material as jellyfish for their food [19]. Also sometimes different harmful chemicals attached with these plastics or added during manufacturing of this polymeric material become the part of marine debris [20]. Moreover the plastic material creates waste disposal problem due to its durable characteristics [21]. Various synthetic materials found on beaches

are possibly result of human activities. Although many studies exist on marine litter [22] [23]; however some areas are still not considered for such studies including Brunei Darussalam. This is one of the pioneer studies of its kind which analyses the debris on four selected beaches of Brunei Darussalam. Brunei Darussalam has a unique attraction for tourists in the region due to its historical places such as "Kampong Ayer" (water villages) and "Istana Nurul Iman Palace" (Palace of the light of Faith). Chen reported that Kampong Ayer is about 1000 years old and was named as "Venice of the East" by Antonio Pigafetta in 1521 [24]. Marine debris is one of the growing environmental issues in Brunei Darussalam like many other parts of the world including direct and indirect littering. Hence, tourism activities may put extensive pressure on these beaches which is an alarming situation especially in context of 2035 clean environment vision of Brunei Darussalam [25]. Therefore, the study is an effort to identify and analyses marine debris in Brunei Darussalam, as it can influence the water quality in tidal rivers and thereby put pressure on aquatic lives and mangrove ecosystem for which Brunei Darussalam is well known. The current study is unique as it provides a baseline for further research in this area, as studied sites cover direct tourism based and riverine based littering on beaches. Different methods exist for surveying, however marine debris is generally handled by land-based surveys [26] [25] [27] [23]. Samples were collected in May 2016 for this study. Based on land and riverine impacts, the study sites were classified into two groups namely A and B. Two beaches (Muara and Tungku) with land-based effects are in group A while Lumut and Seri Kenangan beaches with riverine impacts are put in group B. i.e. the latter two beaches are linked to rivers. Samples were segregated on the basis of different criteria such as number, weight, size, colour [28]. Non-biodegradable and the most abundant materials "plastic" was then focused in current study.

II. MATERIALS AND METHODS

A. Study Area and Analysis

161 km long coastline along South China Sea, Brunei has 100% coastal population (within 100 km of coast) whereas its total population was about 4,23,000 people [29]. Besides tourism and recreational activities; there are commercial and residential activities which contribute in littering. Brunei has attractive and very nice sandy beaches which attract more people. More people are observed on Muara and Tungku beaches especially during weekends. The hotspots were considered between coordinates 05°02.284N, 115° 04.648E, 05°02.298N, 115° 04.648E, 05°02.278N, 115° 04.586E and 05°02.294N, 115° 04.589E for Muara beach, coordinates 04°58.376N, 114° 52.374E, 04°58.362N, 114° 52.383E, 04°58.341N, 114° 52.324E and 04°58.358N, 114° 52.324E for Tungku beach, coordinates 4°40.211N, 114° 27.364E, 4°40.187N, 114° 27.312E, 4°40.227N, 114° 27.394E and 4°40.199N, 114° 27.364E for Lumut beach, and coordinates 04°08.171N, 114° 37.922E, 04°08.185N, 114° 37.912E, 04°08.145N, 114° 37.945E and 04°08.145N, 114° 37.869E for Seri Kenangan beach. Each site for group A was 110x30 m2 while (110x25 m2) and (110x27 m2) for Lumut and Seri Kenangan beaches in group B. The difference in width is due to narrow location of study sites. Study areas are shown in Figure 1. Samples were washed to remove attached material including sand, salt etc and dried well in oven at 40°C.

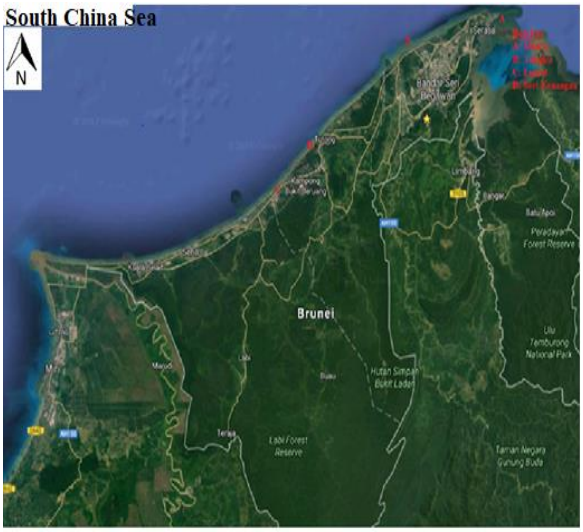


Figure 1 The selected beaches along Brunei coast (A: Muara (M); B: Tungku (T); C: Lumut (L) and D: Seri Kenangan (SK))

B. Sampling

The month of May was selected for study to check the effect of rivers as this season is wet in Brunei. These sites are open for public, commercial and recreational activities.

Figure 2 Representative samples collected from different beaches

Before 1st day of sampling, the area selected and cleaned for visible debris. The visible debris from all beaches was collected. Few representative samples are shown in Figure 2 (a, b, c and d).

2.3 Classification

The debris collected, washed and classified into seven main categories namely plastic, metal, rubber, glass, wood, cloth/fibre and miscellaneous [30]. Due to its abundance and non-biodegradable nature; plastic was further classified based on size and colour. The concentration of debris was calculated as;

C= n/(w*l)

Where;

C= Concentration of debris (Number/square meter)

n= No. of macro-items observed

w= Width of the sampling site

l= Length of sampling site

Table 1,

Table **2**, Table 3 and

Table 4.

III. RESULTS

A. Quantities of Debris

By following the method prescribed by Lippiatt, the collected marine debris during May 2016 on daily basis for seven days from each site was classified into 7 major types [30]. The total number of collected items was 2050 items having weight of 176.09 kg shown in

Figure **3**. The average number of items (weight) were 84.57 (18.73 kg), 75.14 (2.62 kg), 56 (2.21 kg) and 77.14 (1.59 kg) counts/day (weight, kg/day) on Muara, Tungku, Lumut and Seri Kenangan respectively shown in

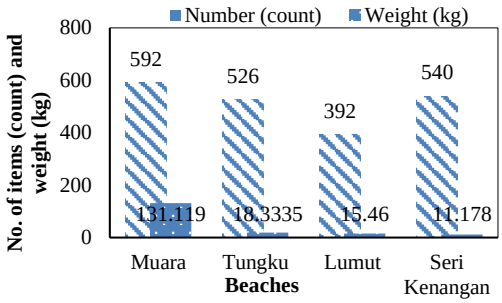


Figure 3 Number and weight of debris collected from four beaches

Also, abundance (%) by number and weight on all study sites can be seen in Figure 4 and Figure 5 respectively.

Table 1 Abundance of debris (A, number of items; B, weight in kg) at Muara beach. (May 6-12, 2016)

S#	Day	Material							Total (No.)
		Plastic	Metal	Glass	Rubber	Cloth	Lumber	Miscellaneous	
1	Fri	73	0	2	0	0	2	3	80
2	Sat	124	5	0	0	1	1	6	137
3	Sun	76	0	0	0	0	1	5	82
4	Mon	102	2	0	1	2	5	6	118
5	Tue	79	1	1	0	0	1	6	88
6	Wed	18	2	0	0	1	0	0	21
7	Thu	49	5	2	0	0	8	2	66
Total		521	15	5	1	4	18	28	592
Mean value		74.428	2.143	0.714	0.143	0.571	2.571	4	84.571
Std. deviation		34.33	2.115	0.951	0.378	0.786	2.878	2.380	37.175

B. Weight of items in kg

S#	Day	Material							Total (kg)
		Plastic	Metal	Glass	Rubber	Cloth	Lumber	Miscellaneous	
1	Fri	1.837	0	0.68	0	0	0.06	0.05	2.627
2	Sat	5.335	3.955	0	0	0.005	0.015	0.07	9.38

3	Sun	5.976	0	0	0	0	0.01	0.10	6.085
4	Mon	4.835	2.94	0	0.005	0.09	0.28	0.18	8.33
5	Tue	8.93	0.075	0.22	0	0	0.015	0.185	9.425
6	Wed	7.065	1.005	0	0	0.013	0	0	8.083
7	Thu	2.684	64.685	0.55	0	0	14.02	5.25	87.189
Total		36.661	72.66	1.45	0.005	0.108	14.40	5.835	131.119
Mean value		5.237	10.38	0.207	0.0007	0.015	2.057	0.833	18.731
Std. deviation		2.441	23.99	0.292	0.0019	0.033	5.276	1.948	30.28

Table 2 Abundance of debris (A, number of items; B, weight in kg) at Tungku beach. (May 6-12, 2016)

S#	Day	Material							Total (No.)
		Plastic	Metal	Glass	Rubber	Cloth	Lumber	Miscellaneous	
1	Fri	43	1	1	0	0	0	1	46
2	Sat	96	2	0	0	2	4	3	107
3	Sun	55	0	0	0	1	0	3	59
4	Mon	140	1	0	1	0	16	0	158
5	Tue	63	0	0	0	0	2	1	66
6	Wed	35	0	0	0	0	0	3	38
7	Thu	47	0	1	0	0	2	2	52
Total		479	4	2	1	3	24	13	526
Mean value		68.428	0.571	0.286	0.143	0.428	3.428	1.857	75.143
Std. deviation		37.228	0.787	0.488	0.378	0.787	5.740	1.215	42.795

B. Weight of items in kg

S#	Day	Material							Total (kg)
		Plastic	Metal	Glass	Rubber	Cloth	Lumber	Miscellaneous	
1	Fri	3.1	0.1	0.115	0	0	0	0.05	3.365
2	Sat	1.745	0.105	0	0	0.085	0.03	2.365	4.33
3	Sun	1	0	0	0	0.015	0	0.005	1.02
4	Mon	1.2275	0.05	0	0.01	0	0.17	0	1.4575
5	Tue	1.16	0	0	0	0	0.45	0.005	1.615
6	Wed	3.89	0	0	0	0	0	0.105	3.995
7	Thu	2.261	0	0.175	0	0	0.045	0.07	2.551
Total		14.3835	0.255	0.29	0.01	0.1	0.695	2.6	18.3335
Mean value		2.055	0.036	0.041	0.00143	0.014	0.099	0.371	2.619
Std. deviation		1.095	0.04	0.07	0.00378	0.03	0.166	0.88	1.310

Table 3 Abundance of debris (A, number of items; B, weight in kg) at Lumut beach. (May 20-26, 2016)

S#	Day	Material							Total
		Plastic	Metal	Glass	Rubber	Cloth	Lumber	Miscellaneous	
1	Fri	61	0	0	0	1	1	5	68

2	Sat	55	0	0	0	0	0	2	57
3	Sun	59	1	0	2	0	1	2	65
4	Mon	72	0	0	1	1	0	1	75
5	Tue	72	0	0	0	0	1	0	73
6	Wed	39	0	0	1	0	1	0	41
7	Thu	13	0	0	0	0	0	0	13
Total		371	1	0	4	2	4	10	392
Mean value		53	0.143	0	0.571	0.286	0.571	1.428	56
Std. deviation		20.90	0.278	0	0.787	0.488	0.534	1.813	22.173

B. Weight of items (kg)

S#	Day	Material							Total
		Plastic	Metal	Glass	Rubber	Cloth	Lumber	Miscellaneous	
1	Fri	0.605	0	0	0	0.265	0.02	0.19	1.08
2	Sat	1.78	0	0	0	0	0	0.07	1.85
3	Sun	1.28	0.22	0	0.005	0	0.025	0.145	1.675
4	Mon	0.615	0	0	0.005	0.05	0	0.03	0.7
5	Tue	0.615	0	0	0	0	0.005	0	0.62
6	Wed	0.155	0	0	9.255	0	0.01	0	9.42
7	Thu	0.115	0	0	0	0	0	0	0.115
Total		5.165	0.22	0	9.265	0.315	0.06	0.435	15.46
Mean value		0.738	0.03	0	1.323	0.045	0.008	0.062	2.208
Std. deviation		0.599	0.08	0	3.497	0.988	0.010	0.077	3.237

Table 4 Abundance of debris (A, number of items; B, weight in kg) at Seri Kenangan beach (May 20-26, 2016)

S #	Day	Material							Total
		Plastic	Metal	Glass	Rubber	Cloth	Lumber	Miscellaneous	
1	Fri	176	0	0	2	0	7	8	193
2	Sat	76	0	1	0	0	2	4	83
3	Sun	99	1	0	1	0	1	1	103
4	Mon	50	0	0	0	0	1	0	51
5	Tue	45	0	1	2	0	1	1	50
6	Wed	49	0	0	0	0	1	1	51
7	Thu	9	0	0	0	0	0	0	9
Total		504	1	2	5	0	13	15	540
Mean value		72	0.143	0.286	0.714	0	1.857	2.143	77.143
Std. deviation		53.653	0.378	0.488	0.951	0	2.34	2.911	58.98

B. Weight of items in kg

S#	Day	Material							Total
		Plastic	Metal	Glass	Rubber	Cloth	Lumber	Miscellaneous	
1	Fri	3.03	0	0	0.015	0	0.125	0.09	3.26
2	Sat	1.596	0	0.485	0	0	0.01	0.07	2.161
3	Sun	1.64	0.11	0	0.09	0	0.015	0.015	1.87
4	Mon	2.36	0	0	0	0	0.001	0	2.361
5	Tue	0.67	0	0.001	0.005	0	0.05	0.03	0.756
6	Wed	0.29	0	0	0	0	0.005	0.02	0.315
7	Thu	0.455	0	0	0	0	0	0	0.455
Total		10.041	0.11	0.486	0.11	0	0.206	0.225	11.178
Mean value		1.434	0.016	0.069	0.016	0	0.029	0.032	1.597
Std. deviation		1.026	0.041	0.183	0.033	0	0.045	0.035	1.11

By number, plastic is the most abundant part (91.46%) followed by miscellaneous (3.22%) while by weight, metal is the leading portion (41.60%) followed by plastic (37.62%) shown in Figure 4 and Figure 5. Muara and Tungku beaches were found more littered. The concentration was calculated by using NOAA method which shows 0.331028, and 0.323751 items/m^2/week on beaches of group A and B respectively shown in Table 5 separately. The density by number (n/m^2) and by weight (kg/m^2) per week on four mentioned beaches of Brunei is shown in Figure **6** and Figure **7** respectively.

Table 5 Density of collected debris in count /m^2 and kg/m^2 per week

Gp	Beach		Material {Count (weight)/m^2/week}						
			Plastic	Metal	Glass	Rubber	Cloth	Lumber	Miscellaneous
A	M	Count	0.158	0.0054	0.0015	0.0003	0.0012	0.0054	0.0085
		Weight	0.011	0.022	0.00044	$1.51*10^{-6}$	$3.27*10^{-5}$	$4.36*10^{-3}$	$1.76*10^{-3}$
	T	Count	0.145	$1.21*10^{-3}$	$6.06*10^{-4}$	$3.03*10^{-4}$	$9.09*10^{-4}$	$7.27*10^{-3}$	$3.93*10^{-3}$
		Weight	$4.36*10^{-3}$	$7.73*10^{-5}$	$8.79*10^{-5}$	$3.03*10^{-6}$	$3.03*10^{-5}$	$2.11*10^{-4}$	$7.88*10^{-4}$
B	L	Count	0.135	$3.64*10^{-4}$	0	$1.45*10^{-3}$	$7.27*10^{-4}$	$1.45*10^{-3}$	$3.64*10^{-3}$
		Weight	$1.88*10^{-3}$	$8*10^{-5}$	0	$3.37*10^{-3}$	$1.14*10^{-4}$	$2.18*10^{-5}$	$1.58*10^{-4}$
	SK	Count	0.169	$3.37*10^{-4}$	$6.73*10^{-4}$	$1.68*10^{-3}$	0	$4.38*10^{-3}$	$5.05*10^{-3}$
		Weight	$3.38*10^{-3}$	$3.70*10^{-5}$	$1.64*10^{-4}$	$3.70*10^{-5}$	0	$6.94*10^{-5}$	$7.57*10^{-5}$

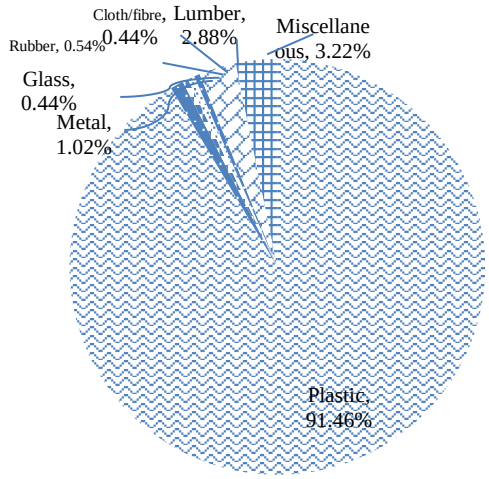


Figure 4 Abundance of different debris types by number on all four beaches

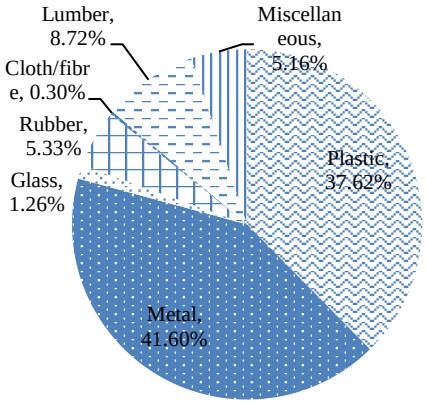


Figure 5 Abundance of different debris types by weight on all four beaches

The results of standard deviation show that plastic has the highest standard deviation while glass has the lowest; whereas, the abundance of glass, rubber and cloth/fibre have not much variation with varying sites. The mean value (average number and weight) and their respective standard deviations for each beach are also plotted in Figure 8 and Figure 9 respectively.

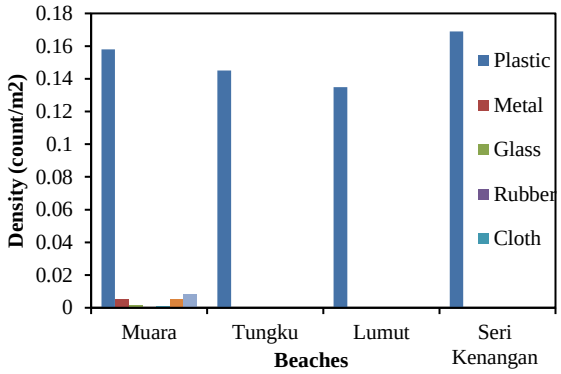


Figure 6 Density of debris on each beach (n/m^2) per week

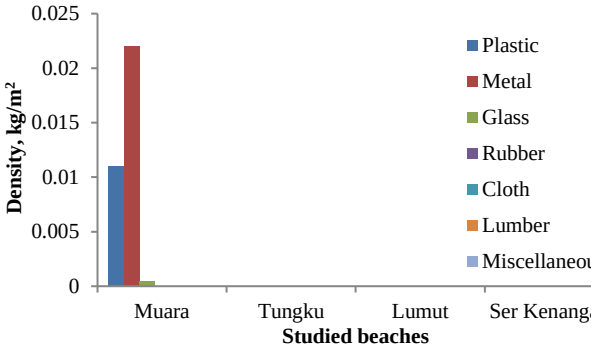


Figure 7 Density of debris by weight (kg/m^2) per week

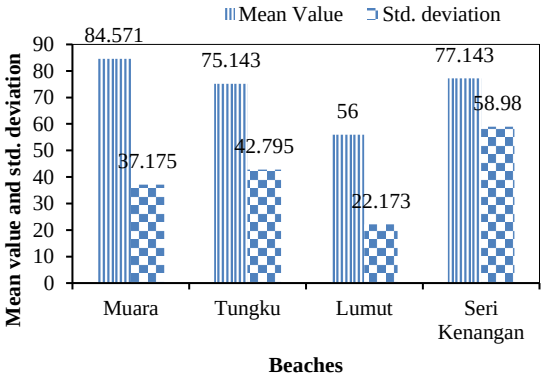


Figure 8 Mean value and standard deviation of debris by number on each beach

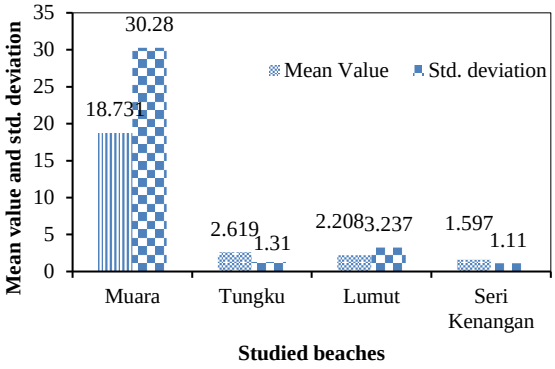
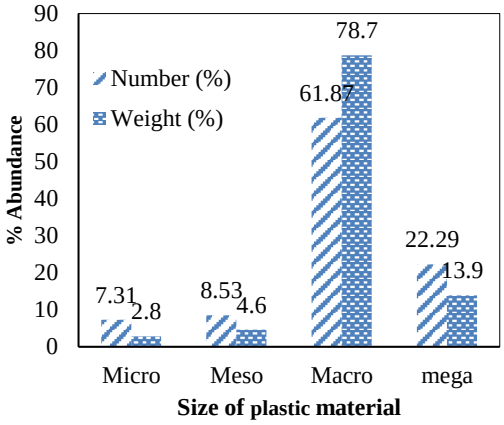


Figure 9 Mean value and standard deviation of debris by weight on



each beach

Figure 10 % Abundance of plastic material on the basis of size

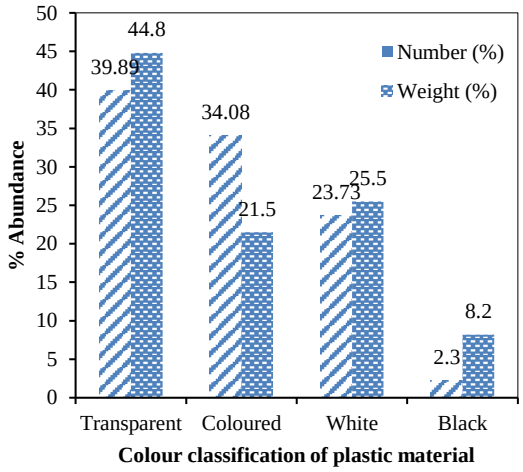


Figure 11 % abundance of plastic material by colour

The plastic products were further classified by size and colour. Micro, meso, macro and mega are used for size ≤5 mm, 5-20mm, 20-100 mm and >100 mm respectively [2] [31]. Based on size and colour,

plastic material was classified as shown in Table 6.

Table 6 Classification of plastic items by size and colour

Beach	Size				Colour			
	Micro	Meso	Macro	Mega	Transparent	Coloured	White	Black
M	10	22	334	148	204	169	127	15
T	41	64	241	131	183	189	95	13
L	54	37	278	68	173	138	112	6
SK	32	37	307	71	188	143	111	9
Total	137	160	1160	418	748	639	445	43

Macro plastics were found abundantly (61.86% in number and 78.7% by weight) followed by mega (22.29% by number and 13.9% by weight), meso (8.53% by number and 4.6% by weight) and micro (7.31% by number and 2.8% by weight); while based on colour, plastics were categorised into transparent, coloured, white and black [28]. Major part was of transparent plastics (39.89% by number and 44.8% by weight) followed by coloured (34.08% by number and 21.5% by weight), white (23.73% by number and 25.5% by weight) and black (2.29% by number and 8.2% by weight) shown in Figure 10 and Figure 11.

B. Composition of Debris

The plastic material was found abundantly among all found debris on these beaches. Plastic by number was 91.46% followed by miscellaneous 3.22% and lumber 2.88%. By weight, metals were found abundantly (41.59kg) followed by plastic (37.62%), lumber (8.72%), rubber (5.33%), miscellaneous (5.16%), glass (1.26%) and cloth (0.29%). Out of 1875 items of plastic in various forms, major contribution of food stuffs (26.51%) followed by plastic fragments (23.25%), PET bottles (15.63%), polyethylene bags (13.76%) and Polyvinyl Chloride (1.92%) was observed as shown in Table 7.

Table 7 Major types of plastic debris

Beach	Material				
	FS	PF	PB	PE	PVC
M	121	146	123	36	4
T	145	57	49	106	1
L	104	110	3	66	19
SK	127	123	91	5	12
Total	497	436	266	213	36
% by number	34.32	30.11	18.37	14.70	2.5

FS: Food Stuffs
PF: Plastic Fragments
PB: PET Bottles
PE: Poly Ethylene
PVC: Poly Vinyl chloride

C. Sources of Debris

Total number of items collected was counted as 2050 items with a weight of 176.09 Kg. These four beaches have been selected to measure the land based and riverine based effects on beaches for marine debris. Beaches in group A were found more littered as tourism and direct littering on these beaches are the major causes of this debris. Mostly the litter found cannot be removed completely during cleaning campaigns. Volunteer or paid campaigns only focus on large material. Although the debris collected on these beaches has some indications about the presence and contribution of neighbouring countries, but major portion is from local sources, as mostly debris found has labels of Brunei Darussalam. These results show that like other countries; Brunei Darussalam is also more affected by land-based sources. The beaches in group A (density 0.331028 n/m^2/week) having recreational or commercial activities were found more littered as compared to beaches in group B (density 0.323751 n/m^2/week).

IV. DISCUSSIONS

As current study is physical based assessment of collected debris from four beaches of Brunei Darussalam; so, no statistical analysis was done for this work. Plastic is found the leading contributor in marine littering. Majorly types of debris and their respective quantities were focused in this work, but sources identification was of the keen interest for proper management. People behaviour towards littering on recreational sites and near waterways is found discouraging like developing countries [31]. Recreational and commercial activities make Maura beach more littered. There were clear signs of human input in littering on these beaches. As sites were not being affected by sea currents or runoff which shows the presence of local sources or land-based sources. It needs proper management and policy implementation to control this litter. Proper environmental education, provision of disposable facilities, public awareness through different means can help in litter reduction. The ban on plastic bags in Brunei Darussalam during weekends is an appreciable initiative; however, the same is being provided to customers in kitchen/small markets at the same time which needs to be considered. Hence, regular monitoring to check the provision of plastic bags to public during weekends is required. Law enforcement in the form of fines can reduce the use of plastic bags during weekends.

V. CONCLUSIONS & RECOMMENDATIONS

The results show anthropogenic pressure on beaches as a result of recreational activities. Plastic products

of various kinds are found abundant on these sites. Also, land-based sources of debris were found dominating. Continuous monitoring, systematic collection and law enforcement simultaneously can give a sustainable solution. Suitable trapping mechanisms are required to restrict the movement of debris from coast to sea. Different sources can be used for controlling plastic litter such as educating people through curriculum, public messages, TV talk shows, newspaper advertisement, displaying sign boards, public figure speeches and many more. The initial study can provide a baseline for further research. The extensive study on more beaches supported by chemical and statistical analysis can demonstrate the condition of the coastline more clearly.

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