Scientific Research Publishing

Journal of Environmental Protection, 2023, 14, 441-469
https://www.scirp.org/journal/jep
ISSN Online: 2152-2219
ISSN Print: 2152-2197

Quantitative Analysis of the Sized Ranged Plastic Debris on Beach Shoreline along the Limbe Coastline, Cameroon

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How to cite this paper: Ndumbe, E.E., Manga, V.E., Foba, J.T. and Yengong, F.L. (2023) Quantitative Analysis of the Sized Ranged Plastic Debris on Beach Shoreline along the Limbe Coastline, Cameroon. *Journal of Environmental Protection*, **14**, 441-469.
https://doi.org/10.4236/jep.2023.146026

Received: April 17, 2023
Accepted: June 27, 2023
Published: June 30, 2023

Abstract

In recent years, increased interest in investigating the accumulation of sized ranged plastic debris has been observed on beaches along coastlines. The abundance and distribution of the 4M's sized class plastic debris were quantitatively assessed on five sandy beaches, in Cameroon. Duplicates of 2 × 2 m (4 m^2) quadrants were sampled in each beach/month with a total of 80 quadrants. Collected plastic samples were washed, sieved and dried. Particles of size, ≥2 mm, were sorted and measured using a 30 cm ruler, and converted to mm. Overall, 12,822 particles by number (530.59 g) with a mean abundance of 40.07 items/m^2 (1.66 g/m^2) plastic debris was recorded. ANOVA ($p = 0.05$) shows a linear relationship between the meso- and micro-sized classes with significantly higher abundance recorded in LDB sites. The highest abundance by weight was recorded in August and June numerically. 80% of the plastic particles were between the size range, of 5 - 20 mm by number and 6 - 100 mm by weight. Moreover, in all beaches micro-sized class plastics were dominated by number 42.40% with fragmented debris dominant, in number/weight, 54.86% (25.69%) while meso-sized class plastics were 29.28% dominated by weight, with fragmented debris type, the most prevalence in number and weight as 46.11% (26.18%). On average, color and shape fractions revealed, colored and irregularly shaped plastics were dominant with an abundance of 80.45 ± 18.17 items/m^2 (2.58 ± 0.68 g/m^2) and 47.24 ± 20.40 items/m^2 (1.39 ± 0.66 g/m^2). Finally, the 0.0001 g plastic debris was dominant with a concentration, of 33.68 ± 7.23 items/m^2. The intense use of beaches for recreation and poor waste disposal has increased the potential for plastic contamination.

Keywords

Plastic Debris, Beach, Size-Ranged Class, 4M's, Abundance, Cameroon

1. Introduction

The dispersive and deteriorative nature of the uncontrolled release of the 4M's different ranged classes of mega, macro, meso and micro-sized plastics debris on the environment has rendered beaches and shoreline aesthetic quality around the world to uneconomically unsustainable for touristic purposes and poisonous to the marine ecological community especially in the African Continent [1] [2]. With the development of society and the economy, the rapidly increasing demand and production of plastic debris have become a global environmental issue [3] [4] [5] [6] [7]. Plastic debris can eventually enter the ocean via human input, inland waterways, wastewater outflows, and transport by wind, waves and tides [8] [9] [10] [11] [12].

Plastic debris in marine environments is resistant to degradation and can leach out toxic components that can influence water quality and present a serious threat to marine biology [13] [14] [15]. Recently, the European MSFD technical subgroup on Marine Litter [16] proposed a unified, size-based nomenclature of mega- (>100 mm), macro- (21 - 100 mm), meso- (6 - 20 mm), and microplastic (<5 mm). Mega-sized sometimes break into macro-sized debris, which can also be fragmented into meso-sized debris and then further break down into micro- and nano-sized plastic debris [17] [18] [19].

Beaches, and shorelines, as an interface between land and ocean, are subjected to plastic debris pollution. Accumulation of plastic debris on beaches is widespread [20]-[25]. The distribution of plastic debris on beaches can be affected by many factors, such as wind, ocean currents, river input, coastal landscape, population level, and sand properties [26] [27] [28]. In addition, beach exposure, width, and slope have been found to be key parameters in sandy beach ecology. The surface sediment of marine beaches is regularly mixed by natural events or anthropogenic activities, leading to organic matter content and sand grain size variations [29].

The transport of particles, whether sand or plastic, is a function of their size, color, shape, and weight/density, and they can interact in the transport process [29]. For instance, plastic aggregation with organic matter might play an important role in microplastic transport and fate [30] [31]. The characteristics of plastic debris in land-based sources can provide useful information in tracking the source and biological effects. For instance, one of the factors often considered to influence the consumption of marine debris is color, as specific colors might attract predators when resembling the color of their prey [32]. On the one hand, plastic shapes can partly provide information on their origin. Fragments are thought to originate mainly from hard plastics via fragmentation [33]. On the other hand, there is a tendency toward increasing toxicity with decreases in particle size [34]. Even plastic weight sometimes gives us an idea of the shoreline deposition capacity together with the floating to sinking potentials [35] [36] [37] [38] [39]. Reference [40] highlighted that knowing plastic weight is vital when computing fluxes and budgets of plastic.

While the management mega and macro-sized has received somewhat advanced knowledge in terms of remediation but the problematic nature of meso-sized (6 - 20 mm) and micro-sized plastics debris (<5 mm) is systematically calling for research focuses [41] recently, although sized fractions are not sampling difficulties associated with large-scale surveys [42]. Reference [43] extensively reviewed the threat of different sized plastics categories in the marine environment. In addition, several authors have pointed out that the risk factor from plastics increases inversely with the particle size [44] [45] [46].

In Africa, few studies have been conducted on plastic accumulation on beaches and shorelines by different authors [47] [48]. Cameroon has a maritime coastline of about 420 km of which 52% comprises sandy beaches [49] [50] with limited reports on beach debris. Thus, this paper seeks to quantify the accumulation of different-sized classes of plastic debris on the sandy beaches on the west coast of Cameroon. To this end, we characterized_(size, color, shape and weights) and estimated the mean abundance/concentration (items (particles)/m^2 and g/m^2) of plastics on beaches and shorelines using a quadrant sampling side-by-side hand-picking collection technique.

2. Materials and Methods

2.1. Location of Study Area

Cameroon is in the Gulf of Guinea between Gabon, Equatorial Guinea and Nigeria with 15.7 million inhabitants covering an area of 475,000 km^2 [51]. Cameroon has great potential with 420 km of maritime coast, mangrove forest, lagoons and many beaches [49]. With Limbe Sea coastal area lies along Ambas Bay in the Gulf of Guinea, at the southern foot of Mount Cameroon [52]. As a metropolitan city, Limbe is a coastal town and an economic center of the South-West Region of Cameroon with a population of about 300,000 inhabitants and a land area of 1596 km^2. It is bordered to the West, East, North and South by Idenau District, Mutengene, Buea, and the Atlantic Ocean respectively [53]. According to Tume [54] Limbe is located between latitudes 3˚20' North and 4˚15' North of the Equator and between longitudes 8˚15' East and 9˚35' East of the Greenwich Meridian (**Figure 1**). Limbe is subdivided into three municipalities (Limbe I, Limbe II, and Limbe III). Climatically, Limbe is dominated by an equatorial climate of high rainfall and high temperature. Average monthly temperatures are like any other part of the Fako Division, with the hottest month recording a monthly temperature of 33˚C (February and March) and the coldest months recording as low as 23˚C (June-October) [55]. Cameroon beaches are described as "LUNGS" of the economy due to their high productivity, lodging a majority of the economic activities, as it is a major hunt for tourists [56].

2.2. Sampling Designs

This work was carried out from March 3rd, 2020 to October 31st, 2020. Before field collection, a reconnaissance survey was done and tide prediction was acquired from online admiralty charts simultaneously before every sampling day

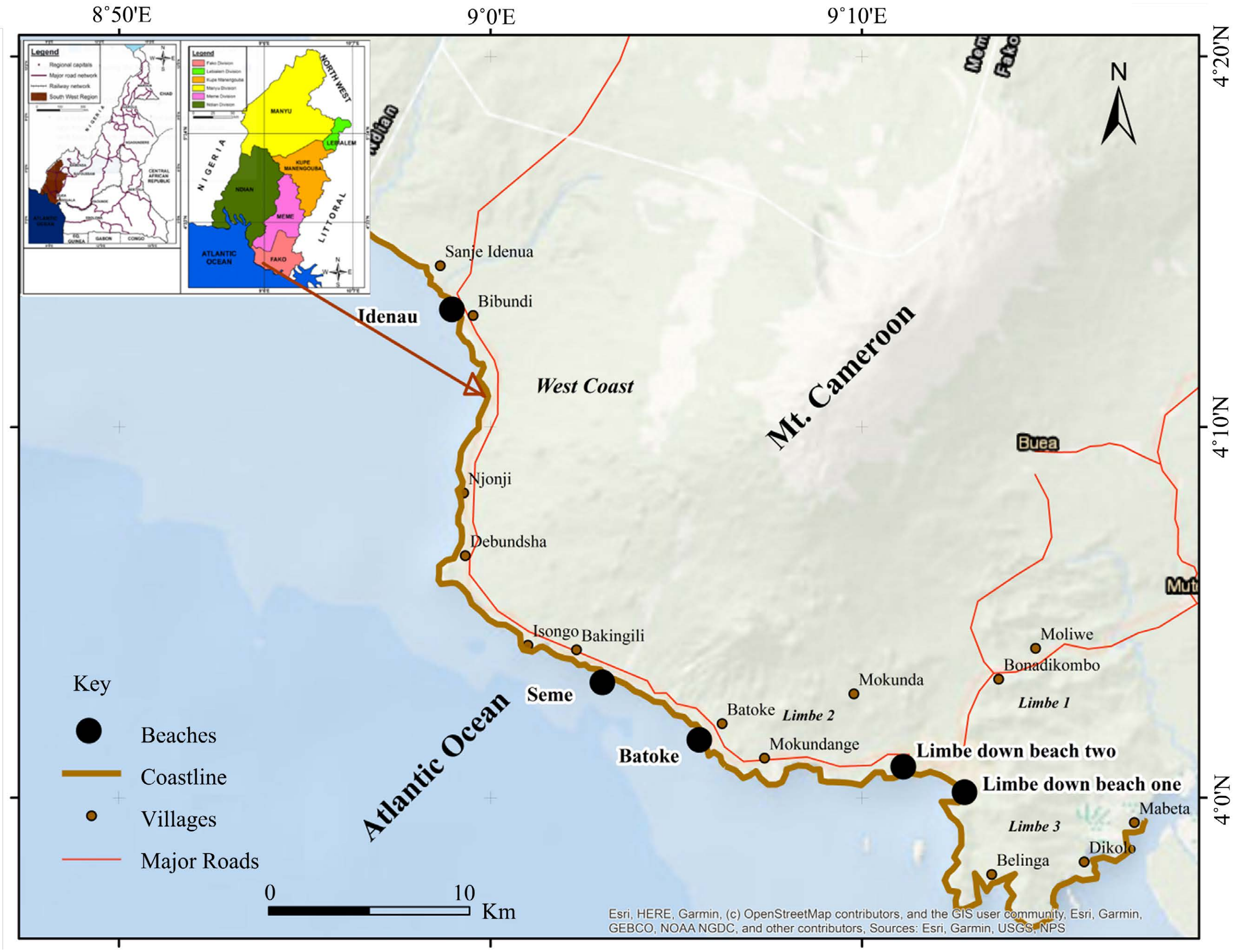

Figure 1. Map of the study area showing sampling sites on Limbe-Idenau Coastline.

during each sampling week to know the low tide level [57]. Five purposive sampling plots were selected along the coast, viz, Limbe down 1 (LDB 1) Limbe down beach (LDB 2), Batoke (BTK), Seme (SEM), and Idenau (IDN) beaches over a coastline length of 50.6 km. A 2.0 m by 2.0 m sampling plot with four 1.5 m iron rods, each painted 1 m red and 0.5 m black was laid with the black end on the sandy ground on each studied beach pathway between high and low tide levels and this is in line with [58]-[63]. Also, the landward edge of each studied beach was determined by either naturally grown/planted trees (sometimes by noting sharply rising sand dunes) or man-made structures such as walls, pavements, steps, etc., depending on the sampling path chosen for the beach. Additionally, the implementation of beach clean-ups by the local authorities and the accessibility of the sampling sites were also taken into account.

2.3. Sample Collection

Beach plastic litter visible with the naked eye was collected, in each sampling plot/day/beach within five days/week respectively, with a systematic sampling done on the first week and the third week, for each month for over eight (8) months studied period. To keep the sampled area constant, red and black ink paint was marked on any permanent sign structure. Each beach was sampled 16 times; hence eighty (80) sampled collections were done in totality. At low tide, plastic debris within each quadrant was collected by hand-picking and placed in a 10 L labeled glass bowl to minimize contamination by post-collection fragmentation impact and immediately closed and carried to the laboratory. We tried to keep the sampling depth as constant as possible at 0.1 cm and only plastic items that are visible on the beach surface and within the plot were included in the survey [64].

2.4. Sample Analysis and Calculations

In the laboratory, the plastic debris was washed and rinsed thoroughly with fresh water to remove sand, shells and other organic debris, in the glass bowl. In addition, a 2 mm stainless sieve was used to separate plastic debris ≥ 2 mm. The ≥2 mm plastic debris were further spread on 1 m^2 trays after each sampling day/beach and air dried for 24 h to remove moisture (**Figure 2(a)**). Then, the individual plastic particles were sorted, counted and quantified based on length measurements either by Ferret's diameter or Martin's diameter [65] [66] [67]; the length was measured using a 30 cm measuring ruler along the longest axis/dimension (for regular and irregularly shaped plastics) (**Figure 2(b)**).

The value obtained was converted to the nearest millimeter (mm) and classified into four (4M's) sized classes (4) as micro- (≤5 mm), meso- (6 - 20 mm), macro- (21 - 100 mm) and mega- (>100 mm) sized ranged debris [68] [69] [70] [71]. Many studies on the quantification of plastic sizes have pointed out the difficulty of comparing results from previous works. The system used in this study is similar to that adopted by UNEP [16] [72], and NOAA [73] which is: micro- (≤5 mm), meso- (5 mm to 2.5 cm), or macroplastic (>2.5 cm) (**Figure 2(c)**).

Figure 2 shows how the collected plastic debris were air-dried, sorted and characterized into 4M's aligned with particle-sized value based on the longest length measurement possible as >100 m, 21 - 100 mm, 6 - 20 mm and ≤5 mm respectively in the laboratory.

In these different-sized plastic fractions, ten types of plastic debris were identified by visual observation and classified (such as fragments, pellets, plastic bottle, single-use plastic, film, fiber, sponge/foam, rope, microbeads and rubber). Also, four color classes (white, black, colored (details as blue, red, green, and brown), others (pale yellow, yellow grey) and transparent) were aided by a 40× magnifier and then into five shape classes (irregular, elongated, rough, broken edges, and degraded). The dry weights of individual plastic particles were further determined and recorded to the nearest 0.0001 g on an electronic balance. The particles were also classified into five weight classes (0.0001 g, 0.001 g, 0.01 g, 0.1 g, >1 g) according to [74] [75] [76].

Classification and quantification: Each plastic-sized class range was then separated per beach from the different beaches (LDB 1 & 2, BTK, SEM and IDN Beaches), counted and placed in separate containers with each labeled based on

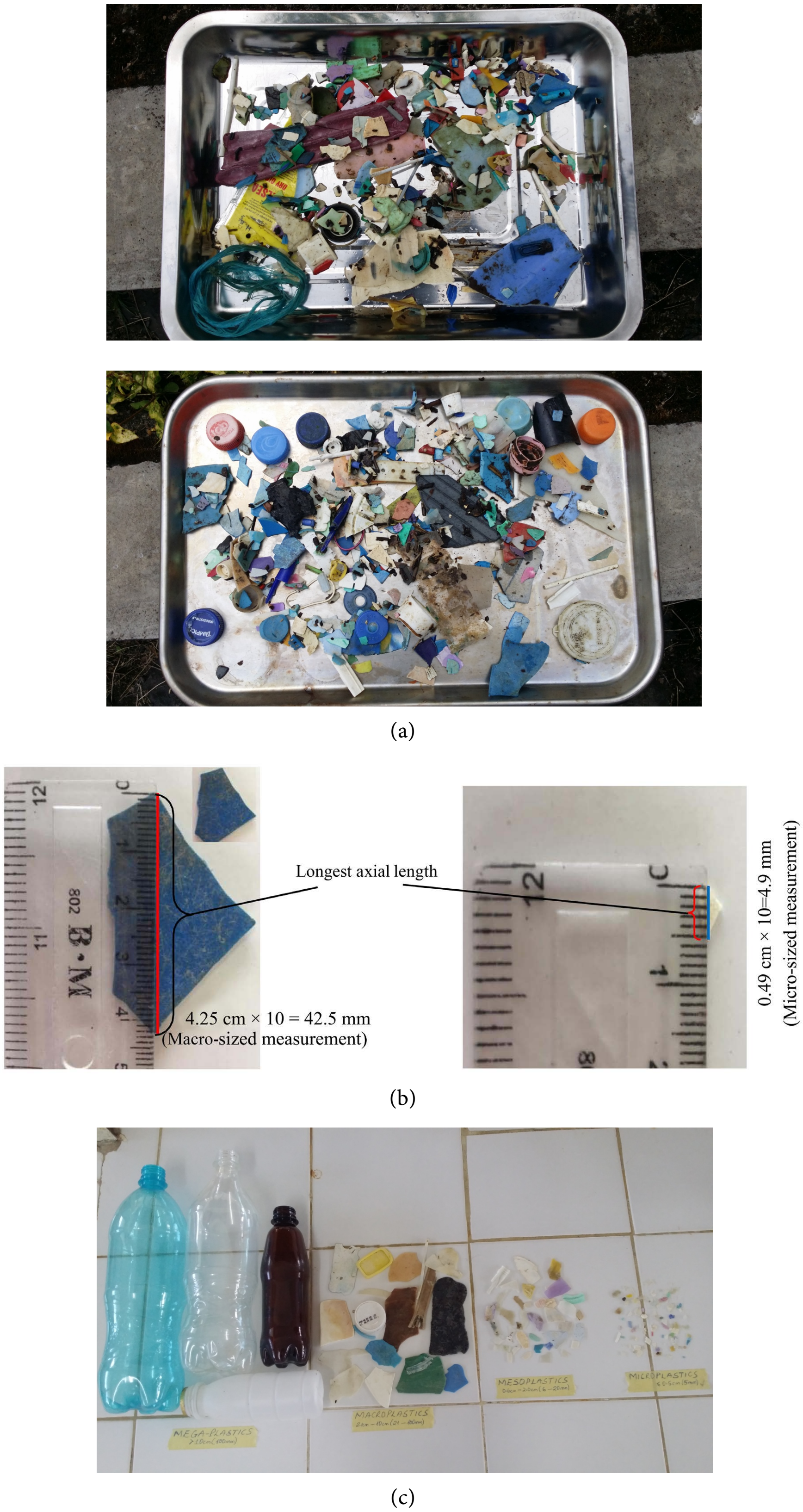

Figure 2. Plastic sample air drying, sorting and sized classification process in the laboratory ((a)-(c)): (a) plastic drying process; (b) plastic debris size determination; (c) plastic sample classification process.

particle-sized ranged category [77] [78]. Plastic debris abundance was expressed in terms of number and weight and as mean density/concentration of items/m^2 and g/m^2. Plastic particles of size less than 1 mm were not considered in this survey. The plastic density and generation rate were obtained from computation in Equation (1) as illustrated. For the purpose of this study, the number of each particular type/class/plot can be obtained as:

Number of particular type/class/beach = I

Total number of particular type/class/beach = $\sum\left(I_1 + I_2 + \cdots + I_\eta\right)$

Plastic density/plot = D

Number of each particular type/class/plot = X

Hence,

$$x = \frac{I}{\sum\left(I_1 + I_2 + \cdots + I_\eta\right)} \times D \quad (1)$$

3. Data Analysis

ArcGIS version 21 was used to map the monitoring beach sampling sites (**Figure 1**). The different-sized class distributions of the total abundance of the plastic debris were performed and drawn using SPSS version 16.0 [79]. Statistical analyses were carried out at $p < 0.05$ for each correlation analysis and also, for significant effects, the temporal and spatial differences in mean abundance of the 4 M's sized classes were analyzed by ANOVA followed by Tukey Pairwise Comparisons tests. The mean abundance /concentration of plastics in all sized class categories was expressed as Mean ± STD/m^2 in terms of items/count and particles/gram and as well in percentages.

4. Results and Discussions

Table 1 is a summary of the characteristics of the studied beaches. The accumulation of sediments and materials is influenced by factors that are inherent in the nature of the coastline and the wave action. Anthropogenic activities influence the level of cleanliness of beaches, particularly activities such as waste disposal and beach cleaning.

Reference [80] pointed out and agreed that the nature of the beach, beach activities, beach community and behaviours play a significant role in the deposition and fragmentation of plastic debris depicted on their work along the coastline, Manila Bay Philippines. This idea was also supported by [81] work carried out on plastic litter accumulation on high-water strandline on four urban beaches in Mumbai, India. Within the same year 2013, [82] further confirmed that the creek-like nature of the Mumbai beach had influences on the accumulation, deposition and fragmentation of plastic debris as in the case studied in this work. In addition, [83] showed that beach litter accumulation patterns are influenced by biotic and abiotic factors, as well as by the distribution of anthropogenic sources around the Mediterranean coastal landscape of Italy. On 12 beaches studied on the Polish coast, the Southern Baltic Sea clearly [84] stated

Table 1. Characteristics of selected beaches for plastic debris quantification.

Physical Parameter	Limbe Down Beach 1	Limbe Down Beach 2	Batoke Beach	Seme Beach	Idenau Beach
Substrate Nature	Sandy (<2 mm)	- Sandy (<2 mm) - Stony, 1 m offshore	Sandy (<2 mm)	Sandy (<2 mm)	- Sandy (<2 mm) - Stony, 1m offshore
Morphology	Long Beach	Long Beach	Long Beach	Long Beach	Long Beach
Slope Structure	- 88.8˚ - Open - At least 10 m high tide trends from the sea	- 81.5˚ - Embankment - At least 10 m high line trends from the sea	- 88.3˚ - Open - At least 7 m high line trends from the sea	- 84.3˚ - Embankment - At least 10 m high line trends from the sea	- 85.9˚ - Open - At least 10 m high line trends from the sea
Land Drainage/ Gutters/Streams	Present	Present	None	None	Present
Tourist Visitation	Large	Large	Low	Large	Low
Ease to Access	Open access	Open access	Open access	Paid access	Open access
Activities	- Fishing - Business - Fish market	- Relaxation site - Business	- Fishing - Fishing market	- Recreational purpose only	- Fishing - Transportation - Business
Beach Cleanings	Periodically/Council	Periodically/Council	Occasional	Regularly/Daily	Occasional
Ownership	Public	Public	Public	Private	Public
Proximity to Settlement	Very close	Very close	≈200 m	≈1.5 km from town	Very close

that differences in terms of the intensity of their touristic exploitation, urbanization and sediment characteristics affect plastic abundance during the rainy and dry seasons. Recent studies suggested furthermore a correlation between the accumulation of plastic on beaches and the currents surrounding the Canary Islands [85] [86]. In Contrast, [87] stated that most of the plastic recorded on beaches and shorelines is not only affected by either beach structure or beach activities and behavior but that ocean plastic particles might have been transported from far distances by wind and currents forces and therefore they are witnessed everywhere in the marine environment, including ocean surface, water column, deep sea or polar regions, were as well confirmed by [88] [89] [90]. Reference [91] data results therefore support the suspicion that plastics tend to accumulate on shorelines due to wave and wind-driven origins [85] [92] rather than touristic pressure or urban nucleus as it was supposed in other studies [69] [93] [94] [95].

4.1. Plastic Abundance

The prevalence of 4M's different-sized ranged plastic debris accumulated on the beach indicated that all the sampled beaches contained plastics ranging in length from 2.10 mm (small fragment particle) to 276 mm (plastic bag) in size. A total abundance of 12,822 items weighing 530.59 g was recorded. The average/mean abundance across the coastline was 40.07 ± 27.36 items/m^2 (7.38 - 83.90 items/m^2) and 1.66 ± 0.97 g/m^2 (0.62 - 3.37 g/m^2). Also, the mean concentration of the different sized classes of plastic debris were as follows; mega 20 items/m^2 (1.28 g/m^2), macro 47 items/m^2 (1.91 g/m^2), meso 54 items/m^2 (2.59 g/m^2) and micro 78 items/m^2 (2.50 g/m^2). Furthermore, the median length of mega-, macro-, meso-, and micro-sized debris were 104 mm, 22.1 mm, 6.1 mm, and 2.1 mm, and within each size class; the dominant ranged sizes are 148 - 173 mm, 21 - 33.3 mm, 8.6 - 11.3 mm and 2.2 - 2.5 mm respectively. It is worth noting that SEM beach, a private recreational beach that is regularly cleaned had the least number of items (7.38 items/m^2) and weights (0.62 g/m^2), whereas LBD1 and LBD2, serving as recreational and fishing beaches that are regularly cleaned by the Council recorded the highest quantity in terms of number of items and weights. LDB1 has the highest average abundance of 83.9 items/m^2, representing the most plastic-littered beach, this is similar to that reported by [96] for the northeast Brazilian Coast (82.1 items/m^2) and Mumbai beaches (68.83 items/m^2) by [82]. Still, higher densities have been reported in other studies *i.e.* in the Portuguese coastline (185.1 items/m^2) [57].

Results of the ANOVA analysis (**Table 2** and **Figure 3**) identify two categories in terms of abundance in the number of items, higher values for group a (LDB1 and LDB2) and lower values for group b (BTK, SEM and IDN). LDB1 and LDB2 with higher abundances are in close proximity to one another. These beaches are exposed to the same activities that are responsible for the high rate of materials deposition, such as proximity to human settlements, fishing-related activities, high littering rates from beach visitors and commercial activities, and serving as the evacuation point of urban drains. A similar grouping is evident in the weight

Table 2. ANOVA results for total plastics and size fractions for the effect of month, beach and their interaction.

Size fraction by weight											
		Total-weight		Mega-weight		Macro-weight		Meso-weight		Micro-weight	
Source	DF	MS	F	MS	F	MS	F	MS	F	MS	F
Beach	4	611.43	7.29*	26.69	6.58*	23.47	5.96*	39.41	5.69*	74.46	6.29*
Month	7	383.67	4.57*	10.19	2.51*	16.99	4.31*	41.42	5.98*	38.29	3.23*
Beach * Month	28	83.88	1.23*	4.06	0.98*	3.94	0.67*	6.93	2.53*	11.84	1.21*
Size fraction by item											
		Total-item		Mega-item		Macro-item		Meso-item		Micro-item	
Source	DF	MS	F	MS	F	MS	F	MS	F	MS	F
Beach	4	557693.79	12.39*	8297.15	11.63*	40818.16	10.49*	28935.46	7.35*	86110.63	10.07*
Month	7	189260.79	4.21*	1884.08	2.64*	11839.11	3.04*	13437.87	3.41*	31106.19	3.64*
Beach * Month	28	44991.05	2.19*	713.14	0.81*	3890.12	1.01*	3936.86	1.23*	8554.05	1.12*

*Significantly different at p = 0.05; df: degree of freedom; MS: mean sum of squares.

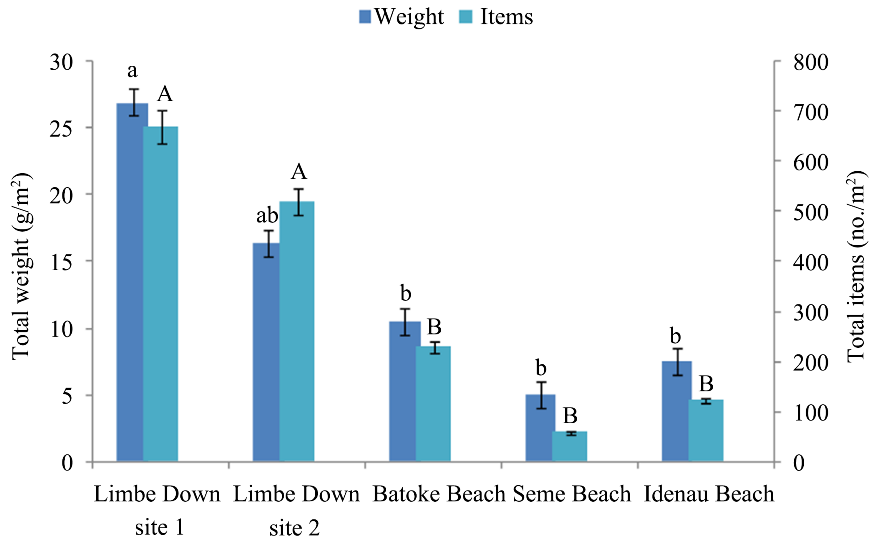

Figure 3. ANOVA analysis comparing the distribution of total plastics (number and weights) in the different study sites.

category with lower abundance in BTK, SEM and IDN beaches; compared to LDB1 which has the highest values of 25.4 g/m², while LDB2 is intermediate. This dichotomous distribution is mainly controlled by the proximity of the population center. Limbe, a major coastal city in Cameroon with one of the highest population densities of 220 people per square kilometer [97] is of immense economic importance (an oil refinery, ports activities and agriculture) and a popular tourism destination (coastal beaches, sports facilities, hotels and bars, botanic garden and wildlife center). LBD1 and LBD2 are both located in the heart of the town and as such exposed to the onslaught of plastic pollution from land-based sources. Previous studies have pointed out that marine litter is found in higher concentrations in areas close to urban centers [98] [99] proximity to centers is a determinant factor in its occurrence [100] [101]. On the contrary, the other beaches are used with some limitations either for recreational purposes or fishing.

The combination of poor urban infrastructure and lack of institutionalized solid waste management gives way to open dumping (open spaces, gutters and streets) as the dominant method of waste disposal accounting for 69% whereas 24% of the waste is disposed of at landfills and only 7% is recovered or recycled [102]. In many African cities municipal waste comprises 9% to 15% of plastics [103] [104]. Cameroon was ranked as the 15th (out of 33) highest plastic importer in Africa (1,391,089 T) [105] between 1990 and 2017 and generates an estimated 600,000 T of plastic waste annually [106].

4.2. Abundance and Distribution of Different Sized Plastics

LDB1, followed by LBD2 has the highest number of items and weights in all the classes while SEM registered the least (**Figure 4**). Previous studies [107] [108], have reported that the presence of higher amount of plastic debris and

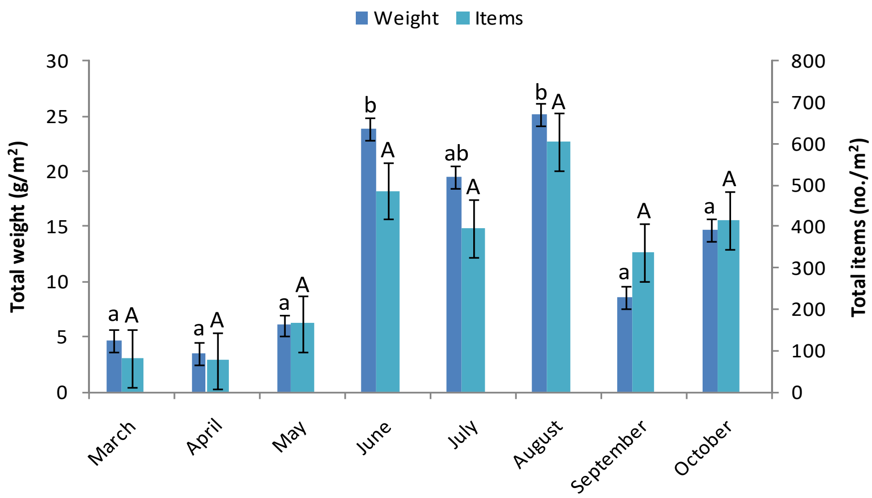

Figure 4. Temporal variation of plastic abundance (mean ± SE) by weight and number of items in five beaches along the coastline.

stronger wave movement enable more physical fragmentation to occur, contributing to a greater number of plastic items in the area. The high abundance of small plastics (meso and micro) may also result from oceanic surface currents transportation onto beaches which are acting as a filter for plastic debris [109]. This phenomenon has been used to infer the presence accumulation of debris and microplastics in non-industrial remote locations, globally [110].

The general trend for a number of items in all beaches is as follows, mega < macro ≪ meso < micro; with micro and meso being an order of magnitude higher than macro and mega sized particles. Reference [111] reported differences of up to four orders of magnitude for large microplastics (1 - 5 mm) on beaches in South Korea. Among the four-sized ranged fractions of plastics, micro-sized ranged were the major component of the plastic debris numerically 5437 (42%) along the coastline while by weight, meso-sized ranged plastics were predominated in the beaches 155.34 (29%). Previous studies by [87] stated that 92% of the total plastic pollution in the oceans is in microplastic form. Few studies have pointed out the similarities in trends of micro and meso particle sizes, with many proposing that these factors could serve as surrogates for the other fraction saving time and resources for future studies [112]. Reference [111] indicated that microplastic abundance increased linearly in proportion to that of mesoplastics. Similarly, [113] [114] found a proportion of mesoplastic items of about 13% with respect to microplastics in pelagic areas of Turkish coasts whereas [82] reported mesoplastic debris as the dominant fraction by number in recreational beaches of India. In the present study, similar to [115] we did not find any consistent relationships which could permit the use of mesoplastics to serve as surrogates for microplastic items. IDN a beach with no regular clean-up activities registered a proportion of 150% mesoplastic items with respect to microplastics while the recreational beaches with regular cleaning registered 68 to 90% (**Table 2**)

4.3. Monthly Variation of Plastic Distribution

Temporarily, the highest plastic abundance was recorded in LDB1 in August in terms of items/count (163.88 ± 17.15 items/m^2) and items/weight (7.93 ± 1.77 g/m^2) whereas June-August is the peak of the rainy season and is dominated by intense storms which often results in floods. Flood waters carry solid wastes containing plastics into the ocean. The lowest abundance in terms of weight was in April and by number of items was in March both recorded in SEM beach (3.13 items/m^2 and 0.21 g/m^2) respectively (**Figure 4**). March is the end of the dry season and the driest month studied. Direct disposal of wastes from activities along the beach is an important contributor to the abundance and distribution of plastics on this coastline. Except for SEM beach, all the beaches studied are located in highly populated urban areas.

There exists a significant difference in the mean abundance of the different-sized ranged plastic debris between the beaches/month along the Limbe-Idenau coastline (f-value = 2.88, p-value = 0.068; $p < 0.05$). The temporal variation revealed that the plastics abundance by the number of items and by weight was highest in August (15.15 ± 14.15 items/m^2) and (1.05 ± 0.58 g/m^2) whereas April registered the lowest amounts in both categories. The results of the ANOVA assign all the months (March to October) in the same category in terms of the total number of items. This could imply that there was no significant variation in the total number of items for the different months; than that of other months (**Figure 4**). The analysis further revealed the disparity within the different sized class plastics which could also be a due low rate of collection during the COVID-19 lockdown, the high rate of national-based touristic influx, the presence of medium size businesses in close proximity to the beach [116], present of indiscriminate fishing activities and finally poor follow up supervision from the beach authorities concerned in official keep-up clean campaign and beach keep-up clean campaign days as in according to [117].

4.4. Sized Plastic Debris Based on Plastic Type

The mean abundance of plastic debris types within the sized class along the Limbe-Idenau Coastline in the five beaches revealed marked differences (**Figure 5**). The mega-sized ranged fractions of the plastics are dominated by large fragmented debris accounting for 2.52 ± 0.74 items/m^2 by the number of items (and 0.44 ± 0.13 g/m^2 by weight). The plastic bottle debris type had the highest abundance of 0.64 ± 0.05 g/m^2 by weight. According to [118] plastic bags particularly white and colorless is the main debris ingested by green turtles. Green turtles that inhabit these coastal waters and are protected under Cameroonian law are at risk from the presence of plastic bag debris that makes up the highest component of the macro-sized ranged fraction (8.83 ± 0.81 items/m^2) and plastic bottles type had the highest abundance by weight, 0.51 ± 0.20 g/m^2. Single-use plastic (SUP) bags are widely used in Cameroon, particularly for product packaging, mineral water packaging, food preservation, and fabrication of daily consumed

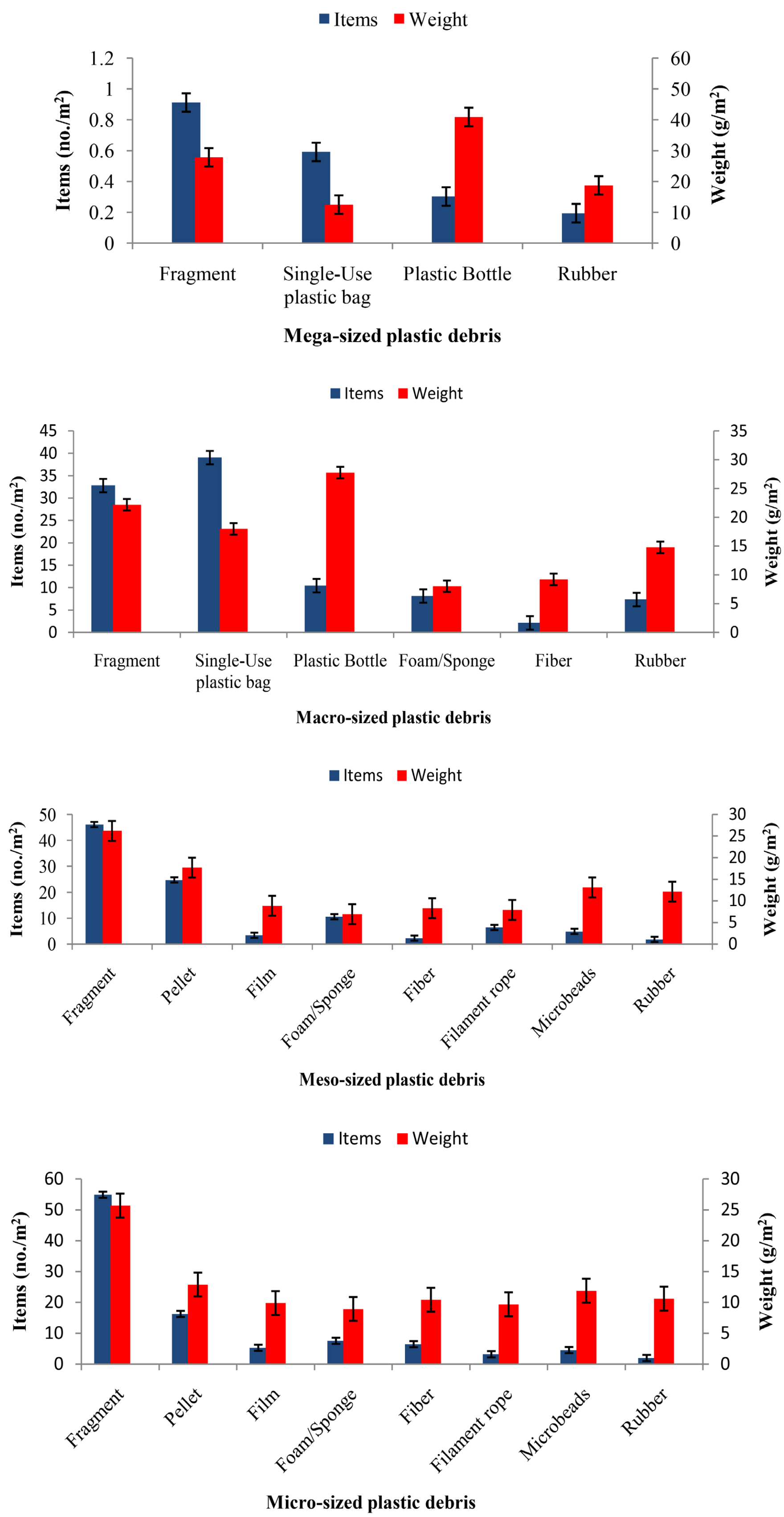

Figure 5. 4M's sized ranged classes and their percentage composition of each type.

products. To curb plastics pollution, the country has imposed a ban on non-biodegradable plastics not exceeding 60 microns with a thickness of 1/1000mm the use of these products, however, still persists. Many developing countries have imposed a ban on plastic bags with a minimum thickness of 20 - 50 microns [119].

Fragments followed by pellets were the most common microplastic (37.27 ± 10.05 items/m^2 and 0.33 ± 0.02 g/m^2 respectively) and mesoplastic types (29.60 ± 5.59 items/m^2 and 0.51 ± 0.11 g/m^2 respectively). A similar observation is reported by [109] for microplastics. Fragments are made of hard plastics of different shapes and roughness with many qualified as jagged fragments [119]. According to [114], [17] the dominance of fragments in microplastics results from the fact that fragments can be pieces of all kinds of plastic materials, and as such it can be expected for them to be present in high amounts. In addition, weathering (*i.e.* thermal, chemical or physical degradation) results in the breakdown larger particles into smaller ones which add unto the quantity of fragments. The abundance of small plastic debris (fragments and pellets) has been attributed to their proximity to urban centers, recreation and commercial activities, which act as local sources of small plastics. [120] explained the high concentration of plastic fragments and pellets as a response to wave convergence zones (WCZ) along coastlines in Brazil. Plastic fragments on sandy beaches cause changes in the permeability and heat transfer between sediment grains, which could affect beach organisms [121]. Pellets are considered primary microplastics and come from engineered micro-sized plastic beads (widely used in cosmetic formulations) [122] [123] and raw materials used in the plastic industry. The possibility of pellets arising from industrial sources in this locality is low, considering the near absence of such facilities in this locality.

Foam/sponge constitutes a significant quantity of plastic types in both meso and micro sized classes. Styrofoam is identified as one of the major sources of foam. References [111] and [124] attributed the high levels of large micro and meso plastics in Korea to the use of Styrofoam buoys in aquaculture. Fishing is a vital economic activity in this area with LDB1 and LDB2 serving as major fishing ports. Foam/sponge most likely originated from the use of fishing buoys and fish boxes. Weathered buoys in the ocean may detach small foam debris from the ocean. Other sources include single-use Styrofoam materials, like plates, cups and boxes originating from direct disposal (beach recreational activities and beach settlements) and indirect disposal (land-based sources). Footwear made from foam is another potential source of this material in this area. Some authors working in South Korea have attributed the dominance of foam fragments to the fact that this material is easily fragmented into pieces too small to be collected during beach cleaning events, and these fragments are left and accumulate on the beaches. Reference [125] has postulated that foam on the beaches (in the air) decomposes at a slower rate compared to seawater, enhancing their accumulation on beaches. The latter is contrary to the suggestion that styrofoam cast ashore may undergo enhanced photo-thermal oxidation due to temperature increases within the sand, as well as UV irradiation [111] [126].

4.5. Sized Plastic Debris Based on Color

The 4M's different class sized has the same color composition and the average color fractionation within different sized ranged plastic revealed that colored plastics are predominant by the number of items, 80.45 ± 18.17 items/m^2 and by weight, 2.58 ± 0.68 g/m^2 followed by white in all classes. Transparent and white plastics have a similar abundance as colored (blue, red, green, brown and other) plastics. The variety of colors according to [127] demonstrates the multiple sources of microplastics. Colored plastics are dominant in the meso- and micro-sized fractions in all the beaches whereas on average, mega and macro-sized fractions had higher proportions in the transparent and white colored fractions. (**Figure 6**) Color influences microplastic ingestion by selective marine species [128], as such, the predominance of colored particles in the micro-sized class range in this study increases the risk of ingestion by marine species. SEM and IDN had the highest proportions of black fractions in the macro-sized fractions in terms of the number of items 48.1% and 39.1% by weight (**Figure 6**) and supplementary material. Microplastics also show a great variety with regard to color as well as shape. Reference [17] stated that among the 68 studies they reviewed, the most dominant colors were white (or colors related to white) and transparent. The ratio of white and transparent microplastics in this study supports this information. Even though the color of microplastics can somewhat indicate the microplastic source (such as white pellets are polypropylene, transparent pellets are polyethylene, etc.), determining the exact sources may require advanced analysis methods. These advanced analyses required advanced instrumentations, expertise and time.

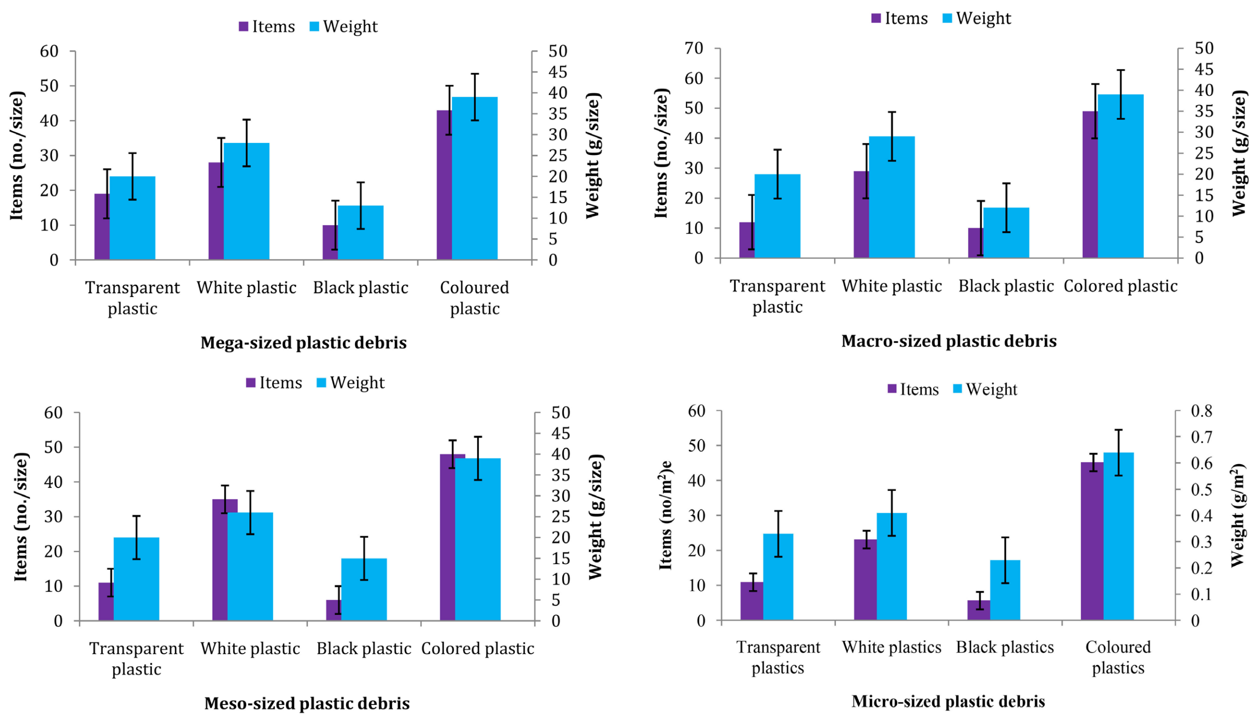

Figure 6. Average concentration of colour fractionation in the different sized ranged.

4.6. Sized Plastic Debris Based on Shape

The mean abundance in the shapes of plastic debris within the different sized class along the Limbe-Idenau Coastline of the five beaches revealed marked differences. (**Figure 7**)

On average, the irregular shaped plastics had the highest plastic mean abundance of 3023.50 ± 1306.02 by items (and weight, 88.76 ± 42.46 g) followed by degraded shaped plastics (1848.0 ± 719.83 by items and by weight, 79.61 ± 35.01 g) on these beaches shoreline. Irregular shaped plastic types were the dominant in terms of number of items in all size categories (**Figure 7**). Meso and micro sized particles had the highest concentrations of irregularly shaped plastic type, in terms of number of items, 42.5% and 53% respectively.

Reference [17] stated that microplastics can have various shapes, due to fragmentation, breaking, and the wear of microplastics, which is caused by multiple factors [37]. The findings regarding microplastic shapes in this study support this (**Figure 7** and **Table 3**).

Meanwhile, micro-sized ranged debris revealed that irregularly shaped plastics types also had the highest concentration in terms of number of items and weight, 53.5% and by weight, degraded shaped plastics had the highest as 40.7% (**Figure 7**) On average, the irregular shaped plastics had the highest plastic mean abundance, followed by degraded shaped plastics respectively in both items and

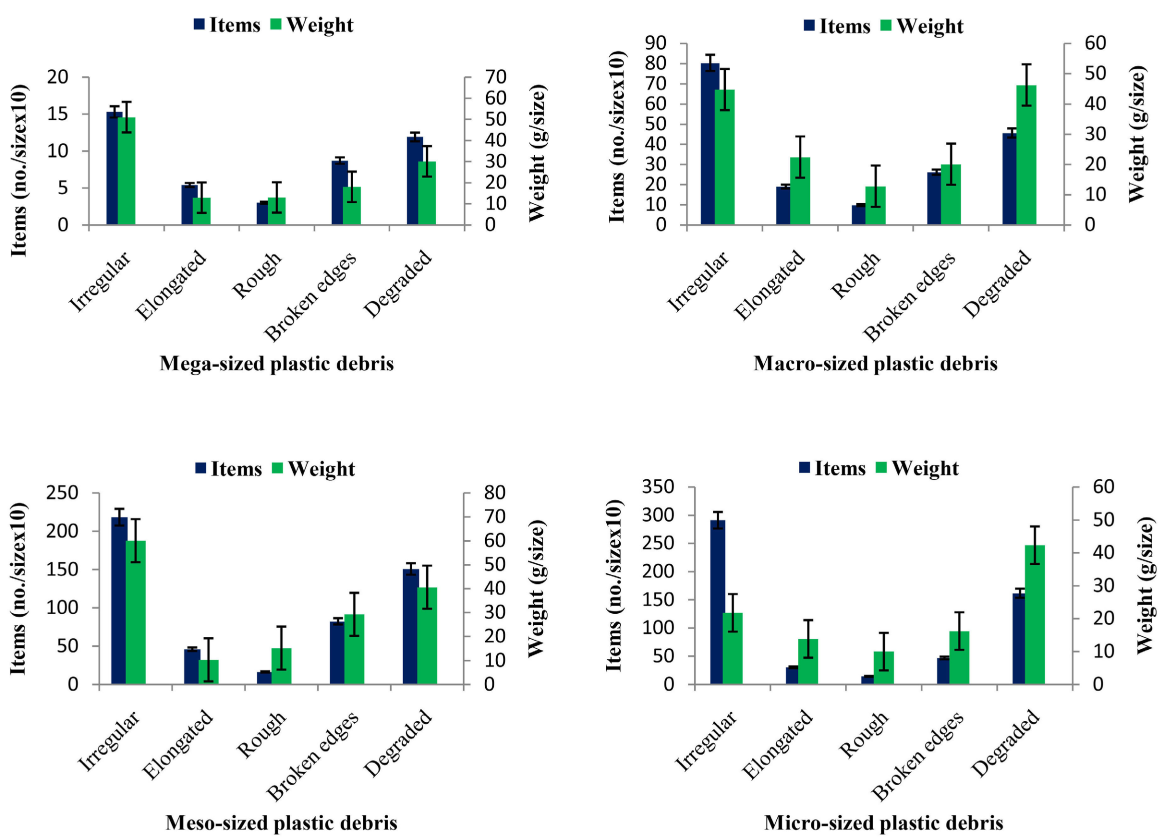

Figure 7. Variations in shape on the beach plastic shoreline debris in the different sized class.

weight on these beaches shoreline due to the combination of mechanical breakdown, photodegradation, and possibly microbial degradation processes result to disintegration of plastic debris from tourism-related activities, household materials, and fishing activities along the surf zone. The degraded shaped plastic is an indication that the fragment has been present on the marine environment for some time and polished by mechanical and chemical actions. Also, photodegradation of the polymer matrix leads to bond cleavage and makes plastics brittle, causing them to disintegrate most often into irregular shaped particles with different fading colours as reported in the cases of [37] [129] [130] [131]. Both researchers have stated that 92% of the total plastic pollution in the oceans is in microplastic form.

4.7. Sized Plastic Debris Based on Weights

The abundance in the weights of plastic debris within the different sized classes along the five beaches revealed no marked differences in mean concentration. ANOVA results show that the relationships were highly significant (p-value < 0.016). The dominant/least weight in mega, macro, meso and micro sized debris were >1 g (65%)/0.001g and 0.0001 g (0%), 0.1 g (56%)/0.0001g (0%), 0.01 g (62%)/>1g and 0.0001 g (0%), and 0.0001 g (79%)/>1g and 0.1 g (0%) respectively. In the micro-sized class, IDN is the most polluted with 0.1 g weigh class but for the other, LDB sites were the polluted zone (**Figure 8**)

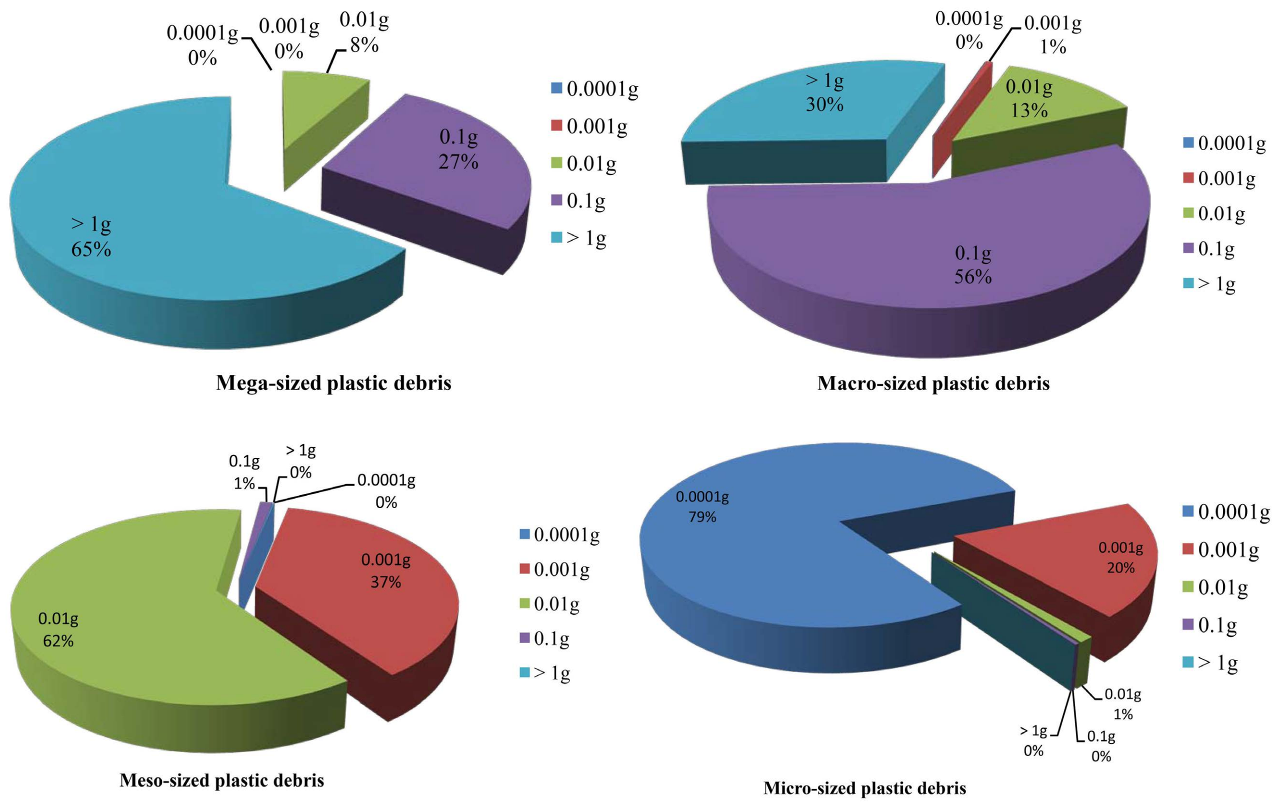

Figure 8. Variations in weights on the plastic shoreline debris in the different sized class.

Generally, the 0.0001 g and 0.01 g weighted plastics had the highest mean abundance amounting to 62.5% of the total number of items/count with microplastic sized plastic particles representing 46.8% making them totally weightless thus it is difficult to properly manage them because of their concentration/m^2. The constant turbulence of the wind force and storm wave towards the seashore on a daily basis (and this increases during the rainy), gives such weightless floated plastics the tendency to be horizontally transported easily to the beach shoreline and sink due to bio-fouling mechanism, this is a vertical phenomenon. This was similarly observed by [17] [74] [75] [132] who attributed this to the fact that floating microplastics are weightless particles that might be transported to shore in a shorter time than is necessary for biofouling to cause it to sink in smaller systems like coastal seas (e.g. the Baltic Sea). Few recent studies such as the works of [133] [134] have supported this idea.

5. Comparison in the Amount of Plastic Debris with Other Beaches around the World

The mean abundance of plastic debris along the Limbe-Idenau coastline is higher (641.1/m^2) than that on beaches at Madagascar (0.16/m^2), Antarctica shoreline (1.3/m^2), Beaches in Britain (6.04/m^2), Sicily of Italy (53.36/m^2), Beach in India (68.83/m^2) and Beach in South Korea (473/m^2) [124] [135] [136] as in **Table 3**. This might be caused by poor waste disposal in quarters around beach areas and it was found to be a direct source of plastic debris in this study. Moreover, fishery and domestic activities are important sources of plastic debris pollution in coastal areas too but have drawn little attention in accordance to [137]. In addition, the mean abundance of plastic debris along the coastline is lower than it is on Indonesia Shorelines (846.81/m^2), Heungnam Beach (976/m^2) and Beach Poris in Spain (2509.66/m^2) [86] [111].

Table 3. Comparing the results of this work with other references in summary.

Location	Contamination Level	References
Beaches, Madagascar	0.16/m^2	Gjerdseth (2017)
Shoreline, Antarctica	1.3/m^2	Barnes and Milner (2005)
Beaches, Britain	6.04/m^2	Marine Conservation Society (2014)
Beaches, Sicily of Italy	53.36/m^2	Allsopp *et al.* (2006)
Beach, India	68.83/m^2	Jayasiri *et al.* (2013)
Beach, South Korea	473/m^2	Heo *et al.* (2013)
Beaches, coastline of Cameroon	**641.1/m^2**	**This study**
Shoreline, Indonesia	846.81/m^2	Allsopp *et al.* (2006)
Heungnam Beach	976/m^2	Lee *et al.* (2013)
Beach Poris, Spain	2509.66/m^2	Reinold *et al.* (2020)

6. Conclusion

This study brings forth the significance of the 4M's different-sized ranged plastic debris in a coastal beach environment in an urban setting. The distribution of the plastic debris accumulation in five beaches was quantitatively assessed along the Limbe coastline, Cameroon and found significantly high spatial and temporal variations with a high abundance of microplastics, especially fragmented items and their color characteristics Seme Beach (SEM), which is approximately 3 km from the urban population that is the least contaminated beach by micro-sized class debris. The study also revealed that more than 80% of plastics in the beaches and shorelines sediments are within the size ranges of 5 - 20 mm by number and 6 - 100 mm by individual weight, suggesting that small plastic particles dominate the beaches sampled. Also, the coastline was significantly predominated by small but old plastic fragments than fresh ones. There is a statistically significant difference in particle weight abundance with respect to the beach. Even though beach cleanup, recirculation between water bodies and between shorelines and beaches was considered prior to this study; there might still be a high risk to marine organisms due to possible ingestion, especially the green turtles. The intense use of beaches for recreation, tourism, religious and business activities mostly during the COVID-19 pandemic lockdown when the studied carry out, is the major inputs. This has helped raise useful baseline data for community awareness at large.

Acknowledgements

This study is part of a Ph.D. research work with collaborative support coming from the Department of Chemistry by providing the laboratory where the research work was done. This study was partially funded by the Faculty of Science, University of Buea and special thanks go to Professor Josepha Fobe-Tendo, HOD of the Department of Chemistry and Mr. Aboh Isaiah, Senior laboratory technician in charge of the Organic and Inorganic laboratories in the same department. Thanks also, go to Mr. Patrick Lifanje Otto and Mrs. Eposi Njembe Theresia for their financial support in the publication of the article.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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