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An Assessment of the Accretion Rate of Pollutants, Chemical Risk and Pollution Load Index on Microplastics in the Coastal Waters of Limbe-Idenau, Cameroon: Using Gravimetric Analysis

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Abstract

Floating MPs is a transboundary pollutant. Its transboundary nature and dynamics warrant deep know-how, not only on its transport and fate properties but also on understanding its mass change, which is a priority that needs relative addition for scientific dataset. This study highlights gravimetric analysis, another relevant technique to assess the accretion rate of pollutants, chemical risk and pollution load index on microplastics in the coastal waters of Limbe-Idenau, Cameroon. Sea-water samples were fished in five offshore distances in three distinct depth points in five purposive beaches on line transects. 9 samples/beach with 45/season amounting to 90 bottled water samples and each collected sample were stored in 1 L glass bottle for further analysis. Systematic sample filtration, content weighing and reweighing after oven drying, and plastic mass calculation were done, aided by 4X magnification for plastic characterisation. 178 MPs particles were identified with five unique particle weighs of 0.0000 g (150/0.0015 g), 0.001 g (20/0.02 g), 0.002 g (1/0.002 g), 0.003 g (5/0.015 g) and 0.011 g (2/0.022 g) weighing 0.605 g. The most frequently observed plastic was the 0.0000 g weighed particle with physical appearance of RWPP > IWPP > OWPP in all the sampled seawater. In terms of weighs MPs analysis, the dominant beach, offshore distance, size ranged, abundance/season and physical outlook parameters in particle/number were recorded as follows: LBD 1 (29.2%), 5 m offshore distance (59.6%), 1 - 1.5 m size ranged (55%) with mean size detection limits of 0.2 cm and dry season (77.5%). Lastly, the plastic physical outlook revealed that old weathered plastic particle, OWPP (51.1%) was dominant with large plastic mass loss experienced more during the rainy season. 0.011 g weight plastic showed the highest average mass loss/particle (17.2%). Evidence from this study has reaffirmed that mass gained by certain weightless plastic indicates their long-time existence, knowledge of distance from sourced and fragmenting capacity within the marine environment. Both CF (2.71) and PLI (1.47) show a level II risk factor meanwhile the RQ value indicates a low rate potential of risk of degrees of injuries or damages to both marine organisms and beach users which requires urgent environmental management and pollution control strategies.

Keywords

Transboundary Pollutant, Weigh Plastic MPs Particle, Weathered Plastic Particle, Plastic Mass Change, Gravimetric Analysis, Limbe-Cameroon

1. Introduction

Plastic particles measuring less than 5 mm, referred to as microplastics (MPs), represent a significant component of plastics in the marine environment. Studies (Baini et al., 2018; Shim et al., 2018) have identified MPs as the most prevalent type of plastics in coastal waters compared to offshore waters, a situation arising from the huge amount of plastic waste discharged into these waters from intensive anthropogenic activities on the coasts (Andrady, 2011; Baini et al., 2018). MPs are very pervasive, difficult to degrade and highly persistent and are globally distributed in soils, inland waters, beaches, seawater and the deep sea. Aided by its low density and buoyancy, MPs are widely distributed in the oceans and have been found in the most remote areas of the world (Jambeck et al., 2015).

The small size of MPs increases their potential to move through ecosystems as they are transferred through the food web. The polluting potential and toxicity of MPs are associated with their ability to accumulate toxic substances. Due to its large surface area per volume-ratio, MPs readily adsorb and accumulate hydrophobic pollutants from aquatic systems (Thushari & Senevirathna, 2020). These substances include certain persistent organic pollutants (i.e., polychlorinated biphenyls, organochlorine pesticides, polycyclic aromatic hydrocarbons, and nonylphenol) and heavy metals (Teuten et al., 2007; Bakir et al., 2014). Considering that the adsorption capacity of MPs is 2 to 6 orders of magnitude higher than those of sediments and ambient seawater respectively (Mato et al., 2001; Teuten et al., 2007), the ability for MPs to accumulate these toxins is considerably high. MPs carrying contaminants can cause negative environmental pollution and threaten the health of aquatic organisms as they can enter their internal organs through the gastro-intestinal tract and cause synergistic toxicity (Le Bihanic et al., 2020; Wang et al., 2021).

The enormous threat posed by MPs has heightened research interests in understanding the polluting nature of this substance (Fu et al., 2021). One such area is unraveling the relationship between MPs and their absorption capacities. Efforts to quantify the amount of material adsorbed by the MP entails the application of a range of methods to identify, isolate and quantify the two components in diverse medium. In water, sediment, and soil, density separation methods or screening/ filtration methods are common (Hidalgo-Ruz et al., 2012; Imhof et al., 2016). Most often, to detect and clearly count microplastics and to characterize their color, shape and sizes, optical (light) microscopy is used alongside other methods which do not consider weight parameter (Vandermeersch et al., 2015). Currently, micro-spectroscopic imaging techniques are gaining in popularity, especially FTIR and Raman, particularly for smaller (<100 μm) particles and which still focus on visual size characterisation (Fischer et al., 2015; Tagg et al., 2015; Wiesheu et al., 2016) but however, lacks the capacity to determine the floatability (weight nature) and biofouling nature of micro-sized plastics in ocean dynamics (Käppler et al., 2018).

Gravimetric analysis is an old weighting analytical technique that measures weight loss of a sample due to organic matter using a weighting instrument most especially an electronic balance. Weight loss influences floatation and transportation of micro-plastic, as well as their sinking process and in this process, the sample is selectively converted to an insoluble form for further processes. The weight of the sample and knowledge of its weights composition can be calculated in their desired form (Yu et al., 2019; Richards, 1914). On the other hand, gravimetric examination is the most accurate and precise methods of macro-quantitative and weight change analysis that focuses on weighting and reweighting measures according to Oladejo (2017) and Käppler et al. (2018). It is a method systematically used to calculate the actual mass loss of an environmental sample (Oladejo, 2017; Giuseppina et al., 2017). In addition, it can further be used to determine the amount of organic matter/surface impurities picked up by individual plastic particle from the ecosystem and that can be done by stepwise determination of the weight of plastic samples before and after analysis according to (Giuseppina et al., 2017). This study seeks to quantify the accretion of pollutants on MP particles using gravimetric analysis which further determines the mass change capacity and microplastics variation in seawater. This paper focuses on the merits of the analytical methodology and presents results from weighting and reweighting microplastics content obtained in Limbe Sea, West coast of Cameroon. This study provides the novel baseline information on plastic debris floatability adjacent to the land-based sources in Limbe Sea during the wet and dry seasons.

2. Materials and Methods

2.1. Location of Study Area

Cameroon has great potential with 420 km of maritime coast, mangrove forest, lagoons and many beaches (Agardy, 1994). 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 596 km^2. It is bordered to the West by the Idenau District, East by Mutengene, North by Buea, and to the South by the Atlantic Ocean (National Institute of Statistics, 2018). 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 tourist (Lawrence et al., 2015). There are many public and private own beaches along the west-coast of Limbe, Cameroon with restricted offshore activities under the control of Merchant Marine located in Limbe Down area. These beaches include; Limbe Down Beach, Mile 6, Wovia, Batoke, Seme, Bakangili, Tsaben, Idenau, etc but Limbe Down Beach site 1 and 2 is closely 0.7 km stretch length to the other (Tume, 2021). Meanwhile, the other beaches are atleast 3.5 km long, and their width/shore stretch fluctuates within about 10 - 30 m along tide level (**Figure 1**). In addition, the transport pathway of plastic debris on these beaches is complex. On one hand, according to the characteristics of tidal changes, plastic debris may accumulate to the high tide line under the action of tides and coastal currents during high tide or spring tide. On the other hand, under the action of a northeast monsoon during low tide, plastic debris in Limbe Sea surface water might also be deposited on the low tide level (Human Development Report, 2006). These beaches are located in the east of the Limbe Sea and they are macro-tidal, wave-dominated beaches with thousands of tourists visiting every year most especially Limbe Down Beach and Seme Beach meanwhile Batoke and Idenau Beaches are pre-dominated by offshore fishing activities thus major pollution input originates from human activities and boat installations (Tume, 2022).

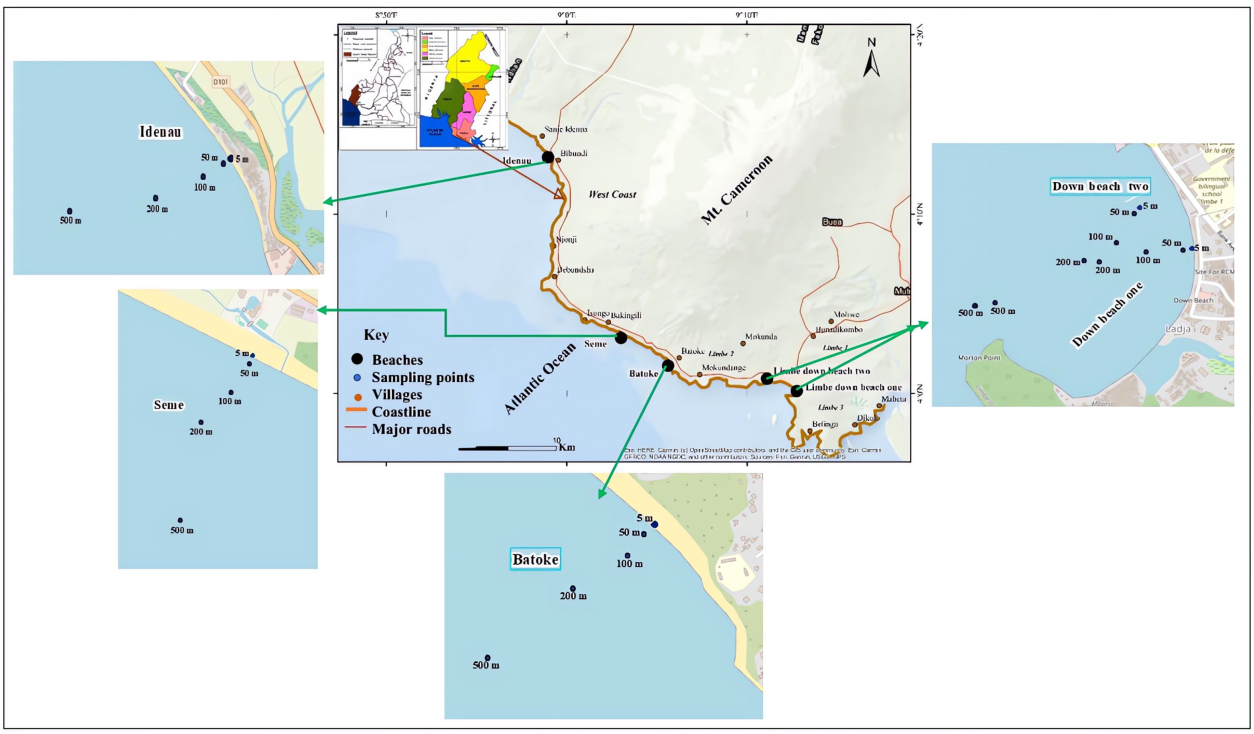


Figure 1. Map of the study area showing sea surface water sampling sites on the ocean.

2.2. Micro-Plastic Field Collection (Fieldwork Analysis)

2.2.1. Sampling Designs

This work was carried in two season i.e., in the rainy season on 15th August, 2020 and in the dry season on January 15th, 2021. At each beach shoreline, sample collection was done as 50 m by employing the expertise of the Limbe Marine Merchant boats which could work at a steady speed, along the straight transect pathway. Sampled were fished from shoreline distance of 5 m, 50 m, 100 m, 200 m, and 500 m offshore. From 5 - 100 m distance, sea water samples were collected at 10 cm depth from the water surface, using a 1 L glass bottle, and then sealed with a designed spherical aluminium foil, and closed with the lid to prevent air borne contamination. From 200 m and 500 m offshore distances, sea water samples were collected at three different depths (10 cm, 2 m and 5 m) for each distance respectively. All samples at 5 m offshore distance were done one day prior to the actual sampling to serve time and protect the boat against sands and stones close to the shoreline. Permission for navigation and research operations in these economic Sea zones was granted from the Limbe City Council in collaboration with Idenau Council and Regional Delegation of the Ministry of Transport, Southwest Region of Cameroon, located in Buea.

2.2.2. Sampling Collection

At 10 cm, collection was done using the hand, while at 2 m and 5 m depths, collection was as done using a 1.5 L water depth sampler which was thoroughly rinsed with distilled water after each sampling. At each collection point along the pathway, corresponding GPS coordinates were recorded using Garmin eTrex 20X simultaneously, while measurements of the electrical conductivity, pH and water temperature for the location were recorded to determine water conditions which might influence plastic stratification. This collection was done once during the dry season and once also during the rainy season, making a total of 90 bottles of sea water samples, 45/season with at least nine (9) sampled collections/beach. The sample 1 L glass bottles were stored in a shock-absorbing plastic box and carried to the laboratory for further analysis. At each sampling point, sea water collections were done at 10 minutes intervals to prevent small waves from interfering with sample collection (Lattin et al., 2004).

2.3. Micro-Plastic Laboratory Analysis

The sea water sample in the 1 L glass bottle was filtered through a clean rinsed and dry standard sieve of 0.0063 mm (63 μm) to isolate the micro-plastics content. Into a clean empty weighed and noted 50 ml beaker, the sieve content was transferred using squirt bottled distilled water, thoroughly rinsed to remove any materials. The mixture was then partially heated on a control hotplate and finally oven dried at 60˚C, to preserve the plastic structure. The dried content with sieve was weighted again at the end process. Furthermore, 25 ml of 0.05 M Fe(II) solution and 25 ml H_2O_2 were added simultaneously to the beaker containing the dried solid content and the Wet Peroxide Oxidation (WPO) mixture, and kept on the Lab bench for 5 mins and a stirring bar was added. The beaker was placed on the hotplate and allowed to heat at 60˚C for 30 mins, stirring to a homogenized mixture, breaking down any organic matter present (Nuelle et al., 2014). After 2 mins, 6 g of $NaCl_{(s)}$ salt was measured (using an electronic balance nearest to 0.001 g) and added to the mixture in the beaker per hydrogen peroxide addition after the first pipetting and heated again continuously. The mixture was further turned into the density separator, covered loosely with aluminium foil, and allowed to settle overnight. Weighted and noted clean white folded 25 × 20 cm (500 cm^2) grade 90 cheesecloth was firmly tied using a woody-rope at the mouth of the 250 ml beaker and placed directly under the density separator to collect floating solids. The Density separator was rinsed several times with distilled water to transfer all particles on the cheesecloth and was further placed on a clean Petri dish and allowed to air dry while loosely covered with aluminium foil for 24 hours. The cheesecloth content was again reweigh and value noted to get the actual weight, and then the weighted cheesecloth content was subtracted from the weighted clean cheesecloth to determine the weight of microplastics content and individual microplastic.

2.4. Gravimetric Examination

This method was carried out to gained ideas on how weights can influence floatation and transportation of micro-plastic, as well the sinking process, due to the engulfment of organic matter. Mathematical results for this computation used weighing and reweighing laboratory processes, alongside the mathematical formulas (Oladejo, 2017).

If

Weight of the beaker without content = $W_{\text{Without content}}$

Weight of the beaker content after drying = $W_{\text{With drying content}}$

Actual weight of the sieved content = $W_{\text{Sieved content}}$

$$\therefore W_{\text{Sieved content}} = W_{\text{With drying content}} - W_{\text{Without content}} \quad (1)$$

Also,

Weight of the Cheesecloth before = $W_{\text{Cheesecloth}}$

Weight of the Cheesecloth + microplastics content = $W_{\text{With cheesecloth content}}$

Actual weight of the microplastics content only = $W_{\text{Microplastic content only}}$

Thus,

$$W_{\text{Microplastic content only}} = W_{\text{With cheesecloth content}} - W_{\text{Cheesecloth}} \quad (2)$$

Finally,

$$\text{Mean concentration of the microplastic content as \%} = \frac{\sum \text{Microplastic content only}}{\sum \text{Total sieved content}} \quad (3)$$

In addition, to obtained the mass loss/individual weigh particle class (Excell, 2011), then, Total mass Loss (due to digestion) in gram, ML = S

Total number of Particles (after extraction) = P

Mass Loss per individual particle = ?

$$\rightarrow \text{Mass}\frac{\text{loss}}{\text{individual}}\text{weighed plastic} = \frac{\text{Total mass loss }(\text{in grams})}{\text{Total number particles extracted}} \qquad (4)$$

Hence, the arithmetic means for both the weighted sieved content and micro plastic content were obtained by simple addition of all the weights, divided by number of sampling distances (including depths portions), where the sea water samples were collected respectively. For variability purposes, the weight of the sieved contents became the actual weight before and that of the micro-plastics content became the actual weight after as illustrated on Table 1 and Table 2. Additionally, the actual weigh/density of individual MPs was measured using an electronic balance (nearest to 0.0001 g) and these weights were further characterised in particles/number in terms of beaches, size ranged, offshore distances, and seasonal variation. The physical outlook of the individual weigh plastic was also closely examined and classified into recently weathered plastic particle (RWPP), Intermediary weathered plastic particle (IWPP) and Old weathered plastic particle (OWPP) by using visual judgement and 4X Magnifier (Tume, 2022; Lattin et al., 2004).

Table 1. Gravimetric results for the dry season sea water sample analysis in the laboratory.

Study Zone	Distance from shoreline	Weight of the empty beaker	Weight of beaker after drying	Weight of the sieved content	Weight of Cheesecloth	Weight of Cheesecloth + Microplastics	Weight of Microplastics content	Weight of Individual microplastic particle
Limbe Down Beach Site 1	At 5 m	170.495 g	173.456 g	2.961 g	5.542 g	5.544 g	0.002 g	0.001 g (02) 0.0000 g (16)
	At 50 m	170.495 g	171.315 g	0.82 g	5.562 g	5.563 g	0.001 g	0.001 g (01) 0.0000 g (05)
	At 100 m	170.495 g	172.498 g	1.003 g	5.485 g	5.486 g	0.001 g	0.001 g (01) 0.0000 g (11)
	At 200 m	170.495 g	170.496 g	0.001 g	5.496 g	5.496 g	0.000 g	
	At 500 m	170.495 g	170.495 g	0.000 g	5.495 g	5.495 g	0.000 g	
Limbe Down Beach Site 2	At 5 m	170.495 g	172.385 g	1.89 g	5.475 g	5.476 g	0.001 g	0.001 g (01) 0.0000 g (23)
	At 50 m	170.495 g	171.189 g	0.694 g	5.784 g	5.786 g	0.002 g	0.002 g (01) 0.0000 g (07)
	At 100 m	170.495 g	171.150 g	0.655 g	5.842 g	5.842 g	0.000 g	
	At 200 m	170.495 g	170.495 g	0.000 g	5.812 g	5.812 g	0.000 g	
	At 500 m	170.495 g	170.495 g	0.000 g	5.637 g	5.637 g	0.000 g	
Batoke Beach	At 5 m	170.495 g	170.650 g	0.155 g	5.682 g	5.683 g	0.001 g	0.001 g (01) 0.0000 g (09)
	At 50 m	170.495 g	170.558 g	0.963 g	5.668 g	5.670 g	0.002 g	0.001 g (02) 0.0000 g (05)

Continued

	At 100 m	170.495 g	170.509 g	0.014 g	5.572 g	5.573 g	0.001 g	0.001 g (01) 0.0000 g (05)
	At 200 m	170.495 g	170.495 g	0.000 g	5.634 g	5.634 g	0.000 g	
	At 500 m	170.495 g	170.495 g	0.000 g	5.600 g	5.600 g	0.000 g	
Seme Beach	At 5 m	170.495 g	171.250 g	0.763 g	5.604 g	5.604 g	0.000 g	0.0000 g (06) -
	At 50 m	170.495 g	170.801 g	0.306 g	5.519 g	5.519 g	0.000 g	0.0000 g (04) -
	At 100 m	170.495 g	170.975 g	0.48 g	5.397 g	5.398 g	0.001 g	0.001 g (01) 0.0000 g (05)
	At 200 m	170.495 g	170.495 g	0.000 g	5.615 g	5.615 g	0.000 g	
	At 500 m	170.495 g	170.495 g	0.000 g	5.622 g	5.622 g	0.000 g	
Idenau Beach	At 5 m	170.495 g	170.812 g	0.317 g	5.775 g	5.779 g	0.002 g	0.001 g (02) 0.0000 g (09)
	At 50 m	170.495 g	170.775 g	0.28 g	5.638 g	5.638 g	0.000 g	0.0000 g (09) -
	At 100 m	170.495 g	170.670 g	0.175 g	5.557 g	5.557 g	0.000 g	0.0000 g (06) -
	At 200 m	170.495 g	170.495 g	0.000 g	5.525 g	5.525 g	0.000 g	
	At 500 m	170.495 g	170.495 g	0.000 g	5.563 g	5.563 g	0.000 g	
				11.477 g/45			0.014 g/45	

Table 2. Gravimetric result for the rainy season sea water sample analysis in the laboratory.

Study Zone	Distance from shoreline	Weight of the empty beaker	Weight of beaker after drying	Weight of the sieved content	Weight of Cheesecloth	Weight of Cheesecloth + Microplastics	Weight of Microplastics content	Weight of Individual microplastic particle
Limbe Down Beach Site 1	At 5 m	170.495 g	188.675 g	18.18 g	5.542 g	5.551 g	0.009 g	0.003 g (03) 0.0000 g (09)
	At 50 m	170.495 g	170.571 g	0.076 g	5.544 g	5.547 g	0.003 g	0.003 g (01) 0.0000 g (01)
	At 100 m	170.495 g	171.200 g	0.705 g	5.539 g	5.539 g	0.000 g	
	At 200 m	170.495 g	170.496 g	0.001 g	5.545 g	5.545 g	0.000 g	
	At 500 m	170.495 g	170.495 g	0.000 g	5.543 g	5.543 g	0.000 g	
Limbe Down Beach Site 2	At 5 m	170.495 g	236.959 g	66.464 g	5.538 g	5.560 g	0.022 g	0.011 g (02) 0.0000 g (12)
	At 50 m	170.495 g	172.690 g	2.195 g	5.541 g	5.542 g	0.001 g	0.001 g (01) 0.0000 g (01)
	At 100 m	170.495 g	170.710 g	0.215 g	5.546 g	5.546 g	0.000 g	0.0000 g (01)
	At 200 m	170.495 g	170.496 g	0.001 g	5.646 g	5.646 g	0.000 g	
	At 500 m	170.495 g	170.495 g	0.000 g	5.543 g	5.543 g	0.000 g	

Continued

Batoke Beach	At 5 m	170.495 g	171.620 g	1.125 g	5.543 g	5.544 g	0.001 g	0.001 g (01) 0.0000 g (01)
	At 50 m	170.495 g	170.540 g	0.045 g	5.545 g	5.545 g	0.000 g	
	At 100 m	170.495 g	170.580 g	0.085 g	5.545 g	5.545 g	0.000 g	
	At 200 m	170.495 g	170.495 g	0.000 g	5.541 g	5.541 g	0.000 g	
	At 500 m	170.495 g	170.495 g	0.000 g	5.542 g	5.542 g	0.000 g	
Seme Beach	At 5 m	170.495 g	170.800 g	0.305 g	5.540 g	5.540 g	0.000 g	0.0000 g (02)
	At 50 m	170.495 g	170.550 g	0.055 g	5.546 g	5.546 g	0.000 g	
	At 100 m	170.495 g	170.530 g	0.035 g	5.546 g	5.546 g	0.001 g	
	At 200 m	170.495 g	170.495 g	0.000 g	5.542 g	5.542 g	0.000 g	
	At 500 m	170.495 g	170.495 g	0.000 g	5.543 g	5.543 g	0.000 g	
Idenau Beach	At 5 m	170.495 g	170.565 g	0.070 g	5.539 g	5.542 g	0.003 g	0.003 g (01) 0.0000 g (03)
	At 50 m	170.495 g	170.600 g	0.105 g	5.544 g	5.545 g	0.001 g	0.001 g (01)
	At 100 m	170.495 g	170.510 g	0.015 g	5.547 g	5.547 g	0.000 g	
	At 200 m	170.495 g	170.497 g	0.002 g	5.541 g	5.541 g	0.000 g	
	At 500 m	170.495 g	170.496 g	0.001 g	5.543 g	5.543 g	0.000 g	
				89.680 g/45			0.047 g/45	

Organic matter/mass loss determination of the individual plastic/weight:

Firstly,

- Total abundance/weigh class = $T_{\text{Ab/wc}}$
- Weigh class value = T_{wc}
- Mass after/weigh class, $M_{\text{A/wc}}$ = ?

$$\rightarrow M_{\text{A/wc}} = T_{\text{Ab/wc}} \times T_{\text{wc}} \quad (5)$$

Implies that,

- Mass after/weigh class = $M_{\text{A/wc}}$
- Total mass before = M_{B}
- Total mass after = M_{A}
- Mass before/weigh class, $M_{\text{B/wc}}$ = ?

$$\rightarrow M_{\text{B/wc}} = M_{\text{A/wc}} / M_{\text{A}} \times M_{\text{B}} \quad (6)$$

Also,

- Maas before/weigh class = $M_{\text{B/wc}}$
- Mass after/weigh class = $M_{\text{A/wc}}$
- Mass Loss/weigh class, $M_{\text{L/wc}}$ = ?

$$\rightarrow M_{\text{L/wc}} = M_{\text{B/wc}} - M_{\text{A/wc}} \quad (7)$$

Therefore,

- Mass Loss/weigh class = $M_{\text{L/wc}}$
- Total abundance/weigh class = $T_{\text{Ab/wc}}$

- Av.Mass loss/weigh class, $M_{\mathrm{AV/wc}} = ?$

$$\therefore M_{\mathrm{AV/wc}} = M_{\mathrm{L/wc}} / T_{\mathrm{Ab/wc}} \tag{8}$$

2.5. Contamination Control

Several restrict actions were taken to totally minimized contamination in the samples. All of the pieces of equipment were pre-cleaned with tap water and rinsed with distilled water. The microplastic gravimetric workspace and the slap inside electronic balance were also carefully cleaned using a clean tissue paper with 70% alcohol prior to each weighting and reweighting process (Velimirovic et al., 2020). One customize cheesecloth was used for each analysis thus all of the 500 cm^2 cheesecloth and wood rope designed and used were placed on a clean Petri dish covered and kept in an enclosed oven when not in use to prevent airborne contamination. During the gravimetric process, oven door were opened for no longer than 30 s for every cheesecloth and wood rope collection. All apparatus used at each process were rinsed three times with distilled water and covered with tinfoil and then placed head down (Randhawa, 2023).

Sample blanks and airborne controls were used as the negative control. A total of 45 sea surface samples and 45 water sample blanks were created during this research. Water sample blanks were created by rinsing the clean 1 L glass bottle from the sieve mouth with distilled water before sieving (Nene et al., 2024) and no sample particles were observed under 4X Magnification Lens for the blank sample analysis.

The flushed distilled water from the sieve was kept and analyzed as other water samples. For the sediment sample blanks, about 600 ml of the NaCl solution used in the density separator was filtered before use. The cheesecloth was then observed using a stereomicroscope and 4X magnifier. Airborne controls were performed by placing three opened 250 ml filled with distilled water next to the electronic balance during the gravimetric process. Controls were placed 10 min before the sample measurement and taken 10 min after the microplastic weighting and reweighting analysis was complete. Controls were then observed visually using the same method that was used for the samples (**Figure 2**).

2.6. Particle Associated Risk Model (PARM)

Pollution load index (PLI): A combined pollution load index (PLI) was used in order to assess the extent of MP contamination in the surrounding environment. The MP concentration (C_i) divided by the background value (C_{oi}), or the lowest MP concentration, at each location is known as the contamination factor (CF) (Isobe et al., 2014; Pan et al., 2020; Ranjani et al., 2021).

$$\mathrm{CF}_i = \frac{C_i}{C_{oi}} \tag{9}$$

Pollution load index (PLI) depends on Contamination Factor (CF) value which is defined as follows:

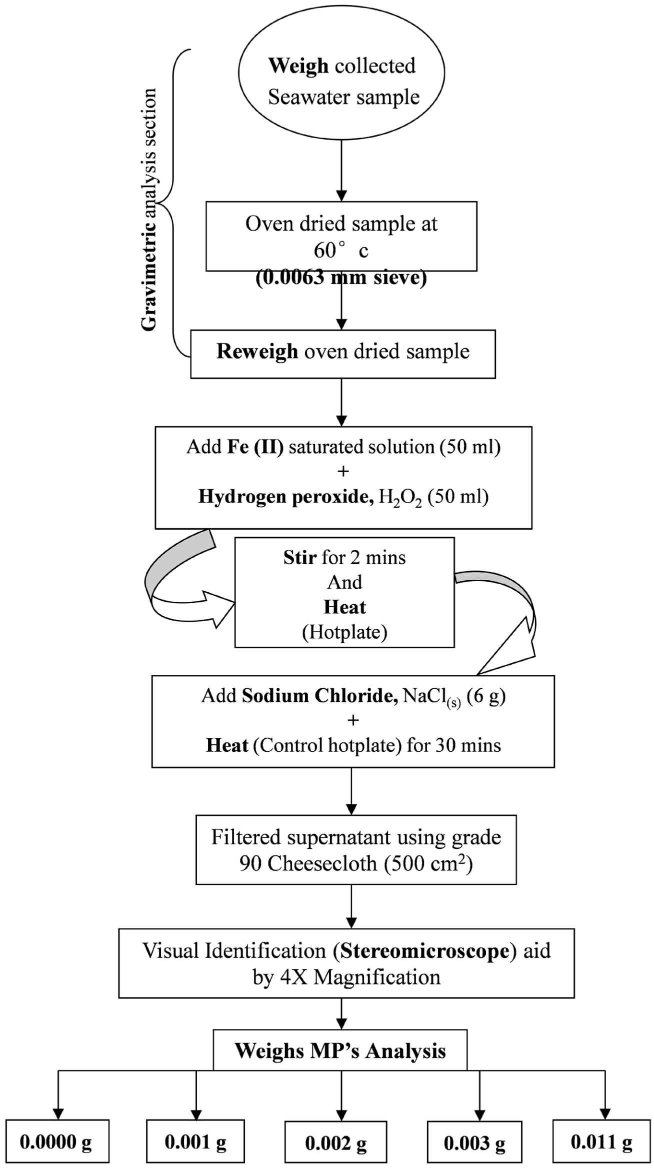


Figure 2. Diagrammatic illustration of the method used; samples were dried, sieved, weigh and reweighed.

$$\text{PLI} = \sqrt{\text{CF}_i} \tag{10}$$

Risk quotient (RQ): According to Zainuddin et al. (2022) and Zhang et al. (2020), the RQ was used to quantify the ecological risk of the MPs in the sea surface water. This method has also been employed in subsequent research to assess the harm associated with the present of small sized plastics on the beach environment. The assumed PNEC value that can results to harm to marine life used was 138 particles/l (Table 3).

Microplastic ecological concentration = MEC

Predicted no-effect concentration = PNEC

$$\text{RQ} = \frac{\text{MEC}}{\text{PNEC}} \tag{11}$$

Table 3. Various categories of Contamination factor, pollution load index, and risk (Adapted from Zhang et al. (2020) and Zainuddin et al. (2022)).

Contamination Factor (CF)		Pollution Load Index (PLI)		Risk Quotient (RQ)	
Range	Category	Range	Category	Range	Category
<1	Minor	<1	I	<0.1	Minimal
1 - 3	Medium	1 - 2	II	$0.1 \le RQ < 1$	Low
3 - 4	High	2 - 3	III	$1 \le RQ < 10$	Moderate
4 - 5	Danger	3 - 4	IV	≥10	Very High

2.7. Statistical Analysis

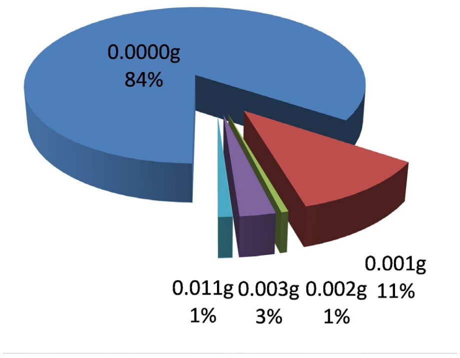
ArcGIS version 20 was used to map the sea surface water collection points in the beaches (**Figure 1**). The trends in organic matter extracted in water and sediment were analyzed using a one-way ANOVA with Tukey's post hoc analysis to determine the seasonal abundance in microplastics between the sampling points. The significant difference in microplastic abundance between the wet and dry seasons was determined using a parametric *t*-test. Spatial distribution graphics and statistical analysis were conducted using (Cai et al., 2017). Win. Statistical analyses were carried out at a significance level of $p < 0.05$ for each correlation analysis. The mean abundance/concentration of sieved and microplastic content was expressed as mean ± SE/L in content/gram and items/count as well in percentages.

3. Results and Discussions

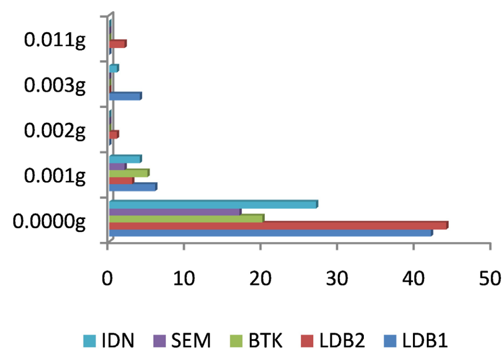
3.1. Microplastic Abundance and Variation

The prevalence of microplastic particles was observed in the samples analysed with unique varying individual weights identified as 0.0000 g (150 particles/0.0015 g), 0.001 g (20 particles/0.02 g), 0.002 g (1 particle/0.002 g), 0.003 g (5 particles/0.015 g) and 0.0011 g (2 particles/0.022 g) with mean weigh abundance value/beach (particles/number) of 30, 4, 0.2, 1.0 and 0.4 only but with the 0.0000 g (weightless) and 0.001 g weighed particles found in all the beaches analytical results (**Figure 3(a)**). In total, 178 microplastic particles (MPs) were extracted weighting 0.0605 g with mean abundance/number and weighs of ≈2/litre (0.0068 g/l). 0.0000 g weighed particles showed no scale reading when placed on the electronic balance since they were insensitive hence they are weightless (**Figure 3(a)**). Furthermore, it had the highest abundance/particle/beach in all the physical parameter examined in this study. In addition, microplastics were only extracted and further quantified at off-coast distance of 5 m, 50 m, 100 m, 200 m and 500 m with zero particles observed at the 200 m and 500 m in all the beaches sampled (See **Table 1** and **Table 2**) (Nene et al., 2024; Huang et al., 2024; Guo & Wang, 2020).

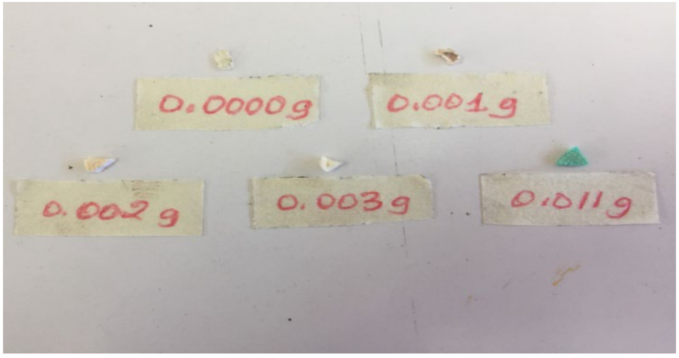
There is a marked difference between the mean value that exist within the weighs MPs particles which is statistically skewed in abundance towards the 0.0000 g weigh MPs particle.



(a) Weigh class variation



(b) Weigh Vs Beach variation



(c) Weigh class illustration

Figure 3. Variation in weigh class illustration (a), MPs class per weighs particles (b) and in beach seawater sampled (c).

3.1.1. Weighs MPs/Beach Abundance

Per beach, LDB2 followed by LDB1 had the highest particles concentration varying from 0 - 44 (52) particle by number and 0 - 42 (50) particle by number with mean weigh value of 10.8 g and 10.0 g respectively, dominated by 0.0000 g weighed MPs particle. SEM beach had the least weighed MPs abundance varying from 0 - 17 (19) with mean weigh value/beach of 3.8 g. There is a marked significant difference between the beach mean MPs value ($p = 0.076$). This could be due to the fact that the site is the most active sections along the coastline due to nearest to population settings (**Figure 3(b)**). This could also be because the West African southwest monsoon (WAM) and northeasterly trade winds (Harmattan) that influences the sea and land breezes in this coastlines is strongest towards the LDB sites thus has the tendency to carry light micro-sized plastics from different part around the Atlantic coastal areas to be deposited or transported by conventional ocean current in the Atlantic to the surf-zone. Dris et al. (2017), IBM.SPSS (2017) and Simpson (1994) reported the same findings as presented by this study.

3.1.2. Weighs MPs/Offshore Distance Abundance

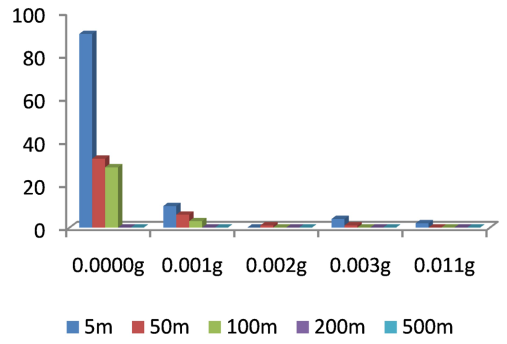
The offshore distance examination showed that the 5 m followed by the 50 m distances had the highest concentration varying from 0 - 90 (106) and 0 - 32 (40) particle/number with distinctive abundance found in 0.0000 g (90), 0.001 g (10), 0.003 g (4) and 0.0000 g (32), 0.001 g (6), 0.002 g (1) weighs class plastic respectively. The least abundance was equally accounted in the 100 m offshore distance distributed in 0.0000 g (28) and 0.001 g (3) only (**Figure 4(a)**). This indicates that the physical and chemical wreck-line wave processes are strongest along the surf-zone within these offshore distances on these beaches coast (Eltahir & Gong, 1996). The combined effects of other factors such as the effective removal of the different weightless fragmented particles from the surface and the faster degradation of large plastic objects along the coastline, provides a rapid flux of weightless MPs towards small-sized (<1.5 cm) classes within short distances from coast and this was also reported by other authors such as Bajamgnigni Gbambie & Steyn (2012) and Bravo et al. (2009). The spatiotemporal variation of weighs MPs particles can also be affected by hydraulic parameters and peripheral environment factors [59]. This offshore distance habour stronger hydrodynamic condition thus retained fewer weighs microplastics than nearshore zones and this similar by this findings according to Cózar et al. (2015) and Liu et al. (2022) but was contradict by Vianello et al. (2013).

3.1.3. Weighs MPs/Size-Ranged Abundance

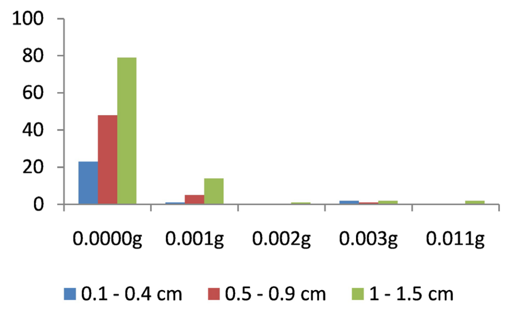
The size fractionation analysis further revealed that 0.1 - 0.4 cm size ranged particles with mean value of 0.25 cm had the highest abundance/number 98 (55%) with numeric higher abundance found in 0.0000 g (79), 0.001 g (14) and 0.011 g (2) is followed by 0.5 - 0.9 cm, 54 particles/number (30.4%) with varying abundance of 0.0000 g (48), 0.001 g (5) and 0.003 g (1). Lastly, 0.1 – 0.4 cm size ranged class had the least abundance of 26 particles/number (14.6) with numeric abundance seen in 0.0000 g (23), 0.003 g (2) and 0.001 g (1) (**Figure 4(b)**). This abundance size-ranged plastics might have been resulted from the continuous influenced and exposure of plastics to sunlight and ultraviolet radiation as they travels from long distances towards the coastline of these beaches. This finding was similarly reported by many authors such as Peng et al. (2017), Nor & Obbard (2014) and Lee et al. (2013).

3.1.4. Weighs MPs/Seasonal Abundance

The microplastics abundance/number was almost thrice higher during dry season, 138 particles by number (77.5%) than in the rainy period, 40 particles by number (22.5%) in all beaches sampled (**Figure 5** and **Table 3**) with higher abundance observed in both 0.0000 g/season, 120 (86.9%) and 30 (75%) followed by 0.001 g, 12 (8.7%) at the dry season and 0.002 g, 5 (12.5%) on the rainy season. The morphological characteristics of the weighed microplastics were dissimilar in both the rainy and dry seasons, indicating that seasonal factors have a convincing effect on their diagnosis. This could be because of the higher average temperature (p = 0.034, $p < 0.05$) and pH (p = 0.021, $p < 0.05$) which might have influenced the water chemistry causing reduction in the sinking potential of the microplastic particles due to the strong bond of the water component thus it higher retention capacity as in **Table 4** (Cole et al., 2013). This findings agreed with the work of Ogonowski et al. (2016) and Ikome (1985). In addition, might be due to the wind dominated action of the West African southwest monsoon (WAM) and north-easterly trade winds (Harmattan) which actions is the main characteristics of these beach morphology durind dry season thus the plastic particles found may have comes from a dispersive means (Ding et al., 2019; Xia et al., 2021).



(a) Weigh Vs Offshore distance

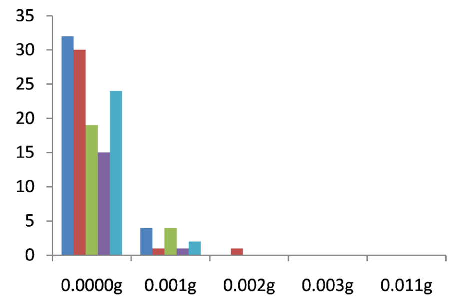


(b) Weigh Vs Size-ranged class

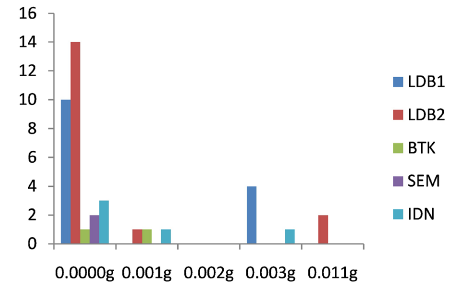
Figure 4. Weigh MPs class variation across offshore distance (a) and sized-ranged classes (b).

Table 4. Variation in mean abundance on the gravimetric analysis results of the sea water sample in the laboratory.

Season	Total Sieved content (grams)	Total Microplastic content (grams)	Percentage of Microplastic only (%)	Number of Microplastic/ count	Percentage of Microplastic (%)
Dry Season	0.225	0.0003	0.12	138	77.5
Rainy Season	1.993	0.0001	0.005	40	22.5



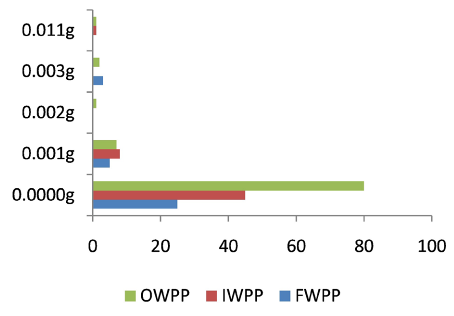
(a) Dry season Vs Beach variation



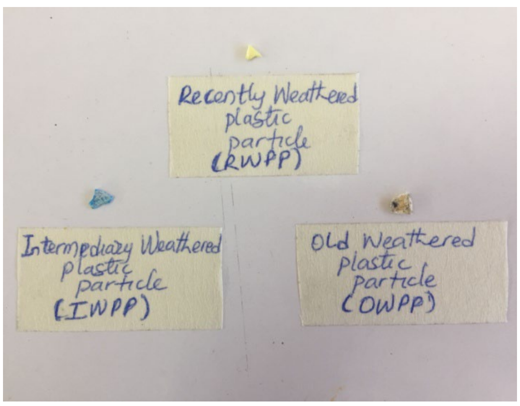
(b) Rainy season Vs Beach variation

Figure 5. Weigh MPs class variation in both the dry and rainy season.

3.1.5. Weighs MPs/Physical Outlook Variation



(a) Weighs Vs Physical outlook variation



(b) Plastic physical outlook class illustration

Figure 6. Weigh MPs class variation physical morphology.

The results in **Figure 6** shows that old weathered plastic particles (OWPP) had the highest abundance in terms of particle/number as 91 particles/number (51.1%) with higher concentration found in LDB 1 (30), LDB 2 (25) and BTK (18), followed by Intermediary weathered plastic particles (IWPP), 54 particles/number (30.3%) with numeric abundance observed in LDB 2 (15), LDB 1 (15) and SB (10). Recently weathered plastic particles (RWPP) have the least abundance of 33 particles/number (18.5%) with numeric abundance in IB (10), LDB 2 (10) and LDB 1 (7). Overall, 81.5% of the plastic particles were dominated by OWPP and IWPP with LDB sites, the most affected. This is an indication that most of the particles are as a result of prolong and continuous degradation and fragmentation either from run-off around beach coastline or from long distance ship fishing installation activities and this is in accordance with the works as in case of MINEP (2010), Lambert & Wagner (2016) and Mattsson et al. (2015).

3.2. Plastic Mass Change Dynamic

In addition, the gravimetric results showed that a large mass loss/moisture content of 101.157 g was observed from the microplastics quantitative process, with mean weigh of 0.57 g impurities/weigh individual micro-sized plastic loss (Equation (4)). This mass loss was also eight times more on the rainy sample (89.640 g) than in the dry season sample (11.463 g) with the highest mean mass impurities digested of 0.52 g from the 0.0000 g weigh plastic followed by 0.39 g in 0.001 g. In the dry season, the higher mass loss of 0.002 g each was found on the 5 m and 50 m offshore distance sample collection in LDB 1 followed by LDB 2. On the other hand, during the rainy, the higher mass loss of 0.022 g was observed at the 50 m offshore distance in LBS 2 followed by LDB 1 with 0.009 g and 0.003 g at the 5 m and 50 m respectively. The mass engulfed plastic is an indication that the fragment particle has been present on the marine environment for some time and might have received lesser polishing activities by mechanical and chemical actions due to less electrical conductivity (less charge flow) of the water surface molecules ($p = 0.98$, $p > 0.05$) (**Table 4** and **Table 5**). This could be because the microplastic particle might have been transported across a distance from it sourced point to the coastline on these beach. On the other hand, this large mass gained during the rainy season could be as a result of mixing interaction of plastic particle with other wastes which might be coming from heavy pour down of rain around the channel and drainage nearby quarter of the Limbe community close to the beaches together with mixed waste plastics carried along by seawater aided by wave and wind speed pushed coastline Plastic particles picks up leached petrol coagulants/substances coming from small petrol dealers around the beach areas and as this particles robbed with waste in the drainages and gutters channel along the streets areas causes grained in weight and as well as fragmentation. Also, this mass gained could be coming from mixed waste with plastics as they robbed too with the released gasoline waste discharge by the Oil refinery located in between the BTK and SEM beach within the Limbe coastline area. The following authors observed a similar trends such as Koelmans et al. (2015), Claessens et al. (2013), Miguel

(2015) and Hidalgo-Ruz et al. (2012). This difference in the weighed MPs abundances during both seasons and sampling beach confirmed the skewed temporal and spatial distribution of this MPs particles along the aquatic dynamics.

Table 5. Variation in physiochemical parameter of the sea water conditions in Limbe Sea.

Study Site	Average Temperature (˚C)	Average Electrical Conductivity (s/m)	Average pH	Density (g/cm³)
Dry Season	29.8	435.7	10.38	1.0276
Rainy Season	27.8	574.4	10.25	1.0084
Total	28.8	505.05	10.32	1.019

Generally, 0.003 g weight plastic class showed the highest mass loss (37.3%) followed by the 0.011 g weight (34.2%) meanwhile 0.0000 g weight plastic class showed the least mass loss (2.5%). Per particle, the 0.011 g and 0.003 g weight class measured the highest average mass loss/particle of 17.2% and 5.3% respectively (**Figure 7**). This show that the larger the surface area of the particle the more the organic matter gained by the environmental sample over time hence there is a linear relationship between particle size/surface and mass loss as highlighted and reported by many researchers (Velimirovic et al., 2020; Randhawa, 2023; Nene et al., 2024) (**Table 6**).

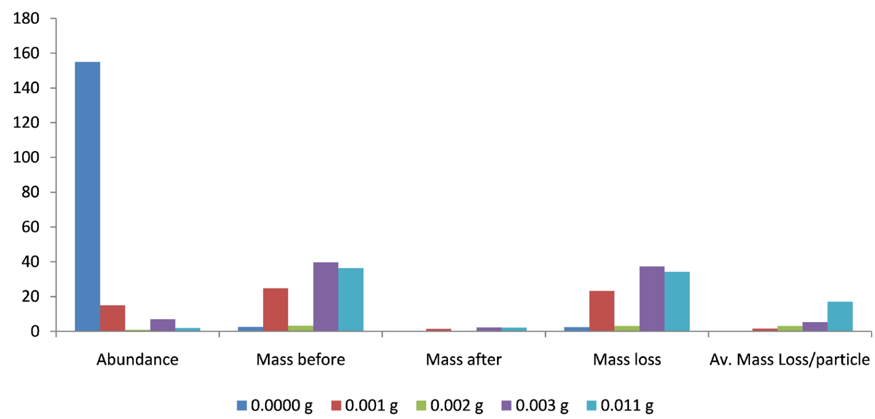


Figure 7. Stepwise determination of MPs mass loss potential of the different weight classes

Table 6. Summary result on the gravimetric analysis of the sea water sample in the laboratory.

Season	Weight of sieved content (Weight Before)/g	Weight of microplastic content (Weight After)/g	Difference in weight (Weight of impurities)/g	MEAN ± STD	Weight of most microplastic
Dry season	11.477 (0.25 ± 0.56)	0.0153 (0.00 ± 0.00)	11.461	5.74 ± 8.10	0.0000 g (90.6%) 0.001 g (8.7%) 0.002 g (0.7%)
Rainy season	89.680 (I.98 ± 10.19)	0.0452 (0.00 ± 0.00)	89.634	44.86 ± 63.38	0.0000 g (75%) 0.001 g (7.5%) 0.003 g (12.5%) 0.011 g (5%)
Total	**101.157**	**0.605**			

Based on the weight microplastics (MPs) risk analysis model (Table 7), the level of contamination (CF) during the dry season had an average CF value of 2.23, with a range from 0 to 14. During the rainy season, the CF value was 4.00, ranging from 0 to 4. The average CF value within the coastline waters is 2.71, indicating level II contamination. In terms of the pollution load index (PLI), the dry season values ranged from 0 to 1.46, with an average of 1.42. Meanwhile, in the rainy season, the PLI values ranged from 0 to 0.74, with an average of 1.66. The overall average PLI value in the zone is 1.47, indicating level II pollution. Additionally, the potential risk quotient (RQ) of the weight MPs within the water is 0.73, indicating level II risk as highlighted by authors like Wang et al. (2021) and Blessed et al. (2021).

Table 7. Microplastics Risk potential in the Limbe Surface Water.

MPs weight	0.0000 g		0.001 g		0.002 g		0.003 g		0.011 g	
Season Dry/Rainy	**D**	**R**	**D**	**R**	**D**	**R**	**D**	**R**	**D**	**R**
CF	2.13	14	4	1	1	0	0	4	0	1
PLI	1.46	3.74	2.00	1.00	1.00	0	0	2.00	0	1.00
PLI_{ZONE}	1.47									
PLL_{SEASON}	PLI_{DRY} = 1.42						PLI_{RAINY} = 1.66			
RQ	**0.73**									

Although both CF and PLI values indicate a level II (medium) risk factor, the potential risk posed by the weight MPs along the Gulf of Guinea, an area with diverse ecological species richness, calls for urgent concern. Bioaccumulation of these particles on the surface water poses a high risk due to the intense oceanic activities in this coastal water. Consequently, maritime organisms, especially the endangered Green Turtles that inhabit this area, are at risk of extinction. This has been observed in similar works such as Nwakanma et al. (2021) and Amrutha et al. (2023).

Higher accretion rates of microplastics can lead to increased PLI values, indicating higher pollution levels, which can elevate chemical risks due to the adsorption of harmful chemicals onto their surfaces (Li et al., 2020; Osorio et al., 2021). Furthermore, the presence of weight MPs after high stormy events results in the bioaccumulation of large amounts of debris, including various plastics, along the beach surface. This not only degrades the aesthetic quality of the coastline but also poses a serious risk of injury to both beach users and visitors. This information can be compounded by further investigation as this serve as a yardstick for research since most of the work done in this environs had their focus only on biological impact of MPs.

4. Conclusion

The spatiotemporal distribution and moisture content digested on floating MPs in the Atlantic coastline of the Limbe seawater were both qualitatively and quantitatively assessed vividly along different coastal beaches. There were marked differences between the mean abundance/number of the different individual weighed MPs at $p = 0.05$ when analysed statistically. Numerically, significant numbers of floated MPs were quantified, made up of 84.3% (150 particles/number) of the 0.0000 g weighed plastic particles (50.00 ± 28.05). In terms of the individual weighed MPs particle analysis, dominant concentration/number were observed in the 5 m offshore distance (21.20 ± 38.64), LDB 1 coastline water (10.40 ± 17.85), 1 - 1.5 m size ranged MPs (32.66 ± 33.63), dry season evaluation, 27.60 ± 51.83 (LDB 1, 7.20 ± 13.97 and 0.0000 g, 24.00 ± 7.17) and old weathered plastic particles, OWPP (30.33 ± 34.63). Lastly, the mass loss during the rainy season was approximately eight times higher than that on the dry season gravimetric analysis (44.83 ± 63.48). While the contamination and pollution levels are moderate, the potential ecological and chemical risks posed by microplastics in the coastal waters of the Gulf of Guinea demand urgent attention. Effective measures are needed to address the bioaccumulation of microplastics and mitigate their impact on marine life and human safety. This study highlights and lays down baseline insights on the knowledge of mass change using gravimetric assessment to associate and reaffirm other technique used in the past to predict long-term transport of floating MPs in seawater but further study is therefore required to link MPs weight, organic matter adsorption and ecological impact.

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Authors' Contributions

The first and second authors have equally contributed to preparing the study design, material preparation, data collection, and analysis. The whole discussion section of the manuscript is written by the first author while the second and third authors have edited the draft. All authors have reviewed the manuscript.

Ethics Declarations

The author has read, understood, and complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors. This study contains no studies with human participants or animal experiments conducted by the author.

Conflicts of Interest

The authors have no relevant financial or non-financial interests to disclose.

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