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Macrodebris and Microplastics Pollution in Nigeria: First report on Abundance, Distribution and Composition

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Abstract

The abundance, distribution and composition of marine debris (> 5 cm) and small microplastics (11 µm) from five rivers in South Eastern, Nigeria was investigated. This study provided the first assessment of the type and quantity of marine litter and microplastics in Nigeria. A total of 3487 macrodebris items/m^2 were counted with the following distribution; plastics (59 %) > metal (10 %) > cloth (7 %), paper /cardboard (7 %), rubber (7 %) > glass/ceramics (5 %), medical and agro-based waste (3 %) > wood (2 %). The cleanliness of the river assessed with clean coast index (CCI) ranged from "very clean" at Okumpi and Obiaraedu river to "extremely dirty" at Nwangele river. Microplastics abundance ranged from 440 to 1556 particles/L, with high accumulation at downstream. Fragment shape was most abundant while fiber and film followed. The distribution of plastic types was; PET (29 %) > PE (22 %) > PVC (16 %) > PP (14 %) > other (6 %) respectively. Significant relationship was found between the total abundances of microplastics and different macrodebris groups suggesting that microplastics were abundant in areas where the macrodebris abundance was high. Our results provide baseline information for future assessments. Management actions should focus on input prevention including proper waste management, recycling of plastics, and strict penalties for illegal dumping of wastes.

Keywords: Anthropogenic activities, Coastal pollution, marine litter, Nigeria environment, Plastics

1. Introduction

There is an increase in the global production of plastics due to its cheapness and versatility required for on-the-go lifestyle of people. Current worldwide production stood at 348 million metric tons in 2017 with an approximate increase of 9 % annually (Verla et. al., 2019a). Majority of the plastic produced each year are non-biodegradable, thereby accumulating in the marine environment (Jambeck et al., 2015). It was estimated that 10 % of plastic produced worldwide ended up as waste in the marine environment (Thompson, 2006; Barnes et al., 2009), due to poor recycling with only 3 % recycled in 2016 (Verla et. al 2019a). The environmental problems posed by the occurrence of plastics in the marine environment have been gaining increasing interest by scientists, governmental and non-governmental organization worldwide, becoming a global issue. Macroplastics while in the environment undergo degradation (secondary) to form microplastics (< 5 mm), which is now ubiquitous in the global ecosystem (Enyoh et. al., 2019; Enyoh and Verla, 2019). However, another source of their presence is primarily from clothing, cosmetics, industrial processes via urban wastewater treatment and nurdles (Verla et. al 2019a).

Microplastics are increasingly being observed in all components of most aquatic ecosystems of the world and posing varying toxicological threats to virtually all aquatic biota. The adverse effects of their presence in the marine environment which include particle toxicity, chemical toxicity and microbial toxin to marine organisms and sea animals have been demonstrated and discussed in many studies (Day et. al., 1985; Boerger et al., 2010; Davison and Asch, 2011; Browne et. al., 2008; Cole et. al., 2015; Murray and Cowie, 2011; Ugolini et. al., 2013; Foekema et. al., 2013; Hall et. al., 2015; Enyoh and Verla, 2019; Enyoh et. al., 2019).

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In Nigeria, plastic waste is poorly recycled, the majority ends up in landfill where it may take centuries for such material to breakdown and decompose (see figure 1). Despite plastics being an internationally recognized pollutant with legislation in place aimed to curb the amount of plastic debris entering the marine environment (Gregory, 2009; Lozano and Mouat, 2009), the problem still persist (see figure 1). The National Environmental Regulations prohibits persons from dropping litter (polyethene bags inclusive) on roads, public space, drainages or other undesignated places, set in 2009 by National Environmental Standards and Regulations Enforcement Agency (NESREA) is poorly implemented/ enforced. Hence, causing increase in the abundance of plastics in her inland freshwater system. The inland freshwater system was estimated to be about 283,293.47 hectares, of which 70 % has been degraded due to pollution (Verla et. al., 2019b).

Many marine environment worldwide have been studied for the occurrence of microplastics such as in the South Pacific and North Atlantic (Law et al., 2010; Eriksen et al., 2013; Desforge et. al., 2014), Kaliningrad region, Russia (Elena, 2017), Norderney (Dekiff et. al., 2011), Indian coast (Tiwari et. al., 2019), South Africa, Mozambique, Ghana following the International Pellet Watch, IPW (Hirai et. al., 2011) while none is existent for inland fresh water system in Nigeria. However, one study was found, which focused on method development rather than quantifying the occurrence of microplastics in Elechi Creek, Rivers State, Nigeria (Briggs et. al., 2019).

Macrodebris or marine litter pollution is particularly common where there are high anthropogenic pressures such harbours and marinas (Enyoh et. al., 2018; Verla et. al., 2018a). According to United Nations Environment Program (UNEP, 2009), marine litter is defined as ‘‘any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment”. The issue has been highlighted for many years and was added in the 11 Descriptors set by Europe's Marine Strategy Framework directive (2008/56/EC) (MSFD) (Galgani et. al., 2013). However, in spite of growing interest and a mounting body of research, it is widely accepted that a major factor that limits our understanding of (and therefore the ability to manage) marine litter, is the lack of clearly identified objectives and inconsistencies in sampling design and litter classification systems between litter surveys (Cheshire et al., 2009). Surveys of accumulated marine litter or debris are the most common means of estimating loads of litter in aquatic environment such as seas and rivers (Ribic et al. 1992, Kiessling 2003, Stuart 2003; Cheshire et al., 2009). Such survey could inform on the quantity of microplastics particles presence in the environment as well as mitigation strategy. Data regarding the description of macrodebris in inland fresh water environment in Nigeria is very scarce. In an effort to counter this issue and address the paucity of data, the current study aim to assess the occurrence and distribution of the two main categories: macrodebris (size > 5 cm) and microplastics of inland rivers in Nigeria.

Figure 1: Indiscriminate dumping of plastics in Nigeria due to ignorance and poor environmental law implementation or enforcement. Plastics dropped on streets normally end up in rivers when carried by erosion during the rainfall (Source: The Authors, 2019)

An estimated 6.4 million tonnes of litter enters the world oceans each year (UNEP, 2009), of which Nigeria is a major contributor. Jambeck et. al., (2015) reported that Nigeria is the 9th largest emitters of oceanic plastic pollution

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worldwide (following China, Indonesia, Philippines, Vietnam, Sri Lanka, Thailand, Egypt and Malaysia), largely through the river Niger, which receives most the waste from inland waterbodies. Furthermore, Nigeria in conjunction with the following countries viz China, Indonesia, Philippines, Vietnam, Sri Lanka, Thailand, Egypt, Malaysia and Bangladesh accounts for "90 % of all the plastic that reaches the world's oceans" (Schmidt et. al., 2017; Franzen, 2017). Therefore, quantifying the abundance of microplastics and identifying their major sources in marine environments of this region is important to understanding the potentially adverse impacts of microplastics to ecological systems. To achieve the aim of the study, the following objectives were followed (1) count, classify and group the macrodebris found 10 m transect from the shore of the river (2) determine the proportion of different category of litter on the total macrodebris (3) count the number of microplastics presence and identify the shape (4) Calculate variation by rivers and stations (upstream, midstream and downstream) based on abundances and shape distribution. Our results may serve as a benchmark for future studies regarding occurrence of macrodebris and microplastics in inland freshwater systems in Nigeria and also used to generate an efficient strategy and policy to control microplastics and marine litters.

2. Materials and method

2.1. Study area

The five rivers studied in Nwangele Local Government area of Imo state, South Eastern, Nigeria are presented in Figure 2. The local government area has an area of 63 km^2 (24 sq mi) and a population of 128,472 as of the 2006 census. The rainy season follows similar tropical rainy season for the entire state, which begins in April and lasts until October, with annual rainfall varying from 1,500 mm to 2,200 mm (60 to 80 inches). An average annual temperature above 20 °C (68.0 °F) creates an annual relative humidity of 75% and reaching 90% in the rainy season. the soil has been degraded due to over farming. Overall, all three sampling location are affected by different anthropogenic activities and summarized in Table 1.

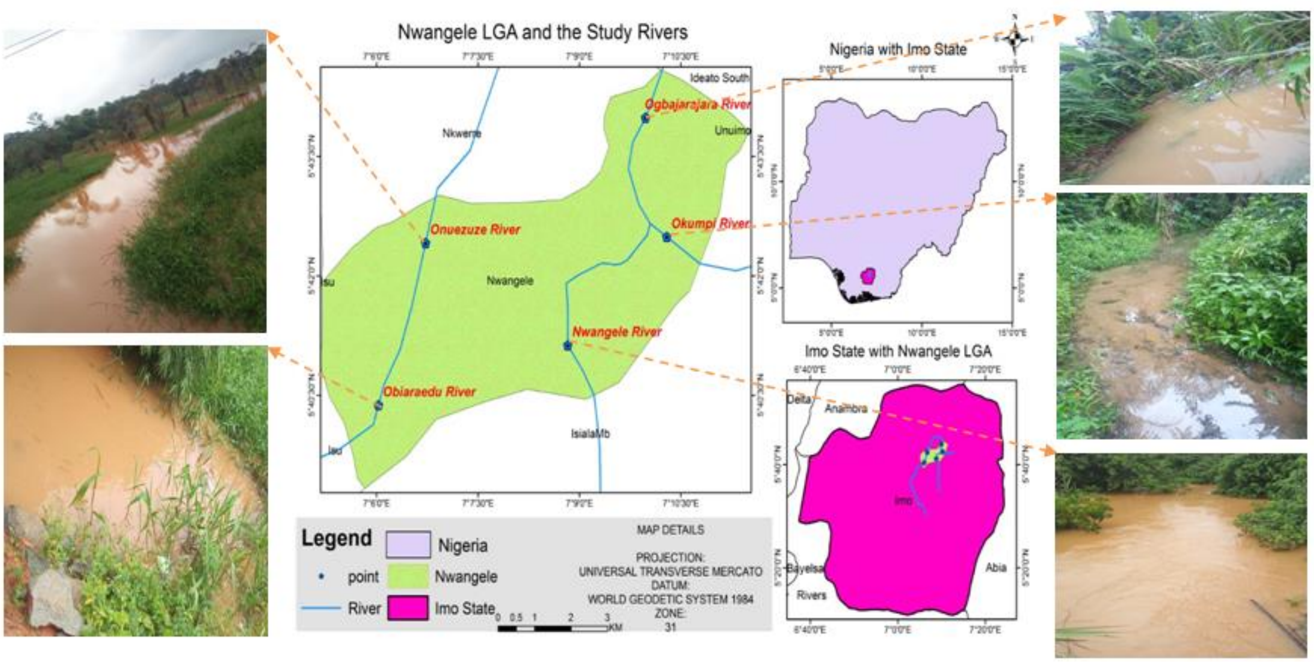

Figure 1. Map of study location and rivers

Table 1. River name, elevation, close land use and comments

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Location	Name of River (community)	Elevation (m)	Close land use	Comment
I	OBIARAEDU (Abajah)	198	Farm lands, Laundry activities	*Mild anthropogenic input,* major wastes received generally include debris from laundry activities etc with little marine litter.
II	NWANGELE (Abba)	153	Market (Nkwo mmiri), Car wash, Major road, Hospital	*High anthropogenic input*, receives loads of wastes (mixed) from market < 100 m away during heavy rainfall. Wastes received generally include agro-waste, debris from automobile cars, detergents, spent oils etc.
III	OKUMPI (Umuozu)	165	Farm lands, Laundry activities	*Mild anthropogenic input*, most of the river has been lost to vegetation and not accessible at the time of the study. However, little marine litter such as degrading laundry soap pack was found. Major input is from runoff from farm lands.
IV	OGBAJARAJARA (Isu)	210	Farm lands, Laundry activities, Car wash	*Mild anthropogenic input,* major wastes received generally include debris from laundry activities etc with moderate marine litter.
V	ONUEZUZE (Amaigbo)	159	Road construction	*Mild anthropogenic input,* major wastes received generally include debris from automobile cars, detergents, spent oils etc with little marine litter.

2.2. Sampling

The overview of the sampling scheme for macrodebris and microplastics is presented in figure 2. Sampling date were 15/06/2019 (for location IV and V) and 19/07/2019 (for location I-III) respectively. Sampling was done in the rainy period.

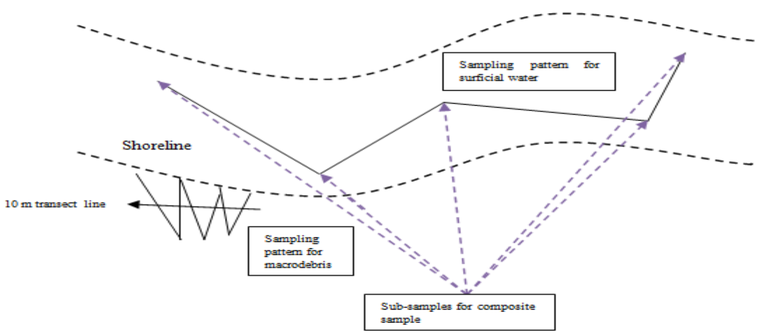

Figure 2. Macrodebris and microplastics sampling scheme

2.2.1. Macrodebris

The macrodebris sampling followed the operational guidelines as described by Cheshire et al. (2009) for UNEP/IOC Guidelines on Survey and Monitoring of Marine Litter with stringent modification. The guideline was originally designed for beach assessment, but was applied in this study for the rivers in which area from the shoreline are majorly filled with short grasses. Sample width was measured along the curve of the shoreline about 100 m while the length was measured 10 m transect parallel to the shore shown in Figure 2. Each sampling unit represents the entire area along each transect from the water's edge as to the back of the river identified using coastal features such as the presence of high vegetation, dunes, cliff base, road, fence or other anthropogenic structures e.g market. All debris > 5 cm in the area (100 by 10) was collected and counted in situ.

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2.2.2 Microplastics

The sampling scheme is presented in Figure 2. At particular sampling point, five sub-samples were collected using the grab sampling technique at the depth of collection of 0-3 cm following a "W'' shaped design with an average area of 0.2 m^2 (Figure 2). The surifical water sub-samples were collected against water current and were homogenized to form a sample (composite) for that point. This was done for all sampling points in all rivers. Overall, six composite surficial water samples were collected from each sampling site (total 30) using clean quart glass bottles (one liter). The bottles were capped tightly, shielded from light and stored at 4 °C to prevent evaporation and transported to the New Chemistry laboratory, Imo State University for analysis. The rationale for collecting surface water was due to the ability of microplastics accumulating in surface water microlayer due to their microsize dimension.

2.2.2. Analysis

2.2.2.1 Macrodebris

Macrodebris particles were classified according to the approach described by Cheshire et al., (2009) for UNEP/IOC Guidelines on Survey and Monitoring of Marine Litter and as used by Laglbauer et. al., (2014). Classification was in 59 categories and 8 major groups. The particles were counted, and expressed in items/m^2. River cleanliness was assessed with the Clean Coast Index (CCI) (Alkalay et al., 2007). The CCI was obtained by applying the equation (1).

$$CCI = \left({}^{TPPT}/_{TAT}\right) * K \qquad (1)$$

Where CCI is the number of plastic items/m^2, TPPT = Total plastic parts on transect, TAT = Total area of transect, 1000 m^2; calculated as the product of the transect length (10 m) and width (100 m) and k (constant) = 20. The rivers were classified from clean to extremely dirty according to the scale provided for the number of plastic particles on the coast (Table 2).

Table 2. Clean Coast Index ranking.

Value	Grade	Visual assessment
0–2	Very clean	Very little debris is seen
2–5	Clean	little debris is seen over a large area
5–10	Moderate	A few pieces of debris can be detected
10–20	Dirty	A lot of debris on the shore
20+	Extremely dirty	Most of the shore is covered with plastic

2.2.2.2. Microplastic

The water samples were filtered sequentially through a cellulose filter with a nominal pore size of 11 μm (Whatman No. 1, Catalog No. 1001 110, UK) with the aid of a glass funnel. After the filtration was complete, particles (plastic pieces and organic material) were recovered on the filter paper. The filter paper was placed in a dessicator, allowed to dry under room temperature away from light and stored in Petri dishes. To isolate and count microplastics, the dried filter papers were examined under a light microscope (AmScope M150C-PS25). The microplastics was isolated using the hot needle test as described by De Witte et al., (2014) while the filter was read from left to right, then move down one row, and read from right to left to ensure pieces are not double counted. Pictures of the isolated microplastic particles were taken and classified into three dominant types, according to their shape (fibres, films, fragments) and type based on their physical characteristics and response to heat (Table 3). Throughout the entire analysis, we ensured that filter papers were covered when not looking under microscope to prevent contamination from airborne fibers (Enyoh and Verla, 2019) and rubber gloves were used and care was taken to minimise sample contamination by avoiding the use of plastic materials were possible.

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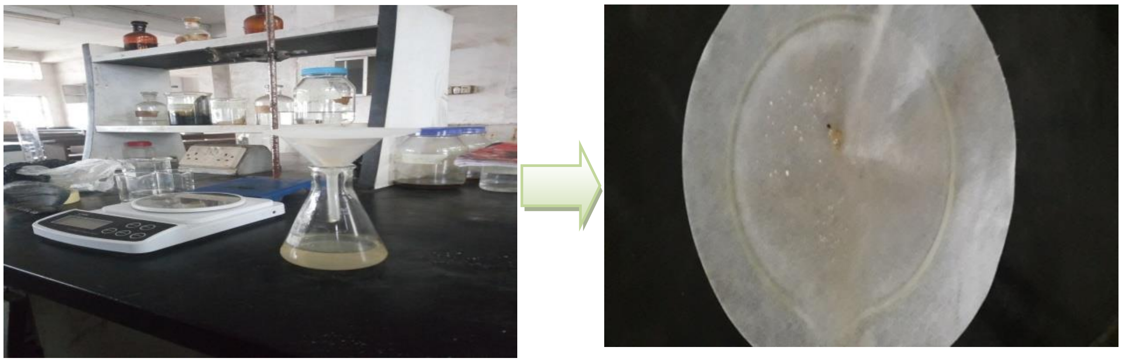

Figure 3. Surficial water filtration and microplastics recovered on cellulose filter paper

Table 3. Microplastics shape, type and their physical characteristics

Microplastics shape and type	**Physical characteristics**
Shape	
Film	Flexible and thin
Fiber	Very thin, long and can also be short
Fragment	Irregular shape, thick, sharp crooked edge
Type	
PP	Slippery and elastic
PE	Slightly rigid, hard and of low strength
PVC	Rigid, very hard and very dense
PS	Rigid, transparent and looks like glass
PET	Transparent, strong, lightweight and shatterproof

2.4. Statistical analyses

Statistical analyses of macrodebris and microplastics data were performed using Microsoft excel 2010. Macrodebris quality and quantity (by count) was compared between rivers within 59 categories across eight major groups. Microplastic quantity was also compared between rivers across four categories. Significant differences and variations between rivers for macrodebris and microplastic quantity were tested using one-way analysis of variance (ANOVA) at 5 % level of significance and coefficient of variations (CV) (Enyoh et. al., 2018; Verla et. al., 2018b; Verla et. al., 2019b). Coefficient of variance was calculated as the ratio of the standard deviation (SDV) to the mean presented in equation (2)

$$CV\ (\%) = \left({}^{SDV}/_{mean} \right) * 100 \qquad (2)$$

Variation was categorized as little variation (CV% <20), moderate variation (CV%=20-50) and high variation (CV% >50) (Enyoh et. al., 2018). Relationships were also tested between marine litter groups and Microplastics using linear regression analysis.

3. Results and discussion

The findings and discussion of findings from this study is presented in this section.

3.1 Macrodebris

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The macrodebris classification system was in 59 categories and 8 groups as recommended (Galgani et al. 2010). Previous researchers had explained the reason for this classification system, due to low error rate and more consistency in data analysis and therefore allows for easy identification of changes in debris composition, source, and usage of items (Cheshire et al. 2009; Galgani et al., 2010; Laglbauer et. al., 2014). The occurrence of litter on shore of surface waters in Nigeria is scarce. Considering poor knowledge on litter accumulation in inland surface waters, this survey is therefore of great value for obtaining information on litter quantity and distribution. In the present study, data we collected provides insight on the quantity and composition of litter across typical freshwater system in Nigeria.

Table 4. Macrodebris classification system for the rivers, showing the amount per each of categories and major groups

Categories	Location I (Proportion in total amount of item in category, in %)	Location II (Proportion in total amount of item in category, in %)	Location III (Proportion in total amount of item in category, in %)	Location IV (Proportion in total amount of item in category, in %)	Location V (Proportion in total amount of item in category, in %)	Total amount of item (Proportion of each category in group, in %)
Groups						
Plastics (PL)						
Caps and lids	9 (9.6)	57 (61.29)		16 (17.2)	11 (11.83)	93 (12)
Lolly sticks, cutlery, cups	4 (5.9)	54 (80.59)	2 (2.99)	7 (10.14)		67 (0)
Drink bottles	13 (9)	98 (69)	2 (1)	21 (15)	8 (6)	142 (17)
Straws	2 (1)	103 (59)	3 (2)	62 (36)	3 (2)	173 (3)
Packaging for food	2 (3)	29 (42)	6 (9)	12 (18)	19 (28)	68 (3)
Bags+ nylon (including sachet water nylon) + sacs	4 (1)	321 (82)	13 (3)	41 (11)	9 (2)	388(5)
Toys	3 (6)	46 (92)		1 (2)		50 (4)
Cigarette lighter		19 (100)				19 (0)
Cigarette filter		8 (80)	1(10)		1(10)	10 (0)
Syringes		29(91)		2 (6)	1(3)	32 (0)
Mussel bags + pieces	4(29)	6(43)	2(14)		2(14)	14 (5)
Cotton bud sticks	11(5)	168(72)	2(1)	37(16)	14(6)	232 (15)
Fishing ropes, string, cord	1(4)	12(43)	6(21)	2(7)	79(25)	28 (1)
Cosmetics packaging		23(85)		4(15)		28 (0)
Fishing net floats		2(66.67)		1(33.33)		3 (0)
Foam (pieces)	3(7)	19(45)	17(41)	1(2)	2(5)	40 (4)
Plastic pieces (unrecognizable)		94(85)	11(10)	6(5)		111 (0)
Jerry cans		7(100)				7 (0)
Masking tape		14(78)		3(17)	1(5)	18 (0)
Condoms + packaging		9(100)				9 (0)
Packaging for biscuits	5(1)	179(85)		18(9)	8(4)	210 (7)
Packaging for soap	11(50	164(76)	5(2)	27(13)	9(5)	216 (15)
Panty liners + packaging		28 (85)		5(15)		33 (0)
Construction waste		12(30)			28(70)	40 (0)
Cigarette box	1(5)	5(24)	1(5)	2(9)	12(57)	21 (0)
Buckets, flower pots		10(67)	2(20)	3(17)		15 (0)
Pens	2(4)	39(78)	1(2)	2(4)	6(12)	50 (0)
Other		24(83)	3(10)		2(7)	29 (0)
Total	75	1579	7	273	141	
Rubber (RB)						
Balloons, balls, toys		101(89)	1(1)	8(7)	3(3)	113 (47)
Shoes		32(53)	1(2)	21(35)	6(10)	60 (25)

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Gummies		3(37)	1(13)		4(50)	8 (3)
Other pieces	2(4)	45(76)	3(5)		9(15)	59 (25)
Total	2	181	6	29	22	
			Cloth (CL)			
Clothing, shoes, hats, towels	1(1)	67(84)	2(2)	4(5)	6(8)	80 (34)
Ropes	2(2)	127(90)	1(1)	2(1)	9(6)	139 (59)
Other		11	5		1	17 (7)
Total	3	205	8	6	16	
			Glass/ceramics (GC)			
Pieces	2(5)	23(57)		4(10)	11(28)	40 (22)
Bottles, glasses	3(7)	36(80)	6(13)			45 (24)
Plates, pots (cups)		52(69)	1(1)	19(25)	4(5)	76 (41)
Construction material		14(61)			9(31)	24 (13)
Total	5	125	7	23	24	
			Paper/cardboard (PC)			
Cardboard (pieces, boxes)	5(5)	72(74)	4(4)	13(14)	3(3)	97 (42)
Paper (incl. magazines)	9(7)	92(75)	1(1)	17(14)	4(3)	123 (53)
Other (pieces)	2(17)	5(41)		3(25)	2(17)	12 (5)
Total	16	169	5	33	9	
			Metal (ME)			
Caps, can lids	6(7)	57(63)		14(16)	13(14)	90 (26)
Drink cans	21(16)	82(64)	2(2)	9(7)	14(11)	128 (38)
Aluminium wrapping	2(8)	21(88)			1(4)	24 (7)
Pieces		16(41)	4(10)	11(28)	8(21)	39 (12)
Wire, barbed wire		3(30)			7(70)	10 (3)
Construction		16(46)		5(14)	14(40)	35 (10)
Other	5(33)	3(20)	2(13)	1(7)	4(27)	15 (4)
Total	34	198	8	40	61	
			Wood (WD)			
Cork	2(40)	2(40)		1(20)		5 (6)
Ice lolly sticks		4(50)	1(12.5)	2(25)	1(12.5)	8 (9)
Matches, fireworks	4(8)	27(53)	2(4)	14(27)	4(8)	51 (61)
Other	5(25)	3(15)	3(15)	2(10)	7(35)	20 (24)
Total	11	36	6	19	12	
			Other (OT)			
Medical waste (container)		12(75)		4(25)		16 (17)
Agricultural waste (Maize)	2(3)	41(53)	18(23)	11(14)	5(7)	77 (83)
Total	2	53	18	15	5	

* Empty spaces represent no items

A total of 3487 macrodebris items were classified into 59 categories and 8 major groups (Table 2). The total number macrodebris items reported in this study was lower to the total number of macrodebris on Slovenian beaches, Santa Catarina, Brasil (Widmer and Hennemann, 2010), Armacao dos Buzios, Brazil (Oigman-Pszczol and Creed, 2007), South Korea (Lee et. al., 2013) and Japan (Kusui and Noda, 2003) (Table 6) due to lesser influx of people, probably period of study and those locations serving as a tourist center for beachgoers. Between rivers, all group of litter was most abundant at location II (Nwangele river) which is due to high anthropogenic activities such as the Nkwo mmiri market < 100 m away from the river.

Table 6. Comparison of total number of macrodebris with selected studies

Location	Total number of items/m^2	Season	Reference
Nwangele, South East, Nigeria	3,487	Rainy	Present study
Slovenia	5,840	Dry	Laglbauer et. al., (2014)
Armacao dos Buzios, Brazil	15,832	Dry	Oigman-Pszczol and Creed, (2007)

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South Korea	27,606	Rainy	Lee et. al., (2013)
South Korea	8,205	Dry	Lee et. al., (2013)
South China Sea	37,500	Not specified	Zhou et. al., (2011)
Northern Taiwan	9,319	Rainy	Kuo and Huang, (2014).
Japan	32,212	Dry	Kusui and Noda, (2003)

Figure 5. Macro litter at the shore comprised mainly of plastics (59 %), metal (10 %), cloth (7 %), paper /cardboard (7 %), rubber (7 %), glass/ceramics (5 %), medical and agro-based waste (3 %) and wood (2 %).

Compositional profiling revealed that the majority (59 %) was made of plastic, a category generally dominant within the rivers (Figure 6). Other studies have reported plastic group to be in high abundance in the marine environment and in seafloor (Kusui and Noda, 2003; Santos et. al., 2009; Zhou et. al., 2011; Widmer and Hennemann, 2010; Laglbauer et. al., 2014; Lee et. al., 2013). Metal was the second most abundant group at the rivers (10 %), followed by rubber, cloth, paper and cardboards (all had 7 %), then glass and ceramics (5 %), followed by other (mainly agricultural waste, 3 %) while the least was wood (2 %), shown in Figure 5.

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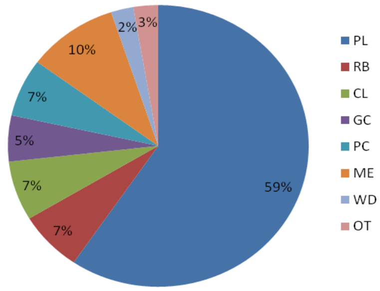

Figure 5. Proportion (%) of macrodebris in the entire area of study

Compositional profile by location revealed the following the order of abundance: PL (51 %) > ME (23 %) > PC (11 %) > WD (8 %) > GC (3 %) > CL (2 %) > RB/OT (1 %) respectively for Location I (Figure 6a); PL (62 %) > ME/CL (8 %) > PC/RB (7 %) > GC (5 %) > OT (2 %) > WD (1 %) respectively for Location II (Figure 6b); OT (28 %) > ME/CL (12 %) > PL/GC (11 %) > RB/WD (9 %) respectively for Location III (Figure 6c); PL (62 %) > ME (9 %) > PC (8 %) > RB (7 %) > GC (5 %) > WD/OT (4 %) > CL (1 %) respectively for Location IV (Figure 6d); PL (49 %) > ME (21 %) > GC/RB (8 %) > CL (5 %) > WD (4%) > PC (3 %) > OT (2 %) respectively for Location V (Figure 6e).

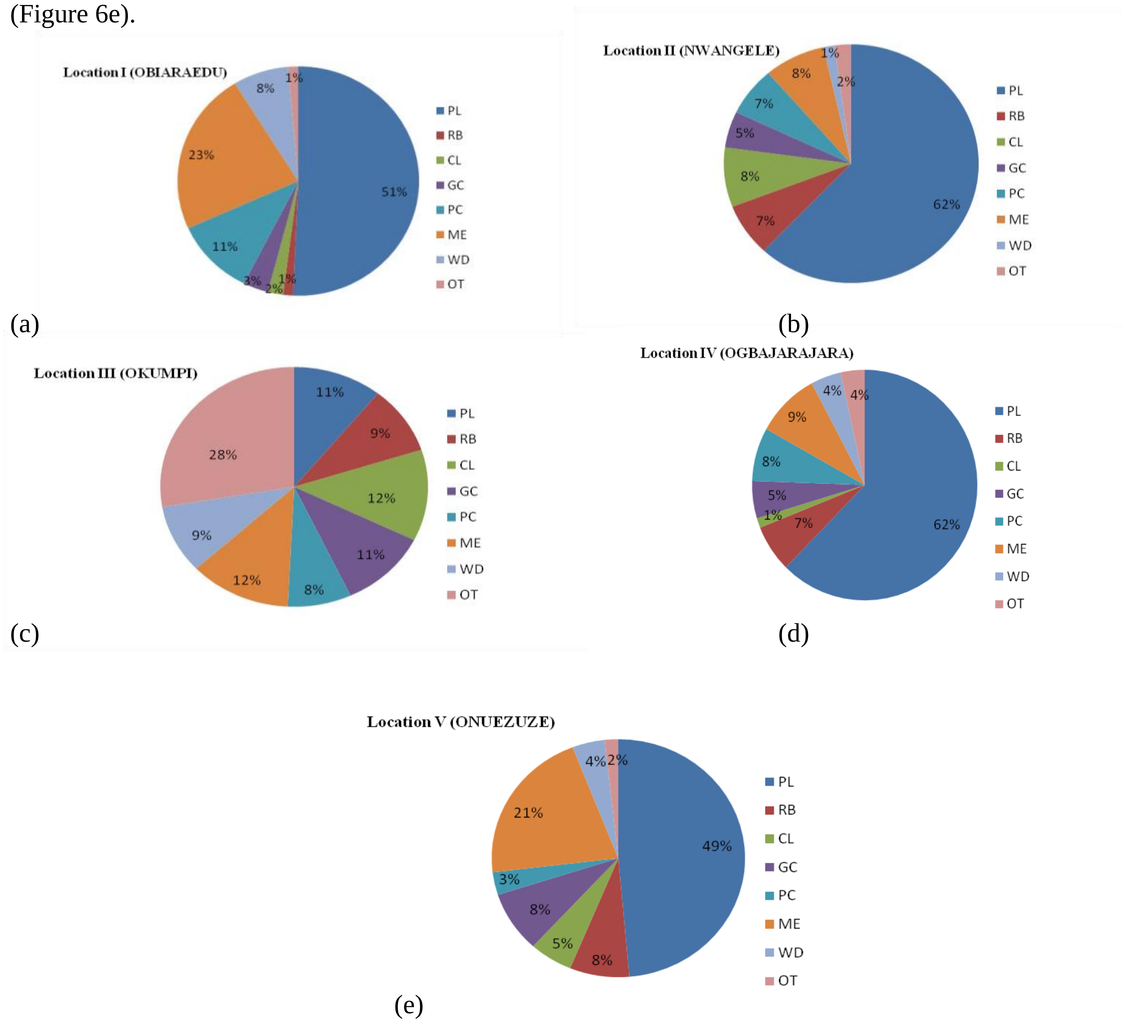

Figure 6. Proportion (in % of number of items/m^2) of macrodebris of each of eight major groups at each river.

In terms of category distribution in groups for the rivers, the order of litter abundance followed (Table 4): drink bottles (17 %) > packaging for soap (15 %) and cotton bud sticks (15 %) > caps and lids (12 %) > packaging for

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biscuit (4 %) and toys (4 %) > straws (3 %) and fishing ropes, string and cord (1 %) > others (0 %) respectively for plastic (PL) group; Balloons, balls, toys (47 %) > Shoes (25 %) and other pieces (25 %) > Gummies (8 %) for rubber group; ropes (59 %) > clothing, shoes, hats and towels (34 %) > other (7 %) respectively for cloth group; plates, pots (cups) (41 %) > Bottles, glasses (24 %) > Pieces (22 %) > construction material (13 %) for respectively glass/ceramics group; Paper (incl. magazines) (53 %) > Cardboard (pieces, boxes) (42 %) > Other (pieces) (5 %) respectively for paper/cardboard group; Drink cans (38 %) > Caps, can lids (26 %) > Pieces (12 %) > Construction (10 %) > Aluminium wrapping (7 %) > Other (4 %) > Wire, barbed wire (3 %) respectively for metal group; Matches, fireworks (61 %) > Other (24 %) > Ice lolly sticks (9 %) > Cork (6 %) respectively for wood group Agricultural waste (Maize) (83 %) > Medical waste (container) (17 %) respectively for other group.

3.1.3 River cleanliness assessment

The river cleanliness assessment was done using the clean coast index as described in section 2.2.2.1 in the analysis of macrodebris. The computed result for the rivers is presented in Figure 7.

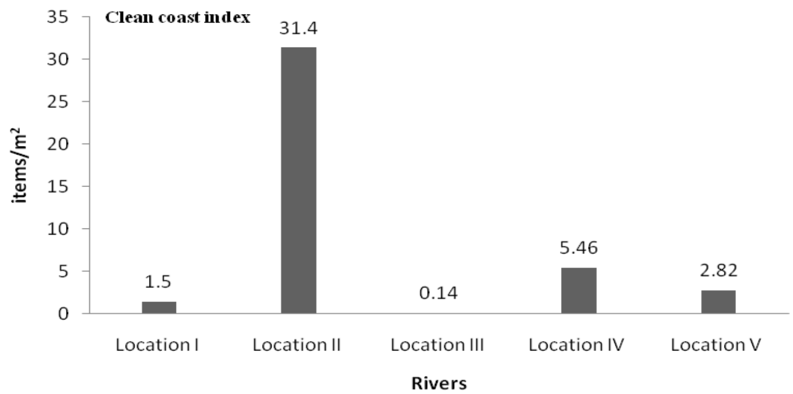

Figure 7. Clean coast index (CCI) for the rivers

Following the grading provided by Alkalay et al., (2007) presented in Table 2, only location II (Nwangele) was "extremely dirty" with CCI of 31.4 items/m^2 , two other rivers were "very clean" viz location I (Obiaraedu) and location III (Okumpi) with CCI of 1.5 items/m^2 and 0.14 items/m^2 respectively. The remaining two rivers ranged from "clean" with CCI of 2.82 items/m^2 at location V (Onuezuze) to "moderate" with CCI of 5.46 items/m^2 at location IV (Ogbajarajara) respectively. The order of decreasing macrodebris pollution followed: location II > IV > V > I > III. (Figure 7). The high CCI grade for Nwangele river is mainly due to high anthropogenic activities experienced in the area which decreased with intensity of anthropogenic activities. The current study reported low CCI when compared to CCI reported for some beaches in Slovenia with a CCI ranged of 5.67 (moderate) to 49.29 (extremely dirty) (Laglbauer et. al., 2014) perhaps due differences regarding plastics consumption and local land-based sources.

3.2 Microplastics

The amount of microplastics counted in terms of shape in one liter of water sample collected upstream, midstream and downstream is presented in Table 5 while image of dominant microplastic shape is presented in Figure 8.

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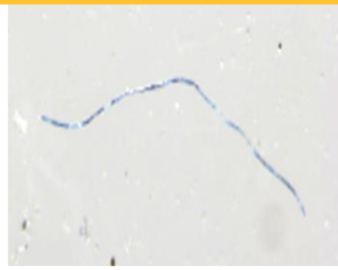
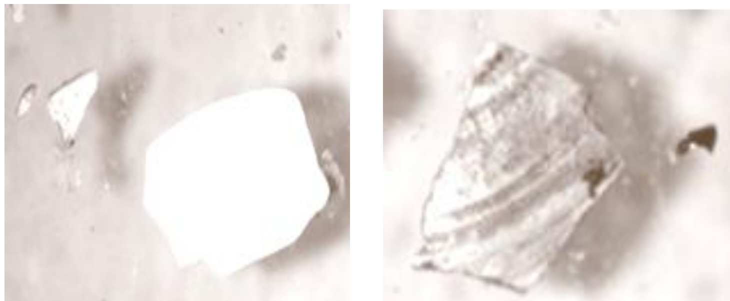


(a) Fiber

(b) Film



(C) Fragment

Figure 8: Images obtained under a microscope of the three major shape of microplastics encountered in the surficial water from the rivers; fibre (a) film (b) and fragment (c). Scale bar was 1 mm.

Table 5. Quantity of microplatics in surficial water (in Particles/L)

Shape	Sampling points	Location I	Location II	Location III	Location IV	Location V
Fiber	U1	24	44	19	31	27
	U2	19	28	14	19	21
	M1	27	67	27	50	30
	M2	26	88	20	31	29
	D1	34	95	71	65	42
	D2	89	61	63	92	64
	Total	219	383	214	288	213
Film	U1	9	12	2	33	31
	U2	7	29	14	19	9
	M1	19	68	5	27	22
	M2	15	72	8	22	28
	D1	39	91	23	69	41
	D2	43	102	41	93	39
	Total	132	374	93	263	170
Fragment	U1	23	66	8	51	17
	U2	14	86	2	57	45
	M1	27	95	5	62	49
	M2	20	102	9	97	60
	D1	91	120	11	101	96
	D2	93	129	6	94	98
	Total	268	598	41	462	365
Other	U1	26	34	9	35	31
	U2	13	43	5	45	36
	M1	18	14	7	49	19
	M2	11	28	11	36	29
	D1	9	47	21	17	11
	D2	21	35	39	21	28
	Total	98	201	92	203	154
	Grand Total	717	1556	440	1216	902

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	Mean	179.25	389	110	304	225.5
	SDV	78.08	162.57	73.46	111.21	96.28
	CV (%)	43.56	41.79	66.78	36.58	42.70

U-Upstream, M-Midstream, D-Downstream, Other may include granules, foam etc

Table 6. Quantity of microplastics based on plastic types (in Particles/L)

	Sampling points	**Location I**	**Location II**	**Location III**	**Location IV**	**Location V**
PE	Upstream	41	78	14	90	37
	Midstream	56	92	7	74	66
	Downstream	83	70	107	197	42
	Mean	60	80	42.67	120.33	48.33
	SDV	17.38	11.14	55.82	66.88	15.50
	CV (%)	28.97	13.93	130.82	55.58	32.07
PP	Upstream	6	14	3	45	27
	Midstream	17	48	11	69	13
	Downstream	74	169	19	73	66
	Mean	32.33	77	11	62.33	35.33
	SDV	29.80	81.47	8	15.14	27.47
	CV (%)	92.17	105.81	72.73	24.29	77.75
PVC	Upstream	26	79	3	72	23
	Midstream	47	104	18	89	38
	Downstream	69	74	29	41	72
	Mean	47.33	85.67	16.67	67.33	44.33
	SDV	17.56	16.07	13.05	24.34	25.11
	CV (%)	37.10	18.76	78.28	36.15	56.64
PS	Upstream	23	69	39	27	41
	Midstream	39	85	10	11	24
	Downstream	67	56	68	21	62
	Mean	43	70	39	19.67	42.33
	SDV	18.18	14.53	29	8.08	19.04
	CV (%)	42.28	20.75	74.36	41.08	44.98
PET	Upstream	34	98	11	46	80
	Midstream	4	143	40	127	113
	Downstream	70	263	23	201	143
	Mean	36	168	24.67	124.67	112
	SDV	26.98	85.29	14.57	77.53	31.51
	CV (%)	74.94	50.77	59.06	62.19	28.13
Other	Upstream	5	4	3	10	9
	Midstream	0	62	6	4	12
	Downstream	56	48	29	19	34
	Mean	20.33	38	12.67	11	18.33
	SDV	25.30	30.27	14.22	7.55	13.65
	CV (%)	124.45	79.66	112.23	68.64	74.47

*PP-polypropylene, PE-poly ethylene, PVC- polyvinyl chloride, PS- polystyrene, PET- polyetyhylene Terepthalate, Other- Not identifiable

3.2.1 Distribution based on stations

The distribution of total number of microplastics based on locations and stations is presented in Figure 9. The quantity of particles ranged from 73 particles/L at upstream of location III to 680 particles/L at downstream of location II. Location II had the highest count of microplastics for all stations while location III was the lowest.

In terms of stations, distribution showed significant differences [$p < 0.05$, df = 14, $F_{critical}$ (3.88) < F_{ratio} (3.98)] with general high load of particles in downstream probably due to flow pattern and topography. The order of mean count was downstream (469±153.33 particles/L) > midstream (285.8±174.94 particles/L) > upstream (211.4±109.84

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particles/L). The variations ranged from "moderate" at downstream (32.69 %) to "high" at midstream (61.21 %) and upstream (51.96 %). The variations followed the order downstream < upstream < midstream.

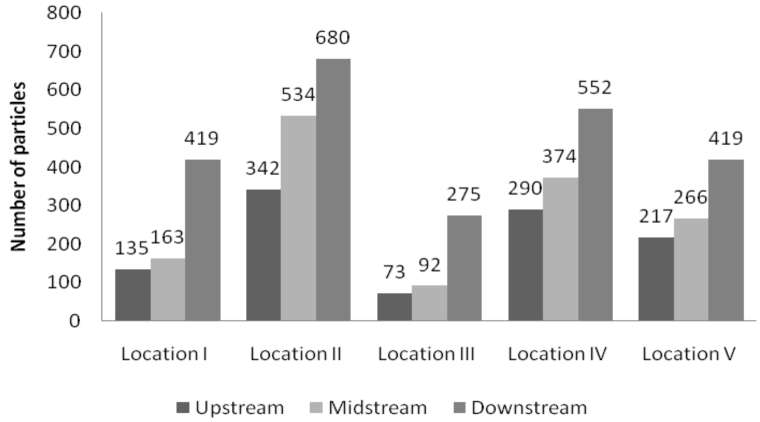

Figure 9. Quantity of microplastics based on stations (in Particles/L)

3.2.2 Distribution based on shape

Generally, fragments were the most dominant shape except at location II which had high fiber counts (214 Particles/L) (Figure 10). The distribution order for shape abundance was fragments (346±210.02 Particles/L) > fiber (263.4±73.93 Particles/L) > film (206±112.93 Particles/L) > other (149±70.08 Particles/L) respectively. Furthermore, distribution by location followed the order: location II > IV > I > V > III respectively for fiber and film shape while fragments were location II > IV > V > I > III respectively. Shape variability analysis showed "moderate variation" for fiber (28.07 %) and other (46.84 %) while "high variations" for film (54.71 %) and fragment (60.56 %).

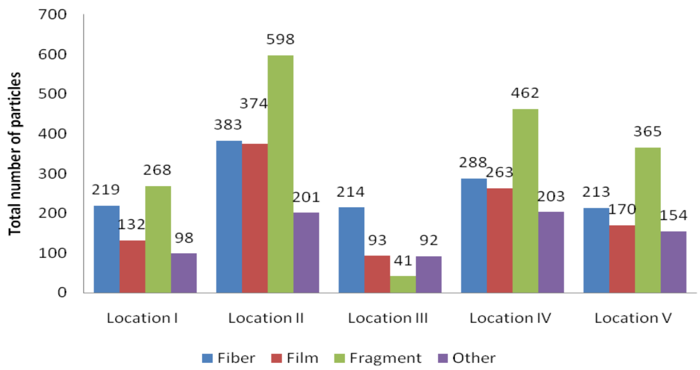

Figure 10. Distribution of microplastics based on shape

3.2.3 Distribution based on type

The distribution of plastic types by location is presented in Figure 11. PE was highest at location IV while lowest at location III, PP, PVC, PS and other type was highest at location II and lowest at III. Distribution based on typed showed significant differences [$p < 0.05$, df = 29, $F_{critical}$ (2.62) < F_{ratio} (2.93)] but positive correlations. PVC with PET (r = 0.87) and other (r = 0.66), while others with PS (r = 0.94) and PET (r = 0.58) respectively showed

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significant and high correlations. The positive and high correlations indicated that the source of these plastics form are from macrodebris and therefore from secondary sources through fragmentation of large plastics by sunlight. The distribution of plastic types was; PET (29 %) > PE (22 %) > PVC (16 %) > PP (14 %) > other (6 %).

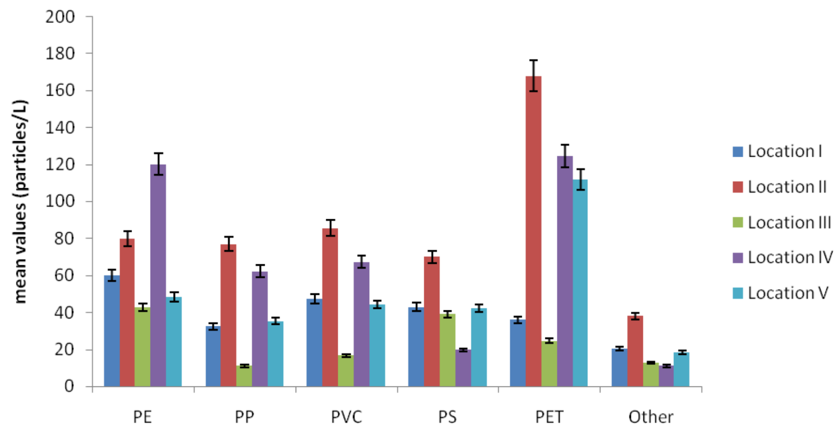
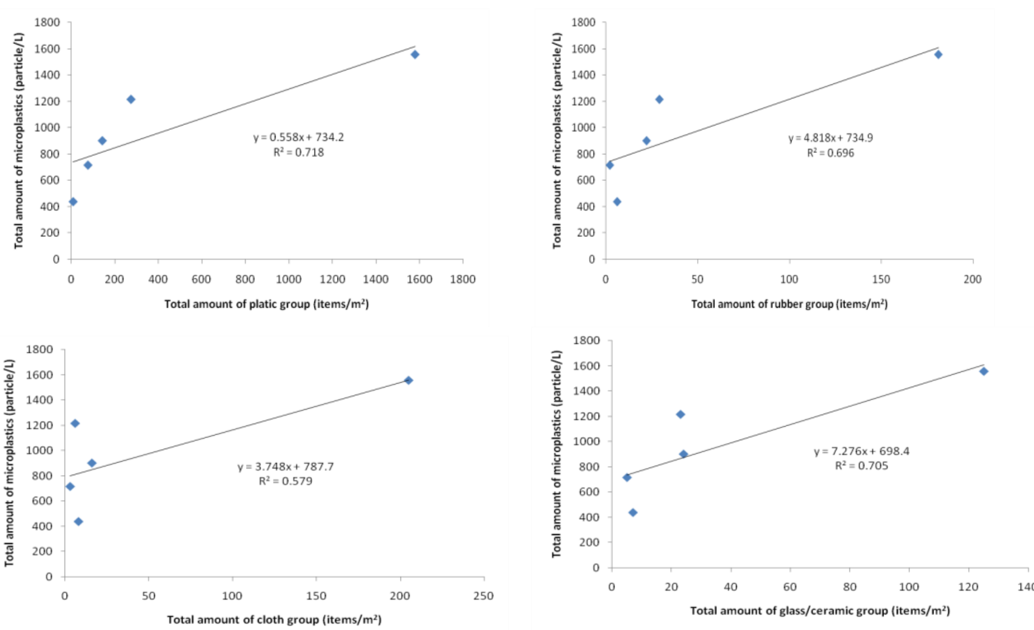


Figure 11. Distribution of microplastics based on type. Error bars revealed 5 % standard error

Coefficient of variations for plastic type for the different locations (I-IV) is presented in Table 6. Variability was high at II and IV, low at III and moderate at I and V for PE; for PP, variability was high in all location except at IV (moderate); PVC showed low variability at II, moderate III while remaining locations showed high variations; PS was moderate all through except at III which was high; PET was low at I and moderate III while II, IV and V were high, lastly non-identifiable type (Other) showed high variations at all locations.

3.3 Macrodebris group vs Microplastics: Regression analysis

The regression analysis between different macrodebris group and microplastics are presented in Figure 10. Generally, a significant relationship was found between the total abundances of microplastics and different macrodebris group. The correlation analysis results suggest that microplastics were abundant in areas where the macrodebris abundance was high. The regression coefficient for the different groups of debris was in the order; wood > plastic > metal > paper/cardboard > glass/ceramic > rubber > cloth > other respectively. Significance relationships have been observed for macrodebris and microplastics for beaches in South Korea (Lee et. al., 2013).



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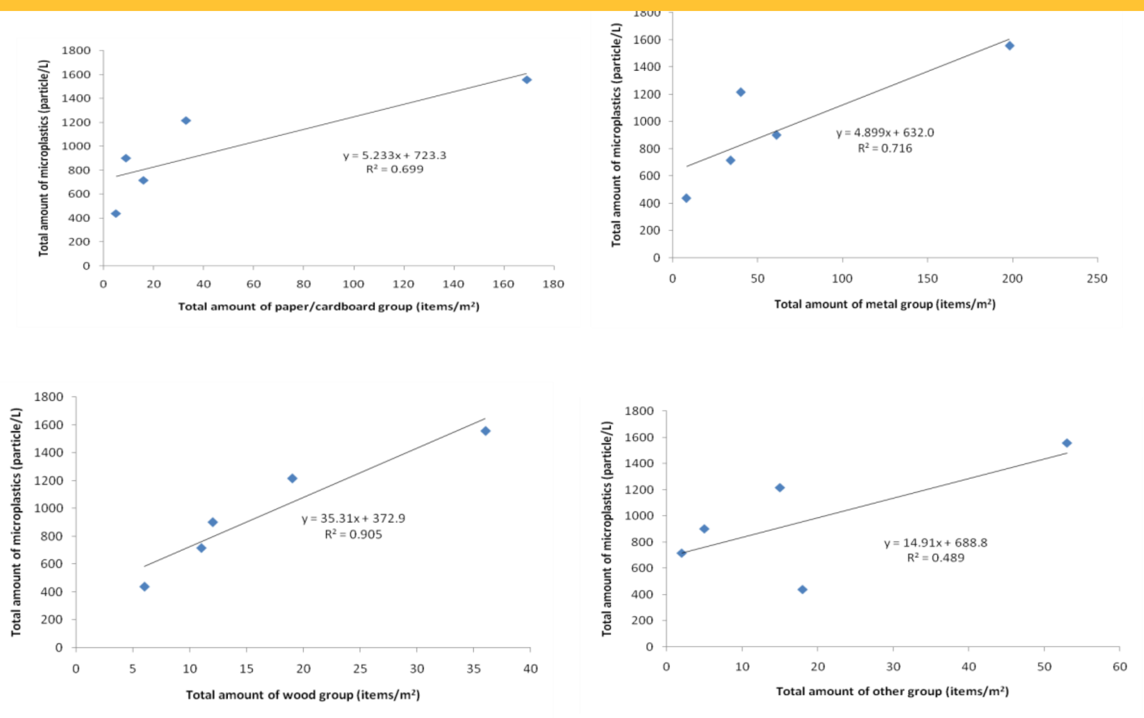

Figure 12. Regression analysis between macrodebris groups and microplastics

4. Conclusion and recommendation

The majority of items found on the shore of the rivers were plastics, with moderate pollution (mean CCI of 8.26). However, Nwangele river was extremely dirty. Major shape of microplastics found were fragments (most abundant), fiber and film which are of secondary sources that arise from the fragmentation of macroplastics in the area through light, heat, chemical, or physical processes while downstream accumulated most microplastics compared to midstream and upstream. There was significant occurrence of microplastics in smaller size (11 µm), which could pose ecological problems, because at this size they are readily bioavailable and easily injected by animals. The dominant type of plastic was PET probably from plastic water bottles. Finally, macrodebris (> 5 cm) surveys could serve as surrogates for small microplastics (0 –25 µm) monitoring and also be used to identify hot spots of microplastic pollution in large geographical areas with limited resources. Due to time limitations of time, instrument and sampling size, we recommend a follow-up study including large sample sizes, with better instrument (for microplastics analysis; reviewed by Verla et. al., 2019a) and study covering both dry and rainy periods. However, more inland rivers in Nigeria should be assessed for macrodebris and microplastic pollution for more understanding of their distribution within the country. However, strategies to reduce waste generation include proper waste management, recycling of plastics, and penalties for illegal dumping and a long-term monitoring program.

Conflicts of interest

The researchers declares no conflicts of interest regarding the publication of this manuscript

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