Characterization of tidally accumulated plastic waste and its effect on seedling growth in sand-filled mangrove forest at Eagle Island, Niger Delta, Nigeria

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Abstract

Plastic pollution has become a global problem with the proliferation many plastic goods. This study thus hypothesized that accumulated plastic waste will have adverse effect on mangrove growth. The study was carried out at a sand-filled and deforested mangrove forest at Eagle Island. Ten soils samples each (n =20) were collected underneath accumulated plastic waste vertically and horizontally. The soils were put in polythene bags and sent to the laboratory for analysis of total hydrocarbon content (THC), and heavy metals i.e., Zinc (Zn), Lead (Pb) and Cadmium (Cd) using the HACH DR 890 colorimeter (wavelength 420 nm) and microwave accelerated reaction system (MARS Xpress, North Carolina) respectively. In addition, mangrove (Rhizophora species) seedlings were also collected with soils from the plastic waste and non-plastic waste sites (control). The result shows that there is no significant difference in heavy metal concentration along the profile i.e., surface, and sub-surface soils ($F1, 30 = 1.83$, $P = 0.186$), and soil gradients ($F3, 28 = 0.60$, $P = 0.619$) of the soil. In contrast, there is significant difference in seedling growth between the control and plastic soils ($F4, 200$, 65.24, $P<0.001$). Furthermore, microbial population showed significant difference horizontally ($F3, 11 = 3.86$, $P = 0.04$) but not vertically ($F1, 11 = 4.60$, $P = 0.055$) in plastic soil. This result implies that plastic pollutants can migrate horizontally to contaminate nearby mangroves. Thus, plastic waste should be managed to prevent pollutants from entering the food chain to contaminate humans.

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Running Head : Plastic waste accumulation in mangrove forest

Abstract: Plastic pollution has become a global problem with the proliferation many plastic goods. This study thus hypothesized that accumulated plastic waste will have adverse effect on mangrove growth. The study was carried out at a sand-filled and deforested mangrove forest at Eagle Island. Ten soils samples each (n =20) were collected underneath accumulated plastic waste vertically and horizontally. The soils were put in polythene bags and sent to the laboratory for analysis of total hydrocarbon content (THC), and heavy metals i.e., Zinc (Zn), Lead (Pb) and Cadmium (Cd) using the HACH DR 890 colorimeter (wavelength 420 nm) and microwave accelerated reaction system (MARS Xpress, North Carolina) respectively. In addition, mangrove (*Rhizophora* species) seedlings were also collected with soils from the plastic waste and non-plastic waste sites (control). The result shows that there is no significant difference in heavy metal concentration along the profile i.e., surface, and sub-surface soils ($F_{1,\ 30}$ = 1.83, P = 0.186), and soil gradients ($F_{3,\ 28}$ = 0.60, P = 0.619) of the soil. In contrast, there is significant difference in seedling growth between the control and plastic soils ($F_{4,\ 200}$, 65.24, P<0.001). Furthermore, microbial population showed significant difference horizontally ($F_{3,\ 11}$ = 3.86, P = 0.04) but not vertically ($F_{1,\ 11}$ = 4.60, P = 0.055) in plastic soil. This result implies that plastic pollutants can migrate horizontally to contaminate nearby mangroves. Thus, plastic waste should be managed to prevent pollutants from entering the food chain to contaminate humans.

KEYWORDS: plastic waste, tides, heavy metals, sand fill, Niger Delta, soil profile

INTRODUCTION

Plastics are petrochemical products that are manufactured for multipurpose use such as packaging in the culinary, food, electronics, and automobiles industries (Moshood et al. 2021). It is also used in the manufacture of home appliances. Plastic wastes are unwanted plastics materials that are no longer useful to the system and are thrown away into refuse dump instead of being recycled (Moretti et al. 2020). However, their uncontrolled disposal into the environment has generated a nightmare for waste managers globally (Deme et al. 2022; Van et al. 2022). This is because their improper disposal into open dumps and landfills in municipal areas have exposed them to flood and erosion which wash them from city drainages into the aquatic environment.

The presence of plastic waste in the water body is detrimental to aquatic organisms when they decompose into fine particles called microplastic and are consumed (Li et al. 2022; Jiang et al. 2022). Decomposed plastics increase the heavy metal and petrochemical contents of the water (Marchant et al. 2022), which reduces the water quality and affects the reproductive and physiological functions of fishes and other aquatic organisms (Luo et al. 2022). The lodging of harmful metal in the bodies of fish bioaccumulates in humans when they consume them (Ouyang et al. 2022). Furthermore, plastic waste travels thousands of kilometers from the point of disposal to the point of deposition mostly in mangrove forest or on terrestrial sandy beaches during periods of high tides and splashing waves (Sibaja-Cordero et al. 2022). The adventitious root of mangrove traps some waste while the rest are carried away by tidal currents (Silburn et al. 2022). However, the case is different for sand filled mangrove forest because the sand barrier serves as an embankment that prevents the retreat of the plastic waste when brought in by tidal currents. Therefore, the deposited plastic waste on the sand remains for long without being flushed back to the river. This situation is different for the mangrove forest because they are right in the river and face intense tidal flushing actions which wash away most of the debris from the forest floor back to the river.

Settled plastic wastes get scorched by intense sunlight and disintegrate into finer particles (Huber et al. 2022). These microplastics are decomposed further by soil microbes (Baig et al. 2022) and settle on and within the sand. Chemical components of the plastics are further washed deep down the soil profile (Nasseri and Azizi, 2022). The accumulation and disintegration of the plastic wastes increases the heavy metal and microbial load of the soil underneath. Release of chemicals from the decomposed plastic materials can percolate into the soil to contaminate the groundwater aquifer (Sajjad et al. 2022). It may also be carried into the river by surface erosion during heavy rainfall and high tides thereby leading to some maritime accidents (e.g., Moore, 2008; Pattiaratchi et al. 2022). Based on the health and environmental risk the plastic waste poses to the people that consume seafood from the nearby river (Adeniran and Shakantu, 2022), The goal of this study, therefore is to characterize accumulated plastic wastes, determine soil metal composition, microbial population and the effect of plastic waste on mangrove seedling growth in the sand filled area. plastic waste were chosen because they are the most abundant waste type in the study area. Similarly, the grass species *Mariscus longibracteatus*(Numbere, 2020) was used to test the transmission of chemicals via soil plant pathway because they are the most dominant grass species in the study area. The following research questions were thus, addressed: (1) Are there differences in the accumulated plastic waste types at different sites horizontally or vertically (2) Are there differences in chemical and microbial properties of the soil on which the plastic waste accumulated, (3) Are there differences in seedling growth in accumulated plastic waste soil and soil without plastic waste (control)? And if so, are there correlations between mangrove seedling growth and heavy metal and microbial concentrations?

MATERIALS AND METHODS

Description of study area

The research was carried out on a section of a deforested and sand filled mangrove forest at Eagle Island Niger Delta (Figure 1). The area is surrounded by swampy soil that is chocolate brown in color and borders a river course that is used for boat transportation. During high tide the river flushes water borne plastic waste into the grassy sand filled area, which get trapped in the grasses. The sandy area has a combination of mangrove and non-mangrove species growing. The species found in the area are red (*Rhizophora racemosa*), black (*Laguncularia racemosa*), and white (*Avicenniagerminans*) mangroves while the non-mangrove species are dominated by grasses e.g., *Mariscus longibracteatus* (Numbere, 2020). There are also some Nypa palm species (*Nypa fruticans*) growing in the sand. There are also numerous fiddler crab (*Ucatangeri*) burrows on the sand. The soil is slightly alkaline with a pH of 7.5. The temperature of the soil is 26.1$\pm$0.01 and the salinity is 1.16ppt and the TDS is 360$\times$10 ppm. The area has two seasons, the wet and dry seasons. Dry season occurs from November to March while the wet season is between March to October each year (Numbere and Camilo, 2018).

Experimental design

The study used a random block design (e.g., Numbere, 2021a) in an area measuring 55.8m $\times$ 42.6m (2, 377.08m^2). Within this area five accumulated plastic waste deposition sites were identified and delineated (Figure 2) using a standard measuring tape at an accuracy of 0.1m. The height and circumference of the area occupied by the waste was measured. Each plastic deposition site is made up of grassy and sandy to muddy soils. The sandy soil is made up of 90% sand; the semi-muddy soil is made up of a mixture of sand and mud (i.e., 30% clay and 50% sand); and the muddy soil is made up of 90% silt. The soils were identified in situ and classified using soil textural triangle and soil characteristic of western Nigeria (Smyth and Montgomery, 1962). The five sites were georeferenced with a Garmin GPS (USA) (Table 1) and photographs and video of the sites recorded for accurate counting of the plastic waste.

Plastic waste characterization

The plastic waste is brought into the deforested mangrove forest by tidal current. They are often deposited on the sandy coast in circular formation at different sites close to the river. The plastic waste was delineated into five groups, which were studied in situ. Although, there are few scattered plastic wastes around the study area, but they don't form a heap. Within each group the different types of plastic wastes were manually sorted and identified before being grouped and taken to the lab for weighing. The circumference of each waste site was taken using distance measurement tool in GARMIN GPS. The diameter and height across the waste column was also taken with a measuring tape (0.1m). Thereafter the volume of the plastic waste column at each site was calculated using the formula (Eq. 1) and recorded in Table 2.

$V=\pi r^2 h$ (1)

Plastic waste at each sample point were physically counted and grouped into their different components (e.g., plates, water bottles, packaging etc.). Pictures and videos of each waste heap were also recorded and taken to the laboratory where they were counted in camera and in video to derive the best estimate of the number of different plastic waste per site. This is in addition to the physical in situ enumeration. After grouping, one sample of plastic waste was collected and taken to the laboratory for weighing with an Ohaus weighing machine (Model PS251).

Sample collection

A hand-held soil augur was used to randomly collect soil samples in October 2019 at the six accumulated plastic waste deposition sites. The soils were collected vertically and horizontally at the waste dump. The vertical samples were collected on the surface and in the sub-surface (i.e., 5cm below). The horizontal samples were collected at three gradients from the waste site namely near (low), middle (medium) and far (high). This gives a total of 18 samples per site and in the overall 90 (16 x 5) samples. The subsurface soils were collected with soil augur 10cm below the surface. Another set of soil. The coordinates of the sample collection points were derived with a Garmin GPS as shown in Table 2.

Seedling growth experiment

To test the effect of plastic waste on seedling growth some seeds of the two species of mangrove were picked up at the study site. Thirty seeds each of *Rhizophora racemose* (giant seeds) and *Rhizophora mangle* (dwarf seeds) were picked from the floor or plucked from the tree, bagged, and taken to the laboratory for planting. Soil samples were collected in situ beneath the accumulated plastic waste site and non-accumulated plastic waste site (control) using a hand-held soil augur. The soil samples were bagged separately and sent to the laboratory for the seedling experiment. At the laboratory twelve plastic containers each with height, width, and weight measuring 17.5cm $\times$ 15cm and 2.2 kg were filled to equal level with soils collected from the accumulated plastic and control soils. The physico-chemistry of the soil was then taken as follows: pH (4.0-5.5), Temperature (28-29C°), and moisture content (very wet). Similarly, the seed weight, seed length, and bud length were measured in meters, thereafter, five seeds each were then planted in each container i.e., plastic, and non-plastic (control) soils to give a total of 30 seeds per species (i.e., $n=5\times6$). The seedling growth were then monitored for one year (March 2021-March 2022) by measuring the number of sprouting leaves, and the seedling height.

Laboratory analysis

Total hydrocarbon (THC) and heavy metal analysis

The procedure of total hydrocarbon content involves the use of spectrophotometric method using the calorimeter (i.e., HACH DR 890). Samples were crushed and 2 g of it retrieved and weighed into a glass beaker and 20 ml of hexane was added. The mixture was stirred and then filtered in a glass funnel filled with cotton wool, silica gel and anhydrous sodium sulphate. Thereafter, 10 ml of organic extract was put into a 10 ml sample curvet and introduced into the calorimeter. The detection limit for THC is 0.01 mg/l (APHA, 1995).

Heavy metal analysis: extraction of heavy metals followed the method of Aigberua and Tarawou (2019). It involves the air drying of 0.25 g of soil sample, which is weighed into a Teflon inset of a microwave digestion vessel and 2 ml concentrated (90%) nitric acid (Sigma-Aldrich,Dorset, UK) added. The metals were extracted using a microwave accelerated reaction system (MARS Xpress, CEM Corporation, Mathews, North Carolina). The detection limit for the three metals analyzed in mg/l i.e., Zinc, Cadmium and Lead were 0.001, 0.001 and 0.002 respectively (Aigberua and Numbere, 2019).

Microbial analysis

Total heterotrophic bacteria (THB)

1g of soil is weighed into 9 ml sterile diluents (0.85% NaCl) under aseptic condition. It is thoroughly shaken to homogenize and serially diluted. Then 0.1 ml aliquot of the inoculums is collected using a sterile pipette and inoculated on the surface of a nutrient agar (NA). The inoculum is spread evenly with a sterile hockey stick (bent rod). Plates are inoculated at 370C for 24 hours. Thereafter, colonies are counted to obtain colony forming unit (cfu) value per ml of the soil sample. Distinct colonies are picked and streaked on freshly prepared nutrient agar to obtain pure culture after 24 hours of incubation at 370C. The pure culture is gram stained for microscopic examination.

Total heterotrophic fungi (THF)

One gram (1g) of soil is weighed into sterile diluents (0.85% NaCl) under aseptic condition. It is then thoroughly shaken and serially diluted. 0.1 ml aliquot of inoculums is inoculated on sabouraud dextrose agar (SDA) acidified with 0.1% lactic acid to inhibit growth of bacteria and allow for only the growth of fungi. Inoculated plates are incubated at ambient temperature for 3-5 days. Cultural characteristics of isolates are observed and sub cultured for purification. Microscopic examination is done using lactophenol cotton blue stain with × 400 magnifications.

Statistical analysis

An analysis of variance (ANOVA) was conducted to determine whether there was a significant difference in chemical and microbial contents between surface and subsurface soils harboring tidally accumulated plastic waste. Similarly, an ANOVA was done to determine whether there was significant difference in chemical and microbial contents between lower, medium and higher gradients from plastic waste. A two-way ANOVA was also conducted to determine whether profile and gradient have effect on microbial and heavy metal concentration (i.e., additive effect). The data was initially log transformed to ensure that they were normal, and the variances were equal (Logan, 2010). Later bar graphs were then used to illustrate the results (Quinn and Keough, 2002). Similarly, a post-hoc Tukey's HSD test was done to investigate pair wise mean differences between groups. Pearson's product-moment correlation was done to compare whether there was any significant difference between heavy metal concentration and mangrove seedling growth. All analysis was performed in R statistical environment (R Development Core Team, 2013).

RESULTS

Plastic waste characterization

In all 13 different plastic waste types were identified in the five accumulated plastic waste sites (Table 1). In each category several plastic waste components of all sizes were identified ranging from syringes with their needles still intact, medicine, cream, perfume, mouth wash, kitchen detergent, soda, and water containers. The individual weight ranges of the plastic waste were from 6.7-350.1g. The waste was found on either grassy or sandy areas. Grassy areas have the highest accumulated waste.

Furthermore, site 5 has the highest waste volume (4.50kg) in terms of diameter, radius, and height of waste column (Table 2). However, site 3 has the highest total plastic weight per mass (974.4kg) followed by site 1 (535.7kg) and site 2 (323.2kg). Nevertheless, Site 1 has the highest number of waste types (19) followed by site 3 (17) and Site 2 (13).

The most dominant individual waste is bottled drinks (41.51%) followed by bottled water (19.16%) and food pack (14.01%) (Table 3).

Seedling growth experiment

Plastic vs. control :

The t-test result showed that there is no significant difference between growth in control and plastic soil (t =1.25, df =192.45,P =0.21). However, there was slightly higher mean growth in height (cm) in control soil (6.19cm) than in plastic soil (5.64cm) (Figure 3a).

Weekly to one year growth of seedlings (height) :

The ANOVA result showed that there is no significant difference in seedling growth between control and plastic soils ($F_{1,\ 325,}$ 1.09, P=0.30). However, mangrove seedlings have higher bud growth in control soil initially after planting, but at the 5^{th}-6^{th} week the seedlings in plastic soil grew taller, then at the 7^{th} week to on year seedling in control grew taller. This pattern shows a fluctuating growth (Figure 3b).

Number of leaves:

The ANOVA result showed that there is no significant difference in the number of leaves of seedlings between control and plastic soils ($F_{1,\ 325,}$ 1.27, P=0.26). There was also an increase in the number of leaves from 2 to 10 within one year period. Seedlings in the control soil retained their leaves longer than seedlings in the plastic soil (Figure 3c).

Inter species comparison (*R. Racemosa vs. R. mangle*) :

The ANOVA result showed that there is significant difference in growth between the two species ($F_{1,\ 285}$, 9.66, P<0.002; Figure 3d). *Rhizophora mangle* seedling grew faster than *Rhizophora racemosa* in control soil compared to plastic soil. This shows that pollutants from plastic waste can impact *R. mangle* growth in deforested mangrove forest (Figure 5).

Total hydrocarbon and heavy metal concentration

Total hydrocarbon content :

The ANOVA result showed that there is no significant difference along soil profile (i.e., surface, and sub-surface) ($F_{1,\ 30}$ = 1.83, P = 0.186, Table 4). But there is significant difference between the metals ($F_{3,\ 28}$ = 5.18, P = 0.0057). Total hydrocarbon content (THC) has the highest concentration followed by zinc and lead (Table 4). For THC surface and sub-surface concentrations are 40.85±32.52mg/kg and 4.26±2.16kg/mg respectively while for zinc the concentrations are 2.14±0.53kg/mg and 0.37±0.01kg/mg for surface and sub-surface respectively. The same result is replicated in soil gradients.

Heavy metals :

The ANOVA result indicates that there is no significant difference in metal concentration along soil gradient ($F_{3,\ 28}$ = 0.60, P = 0.619, Table 4). Furthermore, a two-way ANOVA indicates that the profile and gradient have no effect on metal concentration (P>0.05).

3.4. Microbial analysis (Conc. vs microbe)

The one-way ANOVA indicates that there is no significant difference in bacteria and fungi population between soil profile ($F_{1,\ 14}$ = 3.89, P = 0.0687, Figure 4). Similarly, there is no significant difference in microbial concentration along soil profile ($F_{1,\ 14}$ = 2.85, P = 0.11) and soil gradient ($F_{3,\ 12}$ = 2.97, P = 0.08). However, a two-way ANOVA (interaction of gradient × profile) indicates that the microbial population is significantly different in soil gradient ($F_{3,\ 11}$ = 3.86, P = 0.04), but not significantly different in soil profile ($F_{1,\ 11}$ = 4.60, P = 0.055) in the plastic accumulation sites (Figure 4). Bacteria (THB) have higher population than fungi (THF).

Correlation between plant species abundance and metal concentration

There was no correlation between mangrove seedling growth and heavy metal concentration (t = 0.856, *df* = 28, *p-value* = 0.399; *cor* = 0.1596273; Figure 5a). Similarly, there was no correlation between seedling growth and microbial concentration (t = 0.596, *df* = 14, p-value = 0.56043, *cor* = 0.1574088; Figure 5b).

DISCUSSION

The identified wastes have floating ability that is why they are easily carried by tidal currents into the sand filled area. More waste was found in the grassy area because grass serves as a trap to the waste when brought in by tides. The dominant grass species that does the trapping is *Mariscus longibracteatus* (Numbere, 2020). Site 3 has the highest accumulated waste because they are trapped by the grasses, which prevent them from being carried back to the sea. The proliferation of bottled water in this region is because of lack of provision of public water facility, which has made many to resort to buying bottled water from stores. The waste bottle is thrown away into the environment after the content is consumed because there is no strict enforcement and punishment of offenders for dumping waste in the public space. Waste dumped into the open is carried by flooded water into public drainage system during heavy rainfall. Subsequently, the plastic waste is eventually carried into the river from the municipal drainage system which are often connected to the water body (Rakib et al. 2022). Boat travelers and people living in shanties along at the coastal areas dump their waste directly into the river because of poor waste management.

Mangrove seeds were planted in soils collected from accumulated plastic waste dump site to show the impact of plastic pollution on seedling growth. Seedlings in control soil grew taller than those in plastic soil probably because of low plastic-mediated metallic content (Table 4). The entire study area is polluted from oiling activities around the creeks and these pollutants along with plastic and other hazardous waste are continuous circulated around the sand filled area during high tides and during flooding and erosion. Nevertheless, it was observed that sites with accumulated plastic waste have higher metallic content compared to sites without accumulated plastic waste because of the decomposition of the plastic material by solar radiation and microbes. The decomposed materials therefore percolates into the soil underneath (Lin et al. 2022).

The growth in height of mangrove seeds in control and plastic soil has fluctuating pattern (Figure 3b). This is because during the first four weeks of planting the seeds in control soil grew taller than the seeds in plastic soil (i.e., bud length). This pattern reversed at the 6-7th week where seeds in plastic soil grew taller. But from the 7th week to on year the seedlings in control soil continueed to grow taller than seedlings in plastic soil. Even though no correlation (*R=0.16*) was found between seedling growth and the chemical and microbial composition of the soil (Figure 5)**.** The result implies that the decomposed plastic is harmful and thus slows the growth of the seedlings.

The seedlings of *R. mangle* (dwarf seeds) grew taller than the seedlings of *R. racemosa* (giant seeds) in both control and plastic soil because of their small size and low nutrient utilization ability, which enabled them to grow in poor soil. This shows that they have the ability of surviving better in polluted soil than the *R. racemose* . This result was supported by the stud of lamparelli et al. (1997), which revealed that *R. mangle* has lesser defoliation in soil polluted soil compared to *Laguncularia racemosa* and*Avicennia schaueriana.* Since *R. mangle* has high ability to grow faster in polluted soil compared to the giant seed that require higher nutrients for growth, the dwarf mangrove seeds can be used more often to restore remediated sites as nursery seedling recruits

There was no difference between THC concentration between surface and sub-surface soils. This means total hydrocarbon contents from plastic waste percolates into the sub-surface quickly after decomposition to contaminate the ground water aquifer. The result of no significance of heavy metals and THC across soil gradients show that soil pollutants from accumulated plastic waste sites can migrate and spread outwardly or circumferentially to contaminate neighboring soils (Jin et al. 2022). This can be harmful to organisms around the plastic waste dump sites such as the fiddler crabs (*Uca tangeri*), west African red mangrove crab (*Goniopsis pelii*), mud skipper and tilapia species, which are captured and eaten by the local people.

Soil microbes are found everywhere and helps in the breakdown of plastic waste into fine materials leading to the release of heavy metals into the soil (Byrne et al. 2022; Joshi et al. 2022). Microbial distribution varies horizontally across the plastic waste dump site (gradients) compared to the vertical distribution at surface and sub-surface soils. This result agrees with the study of Numbere (2021b), who revealed that leaf litter decomposition by microbes was cumulatively higher in surface than in sub-surface soil.

CONCLUSION

This study shows that the mangrove forest is a recipient of plastic waste that is brought in by tidal currents. The quantity of each plastic waste that is brought is determined by their level of floatability in aquatic medium. The decomposition of the plastic waste by microbes lead to the increase in the chemical load of the soil which may have negative effect on the growth of young mangrove seedlings. Our laboratory study reveal that seedlings in control soil grew taller than their counterparts in plastc soil. Although the growth difference was not much probably because of the duration of the experiment, however, the result has great implication for the natural enviornment where hazardous plastic components remain in mangrove soils to contaminate organisms consumed by humans such as crsba, periwinkle and fingerlings of fish that spawn and breed in the soil and root of mangovr trees. The study also revealed that *R. mangle* has greater ability than *R. racemosa* to grow in polluted soil, which makes it useful in restoration ecology.

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AUTHORS' CONRIBUTIONS

AON conceptualized the research design, carried out field work, analyzed the data and wrote the manuscript while AOA did the laboratory analysis analyzed the data and wrote the manuscript.

DATA AVAILABILITY STATEMENT

Laboratory and seedling experiment data of this study will be made available publicly on Dryad website.

CONFLICT OF INTEREST

The author claims no competing interests.

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TABLES: Table 1. Waste characterization indicating waste type, components and weight at Eagle Island, Niger Delta Nigeria.

Site ID	**Plastic waste types**	**Waste components**	**Number per site**	**Size range of plastic**	**Individual weight (g)**	**Total weight (g)**	**Site description**
1	Hospital containers	Syringe, medicine container	6	Medium small	25.5 68.5	94	Grassy
	Body care containers	Antiseptic cream, hair conditioner, perfume, body lotion, talc powder	13	Small Medium Large	6.7 350.4 84.6	441.7	Grassy
2	Bathroom/Kitchen Containers	Kitchen detergent, Dettol, bleach, toilet wash	5	Small Medium	83.7 42.1	125.8	Sandy
	Drinks and soda container	Ginger, energy drink, multina, plastic wine bottle	8	Small medium	163.4 34.0	197.4	Sandy
	Bottled water container	Plastic water bottle	3	Small Medium large	30.0 30.1 34.8	94.9	Sandy
3	Juice container	Fruit drink, fruit wine, ice cream container, juice container	6	Small Medium Large	30.8 79.8 270.1	380.7	Grassy
	Footwear	Slippers, sandals, baby shoe	8	Small Medium Large	183.6 60.3 254.9	498.8	Grassy
	Mouth wash container	Toothpaste container, toothbrush	3	small	39.6	39.6	Grassy
4	Food pack, cooking utensils	Food pack, spoon, plates, sachet	6	medium	26.4	26.4	Sandy
	Floatable materials	Foam, plastics, polystyrene	2	Small	12.8	12.8	Sandy

Site ID	Plastic waste types	Waste components	Number per site	Size range of plastic	Individual weight (g)	Total weight (g)	Site description
	Hand wear	Rubber hand glove	1	Small	142.1	142.1	Sandy
5	Teaching aid	Plastic marker	1	Small	13.1	13.1	Sandy
	Electrical fittings	Plastic base of electric bulb	1	Small	30.2	30.2	Sandy

Table 2. estimates of plastic waste volume* (quantity) in kilograms at coastal deposited sites at Eagle Island, Niger Delta, Nigeria

Sample ID	Coordinates	Waste volume (kg)	Diameter	Radius	Height (m)	Total weight o
Site 1	N04°47.295'; E006°58.534'	1.13	3.1	1.55	0.15	535.7
Site 2	N04°47.289'; E006°58.558'	2.39	3.9	1.95	0.20	323.2
Site 3	N04°47.305'; E006°58.553'	1.36	3.8	1.90	0.12	974.4
Site 4	N04°47.315'; E006°58.561'	2.64	4.1	2.05	0.20	98.8
Site 5	N04°47.334'; E006°58.599'	4.50	5.1	2.55	0.22	185.4

*Volume of circle=$\pi r^2 h$

Table 3. Total number of individual plastic materials enumerated per site at Eagle Island, Niger Delta, Nigeria

Waste type	Site 1	Site 2	Site 3	Site 4	Site 5	Total waste	% waste
Bottled water	65	92	62	35	79	333	29.16
Bottled drinks (soda)	92	76	116	67	123	474	41.51
Foamy food pack	28	28	31	10	63	160	14.01
Paper drinks	3	2	2	3	5	15	1.31
Other drink container	6	5	3	2	6	22	1.93
Medicine containers	14	6	10	3	0	33	2.89
Footwear	5	6	2	5	11	29	2.54
Polystyrene foam	12	1	6	1	5	25	2.19
Waterproof	2	3	5	2	15	27	2.36
Cream container	5	0	3	6	8	22	1.93
Mouth wash container	1	0	0	0	1	2	0.18

Table 4. Mean levels of total hydrocarbon content (THC) and heavy metals ± 1 SE at different soil profiles and gradient at accumulated plastic waste site at Eagle Island, Niger Delta, Nigeria

Profile		Metal (mg/kg)		
	THC	Zn	Cd	Pb
Surface	40.85±32.52	2.14±0.53	0.001±0.00	0.11±0.01
Sub-surface	4.26±2.16	0.37±0.01	0.001±0.00	0.001±0.00

Profile		Metal (mg/kg)		
***Gradient**				
Control	4.52±4.29	1.30±0.91	0.001±0.00	0.001±0.00
Far	9.15±0.25	1.02±0.89	0.001±0.00	0.001±0.00
Middle	4.25±3.05	2.03±1.48	0.001±0.00	0.23±0.02
Near	72.30±66.10	0.69±0.27	0.001±0.00	0.001±0.00

*Control (no accumulated plastic waste), far (4m), middle (2m) & near(0m) from accumulated waste site.

Figure legends

FIGURE 1 Map of study area at Eagle Island, Rivers State, Nigeria.

FIGURE 2 Experimental design of accumulated plastic waste deposition in (a) 55.8m × 42.6m () area at Eagle Island, Niger Delta, Nigeria. The picture indicates the site where the plastic waste was deposited by the in flowing river. It shows waste heaps of different circumference (b) pictorial view of the study plot captured by DJI Spark drone at Eagle Island, Nigeria Delta.

FIGURE 3 Seedling growth experiments indicating (a) boxplot of seedling growth in control versus plastic soils and bar chart of (b) weekly seeding growth in height (cm), (c) no. of leaves and (d) growth of two mangrove species (*R.mangle* and *R.racemosa*) of mangrove seedling in control and plastic soils at Eagle Island, Nigeria.. where W-1 to W-7 means weeks one to seven and Y-1 means one year.

FIGURE 4 Microbial population in (a) surface and sub- surface soil and (b) different gradients in plastic waste accumulated site at Eagle Island, Niger Delta, Nigeria. The farther from the accumulated plastic waste the higher the microbial population.

FIGURE 5 Correlation of seedling growth versus nutrient (a) and heavy metal concentrations (b) at Eagle Island, Niger Delta Nigeria.

List of Figures

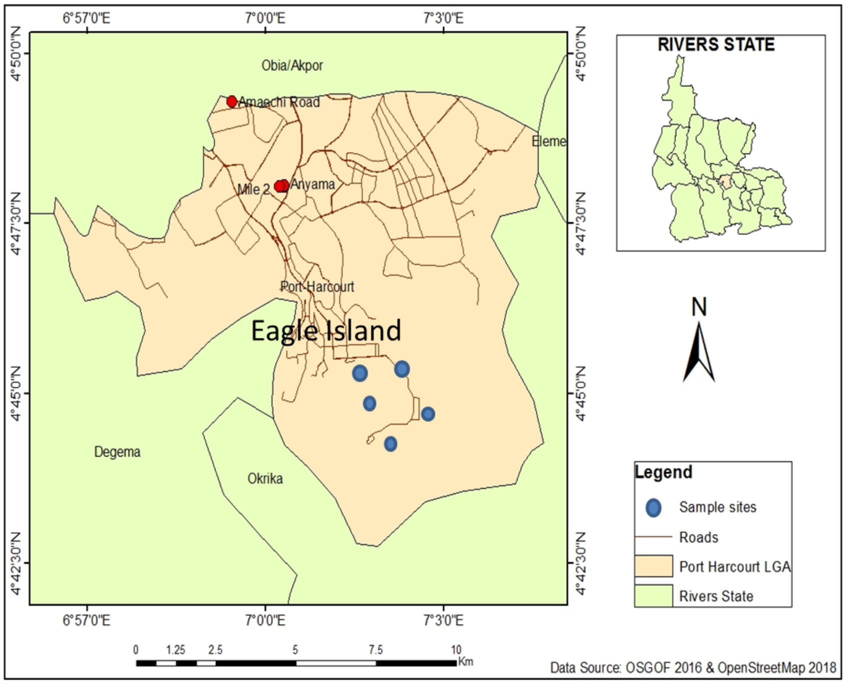


FIGURE 1

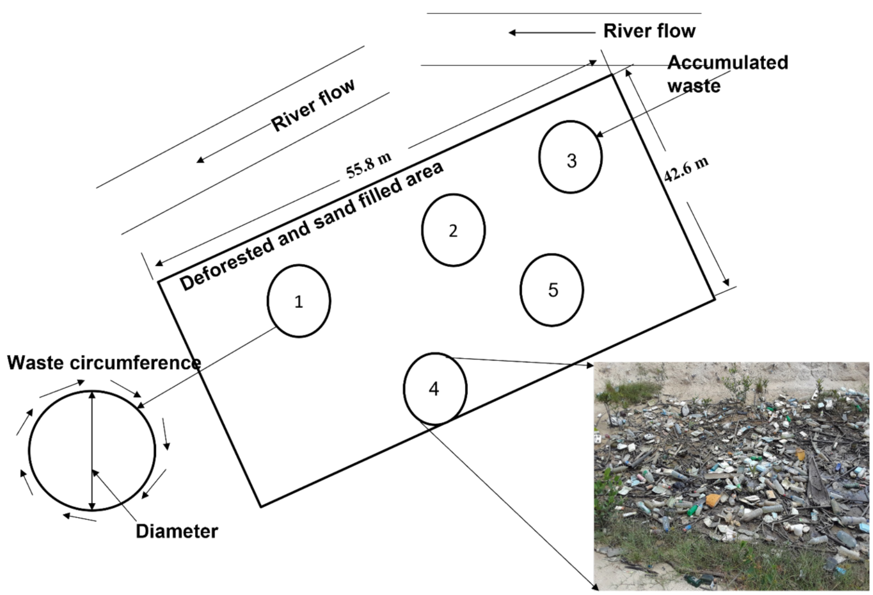
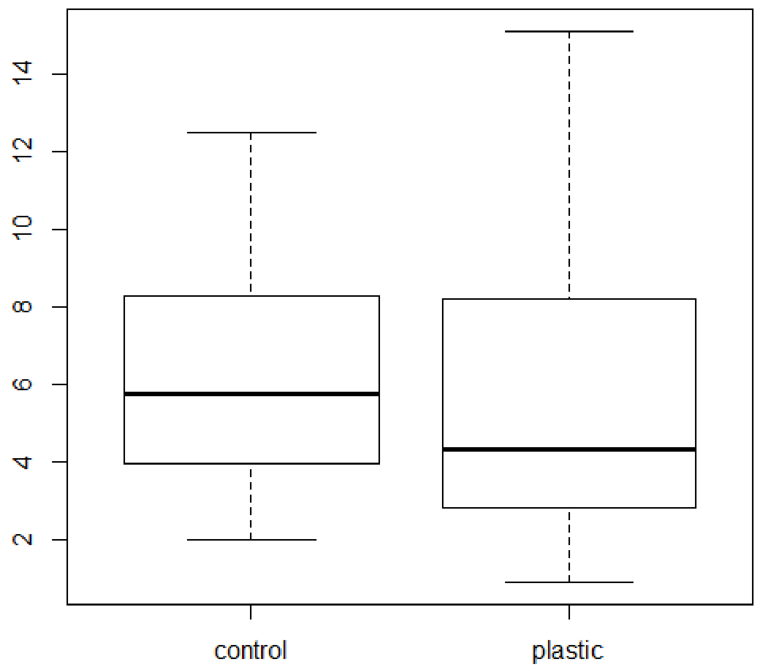


FIGURE 2



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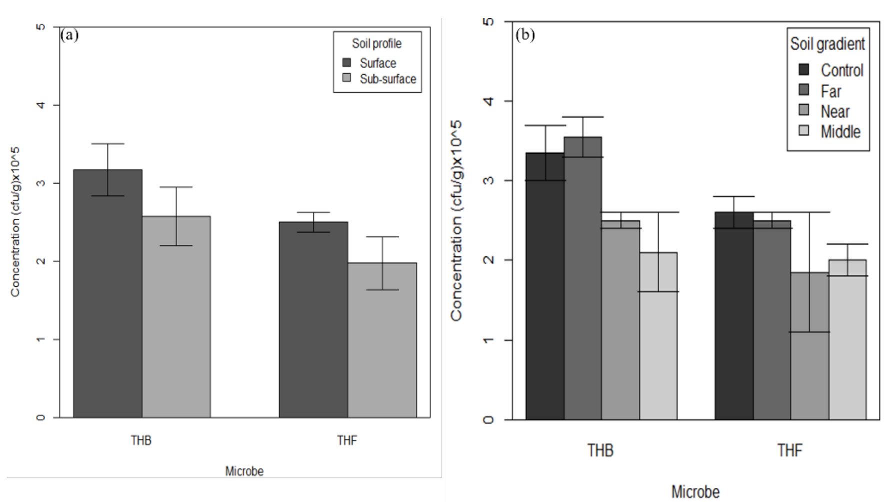

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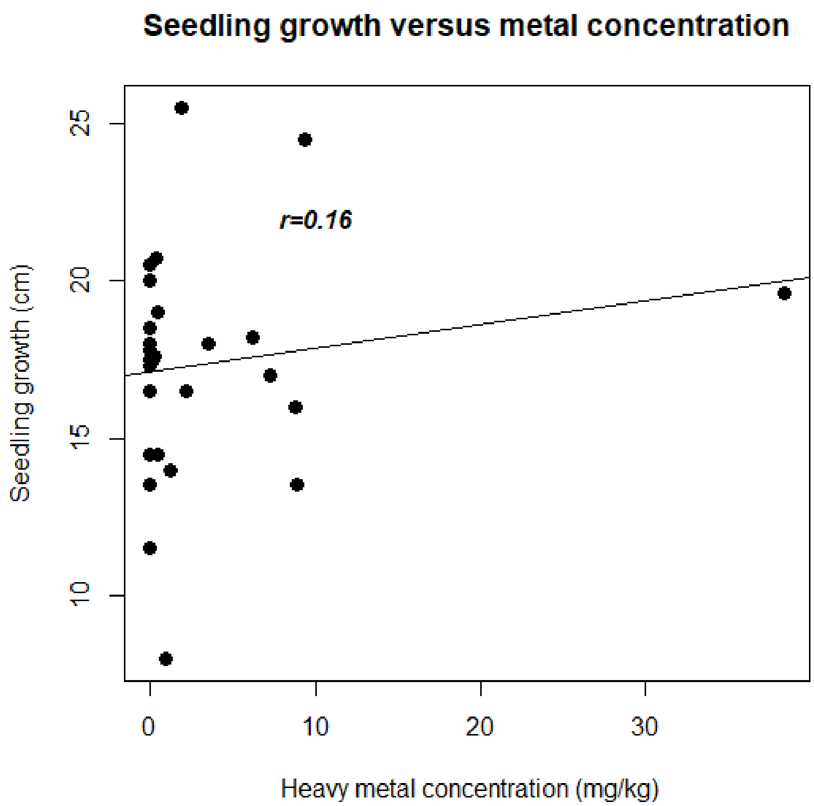

FIGURE 5

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