Investigation of The Use of Mangrove and Nypa palm parts as tools for remediating Polluted Soils in the Niger Delta, Nigeria

ABSTRACT

This study is based on the theory that mangrove parts can be used to remediate polluted soils. Using chemicals to clean oil spill sites can cause negative feedback by increasing the heavy metal load of the soil and river. However, ground mangrove parts are harmless and can biodegrade faster when introduced on polluted soils. We thus postulate that mangrove parts can be used to remediate polluted sites by conducting an experiment with some parts of mangrove (leaves, root, stem seed, and branch) and nypa palm (leave, root, and seed) that were collected in situ, ground into fine powder applied to polluted soil. We also decided that reduced reduced hydrocarbon content (THC) and heavy metal concentration (Cadmium, Cd, Iron Fe, Zinc, Zn, and Lead Pb) over time means remediation. Soil samples were collected monthly for six months from the treated and control soils. The results show that THC and heavy metal concentrations reduced in the soil over time because of the remediating effect of the plant parts applied. The ANOVA result showed that there was significant difference in heavy metal concentration between treated and control soils ($P< 0.05$) where mangrove-treated soils had lower concentration of total hydrocarbon content and heavy metals from control (i.e., non-treated soils) for three of the five heavy metals analyzed (Cd, Fe and Zn) compared to the low concentration of two metals for nypa palm-treated soils (THC and Pb). Season has little or no effect on THC and heavy metal concentration apart from Fe that has low concentration during the wet season ($P<0.05$). There is more correlation in chemical concentration between the roots and soils of both plant species ($R=0.95$). More experiment is needed with mangrove and nypa palm parts to determine their effectiveness in remediation so that they can be used in a large-scale clean-up of polluted sites globally.

KEYWORDS: bioaccumulation, heavy metals, hydrocarbon pollution, mangrove, nypa palm, remediation

1. INTRODUCTION

Mangrove forest is a biodiversity hotspot [1] because it is a host to numerous species ranging from micro to macro-organisms and from invertebrates to vertebrates. But its position at the interface between the land and the sea predisposes it to the impact of hydrocarbon pollution from oil and gas exploration activities. Mangrove forest in the Niger Delta region is affected by other anthropogenic activities such as improper disposal of waste into the marine environment. Examples of some waste disposed are plastic, domestic and industrial waste [2]. Urban runoff also washes municipal waste into the mangrove swamp during heavy rainfall [3]. A combination of hydrocarbon pollution and hazardous waste in the mangrove forest has led to the increase in heavy metal concentration in mangrove soil leading to poor growth and development of young seedlings [4]. The fact that mangroves are resilient, resistant, and stable because of their ability to withstand adverse environmental perturbations and continue to grow into maturity is what distinguishes them from other coastal species [5] (Alongi, 2015). In the other parts of the world adverse climatic conditions such as tsunami, hurricane and cyclone destroy mangroves and create a fragmented forest with canopy gaps [6] (Spalding et al. 2014). However, in the Niger delta, climatic condition does not impact mangrove rather negative human activities impact the mangroves and reduce their stand to few trees [7] (Sam et al. 2022). In the Niger delta the major factor of mangrove degradation is oil and gas exploration. Exploratory activity has the most significant effect on mangrove among other factors because of other associated effects such as deforestation, spillages, waste disposal, seedling trampling, and soil destabilization. Expulsion of crude oil into the environment lead to the entry of contaminants into the food chain, which bioaccumulate and bio magnify with adverse effect on humans who consume sea food caught from the river [9] (Milenkovic et al. 2019).

Therefore, to restore any polluted mangrove soil remediation is carried out on the sites with chemicals, which break down the oil molecules and convert them to harmless substances that are further digested by microbes. This method of remediation cleans up the soil from harmful heavy metals, but there is a trade off from the side effects of the chemicals applied to the soil because of reactions, presence of active components, and the quantity of chemicals used. Based on the adverse effect of the chemicals, a biological method (bioremediation) is now used to clean up polluted soils known as bioremediation. Bioremediation is the use of plant and animal matter to clean up polluted soil and it has been found to be effective in remediating the soil [9]. Water hyacinth, duckweed and water lettuce have been used in the past to remediate polluted soils [10]. The method of remediation where the roots of the plant absorb the pollutants is called rhizofiltration or phyto filtration of environmental pollutants [11]. Other filtration types involving plant parts include shoot (caulifiltration) and seedlings (blastofiltration). Similarly, animal waste, cow dung [12], sewage [13] and organic and inorganic nutrients [14] are used for bioremediation. Although, plants can absorb heavy metals because of their renewable biomass [15]. However, their growth will be affected when there is a high concentration of soil heavy metals [16], hence our proposition of using dried ground mangrove and nypa palm parts as means of remediation.

Some mangrove species are metallophytes because of their ability to absorb and accumulate metals. There are two categories of metallophytes: the metal hyperaccumulators, for example *Rhizophora mangle*, which accumulate Hg, Al, As, and Cd and *Laguncularia racemosa*, which absorb Cr, Cu, Fe, Pb, Mg and Zn [17, 18]. The second category is metal excluders, for example *Bruguiera gymnorhiza*, which accumulate Cu and Cd [19]. Mangrove forest have a self-cleaning ability during major oil spillages [20, 21]. Therefore, it is hypothesized that using mangrove and nypa palm parts (leaves, root, stem, seeds etc.) as remediation tools will help reduce the total hydrocarbon content and heavy metal concentration and thus, clean up the polluted sites with little or no harm to the environment. Already mangrove forest in the Niger Delta has high litter fall (i.e., high productivity), which has reduced the impact of hydrocarbon pollution on mangroves. The aim of this study, therefore, is to treat polluted mangrove soil with ground mangrove and nypa palm parts in a laboratory in other to determine, which of the two species have better capacity to reduce the total hydrocarbon content and heavy metal concentration within the soil. The objectives of this study are: (1) to determine whether there is difference in heavy metal concentration in polluted soils treated with ground mangrove and nypa palm parts, (2) to compare the 1otal hydrocarbon content and heavy metal concentrations in soils treated with ground mangrove and nypa palm parts and (3) to determine which of the treatments have low hydrocarbon content and heavy metal concentration, and hence more remediating ability.

2. MATERIALS AND METHODS

The study area is Eagle Island (Figure 1), a coastal community, situated on the outskirt of Port Harcourt in the Niger Delta area of Nigeria. The area has humid climate with two major seasons, the dry and the wet seasons, which occur between October-February and March-October each year respectively. There is brief stoppage of rainfall in August called "August break". The temperature range is 27-30C°, and the soil is swampy and dark brown to black in color. The salinity of the pore soil water ranges from 1-15-1.67ppt. there is a six-hourly high and low tidal cycle in this location. Some anthropogenic activities that occur in this site include sand mining, commercial activity, fishing, and marine transport.

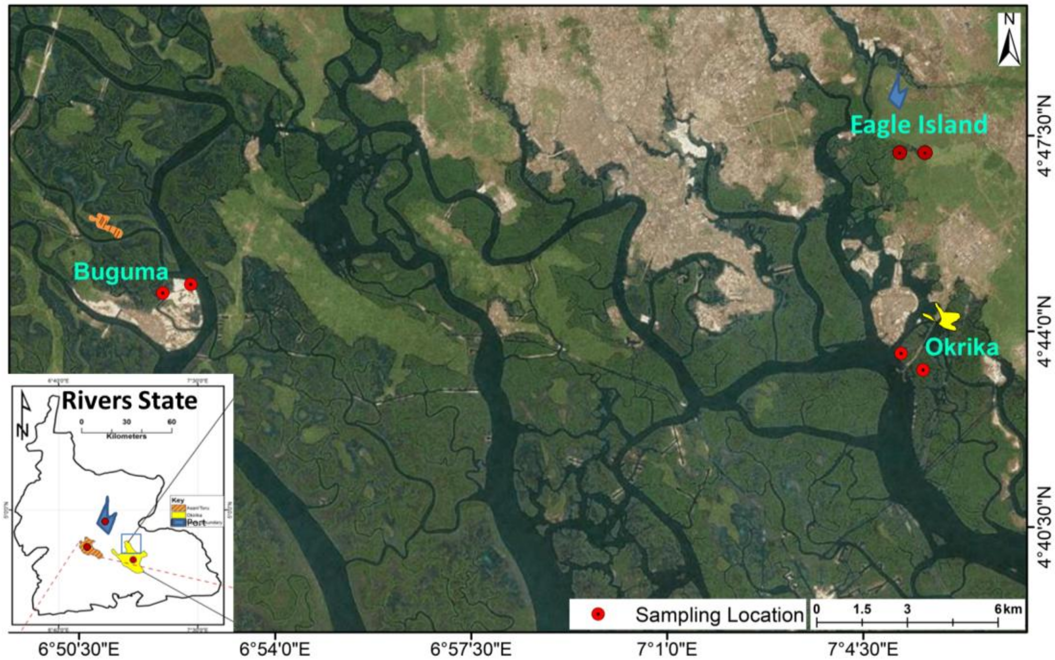

Figure 1. Map of study area where mangrove and nypa parts and soil samples were collected at Eagle Island, Niger Delta, Nigeria

2.1. Sample collection

Soil samples were collected on the 27th of March 2019 and placed in equal-sized plastic containers. Dry mangrove and nypa palm parts including leaves, seed, branch, stem, and roots were collected from a patch of forest at the study area. The samples were oven-dried at 70C° for 48 hours, after which they were ground into fine powder, using a manually operated grinding machine (model Corona), and bagged (Figure 2). Twenty-five grams of each ground plant parts were measured and added to the polluted soils in different treatment combinations (Figure 2).

2.2. Experimental design

Nine different experimental treatments (*n=9*) were established, which include polluted mangrove soil plus the various grinded plant parts as shown in Figure 2. Nypa palm don't have stem and branch that is why it is not included in the present design. Soil samples were then collected monthly for six months (i.e., March to August).

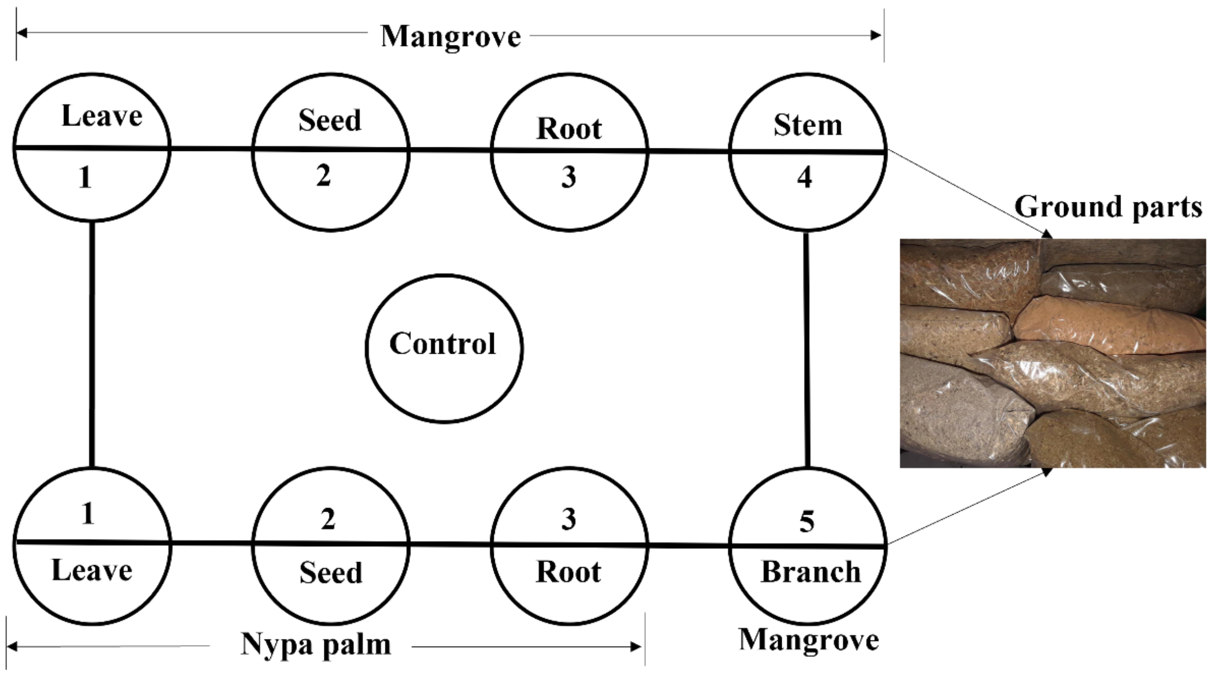

Figure 3. Experimental design of soil treatments with ground mangrove and nypa palm parts (the picture on the left show eight bags of grinded plant parts)

2.3.Laboratory analysis

Soil samples were sent to the laboratory for physico chemical analysis for cadmium (Cd), lead (Pb), zinc (Zn) and iron (Fe). Similarly, the samples of the ground nypa and mangroves parts were also sent to the laboratory for analysis of the above metals before they were mixed with the soil.

2.4.Statistical analysis

An analysis of variance (ANOVA) was used to determine if there were significant differences in the concentration of the total hydrocarbon content and heavy metals between the soils treated with ground mangrove and nypa palm parts. ANOVA was also used to determine if there was a significant difference between treated and control soils, and between dry versus wet season. Pearson's product-moment correlation was done to compare whether there was any significant difference between concentration of THC and heavy metals between mangrove and nypa palms parts (i.e., leave, root, and seed). Regression analysis was also done to compare chemical concentration between soil and plant parts for both species. The data was initially log-transformed to ensure that they were normal and had equal variances [22]. Bar graphs and correlation graphs were then used to illustrate the results [23]. All analysis was performed in R statistical environment [24].

3. RESULTS

3.1.Physico-chemistry of mangrove and nypa palm parts

Table 1 showed that nypa palm root had the highest THC concentration (750.7mg/kg) followed by mangrove branch (513.2mg/kg) and leaves (452.3). Similarly, nypa palm root has the highest Cd concentration (0.45mg/kg) followed by mangrove leave (0.44mg/kg) and seed (0.43mg/kg). Nypa palm seed has the highest concentration of Pb (8.2mg/kg) followed by mangrove seed (6.00mg/kg) and nypa palm root (4.97mg/kg). Mangrove seed has the highest Fe concentration (1755.42mg/kg) followed by mangrove branch (1657.08mg/kg) and nypa seed (1587.52mg/kg).

Mangrove seed has the highest Zn concentration (23.36mg/kg) followed by nypa seed (20.12mg/kg) and mangrove leave (17.71mg/kg).

The mean THC in nypa palm is higher (430.23±163.25) than mangrove (401.23±44.67). Similarly, mean Pb in nypa palm is higher (5.37±1.53) than mangrove (4.02± 0.54 mg/kg) while the mean Cd, Fe and Zn in mangrove are higher (0.31±0.07mg/kg, 1518.91±89.00 mg/kg and 15.84±2.35 mg/kg) than nypa palm (0.29±0.13, 1322.50±136.72 mg/kg and 14.55±2.93 mg/kg) respectively.

Table 1. Mean physico chemistry of mangrove (*R. racemosa*) and nypa (*N. fruticans*) palm parts before experiment and the Maximum permissible limit of THC and heavy metals in plants (SEM).

Species	Parts	Metals (mg/kg)				
		THC	Cd	Pb	Fe	Zn
Mangrove	Branch	513.1	0.39	2.72	1657.08	15.15
Mangrove	Leave	452.3	0.44	3.96	1261.60	17.71
Mangrove	Root	263.4	0.15	3.58	1531.96	13.94
Mangrove	Seed	337.6	0.43	6.00	1755.42	23.36
Mangrove	Stem	443.0	0.16	3.86	1388.47	9.04
Nypa	Leave	215.9	0.04	8.20	1131.69	10.17
Nypa	Root	750.7	0.45	4.97	1248.30	13.36
Nypa	Seed	324.1	0.38	2.94	1587.52	20.12
R. racemosa	-	401.23±44.67	0.31±0.07	4.02±0.54	1518.91±89.00	15.84±2.35
N. fruticans	-	430.23±163.25	0.29±0.13	5.37±1.53	1322.50±136.72	14.55±2.93
International limit		500.00	0.02*	0.1-0.3*	20.00	50.00

*Source: [25]

3.2.Comparison of THC and heavy metal concentration between Species

The ANOVA result show that there is a significant difference in the THC and heavy metals in treated and control soils ($F_{4, 75}$, =159.5 P< 0.001, Table 2, Figure 3). There was a decrease in the

THC and heavy metal concentration in soils treated with plant parts compared to soils without plant parts, i.e., control. Nypa palm treated soil gave lower THC and Pb while mangrove parts treated soil gave lower Cd, Fe and Zn (Table 2). Similarly, there was a decrease in Fe concentration when soils treated with plant parts and control soils are compared.

Table 2. Mean levels of THC and total hydrocarbon content and heavy metals ± 1SE in soils treated with ground mangrove (*R. racemosa*) and nypa palm (*N. fruticans*) parts and control in Eagle Island, Niger Delta Nigeria.

Soil treatments	Metals (mg/kg)				
	THC	Cd	Pb	Fe	Zn
†Nypa + soil	403.26±29.83	0.31±0.05	4.23±0.51	1366.90±145,96	15.94±1.72
†Mangrove + soil	429.18±103.78	0.29±0.08	5.35±0.95	1324.60±86.86	14.71±1.61
*Soil only (Control)	607.00±0.60	0.36±0.01	12.02±0.24	2562.15±0.25	14.18±0.40
*Parts only (Control)	412.51±59.96	0.31±0.06	4.53±0.65	1445.26±78.25	15.36±1.72
International limit	500.00	0.3-0.6[a]	0.1[b]	20.00	50.00

†Combination of grounded parts and soil, *Physico chemistry of soil and plant parts before experimental treatment; [a][26]; [b][27]

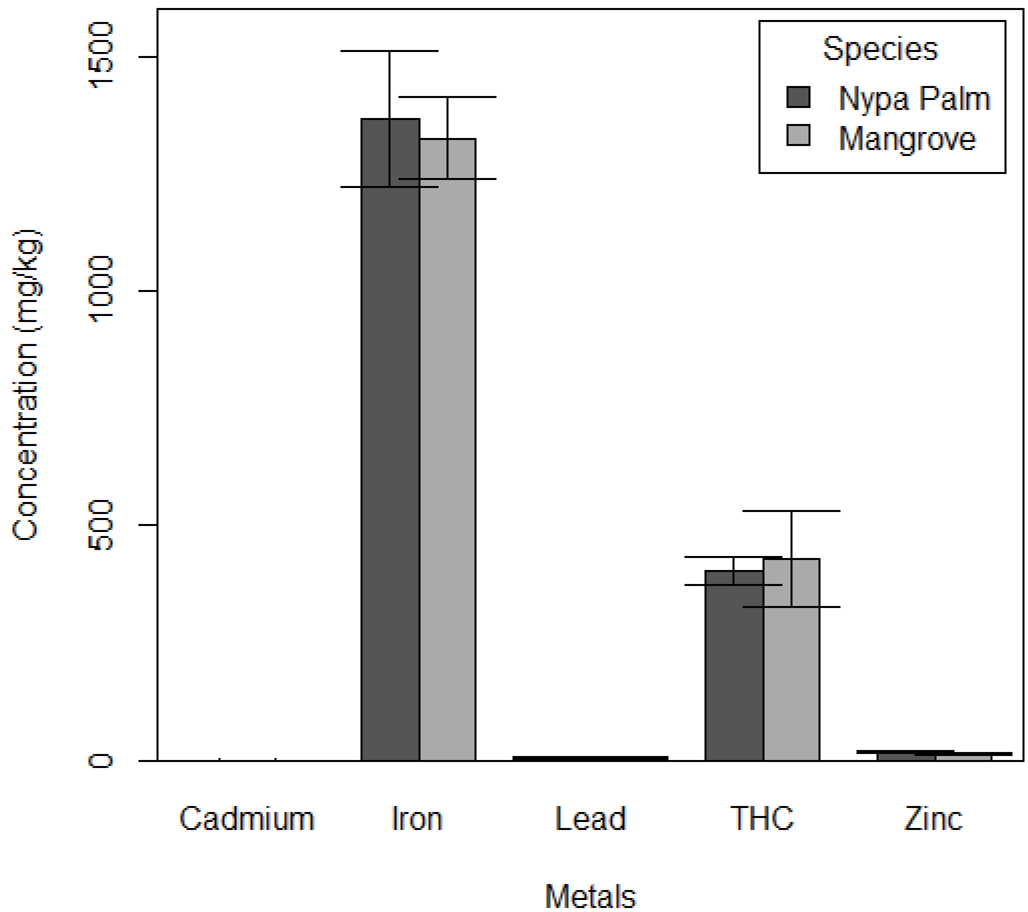

Figure 3. Mean concentration of THC and heavy metals (±SE) in mangrove and nypa palm treated soils collected from Eagle Island, Niger Delta, Nigeria.

3.3.Comparison of THC and heavy metal concentration between parts

The ANOVA result show that there was no significant difference in THC and heavy metal concentration between the parts of mangrove and nypa palm ($F_{4\ 75}$, =0.12 P= 0.98, Table 3, Figure 4). The result show that soil treated with nypa palm leave and seed have lower concentration of heavy metal than soils treated with mangrove leave and seed. While soils treated with mangrove root has lower concentration of heavy metals than soils treated with nypa palm root. This result shows that using nypa palm parts is a better remediating agent than mangrove parts. As for branch and stem there is no basis for comparison since nypa palm don't have those parts.

Table 3. Mean cumulative levels of THC and total hydrocarbon content and heavy metals ± 1 SE in soils treated with ground mangrove (*R. racemosa*) and nypa palm (*N. fruticans*) parts

Species	Metals (mg/kg)				
	Branch	Leave	Root	Seed	Stem
†Mangrove+ soil	288.06±165.68	346.90±162.50	362.40±197.53	424.49±225.27	368.80±178.77
†Nypa+ soil	n/a	273.24±145.76	404.08±170.71	387.16±204.68	n/a
*Mangrove only	437.69±320.28	347,20±244.32	362.61±296.57	424.56±338.73	368.91±268.67
*Nypa palm only	n/a	273.20±218.44	403.56±255.71	387.01±306.33	n/a

†Combination of grounded parts and soil; *Heavy metal concentration before treatment; n/a means nypa palm (*Nypa fruticans*) do not have those parts

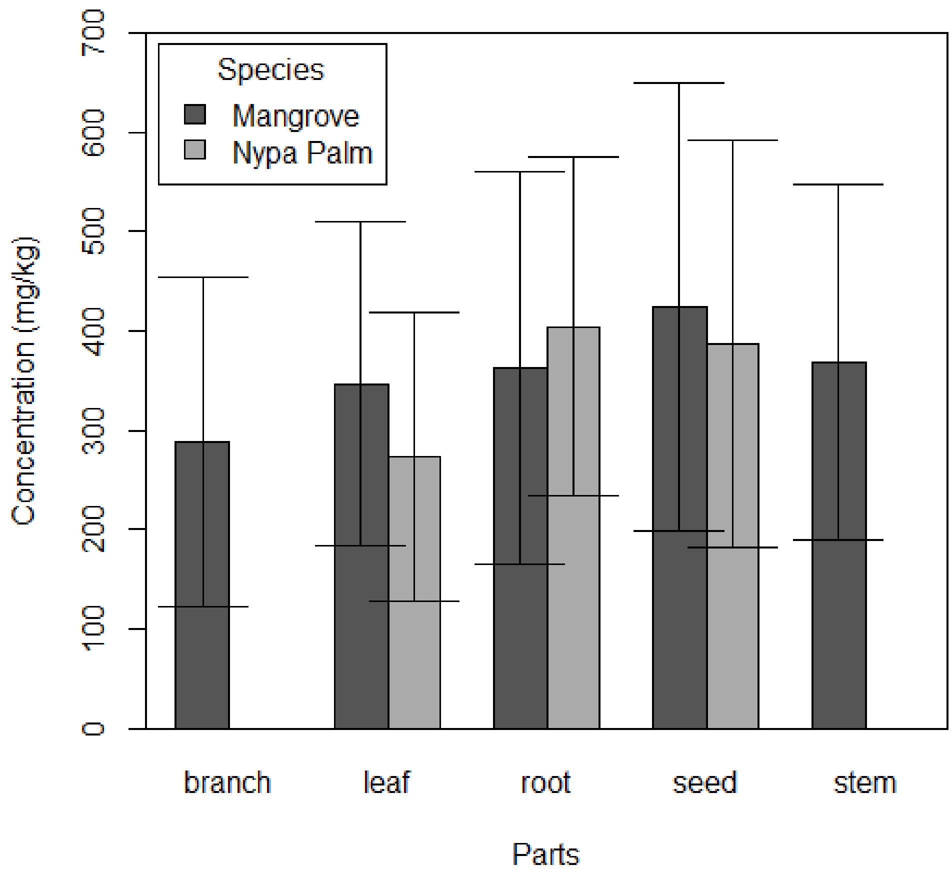

Figure 4. Mean concentration of THC and heavy metal (±SE) in mangrove and nypa palm parts collected from Eagle Island, Niger Delta, Nigeria

3.4. Comparison of THC and heavy metal concentration in nypa palm treated soil with time

The ANOVA result show that there was no significant difference in heavy metal concentration in nypa palm treated soil with time ($F_{5, 84}$, = 1.92, P=0.1, Table 4, Figure 5). Although, there was overall decrease in each of the heavy metals from March to August as shown in Table 4. For instance, the concentration decreased from March to August as follows: THC (607.30±0.00 to

430.23±163.25), Cd (0.36±0.00 to 0.29±0.13), Pb (11.78±0.00 to 5.37±1.53), Zn (14.58±0.00 to 14.55±2.93), and Fe (2561.90±0.00 to 1322.50±136.72).

Table 4. Mean levels of monthly total hydrocarbon content and heavy metals ± 1 SE of nypa palm treated soil in Eagle Island, Niger Delta Nigeria.

Months	Heavy metals (mg/kg)				
	THC	Cd	Pb	Zn	Fe
March	607.30±0.00	0.36±0.00	11.78±0.00	14.58±0.00	2561.90±0.00
April	88.09±11.25	0.05±0.05	0.001±0.00	8.21±1.74	437.72±10.36
May	116.01±32.30	0.001±0.00	0.001±0.00	9.54±2.56	3143.63±894.61
June	616.10±70.70	0.13±0.13	0.71±0.71	10.80±1.22	474.96±12.45
July	10.80±6.12	0.00±0.00	1.82±0.33	0.00±0.00	0.00±0.00
August	430.23±163.25	0.29±0.13	5.37±1.53	14.55±2.93	1322.50±136.72

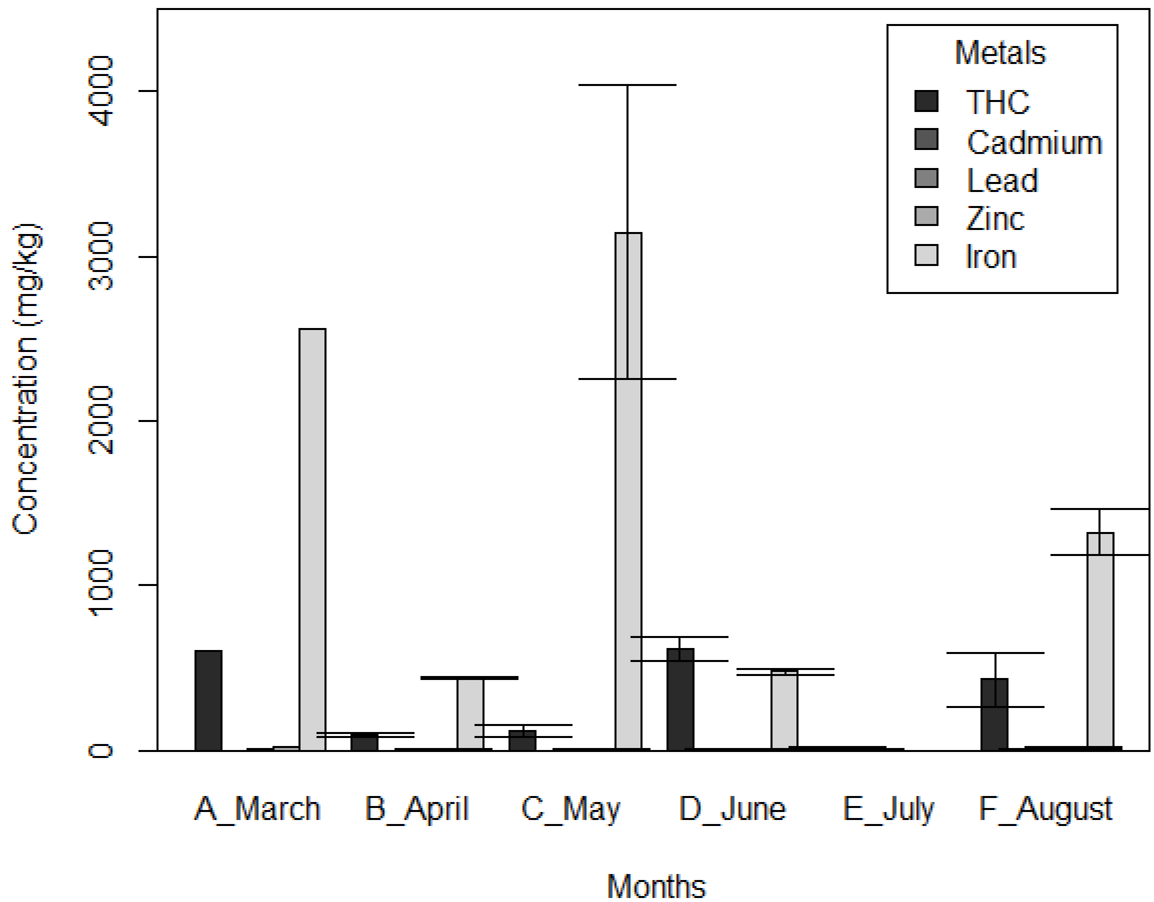

Figure 5. Mean monthly heavy metal concentration (±SE) of nypa palm (*Nypa fruticans*) parts treated soil

3.5. Comparison of THC and heavy metal concentration in mangrove treated soil with time

The ANOVA result show that there was a significant difference in THC and heavy metal concentration in mangrove treated soil with time ($F_{5,}$ 144, = 2.49, P< 0.034, Table 5, Figure 6). There was a decrease in each of the heavy metals from March to August apart from Zn as shown in Table 5.

Table 5. Mean levels of monthly THC and total hydrocarbon content and heavy metals ± 1 SE of mangrove treated soil in Eagle Island, Niger Delta Nigeria.

Time	Heavy metals (mg/kg)				
	THC	Cd	Pb	Zn	Fe
March	617.30±0.00	0.35±0.00	10.27±0.00	14.12±0.00	2488.90±0.00
April	340.41±203.10	0.28±0.17	0.00±0.00	7.32±1.49	438.68±6.34
May	74.59±25.09	0.001±0.00	0.001±0.00	5.46±1.94	2459.16±577.15
June	1280.48±522.98	0.52±0.16	9.69±4.62	15.50±1.38	478.36±5.36
July	15.89±5.87	0.00±0.00	2.17±0.96	0.00±0.00	0.00±0.00
August	401.88±44.67	0.31±0.07	4.02±0.54	15.84±2.35	1518.91±89.00

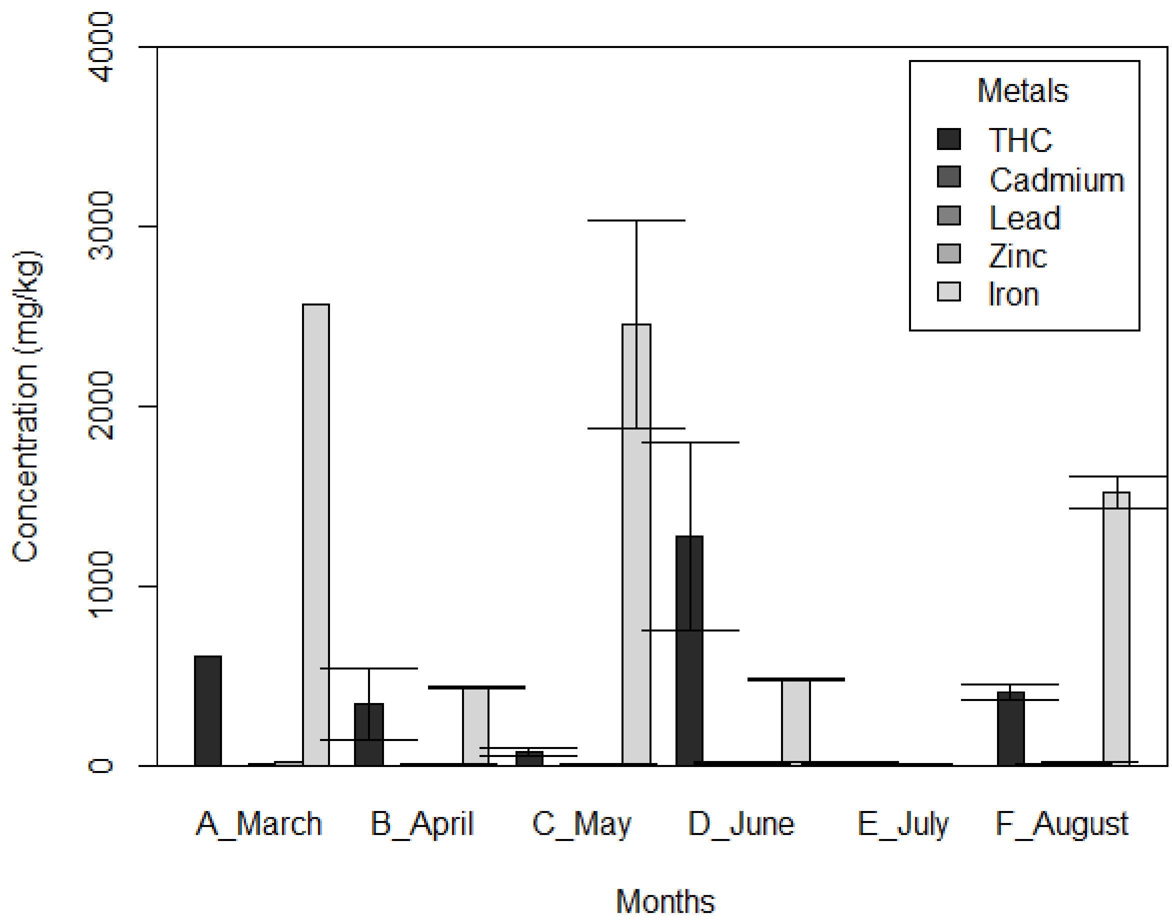

Figure 6. Mean monthly THC and heavy metal concentration (±SE) of mangrove (*Rhizophora racemosa*) treated soil.

3.6. Concentration of THC and heavy metals in the different parts of mangrove (metals versus parts)

The ANOVA result reveal that there is a significant difference in THC and heavy metal concentration in soils treated with different mangrove parts ($F_{4, 145}$, = 25.93, P<0.0001, Figure 7). The Tukey HSD result shows that the interaction of Fe-THC, Fe-Zn and Fe-Pb vary significantly from each other and from Cd, Pb and Zn at P< 0.001.

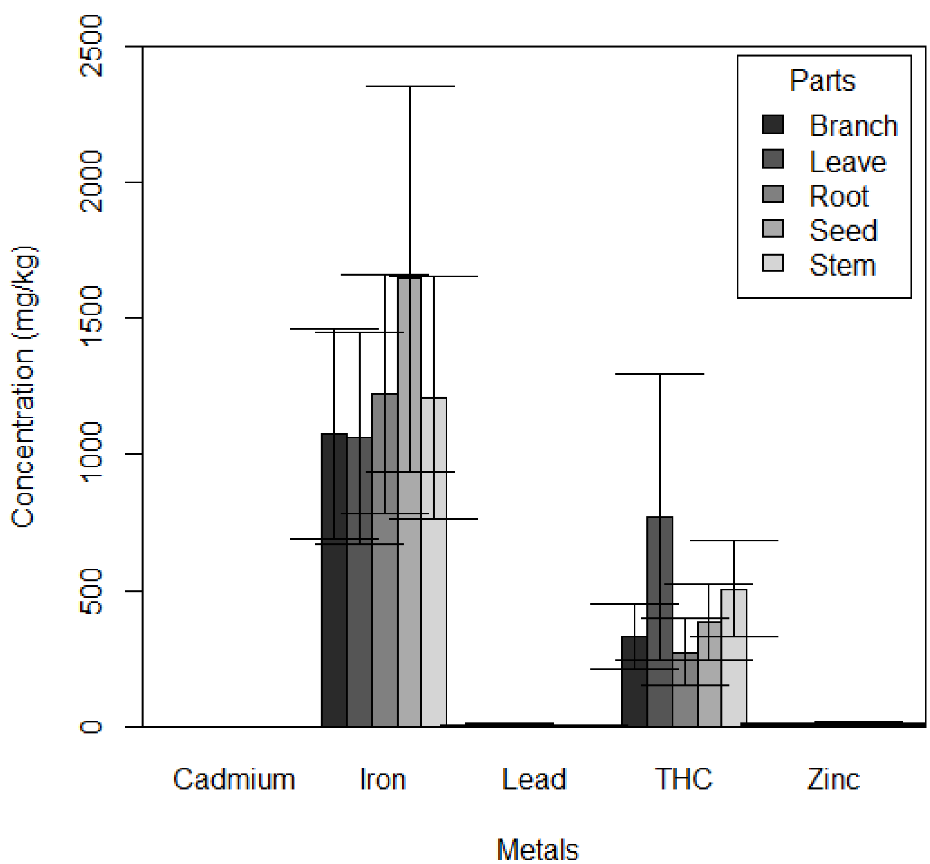

Figure 7. Mean concentration of THC and heavy metals (±SE) in mangrove part treated soils. Leave treated soil have the lowest concentration of Fe whereas root treated soil have the lowest THC concentration.

3.7. Comparison of seasonal effect on THC and heavy metal concentration in soils treated with mangrove and nypa palm parts

Seasonal effect on mangrove treated soil show that there was significant difference in Fe concentration compared to other metals ($P < 0.05$, Figure 8). Wet season has a lower concentration of Fe than the dry season for mangrove and nypa palm treated soils, which may be because of the diluting effect of the rainfall in mangrove treated soil. In contrast, the opposite is the case in THC concentration because dry season has lower THC concentration for mangrove and nypa palm treated soil.

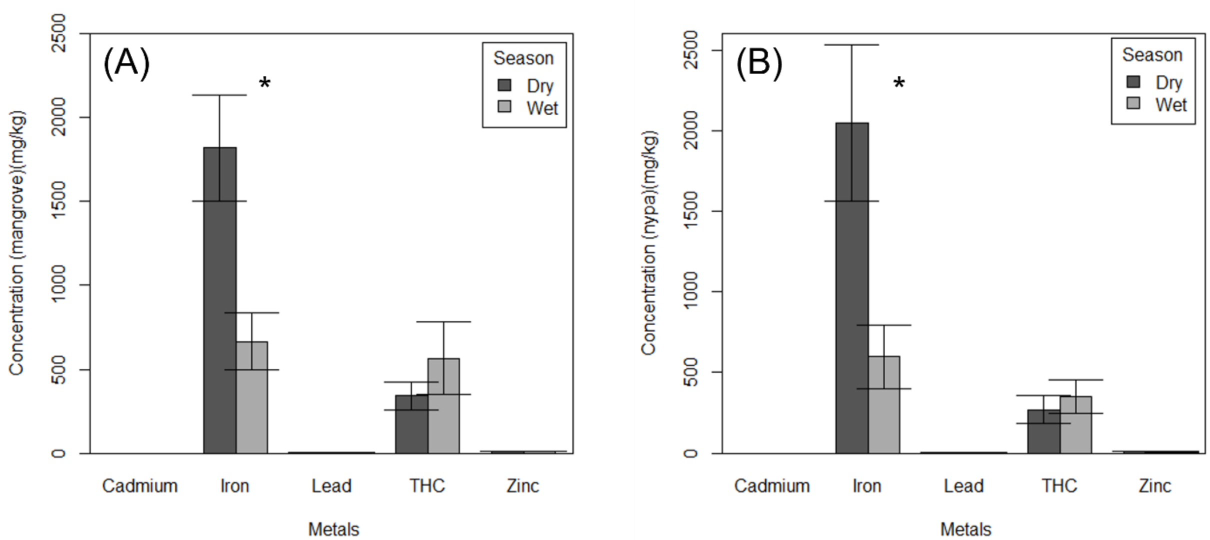

Figure 8. Mean seasonal effect of THC and heavy metal (±SE) on (A) mangrove and (B) nypa palm treated soils collected from Eagle Island, Niger Delta, Nigeria.

3.8. Correlation of THC and heavy metal concentrations in leaves, roots, and seeds of nypa palm and mangrove

There was correlation between mangrove leave concentration and nypa palm leave concentration (t = 4.709, df = 28, p-$value$ = 0.001; cor = 0.66447613). Similarly, there was correlation between mangrove root concentration and nypa palm root concentration (t = 19.808, df = 28, p-$value$ = 0.001; cor = 0.9661219). There was also a correlation between mangrove seed concentration and nypa palm seed concentration (t = 8.530, df = 28, p-$value$ = 0.001; cor = 0.849771; Figure 7).

3.9. Concentration of soil versus plant parts in mangrove

There was correlation between soil concentration and plant parts concentration in mangroves (t = 8.042, df = 123, p-$value$ = 0.001; cor = 0.5870115). There was also correlation between soil concentration and plant parts concentration in nypa palm (t = 5.587, df = 73, p-$value$ = 0.001; cor = 0.5472786).

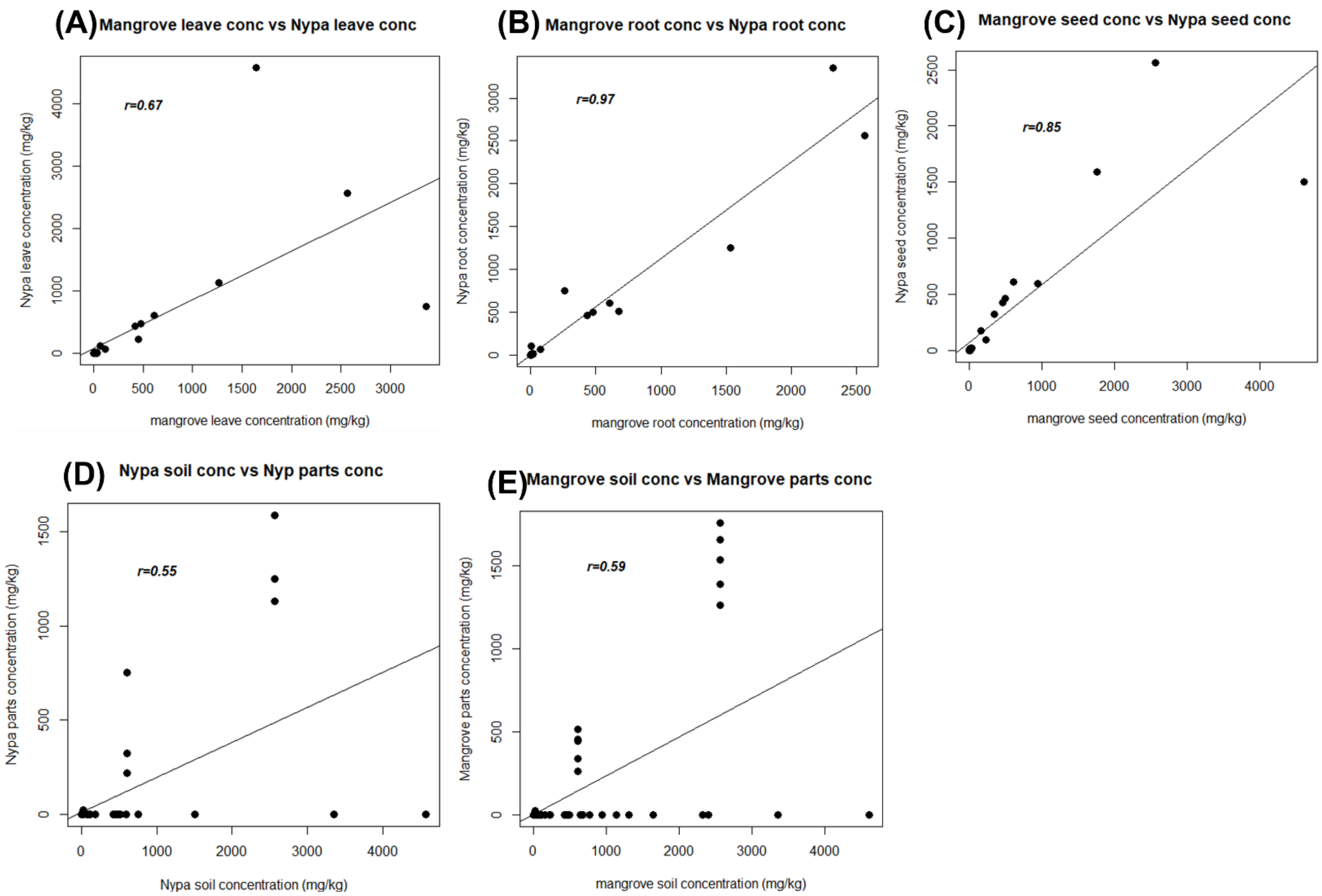

Figure 7. Correlation of mangrove parts concentration versus nypa parts concentration for (A) leave, (B) root, (C) seed, (D) nypa soil and (E) mangrove soil collected at Eagle Island, Niger Delta Nigeria

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4. DISCUSSION

The result shows that nypa palm (*N. fruticans*) accumulates more THC than mangroves (*R. racemosa*), which makes them survive highly polluted environment compared to the mangroves. However, mangroves absorb more heavy metals compared to the palm, which agrees with [17, 18] who reveal that *L. racemosa* are metal hyper accumulators and absorb Cr, Cu, Fe, Pb, Mg and Zn. The role of the mangroves absorbing pollutants from the environment makes them good agents of bioremediation

Cumulatively, mangrove treated soil gave lower values (Table 2) in three out of five heavy metals (Cd, Fe and Zn) analyzed compared to nypa palm treated soil whose concentration is lower in two, THC and Pb. This shows that mangrove has a high self-cleaning ability because of the high litter fall which reduces the impact of pollution [28, 29]. However, other studies have shown that nypa palm too has higher ability to withstand hydrocarbon pollution compared to mangrove [30, 31]. This may be the reason they are quickly colonizing more polluted areas in the Niger Delta mangrove ecosystem [31]. The presence of a large quantity of litter on the forest floor enables the mangrove to serve as a bio remediating agent, which helps to attenuate the effect of oil spill on mangrove vegetation. High litter fall leads to high productivity, which in turn encourages faster litter decomposition in the mangrove forest [32]. Mangrove and nypa palm litter remain on the forest to floor to decompose and subsequently degrade chemicals into harmless form. For example, hydrocarbon utilizing bacteria act on pollutants to neutralize their harmful effect [31]. Furthermore, the physico chemistry of the leave was also considered (Table 1) because the leave chemistry too influences the decomposition rate [33]. High concentration of metal in soil can be transmitted through mangrove and mangrove associated organisms into humans through bioaccumulation. For instance, Pb, Cd and Zn are among the most toxic and environmentally significant metals [34] that can affect health. Lead is a zenobiotics, which are metals that have no biological roles to humans, plants, and animals [35]. This study is important because it shows that mangrove and nypa palm parts can be used to solve the pollution problem in the region without resorting to the use of chemicals or other organic materials that may have negative effect on the coastal environment.

Although, there was no significant difference in THC and heavy metal concentration between soil treated with mangrove and soil treated with nypa palm, some parts of each species showed some marked differences in concentration. For the palms the leaves and the seeds have better remediating properties because the soil treated with these parts had lower concentration of chemicals than soils treated with mangrove parts. Previous study had shown that mangrove leaves have lignin, which delays microbial action [36] compared to nypa palm. Mangrove (i.e., *R. racemosa*) leave decomposed faster than nypa palm (*N. fruticans*) leave in sub surface compared with *N. fruticans* leaves that decomposed faster on surface soil [37]. The rate of litter decomposition is significant in bioremediation because it can influence the actions of bio remediating microbes [38].

The decrease in heavy metal concentration with time from March to August may be because of the activities of soil microbes acting on the nypa palm (Table 4) and mangrove (Table 4) treated soils, which also break down the soil pollutants into a less harmful form. For instance, hydrocarbon utilizing bacteria breaks down crude oil into less toxic particles [39, 40]. Environmental and climatic condition can also contribute to the decrease in heavy metal concentration in soil. Since the experimental set up was placed in the open raindrops can also dilute the pollutants and produce a lower concentration of THC and heavy metal especially during the rainy season. Although seasonal comparison, showed no major difference in the analyzed heavy metals (*P > 0.05*) apart from Fe, that showed significant different between wet and dry season (Figure 8). There was no decrease in Zn concentration from March (14.58±0.00mg/kg) to August 15.84±2.35mg/kg. Previous research has shown that the study area is rich in Zn concentration [41]

Climatic factor plays key roles in the level of concentration of THC and heavy metals in the soil [42]. Increased rainfall can liquify and mobilize heavy metals, which make them mobile and migrate into ground water. The mobility of the heavy metals decreases their concentration in the surface soil when they move down the soil profile. Chemical reactions of evaporation, solubilization, hydrolysis, etc. can also reduce or increase THC and heavy metal concentration in a particular soil.

In the overall, there was high correlation of chemical content between each species parts. However, the root has the highest correlation in chemical content for both species because it serves as the link between the plant-soil pathway for the transmission of metallic compounds in the forest. Similarly, there is more correlation between soil and plant parts of mangrove than soil and plant parts of nypa palm. This is because the mangroves are better absorbers than the palms as noted by previous research [17, 18]. Th concentration of THC and heavy metals is above the international standards (Tables 1 and 2) and can be detrimental to health once transmitted along the food chain. This is because the soil-mangrove-nypa palm pathway serve as the route for the transmission of coastal pollutants to marine organisms that are then consumed by humans, which may pose as a danger to human health [43] if proper remediation is not done.

5. CONCLUSION AND RECOMMENDATION

Our study has shown that mangrove and nypa palm parts can be used to remediate polluted sites, which is another form of bioremediation with organic materials. However, in this case instead of using organic materials from other plant species mangrove and nypa palm species were used, which will allow quick acclimation of the litter to the soil and thus, ensure faster remediation of the polluted site. Mangrove litter can absorb and reduce the total hydrocarbon and heavy metal content of the soil. The significant aspect of this study is the application of this knowledge in the restoration of numerous polluted sites across the Niger Delta without the need to incur much cost by using expensive oil spill cleaning chemicals. Furthermore, its contribution to knowledge is the grinding of the plant litter into fine powder in other to facilitates soil-litter mixture and thus, accelerates the breakdown of harmful chemicals by microbes. The implication of this study to the field of bioremediation and restoration ecology is that tree parts and stumps from deforested and polluted forest can be recycled and re-used for bioremediation purpose instead of being discarded as waste product. The concept of this study can be expanded further by conducting a larger field experiment using more quantities of mangrove and nypa palm biomass to remediate polluted sites.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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