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Research Article
Assessing the Impact of Artisanal Petroleum Refining on Vegetation and Soil Quality: A Case Study of Warri South West Salt Wetland of Delta State, Nigeria

M. Yabrade and F.B.G. Tanee

Department of Plant Science and Biotechnology, Faculty of Science, University of Port Harcourt, Port Harcourt, Nigeria

Abstract

Objective: Assessment of the impacts of artisanal petroleum refining on vegetation and soil quality in Warri South West Salt Wetland of Delta State, Nigeria were carried out. **Methodology:** Three refining sites designated as A, B and C alongside a D (control) with no refining activity were used. In each site, 3 randomly located plot of 5×5 m were sampled for vegetation (frequency, abundance, density and cover), Total Hydrocarbon Content (THC) and soil chemical (Total organic carbon, pH, conductivity, nitrate, phosphate, Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) properties. **Results:** Results showed drastic reduction in vegetation indices such as species frequency of occurrence (66.6-166.6%), abundance (11.67-29 m^{-2}) and density (4-9.66 m^{-2}) as against the control of 200%, 34.0 and 177 m^{-2}, respectively. Total species contents were A (29), B (12), C (19) and D (53) while cover value was in order of D (100%) >C (60%) >B (33.3%) >A (15%). Significant ($p = 0.05$) increase were recorded in Total Hydrocarbon Content (THC) (1325±95-2785±57.6 mg kg^{-1}), Total organic carbon (1.74±0.2-3.00±0.3%); Ca^{2+} (776.75±19.7-1625.1±10.8 mg kg^{-1}); Mg^{2+} (1234.6±25.1-1639.1±31.4 mg kg^{-1}); K^{+} (1297±54.9-200.8 mg kg^{-1}) in refining sites as against THC (175±25 mg kg^{-1}) TOC (1.39±0.1%), Ca^{2+} (146.0±16.7 mg kg^{-1}), Mg^{2+} (901.3±42.6 mg kg^{-1}) and K^{+} (34.0±13.9 mg kg^{-1}) in the control. **Conclusion:** Therefore, artisanal petroleum refining activity is disastrous to the wetland ecosystem and should be discontinued at all cost. Also, remediation of such site should be vigorously pursued in order for the ecosystem to continue to provide its goods and services to the locality.

Key words: Artisanal refining, soil, nutrients, wetland ecosystem, plant composition

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Corresponding Author: F.B.G. Tanee, Department of Plant Science and Biotechnology, Faculty of Science, University of Port Harcourt, Port Harcourt, Nigeria

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Despite the fact that the Niger Delta region is rich in oil and gas deposits; it also has very rich, fertile and diverse wetland vegetation. Wetlands are ecosystems naturally endowed with distinct and special characteristics. They are important environmental resource of the world with high biota. They are classified into marshes, swamps and bogs depending on the vegetation type, salinity of water and soil type. Prominent among them is the mangrove swamp vegetation wetland. The Niger Delta mangrove vegetation is the largest in Africa and the sixth largest in the world[1], with up to 0.8 million ha of mangrove stands in this area constituting about 35% of all West African mangroves[2].

Wetlands are regarded as the most productive ecosystem on earth, rivalling the tropical rainforest ecosystem. As a result, they are accorded a high level protection by the Clean Water Act. A lot of benefits (economic, social and ecological) have been identified to be provided by the wetlands. The vegetation cover of wetlands helps to regulate local climate, maintain hydrological cycles and stabilizes soil, which are important in watershed regulations and erosion control[3]. Mangroves have been shown to be important fish habitats, particularly functioning as a fish nursery. The vegetation is used by local communities as sources of energy (fuelwood), construction work, yam staking, scald folding and manufacture of local dye. Many aquatic species such as fishes, crustaceans, molluscs, amphibians, reptiles and birds are found in mangroves.

However, in the Niger Delta, a large proportion of the wetland vegetation has been devastated by anthropogenic activities such as crude oil pollution over the years. It is estimated that crude oil theft (commonly called illegal bunkering) accounts between 200,000 and 300,000 barrels of crude oil daily lost in Nigeria; with a significant proportion of the stolen oil going into artisanal refining in make-shift facilities into low quality petroleum products[4]. The inefficiency of the process is so high such that it is most likely that as much as 80% of the heavy end of the crude oil cannot be refined and are just discharged into the environment[5]. It is in the process of stealing the crude oil from pipelines and refining (artisanal refining) that great environmental and economic devastation is done to the environment. Artisanal refining activity is not new, but since the end of the militant crisis in Nigeria in 2009, the scale has grown beyond control[5]. The devastation of this activity resulted in local communities losing their traditional means of livelihoods such as fishing and farming. The refining process may also pose serious health risks[6]. The UNEP[7] reported several incident of artisanal refining activity in Ogoni land. Fire accidents are also usually associated with this artisanal refining activity resulting in loss of human lives and further destruction of the ecosystem.

The thrust of this study was to assess the level of devastation in abandoned artisanal refining sites with emphasis on plant composition/diversity, hydrocarbon content and soil chemical characteristics using Warri South West Salt Wetland Ecosystem of Delta State, Nigeria as a case study. Results obtained from this study will provide the basis for the remediation of such sites so that such wetland will continue to provide it numerous good and services for the local communities.

MATERIALS AND METHODS

Experimental site or study site: The study was carried out at 3 artisanal refining sites A, B, C in addition to a site D (control) in relatively tidal inundated salt water wetland in Ikpokpo and Okpele-Ama/Tebujor communities located opposite chevron yard, along Escravos River in Gbaramatu Kingdom, Warri South West local government area of Delta State Nigeria (Fig. 1).

Site A is located at latitude 5°35′ 33.278″N and longitude 5°13′ 29.562″E, site B at latitude 5°35′ 32.952″N and longitude 5°13′ 31.296″, site C at latitude 5°35′ 40.710″N longitude 5°13′ 42.888″E; while the site D (i.e., control) at latitude 5°35′ 54.336″N, longitude 5°14′ 6.042″ E.

The Vegetation of the area is a salt water wetland, characteristically dominated by red mangrove (*Rhizophora racemosa* and *Rhizophora mangle*). Some other plant species like *Paspalum viginatum* and *Achrostichum aureum* were also found in the area.

The climate of the area is basically that of equatorial tropical climate. Rainfall occurs throughout most of the year with uni-directional flooding (inundation) during high tides and receding at low tide regimes.

The soil type is mainly peaty clay (chikoko soil), dark in colour and has a sticky feel. The soil contains debris, root fibres and leaf parts of plants.

Sample collection and analysis: At each artisanal polluted site (A, B and C) and the control site (D), 3 randomly located sample points measuring 5 m×5 m were mapped out for sampling. At each sample point, the vegetation and soil parameters were collected and analyzed.

Surface soil of 0-15 cm depth was collected at 3 different spots in a particular sampling unit from the study sites during tidal recession. The wet surface soil samples were placed in a collection bag, labelled with a masking tape and pen. The samples were then sent to the laboratory for analysis. Total Hydrocarbon Content (THC), Total Organic Content (TOC),

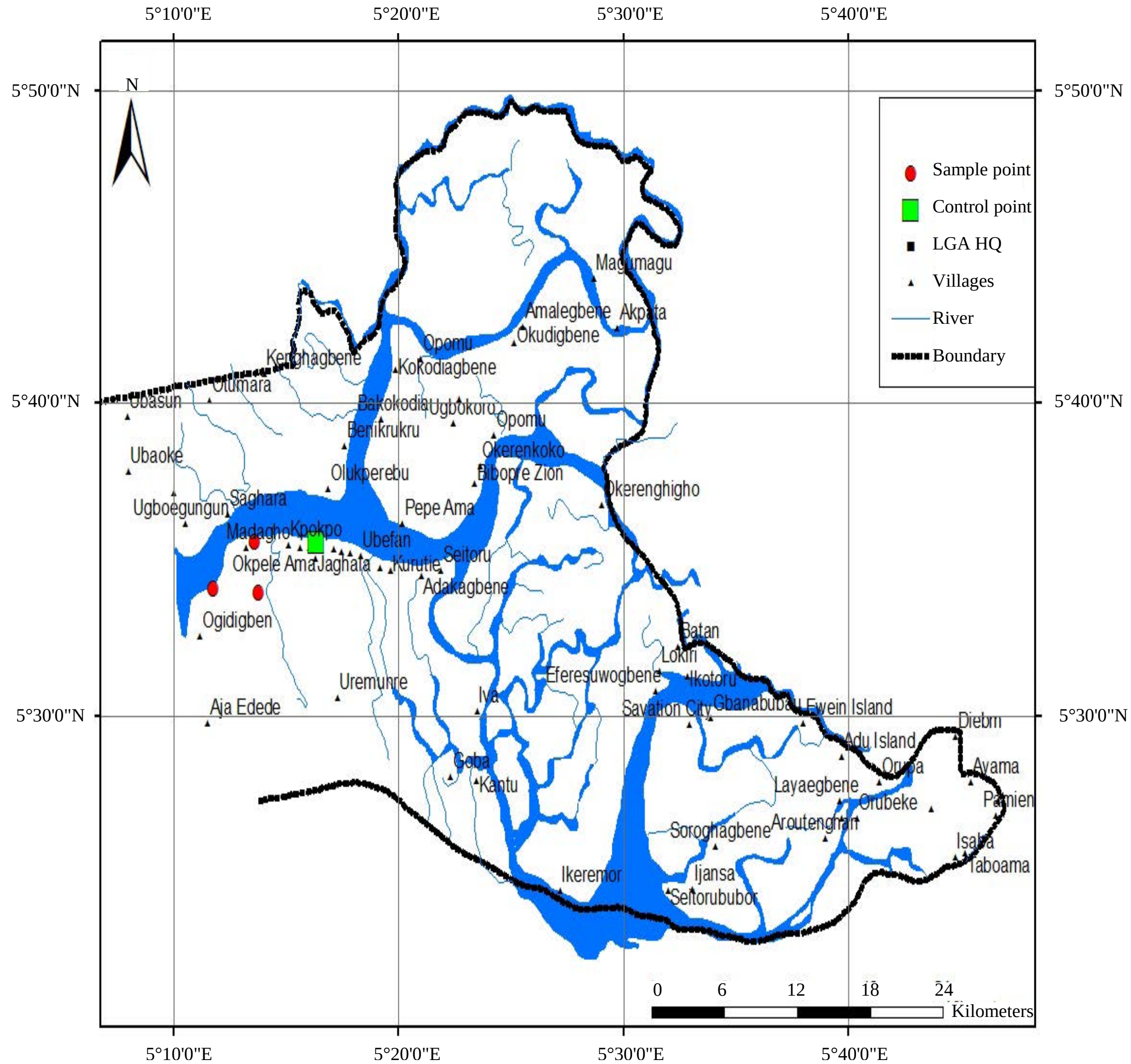

Fig. 1: Experimental site

soil nitrate, soil phosphate, total exchangeable cation of potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}) and sodium (Na^+) contents were all determined in the laboratory.

Vegetation analysis: Vegetation parameters such as species composition, plant cover values, species abundance and relative abundance, percentage frequency of occurrence and relative density, species density and relative density were determined.

Species abundance and relative abundance were calculated according to Anyanwu *et al.*[8] using the formula:

$$\text{Species abundance} = \frac{\text{Total No. of individuals of the species in all the sample units}}{\text{Total No. of sampling unit in which the species occurred}}$$

Relative Abundance (RA) is the abundance of a species divided by the sum of abundance of all species sampled to determine the relative abundance of the species as follows:

$$\text{Relative abundance} = \frac{\text{Abundance of a particular species}}{\text{Sum of abundance of all species recorded}}$$

Frequency refers to the degree of dispersion in terms of percentage occurrence. The percentage frequency and relative frequency were calculated according to Anyanwu *et al.*[8] using formula:

$$\text{Frequency (\%)} = \frac{\text{Total No. of sample plot in which the species occur}}{\text{Total No. of sample plots studied}} \times \frac{100}{1}$$

$$\text{Relative frequency} = \frac{\text{Frequency (F) of a particular species}}{\text{Sum of frequencies of all species recorded}}$$

Population density refers to the number of individuals of a given species per unit area. Population density and relative density were calculated according to Anyanwu *et al.*[8]:

$$\text{Population density (per unit area i.e., square metre)} = \frac{\text{Total No. of individuals of the species in all the sample plots}}{\text{Total No. of sample plots studied}}$$

$$\text{Relative density (RD)} = \frac{\text{Density of a particular species}}{\text{Sum of density of all species recorded}}$$

The plant cover value, an estimation of the area covered by a given species expressed in percentage of the total area was calculated according to Anyanwu *et al.*[8] using the formula:

$$\text{Cover value} = \frac{\text{Area of ground occupied by above-ground part of the species}}{\text{Total area of the sample plot studied}} \times \frac{100}{1}$$

Soil chemical analysis: The soil samples analyses were carried out at the Research Laboratory of Department of Plant Science and Biotechnology, University of Port Harcourt for determination of pH, electrical conductivity, Total Hydrocarbon Content (THC), Total Organic Carbon (TOC), soil nitrate, soil phosphate, potassium ion, calcium ion, sodium ion and magnesium ion concentration.

The pH value of the soil was determined using Equip-tronics (Model EQ-610) pH meter. Sample soil conductivity ($\mu S\ cm^{-1}$) was determined using Jenway conductivity meter (Model No. 4010). The spectrophotometer method was used to determine Total Hydrocarbon Content (THC). One gram (1 g) of oven dried sample was weighed and transferred into a test tube. Ten milliliters of 99.9% chloroform was added to the sample in the test tube. The test tube was then corked and shaken for 15 sec, after which it was placed on a rack till a clear supernatant and sediment was observed. The extract supernatant was read in spectrophotometer (Shooter spectrophotometer) at 420 nm wavelength using pure chloroform as blank. The concentration of THC was then extrapolated from a standard bonny light bonny medium crude graph plotted.

The Total Organic Carbon (TOC) and soil phosphate were determined by ascorbic acid and oxidation methods, respectively[9]. The Brucine method[10] was used to determine the soil nitrate. Atomic Absorption Spectrophotometer (AAS) was used to determine the K^+, Ca^{2+}, Mg^{2+} and Na^+ concentration through the digestion method.

Statistical analysis: Analysis of variance (ANOVA) and Least Significant Difference (LSD) were used to analyze the data obtained.

RESULTS

Table 1 showed vegetation analysis result of the species composition for the different impacted sites and the control site. The artisanal refining activities on the various impacted sites had adverse effect on species composition compared with the control site. It was observed that the control site had higher number of species than the impacted sites. The impacted site A recorded more species composition than site C. While impacted site B recorded the lowest amount of species. *Rhizophora racemosa* and *Paspalum* sp. were the dominant species in control while *Alchornia cordifolia* dominated site A.

Table 2 showed the abundance of species of the various impacted sites and the control site. The results showed that species abundance was higher in the control site than the artisanal refining sites. *Rhizophora racemosa* was observed to be associated with all the 3 impacted sites and the control site; hence *Rhizophora racemosa* was the most

Table 1: Species composition in the different sample sites

		No. of species in each sample sites			
Name of species	Family	A	B	C	D (control)
Rhizophora racemosa	Rhizophoraceae	1	-	11	21
Acrostichum aureum	Adiantaceae	-	-	8	10
Paspalum vaginatum	Poaceae	-	-	-	22
Phoenix reccinata	Arecaceae	-	9	-	-
Dissotis sp.	Melastamataceae	9	-	-	-
Alchornia cordifolia	Euphorbiaceae	14	-	-	-
Gmelina sp.	Verbenaceae	4	3	-	-
Raphia sp.	Arecaceae	1	-	-	-
Total		29	12	19	53

Table 2: Species abundance (m^{-2}) and relative abundance (%) at the various sample sites

	Site A		Site B		Site C		Site D (control)	
Species	A	RA	A	RA	A	RA	A	RA
Rhizophora racemosa	1	3.45	-	-	3.67	31.45	7	20.59
Acrostichum aureum	-	-	-	-	8	68.55	5	14.71
Paspalum vaginatum	-	-	-	-	-	-	22	64.71
Phoenix reclinata	-	-	9	75	-	-	-	-
Dissotis sp.	9	31.03	-	-	-	-	-	-
Alchornia cordifolia	14	48.28	-	-	-	-	-	-
Gmelina sp.	4	13.79	3	25	-	-	-	-
Raphia sp.	1	3.45	-	-	-	-	-	-
Total	29	100	12	100	11.67	100	34	100

A: Abundance and RA: Relative abundance

Table 3: Population density (m^{-2}) and relative population density (%) at the various sample sites

	Site A		Site B		Site C		Site D (control)	
Species	D	RD	D	RD	D	RD	D	RD
Rhizophora racemosa	0.33	2.63	-	-	3.67	57.89	7	39.64
Acrostichum aureum	-	-	-	-	2.67	42.11	3.33	18.87
Paspalum vaginatum	-	-	-	-	-	-	7.33	41.51
Phoenix reclinata	-	-	3	75.00	-	-	-	
Dissotis sp.	3	31.58	-	-	-	-	-	-
Alchornia cordifolia	4.67	50.00	-	-	-	-	-	-
Gmelina sp.	1.33	13.16	1	25.00	-	-	-	-
Raphia sp.	0.33	2.63	-		-	-	-	-
Total	9.66	100	4	100	6.34	100	17.66	100

D: Species density and RD: Relative density

Table 4: Percentage frequency of occurrence and relative frequency (%) at the various sample sites

	Site A		Site B		Site C		Site D (control)	
Species	F	RF	F	RF	F	RF	F	RF
Rhizophora racemosa	33.3	20.0	-	-	100.0	75.0	100	50.0
Acrostichum aureum	-	-	-	-	33.3	25.0	66.7	33.3
Paspalum vaginatum	-	-	-	-	-	-	33.3	16.7
Phoenix reclinata	-	-	33.3	50.0	-	-		
Dissotis sp.	33.3	20.0	-	-	-	-		
Alchornia cordifolia	33.3	20.0	-	-	-	-		
Gmelina sp.	33.3	20.0	33.3	50.0	-	-		
Raphia sp.	33.3	20.0	-	-	-	-		
Total	166.7	100.0	66.6	100.0	133.3	100.0	200.0	100

F: Frequency of occurrence and RF: Relative frequency

abundant species in the salt water wetland studied. *Acrostichum aureum* was also recorded in polluted site C and the control site, while the other species were only recorded in the polluted sites.

Plant population density and relative density of species at the control and the impacted sites were as presented in Table 3. The result showed that the density of plant in the control site was more than those in the impacted sites. Site A had the highest plant population density among the impacted sites, while site B recorded the lowest amount of plant population density.

Table 4 showed the frequency of occurrence for the control and the impacted sites (A, B and C). The frequency of occurrence was higher at the control than the impacted sites. Site A recorded the highest frequency of occurrence among the impacted sites, which was followed by sites C and site B in decreasing order. *Rhizophora racemosa* had the highest percentage frequency of occurrence in the control site and site C. The frequency of occurrence for all the plants recorded in site A was equal (*Rhizophora racemosa*, *Dissotis* species, *Alchornia cordifolia*, *Gmelina* sp. and *Raphia* sp.). Also, the frequency of occurrence was equal for *Phoenix reclinata* and *Gmelina* sp. in site B.

Figure 2 showed the plant vegetation cover values for the control site and the impacted sites. The control site recorded the highest amount of plant canopies (i.e., the

Table 5: Soil chemical characteristics at the different sites

	Sites			
Soil parameters	A	B	C	D (control)
pH	6.69±0.3[a]	7.08±0.1[a]	7.03±0.1[a]	7.01±0.0[a]
Electrical conductivity (μs cm^{-1})	8210.00±341[a]	4365.30±197[b]	4876.00±119[b]	1970.00±194[c]
Total organic carbon (%)	3.00±0.3[a]	2.69±0.2[ab]	1.74±0.2[b]	1.39±0.1[bc]
Nitrate (mg kg^{-1})	72.06±26.1[a]	52.94±8.8[a]	92.65±21.8[a]	95.59±29.4[a]
Phosphate (mg kg^{-1})	53.35±1.9[a]	52.02±5.1[a]	52.25±3.9[a]	52.39±3.7[a]
Ca^{2+} (mg kg^{-1})	1450.90±10.8[a]	1625.10±10.7[a]	768.80±19.7[b]	146.00±16.7[c]
Mg^{2+} (mg kg^{-1})	1234.60±25.1[a]	1458.28±29.8[a]	1639.10±31.4[a]	901.30±42.6[b]
Na^{+} (mg kg^{-1})	1366.80±10.6[d]	9608.40±10.8[a]	6700.90±10.4[b]	2087.30±10.1[c]
K^{+} (mg kg^{-1})	169.10±49.1[a]	200.80±42.7[a]	129.70±54.9[a]	34.00±13.9[b]

Mean±SEM with different superscripts between column represent significant difference@ p = 0.05

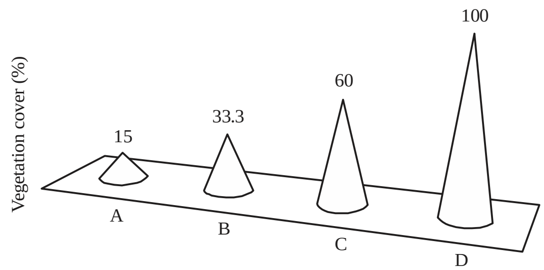

Fig. 2: Vegetation cover value (%) at the different sites

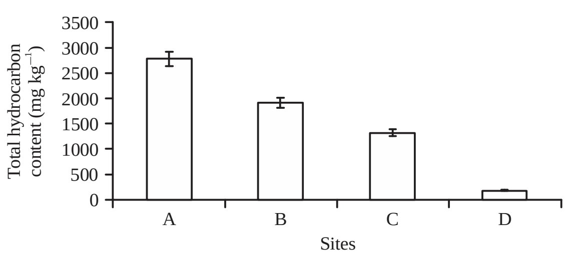

Fig. 3: Mean±SEM total hydrocarbon contentat different sites

highest percentage of vegetation cover). Impacted site C recorded the highest percentage plant vegetation cover, while impacted sites B and A recorded the lowest percentage of plant vegetation cover.

It was observed that total hydrocarbon content was high in the impacted sites than the control. Significant difference ($p = 0.05$) was observed in THC between the sites with site A recording the highest and control site with the least. The THC in the different site was in order of A>B>C>D (Fig. 3).

The soil chemical parameters results are shown in Table 5. No significant difference ($p = 0.05$) were observed in soil pH, nitrate and phosphate between the artisanal sites and control. Significant differences between the refining sites and control were observed in electrical conductivity, K^{+}, Ca^{2+}, Mg^{2+} and total organic carbon in which the refining sites recorded higher values than the control site.

DISCUSSION

Vegetation is the functional array of plants on a landscape[11]. The health of any vegetation is an indication of the health of the soil such as the presence of the required amount of nutrients, absence of toxic substances, susceptibility and tolerance of the vegetation to some changes in environmental factors etc. Crude oil pollution resulting from artisanal refining activity caused devastating effect on the vegetation as well as altering the soil chemical characteristics. The devastating effect of such pollution depend on the amount/type of oil spill, prevailing condition of the environment, the type of ecosystem, season, nature and type of oil and other activities associated with the spill[12]. Reduction in growth, biomass, leaf chlorophyll and complete death of biota (flora) are some of the devastating effect of crude oil pollution[13-15].

Result showed that the plant species compositions in the artisanal sites were less than the control. The species composition was in the order of (control) site D>site A> site C>site B. This corroborates with Baruah and Sarma[16] who report that species number and live standing biomass of herbaceous crops were reduced in a crude oil polluted ecosystem. The low species composition in the polluted sites may be attributed to the susceptibility of the species to the toxicity of hydrocarbon content causing death of plant species. This assertion is considerable since the polluted sites were found to be higher in THC than the control.

The percentage frequency of occurrence, species abundance and population density are indices of vegetation condition and health. Lower values of these indices are indications of severe devastation and negative impact on the ecosystem. Results showed that these indices were found to be lower at the polluted sites than at control site. Papageorgiou[17] observed that the richness and diversity of species in a habitat depend on the soil quality, which alters the growth characteristics of the plants. In line with that observation, it may be deduced that the lower vegetation frequency, abundance and density may be caused by the poor soil quality resulting from low nutrient content and high THC toxicity.

The vegetation cover value was in the order of (control) D>C>B>A. The reduction in the cover value may be attributed to the amount of crude oil or its derivative deposited in the environment due to the artisanal refining leading to the death of more plant species in the polluted sites than that of the control site. The implication of this is that the soil is rendered bared leading to accelerated riparian erosion in the habitat.

The THC was high in the artisanal activity sites. This gives an insight of the level of pollution caused by the refining activities in the area. The values obtained were more than the acceptable limit set up by environmental guidelines and standards for the oil industry in Nigeria[18]. The high value of THC is understandable since, crude oil contains high percentage of hydrocarbon. The high values recorded might have been cause of high mortality of mangrove species. Similar instance was reported by Ndukwu *et al.*[19] where the entire mangrove area in Bodo Creek, Rivers State, Nigeria in 2008 was completely devastated by oil spillage. Mangroves are vulnerable to crude oil pollution because oil interferes with oxygen absorption in the mangrove roots. This is in line with Kio and Ola-Adams[20] who report that oil spillage results in death of mangrove seedlings and trees.

There was a negative correlation between THC and cover value in the polluted sites and control. The cover value was inversely proportional to THC value. This showed that the death and subsequent reduction in the cover value was due to the toxicity of THC.

The soil pH of the sites were around the neutral zone (6.69-7.08) which was not significant. The conductivity of the soil was also observed to be high. These pH and conductivity values may be attributed to the saline condition of the soil caused by the inundation of salt water into the habitat. The nutrient contents (nitrate, K, P and Mg) in the polluted sites were high in contrast to other reports of low nutrient contents in crude oil polluted soil[21,22]. Mangrove vegetation contains nutrients in their biomass and their death due to the crude oil toxicity may have added nutrient contained in their biomass into the soil. This may have been the cause of high nutrient contents in the polluted soil. It is also known that mangrove seafood such as fishes, crustaceans, molluscs, amphibians, reptiles and birds are rich in calcium and other ions. Hence, the suffocation, death and subsequent decomposition of these aquatic animals due to oil toxicity especially in the polluted site may have been responsible for the increase in Ca^{2+} and other ions in the polluted sites.

CONCLUSION

This assessment presents insight on the activity of artisanal refining in the Niger Delta. Results showed that the THC was above the toxicity level leading to alterations of other soil chemical properties. Species content/composition, percentage frequency of occurrence, abundance, density and cover values were significantly lower in the impacted sites than the non-impacted site. Hence, artisanal refining activities have severe devastating effects on Salt Water Wetland Ecosystem of Niger Delta and if not controlled could lead to the complete destruction of this ecosystem.

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