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Reconnaissance Assessment of Long-Term Effects of Crude Oil Spill on Soil Chemical Properties and Plant Composition at Kwawa, Ogoni, Nigeria

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ABSTRACT

Long-term effects on soil chemical properties and plant composition of a crude oil polluted site were assessed using random surface soil samples and quantitative vegetation data collection methods. Results showed that total hydrocarbon content (542.50±28.58 mg kg^{-1}) and total organic carbon (1.06±0.18%) of polluted site were significantly ($p = 0.05$) higher than the unpolluted site of 27.90±22.10 mg kg^{-1} and 0.73±0.06%, respectively. Plant species composition showed that *Aspillia busei* and *Heterotis rotundofolia* were abundant at polluted site and absent in unpolluted site while *Panicum maximum* and *chromolaena odoratum* were absent in polluted site. Species diversities records were 0.37 (polluted site) and 0.64 (unpolluted). *Aspillia busei* recorded the highest frequency of occurrence (90%) and density (28.2 m^{-2}) in the polluted site while *Starchytarpheta jamaicensis* recorded the highest frequency of occurrence (40%) and *Andropogon tectorum* the highest density (3.9 m^{-2}) at the unpolluted site. It can be concluded that the effects of crude oil pollution persists for a long time and negatively affect soil chemical properties, plant species composition and species diversity.

Key words: Pollution, environment, total hydrocarbon content, *Aspillia busei*, species diversity

INTRODUCTION

The environmental challenges in Nigeria especially in Niger Delta have become a source of concern. The Niger Delta environment which is known for its rich biodiversity and sustenance of traditional livelihoods of its local people for centuries has been under severe threat from anthropogenic factors including oil and gas mining activities. In short, there is hardly any year without recorded incidences of oil pollution in the Niger Delta as such crude oil pollution is a common experience to the Niger Delta people. Crude oil as used in this context can be defined as the introduction of crude oil or its derivatives with it associated gases in the environment (land, air and water) in quantities that is capable of causing immediate physical, chemical and biological damage to the affected ecosystem (Tanee and Anyanwu, 2007).

Right from the discovery of crude oil in commercial quantities in 1956 at Oloibiri in present day Bayelsa State, Nigeria, several incidences of oil spillage and its associated negative activities have been recorded. For instance, in 1970 only a single oil spill was recorded in Nigeria while the number shot up to 14 in 1971 and 105 in 1974 (NEST., 1991). From 1976-2005, 9,107 oil spill incidents were recorded in the Niger Delta of Nigeria with a total spill volume of 496,343.07 m^3

out of which only 87,479.88 m^3 were recovered (Okparanma, 2013). It has been observed that the system of reporting oil spills especially in the Niger Delta has been dysfunctional and figures presented by oil companies and Department of Petroleum Resources (DPR) do not reflect true position since not all spill incidents are reported (Amnesty International, 2009).

Various factors have been identified to be responsible for the frequent oil spills. These include corrosion of oil pipes, over pressure failure and over flow process components; poor maintenance of infrastructure, spills or leaks during processing at refineries, tankers accidents, human error, sabotage and oil theft (Kinako and Awi-Waadu, 2000).

Crude oil pollution is a serious multi-dimensional problem as it affects all aspects of the environment. The effects depends on the amount of oil spill, type of oil, extent of oil coverage, oil composition and season of the spill (Pezeshki *et al*., 2000). Its effects include suffocation and death of aquatic lives as it prevents oxygen diffusion into water. Crude oil has also been known to affect plant through inhibition of germination, reduction in plant growth (height and stem diameter) and photosynthetic rate and complete mortality (Pezeshki *et al*., 2000; Tanee and Anyanwu, 2007; Anyanwu and Tanee, 2008). Crude oil has also been known to reduce nutrients (especially nitrogen and phosphorus) availability (Xu and Johnson, 1997; Tanee and Kinako, 2008). A number of plant species have been reported extinct as protracted effect of crude oil environmental pollution. A number of oil pollution impact assessment studies in the Niger Delta suggest that the high level of oil pollution show that the habitats, livelihood and people are severely impacted (Emoyan *et al*., 2008; UNEP., 2011).

There have been several cases of crude oil spill incidents in Ogoni-land without any attempt to cleanup or remediate the spill sites. The Kwawa oil spill of Yorla oil well 10 location (popularly Yorla 10) in Yorla oil field is one of such cases. This spill occurred over 15 years ago and was left uncleaned i.e., without remediation. This paper attempts to assess the long term effects of this uncleaned crude oil spill on soil properties and plant species composition and diversity. It is expected that the findings from this assessment will add to knowledge of the effects of crude oil spill as a pollutant and its long term ecological damages on the ecosystem especially on soil chemical properties and plant population characteristics.

MATERIALS AND METHODS

Site description: This study was carried out at an uncleaned crude oil spill site i.e. Yorla 10 at Kwawa (Fig. 1). Yorla 10 is one in a cluster of oil wells in Khana Local Government Area of Rivers State. Kwawa is a rural Ogoni community in Khana Local Government Area of Rivers State, Niger Delta of Nigeria. The location is a terrestrial environment with patchy regenerating vegetation after the crude oil spill. The vegetation is dominated by herbaceous plants and few shrubs. This location like the rest of the Niger Delta experiences two seasons: rainy and dry seasons. It is also characterized by high temperatures, high rainfall (2000-2500 mm $year^{-1}$) and high relative humidity. The soil of the area is poorly drained and low in nutrient content due to leaching effect as a result of the high precipitation of the area (Kinako *et al*., 1993).

Sampling and determination of assessment parameters: This assessment used two sites-an uncleaned crude oil spilled site at Yorla 10 location as polluted site and a fallow land 1 km away from the polluted site as an unpolluted (i.e., control) site. At the polluted site, using Yorla 10 christmas tree located at latitude 4°39' N and longitude 7°26' E as the epicentre of the spill, a

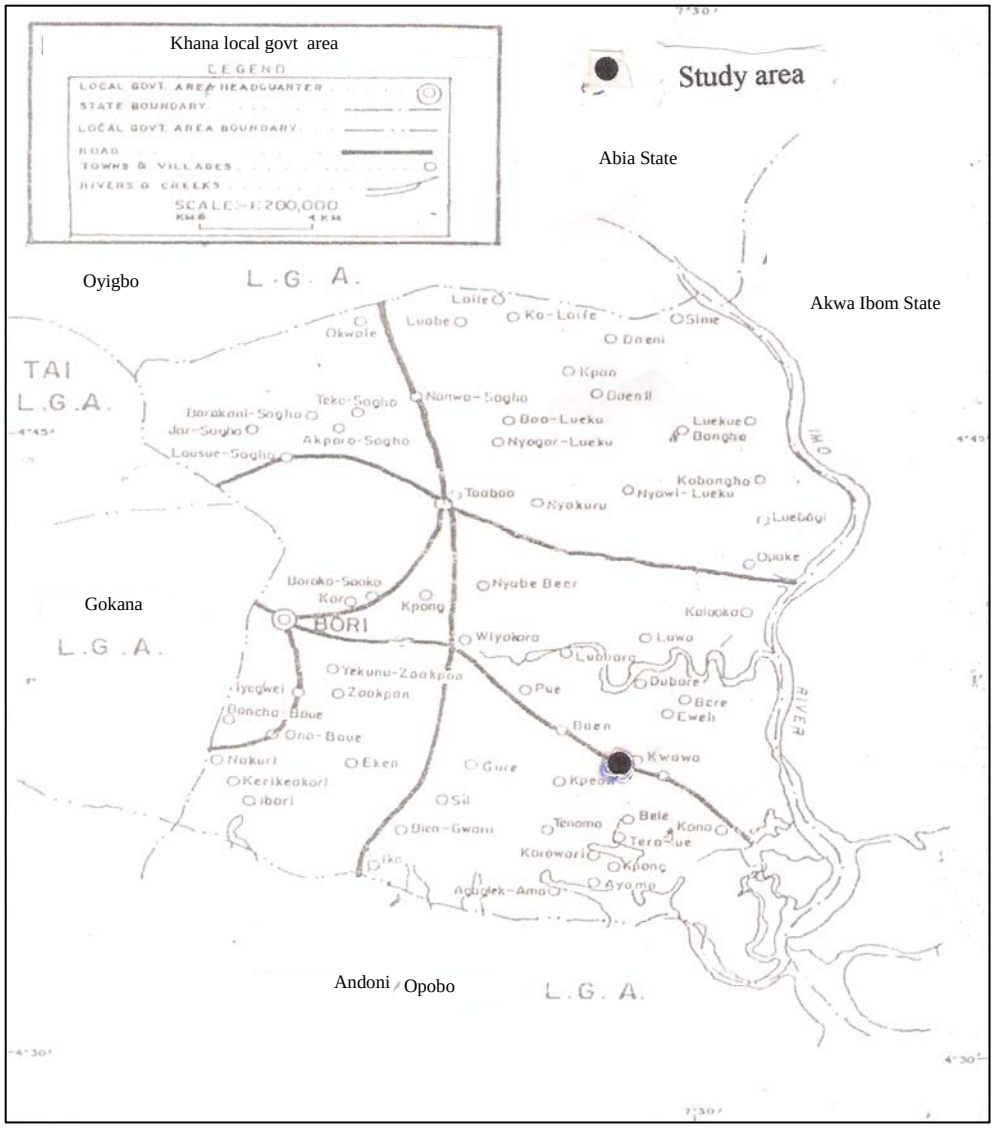

Fig. 1: Map showing study area

perimeter area of 100×100 m^2 was marked out (i.e. study area). From the Christmas tree, 50 m transects in the four cardinal directions were marked and this divided the study area into four sample plots. In each plot, two random quadrat (size: 2×2 m) throws were made. At each quadrat throw, plants species content within the quadrat area were identified, counted and recorded. Plants which were not immediately identified were collected, sandwiched between newspapers as absorbent and taken to University of Port Harcourt Herbarium for taxonomic identification.

Within the perimeter of the quadrat throw, surface soil (1-15 cm depth) samples were collected by means of soil auger from each quadrat. The soil samples immediately on collection were placed in polythene bags, tightly tied and labeled. The samples were taken to the Plant Physiology Laboratory, University of Port Harcourt for chemical analyses.

At the control site, the same 100×100 m^2 was measured and divided into four study plots which were used for the assessment. Within the plots, four randomly located study plots were used for sampling. Plant and soil collections were made as was carried out at the polluted site.

Soil pH, conductivity, Total Hydrocarbon Content (THC), Total Organic Carbon (TOC), nutrients (nitrate and phosphate) and total exchangeable cations (Mg^{2+}, Ca^{2+}, Na^{+}, K^{+}) were analyzed from the soil samples while species number, composition, diversity, frequency of occurrence, abundance and density were determined for data on plants.

Soil pH and conductivity were determined by meter method from slurry of 50/50 (w/v) soil sample in water. Sample pH and conductivity displayed by pH meter (model: Jennway 3015) and conductivity meter (HACH Ecttesr microprocessor series) were recorded. Total Hydrocarbon Content (THC) was obtained through spectrophotometric method by oven-drying 1 g of soil sample at 70°C for 24 h. The THC content of the dried soil sample was extracted using chloroform as extraction solvent and its concentration measured using spectrophotometer. Soil Total Organic Carbon (TOC) was determined by ascorbic acid method. Phosphate and nitrogen contents were obtained by oxidation and Kjedahl methods, respectively as described by Stewart *et al*. (1974).

Plant species diversity was calculated using Shannon-Weaner diversity index (H), as stated in Spellerberg and Fedor (2013) as stated below:

$$H = -\Sigma (n! /N) \ln (n! /N)$$

Where:

H = Shannon-Weaner diversity index
n! = No. of species
N = Total number of all species
In = Natural logarithm

Frequency of occurrence (F) was calculated by dividing the number of quadrats in which species occur by the total number of quadrat throws multiplied by hundred. Frequency of occurrence was expressed as percentage.

Mathematically:

$$\text{Frequency (F)} = \frac{\text{No. of quadrats in which species occur}}{\text{Total quadrat throws 1}} \times 100$$

Relative Frequency (RF) was determined by dividing the frequency of a species by the sum of frequencies of all species sampled:

$$\text{Relative Frequency (RF)} = \frac{\text{Frequency (F) of a species}}{\text{Sum of frequencies of all species}} \times 100$$

Abundance (A) was calculated by dividing the sum of the number of a species by the number of quadrats in which the species occur:

$$\text{Abundance (A)} = \frac{\text{Total number of a species in all quadrats}}{\text{Total number of quadrats in which species occur}}$$

Relative Abundance (RA) is the abundance of a species divided by the sum of abundance of all species sampled. Relative abundance was calculated as follows:

$$\text{Relative Abundance (RA)} = \frac{\text{Abundance of a species}}{\text{Sum of abundance of all species}}$$

Density (D) was determined by multiplying the reciprocal of quadrat area by the mean of occurrence of species in all quadrat:

$$\text{Density (D)} = \frac{1}{\text{Quadrat area}} \text{Mean occurrence of a species}$$

Density was expressed in meter square (m^2).

Relative density, RD was taken as the density of a species over the sum of density of all species sampled:

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

Analysis of data: Soil chemical analyses data was subjected to Students' statistical t-test analysis at p = 0.05. Mean and Standard Error Mean (SEM) were also calculated. The data generated on these parameters were presented in Tables.

RESULTS

Results of the assessment of an uncleaned (unremediated) crude oil spill on soil chemical properties are shown in Table 1-3.

Results of soil chemical properties of polluted soil are shown in Table 1. All sampled polluted plots had higher total hydrocarbon contents than the unpolluted plots. Total Hydrocarbon Content (THC) was significantly higher in the polluted site than the control site (p = 0.05). The total hydrocarbon content in the polluted site was 514.6 mg kg^{-1} higher than that of the control. Result also showed that mean Total Organic Carbon (TOC) in the polluted site was significantly (p = 0.05) higher than the unpolluted site with a difference of 33.13%.

No significant differences in pH, soil nitrate, soil phosphate and total exchangeable cations were observed between the polluted and the unpolluted site (Table 1) as high values were recorded for the both sites assessed. It was also observed that the pH of the two sites were generally acidic

Table 1: Soil total hydrocarbon content and chemical properties

Parameters	Polluted soil	Unpolluted soil	T-test
THC (mg kg^{-1})	542.50±28.58	27.90±22.10	11.64*
pH	4.25±0.06	4.15±0.01	1.21
TOC (%)	1.06±0.18	0.73±0 .06	4.02*
Conductivity (µS cm^{-1})	6.33±0.33	10.33±2.04	1.92
Nitrate (mg kg^{-1})	132.36±48.60	95.57±47.86	1.52
Phosphate (mg kg^{-1})	75.62±6.87	103.12±11.10	1.53
Na^+	0.20±0.06	1.85±1.60	1.05
Mg^{2+}	2.16±1.67	1.63±0.95	0.71
K^+	0.30±0.08	1.40±0.27	1.70
Ca^{2+}	8.33±0.88	4.60±2.38	2.41

Values: Mean±SEM, *: Statistically significant difference at p = 0.05, TOC: Total hydrocarbon content, TOC: Total organic carbon

Table 2: Species number, composition and diversity of the sites

Species	Polluted sites	Unpolluted sites
Aspillia busei	282.0	-
Heterotis rotundofolia	66.0	-
Andropogon tectorum	25.0	37.0
Starchytarpheta jamaicensis	2.0	22.0
Axonopus compressus	2.0	3.0
Paspalum conjugatum	7.0	21.0
Chromolaena odorata	-	2.0
Panicum maximum	-	13.0
Total	384.0	98.0
Species diversity	0.37	0.64

Table 3: Quantitative analysis of study sites vegetation

	F (%)		Abundance (m^{-2})		Density (m^{-2})		RF (%)		RA (%)		RD (%)	
Species	P	U	P	U	P	U	P	U	P	U	P	U
Aspillia busei	90	-	33.30	-	28.20	-	0.39	-	0.56	-	0.73	-
Heterotis rotundofolia	70	-	9.43	-	6.60	-	0.30	-	0.16	-	0.17	-
Andropogon tectorum	40	10	6.25	37.0	2.50	3.90	0.17	0.08	0.11	0.60	0.07	0.31
Starchytarpheta jamaicensis	10	40	2.00	5.5	0.20	3.14	0.04	0.33	0.03	0.09	0.50	0.25
Axonopus compressus	10	10	2.00	3.0	0.20	0.43	0.04	0.08	0.03	0.05	0.01	0.03
Paspalum conjugatum	10	20	7.00	10.5	0.70	3.00	0.04	0.17	0.12	0.17	0.02	0.24
Chromolaena odorata	-	10	-	2.0	-	0.29	-	0.08	-	0.03	-	0.02
Panicum maximum	-	30	-	4.3	-	1.86	-	0.25	-	0.07	-	0.15

P: Polluted site, U: Unpolluted site, F: Frequency of occurrence, RF: Relative frequency, RA: Relative abundance, RD: Relative density

(pH 7). Phosphate content was generally lower in the polluted soil compared with the amount in the unpolluted soil. The mean phosphate content of the polluted soil (75.62±6.87 mg kg^{-1}) and the unpolluted site (103. 12±11.1 mg kg^{-1}) showed no significant statistical difference ($p = 0.05$).

The result of soil exchangeable cations (Na^+, Mg^{2+}, K^+ and Ca^{2+}) assessment did not exhibit any clear order with no significant difference between the polluted site and the control (Table 1).

Species number, composition and diversity results are shown in Table 2. *Aspillia busei* and *Heterotis rotundofolia* were only recorded in their respective numbers in the polluted site while they were not found at unpolluted site. Conversely, *Chromolaena odorata* and *Panicum maximum* were only found at the unpolluted (control) site and were not in the polluted site. *Andropogon tectorum, Starchytarpheta jamaicensis*, *Axonopus compressus* and *Paspalum conjugatum* were observed at both sites.

Determination of species diversity of the two sites showed that the unpolluted site had higher diversity compared with the polluted site (Table 2).

In the polluted site, the highest frequency (90%) was recorded for *Aspillia busei*. The magnitude of frequency of occurrence followed the order: *Aspillia busei >Heterotis rotundofolia >Andropogon tectorum>Starchytarpheta jamaicensis>Axonopus compressus>Paspalum conjugatum* (Table 3). There were nil occurrences for *Chromolaena odorata* and *Panicum maximum*. Abundance and density followed the order of frequency. Similarly, relative frequency, relative abundance and relative density all were in the order of frequency and abundance for the site.

In the control site, the frequency of occurrence were observed in the order: *Starchytarpheta jamaicensis>Panicum maximum>Paspalum conjugatum* while *Andropogon tectorum, Axonopus compressus* and *Chromolaena odorata* have the least and equal frequency of 10% each. Species abundance, density and relative frequency, abundance and density followed similar pattern as the frequency of occurrence (Table 3).

DISCUSSION

Petroleum hydrocarbon pollution has been reported to have negative effects on plants, animals and the ecosystem. The effects of oil pollution include alteration of physical and chemical properties of soil and subsequent effects on growth of plants (Chronopoulos *et al*., 1997). Petroleum hydrocarbon products also affect the soil in many ways and persist for many years when it infiltrates into soil (Baker *et al*., 1993).

The observed high concentration of total hydrocarbon content of soil samples from the polluted site fifteen years after spill gives an empirical insight as to the extent of pollution that took place. This goes with its toxicity especially as it was left unremediated. Similar result have been reported by Osuji and Nwoye (2007), Osam *et al*. (2011), UNEP (2011) and Gighi *et al*. (2012). The high THC of the polluted site is the result of the crude oil spill which occurred in the past as nothing by way of cleaning of the pollution was undertaken at the polluted sited after the incident. It also shows how persistent petroleum hydrocarbon could be in the environment in the event of its heavy spill into the environment.

High total organic carbon was reported in the polluted site. This is in order since crude oil contains high percentage of carbon. The higher TOC content of the polluted soil could have been derived from the input of carbon from the petroleum hydrocarbon, the pollutant of the spill incident as the analysis of crude oil composition showed that it consist of 83-87% carbon (Aske, 2002). Benka-Coker and Ekundayo (1995) and Abii and Nwosu (2009) reported high TOC contents in crude oil impacted soil of Niger Delta area. The weakly acidic pH result shows that crude oil spill has no significant effect on soil pH of the area as similar result was also reported by Tanee and Albert (2011) and Gighi *et al*. (2012).

Results showed that nutrient content especially nitrate in the studied sites (i.e. polluted and control) were high. The high values of soil nutrient contents for the both sites corresponds with the findings of Nkwopara *et al*. (2012) in the study of Uzere, Delta State crude oil polluted site. However, the findings vary with Akpan and Udoh (2013), Tanee *et al*. (2014) and Nkwopara *et al*. (2012) findings in another study of crude oil polluted site at Egbema, Imo State. The observed higher nitrogen content of the polluted site could have resulted from accumulated slow release of nitrogen compounds from organic sources such as death of plants, wildlife that were affected by the oil spill event. The lower values of phosphate in the polluted site agrees with Osuji and Nwoye (2007) and Gighi *et al*. (2012). The low phosphorus content of polluted soil was explained by Baruah *et al*. (2011) to probably be due to high C/P ratio resulting from the crude oil spill and that microbial degradation of the hydrocarbons may have immobilize inorganic phosphorous of the polluted soil thus brought about low soil phosphorous content. Soil total exchangeable cations (i.e. Mg^{2+}, Na^{+}, K^{+} and Ca^{2+}) result correspond with Tanee and Albert (2011). The low values recorded in the study site may be attributed to leaching of the cations due to the high precipitation of the Niger-Delta ecozone (Kinako *et al*., 1993).

Generally, crude oil spill negatively affect species number and performances directly by its phytotoxic characteristics or indirectly by limiting nutrients in the soil needed for plant growth and development.

Results showed that some species were absent in the polluted site and present in control site and vice versa. The presence of *Aspillia busei, Heterotis rotundofolia, Andropogon tectorum*, *Starchytarpheta jamaicensis*, *Axonopus compressus* and *Paspalum conjugatum* at the polluted site could be due to abilities of the species to tolerate high soil petroleum hydrocarbon content with the availabilities of essential plant nutrients such as nitrogen, phosphorus and macro-nutrients

(Na^+, Mg^{2+}, K^+ and Ca^{2+}). While the absence of *Chromolaena odorata* and *Panicum maximum* at the polluted site could be attributed to the inabilities of the species to thrive in a soil environment with high THC. Crude oil has being reported to inhibit germination, growth and development of plants (Ekpo *et al*., 2012; Eze *et al*., 2013). Kinako (1981) reported that in a crude oil polluted site, vegetation is drastically destroyed and recovering may take a long time as some species may even become extinct. Species diversity in the control was calculated to be higher than the polluted site. This agrees with Tanee (2011), who observed lower species diversity in a carbide waste polluted soil. The number of many of the observed species was found to be lower in the polluted site than at the control. The observed reduction in species number of the polluted site agrees with Baruah and Sarma (1996), Nkwocha and Duru (2010) and Wegwu *et al.* (2011). This reduction in species number may be due to the inhibitory and hydrophobic properties of crude oil leading to poor germination, stunted growth and complete mortality of plants (Lin and Mendelssohn, 1996; Pezeshki *et al*., 2000). This might also accounts for the change and reduction in species diversity in the polluted site.

CONCLUSION

The results obtained are indicative of long-term influence of crude oil spill on terrestrial ecosystem. *Aspillia busei* and *Heterotis rotundofolia* being conspicuously dominant and *Chromolaena odorata* and *Panicum maximum* completely eliminated in the polluted site showed their tolerance and susceptibilities to high THC, respectively. This result therefore suggests that further studies be carried out on the tolerance and intolerance of these species to high total hydrocarbon content for phytoremediation purposes. Furthermore, thorough remediation work should be carried out in all oil pollution sites to reduce negative effect of crude oil pollution impacts.

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