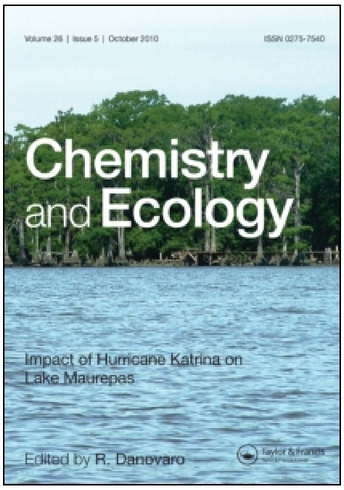

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Impact of four-dimensional seismic and production activities on the mangrove systems of the Niger Delta, Nigeria

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Reconnaissance survey and laboratory appraisal of the mangrove system in seven communities in the Niger Delta (Nigeria) endangered by seismic and production operations revealed several alterations of soil, sediment, and vegetation. Hydrocarbon content in the range of 0.3–1.1 mg/100 g was extracted within the proximities of spill sources and seismic lines. The prospect area covered by our investigation was characterized by a mixed mangrove forest dominated by *Rhizophora racemosa*. It was observed that the construction of the seismic lines was responsible for the vegetal disorientation recurrent in the area. The grass, *Paspalum vaginatum*, and the saltwater fern, *Acrostichum aureum*, were found at the fringe of most dredge spoils. The characteristic tidal inundation which increases mobility of the substrate, salinity fluctuation, and anoxia may also have contributed, at least in part, to the observed despoliation of some of these species found within the vicinities of the seismic lines and hydrocarbon percolation. Extensive revegetation program is recommended to ensure an effective restoration process of this ecologically fragile zone.

Keywords: Seismic; Oil production; Mangroves; Soil; Sediment

1. Introduction

One of the major activities of petroleum prospecting is the running of seismic lines usually undertaken to obtain information on the subsurface geologic structure, and to estimate the potential for oil and gas accumulation in prospective reservoirs. Seismic prospecting has developed rapidly from 2-D surveys of the 1970s to 4-D surveys. Environmental problems associated with these activities derive from land clearing as well as noise and waste generation due to the detonation of explosives and construction of seismic lines, some of which are several tens to hundreds of metres apart [1]. While seismic lines that were run over 10 yrs ago in some prospect areas of the Niger Delta (Nigeria) are still visible from the air, the extent of repeated

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seismic operations in that region, and associated land deformation, loss of biodiversity, and forest degradation over the last decade are still unknown.

Remarkably, one major receptacle of both seismic and production activities in the Niger Delta has been the mangrove system. The mangrove ecosystem forms more than 70% of the vegetation of tropical and sub-tropical coasts of the world, with the Niger Delta ranking the third largest with an estimated landmass of 9723.14 km^2 [2, 3]. The system is dominated by the red mangrove, *Rhizophora racemosa*, distributed in over 90% of the area. The backswamp areas have other smaller mangrove species such as *R. mangle* and *R. harrisonii*, the white mangrove, *Avicennia germinans*, and the black mangrove, *Laguncularia racemosa*. A physiognomic feature of the mangrove system is its stilt or prop roots which holds the plant firmly to the soft alluvial soil. This is the target material for removal during cutting of seismic lines and other operational activities directly linked with land take.

The usefulness of preserving biodiversity in the mangrove ecosystems is rated very highly due to its numerous benefits. This was why the world conservation union (IUCN) in association with the international oil exploration and production forum recently released guidelines for environmental protection of mangrove areas during oil exploration and production activities. For our part, we decided to assess the impact of these activities in the petroliferous Niger Delta, with a view to providing the necessary impetus for protection and rehabilitation; this article chronicles the report of one of the phases of such investigations. In the article, we are examining both seismic exploration and oil-spill areas.

1.1 *Geo-characteristics of Niger Delta soils, sediments, and vegetation*

The Niger Delta, a typical example of an acuate delta, is basically a floodplain landscape. One of the geo-characteristic features recognized is the composition of fine-grained deposits of tidal plants and mangrove swamps. Three-dimensionally, sediments date from the lower middle Eocene epoch to the present, consisting of sediments laid down over millions of years as the delta grew into the Gulf of Guinea. The Niger Delta is therefore a region of continued subsidence, which explains the long history of great depth of sediment deposition. The mangrove zone comprises (1) mangrove forests in the upper tidal zone and (2) the mangrove swamps in the lower tidal zone and along distributaries and estuaries. The soils fall into the major group of hydromorphic soils, that is, they are poor to imperfectly drained soils. This is understandable given the low floodplain relief. The soils are developed mainly on alluvium but also on marine deposits near the coast [4, 5].

Thus, the Niger Delta has a fairly extensive area of peat and peaty soils mainly in the mangrove zone. The poor ground drainage encourages the accumulation of raw organic matter (litter from the mangrove trees) on the soil surface which decays slowly to form peat. Its vegetation type, characterized by the upper tidal zone, is basically mangrove forest. The forests also habour a wide variety of wildlife including mammals, reptiles, birds, insects and invertebrates, a number of which are quite endemic; the birds from Europe and fish from offshore waters give the mangrove system of the Niger Delta global importance [1, 3, 5].

2. Materials and methods

2.1 *Field reconnaissance and sampling*

Field reconnaissance surveys were undertaken to assess extent of seismic and oil despoliation of soil and vegetation (cf. figures 1–3). A simple field technique was adopted after

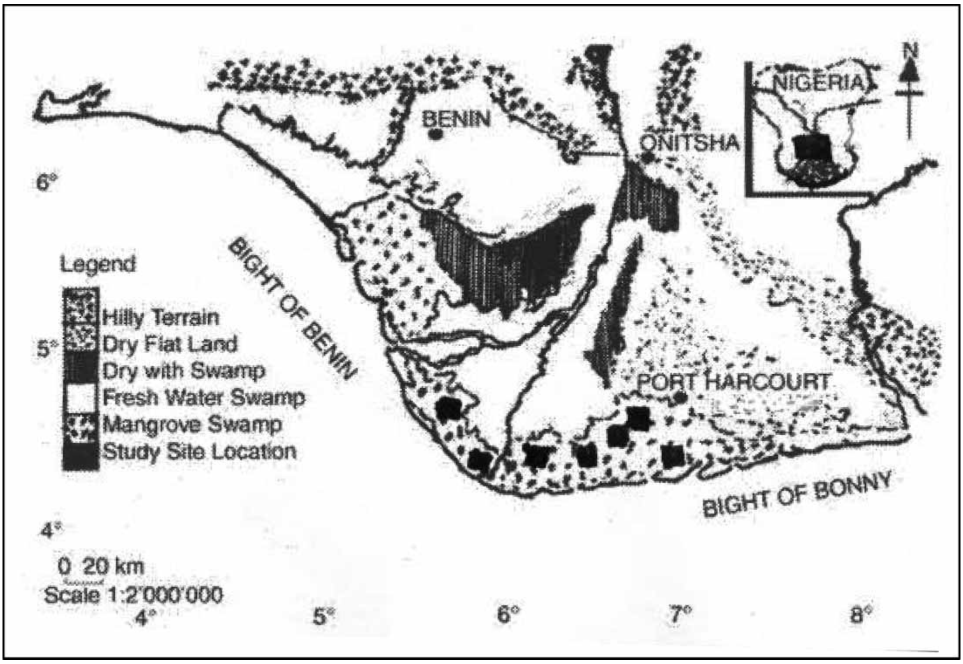

Figure 1. Location map of the Niger Delta (Nigeria) showing Igbematoru and other communities.

Figure 2. Photograph of a section of a mangrove system inundated by discharged oils at Igbematoru in the Niger Delta, Nigeria.

Figure 3. Section of the mixed mangrove system at Osokorosoi in the Niger Delta (Nigeria).

Osuji *et al.* [4] to assess vegetation variation and orientation. To sample each chosen area, quadrats were established as follows:

(1) 4 m × 4 m for shrubs;
(2) 1 m × 1 m for herbs and grasses (where present).

Quadrats were established by measuring the prescribed landmass using a metre rule in randomly selected areas within each of the six zones sampled. From each quadrat, soil samples from top (T) (0–15 cm) and bottom (B) (15–30 cm) depths were collected. Relevant biotypes were subsequently characterized by the indicative composition of species. Specimens of unidentified mangrove species were collected and later identified with the aid of previously identified herbarium specimens at the University of Port Harcourt Herbarium (UPH).

2.2 *Oil extraction and estimation of hydrocarbon content*

A 10 g portion of the soil sample was shaken in 10 ml of carbon tetrachloride (CCl_4). The hydrocarbon content of the CCl_4/hydrocarbon mixture was determined by the absorbance of the extract at 420 nm in a Spectronic 70 spectrophotometer. A standard calibration curve of the absorbance of different known concentrations of equal amounts of crude oil in the extractant was first prepared after taking readings from the spectrophotometer. The hydrocarbon content in soil samples was calculated from the calibration curve.

2.3 *Soil and sediment assessment*

Physicochemical characteristics (pH, temperature, moisture content, and electrical conductivity) were determined as described by Osuji and Onojake [6]. Total hydrocarbon content (THC), soil phosphorus ($PO_4^{3-}-P$), soil nitrogen (NO_3-N), soil potassium, total organic carbon (TOC), and total organic matter (TOM) were assessed as described in Osuji and Adesiyan [7].

3. Results and discussion

3.1 *Soils and sediments*

Surface and subsurface soils from the sampled areas of Igbematoru and Tebidara were acidic with pH ranging from 4.6 to 6.9 across the lines (cf. table 1). The soil sample taken from the surface depth of Tebidara Brass Line 2 was found to be the most acidic (lowest soil pH), while the subsurface soil of Igbematoru Brass Line sample B was the least acidic (highest soil pH). Complementarily, the alkalinity ranged from 10 to 15 across the sampled lines (table 1). In contrast, the sediment pH ranged from 7.3 to 7.9 (i.e. from slightly above neutrality to slightly alkaline) with a corresponding alkalinity varying from 15 to 20 (table 2).

The degree of acidity or alkalinity is usually considered a master variable that affects nearly all soil properties: chemical, physical, and biological. While some organisms are affected by a rather broad range of pH values, others may exhibit considerable intolerance to even minor variations in the pH [4]. pH influences aggregate stability as well as air and water movements in the soil. The amount of acid or alkali in the soil determines the availability of many nutrients for plant growth and maintenance. If the soil pH is too high or too low, the nutrients are either locked onto the soil particles or washed out of the soil. Most plants grow best when the soil pH is between 5.5 and 6.5 (i.e. from the slightly acidic side to neutral). Again, the pH greatly affects the solubility of minerals; strongly acidic soils (of pH 4–5) like the sampled soils of Tebidara usually have high concentrations of soluble aluminium and manganese which are toxic and thereby affect plant growth. Nitrogen fixation and decomposition activities are also hindered in such strongly acidic soils [8]. The pH values between 5.3 and 5.9 close to the neutral range (table 1) must be the result of the salt-buffering activity of the soils and sediments.

The electrical conductivity (EC) varied from 6 to 30 mS cm^{-1} in the soil samples and from 32 to 207 mS cm^{-1} in the sediment samples (cf. tables 1 and 2). The variation in EC might be a result of leaching of nitrate salts due to the tidal influence on the consistently silty soil-type. EC is related to dissolved solutes and correlates strongly with soil grain size and texture. The data show the presence of ionic salts in both the soil and sediment samples.

There was evidence of hydrocarbon contamination in all the sampled lines of Igbematoru Brass of the THC range of 0.28–1.06 mg per 100 g. The values provide substantial evidence of hydrocarbon deposition especially in surface soils which had somewhat higher THC levels than the subsurface soils. The presence of hydrocarbons in the affected areas must have stimulated aerobic and anaerobic metabolism; alterations in metabolic processes likely affected the physico-chemical properties and mineralization cycle of the soil (tables 1 and 2). For instance, the presence of hydrocarbons usually creates anoxic situations which limit gaseous exchange in surface and subsurface soils [3]. Therefore, as oxygen became limiting, utilization of alternate electron acceptors must have produced an increasingly reducing environment. It is also likely that the soil type may have been largely responsible for these alterations. The sampled areas are located in the mangrove swamps around where the lower flood plain (freshwater

Table 1. Physico-chemical properties of soils from the pipeline sites within the proximity of spill source.

Sample identity	pH	EC ($mS\,cm^{-1}$)	TOC (mg per 100 g)	SO_4^{2-} (mg per 100 g)	NO_3^- (mg per 100 g)	THC (mg per 100 g)	Cl^- (mg per 100 g)	Alkalinity (mg per 100 g)	PO_4^{3-} (mg per 100 g)
Gbem. Brass Line B(T)	5.9	6	0.468	Nil	0.799	0.56	50.0	10.0	Nil
Gbem. Brass Line B(B)	6.9	10	1.110	Nil	0.667	0.35	50.0	10.0	Nil
Gbem. Soil Brass Line(T)	5.3	14	0.606	147.06	0.733	1.02	50.0	10.0	Nil
Gbem. Soil Brass Line(B)	5.4	9	0.780	Nil	0.667	0.38	50.0	15.0	Nil
Tebidara Brass Line 1(T)	4.8	11	0.570	Nil	0.799	0.30	50.0	15.0	Nil
Tebidara Brass Line 1(B)	4.8	14	0.378	Nil	0.667	0.28	62.5	10.0	Nil
Tebidara Brass Line(T)	5.2	6	0.180	Nil	0.933	1.06	50.0	10.0	Nil
Tebidara Brass Line(B)	4.9	8	0.750	Nil	1.266	0.44	62.5	15.0	Nil
Tebidara Brass Line 4(T)	4.7	10	1.470	Nil	1.199	0.36	62.5	15.0	Nil
Tebidara Brass Line 4(B)	5.2	11	0.786	23.53	2.666	0.35	50.0	15.0	Nil
Tebidara Brass Line 7(T)	5.2	9	0.834	Nil	1.866	0.46	50.0	15.0	Nil
Tebidara Brass Line 7(B)	5.2	9	0.480	11.77	1.333	0.40	50.0	15.0	Nil
Tebidara Brass Line 2(T)	4.6	10	0.522	Nil	1.266	0.42	62.5	15.0	Nil
Tebidara Brass Line 2(B)	4.7	13	1.314	Nil	1.666	0.42	50.0	10.0	Nil
Tebidara Brass Line 8(T)	5.5	29	0.450	Nil	0.533	0.88	50.0	15.0	Nil
Tebidara Brass Line 8(B)	4.7	30	0.600	Nil	1.466	0.51	50.0	10.0	Nil

Table 2. Physico-chemical properties of sediments from the pipeline sites within the proximity of spill source.

Sample identity	pH	EC ($mS\,cm^{-1}$)	TOC (mg per 100 g)	SO_4^{2-} (mg per 100 g)	NO_3^- (mg per 100 g)	THC (mg per 100 g)	Cl^- (mg per 100 g)	Alkalinity (mg per 100 g)	PO_4^{3-} (mg per 100 g)
Tebidara FLS Brass Line 7	7.3	32	0.486	Nil	1.20	0.92	50.0	15.0	Nil
Tebidara FLS Brass Line 8	7.5	63	1.740	35.29	3.07	0.34	50.0	10	Nil
Gbem. Brass Line 6	7.9	110	0.090	Nil	0.67	0.46	50.0	15	Nil
TB Sed. 1	7.5	32	1.098	Nil	1.20	1.04	62.5	15	Nil
TB Sed. 3	7.3	533	0.858	123.53	1.33	0.55	300.0	15	Nil
TB Sed. 5	6.8	74	0.840	23.53	2.00	0.90	150.0	10	Nil
TB Sed. 4	7.5	207	0.774	23.53	1.33	0.38	150.0	20	Nil
TB Sed. 2	7.6	180	1.470	5.88	2.00	0.86	25.0	20	Nil

swamps) gives way to saline mangrove swamps. Thus, the area is characterized by some acidic sulphate soils and high salinity, as observed in tables 1 and 2.

Data obtained from the sediment samples are similar to those of the soil samples except for SO_4^{2-}, Cl^-, and alkalinity (table 2). The wider variation in pH range (from a highly acidic 3.7 to a slightly alkaline 7.4) is corroborated by the SO_4^{2-}, Cl^-, and alkalinity values. As shown in table 2, it is clearly conceivable that there were extraneous sources of acidification that probably resulted in the lowering of the pH values of the sediment samples. The total extractable hydrocarbon range of 0.08–1.01 mg per 100 g clearly provides evidence of hydrocarbon sediment contamination which will have affected the physico-chemical characteristics of the sediment samples. The soil type might be responsible for the presence of such high acidity and wide variations in pH. The hydrocarbon may have had some indirect impact in lowering the pH through the production of organic acids by the microbial metabolism that was enhanced by the hydrocarbon contamination.

These alterations in soils and sediment characteristics may have been aggravated by topographic interferences. As observed from the baseline assessment of the sampled areas, the mangrove areas, usually characterized by soils with large quantities of iron sulphides, are stable as long as they remain submerged. They quickly become acidic on exposure to air because of oxidation of sulphides. The resulting strongly acidic soil releases excess aluminium and other toxic chemicals, which are toxic to plants and animals.

3.2 *Vegetal impact*

Generally, a reduction in vegetal population and species diversity was observed within the vicinity of the seismic lines and along the creeks. Trees and plant cover, wherever they were found in the prospect area, were recumbent not with age, but as a result of the long-term effect of the toxic petroleum pollutants. As shown in figure 3, there were long-term effects of the spilled oil on the tree forms within the vicinity of the shoreline perhaps as a result of possible incursions of spilled oils by wave actions. Under such conditions, there must have been a limited supply of oxygen and low oxygen diffusion. Thus, the soils bearing the exposed roots of these tree forms became anaerobic. With this imposed anaerobiosis, the rate of glycolysis might have increased sharply in order to maintain energy supplies near to the aerobic level. This 'Tasteur Effect' usually leads to rapid and inefficient exhaustion of available carbohydrates, a rapid buildup of toxic metabolites and eventual death of both roots and shoots [9, 10]. Lack of adequate oxygen supply to the roots of the affected mangroves may have initiated changes in the amino acid methionine to *S*-adenosylmethionine; this leads to a high concentration of ethylene in the plant system. A high ethylene concentration in petioles is known to cause rapid cell expansion and epinasty, followed by the eventual shedding of leaves and subsequent death of the plant [11].

Some of the tree forms might defoliate and shrivel with time; curling up of leaves, arrested expansion of buds, and some degree of foliar necrosis have also been identified as marked stress signs of some tree forms and crops plagued with petroleum hydrocarbons. Other symptoms include premature abscission and total devegetation, depending on the extent of oiling, crop type, and crop age [12]. The drooping vegetation in the oil-affected area shown in figure 3 might have been recumbent as a result of such effects of the released hydrocarbons. Osuji *et al.* [4] had earlier reported a marked decrease in the population densities of flora and fauna, many months after oil spillage in the Agbada west plain of the Niger Delta. Again, such superficial patches and marked stress signs over long-term effects of oiling were recently observed on several juvenile red mangroves along the Nembe axis of the Niger Delta (G. C. Obute, personal communication, 2005). Therefore, it is foreseeable from field observations, analytical results,

Table 3. Summary of vegetation types in the some prospect areas in Niger Delta (Nigeria) affected by the seismic and production activities.

Location/community	Description of vegetation type
Reubenkiri	Short mangrove system of dominantly *Rhizophora mangle* and *Laguncularia racemosa*
Osokorosoi	Mixed mangrove forest dominated by *R. mangle, L. racemosa, A. germinans, Acrostichum aureum*, and *Paspalum vaginatum*
Wilikiri	Dominated by *Avicinia Africana* (10–15 stands per $100\,m^2$), with patches of *R. racemosa* and *L. racemosa* (2%) intermingled with *R. mangle* and *R. harrisonii*
Piribiri	Thick mangrove forest of *R. racemosa* (up to 70 m)
Tebidara	Thick mangrove system dominated by *R. racemosa* (and about 2% *L. racemosa*)
Adamakiri	Mixed mangrove forest made up of *R. mangle*, *R. harrisonii*, *L. racemosa*, and *Nypa fruticans*
Igbematoru	Mangrove vegetation donated by *R. racemosa* and *R. mangle*

and information from the literature that the 'unhealthy-looking' mangroves may not be the direct consequence of hydrocarbon incursion. There was an indirect impairment by the anoxic conditions imposed as a result of oxygen depletion which was perhaps worsened by the water logging, especially among shoreline vegetations. This may have affected the vegetation characteristics of the study area because in some areas with extensive, firmer soils, as found around Wilikiri, *A. germinans* was dominant with 10–15 stands per $100\,m^2$ (table 3). However, *R. racemosa* plants fringed the creeks and creeklets with a density of four to eight stands per $100\,m^2$, although there was a clear dominance of this species. There was also an intermingling of *R. mangle* and *R. harrisonii*. Thus, the characteristic tidal inundation which increases the mobility of the substrate, salinity fluctuation, and anoxia may have contributed at least in part to the observed despoliation of some species within the vicinity of seismic lines and hydrocarbon percolation. The grass, *Paspalum vaginatum*, and the saltwater fern, *Acrostichum aureum*, were found at the fringes of most dredge spoils.

The affected area can be revegetated as a means of rehabilitating the affected system. Such measures, however, must be adopted with sufficient caution [13] (B. C. Ndukwu, personal communication, 2005). This is because past studies have shown that detrimental effects and subsequent revegetation of soils contaminated with petroleum hydrocarbons ultimately rest on the type of flora indigenous to the affected area.

4. Conclusion

Soil, sediment, and vegetation of seven communities in the Niger Delta (Nigeria) were physicochemically altered by the 4-D seismic and production activities taking place in the region. For instance, electrical conductivity (EC) varied from 6 to $30\,mS\,cm^{-1}$ in the soil samples and from 32 to $207\,mS\,cm^{-1}$ in the sediment samples; a pH range of 4.6–6.9 was measured across the lines in Igbematoru and Tebidara. Generally, the prospect area covered by our investigation was characterized by a mixed mangrove forest dominated by *Rhizophora racemosa*. It was observed that the cutting of the seismic lines was responsible for the vegetal disorientation recurrent in the area. The grass, *Paspalum vaginatum*, and the saltwater fern, *Acrostichum aureum*, were found at the fringe of most dredge spoils. The characteristic tidal inundation which increases the mobility of the substrate, salinity fluctuation, and anoxia may have also contributed, at least in part, to the observed despoliation of some species within the vicinities of the seismic lines and hydrocarbon percolation. An extensive revegetation program is recommended to ensure an effective restoration process of the ecologically fragile zone.

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