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Petroleum Hydrocarbons Contamination Profile of Ochani Stream in Ejamah Ebubu, Eleme Local Government Area of Rivers State, Nigeria

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ABSTRACT: Petroleum hydrocarbon contamination profile, heavy metals and some physicochemical parameters were investigated in Ochani Stream site in Ejamah Ebubu, Eleme Local Government Area of Rivers State. The results show that a major crude oil spillage occurred at Ejamah Ebubu, Rivers State, Nigeria approximately 30 years ago. This assessment of study of the status of the site within the immediate vicinity of the spill revealed the existence of the Ochani Stream site further downstream. With this study, the state of the hydrocarbon contamination resulting from the spill has been identified. The nature and extent of the petroleum hydrocarbon contamination across the Ochani Stream site has been defined. The study revealed a total number of nine dump pits on this site. The pits contained weathered crude oil. Seven of them were located on the elevated dry land to the southwest and slope towards the swampy bush. The other two were located on the opposite side of the stream, to the north of the swamps. The pits which had an average depth of 1.14m, representing a total surface area of about $184m^2$ and a total volume of the order of $220m^3$ of heavily contaminated sludge. The contamination within the swampy area was non-homogenous and randomly distributed. Total Petroleum Hydrocarbon contamination levels varied widely across the site, from negligible, to heavily contaminated. Depth of contamination was very shallow. At an estimated average depth of 150mm over an area of 6.05 Ha the total volume of contaminated soil/sediment was $9075m^3$. The levels of toxic species such as heavy metals, PAH and BTEX compounds were found to be very low and they do not pose a significant environmental hazard. @JASEM

Oil exploration and production activities have significant environmental consequences that occur. The search for oil in Nigeria begun in 1937 (Awobajo, 1981, Ifeadi and Nwankwo, 1980), with increasing production of crude oil and discovery of major oil reserves, more effort was added to exploit this resource. Operations include oil exploration, oil drilling, oil production, oil transportation, oil processing and oil storage (Bossert and Bartha, 1984, Odeyemi and Ogunseitan, 1985). Oil spillages occur through tanker accidents, well blow out, sabotage and accidental rupture of pipelines, resulting in the release of crude and refined oil into terrestrial and aquatic environments (Atlas, 1981, Colwell and Walker, 1977). The highest incidence of oil spills occurred in the mangrove swamps zones and near off shores areas of the Niger Delta which was shown in an analysis of oil spillage statistics in Nigeria during the period, 1976 to 1988. (Ifeadi and Nwankwo, 1989, Awobajo, 1981). These areas are the most productive and sensitive areas in the ecosystem. The oil spillages introduce non-organic, carcinogenic and growth-inhibiting chemicals present in the crude oil and their toxicity to microorganisms and man is well known (Atlas and Bartha, 1973a, 1973b, Odu, 1972, 1978, Okpokwasili and Odokuma, 1990).

The growing demand and supply of fuel oil and new chemicals by the industrialized society of the twenty first century has placed increasingly higher stress on the natural environment (Jaffe, 1991). Large amounts of diverse chemicals enter the environment via industrial discharges and other anthropogenic activities. Of particular concern are the hydrophobic organic compounds, because of their toxicological characteristics and their ability to accumulate in the environment. Soil and water represent the first lines of recipients of oil pollution. Ground water contamination by crude oil therefore is becoming an increasing sensitive issue in Nigeria because most of the water supply is derived from shallow and unconfined aquifers. Furthermore, contamination of land is of paramount importance of man in that it is on this portion of the earth that the anvil of man's existence and activities lie.

Background: Approximately 30 years ago, a major crude oil spillage occurred at Ejamah Ebubu in Eleme Local Government area of Rivers State. The exact source of the oil spill is unknown, but it is suspected to have come from an SPDC pipeline running inside the western boundary of the main site - the Ejamah Ebubu Oil Spill Site.

An undisclosed quantity of crude oil was released and it flowed following the slope of the site in an easterly direction. During the spillage, the crude oil ignited and burned for several days before the fire was brought under control. As a result of the spill, soil and

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surface water at the location became impacted by hydrocarbons.

The Ochani stream is an important seasonal stream in Ejamah Ebubu, a significant conglomerate of small communities in Eleme Local Government area of Rivers State. Based on local information the stream used to be the main source of drinking water and the focal point of most commercial and cultural activities until it was contaminated by crude oil.

The present study - the Site Assessment of Ochani Stream should facilitate an integrated approach to the remediation of the impacted areas resulting from the Ejamah Ebubu oil spill.

Objective of Study: The objective of the study was to provide information and data that may be necessary for and incidental to executing a thorough remediation of the impacted area, through detailed site investigation and assessment.

Study Location: The Ochani Stream site in Ejamah Ebubu, Eleme Local Government Area of Rivers State is approximately situated at geographical latitude 05^0 N and longitude 07^0 8' E.

The entire site is covered by sheet number NB 32 TII NW of the International Map of the World (IMW) Graticule System at a scale of 1 : 50,000.

The site covers an area of approximately 24.19 ha almost completely flanked by farmlands except at the north-west end where a dirt road separates it from the Ejamah Ebubu site. The stream runs south-east of the Ejamah Ebubu site beyond the East-West road, and empties into Ogu Creek - a minor tributary of the Bonny River, near Wakama village in Okrika Local Government Area.

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Summary of Field Investigation: The field investigation consisted of a topographic survey, borehole investigation, and an extensive sampling exercise. The topographic site survey comprised mainly field reconnaissance.

Overall, this exercise was aimed at providing data to facilitate the identification of the extent and severity of the contamination on the site, the characterisation of the geology and the hydrogeology of the site, and the identification of pathways and targets which may be impacted by any contaminants identified.

Topographic survey

Reconnaissance: Physical investigation revealed the following:

- The stream is seasonal and the direction of flow is south-eastwards from the spill site.
- At an approximate chainage of 1km. along the Ejamah-Onne access road, a foot path exists to the farm lands on the left. Nearly 300m along this path a farm hut / hunting shed stands out clearly as an offset with a chain of seven crude oil containment (dump) pits. Local scouts affirm that the crude oil was mopped from the stream after the spillage.
- The stretch of the stream near the farm hut is a swampy jungle, about navel deep, with visible signs of crude oil contamination.

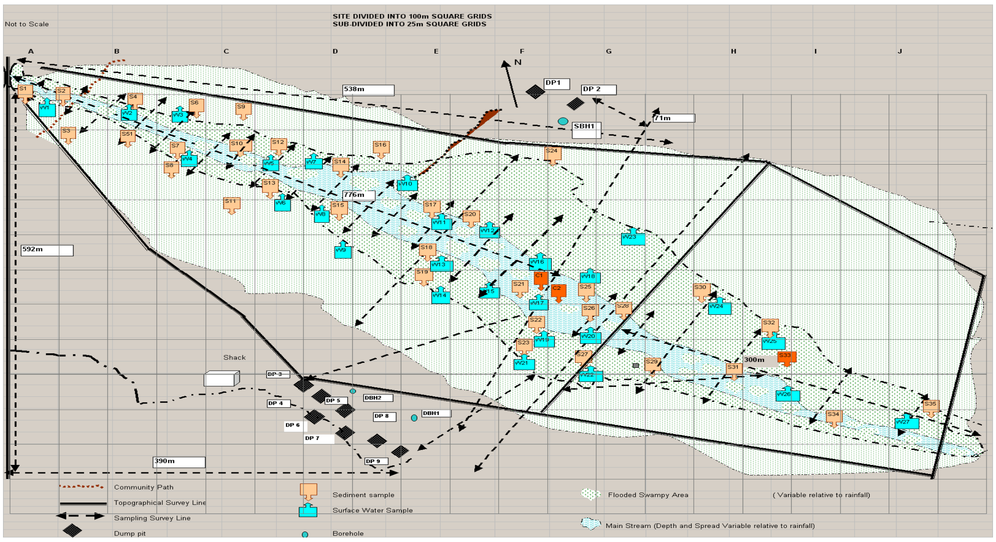

Fig 1: Site Sampling Layout

- On the opposite side of the stream to the north of the swamps, two additional crude oil dump pits were located.
- Generally the seasonal stream is sandwiched by vast stretches of farmlands and plantations.
- No survey beacons, pipeline, utility, or other land use except agriculture was observed along the course under investigation.

Borehole Investigation - Location, Methods and Procedures: This exercise involved the drilling of 2No. 150mm diameter cased boreholes to a depth of 36m adjacent the dump pits on the southern perimeter of the swamp, and 1No. 50mm diameter unlined borehole to a depth of 6m adjacent the dump pits on the northern perimeter of the swamps.

A tripod rig was used for drilling the deep borehole, while the shallow borehole (SBH) was generated using a hand auger. The deep borehole work involved the use of drilling mud (bentonite and water), but no lubricating mud was used for the shallow borehole. The deep boreholes (DBH) were intended to characterise the geology and hydrogeology of the site, and the shallow borehole was intended as part of the soil sampling exercise.

Soil, Sediments and Water Sampling - Rationale, Methods and Procedures: In order to assess potential contamination within the area a large number of paths were cut through the dense bush. These included perimeter paths for topographical survey purposes. Several traverses were cut across the swamp in a North-South direction, for both topographical and sampling purposes, a central path West-East through the flooded swamp and lateral paths at regular intervals along the central path for sampling purposes.

Due to the density of the bush and the variable surface water profile relative to rainfall, it was not possible to define accurately the spatial limits of permanent or temporary surface water. The swamp area was divided into grids measuring approximately 100m by 100m for sampling purposes. Each major grid quadrant was then sub-divided into four 50m by 50m sections in order to locate sampling points with greater accuracy.

Sludge samples were collected from each of the dump pits (DP). Within the swamps samples of surface water, sediment and soil were collected, concentrating on the central flooded areas which would act as potential conduits for oil and water migrating from the main spill site at Ejamah Ebubu.

All samples were logged on chain of custody forms with an indication of date and depth of sampling together with any appropriate notes on the sampling procedure. These documents accompanied the samples from the time they were removed from site, during transport, and through to their delivery to the analytical laboratory.

Site Quality Assurance / Quality Control: Sampling procedures used at the site were monitored at all times to ensure that no cross contamination occurred between samples. The most important method used to eliminate cross contamination was to ensure all sampling equipment was thoroughly washed with Decon-95 laboratory detergent after each sample had been taken. Soil and water samples were stored in dark amber glass jars which were completely filled with sampled material to reduce headspace into which volatile components might partition. Sample covers were properly taped and sealed to ensure that sample integrity was preserved and no moisture would be lost. For the soil samples a mark indicating the top of the sample was drawn on the bottle label. All samples were stored cool (4^0C) in appropriate sample boxes.

The laboratory analyses were conducted using ASTM, APHA and DSM test methods. These methods ensure reproducibility of results and parity of results among all accredited laboratories.

Data generated during the survey was co-ordinated and stored centrally. Records were kept of all correspondence, actions, and analytical results. All computer data entry was checked and cross-referenced.

LABORATORY ANALYSES

Summary of Laboratory Analyses: A large number of soil, sediment and water samples were collected during the fieldwork stage of this site assessment. After collection, the samples were stored in ice chests and transported to the laboratory.

A wide range of analytical tests were carried out to assess the chemical and organic constituent contamination of the samples, namely: TPH, PAH, BTEX, Heavy Metals, pH, conductivity, chloride, sulphate, nitrate, nitrite, phosphate, grain size and microbial species.

Total Petroleum Hydrocarbons (TPH) by IR: Samples were extracted using carbon tetrachloride. The extracts were treated with silica gel to absorb the polar groups. Duplicate and spiked samples were extracted under the same conditions as the original samples. Extracts were scanned from $4000cm^{-1}$ to $400cm^{-1}$ after which peaks occurring between $3000cm^{-1}$ and $270000cm^{-1}$ were quantified from the calibration graph of absorbency against concentration in mg (*Method Reference*: ASTM D3921).

Polynuclear Aromatic Hydrocarbons (PAH) by Gas Chromatography: Solid samples were oven dried and extracted with dichloromethane in a shaking / sonication bath. Water samples were extracted with dichloromethane in a separatory funnel. Duplicate and spiked samples were extracted under the same conditions as the original sample. Sample extracts were analysed with GC / FID (*Method Reference*: ASTM D4657)

Benzene, Toluene, Ethyl Benzene and Xylene (BTEX) by Gas Chromatography: Soil / sediment / sludge samples were extracted with carbon disulphide in a sonication bath while the water samples were extracted with carbon disulphide in a separatory funnel. Duplicate and spiked samples were extracted under the same conditions.

The sample extracts were analysed by GC Unicam 610/FID. The extracts were quantified for BTEX against standards of benzene, toluene, ethyl benzene and xylene of known concentration used to calibrate the GC (**Method Reference:** ASTM D5830)

Heavy Metals: Heavy metals were determined in accordance with ASTM methods by atomic absorption spectrophotometry.

Acidified water samples were aspirated at wavelengths specific to metals of interest and concentrations deduced from the calibration graph. Soil samples were digested in accordance with ASTM D3974 in a semi-automatic digestion unit with Turbosog fume scrubber. Oven dried samples were acid digested with known volume and ratio of distilled water and nitric acid / hydrochloric acid. In both cases, the reported metals were cadmium, chromium, manganese, iron, lead, nickel and vanadium.

Mercury was determined spectrophotometrically at a wavelength of 492nm in accordance with APHA 320B. Extraction was in a separatory funnel with dithizone.

Method References: Cadmium - ASTM D3557, chromium - ASTM D1687, manganese - ASTM D858, iron - ASTM D1068, lead - ASTM D3559, nickel - ASTM D1886, vanadium - ASTM E885 and mercury - APHA 320B

Organic Carbon: Soil samples were ground and sieved through 0.5mm sieve. Potassium dichromate solution was added to sample and swirled. Concentrated sulphuric acid was then added and swirled immediately. Flask containing solution was allowed to stand for given time, and then distilled water was added. Ferroin indicator was added and titrated with ferrous sulphate solution to a maroon colour end point.

$$\text{Organic Carbon (\%)} = \frac{(\text{Meq } K_2Cr_2O_2 - \text{Meq}FeSO_4) \times 0.003 \times 100 \times 1.30}{\text{Weight of sample used}}$$

pH: pH was determined by using pH / temperature meter (ELE 3071). The meter was calibrated with pH buffer of 4 and 7 to correspond with the expected pH range of the sample by adjusting slope calibration controls. Water samples were measured directly by immersing the probes into the samples, while soil samples were extracted with distilled water.

Conductivity: This was measured by using a conductivity meter with temperature compensation (ELE 4071). Calibration was with potassium chloride. Water samples were measured directly, while soil samples were extracted with distilled water.

Chloride: Mixed indicator was added to sample and swirled. Nitric acid was then added and the solution titrated against mercuric nitrate. A blank titration with distilled water was carried out using the same reagents applied to sample (**Method Reference:** ASTM D512)

Sulphate: Sulphate is precipitated in a hydrochloric acid medium with barium chloride to form barium sulphate crystals.

A conditioning reagent was prepared by mixing glycerol with a solution containing HCl, distilled water, ethanol and NaCl (**Method Reference:** APHA 426C)

Microbial Analysis: Dilutions prepared from soil-water suspension were deposited unto the surface of an appropriate solid medium. The inoculum was spread on the media and the inoculated plates incubated at 37^0C for 24hrs.

Plates were observed for growth of organisms into colony, noting colony shape, size, colour and elevation.

On obtaining discrete colonies, successive transfer was made unto fresh and appropriate nutrient media, to obtain pure cultures. Pure cultures were maintained and used for characterisation.

Characterisation was achieved by placing the organisms into groups based on observed phenotypic similarities, thereby assigning names to the isolates. Enabling these were oxidative-fermentation (O-F) test, spores, acid-fast, growth in wet air, wet preparations and motility test.

RESULTS AND DISCUSSION

Swamp: Thirty-seven sediment and twenty-seven water samples were collected from the swamp area, concentrated in the flooded, central stream and its margins. During field operations, visual inspection of the water and sediment indicated that hydrocarbon contamination was unevenly distributed along the apparent route of the stream. In several areas with static water present, oil contamination existed as small patches of weathered, partially degraded oil on the surface of the water. Disturbance of contaminated sediment released hydrocarbon odours and films or globules of oil onto the surface of the water.

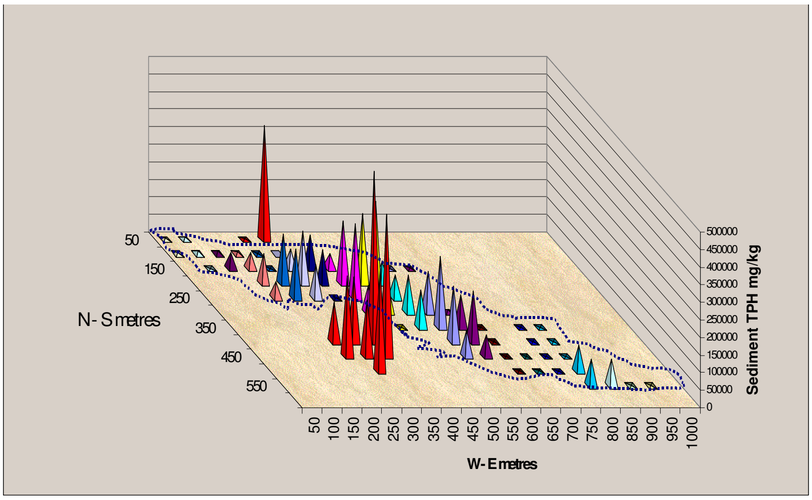

Fig. 2: Sediment TPH (IR) Distribution Profile

The analytical data (Tables 1 to 3) confirm the uneven distribution profile of hydrocarbons within the survey area but that the oil has followed a clear migration pathway in a NorthWest to SouthEast direction along the route of the Ochani stream (Figs 2 and 3).

Swamp sediment TPH values determined by IR ranged from 0 to 538,190 mg/kg. Twenty one (56%) of the sediment samples contained in excess of 5000 mg/kg TPH.

Swamp sediment TPH values determined by GC ranged from 14.6 to 28,687 mg/kg with an average value of 4979 mg/kg. Swamp sediment BTEX values did not exceed the detection limit of 0.1 mg/kg while PAH values ranged from 8.42 mg/kg to 14130 mg/kg with an average value of 2517 mg/kg.

Organic carbon in swamp sediment samples ranged from 1.26% to 14.6% in samples with less than 5000 mg/kg TPH. However, in samples with greater than

5000 mg/kg TPH organic carbon levels increased to between 32.9% and 38.6%.

Swamp water TPH values determined by IR were generally below 10 mg/l, however, six samples contained in excess of 10mg/l with two samples containing 3200 and 6214 mg/l with free oil present. Three swamp water samples were analysed for TPH by GC, BTEX and PAH. TPH by GC levels of 17.5, 0.1 and 27.2 mg/l were recorded. BTEX of 0.1 mg/l was recorded in one water sample at location E23. PAH levels of 7.67, 0.05 and 10.3 mg/l were recorded. One swamp water sample was analysed for Chloride (6.48 mg/l), Sulphate (8.1 mg/l) and conductivity (16.6 µS/cm).

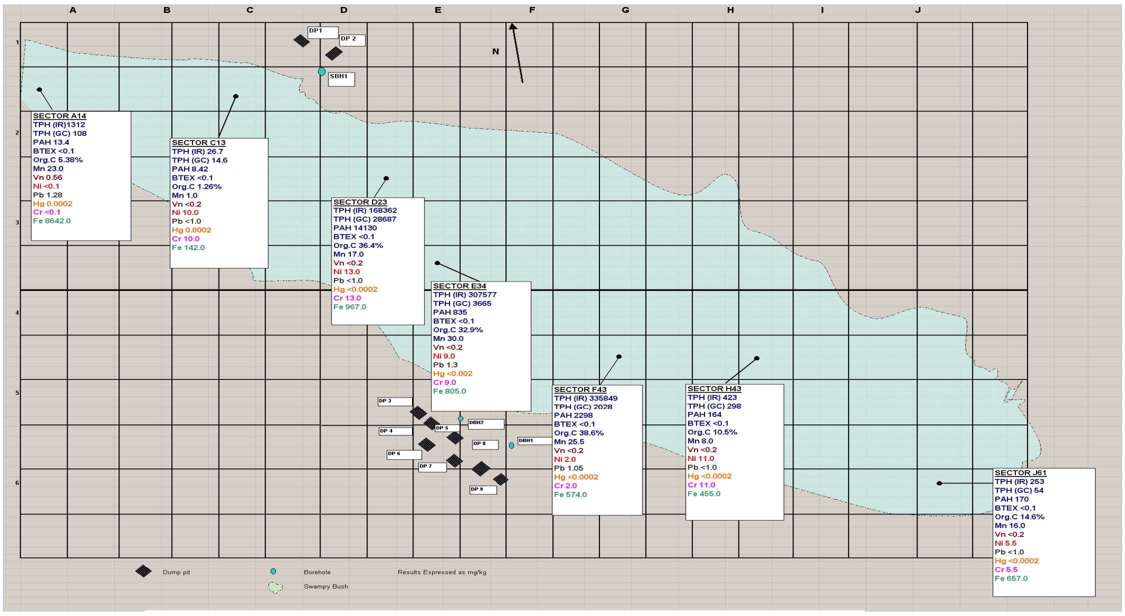

Fig 3: TPH and Metals Analysis in Swamp Sediment Samples

Heavy metal levels in swamp soil and water samples were generally low. *Dump Pits:* With the exception of DP1 on the North perimeter of the swamp, all of the dump pits contain high concentrations of petroleum hydrocarbons as shown in Table 2. The contents of the dump pits were variable ranging from visually clean, sandy soil in DP1 to viscous, weathered oil in DP9. DP9 contained free floating oil and water which overflows onto adjacent soil during rainfall causing staining. A sample of the water in DP9 was collected for analysis.

TPH by IR ranged from 2,584 to 484,586 mg/kg with an average of 243,845 mg/kg. TPH by GC ranged from 433 to 127,650 mg/kg with an average of 26,589 mg/kg. BTEX values did not exceed the detection limit of 0.1 mg/kg. PAH ranged from 510 to 24,948 mg/kg with an average of 6,181 mg/kg. The concentrations of heavy metals in the dump pits are relatively low. Manganese ranged from 4 to 74 mg/kg with an average of 24 mg/kg. Vanadium, Lead, Mercury and Cadmium were below detection limit in all pit samples. Nickel ranged from 0 to 7 mg/kg with an average value of 2.89 mg/kg. Chromium ranged from 0 to 7 mg/kg with an average of 3.1 mg/kg. Iron ranged from 252 to 9008 mg/kg with an average of 2995 mg/kg. Comparables levels of contaminants have been reported by UNEP (2011).

Bore Holes: Soil samples were taken from DBH2 and SBH1 at approximately 3m and 1.5m intervals respectively. The analytical data is shown in Table 3. Due to the washed, sandy properties of the strata underlying the shallow surface soil and clay, low levels of hydrocarbons were recorded in all samples from the shallow bore hole and in the majority of samples from deep bore hole 2 (DBH2).

In DBH2, low TPH (IR) values of 15.4, 46.4, and 4.34 mg/kg were recorded at 3 to 6m, 9 to 12m and

33 to 36m respectively. Ground water collected from DBH 2 contained 1.68 mg/l TPH (IR). BTEX, PAH and TPH (GC) levels in all borehole soil and ground water samples were below detection limits. Heavy metal levels in borehole soil and water samples were low. The physical composition of three, borehole soil samples was examined. Each of the samples contained 95.6% or higher sand, between 1.54 and 3.8% clay and 0.06 to 0.3% silt. Moisture content averaged 21.6%.

Table 1a: Petroleum Hydrocarbon, Oganic Carbon, Chloride, Sulphate and Conductivity Analysis of water and sediment (Unit for Conductivity is uS/cm while other parameters are in mg/kg)

Sediment	Date	TPH IR	TPH GC	BTEX	PAH	Organic Carbon	Cl	SO4	Cond-vity
	13-Aug-98	0.96							
1	13-Aug-98	13359							
1	13-Aug-98	1312	108	<0.1	13.4	5.38%			
1	13-Aug-98	4886							
	13-Aug-98	<0.01							
1	13-Aug-98	4505							
	13-Aug-98	25.6	17.6	<0.1	7.67				
1	13-Aug-98	13285							
1	13-Aug-98	137							
1	13-Aug-98	22669							
	13-Aug-98	<0.01							
1	13-Aug-98	157775							
1	13-Aug-98	26.7	14.6	<0.1	8.42	1.26%			
1	13-Aug-98	127							
	13-Aug-98	1.39							
1	13-Aug-98	<0.01							
1	13-Aug-98	6547							
1	13-Aug-98	180645							
	13-Aug-98	<0.01							
1	13-Aug-98	373056							
	13-Aug-98	4.84							
1	14-Aug-98	168362	28687	<0.1	14130	36.40%	2.22	1.63	67.5
1	14-Aug-98	214971							
	14-Aug-98	247							
1	14-Aug-98	145998							
	14-Aug-98	2.35							
	14-Aug-98	<0.01	<0.01	<0.1	<0.05	not done	6.48	8.1	16.6
	14-Aug-98	<0.01							
1	14-Aug-98	538190							
	14-Aug-98	<0.01							
1	14-Aug-98	256492							
	14-Aug-98	2.95							
1	14-Aug-98	307577	3665	<0.1	835	32.90%			
	14-Aug-98	6214							
1	14-Aug-98	886							
	14-Aug-98	6.67							
1	14-Aug-98	2596							
	14-Aug-98	91.2							
	14-Aug-98	3200							
1	14-Aug-98	425954							
	13-Aug-98	85	27.2	<0.1	10.3				
1	13-Aug-98	38724							
1	17-Aug-98	22844							
1	17-Aug-98	7859							
	13-Aug-98	742							
1	13-Aug-98	335849	2028	<0.1	2298	38.60%			
	13-Aug-98	0.85							
1	13-Aug-98	2167							
	13-Aug-98	<0.01							
1	13-Aug-98	51040							
	13-Aug-98	5875							
1	13-Aug-98	245201							
	13-Aug-98	26.5	4.37	<0.1	2.08				
1	13-Aug-98	632							
1	13-Aug-98	4904							
	14-Aug-98	<0.01							
	14-Aug-98	2.7							
1	14-Aug-98	423	298	<0.1	164	10.50%			
1	14-Aug-98	366							

	14-Aug-98	0.43							
1	14-Aug-98	188							
1	14-Aug-98	298485							
	14-Aug-98	<0.01							
1	14-Aug-98	253	54	<0.1	170	14.60%			

The groundwater was slightly acidic with pH values of 4.34 and 5.34 recorded. Chloride and Sulphate levels were below 6 mg/l and 8.4 mg/l respectively. Conductivity of groundwater recovered from the two deep boreholes was 13.4 and 19.9 µS/cm.

Biology: A composite soil sample from the swamp that was subjected to microbiological analysis was found to contain mainly seven families of bacteria (*Bacillus, Proteus, Staphylococcus, Pseudomonas, Aerococcus, Micrococcus and Actinomyces*) and two of fungi (*Aspergillus, Rhizopus*).

Table 1b: Heavy Metals (mg/kg) Analysis for Swamp Water and Sediment

Section	TYPE	Mn	Vn	Ni	Pb	Hg	Cd	Cr	Fe
A14	sediment	23	0.56	<0.10	1.28	0.0002	<0.05	<0.10	8642
C13	sediment	1	<0.20	10	<1.0	<0.0002	<0.05	10	142
D23	sediment	17	<0.20	13	<1.0	<0.002	<0.05	13	967
E34	sediment	30	<0.20	9	1.3	<0.0002	<0.05	9	805
F43	sediment	25.5	<0.20	2	1.05	<0.0002	1	2	574
H43	sediment	8	<0.20	11	<1.0	<0.0002	<0.05	11	455
J61	sediment	16	<0.2	5.5	<1.0	<0.0002	<0.05	5.5	657
E23	Water	0.03	<0.2	0.02	<1.0	<0.0002	<0.050	<0.10	0.32
Comp.	Soil	88	<0.2	8	<1.0	<0.0002	<0.05	8	7028

Table 2a: Petroleum Hydrocarbon, Organic Carbon, pH, Chloride Analysis of sludge and water from dump pits (mg/kg)

Pit No.	Sludge	Water	TPH IR	TPH GC	BTEX	PAH	Organic Carbon	Ph Value	Cl
DP1	1	0	2584	433	<0.1	510	4.95%		
DP2	1	0	325038	17032	<0.1	24948	28.90%		
DP3	1	0	113444	2266	<0.1	2503	18.2		
DP4	1	0	185266	11021	<0.1	1702	17.00%		
DP5	1	0	228079	13595	<0.1	21798	28.20%		
DP6	1	0	159755	7252	<0.1	2549	22.20%		
DP7	1	0	484576	127650	<0.1	543	29.50%		
DP8	1	0	291600	49527	<0.1	584	39.30%		
DP9	1	0	404259	10525	<0.1	489	51.40%		
Average			243845	26589	<0.1	6181	23%		
DP9	0	1	11231	196	<0.1	35.2	6.83%	4.55	2.22

SITE SENSITIVITY AND RISK ANALYSIS

Description of Areas / Communities: The downstream spill area consists of low-lying, dense swampy bush. To the north and south of the swampy bush is elevated, dry land that is extensively farmed by the Ejamah Ebubu community. Crops such as Cassava, Yam, Plantain, Banana, Palm and other fruits and vegetables are grown in the area.

The Ochani stream flows from the main spill site, under a tarmac road and through a swampy bush. The inner low-lying bush is extremely dense, difficult to access and includes a central permanently flooded swamp, the extent of the swamp being determined by seasonal and occasional rainfall. The Ochani stream therefore diffuses into innumerable streamlets within the swamp until eventually re-forming several kilometres downstream.

During the survey work the depth and area of the flooded swamp, and the flow rate of water passing through the swamp changed quickly and significantly immediately following moderate to heavy rainfall. Within the dense swamp, community activity is limited to occasional hunting, fish trapping and palm cultivation. Palm wine is tapped within the swamp. A hunting shelter is situated adjacent to the crude oil dump pits on the southern perimeter of the swamp. On the northern perimeter of the swamp water is collected regularly by members of the community for washing, cooking and drinking.

*Pollution Pathway and Receptors***:** The Ochani stream site exhibits both mobile (e.g. floating oil and water-soluble components) and immobile (crude oil fractions contained in the dump pits) which have penetrated the soil and aqueous environments to various degrees. The more mobile elements of this product have obviously impacted the environment to a greater extent.

Table 2b Heavy Metals (mg/kg) Analysis of sludge from Dump Pits

Section	TYPE	Mn.	Vn.	Ni.	Pb	Hg	Cd	Cr	Fe
DP1	sludge	12	<0.2	7	<1.0	<0.0002	<0.05	7	9008
DP2	sludge	21	<0.2	4	<1.0	<0.0002	<0.05	4	1838
DP3	sludge	13	<0.2	5	<1.0	<0.0002	<0.05	5	4728
DP4	sludge	38	<0.2	5	<1.0	<0.0002	<0.05	5	4069
DP5	sludge	41	<0.2	2	<1.0	<0.0002	<0.05	2	1508
DP6	sludge	4	<0.2	<0.1	<1.0	<0.0002	<0.05	2	1752
DP7	sludge	7	<0.2	<0.1	<1.0	<0.0002	<0.05	<0.10	489
DP8	sludge	74	<0.2	3	<1.0	<0.0002	<0.05	3	3309
DP9	sludge	7.5	<0.2	<0.1	<1.0	<0.0002	<0.05	<0.1	252
DP9	Water	0.1	<0.20	<0.10	<1.0	<0.0002	<0.05	<0.10	0.82

Table 2c: Dimensions and Mass Balance for Dump Pits

Pit No.	L (m)	W (m)	D (m)	Area (m2)	Volume (m3)	TPH (IR) (mg/kg)	TPH (IR) (kg)
DP1	4	4	1	16	16	2584	41
DP2	4	4	1	16	16	325038	5200
DP3	5	4	1	20	20	113444	2268
DP4	4	4	1.25	16	20	185266	3705
DP5	4	4	1	16	16	228079	3649
DP6	5	5	1.25	25	31.25	159755	4992
DP7	5	4	1	20	20	484576	9691
DP8	5	5	1.25	25	31.25	291600	9112
DP9	6	5	1.5	30	45	404259	18191
Combined				184	215.5	263800	56849

At about one and half kilometres downstream of the survey, area sand is manually removed from the stream bed for sale as a building and construction material. Workers at one of the sand extraction points at Okpako Bridge commented that oil residues are visible in the stream water during the rainy season.

Evaluation of Extent and Volume of Contamination: The division of the site into distinct zones of contamination, each with different characteristics, requires a good estimate of the area and volume covered by each zone in order to devise appropriate remediation options. The dump pits are on good ground and their boundaries are therefore defined with reasonable accuracy. However, the boundaries of the contamination in the swamp are mobile (or dynamic), as they depend largely on the intensity and duration of precipitation, and the season of the year. Nevertheless, an attempt has been made to provide a good working estimate. The values given below are based on a combination of observation of the site, physical measurements on the site, and measurements from samples and borehole logs. The deposits on the swamp were mapped using survey data and ground observation, and the areas covered were estimated from the computer aided drawing of the site.

*Area of Coverage***:** The survey map of the site was prepared using computer aided drawing software. Coordinates obtained from the site survey were used to generate the map. The contamination within the swamp is very unevenly distributed and non-homogenous. An attempt was made to capture on the map the section with the most contamination using first hand observation at the site supported by evidence from analytical data. Measurement of area was then made using the computer aided drawing software. The dimensions of the dump pits were physically measured on the site end their plan areas calculated from the resulting data (See Table2c). The total plan area of the pits was approximately 184 m^2. The heavily impacted area of the swamp measured approximately 6.05 Ha.

Depth of Travel from Sampling Results: The depth of sludge in the pits was measured by coring (see Table 2c), the average value being 1.14m. The non-uniform contamination within the swamp has a depth that varies widely across site. An average depth of 150mm was estimated for this material.

Volume of Wastes: The crude oil dump pits held a combined volume of waste estimated at about 215.5m^3 (see Table 2c).

Table 3a: Petroleum Hydrocarbon, Organic Carbon, Chloride, Sulphate and Conductivity Analysis of Soils and Water from Boreholes

BOREHOLE Depth (m)		Type	TPH (IR)	TPH (GC)	BTEX	PAH	Organic Carbon	pH Value	Cl	SO_4	Cond-vity
DBH1 0 - 3m	S1	Soil	<0.01	<0.01	<0.1	<0.05	<0.04%		1.33	0.08	
3 - 6m	S2	Soil	15.4								
6 - 9m	S3	Soil	<0.01	<0.01	<0.1	<0.05	<0.04%				
9 - 12m	S4	Soil	46.4								
15 - 18m	S6	Soil	<0.01	<0.01	<0.1	<0.05	<0.04%		ND	ND	
21 - 24m	S8	Soil	<0.01								
27 - 30m	S10	Soil	<0.01	<0.01	<0.1	<0.05	<0.04%				
33 - 36m	S12	Soil	4.34								
DBH2	DBW2	Water	1.68	ND	<0.1	<0.05	<0.04%	5.34	0.244	2.79	19.9
DBH1	DBW1	Water	<0.01	ND	<0.1	<0.05	<0.04%	4.34	5.77	3.2	13.4
SBH1 0 - 1m	S1	Soil	<0.01	<0.01	<0.1	<0.05	1.77%	4.12	5.77	0.38	
2 - 3m	S2	Soil	<0.01								
3 - 4m	S3	Soil	<0.01	<0.01	<0.1	<0.05	0.31%	3.86	1.33	1.27	
5 - 6m	S4	Soil	1								
	SBW1	Water	<0.01	ND	<0.1	<0.05	0.01%	ND	1.33	8.4	

Table 3b: Heavy Metals (mg/kg) Analysis of Water and Soils Samples from Boreholes

Section	TYPE	Mn.	Vn.	Ni.	Pb	Hg	Cd	Cr	Fe
DBH1	Water	0.02	<0.2	<0.10	<0.1	<0.0002	<0.05	<0.01	0.09
DBH2	Water	0.02	<0.2	<0.10	<0.1	<0.0002	<0.05	<0.01	0.1
SBW1	Water	0.1	<0.2	<0.10	<0.1	<0.0002	<0.05	<0.01	3.96
DBH1S1	Soil	<0.1	<0.2	<0.1	<0.1	<0.0002	<0.05	<0.10	540
DBH1S3	Soil	<0.1	<0.2	<0.1	<0.1	<0.0002	<0.05	<0.10	391
DBH1S6	Soil	2	<0.2	<0.1	<0.1	<0.0002	<0.05	<0.10	390
DBH1S1	Soil	1	<0.2	<0.1	<0.1	<0.0002	<0.05	<0.10	111
Comp.	Soil	88	<0.2	8	<0.1	<0.0002	<0.05	<0.10	7028
SBH S1	Soil	4	<0.2	2	<0.1	<0.0002	<0.05	<0.10	2273
SBHS2	Soil	2	<0.2	7.5	<0.1	<0.0002	<0.05	<0.10	7467

Table 3c: Grain (particle) size distribution of soils from Boreholes

Section	Type	Clay (%)	Silt (%)	Moisture (%)	Sand (%)
DBH S3	soil	1.54	0.06	21.4	98.4
DBH1	soil	3.8	0.3	22	95.9

DBH1S1	soil	1.81	0.19	21.3	98

Within the swamp the contamination was confined to the surface sediments. Core samples to a depth of 1 metre indicated that hydrocarbon concentration declined rapidly with depth of sediment, the highest values being recorded in the first 150mm.

From the estimated impacted area of 6.05 Ha with a sediment depth of 150mm the contamination within the swamp was estimated to have a volume of about 9075 m^3. However, it was noted that this contamination was non-uniform and non-homogenous and was randomly distributed.

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