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Soil and Groundwater Characteristics of a Legacy Spill Site

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ABSTACT: The soil and groundwater of a legacy spill site in Eleme Local Government Authority Area of Rivers Stae were investigated. The general land use of the area within 1500m radius of the spill site is devoted to farming, fishing and hunting. The main crops grown include yams, cassava, maize, sugarcane, plantain, banana, oil palm, coconut, raffia palm. Families own the land and this ownership is by inheritance. In recent times, people can purchase land for use and others can also hire. The stratigraphy of the subsurface at the study site is closely related to the local geology of the site. Basically, the local geology is that of the coastal plains sands. Generally, the water table at the study area ranges from a low of 0.0m (at ground surface) to a high of about 5.10m. Where it occurs within the subsurface, the groundwater was observed to occur either within the lower part of the sandy clay or within the sands and gravels layer. The general direction of the groundwater flow within the area was observed to be from the North West to the South East. Underground pollution plumes were also in this general direction with possible local variations as dictated by the variations in subsurface lithography from point to point. The potential sources of contamination were: The primary Source of contamination at the study site were the stock piles of excavated surface material deposited at the site; Past accidental leak of crude oil from the 28” pipeline that passes through the western site boundary of the location. The secondary sources were impacted surficial and subsurface Soils (Trial Pits: TP1, TP3, TP5, TP9, TP13, TP15, TP17 and TP21) and Impacted Groundwater (Boreholes: BH1 to BH10); Dissolved Surface Water (Surface Water SW1 to SW6). The chemicals of potential concern (COPCs) are Total Petroleum Hydrocarbons and Heavy metals (chromium and lead). 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 still 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 Information of Spill Site: The legacy spill site is located in Eleme Local Government Area of Rivers State. A major spillage occurred at the western site boundary of the location about 1970 when an undisclosed quantity of crude oil was released from a 28” pipeline that transports crude to Bonny Terminal.

During the spillage, the crude oil ignited and burned for several days before the fire was brought under control. As a result of the fire, a layer of burned, carbonised residue has formed a crust on the surface of the site between the pipeline and surface-water pond approximately in the centre of the site. Photograph of the site are displayed below showing pile of surface material that had been scrapped by others from the North-West area of the site.

Assessment of the spill site had been carried out previously and recently (IPS, 1989; IBS/Devin Associates, 1998; Amajor, 1984).

*Study Objectives:*The study seeks to develop a detailed site specific Conceptual Site Model (CSM) that would identify any potential complete source-pathway-receptor (SPR) linkages.

This was done by: Acquiring information in preparation for the field work at the site; Fieldwork implementation and data collection to enhance understanding of the CSM; Evaluation of the likelihood of occurrence, nature and potential magnitude of contamination at site; Evaluation of potential transport mechanisms and migration pathways by which contamination could migrate off-site; and Estimation of the potential effects of contamination on the subject property and surrounding areas.

Scope of Work for the Investigation: The scope of work covered a desktop investigation, site inspection, fieldwork investigation and laboratory analysis. Components covered through performance of each activity are listed below:

Desktop Investigation: Detailed Site Identification; Description of location and Features of Spill Area; Detailed description of Chronology of Activities; Acquisition of Regional/Local Geological Information

Site Inspection: Community consultations; Site tour and Interview of Residents; Mapping/Location of Sampling Points; Acquisition of Notable Features; Record of present status; Acquisition of data for Scoping of Phase 2 Assessment

Fieldwork: Trial pitting/Probe hole; Borehole drilling and logging; Soil sample collection; Groundwater sampling and in-situ analysis via borehole development and existing community wells; Sediment and surface water sample collection and insitu-analysis; Sample preservation and subsequent conveyance of sample to Laboratory

Laboratory Analyses; Sample preparations; Air drying, Grinding, Sieving and digestion of soil and sediment sample; Actual Laboratory analysis e.g. cations and anions, nutrients, heavy metals, total petroleum hydrocarbons (TPH), etc.

MATERIALS AND METHODS

In order to acquire present/current environmental data and risks about the site, an intrusive ground investigation was carried out from 20th September to 30th September 2010. Samples of the soil, surface water and sediment and underground water were collected and analysed accordingly.

The sampling and analysis was performed in accordance with the work scope, regulatory and other scientific standards. Quality Assurance (QA) of fieldwork and chemical measurements were applied throughout in a consistent manner to ensure reliable results with a high level of reliability

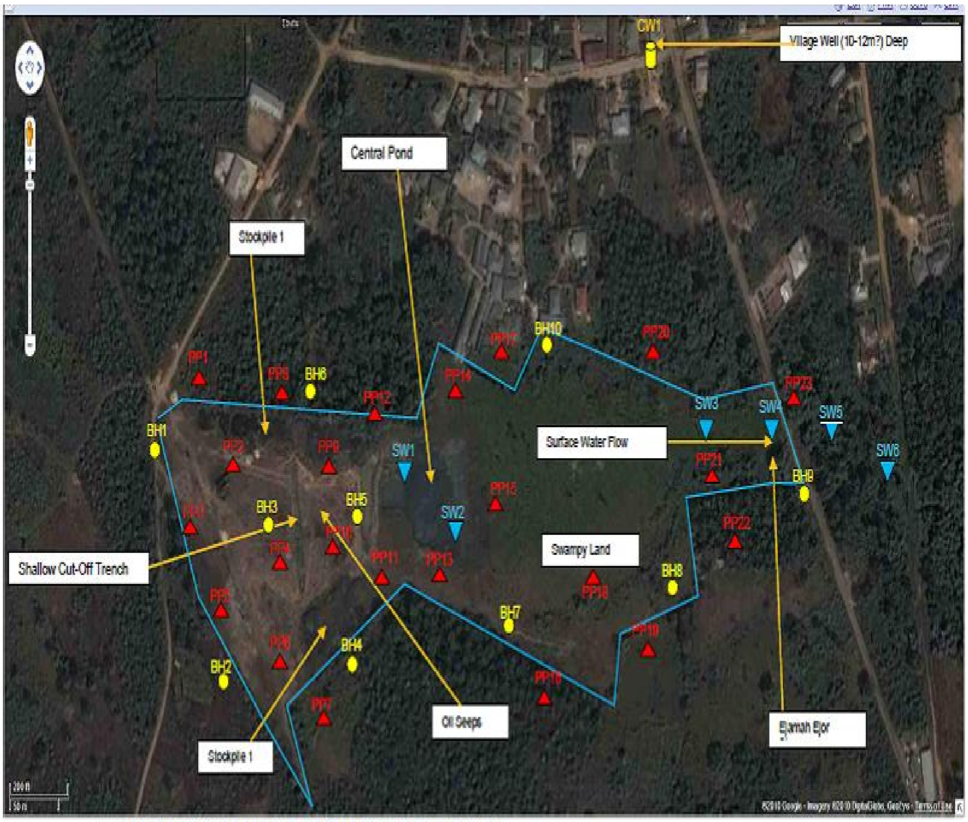

Fig 1: Site Features and Sampling Points Distribution

LEGEND

BH : Bore Holes (10 Nos points)

Surface Water & Sediment (6

Profile Pits (23 points)

Community Water Well (1 No.)

Sampling Design and Positioning: Positioning was carried out with the aid of the GPS in line with sampling points distribution plan.

Soil Sampling Procedure and Investigation: Soil sampling was carried out at designated points during test pitting and borehole drilling. At each sampling point, grab soil samples were collected with the aid of a hand trowel and transferred into various containers based on parameter to be analysed.

Test Pitting: Twenty-three (23) trial pits were dug with the aid of Spade and Hand trowel. All trial pits were completely backfilled with the excavated material after completion of all investigations for and sampling for soil profile using the Unified Soil Classification System (USCS), visual observations, the presence of fill or reworked material; field headspace screening measurements, the presence of moisture, product, staining and odours, and any other observations relevant to the investigation of potentially impacted soil.

Borehole Drilling: Ten (10) exploratory boreholes were drilled with the aid of a percussion drilling rig. The groundwater monitoring wells were strategically located at the site in a manner that will support the investigation or delineation of the extent of the plume. Reinforced Polyvinyl Chloride (PVC) pipes that were duly sterilized were used for the casing of the boreholes inorder to stabilize the borehole. Suitable screens with slots corresponding to the grain size distribution of the aquifer materials, were also installed at the base of the borehole, where the water table was intersected.

Gravel pack materials and size were selected to mark the grain size distribution of the aquifer material to ensure a good filter zone around the screen. Bentonite seals were placed on top of the aquifer layer prior to backfilling of the manhole to protect the groundwater system from external pollution through seepage along the hole annulus.

The outer casing of the borehole made up of galvanized iron pipe, was raised at least 0.5m above the ground level, and was properly secured with proper lock to prevent third party interference.

Fig 2: Visible oil seepage on the soil surface

Fig 3: Caked soil at the site

Fig 4: Farmland around the site

Figure 5: Trial pit for soil profile determination

Figure 6: Existing Community Well

Figure 7: Section of the Ochani Stream

Development of Borehole: After the drilling, and installation of casing, screen and gravel pack, the borehole was developed by surging, flushing and back washing, till all the fines were removed and the hole was clean.

Water Sampling Procedure: Water sampling was carried out on the pond, surface water flow from the Ejamah-Ejor stream, other points beyond the spill site and boreholes as indicated in the sampling points distribution plan. Generally, the sampling procedures were in line with DPR (2002) guidelines and standards (Part D) and American Society for Testing and Material (ASTM) and American Public Health Association (APHA) sampling protocols.

Fig. 8: Top view of exploratory borehole

Fig. 9: Oil seepage hotspot near exploratory well

In-situ measurements were carried out for some parameters in all water samples with the aid of the in-situ meters. These parameters were pH, temperature, dissolved oxygen (DO), salinity, total dissolved solids, turbidity and conductivity.

Sediment Sampling Procedure: Sediment sampling was carried out at designated points across the surface water with the use of sediment Grab. At each sampling point, sediment samples were scooped from the grab cup, and transferred into various containers based on parameter to be analysed.

General Information on Exploratory Well	
B/Hole depth(M)	18
Casting depth (M)	0-14
Gravel Pack (M) screen depth	14-17.5
Sand Tilling	0-13
Depth from casting to ground surface (M)	0.08
Depth from ground surface to water table	5
Gravel pack depth (M)	13-17.5

Soil Description with Depth:
1.2m of soil is brown to dark due to oil impact.
4m of sandy grey clay with silt intercolations
2.5m grey brown clay
3.5m fine/medium coarse white grey (Screen zone)
2m white clay thick and compacted

Observations: Oil film on top of water is 2.5cm

Laboratory Analytical Methods and Procedures: The analytical procedures adopted for the various parameters are APHA methods.

Table 1: TPH, PAH and BTEX levels in trial pits

SAMPLES	Depth	RESULT		
		TPH, mg/kg	PAH, mg/kg	BTEX, mg/kg
DPR EGASPIN Intervention Levels in (mg/kg) P.280	-	5000	40	246
TP1	1m	6,900	252	<0.01
TP3	1m	6,300	309	<0.01
TP5	1m	5,100	90	<0.01
TP7	1m	3,900	89	<0.01
TP9	1m	157,500	1,876	<0.01
TP11	1m	4,800	267	<0.01
TP13	1m	12,300	600	<0.01
TP15	1m	42,300	1290	<0.01
TP17	1m	37,200	1410	<0.01
TP21	1m	3,450	62	<0.01
TP23	1m	1,650	44	<0.01

RESULTS AND DISCUSSION

Site Identification: The spill site in Eleme Local Government Area in the Niger delta area of Nigeria is approximately at latitude 4°46' N and longitude 7°7.5' E. The sheet number on the International Map of the World (IMW) graticule system containing the site is NB32 TII NW at a scale of 1 : 50 000.

The site covers an area of approximately 8.6 hectares almost completely flanked by farmlands except at the north-easterly end where a graded (but much eroded) secondary road serves as an access to the East-West Road near Onne.

Site Location: The general land use of the area within 1500m radius of the spill site is devoted to farming, fishing and hunting **(Fig 1)**. The main crops grown include yams, cassava, maize, sugarcane, plantain, banana, oil palm, coconut, raffia palm. Families own the land and this ownership is by inheritance. In recent times, people can purchase land for use and others can also hire.

A village access road runs along the East boundary of the site, in a South Easterly direction, and passes through local communities. A stream also runs from the Eastern edge of the site in a south East direction and passes through local communities.

Stratigraphy of the Area: The geology of the area is that of coastal plains sand of material that are of Pleistocene-Oligocene in age. This forms part of the uppermost seat of the Benin formation which are generally friable silts, sands, shales and clays. Basically the stratigraphy at the site location is expected to consist of upper top soils that support vegetation. Beneath these should be sand and gravels of varying depth levels

PIA report on the area showed that the water table of the location ranged from 0.1m to 5.10m while the general direction of the groundwater flow is from Northwest to SouthEast. Potential offsite underground hydrocarbon release is likely to be in this direction. Monitoring wells and hand dug well were noted at two points within the location. 3 wells were also sighted at strategic points around the site. Dates of drilling and objectives of the existing wells could not be ascertained at the time of the visit to the site.

*Site Features***:** The spill site is bordered by a number of villages and farms, which constitute potential, sensitive receptors of contamination from the site. Notable features in the spill site include stockpiles of excavated caked crust, shallow cut-off trench, swampy land, oil seep area, central pond, pipeline route and Ejamah-ejor stream. **(Figures 1 - 4).**

Although the spill site has been enclosed by a block concrete wall and no farming takes place within the enclosed area, it is still accessible to the local community who use it as a pathway to local farms and to by-roads/paths. A village access road runs along the East boundary of the site, in a South Easterly direction, and passes through local communities. A stream, named the Ejamah-Ejor stream, also runs from the Eastern edge of the site in a South East direction and passes through local communities.

At the central area is a pond which flows into the Ejama-Ejor stream. The Ejamah-Ejor stream connects with the Kuleke stream which subsequently flows into the Ochani stream. The Ochani stream stretches through the East West Road follows a course of rivers into the sea. Beyond the central pond is a swampy area with degraded crude oil visible in the wet land.

Geological Information: The stratigraphy of the subsurface at the study site is closely related to the local geology of the site. Basically, the local geology is that of the coastal plains sands as shown in the Shell B.P. Development Company of Nigeria Limited, Geological Series Maps (1962), sheet 84 (Port Harcourt Sheet).

Table 2: Results of Analysis of soil samples from some boreholes

Parameter / Borehole	Borehole Depth (M)	Aquifer Depth (M)	Permeability (Cm/Sec)	Permeability Class	Moisture Content (%w/w)	Liquid Limit (Ll %)	Plastic Limit (Pl %)	Plasticity Index (Pi %)	Plasticity Class	Soil Fractions	Aquifer Lithologic Description	Aquifer Nature
BH_1 (1)	18	6	6.3161×10^{-4}	S P	14.6	36	19	17	Medium Plastic	52% Sand, 42% Clay	Medium-Grain Firm Grayish Sandy-Clay	U
BH_1 (2)	18	12	3.1582×10^{-3}	M P	9.4	0	0	0	Non – Plastic	86% Sand, 10% Clay	Fine-Medium Grain Poorly Sorted Whitish Sand	C
BH_2 (1)	17.5	6	1.3481×10^{-4}	S P	16.7	43	29	14	Medium Plastic	55% Sand, 38% Clay	Fine Grain Firm Brownish Sandy-Clay	U
BH_2 (2)	17.5	12	7.6256×10^{-3}	M P	15.1	40	28	12	Medium Plastic	58% Sand, 40% Clay	Medium-Grain Whitish Firm Sandy	C

											Clay	
BH_3 (1)	17.5	9	6.412×10^{-3}	M P	15.4	45	34	13	Medium Plastic	51% Sand, 40%, Clay	Medium-Grain Whitish Firm Sandy Clay	C
BH_3 (2)	17.5	14	2.7824×10^{-3}	M P	7.8	-	-	-	Non – Plastic	78% Sand, 14% Silt	Medium-Grain Loosely Sand	C
BH_4 (1)	17	6m	8.1251×10^{-4}	S P	5.9	-	-	-	Medium Plastic	56% Sand, 38% Clay	Medium-Grain Whitish Firm Sandy Clay	U
BH_4 (2)	17	12	5.4134×10^{-3}	M P	5.9	-	-	-	Non – Plastic	89%, Sand, 9% Silt	Fine Grain Whitish Loosely Sand	C
BH_5 (1)	17.5	6	1.2781×10^{-5}	S P	15.6	43	29	14	Medium Plastic	56% Sand 42% Clay	Medium-Grain Grayish Firm Sandy-Clay	U
BH_5 (2)	17.5	12	6.1468×10^{-3}	M P	7.9	-	-	-	Non – Plastic	86% Sand 8%Silt	Medium Grain Whitish Loosely Sand	C
BH_6 (1)	16.5	9	3.8625×10^{-3}	M P	8.7	-	-	-	Non – Plastic	96% Sand, 3%Silt	Fine- Grain Whitish Loosely Sand	C

U = Unconfined; C = Confined; SP = Slightly Permeable; MP = Moderately Permeable

The materials of the site are of Pleistocene-Oligocene in age and form parts of the upper-most sections of the Benin formation which are generally partly friable silts, sands, shales and clays. Basically, the stratigraphy at the study site consists of an upper top soil that supports the vegetation. Beneath these are the sandy clays which are further underlain by sand and gravels to varying depth levels. Possibly below this layer is clayey sand layer. Each of these layers is described in detail below.

Subsoil Description and Profiles

Dark Grey Sandy Clays: This layer extends in places from a depth of about 0.01 metre to depths ranging from 2.75 metres to 6.25metres (See table 2). The layer is composed predominantly of silty clays and sandy clays that possess low t o medium plasticity. The materials in this layer can be classified as CL under the Unified Soil Classification (U. S. C.) system of soil nomenclature. The Plasticity Indices (PI) for the dark grey sandy clays vary from 27.9% to 24.3% thus indicating a moderately plastic consistency. The liquid limit values for these materials vary from a low of 30.0% t o a high of 40.5%.

Sands and Gravels: This layer extends from depths of, between 2.75m and 6.25m to depth of 30.0m and more. In Borehole No.1, for instance, sands and gravels were obtained down to depths of 45.0 metres. Thus, the thickness of this layer varies from 20.0 metres t o over 38.75 metres. The layer is composed predominantly of medium to coarse grained sands and gravels of light brownish colour. The materials in this layer can be classified as SP and SW under the USC system of nomenclature. These materials are basically non-plastic.

Table 3: Geotechnical Analysis of Exploratory Borehole Soil Samples

Parameter Borehole	Borehole Depth (M)	Aquifer Depth (M)	Permeability (Cm/Sec)	Permeability Class	Moisture Content (% w/w)	Liquid Limit (Ll %)	Plastic Limit (Pl %)	Plasticity Index (Pi %)	Plasticity Class	Soil Fractions	Aquifer Lithologic Description	Aquifer Nature
BH_6 (2)	16.5	14	8.7635×10^{-3}	M P	7.0	-	-	-	Non – Plastic	84% Sand, 8% Silt	Medium Grain Whitish Loosely Sand	C
BH_7 (1)	16.5	6	1.6426×10^{-4}	S P	16.0	48	36	12	Medium Plastic	52% Sand 47% Clay	Medium Grain Whitish Sandy Clay	U
BH_7 (2)	16.5	12	2.1345×10^{-3}	M P	11.8	12	8	4	Low Plastic	56% Sand, 38% Silt	Medium Grain Whitish Loosely Silty Sand	C
BH_8 (1)	16.5	6	4.8610×10^{-4}	S P	14.7	40	28	12	Medium Plastic	58% Sand, 34% Clay	Medium Grain Whitish Moderately Firmly Sandy Clay	U
BH_8 (2)	16.5	12	6.1122×10^{-4}	S P	15.2	44	27	14	Medium Plastic	56% Sand 42% Clay	Medium Grain Whitish Moderately Firmly Sandy Clay	C
BH_9 (1)	16.0	6	5.2648×10^{-4}	S P	14.0	34	18	16	Medium Plastic	52% Sand 39% Clay	Medium Grain Whitish Moderately	U

											Firmly Sandy Clay	
BH_9 (2)	16.0	12	4.7149×10^{-3}	M P	8.4	-	-	-	Non Plastic	84% Sand 5% Silt	Fine Grain Whitish Loosely Sand	C
BH_{10} (1)	16.0	6	4.1576×10^{-4}	S P	15.0	40	26	14	Moderately Plastic	55% Sand, 38% Clay	Medium Grain Whitish Moderate Firm Sandy Clay	U
BH_{10} (2)	16.0	12	7.1348×10^{-4}	S P	8.7	-	-	-	Non Plastic	87% Sand 8% Silt	Medium Grain Loose Whitish Sand	C

Clayey Sands: This layer extends in places from depths ranging between 25.0m and in excess of 45.0m. The layer is composed of light brown, fine-medium grained silty sands and clayey sands, which can be classified as SC under the USC classification scheme. The plasticity indices (PI) for these light brown clayey sands ranges from 14.7% to 21.2% while the liquid limit values vary from 27.1% t o 35.0%. Thus, these materials are of low to moderate plasticity (See Table 3).

Literature reviewed showed that the soils that constitute the surface and subsurface materials at the study sites are basically light to dark greyish sandy clays and silty clays in certain localities especially those close to the source of the oil pollution. Beneath these sandy clays are light brown medium to coarse grained sands and gravelly sands.

Groundwater Elevation: Generally, the water table at the study area ranges from a low of 0.0m (at ground surface) to a high of about 5.10m. This information was obtained from the boreholes as well as existing streams within the study area, Where it occurs within the subsurface, the groundwater was observed to occur either within the lower part of the sandy clay or within the sands and gravels layer. The general direction of the groundwater flow within the area was observed t o be from the North West t o the South East. Underground pollution plumes are also believed to be in this general direction with possible local variations as dictated by the variations in subsurface lithography from point to point.

Field Observations: A total of 23 trial pits and 10 exploratory holes were dug at the study site for the site assessment (typical trial pit in Figure 5).

Potential Sources of Contamination: The potential sources of contamination are:

Primary Sources: Stock piles of excavated surface material deposited at the site; Past accidental leak of crude oil from the 28" Trans Niger Pipeline that transports crude from Agbada/Bomu to Bonny Terminal at the western site boundary of the location.

Secondary Sources: Impacted Surficial Soils: Impacted Subsurface Soils (Trial Pits: TP1, TP3, TP5, TP9, TP13, TP15, TP17 and TP21 – see Table 1); Impacted Groundwater (Boreholes: BH1 to BH10); Dissolved Surface Water (Surface Water SW1 to SW6)

Chemicals of Potential Concern (COPCs): The chemicals of potential concern are: Total Petroleum Hydrocarbons; Heavy metals (chromium and lead)

Table 4: Chemical parameters of Exploratory Borehole Soil Samples

SAMPLE ID. /DEPTH		Metals										pH	Organics		
		As	Ba	Cd	Cr	Co	Cu	Hg	Pb	Ni	Zn		PAH	TPH	BTEX
BH1	1.5m	-	-	-	-	-	-	-	-	-	-	6.9	842	8,385	<0.01
	6.0m	<0.01	<0.1	1.44	211	8.79	4.23	<0.001	20.1	11.21	19.34	7.3	779	1,269	<0.01
	9.0m	-	-	-	-	-	-	-	-	-	-	-	1,140	1,449	<0.01
BH2	1.5m	-	-	-	-	-	-	-	-	-	-	-	3,105	9,720	<0.01
	3.0 m	-	-	-	-	-	-	-	-	-	-	-	5,620	9,510	<0.01
	6.0 m	<0.01	<0.1	0.03	158	1.59	0.80	<0.001	19.7	<0.01	9.60	7.4	8,535	9,345	<0.01
BH3	1.5 m	-	-	-	-	-	-	-	-	-	-	-	1,319	3,270	<0.01
	6.0 m	<0.01	<0.1	0.38	428	0.32	9.60	<0.001	9.64	10.6	8.27	-	2,505	8,550	<0.01
	9.0 m	-	-	-	-	-	-	-	-	-	-	-	968	10,620	<0.01
BH4	3.0 m	-	-	-	-	-	-	-	-	-	-	-	78.0	606	<0.01
	6.0 m	<0.01	<0.1	<0.01	77.7	0.93	7.45	<0.001	10.4	14.7	15.9	7.3	123	576	<0.01
	10.5 m	-	-	-	-	-	-	-	-	-	-	-	132	456	<0.01
BH5	3.0 m	-	-	-	-	-	-	-	-	-	-	-	530	1154	<0.01
	6.0 m	<0.01	<0.1	<0.01	152	<0.01	<0.01	<0.001	12.2	<0.01	13.8	7.5	588	884	<0.01
BH6	3.0 m	-	-	-	-	-	-	-	-	-	-	-	131	504	<0.01
	6.0 m	<0.01	<0.1	<0.01	86.4	9.05	0.89	<0.001	<0.01	<0.01	7.29	7.4	84.0	794	<0.01
BH7	6.0 m	<0.01	<0.1	<0.01	109	<0.01	0.41	<0.001	6.95	<0.01	7.47	7.4	42.0	288	<0.01
BH8	6.0 m	<0.01	<0.1	<0.01	103	<0.01	<0.01	<0.001	8.3	<0.01	6.9	7.4	48.4	460	<0.01
BH9	1.5 m	-	-	-	-	-	-	-	-	-	-	-	57.0	524	<0.01

	6.0 m	<0.01	<0.1	<0.01	205	0.27	1.80	<0.001	1.76	<0.01	12.8	7.5	52.5	528	<0.01
	15.0 m		-	-	-	-	-	-	-	-	-	-	66.0	524	<0.01
BH10	3.0 m		-	-	-	-	-	-	-	-	-	-	1,665	5,535	<0.01
	6.0 m	<0.01	<0.1	<0.01	138	8.15	4.66	<0.001	8.60	<0.01	24.65	7.5	510	4,860	<0.01
	7.5 m	-	-	-	-	-	-	-	-	-	-	-	7,320	12,225	<0.01
BH11	6.0 m	<0.01	<0.1	<0.01	88.5	<0.01	1.6	<0.001	4.5	9.0	12.6	7.5	130	2,120	<0.01
BH12	6.0 m	<0.01	<0.1	<0.01	127	<0.01	3.4	<0.001	1.9	7.2	8.5	7.3	40.8	394	<0.01
BH13	6.0 m	<0.01	<0.1	<0.01	93.6	0.44	1.2	<0.001	6.0	4.8	10.4	7.4	31.6	280	<0.01

Table 5: Physico-chemical characteristics of Groundwater at Study Site

PARAMETER	DPR EGASPIN	BH1	BH2	BH3	BH4	BH5	BH6	BH7	BH8	BH9	BH10
	Intervention Levels in (mg/l) P.280	After Purging	After Purging	After Purging	After Purging	After Purging	After Purging	After Purging	After Purging	After Purging	After Purging
pH	N/A	5.9	6.2	6.0	5.9	5.4	6.5	6.1	6.7	6.4	5.9
Temp, °C	N/A	25.7	26.1	26.1	25.8	25.9	25.7	25.1	26.2	25.8	26.4
(TDS), mg/l	N/A	55	109	32	25	18.1	15	10	22	45	15.0
Cond (EC),us/cm	N/A	100	219	65	51	36.4	31	22	45	95	30.1
(DO), mg/l	7.5-8.5	4.5	3.0	5.2	5.0	6.2	4.4	4.5	6.0	5.2	4.8
Turbidity, NTU	N/A	844	76	550	330	150	54	112	208	85	9.0
As, mg/l	0.06	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ba, ,mg/l	0.625 (0.63)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.01	<0.01	<0.01	<0.01	<0.01
Cu, mg/l	0.075 (0.08)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zn, mg/l	0.8	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01
Cd, mg/l	0.006 (0.01)	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ni mg/kg	0.075 (0.08)	0.03	<0.01	<0.01	0.04	<0.01	0.02	<0.01	0.02	<0.01	0.03
Hg, mg/l	0.0003 (sig Fgr.)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.001	<0.001	<0.001	<0.001	<0.001
Pb, mg/l	0.075 (0.08)	<0.01	0.03	<0.001	<0.001	0.14	<0.001	0.02	0.09	0.06	<0.001
Co, mg/l	0.1	<0.01	0.05	0.03	0.05	0.04	0.03	<0.001	0.02	<0.01	0.05
Cr, mg/l	0.03	**0.09**	**0.03**	**0.05**	**0.13**	**0.27**	0.07	0.18	0.05	0.13	0.09
BTEX, mg/l	0.03 (benzene)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
PAH, mg/l	0.07 Total of 10*	**22.6**	**14.2**	**34.4**	**2.8**	**17.6**	**2.06**	**2.36**	**1.21**	**1.97**	**1.51**
TPH, mg/l	0.6	**31.3**	**366**	**203**	**4.6**	**18.4**	**2.50**	**4.50**	**3.70**	**3.70**	**171**

PARAMETER	METHOD	DPR EGASPIN	BH11		BH12		BH13	
		Intervention Levels in (mg/l) P.280		After Purging		After Purging		After Purging
BTEX, mg/l	ASTM D 2908	0.03 (benzene)		<0.01		<0.01		<0.01
PAH, mg/l	ASTM D 4657	0.07 Total of 10*		2.6		3.7		12.5
TPH, mg/l	ASTM D 3921	0.6		14.7		14.7		50.4

TPH levels in borehole soil samples varied with depth and ranged from 280 to 12,225 mg/kg (see Table 4). In groundwater samples these COPCs as presented in Table 5ranged from 1.2 to 344 mg/l (PAHs) and 2.5 to 366 mg/l (TPH). By contrast, Tables 6 & 7 show that BTEX, PAH and TPH were relatively very low in sediment and surface water but very high in sub-surface soil samples (Table 2) on the legacy spill site. pH values ranged from 5.7 to 7.8.

Potential Transport Mechanisms and Exposure Pathways: COPCs are transported through erosion, storm water, volatilization and atmospheric dispersion, leaching and groundwater in relation to the source of contamination. The exposure pathways to COPCs are though soil ingestion and absorption, inhalation of vapour or particulates, use of potable water for domestic and commercial purposes, recreational use of the environment and interaction with the sensitive habitat (see Figs 10 & 11).

Potential Receptors: Potential receptors that could be affected by the exposure to COPCs are in four categories as follows: Residential Receptors (residents of adjoining communities); Commercial/Industrial Receptors (private and public workers); Recreational Receptors (tourists and visitors) and Ecological Receptors (flora and fauna, phyto/zooplankton).

Table 6: Physico-chemical characteristics of Surface water at Study Site

PARAMETER	DPR EGASPIN	Surface Water						
	Intervention Levels in (mg/l) P.280	SW 1	SW 2	SW 3	SW 4	SW 5	SW 6	Comm. Well water
pH	N/A	7.8	7.6	6.4	6.5	5.7	6.3	5.9
Temperature,^{o}C	N/A	30.6	30.1	29.2	29.1	29.4	26.2	27.8
(TDS), mg/l	N/A	6.0	5.0	58	30	8.0	6.0	213
Conductivity (EC),us/cm	N/A	12.0	10.0	10.0	60	16.0	12.0	424
(DO), mg/l	7.5-8.5	6.2	5.5	6.0	4.5	5.5	4.0	6.2
Turbidity, NTU	N/A	24.6	65.0	40.6	38.8	76.2	37.7	10.0
Arsenic (As), mg/l	0.06	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Barium (Ba),mg/l	0.625 (0.63)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Copper (cu), mg/l	0.075 (0.08)	0.04	0.01	0.04	0.03	0.02	<0.01	<0.01
Zinc (Zn), mg/l	0.8	<0.01	0.006	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium (Cd), g/l	0.006 (0.01)	0.01	0.02	0.04	0.03	0.05	0.01	<0.01
Nickel(mg/kg)	0.075 (0.08)	0.08	0.04	0.04	**0.17**	0.08	0.03	<0.01
Mercury (Hg), mg/l	0.0003 (sig Fgr.)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Lead (Pb), mg/l	0.075 (0.08)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cobalt (Co), mg/l	0.1	0.04	**0.11**	0.07	0.07	0.10	0.06	**0.12**
Chromium (Cr), mg/l	0.03	**0.18**	**0.41**	**0.29**	**0.24**	**0.42**	**0.12**	**0.20**
BTEX,mg/l	0.03 (benzene)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
PAH, mg/l	0.07 Total of 10*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
(TPH),mg/l	0.6	**3.1**	**1.7**	**5.1**	**4.3**	**4.3**	**3.6**	<0.1

Table 7: Physico-chemical characteristics of Stream Sediment at Study Site

PARAMETER	DPR EGASPIN	SEDIMENT					
	Intervention Levels in (mg/l) P.280	SWSD1	SWSD2	SWSD3	SWSD4	SWSD5	SWSD6
Arsenic (As), mg/kg	55	<0.01	<0.01	<0.01	<0.01	NO ACCESS	<0.01
Barium (Ba), mg/ kg	625	<0.1	<0.1	<0.1	<0.1		<0.1
Copper (cu), mg/kg	190	<0.01	<0.01	<0.01	<0.01		<0.01
Zinc (Zn), mg/kg	720	15.2	16.7	74.5	65.8		54.4
Cadmium (Cd), mg/kg	12	<0.01	<0.01	<0.01	<0.01		<0.01
Nickel (mg/kg)	210	8.6	13.3	13.0	1.9		18.6
Mercury (Hg), mg/kg	10	<0.001	<0.001	<0.001	<0.001		<0.001
Lead (Pb), mg/kg	530	14.1	15.4	17.4	13.8		119.5
Cobalt (Co), mg/kg	240	14.5	5.9	13.2	6.7		4.3
Chromium (Cr), mg/kg	380	**575**	**624**	115	43.4		48.4
BTEX, mg/kg	246	<0.01	<0.01	<0.01	<0.01		<0.01
PAH, mg/kg	40	<0.01	<0.01	<0.01	<0.01		<0.01
(TPH), mg/kg	5000	<0.01	<0.01	<0.01	<0.01		<0.01

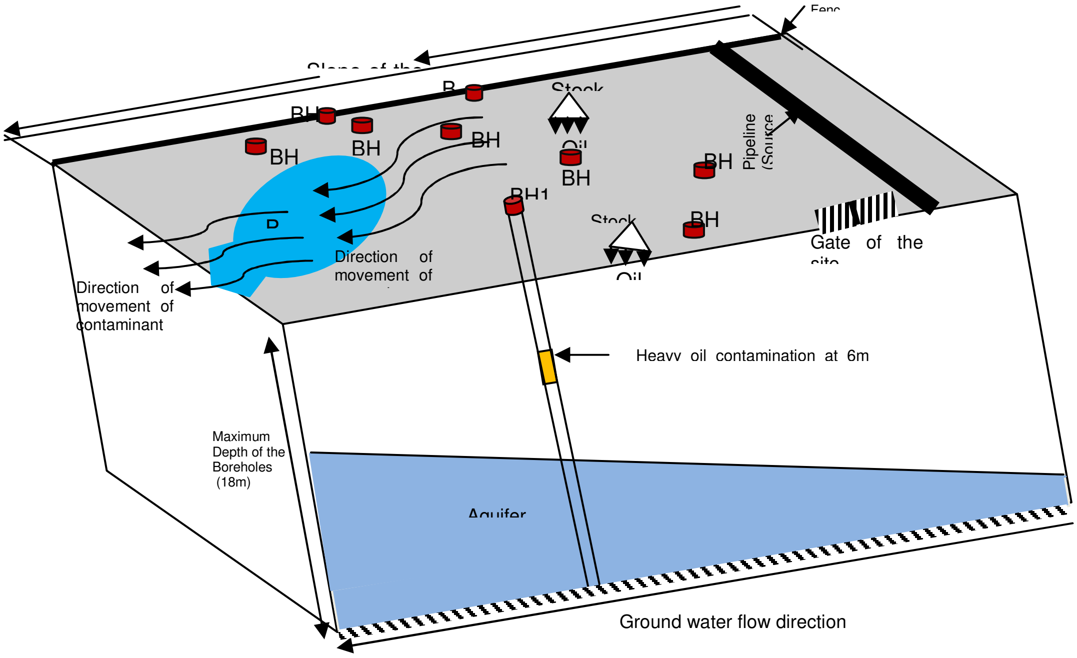

Fig 10: Conceptual Site Model of the Spill Site

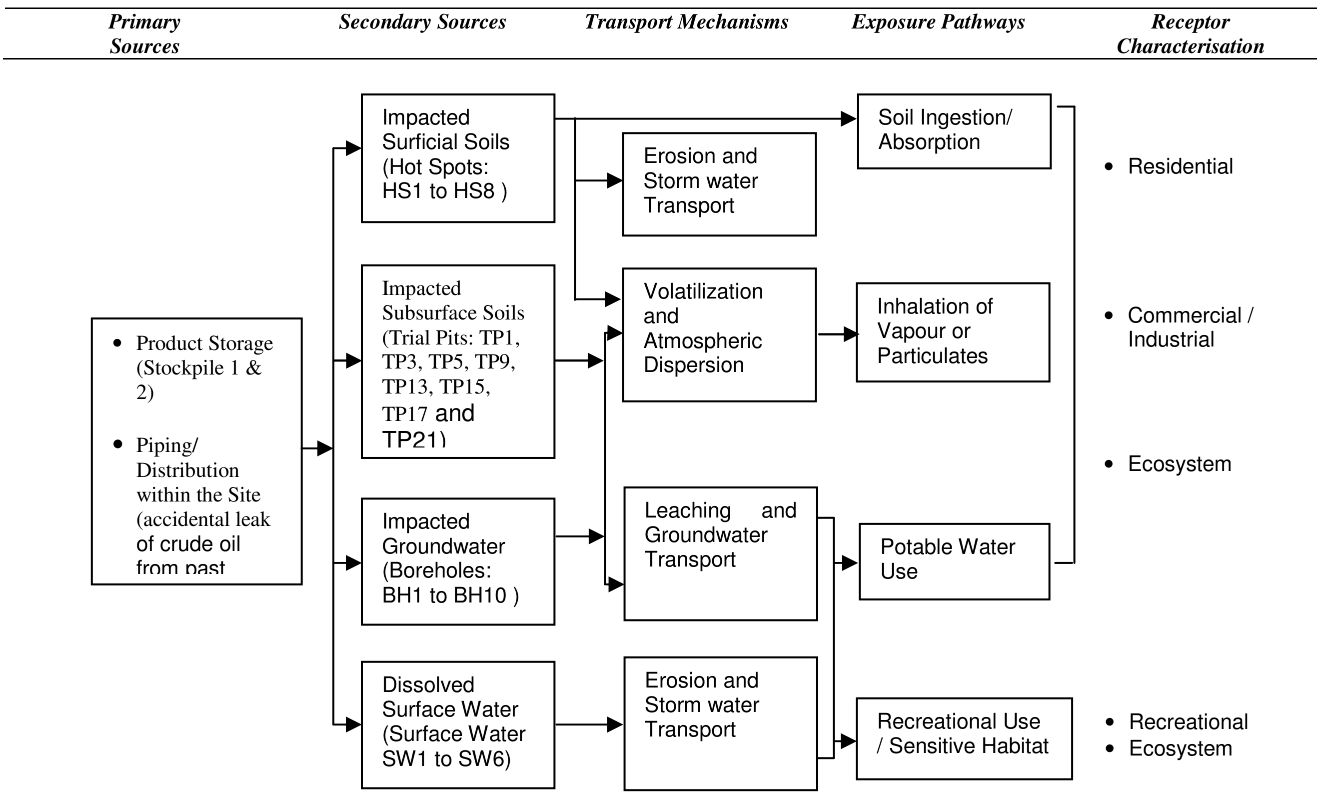

Fig 11: CSM- Exposure Scenario Evaluation Flowchart

Conclusion: The data presented show that TPH, BTEX and PAH levels were above the DPR intervention value at some of the sampling points. This is an indication that remedial intervention was required to restore the site to levels close to pre-spill conditions.

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