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Evaluation of some Geophysical and Physicochemical Characteristics of Soil and Groundwater Resources in Sapele, South-South Nigeria

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ABSTRACT: This study evaluated some geophysical and physicochemical characteristics of soil and groundwater resources in Sapele, Delta Sate of Nigeria using various standard techniques. The results of the resistivity data shows that a high resistive plume with resistivity > 12,000 Ohm-m has penetrated the soils beyond 21m beneath the surface in most parts of the surveyed area. The water samples shows high acidity with pH values in the range 4.6-5.1. Total Dissolved Solids (TDS) is low 46.40- 47.98mg/l and conductivity ranges from 72.80-78.8 µS/cm, There is no incidence of heavy metal pollution, only Iron is high (0.772-0.915mg/l). Total petroleum hydrocarbons-(TPH) as oil and gas revealed by gas chromatography result is below detection level (<0.031mg/l), this can be attributed to the sealing of the confined aquifer by impermeable clay. The average permeability of the soil is 5.514 x 10^{-3}cm/s indicating good drainage condition. The results have shown that shallow boreholes are polluted and the soils of the area are acidic. Groundwater of the area need treatment before it can be consumed and periodic integrated methods of investigation should be carried out in the study area.

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Water is essential for human existence on Earth. Groundwater resources and soil are increasingly being contamination due to man's exploitation of energy resources, especially fossil fuels with the consequent slick and spill of oil, in addition to gas flaring which are being released to the environment. Soil and groundwater are susceptible to contamination and pollution wherever exploitation of oil/gas are carried out. Contaminant load of soil and water is growing steadily each year in parallel with increasing industrialization and energy demand (Wang, 1999).Niger Delta province is a prolific oil producing region in Southern Nigeria, West Africa. Exploration and exploitation of oil and gas since 1958 in the region has led to the environmental degradation in the region. Obasi*et al*., (2001) reported that the most dangerous impact of these degradation are soil and groundwater pollution. Similar findings were also reported by (Tamuno and Felix, 2006). Mode *et al.,* (2010) and other researchers have employed several methods to study the impact of the degradation on the environment as a result of oil and gas exploitation activities in the region. Tse and Nwankwo, (2013) applied an "Integrated geochemical and geoelectrical investigation of an ancient (> 40years) crude oil spill site in south east PortHarcourt, Southern Nigeria" found that Soils Total Petroleum Hydrocarbon (TPH) concentrations generally decrease from a maximum of 6428 ppm at 1 m at the time of investigation to a minimum of 1508 ppm at 5 m depth within the impacted zone. These values are much higher than the Department of Petroleum Resources (DPR) background value of 50 ppm for TPH in soils of the Niger Delta, thereby establishing high level of contamination.

Ehirim *et al*.,(2016) reported that in the Niger Delta region, hydrocarbon contamination in the soil and groundwater investigated showed a characteristic low resistivity anomaly associated with microbial degradation over time. The minimal depth of impact is approximately 13 m below the groundwater table, with a lateral spread in excess of 100 m on either side of the spill point parallel to the pipeline right of way. A research work carried out by Amadi *et al*., (1993) and Ezebuiro, (2004) used geochemical technique to evaluate groundwater quality in Eastern Niger Delta region. They found out that high hydrocarbon content of soils has been known to affect soil physio-chemical properties, which in turn affect the agricultural potentials of such soils. Ughe, (2012) carried out. Environmental Groundwater Monitoring of Jones

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Creek Field, Western Niger Delta, Nigeria" He found out that the physico-chemical condition of the groundwater within the study area is acceptable for domestic purposes as it met WHO maximum permissible standards. The groundwater was found to be mildly acidic without contamination by heavy metals, oil and grease. He reported that the high TDS may be due to the incursion of saline water into the phreatic zone. Finally, He observed that the appreciably high iron content in some of the boreholes may require treatment to further enhance the groundwater quality for domestic purposes. Oghonyon *et al*. (2015) in their work on ''Geotechnical attributes of Niger Delta soils, Warri environs'' found out that grain size distribution test show that the soil samples are mainly sand. The objectives of this study are to: determine the electrical resistivity images of the soil for possible hydrocarbon contaminant, investigate the physicochemical parameters of the groundwater and calculate the permeability of the soil in the study area.

MATERIALS AND METHODS

The study area is Sapele in Delta State of Nigeria (Fig. 1).

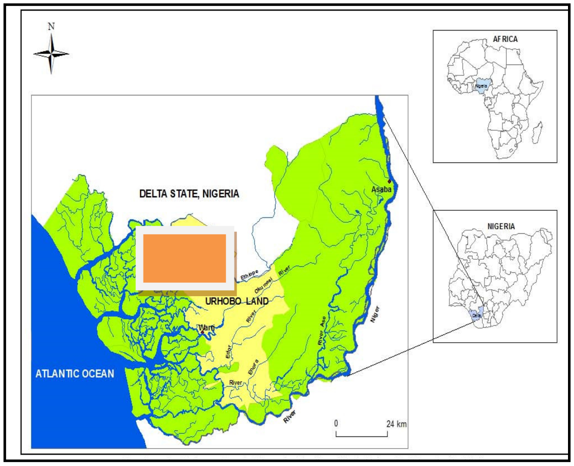

Fig.1 Map of Delta State showing the study area (Modified after Odermerho, 2004)

Description of Study Area: Sapele is located in Delta State, Western Niger Delta. It lies between latitude 5^0 30'N -6^0 N and longitude 5° -5^0 45' E (Fig.1). The city hosts a flow station, oil rigs and oil pipelines crisscrossing residential areas and are owned by some of the oil and gas companies operating in the country. The area consists of fresh water swamp, coastal plain sands, mangrove swamps, and Sombreiro-Warri plains. Soils are generally hydromorphic and poorly drained. Natural vegetation occur as fresh water swamp forest, mangrove swamp forest and ever green lowland rainforest, a major source of timber. River Niger is the major drainage system from which other discrete river systems originate. The region has a humid equatorial climate. The cloud cover is high, with relative humidity and average rainfall above 80% and 3000 mm (Omo-Irabor and Oduyemi, 2006).

Electrical Resistivity data Acquisition: Sixty-Four (64) multi-electrode Terrameter was used for the electrical imaging with 2 m minimum electrode spacing. Each traverse covered a lateral distance of 126 m. It was complimented by the use of PASI Resistivity meter with 5 m spacing. Traverses were occupied proximal to the flow station, oilrigs and pipelines, which are also in residential areas. A small electrode spacing of 2 m was adopted for the multi-electrode and 5 m for the resistivity meter in the acquisition of data, in order to be able to provide considerable details of any plume related to leakages from the oil installations and underground pipelines. Wenner and Gradient arrays were chosen in the acquisition of data because Wenner array is relatively sensitive to vertical changes of resistivity below the centre of the array, and Gradient array has advantages of image resolution and target definition and therefore, provides more details of the subsurface.

Water Sampling: Five (5) samples from boreholes and hand dug wells were collected from the location and stored in glass containers and kept in iced vessels. In-situ Analysis: Analysis measurements were carried out for the ground water collected. Unstable field parameters namely pH and temperature were analyzed in the field and recorded.

pH: Measurement of the pH was done by using HACH pH-meter which was pre-calibrated on the field by using standard buffers.

Temperature: This was determined by means of thermometer calibrated 0.2ºC units from 0-100ºC.

*Sample preservation***:** The purpose of sample preservation is to retard biological action, retard hydrolysis of chemical compounds and to reduce volatility of constituents. To prevent contamination, all sampling materials and containers were sterilized. Samples were also properly labeled before taken to the laboratory. Oil and grease sample were fixed with $5MH_2SO_4$ for preservation.

Soil Sampling: Soil samples were collected from the survey area within the depth of 1-2 m, which were used for the determination of the permeability.

Permeability of the soils were carried out using Variable Head Permeameter in the soil Laboratory.

Electrical Resistivity data Processing: Res2Dinv software was applied to iterate the acquired data. This software simulate the values of the apparent resistivity and that of the current electrode spacing to obtain a two dimensional (2-D) layered model. Consequently, resistivity and the depths of the layers were estimated. Borehole logs from the locations were used as an aid in the interpretation of the resistivity data. The elevation of the study area is about 9 – 10 m. Figure 2 shows the google image of Sapele showing the traverse lines, oil installations and water boreholes.

RESULTS AND DISCUSSION

The results of the geophysical analysis from the study area are presented in the figures below. Figures 3, 4 and 5 show the Lithologic unit of Sapele, Gradient and Wenner array maps of traverse one respectively. Traverse one reveal the resistivity image along the profile. Integration of the two 2-D ERT array results show that subsurface is characterized with soil material with resistivity ranging from 25.8-26,067 Ωm reflective of varying degree of conductivity associated with varying lithology and fluid type. Figure 3 is the borehole data used for constraining the interpretation of the 2-D ERT sections.

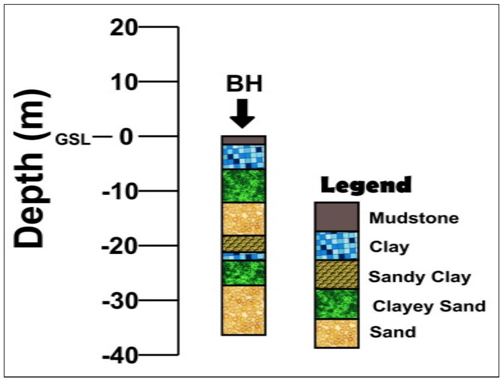

Fig. 3:A typical stratigraphy column of a borehole showing the lithologic units of Sapele.

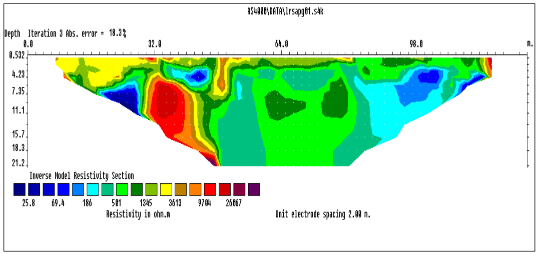

Fig. 4.2D Electrical resistivity image of Sapele along traverse 1 using Gradient array

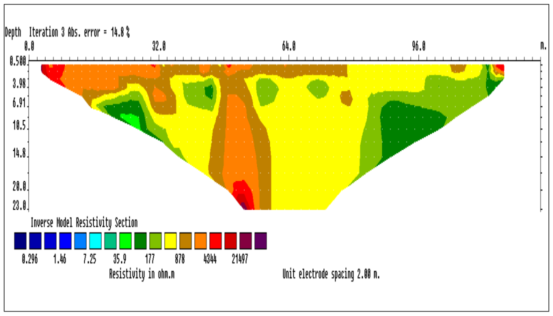

Fig. 5: 2D Electrical resistivity image of Sapele along traverse 1 using Wenner array

The ERT result shows that the subsurface is composed predominantly of sand material from the surface to a depth of about 40 m beneath the surface. The 2-D electrical resistivity imaging result (Fig 4) show the resistivity distribution over a lateral distance of 126m from the surface to a depth of about 21m beneath the surface. The 2-D section revealed an anomalously high resistivity (9704-26067 Ωm) wedge shaped structure (characteristic of a contaminant plume) within a lateral distance of 30-50m, 52-58m and 122-126m at a depth of 4.5-21.2m, 0.6-8m and 0.6-7m respectively. These anomalously high resistivity structures are attributed to the presence of hydrocarbon within the subsurface which may be due to leakages from various pipelines within the study area or possible activity of the vandals. Correlation with the borehole data (Figure 3) show that the subsurface is characterized predominantly with sand, and may compose of clayey sand/clay in some locations. The 2-D ERT result show that the resistivity within the depth of investigation range from 25.8-26067 Ohm-m. Since the lithology in the study area is composed of sand with water table close to the surface, the high resistivity ($\geq$ 9704 Ωm wedge shaped structures) is a possible indication that the aquifer within this area may have been polluted by hydrocarbon. The geophysical data of traverse 2 are shown in the figures below. Figures 6 and 7 show the Gradient and Wenner array structures respectively. The two resistivity structures also show that the subsurface is equally compose of varying degrees of resistivity as can be seen from the resistivity values (43-123,982 Ωm), revealing varying degree of conductivity associated with lithology and fluid type. The 2-D section also revealed an anomalously high resistivity (13,293-123,982 Ωm) wedge shaped structure within a varying lateral and vertical location distributed over the entire traverse.

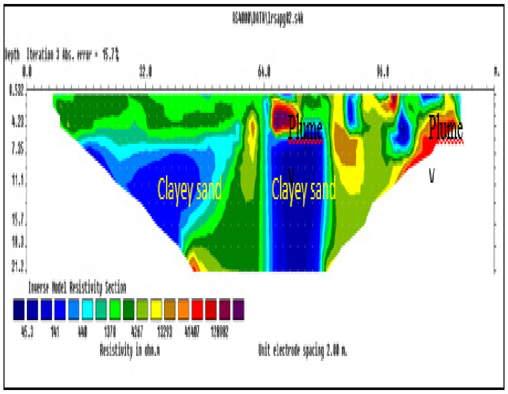

Fig. 6:2D Electrical resistivity image of Sapele along traverse 2 using Gradient array

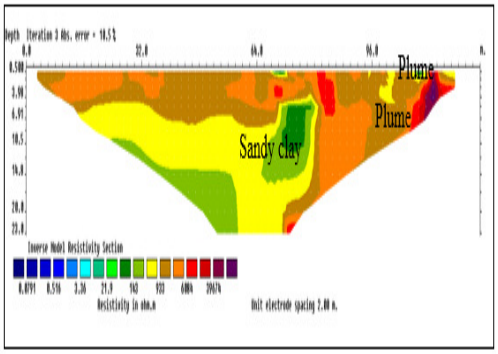

Fig. 7: 2D Electrical resistivity image of Sapele along traverse 2 using Wenner array

At a lateral distance of 40-54m, 60-62m, 66-74m, 78-90m and 98-120m at the depth of 18-21.2m, 4.23-11.1m, 1-6m, 4-10m and 0.5-11m respectively. Possible hydrocarbon pollution were noticed. Integration of the two array maps and correlation with the borehole data (Figure 3) show that the resistivity of the sand layer within the depth of investigation of the 2-D ERT range from 45-123,982 Ωm and may compose of fine to coarse sand/clay in some location. The geophysical results of traverse 3 are shown in the figures below. Figures 8 and 9 show the Gradient and Wenner array 2D resistivity structures. Traverse three (Figures 8 and 9) reveal the resistivity images along the survey line. Figures 8 and 9 show the Gradient and Wenner array structures respectively. The two resistivity structures show that the subsurface is compose of varying degrees of resistivity as can be seen from the resistivity values (28-13,366 Ωm), revealing varying degree of conductivity associated with lithology and fluid type. The 2-D section also revealed an anomalously high resistivity (5538-13,366 Ωm) wedge shaped structure (characteristic of a plume) within a varying lateral and vertical location distributed over the entire traverse.

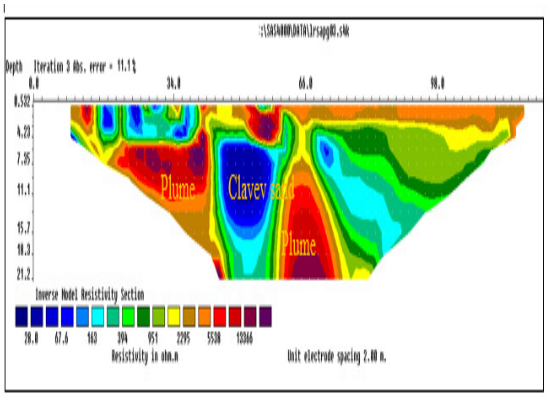

Fig. 8 2D Electrical resistivity image of Sapele along traverse 3 using Gradient array

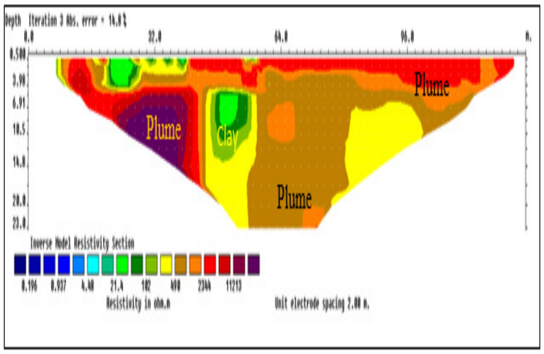

Fig. 9 2D Electrical resistivity image of Sapele along traverse 3 using Wenner array

At a lateral distance of 10-15m, 18-40m, 45-60m, 65-75m and 76-120m at the depth of 1-3m, 4-12m, 0.5-5m, 12-21.2m and 0.5-4m respectively beneath the surface, possible hydrocarbon pollution were noticed. Integration of the two array maps and correlation with the borehole data (Figure 3) show that the resistivity of the sand layer within the depth of investigation of the 2-D ERT range from 28-13,366 Ωm and may compose of fine to coarse sand and clayey sand in some location. Results of traverses 4 and 5 are presented below. Figures 10 and 11 shows the Wenne rarray 2D resistivity structure of traverses 4 and 5 respectively.

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Traverses 4 and 5 (Figures 10 and 11) also reveal the resistivity image along the survey line.. The 2-D resistivity result shows that the subsurface is composed predominantly of sand material from the surface to a depth of about 25m beneath the surface. The 2-D electrical resistivity imaging result (Fig. 10) show the resistivity distribution over a lateral distance of 150m from the surface to a depth of about 25m beneath the surface.

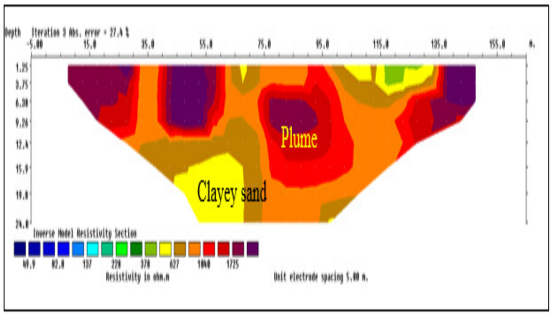

Fig. 10 2D Electrical resistivity image of Sapele along traverse 4 using Wenner array

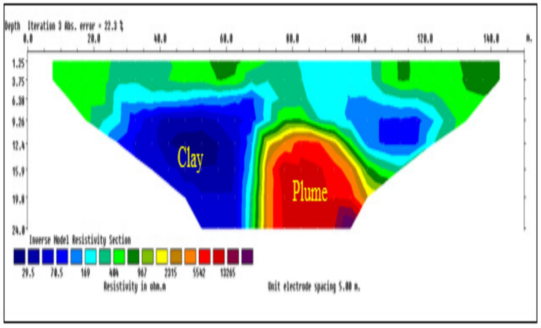

Fig. 11 2D Electrical resistivity image of Sapele along traverse 5 using Wenner array

The results shows that Groundwater in Sapele are mildly acidic as seen from the pH values (4.6-5.8), except for the hand dug borehole 4 , which is 8.3 (Table 1). These can be attributed to the groundwater interaction with the soil and gas flaring in the area. The groundwater is fresh as can be seen from the low conductivity (50.6-153.5µS/cm), the values are in agreement with the low Total Dissolved Solids, TDS values (36.40-89.32mg/l). Meaning that the period of interaction of water with soil is short. The temperature of the water is normal as can be seen from the range (26 - 30^{0}C). The 2-D section revealed an anomalously high resistivity (1046-1723 Ωm) structure within a lateral distance of 10-35m; 36-58m; 75-96m; and 135-150m at a depth of 1.25-12m; 1.25-12.4m; 1.25-20m and 1.25-12m respectively. Traverse 5 (Fig.11) reveal anomalously high resistivity (5542-13265 Ωm) structure within the lateral distance of 70-100m at a depth of 12-24m indicating that Hydrocarbon may have infiltrated into the soil within the surveyed area. The physic-chemical results are shown in the tables below. Tables 1 and 2 shows the hydro-physicochemical and heavy metal parameters respectively.The total Petroleum Hydrocarbon data are presented below. Table 3 show groundwater and surface water Total Petroleum Hydrocarbon as oil and grease.

Table 1: Sample Statistics of Groundwater Hydro-Physical Parameters in Sapele.

	pH	**Temp .^{0}C**	**Cond. µS/cm**	**TDS mg/l**	**Bicarbonate mg/l**
BH 1 (Hand dug)	4.8	28	85.84	44.20	3.66
BH 2	5.1	30	74.30	37.15	3.66
BH 3	4.6	30	74.70	43.33	4.88
BH 4 (Hand dug)	8.3	27	72.80	36.40	4.88
BH 5	4.8	30	82.69	47.98	4.88
WHO/SON Standard	6.5-8.5	40	1000	500	150

Table 2: Sample Statistics of Groundwater Heavy Metals Concentration in Sapele

	Iron mg/l	**Zinc mg/l**	**Copper mg/l**	**Lead mg/l**	**Cadmium mg/l**
BH 1 (Hand dug)	0.915	0.265	0.161	< 0.002	< 0.005
BH 2	0.772	0.080	0.014	< 0.002	< 0.005
BH 3	0.914	0.305	0.135	< 0.002	< 0.005
BH 4 (Hand dug)	0.788	0.084	0.033	< 0.002	< 0.005
BH 5	0.858	0.289	0.176	< 0.002	< 0.005
WHO/SON STANDARD	0.3	3.0	0.5	0.01	0.003

Table 3 Surface and Ground water Total Petroleum Hydrocarbons TPH (Gas Chromatography)

PARAMETERS	**ETHIOPE RIVER**	**SAPELE**BH 1BH 2
TPH mg/l	0.36	< 0.031

Table 4: Average Permeability of Sapele

Test Nos	Initial stand pipe ht (H_1)mm	Final stand pipe ht (H_2)mm	Elapsed time (t_2-t_1)secs.	$\frac{L}{t_2 - t_1}$	**Loge** $\frac{H_1}{H_2}$	$K = \frac{L \log e H_1}{A(t_2 - t_1) H_2}$
1	900	800	0.8	15.375	0.1178	5.977×10^{-3}
2	800	700	1	12.3	0.1337	5.4271×10^{-3}
3	700	600	1.2	10.25	0.1542	5.216×10^{-3}
4	600	500	1.4	8.786	0.1824	5.288×10^{-3}
5	*500*	*400*	*1.6*	*7.688*	*0.2231*	*5.660×10^{-3}*

The average permeability, $K_{av}$is 5.514×10^{-3} cm/sec

The bicarbonate values are in agreement with the pH values. There is no incidence of heavy metal contamination only Iron is fairly high (0.772-0.915mg/l), this may be due to the natural interaction of groundwater with Benin formation of the Niger Delta. Gas chromatography results (Table 3) shows that Total Petroleum Hydrocarbons (Oil and grease) is low (<.0.031mg/L) in the boreholes. The following reasons can be given for the low TPH in the groundwater (i) the groundwater has not stayed long enough in the subsurface. (ii). the groundwater is in confined aquifer, sealed by impermeable clay. (iii) The ion-exchange capacity of clay filters repository of oil and other trace elements. Generally, minerals adhere to clays. Minerals are looked for in clays and (iv) Hydrocarbon degrading bacteria acts on the TPH and reduce (degrade) them to simpler compounds. Ethiope River, the major water body in the study area is 0.36mg/l above WHO permissible limit of 0.3mg/l. The permeability results are shown in the table below. Table 4 shows the permeability of soil. The permeability of the study area ranges from 5.216 x 10^{-3} - 5.977 x 10^{-3} cm/sec (Table 4) which is equivalent to 5.216 x 10^{-5} – 5.977 x 10^{-5} m/sec. Comparing with the coefficient of permeability scale, the drainage is fairly rapid and the soil type is composed of clean and gravel mixture and very fine sands. The implication is that any contaminant on the surface will easily drain to the water table, except in cases where impermeable clay seal the confined aquifer from being polluted by the contaminant plume.

*Conclusion***:** The integrated approach employed in this study has established that confined aquifers in the study area are appreciably sealed from hydrocarbon pollution by impermeable clay. Areas prone to pollution requires routine integrated methods of investigation.

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