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Integrating Geophysical, Geochemical and Geotechnical Characteristics to Assess Soil and Groundwater Resources in Ovade, South-South Nigeria

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Abstract

Integrated methods were employed to assess soil and groundwater resources in an oil and gas producing area. Earth resistivity meter was used for the electrical imaging of the subsurface. Physico-chemical, geochemical and geotechnical parameters of soil and groundwater samples were determined. The results of the resistivity data revealed that a high resistive plume with resistivity > 2,000 Ohm-m has penetrated the soil beyond 20 m beneath the surface in some parts. The water samples show mild acidity with pH values in the range 4.3-5.5. Total dissolved solids (TDS) is low 26.55- 38.05 mg/L and conductivity ranges from 55.38-65.60 µS/cm. Iron content in water is fairly high (0.878-0.994 mg/L). Groundwater samples analysis using ultra violet (UV) detector and gas chromatography (GC) show that total petroleum hydrocarbons (TPH) is very low (< 0.01 mg/L and <0.031 mg/L) respectively. It can be attributed to the sealing of the confined aquifer by impermeable clay in the case of the groundwater. The average permeability of the soil is 8.098×10^{-3} cm/s indicating good drainage. The results have shown that shallow boreholes are prone to pollution. Groundwater of the area needs treatment before it can be consumed and integrated methods of investigation should be carried out periodically.

Keywords: Hydrocarbon; Lithology; Plume; Resistivity.

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1. Introduction

Oil and gas exploitation in the Niger Delta region of Nigeria has been a menace due to the attendant pollution of the ecosystem. Twumasi and Merem [1] applied remote sensing and geographic information system to study the effect of environmental degradation in the Niger Delta region. The oil rich Niger Delta is a geologic province in Southern Nigeria. It situates in an area lying between latitude 4° - 6°N and longitude 4° - 9°E. The region is bounded in the west by the calabar flank, in the north by the Anambra platform and in the south by the Atlantic Ocean under which it extends (Fig. 1). The province occupies an area of about 75,000 km^2 (28,957 mile^2). Uko *et al*. [2] observed that the Niger Delta discharges its water into the Atlantic Ocean through a series of tributaries. The region is

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described by water bodies and mixed continental deposits. 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. Sharma *et al*. [3] observed that biodegradable and non-biodegradable waste has been an environmental problem in recent time. The most dangerous impact of this degradation is soil, groundwater and water body pollution as reported by Tamuno and Felix [4] and Obasi and Balogun [5]. Exploration and exploitation activities always lead to hydrocarbon pollution and contamination which constitutes serious problem. Baird [6] equally reported that an estimated 9 to 13 million barrels of oil has spilled since oil drilling started in 1958 in the Niger Delta region. Electrical resistivity imaging is a useful tool in mapping soil and groundwater contamination. Ameloko *et al.* [7] utilized the method in modelling groundwater contamination in a dumpsite in a major city in Nigeria.

The map of Niger Delta showing oil fields and pipelines is shown in Fig. 1. The study utilized integrated methods of geophysical, physico-chemical and geotechnical techniques to be able to effectively assess the condition of soil and groundwater in the study area.

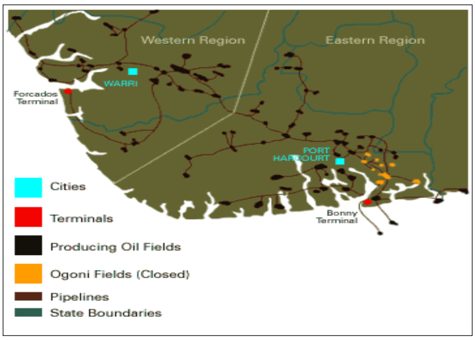


Fig. 1. Urhobo Historical Society [8] A Map of Nigerian Niger Delta showing some oil fields and pipelines.

2. Experimental

2.1. *Materials and methods*

The integrated methods of geophysical, geochemical and geotechnical characterization offer a comprehensive assessment of the soil and groundwater in the study area, hence the employment of the techniques.

2.2. *Description of the study area*

Ovade is in Western Niger Delta, Delta State of Nigeria (Fig. 1). It lies between latitude 5°42′0″ N - 5°42′15″ N and longitude 6°0′0″ E - 6°0′10″ E in geographic coordinate (Fig. 2). The community hosts an oil rig and oil pipelines crisscrossing residential areas. Fresh water swamp, coastal plain sands, mangrove swamps, and Sombreiro-Warri plains characterize the area. Soils are generally hydromorphic and poorly drained as reported by Omo-Irabor and Oduyemi [9]. Natural vegetation occurs as fresh water swamp forest, mangrove swamp forest and ever green lowland rainforest, a major source of timber. River Ethiope is the main water body in the area. The area has an elevation of about 25 – 35 m. The region has a humid equatorial climate. Ishaku and Majid [10] observed that the cloud cover is fairly high, with relative humidity and average rainfall above 80 % and 3000 mm respectively. The map of the study area and the google image showing the traverse lines and water wells are shown in Figs. 2 and 3, respectively.

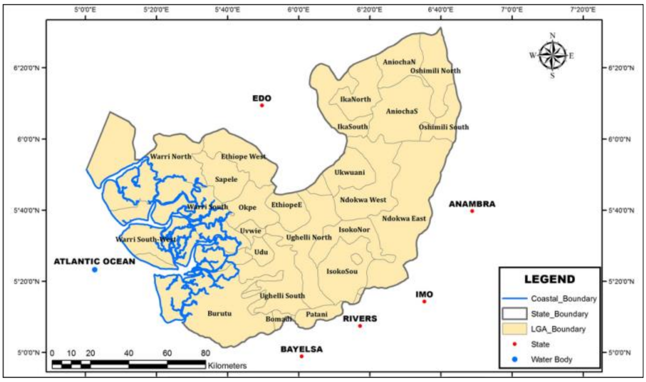


Fig. 2. GAMERS [11] Map of Delta State Nigeria, showing the study area.

2.3. *Electrical resistivity data*

Resistivity meter was employed for the electrical profiling with 5 m electrode spacing. Each traverse covered a lateral distance of 150 m. Traverses were occupied proximal to the flow station, oilrigs and pipelines, which are also residential areas (Fig. 3).

Electrode spacing of 5 m was adopted for the resistivity meter for the acquisition of data, so as to provide considerable details of any plume related to leakages from the oil installations and underground pipelines. Uchegbulam and Ayolabi [12] employed Wenner array in the acquisition of data because it is sensitive to vertical changes of resistivity below the centre and has better lateral coverage. Hence the adoption of the Wenner array because of its advantage in this case.

2.4. *Data processing*

Res2Dinv software was applied to iterate the acquired resistivity data. The two dimensional (2-D) layered models were achieved by the simulation of the values of the apparent resistivity, and that of the current electrode spacing when the software was applied. As a result of this, resistivity and the depths of the layers were estimated. A stratigraphy column of a borehole showing the lithologic unitsof Ovade used as an aid in the interpretation of the resistivity results was obtained from the well data in the surveyed area.

2.5. ***Water sampling***

Water samples were collected from boreholes from three (3) locations and stored in glass containers and kept in iced vessels.
In-situ Analysis: Unsteady field parameters like pH and temperature were analyzed in the field and recorded.
pH: HACH pH-meter which was pre-calibrated on the field by using standard buffers was used.
Temperature: Thermometer calibrated 0.2 ºC unit from 0-100 ºC was used for the determination.
Sample preservation**:** Oil and grease samples were fixed with 5M H_2SO_4 for preservation, these were done to retard biological actions on the samples.

2.6. ***Soil sampling***

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

Variable Head Permeameter was used for the estimation of the soil permeability in the laboratory.

The variable head permeability test involves flow of water through somewhat short compacted soil sample connected to an erect pipe which provides the water head and also permits measuring the volume of water passing through the sample.

The time required for the water in the erect pipe to drop from the upper to the lower level was recorded. Based on the results obtained, the permeability, K of the samples were estimated using the equation

$$K = \frac{L \log eH_1}{A(t_2 - t_1)H_2} \qquad (1)$$

where, L is the sample length and A is the cross-sectional area of the sample. H_1 and H_2 are the initial and final heights above the constant head chamber and their measured time t_1 and t_2 respectively [13]. The permeability test data of the study area is shown in Table 1. The coefficient of permeability scale by West [14] used for interpreting the calculated permeability is shown in Table 7.

Table 1. Permeability test data of Ovade.

Wt. of permeameter + soil sample	(g)	2726
Wt. of dry samples + permeameater	(g)	2394
Wt. of permeameter	(g)	500
Wt. of dry sample (Wd)	(g)	1894
Vol. of water Vw = Ww/℧w(cm^3)		332
Wt. of water	(g)	332

Length of sample (L)	(cm)	12.3
Area of stand pipe (a)	(cm^2)	0.283
Moisture content (%)		17.3
Vol. of permeameter (V)	(cm^3)	1045.3
Area of permeameter (A)		84.9
Bulk density ($M\rho/m^3$)		2.1295
Specific gravity of soil (Gs)		2.66
Vol. of solids (Vs) = Wd/ƱwGs	(cm^3)	712
Vol. of Voids (Vv) = (V-Vs)	(cm^3)	333.3
Void ratio (c) Vv/Vs		0.468
Porosity (n) = Vv/V		0.3189
Degree of saturation (Sr) = Vw/Vv	(%)	99.6

Fig. 3. Google Earth Image of Ovade showing the traverse lines and boreholes.

3. Results and Discussion

3.1. *Resistivity profiling result of ovade*

The resistivity profiling results of Ovade are shown in the Figs. 4 – 7. Electrical image along traverse 1 is shown in Fig. 4, while Fig. 8 shows the lithology log of the area. The resistivity range is from 318-1742 Ωm. The 2-D section showed a moderately high resistivity (318-1742 Ωm) within a lateral distance of 12-40 m; 42-63 m; 70-95 m; 96-132 m and 100- 125 m at a depth of 1.25-19.8 m; 1.25-19.8 m; 1.25-11 m; 1.25-6.38 m and 9.5-19.8 m respectively. These fairly high resistivity may be ascribed to the presence of hydrocarbons within the subsurface which may be due to leakages from various pipelines or activities of Vandals within the study area. Newly spilled oil shows a high resistivity anomaly, while aged oil pollution (>20 years) produces a low resistivity irregularity as reported by Saucks [15]. These depend on the lithology and abundance of hydrocarbon degrading bacteria in the area. A low resistivity anomaly for a biodegraded hydrocarbon in the soils of Niger Delta region has been reported by Ehirim *et al*. [16].

Comparing with the lithologic unit of the area (Fig. 8) reveals that the subsurface contain mainly sand, and may compose of clayey sand/clay in some locations.

TRAVERSE 1

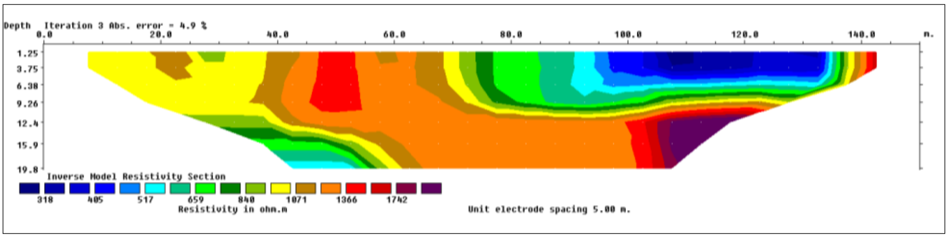


Fig. 4. 2D Electrical resistivity image of Ovade along traverse 1 using Wenner array.

TRAVERSE 2

The 2-D section of traverse two (Fig. 5) also revealed resistivity (328-1895 Ωm) within a lateral distance of 8-25 m; 27-42 m; 43-60 m; and 60-95 m at a depth of 1.25-5 m; 1.25-19.8 m; 1.25-12 m and 1.25-6.38 m, respectively.

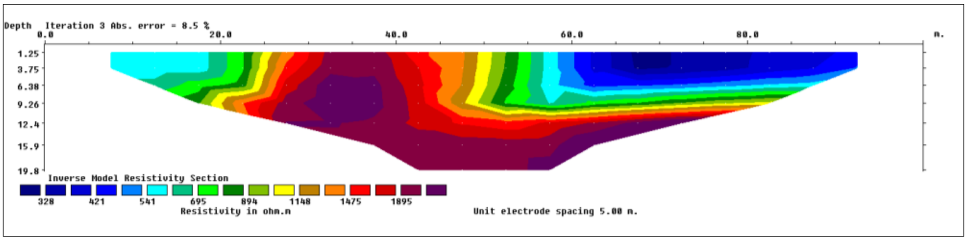


Fig. 5. 2D electrical resistivity image of Ovade along traverse 2 using Wenner array.

TRAVERSE 3

Traverse three (Fig. 6) shows that the resistivity ranges from (138-485 Ωm). It can be seen that the high resistive plume infiltrated through from lateral distance of 8-40 m at the depth of 1.25-10 m. This may be as a result of a high resistive plume released at the surface.

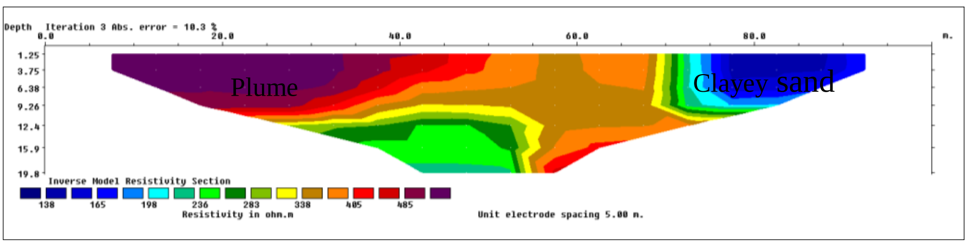


Fig. 6. 2D electrical resistivity image of Ovade along traverse 3 using Wenner array.

TRAVERSE 4

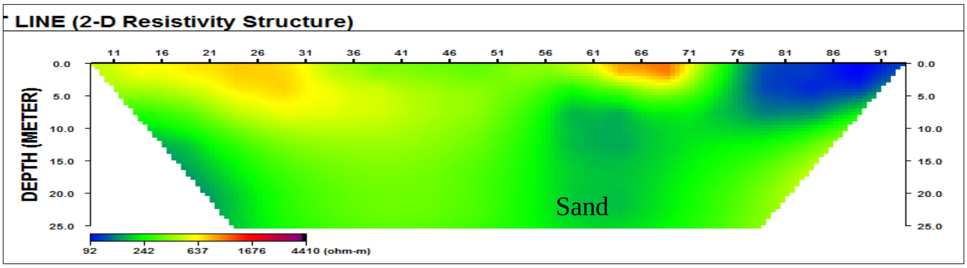


Fig. 7. 2D electrical resistivity image of Ovade along traverse 4 using Wenner array.

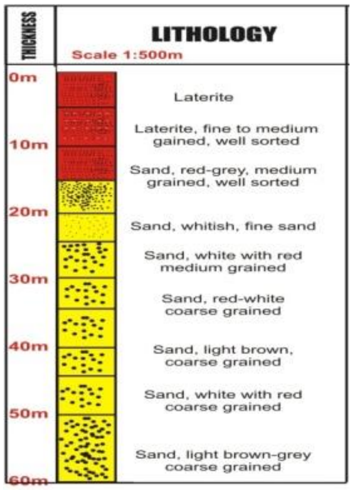


Fig. 8. A typical stratigraphy column of a borehole showing the lithologic units of Ovade.

The resistivity image along the survey line of traverse four is shown in Fig. 7. The resistivity value ranges from (92-1676 Ωm). The traverse show varying lithology as can be seen from the resistivity range. A fairly high resistivity of 637-1200 Ohm-m is observed at lateral distance of 16-31 m and 61-71 m at the depth of 0.5-5 m and 0-3 m respectively. There is no evidence that a high restive plume infiltrated into the soil in this traverse.

3.2. *Groundwater hydro-physical and geochemical parameters*

Hydro-physical parameters, heavy metals concentration, TPH concentration using UV-visible and gas chromatography are shown in Figs. 2-5, respectively.

Table 2. Sample statistics of groundwater hydro-physical parameters in Ovade.

	pH	Temp°C	Cond. µS/cm	TDS mg/L	Bicarbonate mg/L
BH 1	5.4	29	57.08	33.11	4.88
BH 2	5.5	30	55.38	32.12	3.66
BH 3	4.3	30	65.60	38.05	2.44
WHO/SON	6.5-8.5	40	1000	500	150

WHO-World Health Organisation
SON-Standard Organisation of Nigeria

Table 3. Sample statistics of groundwater heavy metals concentration in Ovade.

	Iron mg/L	Zinc mg/L	Copper mg/L	Lead mg/L	Cadmium mg/L
BH 1	0.924	0.083	0.019	< 0.002	< 0.005
BH 2	0.878	0.090	0.015	< 0.002	< 0.005
BH 3	0.994	0.096	0.013	< 0.002	< 0.005
WHO/SON	0.3	3.0	0.5	0.01	0.003

Table 4. Groundwater TPH (UV-visible detector) concentration in Ovade.

BOREHOLES	BH 1	BH 2	BH 3
TPH (as oil and grease) mg/L	<0.01	<0.01	<0.01
WHO/SON STANDARD	0.3	0.3	0.3

3.3. *Gas chromatography results*

Table 5. Groundwater TPH concentration (gas chromatography) in Ovade.

PARAMETERS	ETHIOPE RIVER	OVADE		
		BH1	BH 2	BH 3
TPH mg/L	0.36	< 0.031	< 0.031	< 0.031

0.031mg = 31µg/L

3.4. *Groundwater physico-chemical content and concentration of heavy metals.*

The temperature ranges between 29 to 30 ºC (Table 2). Certain physical and chemical properties of water such as density, solubility of constituents, pH, conductance, the rate of chemical reactions, and microbial activity of water are affected by temperature. The groundwater temperature in the surveyed area is within the WHO/SON standard of 40 °C acceptable for domestic purposes.

The pH of a solution is a measure of the effective hydrogen-ion concentration. The pH of water is influenced by dissolved gases such as carbon dioxide, hydrogen sulphide and ammonia. The pH ranges from 4.3 – 5.5, indicating mild acidity.

Ugbe [17] reported that the groundwater in the Western Niger Delta is acidic. Groundwater is fresh as can be seen from the low conductivity (55.38 – 65.60 µS/cm). The values are in agreement with the low total dissolved solids, TDS values (32.12 - 38.05 mg/L). The low bicarbonate values (2.44 – 4.88 mg/L) are in agreement with the pH values.

Heavy metal concentration in the groundwater is very low (Table 3) as they are within WHO permissible limit; only iron is fairly high (0.878-0.994 mg/L). This may be due to the natural interaction of groundwater with Benin Formation of the Niger Delta. Groundwater sample analysis show that total petroleum hydrocarbons-TPH, as oil and grease is equally low (<0.031 mg/L). This shows that there is no recent spillage in the study area. It can also be attributed to the sealing of the confined aquifer by impermeable clay. Oil and grease are fairly high in surface water (River Ethiope) ≈0.4 mg/L (Table 5). It is above WHO/SON permissive level of 0.3 mg/L. This implies that surface water and shallow boreholes are prone to contamination by total petroleum hydrocarbons in the area.

3.5. ***Permeability of ovade***

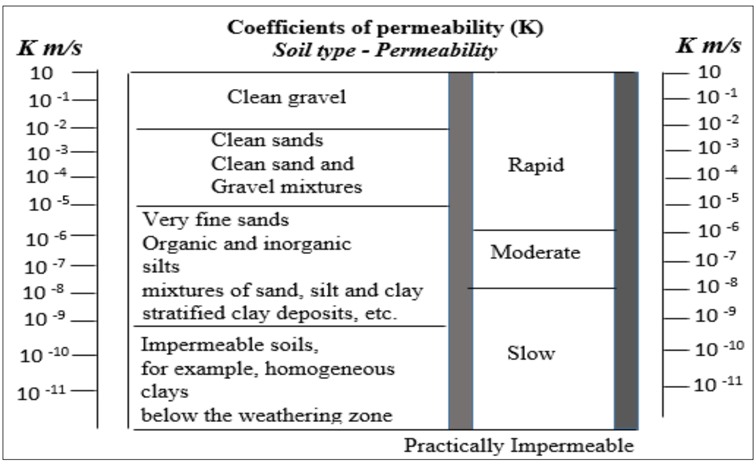
The permeability test rest is shown in Table 6, while the coefficient of permeability scale is shown in Table 7.

Table 6. Permeability test results of Ovade.

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	0.6	20.5	0.1178	7.969×10^{-3}
2	800	700	0.6	20.5	0.1337	9.045×10^{-3}
3	700	600	0.8	15.38	0.1542	7.826×10^{-3}
4	600	500	1	12.3	0.1824	7.4036×10^{-3}
5	500	400	1.1	11.2	0.2231	8.246×10^{-3}

$K_{av} = 8.098 \times 10^{-3}$cm/sec.

Table 7. Coefficient of permeability scale (West, 1995).



Permeability is the capacity of a substance to let a water current flow through it when pressure is applied. The permeability of soil types of the study area ranges from 7.4036×10^{-3} - 9.045×10^{-3} cm/sec (Table 6), which is equivalent to 7.4036×10^{-5} – 9.045×10^{-5} m/sec. The average permeability of soil in the area is ($K_{av} = 8.098 \times 10^{-3}$ cm/sec = 8.098×10^{-5}

m/sec). Comparing the permeability of soil in the area with the coefficient of permeability scale (Table 7), the drainage is fairly rapid and the soil type is mixture of medium, fine and silt sands. The implication is that any contaminant on the surface will easily drain to the water table, except in cases where impermeable clay seals the aquifer. Shallow boreholes are prone to contamination due to the percolation of plume as a result of soil type of the area.

4. Conclusion

The integrated methods employed have revealed that shallow boreholes are prone to hydrocarbon pollution. The confined aquifers are sealed by impermeable clay and are free from pollution. However, the soils and water are generally acidic and therefore needs treatment. It can be inferred that multi-national and indigenous oil and gas companies operating in the area adhere to international best practices in carrying out their exploration and exploitation activities as the soils and water are almost free from oil, grease and heavy metal contaminations. For the fact that the soil and water are acidic indicates that they are prone to be more acidic if not checked. Moreover, being that the permeability of the soil is fairly rapid, any contaminant on the surface will easily infiltrate to the water table beneath the surface, and so the area requires routine integrated methods of investigation as a way monitoring.

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