PRINT ISSN 1119-8362
Electronic ISSN 2659-1499

Full-text Available Online at
https://www.ajol.info/index.php/jasem
https://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 29 (10) 3041-3050 Oct. 2025

Geogenic and Anthropogenic Sources of Groundwater Contamination in Osubi Community and its environs, Warri, Delta State, Nigeria

[1]*OSISANYA, OW; [2]ONIFADE, YS; OLASENI, VB; [4]KORODE, AI; [5]SHARAFA, JO

[1,2,3] *Department of Physics, Federal University of Petroleum Resources, Effurun Delta State, Nigeria*
[4]*Department of Petroleum Engineering and Geosciences, Petroleum Training Institute, Effurun, Delta State, Nigeria*
[5]*Department of Earth Science, Federal University of Petroleum Resources, Effurun, Delta State, Nigeria*

**Corresponding Author Email: wasiu.osisanya@uniben.edu*
**ORCID: https://orcid.org/0000-0001-7280-9771*
**Tel: +234(0)8150914664*

Co-Authors Email: onifade.yemi@fupre.edu.ng; olaseni.victor@fupre.edu.ng; geokorode@gmail.com; sharafa.john@gmail.com

ABSTRACT: Groundwater contamination poses a significant challenge to water quality, especially in regions with limited access to clean water. Consequently, the objective of this paper is to investigate the Geogenic and Anthropogenic Sources of Groundwater Contamination in Osubi Community and its environs, Warri, Delta State, Nigeria using the Wenner-Schlumberger array and vertical electrical sounding (VES). The results revealed resistivity values ranging from 5.5 Ωm to 121,387.6 Ωm, with several zones showing very low resistivity indicative of contamination. Notably, contamination was observed primarily in shallow surface layers, with certain areas such as Samuel Ariko Street and Airport Hotel Street exhibiting significant resistivity anomalies. These low resistivity zones suggest the presence of pollutants, though the specific geogenic or natural origin remains unclear, as no typical anthropogenic sources, such as waste disposal sites or industrial discharge were identified. The findings imply that groundwater contamination in Osubi may result from natural geochemical processes, possibly related to the local geology or subsurface conditions, rather than from human activity. This study underscores the need for a deeper understanding of regional groundwater systems and the application of geophysical techniques in identifying contamination sources in areas where traditional water quality assessments may fall short. Recommendations for further research and mitigation strategies are discussed to address the growing concerns of water safety in the region.

DOI: https://dx.doi.org/10.4314/jasem.v29i10.5

Cite this Article as: OSISANYA, O. W; ONIFADE, S. Y; OLASENI, V. B; KORODE, A. I; SHARAFA, J. S (2025). Geogenic and Anthropogenic Sources of Groundwater Contamination in Osubi Community and its environs, Warri, Delta State, Nigeria *J. Appl. Sci. Environ. Manage.* 29 (10) 3041-3050

Dates: Received: 04 July 2025; Revised: 19 August 2025; Accepted: 23 September 2025; Published: 01 October 2025

Keywords: Groundwater contamination; Electrical resistivity; Groundwater potential; Geogenic source; Anthropogenic source

Groundwater is a major source of fresh water for the global population and is used for domestic, agricultural, and industrial uses. Approximately one-third of the global population depends on groundwater for drinking water (International Association of Hydrogeologists 2020, Eyankware and Akakuru, 2022). Groundwater is a particularly important resource in arid and semi-arid regions where surface water and precipitation are limited (Li *et al*., 2017a). Securing a safe and renewable supply of groundwater for drinking is one of the crucial drivers of sustainable development for a nation. More so, water is a universal solvent that no man can do without, especially for drinking purposes. Hence, the search for portable groundwater in any society is a very paramount subject that cannot be overlooked, especially in areas that are quite susceptible to groundwater pollution, either due to geogenic or anthropogenic sources of groundwater contamination (Peiyue *et al*., 2021). Several studies and

**Corresponding Author Email: wasiu.osisanya@uniben.edu*
**ORCID: https://orcid.org/0000-0001-7280-9771*
**Tel: +234(0)8150914664*

investigations have been conducted near most anthropogenic sources (dumpsite, abattoir, mechanic village, etc.) of groundwater contamination sources at Osubi to investigate their effect on the groundwater bodies within the study area (Orji and Eze 2018; Uwadiegwu *et al*., 2018; Okumoko and Izeze 2020; Ofomola 2015). However, there is no research work that has been conducted to ascertain any natural source of groundwater pollution within the study location, especially in areas that have no or insignificant evidence of surface contamination. Opinions have been divided on the causes of the non-portability of drinking water in Osubi (which have not been established by any research), which necessitate inhabitants of the area going too far distances to fetch water daily for their domestic use rather than enjoying the groundwater resources in their local vicinity. This challenge drew the attention of concerned geophysicists to come to their aid and provide a profoundly viable solution to the peculiar problem faced by the teaming mass of thousands of individuals leaving the study area. From the inquiry, there is no abattoir or any other surface sources of groundwater pollution within the study area that could be attributed to the cause of groundwater contamination except the presence of some filling stations, such as Nero and Foste filling stations, around the area. Being a Niger Delta terrain, one would have presumptuously thought that the source of the pollution might have resulted from oil spillage from nearby filling stations, as reported in most journals (Giadom and Tse, 2015; Giadom *et al*., 2015; Aniefiok *et al*., 2018; Ehirim *et al*., 2016; Tse and Nwankwo, 2013) to be the major factors that pose a threat to groundwater and soil contamination within the Niger Delta oil-producing areas. Geogenic contamination occurs naturally, often due to mineral dissolution or natural processes like leaching of minerals into groundwater. Common geogenic contaminants include Heavy metals (e.g., ferrugenise sandsone with high iron content, arsenic, lead), elements like (fluoride, salts, and dissolved mineral), mineralized layers or certain rock types (e.g., aquifers with high arsenic concentration due to the dissolution of arsenic-bearing minerals), radionuclides (e.g., radon, uranium) etc occurring naturally in the earth surface. Anthropogenic contamination results from human activities such as agriculture (e.g., nitrates), waste disposal (e.g., sewage or chemicals), industrial activities (e.g., solvents), and landfills. Anthropogenic contamination often occurs in areas where human activities intersect with groundwater flow paths, and these areas may show more sharp and isolated resistivity anomalies**,** possibly reflecting buried waste, contaminated groundwater plumes, or leachate from landfills. It was discovered that both the well and borehole water in the study area are brownish, consequently leaving their bathrooms, toilets, and water closets continuously stained with brown. Any white cloth washed with the groundwater in the study area usually turns brown. Observation of the groundwater fetched from the study location also showed that the contaminant could not be traced to underground oil spillage from the nearby filling stations due to its odorless and non-viscous nature. It was inferred that the source of groundwater contamination in the study area might result from a natural factor or any geogenic source at the location. Consequently, the objective of this paper is to investigate the Geogenic and Anthropogenic Sources of Groundwater Contamination in Osubi Community and its environs, Warri, Delta State, Nigeria.

MATERIALS AND METHODS

Location of the study area: Osubi is a growing community near Warri (Fig 1 and 2). The Warri Airport (also known as Osubi Airstrip) is located in the area, and there is rapid infrastructural development around the airport region due to its closeness and prominence to the Niger Delta oil-producing area of Nigeria. Geographically, the area is located between latitudes 5°00` N and 5º30 N and longitudes 6°00`E and 6º40'E. Osubi is fast becoming a busy modern community with the rapid expansion of building projects for modern living. There is the world-renowned Nigeria Petroleum Training Institute (PTI) nearby and other infrastructural developments in the area (Okumoko and Izeze 2020). The study area is characterized by low land (Fig 1) and well-built residential structures. While the control point is location Federal University of Petroleum Resources Effurun, Ugbomro in a nearby location to the study area. FUPRE is located within the Niger Delta which is situated on the continental margin of the Gulf of Guinea in equatorial West Africa between latitude 4°N to 7°N and longitude 5°E to 8°E covering an area of about 108,900km2 (Whiteman, 1982). It extends from the Calabar flank and the Abakaliki Trough in eastern Nigeria to the Benin flank in the west and it opens to the Atlantic Ocean in the south. The development of Niger Delta resulted from the formation of Benue trough as a failed arm of a triple junction associated with the separation of African and South American Plates and subsequent opening of the South Atlantic (Whiteman, 1982). The Benue-Abakaliki trough was filled with sediments during the early Cretaceous time which later underwent folding, faulting and uplift with subsidence of the adjacent Anambra basin to the west and Afikpo syncline to the east during the Santonian. Niger Delta comprises three diachronous Units, Akata, Agbada and Benin Formations (Weber and Daukoru, 1975). It is underlain by Quaternary Warri deltaic sand (Etu-Efeotor and Akpokodje, (1990), Alaminiokuma and Chaanda (2020).

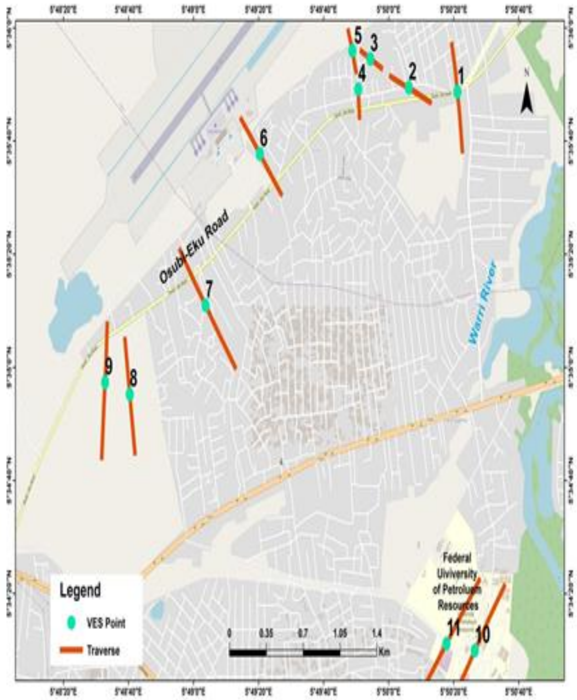

Fig 1: Location Map Of The Study Area

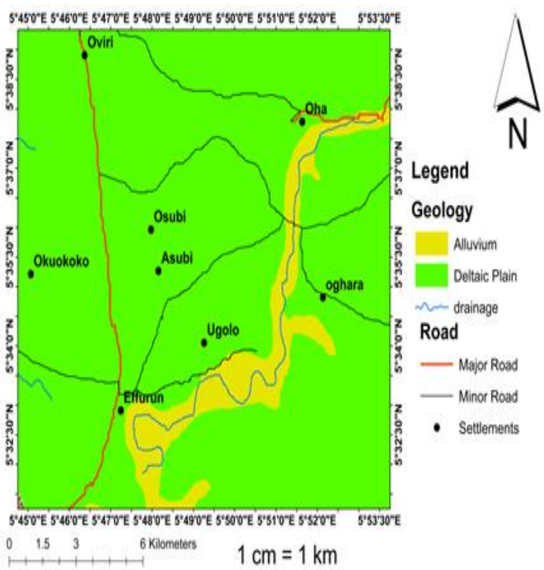

Fig 2: Geology Map of Osubi and it environs

This study integrated field-based geophysical data, specifically 1-D and 2-D geoelectrical resistivity data sets, to conduct a detailed investigation of groundwater pollution within the case study. Nine (9) Wenner-Schlumberger (figs. 4 to 11) and nine (9) vertical electrical sounding arrays were taken at different untarred streets within the study area, while two traverses (figs. 12 and 13) were laid at the control point that was situated within the Federal University of Petroleum Resources Effurun, making a total of eleven (11) traverses. According to Ugwu *et al*. 2016 and Ugbor *et al*., 2021, the points of very low resistivity values below 50 Ωm in electrical resistivity arrays connote points on groundwater contamination.

Electrical Resistivity Method: The electrical resistivity approach takes advantage of the resistance differential between various ground materials. The level of resistance a material exhibits to the passage of electrical current through it is measured as resistivity. Resistivity, generally measured in ohmmeters, is the opposite of conductivity. Ohm's rule, which states that the current flowing through the ends of a conductor with a uniform cross section is proportionate to the applied voltage, theoretically applies to all conductive materials

Therefore equation 1 shows the applied voltage, V (Loke 2002)

$$V = IR \quad 1$$

Where R= Resistance of the medium, I=Current

Therefore, the resistance, R of the medium can be obtained as

$$R = \frac{V}{I} \quad 2$$

Resistance of a medium (R) is proportional to its length (L) and inversely proportional to its cross sectional area (A) (Loke 2002) which can be written as

$$R = \frac{PL}{A} \quad 3$$

$$\rho = \frac{RA}{L} \quad 4$$

$$\rho = \frac{VA}{IL} \quad 5$$

The conventional Wenner array has an advantage in areas with limited open space along the survey line, as increasing the electrode spacing results in a significant reduction in horizontal coverage, allowing for a deeper depth of investigation. For the Wenner array, each deeper data level has 3 data points less than the previous level, while for the Wenner-Schlumberger array (Fig. 3), there is a loss of 2 data points with each deeper data level. The horizontal data coverage is slightly wider than the Wenner array, but narrower than that obtained with the dipole-dipole array. Theapparent resistivity for this array is given by equation 6 (Loke 2002)

$$\rho_a = \pi n(n+1)a\Delta\frac{V}{I} \quad (6)$$

where a is the spacing between the P1and P2electrodes and n is the ratio of the distances between the C1– P1and the P1– P2electrodes.

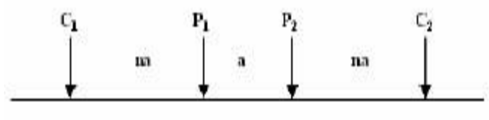

Fig. 3 Wenner– Schlumberger array

RESULTS AND DISCUSSION

The results of the Wenner-Schlumberger arrays and the vertical electrical soundings acquired, processed, and interpreted in the study area, namely Captain Gideiki Street, Edward Efenure Street, Barrister Mademedor Street, Samuel Ariko Street, Colnel Newton Street, Osubi Airport Hotel Street, Beside Trade Fare Street, PTI Osubi Permanent Site, and FUPRE CAMPUS as a control point, are presented and analyzed in this section. The regions of contamination are mapped with red circular broken lines. Human-made sources, such as dumpsites, abattoirs, mechanic workshops, or hydrocarbon spillage from localized filing station underground pipes, could have contaminated these regions, or they could have been naturally occurring. ERT can help identify the **depth** at which contamination occurs. Figs. 6, 7, 8, 9, 10, and 12 illustrate that geogenic contamination generally impacts deep aquifers, whereas anthropogenic contamination frequently impacts shallow groundwater or the near-surface zone, such as from leaking pipes, septic tanks, dumpsites, or landfills.

Captain Gideiki Street: It could be observed that the resistivity values range from 181 Ωm to 1798 Ωm. There is no trace of contamination on this traverse, as it has a lowest resistivity value of 181 Ωm against a low resistivity value of less than 50 Ωm (which depicts the contamination zone), according to Ugwu *et al*. (2016) and Ugbor *et al*. (2021). Positioning the VES 1 at a horizontal distance of 120 m also confirms the absence of contamination on this traverse, as the resistivity values range from 375 29.6 m to 4068 29.6 m.

Edward Efenure street: This resistivity value ranges from 29.6 Ωm to 2548 Ωm. No potential zone of contamination occurs on this traverse, as it could be seen that the resistivity values all over it exceed 50 Ωm. Also, the VES 2 array that was put on top of the 2D array 100 m away confirms that there is no contamination in the groundwater at the deepest point shown by the 2D inverse resistivity model. However, this result contradicts the findings of Okumoko and Izeze (2020), who conducted an investigation on the impact of leachate percolation from a dumpsite within the study area. The study area ranges from unpolluted to moderately polluted, with anthropogenic, not geogenic, pollution.

Barrister Mademedor Street: A few portions of the contamination area could be observed at a lateral distance of 110 m to 120 m and a depth of 7.58 m. Anthropogenic contamination was suspected on this traverse, given its close proximity to the surface. This contamination may be traced back to the portion of stagnant water and a few dirt particles found in the street during the data acquisition process. More so, resistivity variation on this traverse ranges from 12.1 Ωm to 11,988 Ωm. The VES 3 placed on this traverse also revealed that no contamination exists on the traverse.

Samuel Ariko street: The resistivity values on this traverse range from 9.63 Ωm to 79.444 Ωm. The entire surface layer of the study area, from lateral distances of 7.5 m to 95 m and at a maximum depth of 10 m, reveals a high level of contamination. It is surprising to know that there is no evidence of anthropogenic sources of groundwater contamination in the study area, yet all the surface layer revealed a high level of groundwater contamination. The street's length is too short to accommodate the installation of a VES array on this particular traverse. Hence, no VES array was conducted to authenticate this traverse.

Colnel Newton Street: The resistivity values in this traverse range from 14.7 Ωm to 121,3876 Ωm. At a lateral distance of 25m-50m, 80m to 118m, 160m to 182m, and a maximum vertical depth of 18.5m, a layer of contamination is visible. Given their close proximity to the surface, these layers of contamination suggest probable human sources of contamination, which are rarely prominent at the study location. Ofomola conducted an investigation in 2015 that involved integrated geophysical and hydrogeochemical studies of shallow aquifer contamination around a dumpsite in the study area

..

Table 1: GPS coordinates of the aquired wenner schlumberger array

S/N	Name Of Streets	Northing Beginning	Easting	Northing Ending	Easting
1	Captain Gideiki Street	$05^0$35’ 44.7”	$05^0$50’ 21.8”	$05^0$35’ 52.5”	$05^0$50’ 20.5”
2	Edward Efenure	$05^0$35’ 48.9”	$05^0$50’ 07.6”	$05^0$35’ 49.9”	$05^0$50’ 5.1”
3	Barrister Mademedor	$05^0$35’ 52.7”	$05^0$49’ 58.2”	$05^0$35’ 56.1”	$05^0$49’ 51.1”
4	Samuel Ariko	$05^0$35’ 47.9”	$05^0$49’ 50.7”	$05^0$35’ 50.4”	$05^0$49’ 50.6”
5	Colnel Newton	$05^0$35’ 54.38”	$05^0$49’ 49.29”	$05^0$35’ 57.61”	$05^0$49’ 48.36”
6	Airport Hotel Street	$05^0$35’ 34.33”	$05^0$49’ 23.49”	$05^0$35’ 41.2”	$05^0$49’ 17.2”
7	Beside Trade Fare	$05^0$35’ 15.9”	$05^0$48’ 59.6”	$05^0$35’ 5.8”	$05^0$49’ 07.9”
8	Pti/Osubi 1	$05^0$35’ 54.38”	$05^0$49’ 49.29”	$05^0$35’ 57.61”	$05^0$49’ 48.36”
9	Pti/Osubi 2	$05^0$34’ 58.4”	$05^0$48’ 23.1”	$05^0$34’ 59.1”	$05^0$48’ 28..5”
10	Fupre Campus Control Point	$05^0$34’ 15.9”	$05^0$50’ 31.1”	$05^0$34’ 4.2”	$05^0$50’ 22.1”
11	Fupre Campus Control Point 2	$05^0$34’55.”	$05^0$50’ 27.97”	$05^0$34’ 10.2”	$05^0$50’ 16.1”

Table 2: Result of The Vertical Electrical Sounding in the Study Area

Ves No.	Resistivity	Thickness	Depth	Inference
VES1	65.8	0.2	0.2	No evidence of
	6400.4	5.0	5.2	contamination
	645.7	30.4	3.6	
	1406.9			
VES 2	61.7	0.7	0.7	No evidence of
	361.6	3.1	3.8	contamination
	574.9	23.8	27.6	
	614.4			
VES 3	57.5	0.9	0.9	No evidence of
	83.6	6.5	7.4	contamination
	364.9	31.5	38.9	
	555.2			
VES 5	70.2	0.5	0.5	* contaminated
	*33.5	9.5	10.0	geo-electric
	216.5	6.9	16.9	layer
	725.9	11.9	28.9	
	6349.6			
VES 6	130.2	1.1	1.1	* contaminated
	*37.7	2.7	2.8	geo-electric
	2774.9	7.9	11.7	layer
	19257.9			
VES 7	56.3	0.8	0.8	No evidence of
	147.9	3.7	4.5	contamination
	458.4	22.6	27.1	
	445.8			
VES 8	363.1	0.8	0.8	* contaminated
	671.8	2.4	3.2	geo-electric
	144.6	10.9	14.1	layer
	*33.4	49.8	63.9	
	142.5			
VES 9	333.6	0.9	0.9	* contaminated
	82.6	2.1	2.9	geo-electric
	496.4	4.8	7.8	layer
	*39.2	20.4	28.2	
	926.8			
VES 10	627.2	0.7	0.7	No evidence of
	2675.3	2.7	3.4	contamination
	795.5	40.0	43.4	
	194.4			
VES 11	533.1	0.8	0.8	No evidence of
	993.0	7.2	8.0	contamination
	1793.9	14.1	22.1	
	323.3			

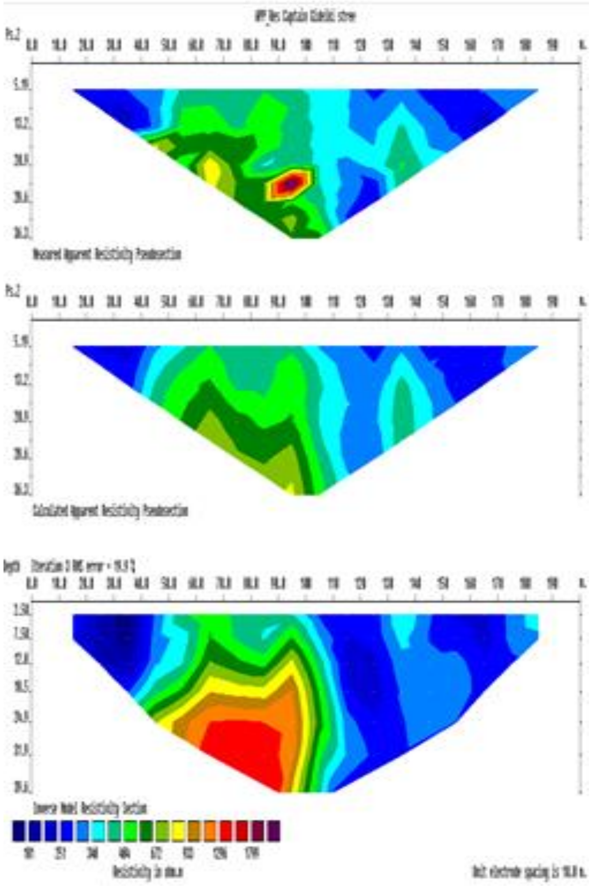

Fig 4 : 2D Inverse Resistivity Model Section for Profile 1

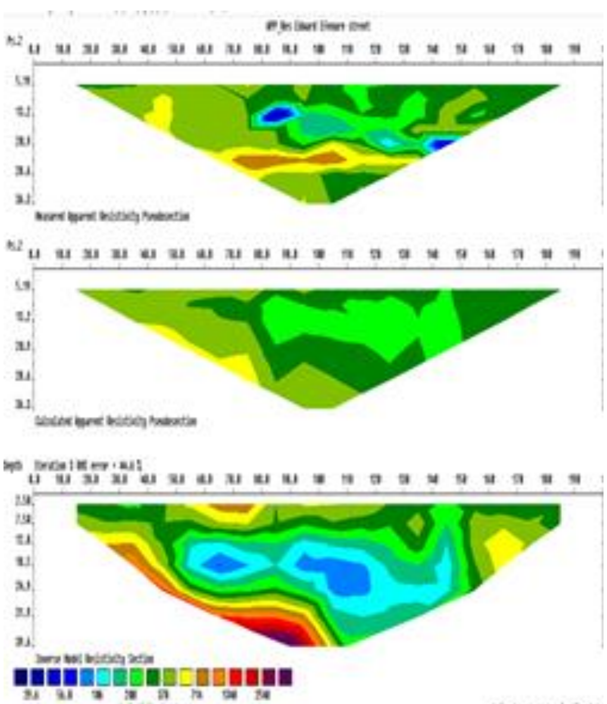

Fig 5: 2D Inverse Resistivity Model Section for Profile 2

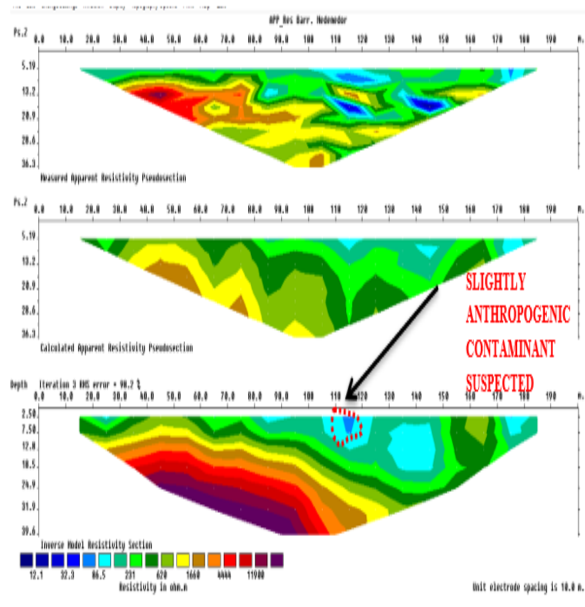

Fig 6: 2D Inverse Resistivity Model Section for Profile 3

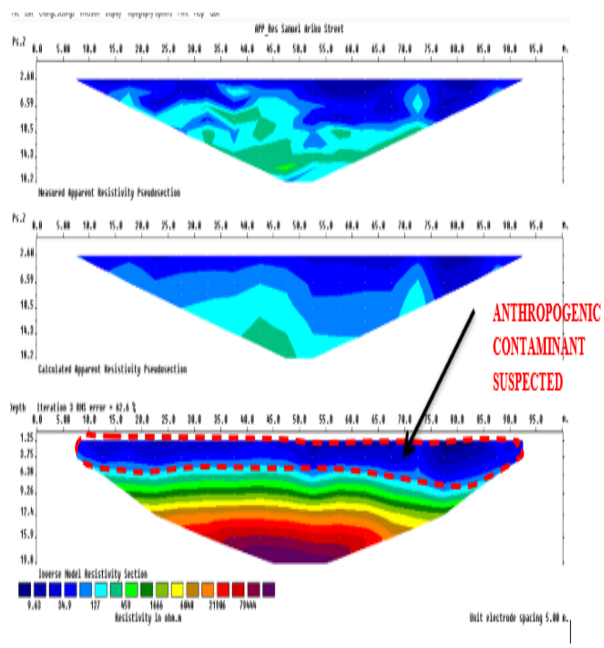

Fig 7: 2D Inverse Resistivity Model Section for Profile 4

The occurrence of low potential and resistivity values around the dumpsite in the study area, an anomaly of the oxido-reduction phenomenon, suggests contaminated groundwater..

Osubi Airport Hotel Street: The resistivity value ranges from 5.5 Ωm to 774 Ωm. The contamination region was observed at the surface, with a vertical depth of 12.8m to 31.9m and a horizontal distance of 20m to 110m. The source of groundwater contamination in this region remains unknown, as there is no evidence of anthropogenic contamination in the study area. The VES array on this traverse revealed contamination at the second geoelectric layer at the investigated point, approximately at the same depth as the Wenner Schlumberger array in the street.

Beside Trade fare street: The resistivity values on this traverse range from 82.9 Ωm to 680 Ωm. The 2D inverted resistivity model does not reveal any evidence of groundwater contamination at the maximum depth it penetrates. However, during the reconnaissance survey, there was evidence of groundwater contamination from the inspected borehole close to the acquired data. The Schlumberger array did not reveal any evidence of groundwater contamination. Due to the limited space in the street and the short maximum depth of 100 m for the current electrode spread, it may have been impossible to image the depth of contamination in this street using the two arrays.

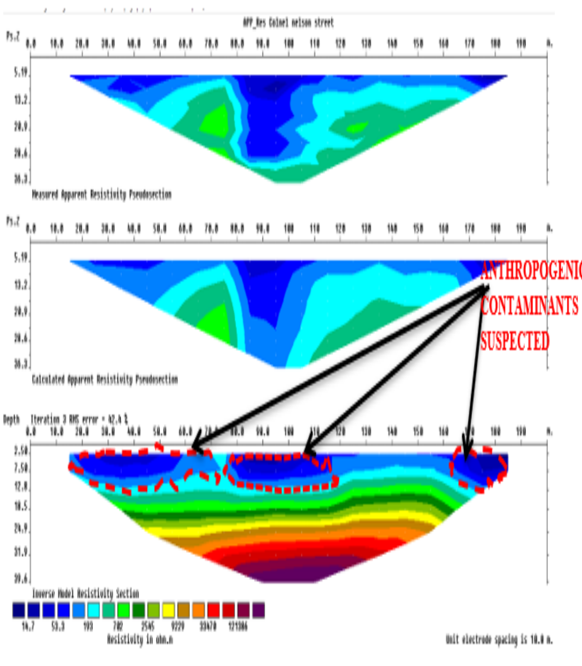

Fig 8: 2D Inverse Resistivity Model Section for Profile 5

PTI Osubi Permanent Site: The resistivity values on this traverse range from 3.89Ωm to 2632Ωm. Groundwater contamination was observed at a horizontal distance of 32m to 70m and at a vertical depth of 18.5m and below. Groundwater contamination at a horizontal range of 88m to 174m, as well as at a vertical depth of 12.8m and below. The location's VES result reveals groundwater contamination at the fourth layer, which has resistivity values of 33.4 m and a thickness of 49.8 m.

PTI Osubi Permanent site: The resistivity value in this traverse ranges from 57Ωm to 9266Ωm. It could be observed that the center portion of the traverse is contaminated from a depth of 12m to 37m and at a horizontal distance of 95m to 105m. The contamination became more evident through VES 9, placed at horizontal position 105 m, which shows a resistivity value of 48.5 m and a thickness of 24.1 m

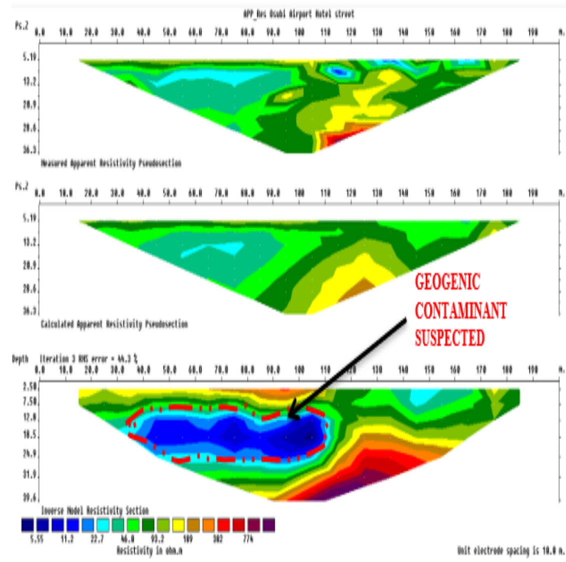

Fig 9: 2D Inverse Resistivity Model Section for Profile 6

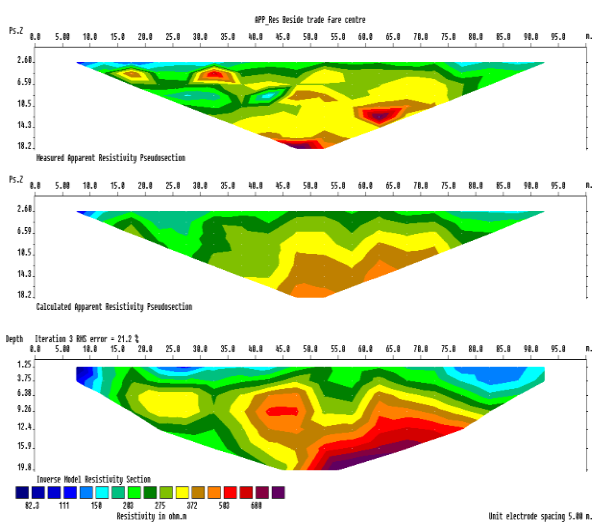

Fig 10: 2D Inverse Resistivity Model Section for Profile **7**

FUPRE Campus Control Point 1: The resistivity value on this traverse ranges from 377Ωm to 4426Ωm. This traverse, as expected from a control point, shows no evidence of contamination. This is also validated by VES 10, whose resistivity ranges from 181Ωm to 2084Ωm, which connotes no evidence of contamination.

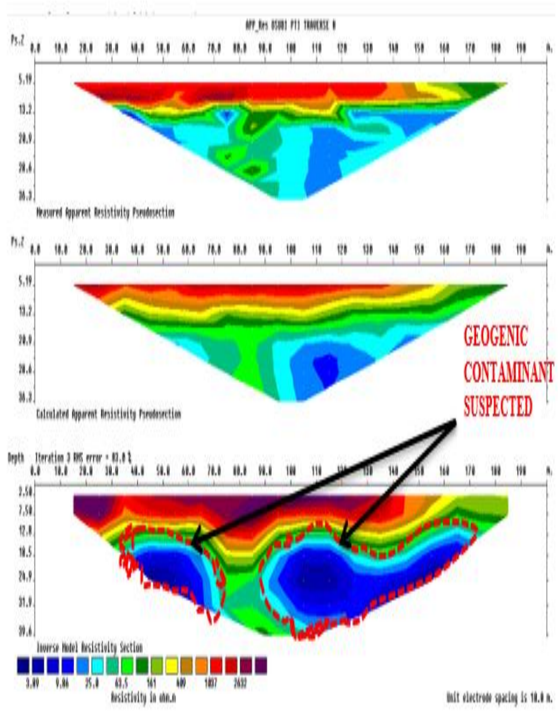

Fig 11: 2D Inverse Resistivity Model Section for Profile 8

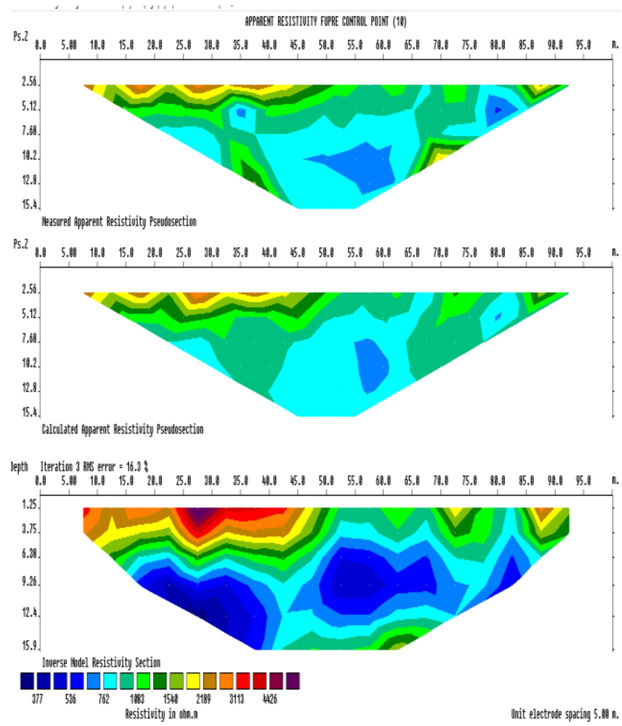

Fig 13: 2D Inverse Resistivity Model Section for Profile 10

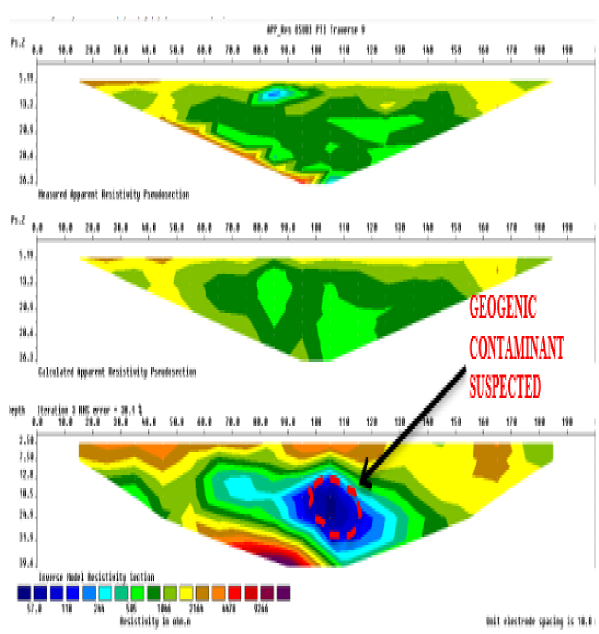

Fig 12: 2D Inverse Resistivity Model Section for Profile 9

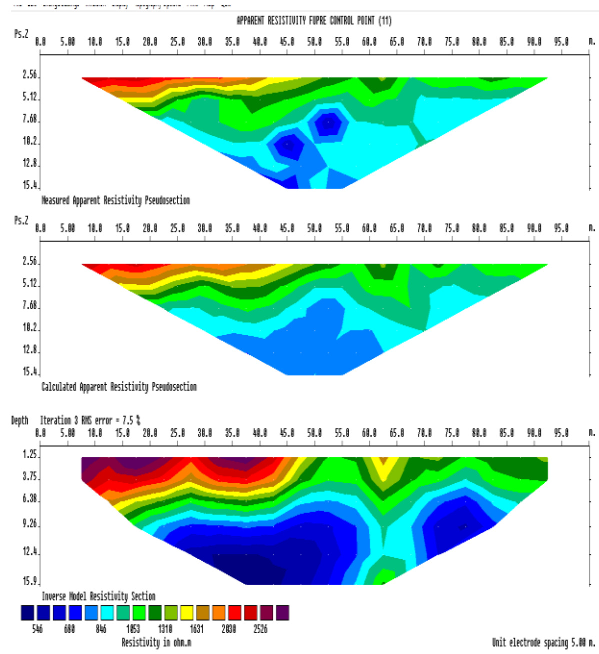

Fig 14: 2D Inverse Resistivity Model Section for Profile 11

FUPRE Campus Control Point 2: The resistivity value on this traverse ranges from 546Ωm to 2526Ωm. This traverse, as expected from a control point, shows no evidence of contamination. This is also authenticated by VES 11, whose resistivity ranges from 1644Ωm to 5559.8Ωm, which connotes no evidence of contamination.

Conclusion: This study used electrical resistivity techniques to identify human and geogenic sources of groundwater contamination in Osubi, southern Nigeria. Results revealed localized contamination zones, especially along Samuel Ariko Street, Colnel Newton, Osubi Airport Hotel Street, and PTI Osubi Permanent Site, even where human activity was minimal. While some pollution stemmed from anthropogenic sources like dumps and surface pollutants, natural geological factors also significantly impacted water quality. Most of the area showed no contamination, highlighting the need to consider both human and natural influences on groundwater. The findings offer valuable insights for managing water quality and emphasize the importance of ongoing monitoring and remediation to ensure safe groundwater access for local communities.

Declaration of Conflict of Interest: The authors declare that no known conflict of interest or personal relationships that could have influence the work reported in this paper.

Declaration of Data Availability Statement: Data are available upon request from the first and corresponding author.

REFERENCES

Alaminiokuma, GI; Chaanda, MS. (2020). Geophysical Investigation of Structural Failures Using Electrical Resistivity Tomography: A Case Study of Buildings in FUPRE, Nigeria. *J. Earth Sci. Geotech. Engr.10 (5):15-33*

Aniefiok, EI; Thomas, AH; Clement, OO; Ekpedeme, RA; Iniemem, JI. (2018). Petroleum Hydrocarbons Contamination of Surface Water and Groundwater in the Niger Delta Region of Nigeria, *J. Environ. Pollute. Human. Health. 6 (2): 51-61*

Ehirim, CN; Adizua OF; Okorie, IPC. (2016). Geoelectrical characterization of matured petroleum hydrocarbon impacted soil in Port Harcourt, Nigeria. *Asian J. Earth Sci., 9: 9 15.*

Etu-Efeotor, JO; Akpokodje, EG. (1990) Aquifer Systems of the Niger Delta. *J. Mining and Geology, 26, 279-285.*

Eyankware, MO; Akakuru, CO. (2022) Appraisal of groundwater to risk contamination near an abandoned limestone quarry pit in Nkalagu, Nigeria, using enrichment factor and statistical approaches. *J Energy Water.* https://doi.org/10.1007/s42108-022-00186-0

Giadom, FD; Tse, AC. (2015). Groundwater contamination and environmental risk assessment of a hydrocarbon contaminated site in eastern Niger Delta, Nigeria. *J. Envr. Earth Sci., 5(14): 166-175.*

Giadom, FD; Akpokodje, EG; Tse, AC. (2015). Determination of migration rates of contaminants in a hydrocarbon-polluted site using non-reactive tracer test in the Niger Delta, Nigeria. *Environ. Earth Sci. .DOI 10.1007/s12665-015-4094-3.*

International Association of Hydrogeologists (2020) Groundwater more about the hidden resource.[https://iah.org/education/general-public/groundwater-hidden-resource. Accessed 13 Nov 2020](https://iah.org/education/general-public/groundwater-hidden-resource)

Li. P; Tian. R; Xue,. C; Wu, J (2017a). Progress, opportunities and key fields for groundwater quality research under the impacts of human activities in China with a special focus on western China. *Environ. Sci. Pollut Res 24:13224–13234*

Loke, MH. (2002). 2-D and 3-D electrical imaging surveys.. (https://personales.upv.es/jpadin/coursenotes.pdf)

Ofomola, MO (2015): Integrated Geophysical and Hydrogeochemical Studies of Shallow Aquifer Contamination in Osubi, Near Warri, Southern Nigeria. *J. Earth Sci. Geotech. Engineer. 5 (4): 79-102.*

Okumoko, DP; Izeze, EO; (2020): Heavy Metal Contamination in Selected Dumpsites of Osubi, Warri, Western Niger Delta, Nigeria. *Interntnal. J. Innov. Res. Develop.* 9 (4) DOI No. : 10.24940/ijird/2020/v9/i4/JAN20090

Orji, OM; Eze, S (2018): Application of Seismic Refraction Tomography in Delineating Subsurface Geology and Weathering Structures in Parts of Osubi Delta State. IOSR *J. Applied Geol. Geophy. 6(4): Ver. I* 11-20

Peiyue, L; Karunanidhi, D; Subramani, T; Srinivasamoorthy, K (2021): Sources and Consequences of Groundwater Contamination. *Arch. Environ. Contaminat. Toxicol. 80:1–10*

Tse, AC; Nwankwo, AC. (2013). An integrated geochemical and geoelectrical investigation of an ancient crude oil spill site in south east Port Harcourt, Southern Nigeria. *Ife J. Sci., 15(1): 125-133.*

Ugbor, CC; Ikwuagwu,. IE; Ogboke, OJ (2021). 2D inversion of electrical resistivity investigation of contaminant plume around a dumpsite near Onitsha expressway in southeastern Nigeria.. *Sci. Reports | (2021) 11:11854*

Ugwu, NU; Ranganai, RT; Simon, RE; Ogubazghi, G. (2016) Geoelectric Evaluation of Groundwater Potential and Vulnerability of Overburden Aquifers at Onibu-Eja Active Open Dumpsite, Osogbo, Southwestern Nigeria. *J. Water Resource and Protection,* 8, 311-329. http://dx.doi.org/10.4236/jwarp.2016.83026

Uwadiegwu, P; Nwankwo, CN; ,Eze, SU (2018): Quantitative Analysis of Seismic Refraction Data to Delineate the Weathering Structures in Parts of Delta State. *SSRG Internati J. Applied Physics* (SSRG – IJAP) - 5 (2) 2018.

Weber, KJ; Daukoru, E. (1975) Petroleum Geology of the Niger Delta.. *J. Min. Geol., 12, 9-12.*

Whiteman, A. (1982) Nigeria: Its Petroleum Geology, Resources and Potential. I and II. Graham and Trotman Ltd., London. http://dx.doi.org/10.1007/978-94-009-7361-9