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VULNERABILITY OF GROUNDWATER INVESTIGATION AROUND DUMPSITE IN UGHELLI AND ENVIRONS IN DELTA STATE USING REMOTE SENSING AND GEOPHYSICAL METHODS.

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Abstract

The increasing number of dumpsites in Nigerian cities is attributed to urban population growth and industrial development. In the Ughelli area of Delta State, several large-scale landfills threaten local geology and groundwater through toxic waste seepage. This study sought to identify subsurface and groundwater pollution within and around two major landfills in Ughelli and neighboring areas using Vertical Electrical Sounding (VES) and remote sensing techniques. Fifteen VES stations were surveyed with a Schlumberger configuration and a maximum electrode spacing of 100 meters. Data from the VES studies were analyzed using IX1D software. Geoelectric parameters, including longitudinal conductance (S), transverse unit resistance (Tr), longitudinal resistance (ρL), and transverse resistivity (ρt), were calculated from the resistivity values. The estimated parameters ranged from 0.07 to 1229 mhos for S, 2.79 to 20126.83 Ωm² for Tr, 1.88 to 3929.04 Ω-m for ρL, and 3.3 to 3758.98 for ρt. Remote sensing was also used as a reconnaissance tool to assess subsurface lithology vulnerability. The results identified three to five geoelectric layers, predominantly of the HK curve type. Further analysis of S indicated that VES 9 and 13, located near waste dumps, are more susceptible to leachate flow compared to other VES points in the study area. Sensing data suggest that regions with higher drainage densities or porosity exhibit faster subsurface leachate movement and a greater risk of groundwater contamination, aligning with findings from other studies.

Keywords: Resistivity, Depth, Layer, Drainage, groundwater contamination, Flow direction

Introduction

The waste generated on a daily basis is an inevitable consequence of human endeavors, within this waste, one can find a variety of materials, including metals, organic matter and non-biodegradable substances (Igwe *et al*., 2022). Despite advancements in global industrialization and technology, the escalation of waste production has not been curbed, primarily due to increased levels of human activity (Ofomola *et al*., 2021). As a result, inadequate waste management practices contribute to pollution, environmental threats, and unsightly conditions. Irresponsible waste disposal contaminates both surface and groundwater sources. Additionally, municipal landfills contribute to soil pollution (Omene *et al*., 2019; Igwe *et al*., 2021; Eyankware and Obasi, 2021). Leachates from waste have the ability to travel several meters through soil, rocks and subsurface water systems, both vertically and horizontally. Factors such as the area's topography, hydrological conditions and the geological composition significantly determine the pathways of leachate flow (Omajene 2023;Okocha and Atakpo, 2011; Atakpo *et al*., 2013; Koda *et* *al*., 2017; Ofomola, 2015b). Consequently, the discharge of leachate poses a threat to the contamination of groundwater sources, rocks, soil and surface water bodies. The indigenous communities in Nigeria heavily rely on both surface and groundwater resources. A significant number of people access drinking water through privately owned wells, some of which can be as shallow as five meters deep (Omajene *et al*., 2024; Qian *et al*., 2016; Ohwoghere-Asuma *et al*., 2013; Eyankware and Aleke, 2021; Naudet *et al*., 2014).

The purpose this research is to explore the possible impacts of leachate on the environment, as well as to assess the quality of groundwater in the vicinity in light of the growing environmental concerns, geophysical techniques have gained prominence as a means of evaluating environmental hazards (Okolie *et al*., 2008). Numerous authors employ geophysical methods and alternative strategies when investigating areas affected by biological and waste residues that have decomposed and generated leachate, which decreases the resistivity of materials due to a high level of dissolved metal ions (Omajene *et al*., 2024;Atakpo, 2013; Atakpo and Ofomola, 2012; Eyankware *et al*., 2021; Ganiyu *et al*., 2016; Raji and Adeoye, 2017). Geoelectric techniques are exceptionally well-suited for environmental investigations of this kind. This efficacy arises mainly because leachate, which is produced through the decomposition of waste, tends to exhibit a considerably higher ionic concentration than that found in groundwater (Ohwoghere-Asuma *et al*., 2014). A multitude of investigations, including those by Sultan *et al*., (2009), Ariyibi (2011), Gaafar (2015) and Ogungbemi *et al*.,(2018), have been conducted globally, employing a combination of geophysical, geochemical and remote sensing methodologies to identify and outline prospective ore deposits. These investigations illustrate the efficacy of integrating multiple techniques to deepen the understanding and characterization of geological structures and resources. Therefore this study employs the resistivity method and remote sensing to investigate the dynamics, accumulations and spread of pollutants in Ughelli and its vicinity.

Figure 1: Dumpsite at Ekuigbo Ughelli

Figure 2: Dumpsite at Ogbovwan Ughelli

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Materials and Methods

Study Area

The geology of the study area is primarily underlain by the Niger Delta Formations. From the top to the base, these formations include the Sombreiro-Warri Deltaic Plainsands (Fig. 3). The Benin Formation, Agbada Formation and Akata Formation have been thoroughly described in various studies (Weber and Daukoru, 1975). The Benin Formation, recognized as the youngest stratigraphic unit of the Niger Delta Basin, is Oligocene in age and consists of continental floodplain sands and alluvial deposits, with an estimated thickness of up to 2,000 meters (Eyankware and Ephraim, 2021). This formation is characterized by coarse-grained, gravelly sandstone, with minor intercalations of shale. It represents a continental deposit from the Miocene to younger periods, exceeding 1,820 meters in thickness.

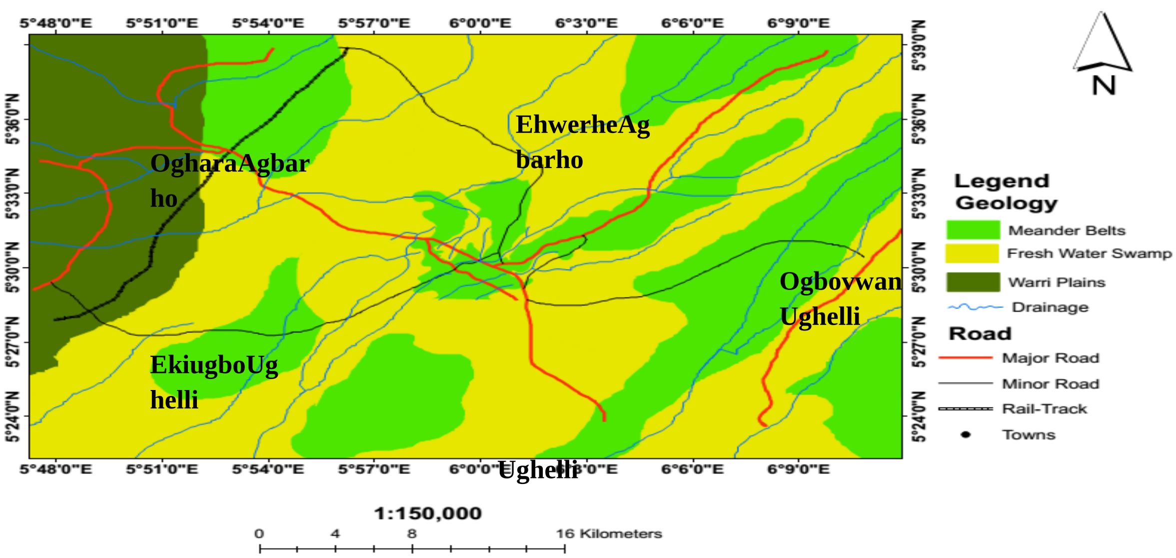

Figure 3: Geology Map of the study area

Fifteen (15) VES were conducted within the study area, as shown in Fig. 3, with the help of an OHMEGA Terrameter and its accessories. For each VES profile, a Schlumberger electrode array was used with a maximum half current (AB/2) electrode separation of 100 m and a half potential (MN/2) electrode separation of 5 m. Surfer software was used to map the spatial distribution ofS, Tr, ρL, and ρt. The equation (1) was used to convert the observed field data to apparent resistivity (a) values. The acquired VES data were processed using IX1D software as shown in Fig. 4 and 5 respectively.

$$\pi\left(\frac{\left(\frac{AB}{2}\right)-\left(\frac{MN}{2}\right)}{MN}\right)\Delta V/I \quad (1)$$

Dar-Zarrouk Parameter

Dar Zarrouk's longitudinal (S) and transverse (T) parameters are derived via

$$S = \frac{h}{p} \quad (2)$$

$$T = hp \quad (3)$$

Where h is the aquifer thickness and p is the aquifer resistivity

Longitudinal Unit Conductance (*S*) was calculated using equation (4)

The longitudinal conductance is equal to the number of layers (n).

$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i} = \frac{h_i}{\rho_i} + \frac{h_2}{\rho_2} + \cdots + \frac{h_n}{\rho_n} \quad (4)$$

as proposed by Asfahani,(2013);Oli*et al*., (2020)

Transverse Unit Resistance (*Tr*) was calculated using equation (5)

The total resistance of the transverse unit is

$$Tr = \sum_{i=1}^{n} h_i\rho_i = h_i\rho_i + h_2\rho_2 + \cdots + h_n\rho_n \quad (5)$$

As proposed by Adeniyi *et al*., (2018); Nwachukwu *et al*., (2019)

Longitudinal Resistance was calculated using equation (6)

$$\rho_L = \frac{H}{S} = \frac{\sum_{i=1}^{n} h_i}{\sum_{i=1}^{n} \frac{h_i}{\rho_i}} \quad 6)$$

As proposed by Suneetha and Gupta, (2018). Transverse Resistance was determined from equation (7) as proposed by Suneetha and Gupta (2018).

$$\rho_t = \frac{T}{H} = \frac{\sum_{i=1}^{n} h_i\rho_i}{\sum_{i=1}^{n} h_I} \quad (7)$$

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Remote Sensing Application

This research adopts a comprehensive methodology that combines remote sensing techniques and Geographic Information System (GIS) analysis utilizing ArcGIS 10.8, and field validation to examine the spatial distribution of leachate plumes originating from an unregulated solid waste disposal site. The investigation employs multi-temporal Landsat imagery, analyzes topography and terrain, calculates the Normalized Difference Vegetation Index (NDVI), maps drainage density, and models flow direction to thoroughly assess the effects of leachate on the adjacent ecosystem.

Remote Sensing Data and Processing

For the multi-temporal analysis of the study area, data from Landsat 8 OLI (Operational Land Imager) were employed. This imagery, characterized by a spatial resolution of 30 meters, was chosen for its capacity to deliver precise information regarding land cover, vegetation health, and surface temperature—factors that are crucial for identifying patterns of leachate migration.

Elevation and Terrain

Elevation data were obtained from the Digital Elevation Model (DEM) provided by the Shuttle Radar Topography Mission (SRTM) and were subsequently processed using ArcGIS 10.8. This DEM, featuring a spatial resolution of 30m facilitated the extraction of elevation values throughout the study area. The SRTM DEM data were further analyzed to compute slope and drainage density. Slope was determined by utilizing the slope tool within ArcGIS, which assesses the maximum rate of elevation change for each individual DEM cell.

Slope Analysis

The slope data derived from the DEM were analyzed to understand the terrain characteristics of the study area. The slope (S) was calculated using the following equation (8):

$$S = arctan\left(\frac{\Delta z}{d}\right) \times \frac{180}{\pi} \qquad (8)$$

where Δz is the change in elevation, and d is the horizontal distance. The slope data were classified into categories (e.g., flat, gentle, moderate, steep) to assess the distribution of different slope classes across the study area.

Normalized Difference Vegetation Index (NDVI)

NDVI serves as an essential metric for observing the progression of vegetation cover across the globe and is frequently utilized by academics. This quantitative measure employs reflections from visible and near-infrared light to assess the health and density of plants. Its importance is underscored by its role in monitoring shifts in vegetation, combating desertification and supporting studies in agriculture and environmental science. The computation of NDVI is grounded in a simple equation (9) outlined by:

$$NDVI = \frac{LandsatBand5 - LandsatBand4}{LandsatBand5 + LandsatBand4} \quad (9)$$

NIR (near-infrared reflectance) and red reflectance pertain to the energy levels associated with specific segments of the spectrum.

LULC Data Analysis

During the data analysis stage, processed data was utilized to evaluate the spatial distribution of slope, drainage density, and changes in Land Use Land Cover (LULC), while also considering their geological and environmental consequences. The classification of LULC commenced with the preprocessing of satellite images to improve the accuracy of the data. This process involved implementing radiometric corrections to mitigate sensor inaccuracies and atmospheric influences, thereby ensuring that pixel values reliably represented surface features.

Drainage Density Analysis

Drainage density (Dd) serves as a crucial metric that measures the cumulative length of streams per unit area within a watershed, providing significant information regarding potential flooding events. The drainage density map was created by extracting drainage networks from the SRTM DEM through hydrologic analysis conducted in ArcGIS. These networks were then utilized to compute drainage density according to the equation (10):

$$D_d = \frac{\sum_{i=1}^{n} L_i}{A} \quad (10)$$

Where $\sum_{i=1}^{n} L_i$ signifies the cumulative length of streams (L) found within the specified area, while A represents the total area measured in square units (L^2). The drainage density map produced from this data reveals regions characterized by differing drainage network densities, ultimately emphasizing areas with diverse potentials for runoff and flood occurrences.

Flow Direction

In order to ascertain the direction of flow within the study area, a digital elevation model (DEM) was analyzed using ArcGIS. The process commenced with the importation of the DEM into the ArcGIS platform. Following this, the Terrain Tools were employed to ready the DEM for subsequent analysis, which involved filling depressions to maintain a seamless surface and eliminating any anomalies that might interfere with the flow calculations. The Flow Direction tool was subsequently utilized to create a flow direction raster, which illustrates the steepest descent from each individual cell, with every pixel receiving a value that reflects the flow direction based on the D8 algorithm.

RESULTS AND DISCUSSION

Table 1: The findings of the analyzed VES survey are presented

VES	Layers	Resistivity (Ωm)	Thickness (m)	Depth (m)	Curves

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1	1	2112.7	0.65	0.65	HK
	2	301.31	4.42	4.07	
	3	28.68	5.37	10.44	
	4	707.4	18.52	28.95	
2	1	345.97	2.6	2.6	QH
	2	118.97	11.3	13.90	
	3	293.0	12.51	26.40	
	4	39.34	42.25	68.70	
3	1	1494.8	2.22	2.22	H
	2	378.1	12.60	14.79	
	3	55.89	50.00	64.80	
4	1	422.2	3.07	3.07	HKH
	2	27.587	3.07	6.14	
	3	45.65	0.91	7.06	
	4	13.21	17.34	24.41	
5	1	102.8	1.72	1.72.	HK
	2	45.89	13.75	15.48	
	3	314.02	32.67	48.15	
6	1	1029.7	3.24	3.24	HKA
	2	232.06	6.91	10.16	
	3	1562.8	9.41	19.56	
	4	19.498	23.86	43.43	
7	1	290.76	0.81	0.81	HKA
	2	53.808	7.58	3.39	
	3	68.88	3.27	6.67	

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	4	164.39	17.42	34.09	
	5	28.138	39.15	63.24	
8	1	404.59	1.67	1.67	
	2	41.104	7.98	9.65	
	3	347.39	10.58	20.2	HKA
	4	8.0168	31.46	51.7	
9	1	147.48	3.49	3.49	
	2	29.2862	0.44	3.94	HK
	3	352.60	13.66	17.61	
10	1	306.50	0.91	0.91	Q
	2	168.44	1.88	2.79	
	3	94.58	42.60	45.39	
11	1	140.89	1.73	1.73	HKH
	2	28.54	4.27	6.06	
	3	3596.6	0.71	6.72	
	4	21.90	62.22	68.952	
	5	90.775			
12	1	1525.9	0.91	0.91	Q
	2	475.15	19.84	20.76	
	3	116.596	79.61	100.3	
	4	8.2708	1.616		
13	1	627.72	1.96	1.96.	
	2	116.36	3.11	5.07	HK
	3	323.20	33.90	38.97	
14	1	533.23	2.20	2.20	

	2	175.43	6.40	9.60	
	3	12.414	0.46	9.07	H
	4	1229.0	19.76	28.84	
15	1	313.53	2.45	2.45	
	2	24.26	4.18	6.63	
	3	1008.5	8.45	15.08	HK

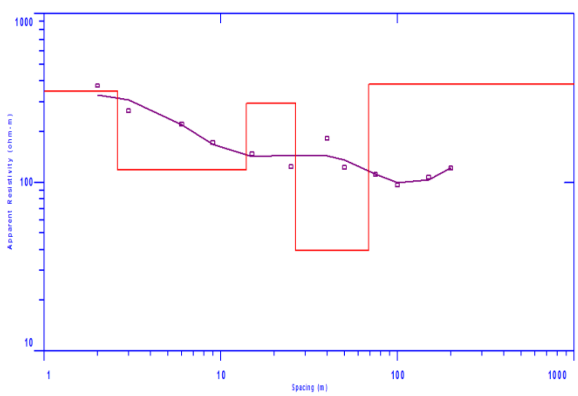

Fig. 4: VES 2 EhwerheAgbraho by dumpsite

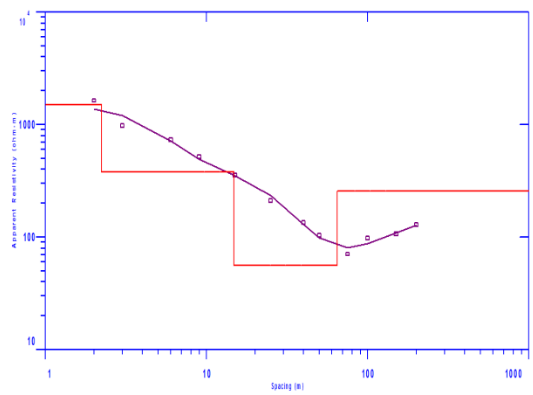

Fig. 5: VES 3 (EhwerheAgbarho Control site

Table 2: Results of Dar-zarrouk parameters (longitudinal conductance, transverse unit resistance, longitudinal resistance, transverse resistivity.)

VES Station	Longitudinal Conductance (S)	Transverse Unit Resistance (Tr)	Longitudinal Resistance (ρL)	Transverse Resistivity (ρt)
1	301.31	5.07	4.42	21.40
2	336.00	10.34	66.09	50.30
3	378.09	46.56	12.57	46.4
4	1.45	1743.90	544.80	538.74
5	314.02	48.14	46.42	35.50
6	232.06	10.15	6.91	120.22
7	233.74	654.44	62.43	46.35
8	347.39	20.24	18.57	31.30
9	0.07	5344.14	212.56	529.44
10	169.44	2.79	1.88	56.34
11	3.00	4231.97	3929.04	3758.98

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12	0.72	20126.8	2135.11	2167.89
13	0.08	16765.20	2069.51	2015.05
14	1229.00	28.84	26.64	4.01
15	1008.50	15.08	12.63	3.30
Min.	0.07	2.79	1.88	3.30
Max.	1229.00	20126.83	3929.04	3758.98
Aver.	340.2318	4069.6060	769.4412	775.7353

Table 3: The rating of the aquifer's protective capacity by Oladapo and Akintorinwo (2007)

S/No	Longitudinal Conductance (mhos)	Protective Capacity	VES Locations
1	>10	Excellent	VES 1,2, 3,5, 6,7,8 and
2	5 -10	Very Good	Nil
3	0.7 - 4.9	Good	VES 4, 11 and 12
4	0.2 – 0.69	Moderate	
5	0.1 – 0.19	Weak	
6	< 0.1	Poor	VES 9 and 13

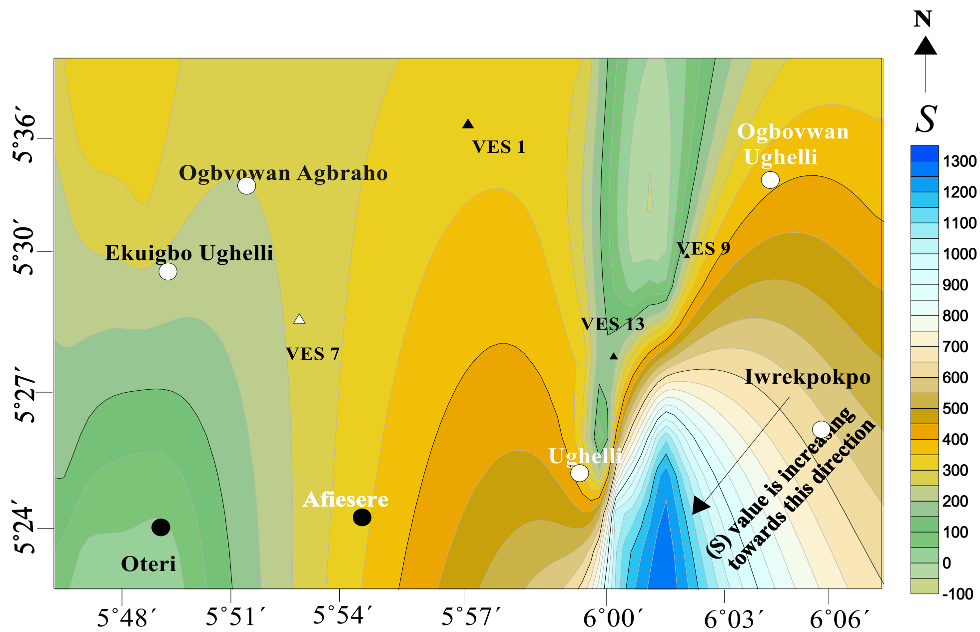

Fig. 6: Spatial variation of longitudinal conductance across the study area

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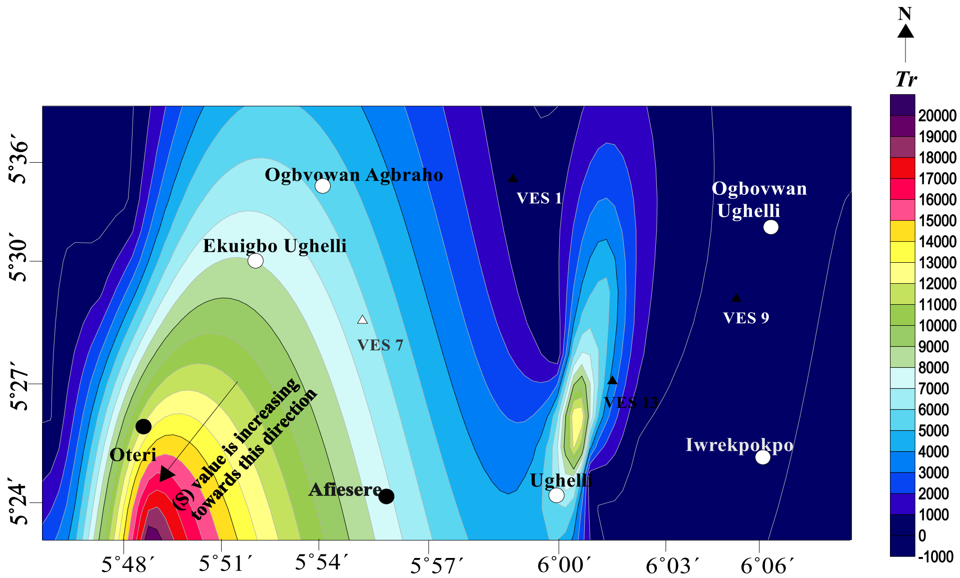

Fig. 7: Spatial distribution map of transverse unit resistance

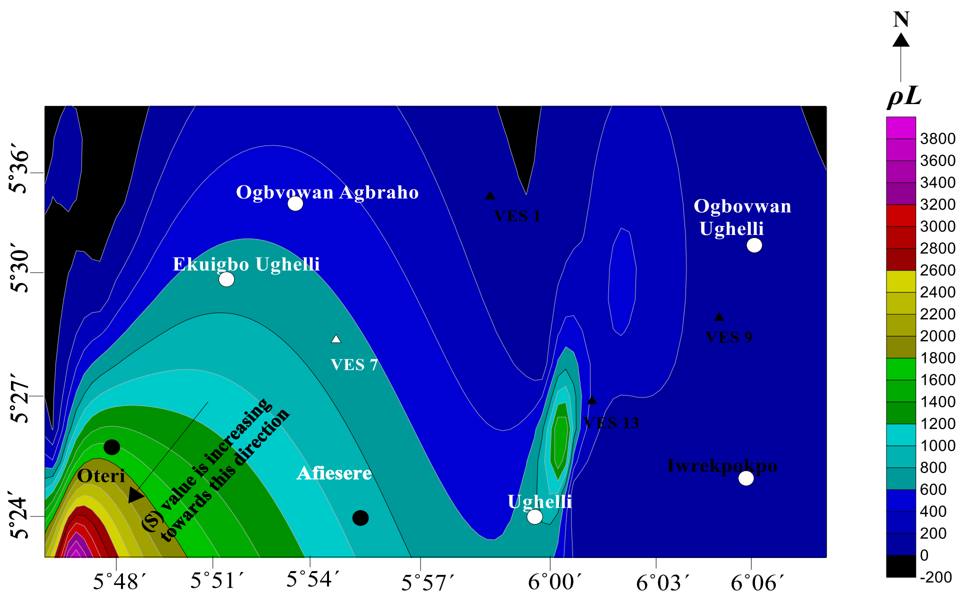

Fig. 8: Spatial distribution map of longitudinal resistance (ρL)

Transverse resistivity (ρt)

Transverse resistivity within an aquifer denotes the opposition that an electric current meets when it travels at a right angle to the aquifer's stratification. This measurement serves as a crucial variable in hydrogeological research for the purpose of defining aquifer characteristics and analyzing groundwater movement. Techniques such as Vertical Electrical Sounding in geoelectrical surveys can facilitate the assessment of transverse resistance, which is subsequently correlated with additional aquifer attributes, including

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transmissivity and hydraulic conductivity. This indicates that the authentic resistivity perpendicular to the stratification plane, exemplified by shale, surpasses the actual resistivity that is aligned parallel to the stratification plane (Dewashish, *et al.*, 2014). Analysis of Table 2 indicates that the ρt values fluctuate from 3.3 at VES 15 to 3758.98 at VES 11, resulting in an average of 775.73.

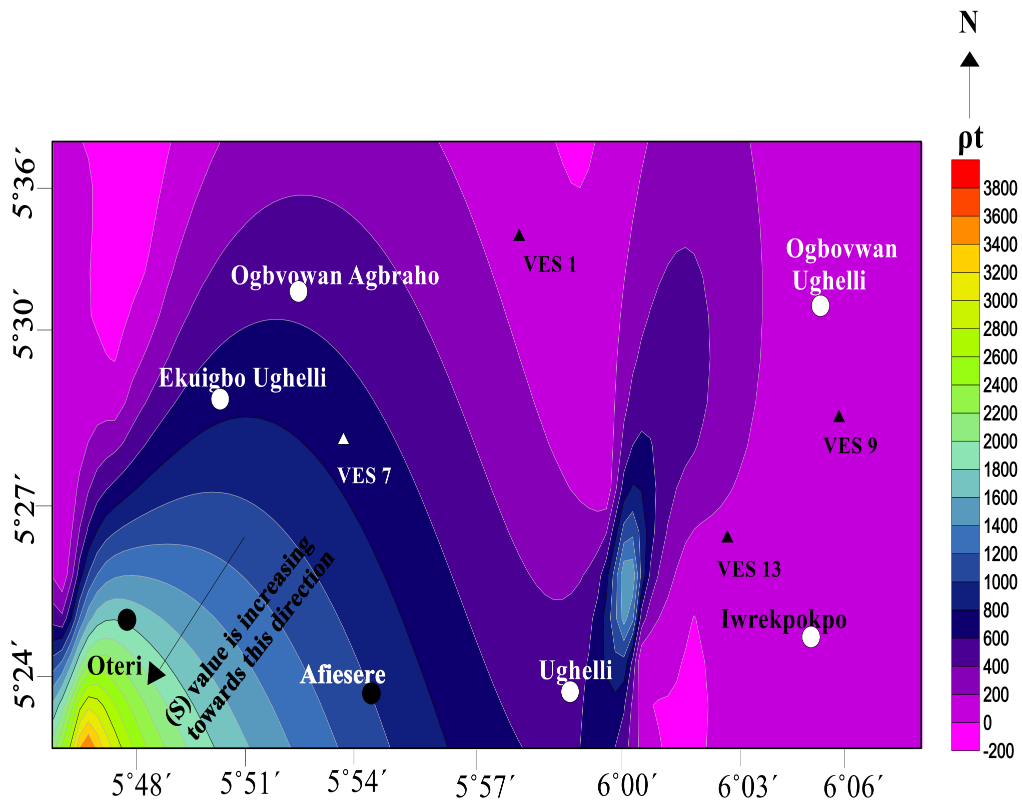

Fig. 9 : Spatial distribution map of transverse resistivity (ρt).

Analysis on remote sensing

The utilization of Landsat imagery for remote sensing is crucial for visualizing these dynamics. Through the application of multi-temporal Landsat data, one can monitor changes in the surface over time, observe fluctuations in moisture levels, and recognize spectral signatures that signify leachate contamination, as illustrated in Fig. 10 to 12.

Elevation data in the study area

In the study area, elevation data spans from -2.0 to 31.0 meters above sea level. The predominant portion of the region is characterized by mid-range elevations between 4.6and 17.8 m, which account for 14.859 km² and 16.584 km²respectively, representing roughly 74% of the overall area, as depicted in Fig 10, and Table 4. The lowest elevation range, from -2.0 to 4.6 m, encompasses only a minor area of 0.076 km², signifying a scarcity of low-lying zones. Likewise, the highest elevation interval, ranging from 24.4 to 31.0 m, occupies a relatively small space of 0.719 km², as shown in Fig. 10. The analysis reveals notable elevation discrepancies within the study area, with the majority of the landscape lying between 4.6 and 17m. The restricted zones at both the highest and lowest elevations, ranging from -2.0 to 4.6 m and 24.4 to 31.0 m, indicate that these areas could potentially function either as leachate collection sites or as obstructions to the spread of the plume.

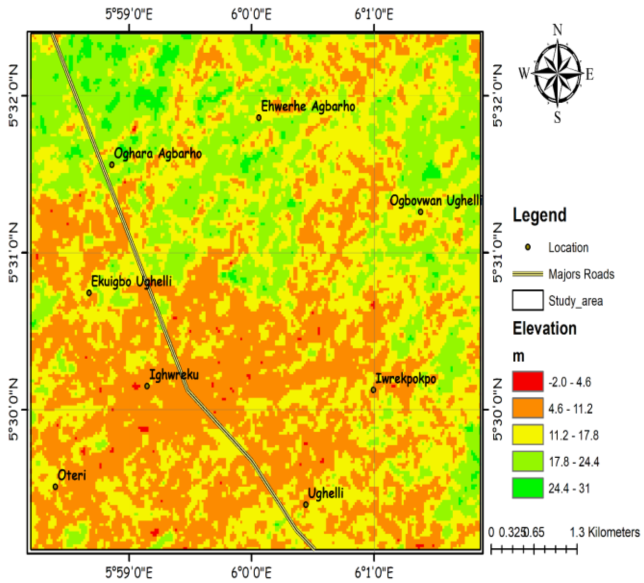

Fig. 10: Elevation Map of the study area

Table 4: Elevation and Terrain of the study Area

Elevation (m)	Area (km²)
-2.0 – 4.6	0.076
4.6 – 11.2	14.859
11.2 – 17.8	16.584
17.8 – 24.4	9.007
24.4 – 31.0	0.719

Land Use/Land Cover (LULC

The examination of Land Use/Land Cover (LULC) based on Landsat imagery was conducted to identify leachate plumes originating from an uncontrolled solid waste disposal site, as depicted in Fig. 11. The identified LULC categories consist of Water, Trees, Flooded Vegetation, Crops, Built Area, Bare Ground, and Rangeland, each playing a distinct role in the environmental dynamics of the area under study. A summary of the LULC classification findings is provided in Table 5. The Built Area, which encompasses 30.838 km², represents the most extensive segment of the study area as indicated in

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Table 5. This reflects considerable urban growth and development, typically linked to an increase in solid waste production.

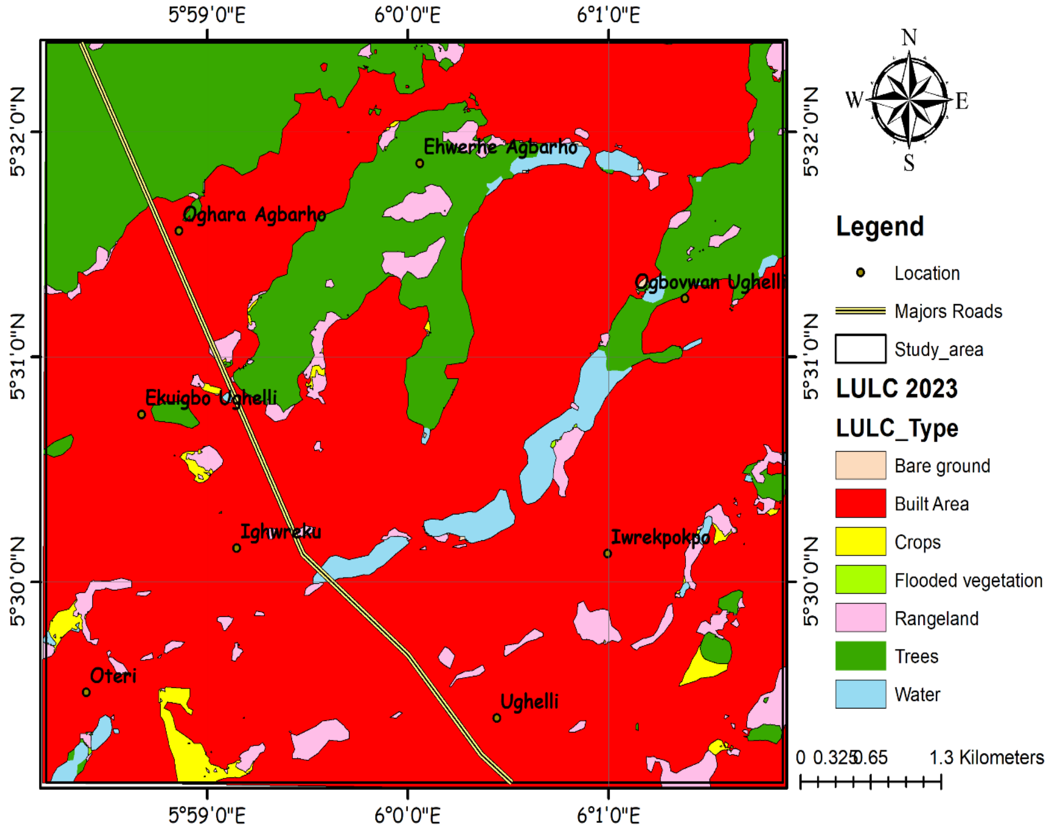

Fig. 11: Land Use/Land Cover

Table 5: LULC classification results

LULC Type	Area (km²)
Water	1.054
Trees	8.339
Flooded Vegetation	0.005
Crops	0.427
Built Area	30.838
Bare Ground	0.016
Rangeland	1.791

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Drainage density

The significant presence of developed regions suggests a potential for pollution to spread via surface runoff, while nearby water bodies pose a risk of leachate contamination that could affect water supplies. On the other hand, the area measuring just 0.053 km² is linked with the highest drainage density, recorded between 924.84 and 1156.06 km/km². This variation in drainage density across the landscape may have important consequences for the movement of leachate plumes.

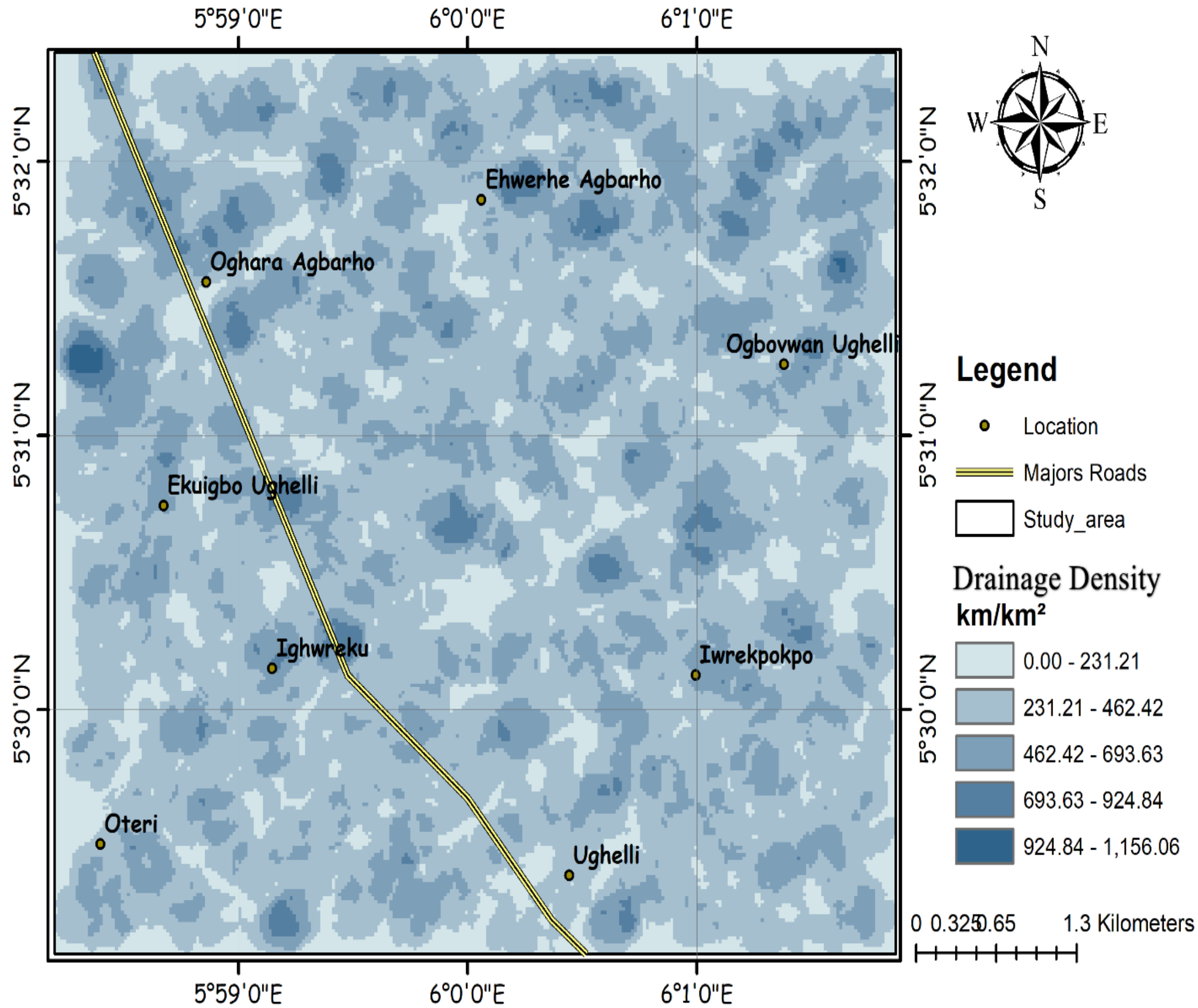

Fig. 12: Drainage density map of the study area.

Table 6: Drainage Density

Drainage Density (km/km²)	Area (km²)
0.00 - 231.21	5.935

231.21 - 462.42	24.195
462.42 - 693.63	10.009
693.63 - 924.84	1.069
924.84 - 1156.06	0.053

Conclusion

Fifteen (15) Vertical Electrical Soundings (VES) were carried out to determine the characteristics of the subsurface layers, such as resistivity, depth and thickness, which are essential for assessing groundwater potential and aquifer susceptibility within the study region. The survey employed the Schlumberger electrode arrangement, which allowed for a maximum half potential electrode separation of 10m and a maximum half current electrode spacing of 100mThis study revealed four unique curve types: HK, HKA, H, Q, HKH and QH.. Analyzing the geoelectric data uncovered differences in both the properties of the aquifer and the Dar Zarrouk parameters. The abundant clay content plays a crucial role in reducing the vulnerability of groundwater to surface contamination in this area, which aligns with the findings derived from the *S* value. Findings from *Tr*, ρL, and ρt, showed that areas of groundwater potential is located in SW parts of the study area. Deductions from findings derived from remote sensing indicate that regions with significant drainage facilitate the movement of leachate, consequently accelerating the contamination of groundwater in the examined area. Remote sensing studies utilizing Landsat imagery were employed to pinpoint areas prone to significant surface runoff and potential pollution risks, including leachate plumes emanating from the uncontrolled solid waste disposal site, thereby necessitating the definition of drainage density zones. The findings indicate that regions with elevated drainage density are more susceptible to the dispersal of leachate, which may transport pollutants from the waste site due to the augmented flow of surface water.

References

Adeniyi, A. E., Osisanya O. W., and Eyankware, M.O. (2024). Delineation of groundwater potential using electrical resistivityimaging techniques at IbuleAkure, Southwestern Nigeria. Malaysian Journal of Geosciences (MJG),doi:

http://doi.org/10.26480/mjg.01.2024.01.09

Asfahani J (2013) Groundwater potential estimation using vertical electrical sounding measurements in the semi-arid Khanasser Valley region, Syria.HydrolSci J 58(2):468–482

Atakpo, E. A. (2013a). Aquifer vulnerability investigation using geoelectric method in parts of Sapele Local Government area of Delta State, Nigeria. Nigerian Journal of Basic and Applied Sciences 21 (1), 11-19

Atakpo, E. A. (2013b). Resistivity imaging of crude oil spill in Ogulaha Coastal Community, Burutu LGA, Delta State, Nigeria. International Journal of Research and Reviews in Applied Sciences 15 (1), 97-101

Dewashish K, Rai SN, Thiagarajan S, Kumari YR (2014) Evaluation of Heterogeneous Aquifers in Hard Rocks from Resistivity Sounding Data in Parts of KalmeshwarTaluk of Nagpur District, India. CurrSci 107:1137–1145

Eyankware MO, Aleke G (2021) Geoelectric investigation to determine fracture zones and aquifer vulnerability in southern Benue Trough southeastern Nigeria. Arab J Geosci.https://doi.org/10.1007/s12517-021-08542-w

George, N, J, Emah JB, Ekong UN (2015) Geohydrodynamic properties of hydrogeological units in parts of Niger Delta, southern Nigeria. J Afric Earth Sci 105:55–63

Golden Software, IX1D, One Dimensional Resistivity Interpretation Software, Golden software Inc., Golden, 2004

Igwe, E. O., Ede, C. O., Eyankware, M. O. (2021). Heavy metals concentration and distribution in soils around Oshiri and Ishiagu lead – zinc mining areas, southeastern Nigeria. World Scientific News. 158; 22-58.

Igwe, E.O., Ede, C.O., Eyankware, M.O., Nwachukwu, C. M.,Onyekachi B. W. (2022). Assessment of Potentially Toxic Metals from Mine Tailings and Waste Rocks Around Mining Areas of Oshiri-Ishiagu Region, Southeastern Nigeria. Earth Systems and Environment, https://doi.org/10.1007/s41748-022-00306-0

Nwachukwu SR, Bello R, Ayomide O, Balogun AO (2019) Evaluation of groundwater potentials of Orogun, South-South part of Nigeria using electrical resistivity method. Applied Water Sci 9:184. https://doi.org/10.1007/s13201-019-1072-z

Ofomola, M. O. (2022). Determination of hydraulic properties of shallow aquifer from electrical resistivity and pumping test data in Aragba-Okpe Delta State Nigeria. International Journal of Hydrology Science and Technology 13 (3), 305-323

Ofomola, M. O.(2019). Delineation of Groundwater Contamination Using Self Potential Method in Effurun, Delta State, Nigeria. Nigerian Journal of Technological Research 14 (3)

Ofomola, MO., Akpolile, AF.,Anomohanran, O., Adeoye, T.O., Bawallah, M. A. (2021). Detection of Trace Metal Contamination Around a Dumpsite in Iyara Area Warri Nigeria Using Geoelectrical and Geochemical Methods. Environmental and Earth Sciences Research Journal, 8 (3)

Ofomola, MO., Akpolile, AF.,Anomohanran, O., Adeoye, T.O., Bawallah, M. A. (2021). Detection of Trace Metal

Contamination Around a Dumpsite in Iyara Area Warri Nigeria Using Geo-electrical and Geochemical Methods. Environmental and Earth Sciences Research Journal, 8 (3)

Omajene .A,Ighrakpata .C.F,Umayah.O.S(2023). Application of Geoelectric indices in Groundwater vulnerability mapping: A case study of Agbor, Delta State, Southern Region Nigeria Discovery 2023;59:e51d1210.

Omajene.Aghogho. 2023. Investigation of Hydro geological Properties using Resistivity Data in parts of Delta State, Nigeria. Nigerian institute of Physics Journal vol. 23(1) 109-121

Omene, M. E., Chokor, J. U., Eyankware, M. O. (2015). The effects of land use on soil physiochemical properties in Ughelli and its environs, Nigeria. International Journal of Research and Review, India. Vol. 2(11): 656-671

Onwe, I. M., Eyankware, M. O., Obasi, P. N., Ifeanyichukwu, K. A. (2022).Hydrochemical and statistical approaches in the evaluation of groundwater quality for drinking and irrigation uses around Ezzangbo–Ngbo area, SoutheasternNigeria.Modeling Earth Systems and Environment, https://doi.org/10.1007/s40808-022-01503-6.

Opara, A. I., Ireaja, A. N., Eyankware, M. O., Urom, O. O., Ikoro, D. O., Akakuru, O. C., Dioha, E., Omoko, N. E. (2023). A critical analysis of the comparative techniques of aquifer protective capacity studies in part of Southeastern Nigeria. International Journal of Energy and Water Resources.

Opara, A. I. , Edward, O.O. I. , Eyankware, M. O., Akakuru, O. C., Oli, I. C., Udeh, H. M. (2022). Use of geo-electric data in the determination of groundwater potentials and vulnerability mapping in the southern Benue Trough Nigeria.International Journal of Environmental Science and Technology https://doi.org/10.1007/s13762-022-04485-1.Proceedings 2, 209-221.