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Geophysical and Laboratory Evaluation of Aquifer Position, Aquifer Protective Capacity and Groundwater Quality in Selected Dumpsites in Calabar Municipal Local Government Area, South Eastern Nigeria

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Abstract

The position of the aquifer, its protective capability, and the quality of the groundwater beneath the dumpsite were all investigated. The techniques employed were laboratory, tritium tagging, electrical resistivity tomography (ERT), and vertical electrical sounding (VES). With a maximum electrode spacing of 500 meters, fifteen VES stations were used, and IPI2win software was used to analyze the data collected. The resistivity map of the dumpsite was determined by deploying six ERT stations for the 2 D survey. To ascertain the degree of soil infiltration beneath the dumpsite, the tritium tagging method was used. Using a conventional laboratory procedure, groundwater samples were taken from neighboring boreholes and examined. The findings showed that there were three to five geoelectric layers, with the aquifer position being inferred to be between 24.2 and 75.1 meters deep in the third, fourth, and fifth levels. Siemens with values in the range of 0.0235 to 0.1908 for the load protection capacity were deemed to be, at most, weakly and badly protected. The obtained porosity values ranged from 44.45 to 89.75. Strong calculated values for transmissivity and porosity indicate a permeable aquifer system with considerable storativity. The area has an infiltration value between 8 and 22 percent, according to the results of the tritium tagging technique, which was used to evaluate the level of infiltration from the dumpsite. Groundwater samples that have been analyzed reveal levels of NO2, DO, Pb2+, magnesium, and cadmium that are higher than what the NSDWQ has approved. Overall analysis of the results from the above-described methodologies shows that the study area's aquifer system is porous and that contaminants will circulate through it quickly if they are contaminated.

Keywords: Aquifer; Dumpsite; Groundwater; Transmissivity

1. Introduction

ASTE generation is an unavoidable aspect of human nature, because consumption has been one of the characteristics of man, who consumes for biological growth as well as physical development. The quest to consume by man, sets him against himself when he extracts water from the subsurface, where he also dumped the waste generated from his consumptive tendency. The scenario above best describes common happenings in our town and cities where heavy dumpsites are situated close to residential areas. While the stench oozing out from the dumpsite easily signal the contamination of the air, thereby causing the attention of community health Inspectors to be drawn to it, but the infiltration of leachate into the groundwater underneath the dumpsite goes un noticed to contaminate the groundwater. Excellent microbiological quality and generally sufficient chemical purity for most uses are found in groundwater. Na, Ca, Mg, $KHCO_3$, CL, SO4, NO_3, and Si are the eight main chemical elements that make up approximately 99% of the solute content of natural groundwater. The groundwater's geology and history are reflected in the proportion of these basic elements, with trace and minor elements making up the remaining 1%.

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Generally, the presence or lack of these components will result in health issues or render them unfit for ingestion by humans or animals. Nigeria has a wealth of solid minerals, hydrocarbons, and groundwater, among other mineral resources. One of the most important resources that every person of a country has access to is portable water [1]. Every area of human effort, including manufacturing, agriculture, transportation, construction, residential use, and so forth, has found use for water. This resource is so important that new technologies have been developed to find it. The search for water has moved from the surface to the ground. Groundwater is defined by a number of factors, including conductivity, porosity, permeability, and transitivity. Any geophysical method, including gravity, seismic, magnetic, and others, can be used to determine these characteristics. The electrical resistivity approach was used in this study to explore groundwater. Groundwater in porous and fissured medium can be found via geoelectrical resistivity surveys. When saturated with fresh water, clean, porosity-rich sands and gravels are always good aquifers. They can be distinguished from bedrock, which is primarily much more resistive, and from lower resistivity impermeable clays and marls [2].

Since the lithological characteristics of the aquifer primarily affect its value, electrical resistivity is also frequently regarded as a helpful metric for hydrogeological investigations. It can also be helpful in establishing a correlation between wells' lithological facies [3]. Nonetheless, resistivity values are sensitive to groundwater salinity and mineralization, as well as the aquifer's porosity and water content [4], [5]. Thus, the data from lithology logs should be used to restrict the field data for an efficient use of geoelectrical resistivity data for hydrogeological investigation. The purpose of this study was to determine whether an aquifer existed, how deep it was, whether the ground above it could shield the aquifer from pollution, and whether the water from the aquifer was safe for human health.

Groundwater is an important natural resource that requires protection against contamination of its quality, in most cases human activities like inordinate waste management methods have portend serious danger to the soil and groundwater. According [6] open dumpsite are the popular source of water and environmental pollution. Open dumpsites have become the common practice the world over for municipal solid waste (MSW) disposal and their environmental impacts have received much attention in the last decades [7]. Developing countries and third world economies have been in the leads of nations who haphazardly disposed their solid and have also reaped the accompanying consequences of their irresponsibility as environmental impacts and public health risks of open dumpsites like soil contamination, groundwater pollution, volatile organic compounds and green gas emissions are commonly experienced [8]. It is common knowledge that most African countries practice open dumpsites approach to waste management in the most primitive manner without standardized sanitary landfills [9]

Nigeria faces a waste management dilemma due to its large population and the lack of seriousness with which the necessary agencies have implemented government laws. This issue has surfaced in the system's health sanitation monitoring and inspection unit. Calabar Municipality is home to numerous trash dumps, with the most notable being the Lemna dumpsite, which is encircled by residential homes and features both manually and motorized water boreholes. In open waste sites or landfills, groundwater flow interaction or precipitation infiltration typically takes place. The first interstitial water, or leachate, is progressively released from the deposited wastes, and some of its broken-down byproducts end up in the water that is passing through the waste deposit. The leachate, which sometimes contains mostly organic carbon in the form of fulvic acids, accumulates at the bottom of the garbage and percolates through the soil, migrating downward and contaminating the groundwater. Toxic materials are typically present, particularly in trash with an industrial origin [10]. The natural environment, wildlife, and people are all at serious risk from this kind of groundwater resource poisoning.

The water table and aquifer level in the study area are thought to vary depending on the season and time of year because hand-dug wells typically yield water at a depth of 5.2–16 meters and motorized boreholes yield water at a depth of 21–68 meters. The water is vulnerable to contamination because of how near the surface the water table is. The transmissivity of the aquifer materials and the protective capacity of the overburden layers must be determined using geophysical methods in order to assess the impact of these leachate materials and how quickly and far they will percolate the ground to the point of adversely affecting the groundwater quality.

One important characteristic of an aquifer is transmissivity, which helps identify rocks as water-conducting media or layers. A measure of the overburden's protective capacity is its power to delay and filter percolating fluid [11], [12]. It can be quite costly and time-consuming to estimate these qualities from pumping tests. Using empirical relationships between hydraulic and geoelectric parameters, surface geoelectrical methods provide a different, quick, and affordable method for evaluating aquifers and assessing the quality of groundwater [13], [14].

The presence of heavy metals in groundwater resulting from the chemical composition of the geologic formation where the groundwater emanates or passes through poses a serious threat to public health because they can cause a variety of physiological effects to human health. Asthma, depression, vomiting and convulsions, diarrhea, cancer, ataxia, cardiovascular and renal disease, neurological disease, hypertension, pneumonitis, skeletal deformities, anemia, and gastrointestinal disorders are just a few of the symptoms and diseases related to biometal poisoning [15]. This study's main goal is to assess the aquifer's properties in relation to the Dar-Zarouk parameters, which will determine the aquifer's transmissivity, the overburden rocks' ability to protect, and the rate at which leachate penetrates the overburden. The investigation's inferred results will provide an indication of the extent of the area's groundwater quality impairment, which can be further verified by laboratory testing of water samples taken from boreholes within the study area throughout the study's duration.

2. Theoretical Foundation

The theoretical foundation for the electro geophysics is the Ohms law, while that for the evaluation of the hydraulic parameters of VES stations is based on the works of NIWAS and Singhal and the relationship established by them, [16]; Niwa and Singhal have an analytical relationship between aquifer Transmissivity and transverse resistance on one hand , and between transmissivity and longitudinal conductance on the other hand. From Darcy's law, the fluid discharge Q is given by

$$Q=KIA \qquad \text{……. (1)}$$

And from Ohm's law

$$J = \sigma E \text{………2)}$$

Where K is the hydraulic conductivity, I is the hydraulic gradient, A is the cross-sectional area perpendicular to the direction of flow, J is the current density, E is the electric field intensity and σ is the electrical conductivity (inverse of resistivity).

Taking into account a prism of aquifer material having a unit cross-sectional area and thickness h, NIWAS and Singhal combined equations (1) and (2) to get

$$T = K\,\sigma R = KS/\sigma \qquad (3)$$

Where T is ~~the aq~~uifer transmissivity, R is the transverse resistance of the aquifer and S is the longitudinal conductance. The parameters R and S are called Dar – Zarrouk parameters and for horizontal, homogeneous, and isotropic layers are defined as

$$S_i = \sum_{i=1}^{n} \frac{\rho_i}{h_i} \qquad (4)$$

$$R_i = \sum_{i=1}^{n} \rho_i h_i \qquad (5)$$

where the layer resistivity (ρ_i) and thickness (h_i) are respectively. The product of layer thickness (h) and hydraulic conductivity (K) yields the aquifer transmissivity T.

$$T = Kh \qquad \text{…….. (6)}$$

The hydraulic conductivity of clean saturated aquifers is proportional to the resistivity of the aquifer, meaning that there is no discernible impact of surface contaminant loads on the overall ground water quality [17], [18]. This suggests that the real resistivity of the aquifer, as determined by geoelectric research, can be used to approximate the aquifer hydraulic conductivity in the absence of pumping test data [12], Consequently

$$T = Kh = \rho h \qquad \text{….(7)}$$

However, transverse resistance (R), which is quantitatively identical to transmissivity T, is the product of resistivity and thickness [19], [20].

$$T = R \qquad \text{……………(8)}$$

A restricting clay or shale layer's impermeability can be gauged by its longitudinal conductance (S), which is low along with its hydraulic conductivity (K) and resistivity. According to Braga [21], the protective capacity Pc of the overburden layers is proportionate to their longitudinal conductivity.

$$P_c = S = \sum_{i=1}^{n} \frac{h_i}{\rho_i} \qquad (9)$$

The relationship between the geoelectric parameters, aquifer porosity, and formation factor (FF) is represented by

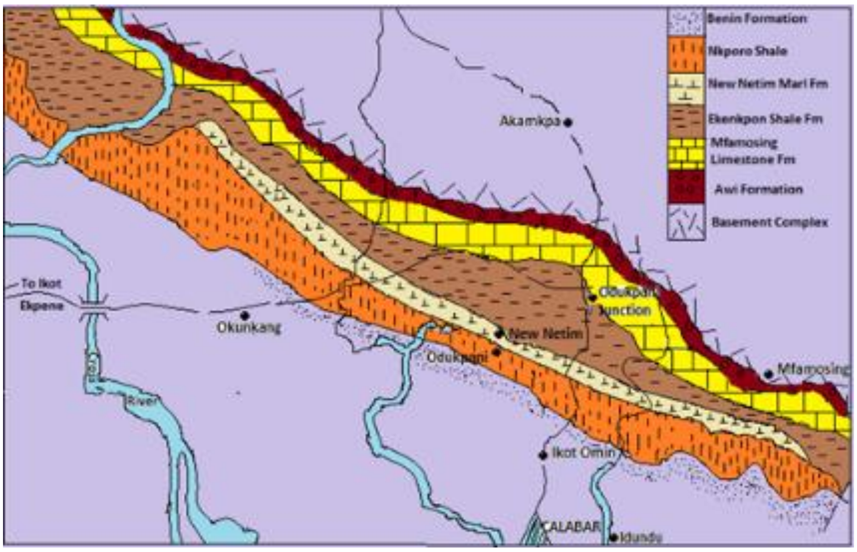
$$F = \frac{1.0}{\Phi} = \frac{\rho_a}{\rho_w} \qquad \text{………… (10)}$$

Where σ is the porosity of the aquifer and ρa and ρw are the groundwater and aquifer resistivities, respectively [22]. The ground water resistivity in the region is 469 Ωm at 250 °C [23].

3. Location and Geology of the Study Area

The research area is the dumpsite at Lemna in Calabar Municipal Local Government Area. The area lies between latitude $4^0$45’12.9" N and $4^0$45’15.4"N of the equator and between longitude $8^0$19’14.7" E and $8^0$19’48."E (Fig 1 The age of the Oban massif has been established by Ekwueme and his colleague. The basement complex is covered in cretaceous to tertiary sedimentary rocks that are a component of the Calabar Flank (Fig. 1) and is thought to have undergone a succession of igneous and metamorphic deformations [24]. As previously stated, the area of the Southern Nigeria basin that is currently referred to as the "Calabar Flank" is bordered to the north by the Oban massif and to the south by the Calabar hinge line, which separates the Niger Delta basin. A NE-SW trending fault also divides it from the Ikpe platform to the west. There were two main tectonic phases that impacted it.

The creation of the different sedimentary sequences is aided by marine transgressions and regressions. Early Cretaceous (likely Aptain) fluviodeltaic cross-bedded sands of the Awi formation marked the beginning of sedimentation. The deposition of other formations is most likely what caused this.



Source: Modified after Geological Map of Nigeria [25].

Figure 1 Geological Map of the Study Area

4. Materials and Method

Considering the number measurable parameters involve in this research because of the objectives of the study, different methods were deployed in data acquisition. Firstly, electrical resistivity method was used. Secondly, water samples were collected around the dumpsites during the duration of the study and analyzed in the laboratory, and finally the level of percolation and infiltration of water and leachate were measured around the subsurface underneath the dumpsite using the tritium tagging method.

The electrical resistivity survey method employed is the vertical electrical sounding (VES) and horizontal profiling technique. The VES profiles had maximum electro spacing AB of 500m which was considered appropriate enough as it gives a depth of penetration AB/2 of 250m and the 2D Electrical resistivity tomography (ERT) Survey was executed using the Wenner. The Wenner array was chosen because it is expected to be helpful in distinguishing sedimentary strata and is sensitive to horizontal variations in the subsurface resistivity distribution. Additionally, the Schlumberger array was employed in order to determine the location of the aquifer due to its sensitivity to both vertical and horizontal resistivity distributions.

We covered fifteen VES sites in the VES survey. While the maximum current electrode separation varied greatly from one place to another due to space constraints, the minimum current electrode separation was 2 meters at all stations. The range of maximum current electrode separations is typically between 480 and 500 meters.

In a vertical electrical sounding survey, the current electrode spacing was enlarged symmetrically around the spread center, while the potential electrode spacing remained unchanged for each particular value of potential electrodes spacing.

To guarantee that high-quality data was produced, Wenner array electrical resistivity tomography was used in addition to the VES process. To guarantee sufficient coverage of the research region, measurements were conducted in a methodical manner. The first electrode along the profile was designated as the first current electrode (C1), the second electrode as the first potential electrode (P2), and the fourth along the profile as the second current electrode (C2). For the second round of measurement, switching between the electrode and different electrode separation was done manually. Electrodes 2, 3, 4, and 5 are used for C1, P1, P2, and C2, respectively. Until the final sets of electrodes were used, this was repeated until the end of the profile time.

The second measurement sequence, which had an electrode separation of 2a, was carried out after the first, which had a minimum of 5m. Later, the distance was expanded to 3a, 4a, and 5a. The initial position of C1 was consistently maintained during all measurement rounds. It was observed that the number of measurements from the previous rounds decreased by three when the distance between C1, P1, P2, and C2 rises.

Six ERTs, each with a profile length of 120 were conducted.

The IGIS model SSR-MP-ATS resistivity meter was utilized to collect both the VES and ERT data. Based on the resistivity values of the stations, tritium tagging tracing was done on three distinct sites along five of the fifteen profile lengths of VES stations. The amount of leachate infiltrations in the subsoil beneath the dumpsite was estimated by tracking the vertical movement of injected tritium downward. A simultaneous injection of 50μcurie/cm3 tritium was made into 15 holes in a circular geometry surface. The tritium was received from the nuclear laboratory of the Department of Physics at Cross River University of Technology Calabar.

When tritium was injected, soil samples were taken during the rainy season of 2023 and five months into the rainy season August 2023. Using a hand auger, soil samples were taken at various depths between 15 cm and 2 meters.

The volumetric moisture content of every soil sample was measured using gravimetric techniques in the laboratory of Cross River Water Board Limited (CRWBL) and entered into Table 1. The volumetric moisture content values ranged from 0.04 to 0.25 and were plotted against depth as illustrated in Fig 2.

A liquid scintillation counter (L.SC) from the nuclear laboratory of physics Department of Cross River University Technology Calabar was utilized to evaluate the tritium activity of soil moisture extracted from individual soil sample. The LSC measures beta counts per minute with an efficiency of 70%. In the scintillation bottles (vials), an aliquot of 3 ml of triturated water collected from each soil sample was combined with 20 ml of cocktail. To calculate the count rate for each soil sample, the LSC system used these vials. In order to calculate the shift in the injected tritium, the center of gravity (C.G.) of the tritium activity peak must be found.

Diffusion, hydraulic pressure, osmotic pressure, and dispersion processes prevented the tritium activity from increasing. Table 2 contains the recorded results. For each site, graphs showing the count rate against depth were created. A illustration of this can be seen in fig1.3. The change in tritium peak was estimated by taking into account the peak's center of gravity and injection depth; at all 15 sites, the shift in tritium peak's position varied between 205 and 143 cm.

Table 1 Normalized volumetric moisture content and depth.

Normalized volumetric moisture content		**Depth (cm)**
Wet season	**Dry season**	
0.08	*0.04*	*0*
0.11	0.10	-10
0.14	0.18	-20
0.15	0.13	-30
0.12	0.06	-40
0.13	0.10	-05
0.20	0.13	-60
0.16	0.10	-70
0.16	0.10	-80
0.14	0.08	-90
0.12	0.04	-100
0.11	0.03	-110
0.20	0.05	-120
0.24	0.06	-130
0.21	0.04	-140
0.22	0.07	-150
0.18	0.10	-160
0.17	0.13	-170
0.08	0.07	-180

Table 2 Tritium activity and depth

Tritium activity (cpm)	**Depth (cm)**
28	0
56	-10
72	-20
76	-30
132	-40
94	-50
310	-60

360	-70
440	-80
500	-90
1100	-100
1300	-110
1600	-120
1900	-130
2400	-140
2100	-150
1400	-160
600	-170
240	-180

The product of the tritium peak shift and the effective mean volumetric moisture content in the tritium shift region was used to calculate the extent of leachate infiltration during the time interval of tritium injection (prior to the rainy season) and sampling (during the rainy season) [26], [27].

Leachate builds up at the dump's bottom and percolates the soil primarily when rainfall causes fluid movement. As a result, leachate infiltration is closely correlated with rainfall, groundwater infiltration, or recharge. This is one of the fundamental concern of this research.

It is possible to compute the percentage of groundwater recharge mathematically using the equation

$$Q = \tilde{v} \, . \Delta S \frac{100}{P} \qquad \text{........} \qquad (11)$$

where ΔS is the shift in the tritium peak in centimeters, P is the rainfall in centimeters, Q is the percentage recharge to ground water, and ṽ is the effective mean volumetric moisture content in the tritium peak shift zone.

Rainfall data was collected from NIMET Calabar.

5. Result

Using the IP12Win software version 3.0 [12], a summary of the apparent resistivity data ρa(Ωm) from measurements in every sounding station is processed and shown in Table 3. Fig 4 (a&b) shows that the studied data revealed HKH, HAK, QHK, and QHA curves type with 4-5 interpretable geoelectric layers.

Table 3 Summary of results of geoelectric survey from computer modeling

VES Station No.	Location	No. of layers	Geoelectric layers Resistivities (Ωm)						Geoelectric layer thickness (m)					Depth to bottom of Geoelectric layer (m)				
			Σρ	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	d_1	d_2	d_3	d_4	d_5	h_1	h_2	h_3	h_4	h_5
1	Lemna 1	4	971.3	87.4	735.0	123.5	25.4		0.8	8.6	47.8	-	-	0.8	9.4	57.2	-	
2	Lemna 2	5	2332	382	61	801	268	820	4.2	8.0	30.8	23.9	-	4.2	12.2	43.0	66.9	
3	Lemna 3	5	1823	337	96	501	630	259	4.9	8.3	28.0	20.6	-	4.9	13.2	41.2	61.8	
4	Lemna 4	5	917	185	198	84	249	201	2.5	15.5	22.4	35.0	-	2.5	517.7	40.1	75.1	
5	Lemna 5	5	1960	780	80	670	160	270	3.5	6.7	43.0	14.7	-	2.5	10.2	53.2	67.2	
6	Lemna 6	5	2065	510	90	804	271	390	3.7	12.2	23.3	9.7	-	3.7	15.9	39.2	48.2	
7	Lemna 7	5	968	276	166	88	332	106	5.1	9.6	24.1	26.0	-	5.1	14.6	38.8	64.8	
8	Lemna 8	5	1384	185	110	95	584	409	3.4	15.0	20.0	23.1	-	3.4	18.4	38.4	61.4	
9	Lemna 9	5	1398	472	220	116	340	250	2.6	9.8	14.3	19.6	-	2.6	12.4	26.7	46.3	
10	Lemna 10	5	974	178	158	118	220	300	3.8	15.8	19.0	28.0	-	3.8	19.6	38.6	66.6	
11	Lemna 11	5	2151	598	172	140	801	440	8.3	12.9	17.6	20.5	-	8.3	21.2	38.8	58.8	
12	Lemna 12	5	2093	476	140	97	412	101	2.8	13.0	21.1	22.0	-	2.8	15.8	36.9	58.9	
13	Lemna 13 (VES 1)	3	259.5	51.3	73	135.2	-	-	2.6	26.6	-	-	-	2.6	29.2	-	-	
14	Lemna 14	5	988	165	278	75	259	211	1.5	5.5	17.4	33.5	-	1.5	7.0	24.4	57.9	
15	Odukpani 1	5	1542	42.4	1126	272.4	25.6	75.6	0.92	7.2	6.7	17.0	-	0.9	8.1	14.8	31.8	

Table 4 Computed aquifer and dar-zarouk parameters of the geoelectric sections

VES No	Aquifer average apparent resistivity ρ_a(Ωm)	Aquifer depth (m)	Aquifer thickness (m)	Protecting capacity Pc (siemens)	Protective capacity rating	Porosity %	Transmissivity T (Ωm²)	Recommender aquifer position for groundwater development (m)
1	242.8	57.2	47.8	0.1975	weak	67.05	11605.84	57.2
2	466.4	66.9	23.9	0.0512	Poor	55.62	11146.9	66.9
3	364.6	61.8	20.6	0.0565	Poor	52.55	7510.7	61.8
4	183.4	75.1	35.0	0.1908	weak	89.75	6419	75.1
5	392.0	67.2	14.7	0.0375	Poor	50.41	5762.4	67.2
6	413.0	48.2	9.7	0.1714	Weak	84.80	4006.1	48.2
7	193.6	64.8	26.0	0.0235	poor	44.45	5033.6	64.8
8	276.8	61.4	23.1	0.0834	Poor	58.42	6394.0	61.4
9	279.6	46.3	19.6	0.0703	Poor	59.05	5480.1	46.3
10	194.8	66.6	28.0	0.1437	weak	85.40	5454.4	66.6

11	430.2	58.8	20.5	0.0465	Poor	47.96	8819.1	58.8
12	418.6	58.9	22.0	0.0526	poor	61.74	9202	58.9
13	86.5	29.2	26.6	0.3082	Moderate	56.43	2300.7	29.2
14	197.6	57.9	33.5	0.1695	Weak	87.96	6619.6	57.8
15	308.4	31.8	17.0	0.0551	poor	61.74	5242.8	31.8

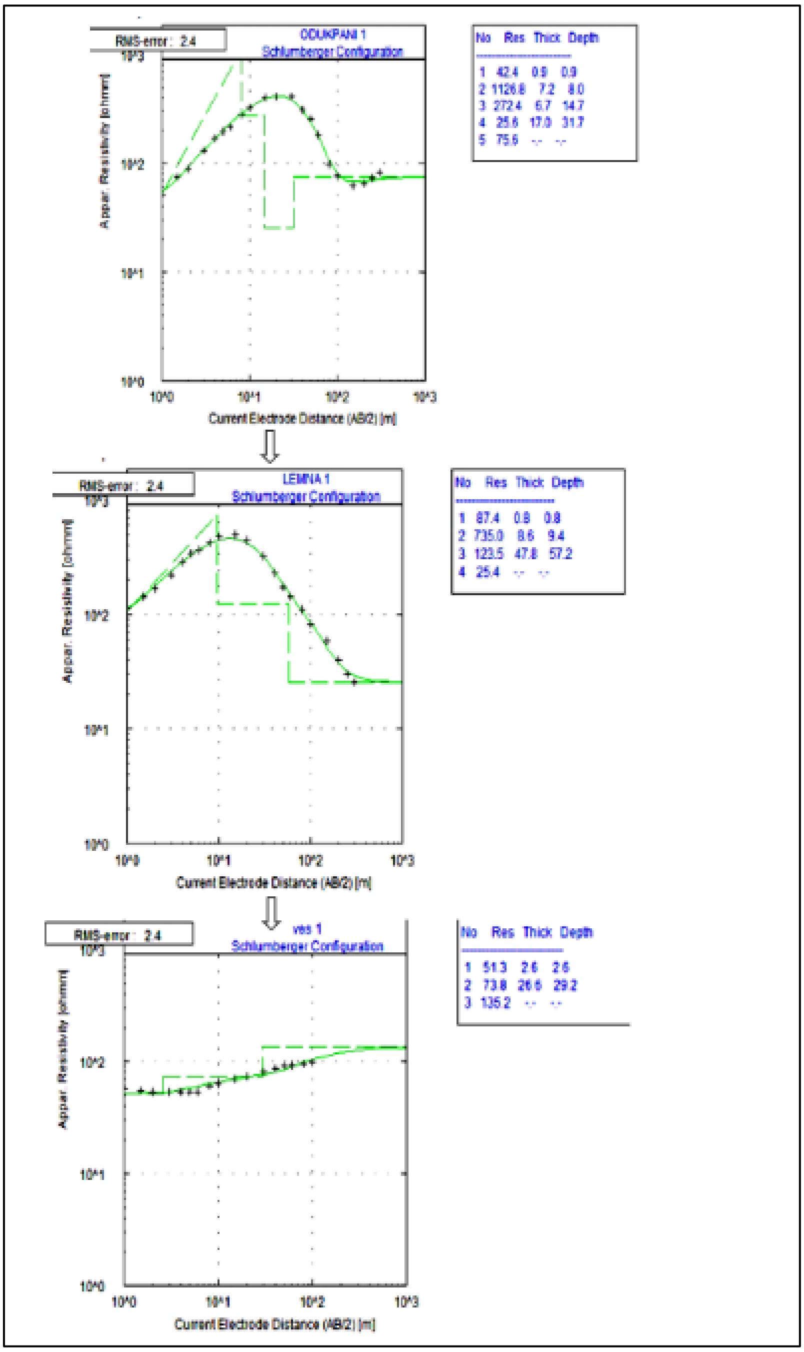


Figure 2 (a,b,& c) VES graphs

The Dar Zarrouk Parameter and geoelectric parameters of the research region are displayed in Table 4. [16] changed the ratings for longitudinal conductance (mhos) and used them to evaluate the protective capability of the layers. The evaluations were as follows: >10, excellent; 5 to 10, very good; 0.7 to 4.9 good; 0.2 – 0.69, moderate; 0.1 to 0.19 weak;

<0.1, poor.
The study region is weakly protected to poorly protected, according to the longitudinal conductance, also known as aquifer protective capacity. At VES 2, 3, 5, 7, 8, 9, 11, 12, and 15, the area is poorly protected; at VES 1, 4, 6, 10, and 14, the area is weakly protected. While at VES 13 it is moderately protected. The aquifers have no boundaries.

The research area's overburden materials contain an insignificant amount of clay, which contributes to the aquifer's enhanced infiltration of contaminated leachate and the apparent low protective capacity value. Due to the garbage in the dumpsite, the local aquifers have some degree of venerability.

5.1. Physicochemical analysis of groundwater

At horizontal surface distances of 90 meters, 110 meters, 138 meters, and 160 meters, respectively, from the first, second, third, and fourth boreholes from the dumpsite, groundwater samples were taken from four boreholes in the area surrounding the dumpsite. Different physicochemical parameters, such as pH, temperature, electrical conductivity, total dissolved solids (TDs) (NH4+, Al3+, Zn2+, Ni2+, F2z, Pb2+, Pb2+, Cadmium, DO, Nitrogen, Copper, TCC, FCC, Salinity, TSS, NO2, Odor, Color, Cynides, Fluorides, Nitrate, Residual Cl2, Sodium, BOD) were examined in the laboratory of CRSWBL.
Water quality is defined as the physical, chemical, and biological elements that affect how well water can be used.

The quantity, diversity, stability, composition, productivity, and physiological conditions of the native population are all impacted by the quality of the water [28]. The physical, chemical, and biological properties of groundwater are major determinants of its quality, and these factors are influenced by the local geology and level of human activity[29]. Table 5 displays the findings from the parameter measurements conducted in the lab.

Table 5 Laboratory results of water quality parameters from nearby boreholes

s/n	Parameter/Unit	Borehole 1	BH_2	BH_3	BH_4	NISDWQ (2015)	Mean Value
1	Ph	4.7	5.8	5.4	8.0	6.5-8.5	5.96
2	Temperature (°c)	28.2	28.1	29.1	28.0	40	28.35
3	Electrical conductivity (Ec)	µs/cm 81.5	97.3	84.1	91.0	400	88.45
4	TDS (mg/t)	20.1	16.4	0.40	0.6	500	9.38
6	Colour	<5	<5	<5	<5	5	<5
7	Odour	Unobj	Unobj	Unobj	Unobj	Unobj	
8	Fluorides (mg/l)	0.11	0.14	0.12	0.10	1.5	0.12
9	Nitrates (mg/l)	2.10	2.40	4.0	2.2	50	2.7
10	BOD (mg/L)	2.30	2.50	3.20	2.20	10	2.55
11	DO (mg/l)	12.54	15.10	14.78	16.07	5.0	14.62
12	Cyanides (mg/L)	0.01	0.01	ND	0.01	0,01	0.01
13	Residual (CL_2 (mg/L)	0.01	0.12	0.10	0.13	0.2-2.5	0.09
14	Sodium ((mg/L))	1.51	2.56	2.10	1.09	200	1.82
15	Copper ((mg/L))	0.17	0.018	0.022	0.012	1	0.056
16	Al_{3+}((mg/L))	0.03	0.02	<0.07	0.01	0.2	0.03
17	NH_{4+} (mg/L)	0.19	0.13	0.15	0.16		0.16
18	Zn_{2+}(mg/L))	0.16	0.10	0.3	0.15	3.0	0.18
19	Ni_{2+} (mg/L)	0.005	0.012	0.021	0.013	0.02	0.012
20	Fe_{2+}(mg/L)	0.14	0.21	0.22	0.26	0.3	0.22

21	Pb_{2+} (mg/L)	0.012	0.020	0.031	0.052	0.01	0.029
22	TCC 100ml/cfu	0	0	18	0	10	6.0
23	FCC 10ml/cfu	0	0	6	0	0	1.2
24	TTSS (Mg/L)	0.002	0.004	0.016	0.112	500	0.034
25	Cadmium (Mg/L)	0.012	0.021	0.010	0.061	0.003	0.026
26	Total Alkalinity (mg/L)	30	50	60	80	120	55.0
28	Turbidity (NTU)	0.14	0.70	0.16	0.19	5	0.59
29	Salinity (mg/L)	72.2	83.1	42.0	55.3	200 (WHO)	63.15
30	Magnesium	40.0	44.5	50.0	48.0	10-30	45.61
31	NO_2	0.06	0.03	0.05	0.02	0.2	0.04

NSDWQ = Nigerian Standard for drinking water quality [30]

WHO = World Health Organization [31]

6. Discussion

Using the tritium tagging tracing technique, the leachate infiltration in the study area was estimated to range between 9 and 24 percent. The leachate infiltration is directly influenced by the infiltration characteristics of the unsaturated topsoil layers. This confirms what is already known from ground resistivity studies: low permeability soils result in low resistivity values, and high permeability soils produce high resistivity values. Soil resistivity is dependent on various factors, including soil type, saturation level, age of rock types, degree of cementation, and infiltration characteristics [32].

The aquifers are thought to be located between the third, fourth, and fifth geoelectric layers, with resistivity ranging from 75 to 820 m, depths ranging from 24.4 to 75.1 m, and layer thicknesses significantly greater than 9.7 m. The overburden rock materials' protective capacity (Pc) varies from 0.0235 to 0.1908 siemens. When the protective capabilities are low—less than 1.0 siemens—it means that there are no substantial impermeable layers of shale or clay above the overburden rock elements. This suggests that there is a significant rate of surface pollutant infiltration into the aquifer. This is understood to mean that overburden layers have a lower ability to guard against contaminants and may provide a danger of contaminating soil and groundwater.

In every VES station, the transitivity values were significantly over 400 m2. The high values imply that the aquifer's materials are very permeable to fluid movement, which may create an ideal environment for contaminants to migrate, infiltrate, and circulate through groundwater aquifers. The groundwater's calculated porosities range from 49.8 to 85.4%. The unconsolidated nature of the aquifer minerals is the cause of the high porosity values. Aquifers with fine-to-medium-grained sands, high water content, and relatively low resistivity are linked to high porosities.

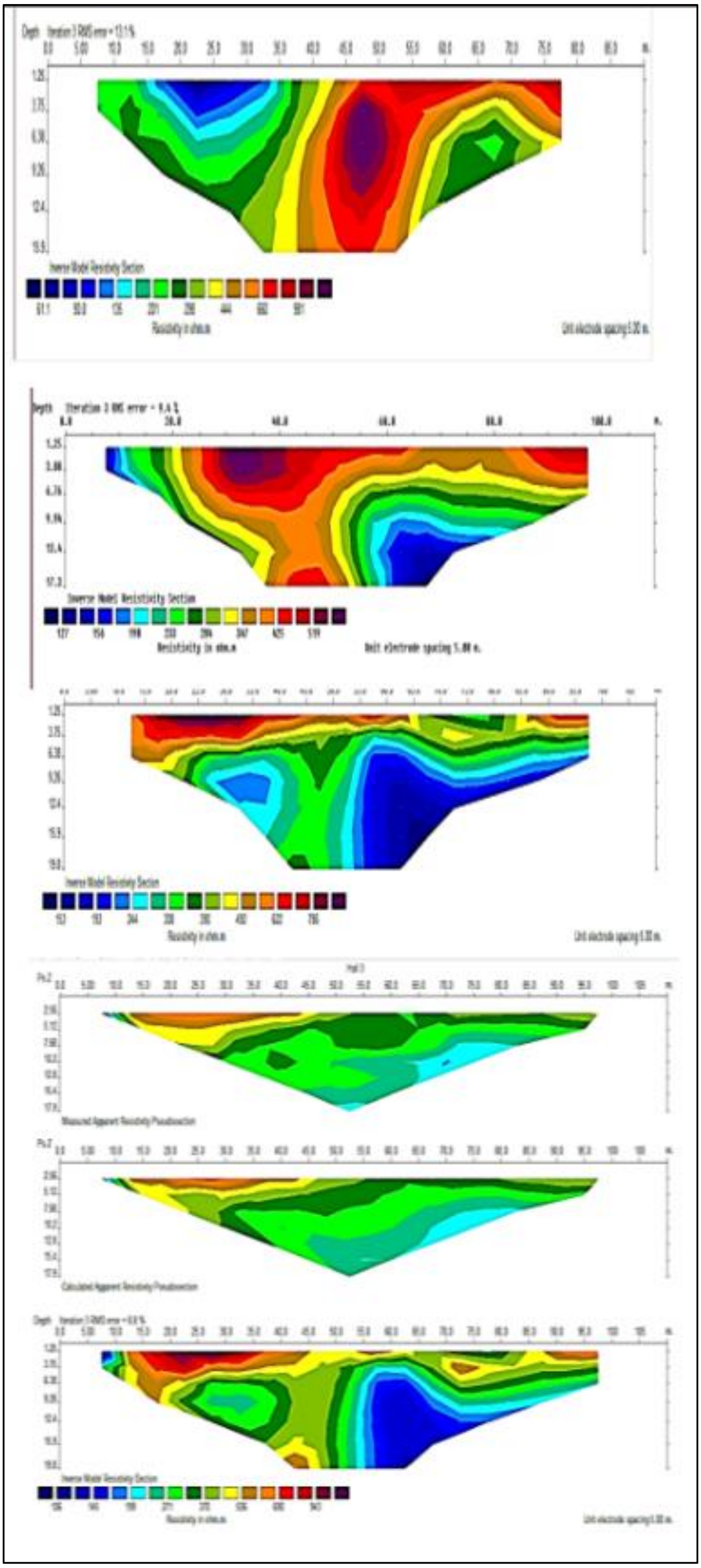


Figure 3 ERT Tomograms from the study area

Fig. 2 displays an example of the 2D resistivity inversion data for the study area. In the 2D picture, sharp variations in resistivity values were seen, displaying high and low resistivity values at several stations, suggesting the existence of a leachate plume in the aquifer at different depths. The inter profile spacing was 25 meters, and the profile length was 120 meters.

The resistivity of the top soil in profile 1 ranged from 127 to 519 Ωm, with a thickness of 4.13 m. The second layer has a resistivity of 156 to 347 m and a thickness of 5.6 m; the third layer has a resistivity of 198 to 425 m and a thickness of 4.5 m; and the fourth layer has a resistivity of 120 to 500 m and a thickness of 6.8 m. The area is well protected and there is no leachate plume.

The area is well protected in station 2, where the resistivity of the topsoil ranged from 65.1 to 834 Ωm and the thickness of the second layer's resistivity is between 94.3 and 579 Ωm. The first layer in station 3 has a thickness of 4.01 m and a resistivity of 61.1 to 662 Ωm. The second layer has a thickness of 2.8 m with a resistivity ranging from 90.0 to 550 Ωm, while the third layer has a thickness of 5.3 m and a resistivity ranging from 250 to 980 Ωm. The resistivity of the fourth layer ranges from 202 to 560 Ωm, and its thickness is 6.2 m. There is no leachate plume in any layer, and the area is well guarded.

In the fourth profile, there is no leachate plume and the area is sufficiently covered. The top layer's resistivity ranges from 60 to 520 Ωm with a thickness of 4.3 m, while the second layer's resistivity ranges from 145 to 750 Ωm with a thickness of 3.6 m. The topsoil in the fifty profile is 17.1 m thick and has a resistivity range of 52.0 to 479 m. There is no leachate plume nearby, and the land is well-protected.

6.1. Discussions based on physiochemical parameters

Table 5, when carefully examined, reveals that the pH values, which indicate the concentration of hydrogen ions in the water samples, range from 4.7 to 8.0, with an average of 5.96. This generally indicates that all of the water samples are acidic, with the exception of the BH4, whose value is within allowable bounds. The presence of organic matter or acidic substances, such as microorganisms and high levels of $CO_2(g)$ and $SO_2(g)$, may be the cause of the low values seen in the other three boreholes. The body prefers a small alkalinity to maintain a delicate alkalinity-acidity balance, even if some experts claim there are no direct health effects from humans consuming water with a pH value that deviates from the required requirements.

A closer look at Table 5 reveals that the alkalinity values for the first three boreholes range from 30 to 60 mg/l, while the fourth borehole has 80 mg/l. All of these values are below the WHO's recommended maximum of 120 mg/l for recreational and portable water usage. It is important to remember that water usually needs a small amount of alkalinity to counteract its acidic properties. The average salinity value was 63.15 mg/l. The salinity values ranged from 42.0 mg/l to 83.1 mg/l. This suggests that the water can be used for domestic purposes as all of the values are below the 200 mg/l WHO maximum salinity level for portable water, lowering the risk of hypertension in human users.

The turbidity levels of all the boreholes ranged from 0.14 to 0.19 NTU, with an average of 0.59 NTU. These values are below the maximum turbidity value of 5.00 NTU for portable water as specified by the WHO. The term "turbidity" refers to the degree of clarity or cloudiness in water, and it is caused by the presence of suspended or colloidal particles.

The borehole water samples' electrical conductivity (EC) ranged from 81.5 μS/cm to 91.0 μS/cm, with a mean value of 88.45 μS/cm. These values are far lower than the 400μS/cm WHO maximum EC limits for portable water.

The water samples' average temperature was 28.35 degrees Celsius, ranging from 28.10 to 29.10 degrees Celsius across the four boreholes. These results are below the 400 degrees Celsius WHO maximum temperature threshold for portable water. Since water may always be allowed to cool to room temperature before being drunk, there is no negative health effect associated with temperatures higher than the WHO maximum of 400 degrees Celsius. The average magnesium (Mg) value was 45.61 mg/l, with values ranging from 40.0 mg/l to 50.0 mg/l across the four boreholes. These values exceeded the permissible magnesium level of 10-31.0 mg/l for portable water as specified by the WHO and NSDWQ.

The water samples' nitrate $NO_3(aq)$ readings varied from 2.10 mg/l to 4.0 mg/l, with an average of 2.7 mg/l. Once more, all of the values were below the WHO's recommended maximum nitrate threshold of 50 mg/l. The average total dissolved solid (TDS) value was 9.38 mg/l, falling short of the WHO maximum TDS threshold of 500.0 mg/l for portable water. Total dissolved solid (TDS) readings ranged from 0.4 to 20.1 mg/l.

Conversely, the average total suspended solid (TSS) value was 0.034 mg/l, with a range of 0.002 to 0.112 mg/l. The results are below the 500 mg/l WHO maximum TSS threshold for portable water. The values of Biochemical Oxygen Demand (BOD) ranged from 2.20 mg/l at BH4 to 3.20 mg/l at BH3 with an average value of 2.55 mg/l. All of the values were below the WHO maximum BOD value of > 6.0 mg/l for potable water, a condition that implied that each of the boreholes has less organic pollution. The values of Dissolved Oxygen (DO) ranged from 12.54 mg/l at the first borehole to 16.07 mg/l at the fourth with an average of 14.62 mg/l.

Pb_2+, Zn_2+, and Fe_2+ are among the heavy metals that were found in the samples. The average value of Pb2+ ranged from 0.012 mg/l at BH1 to 0.05 mg/l at BH4, with an average value of 0.029 mg/l. The Pb_2+ values at BH2 to BH4 are higher than the WHO's maximum Pb_2+ value of 0.01/mg/l, which is extremely harmful to human health because it can accelerate the growth of cancer cells and have an impact on the nervous system. Pb_2+ at BH1 is in danger according to WHO standards.

The four boreholes' Zn_2+ values range from 0.10 mg/l to 0.16 mg/l, all of which are below the NSDWQ's and the WHO's maximum values of 3.00 mg/l and 5.00 mg/l, respectively, for potable water. It is noteworthy to note that, as of yet, no adverse health effects have been conclusively linked to high levels of zinc in drinking water.

The Fe_2+ values found in all the samples were higher than the 0.100 mg/l WHO maximum Fe_2+ value, but lower than the 0.300 mg/l NSDWQ for drinkable water. As of yet, there is no conclusive evidence linking abnormally high Fe_2+ levels in transportable drinking water to adverse health effects.

The average cadmium value in the boreholes was 0.026 mg/l, with a range of 0.01/mg/l to 0.06 mg/l. All of these results are greater than the NSDWQ and WHO maximum cadmium threshold of 0.003 for drinking water. Adequate cadmium intake can lead to kidney-related disorders in people.

Regarding total coliform count (TCC), the World Health Organization states that water must be totally free of total coliform (100 ml/cfu) in order to be considered potable (safe to drink). Regrettably, the third borehole contained 18 (100 ml/cfu) of TCC. It is important to remember that even the tiniest detectable level of TCC is probably proof positive that the contaminated water sample contains feces, as was previously suspected. A sample with a TCC range of 1–10 counts/100 ml is considered low risk contaminated, according to WHO guidelines.

7. Conclusion

Bearing in mind, the theme of the research, which is geophysical and laboratory evaluation of aquifer position, aquifer protective capacity and groundwater quality in selected dumpsites in Calabar Municipal Local Government Area, South Eastern Nigeria. Several techniques were deployed in the study among which were: laboratory, tritium tagging, electrical resistivity tomography (ERT), and vertical electrical sounding (VES). The VES survey had a maximum electrode spacing of 500 meters, fifteen VES stations were used. IPI2win software was used to analyze the data collected. The resistivity map of the dumpsite was determined by deploying six ERT stations for the 2 D survey. The tritium tagging method was used to ascertain the degree of soil infiltration beneath the dumpsite. Using a conventional laboratory procedure, groundwater samples were taken from neighboring boreholes and examined. The findings showed that there were three to five geoelectric layers, with the aquifer position being inferred to be between 24.2 and 75.1 meters deep in the third, fourth, and fifth levels. Aquifer protective capacity had values in the range of 0.0235 to 0.1908 Siemens and were considered to be weakly and badly protected. The obtained porosity values ranged from 44.45 to 89.75. Strong calculated values for transmissivity and porosity indicate a permeable aquifer system with considerable storativity. The area has an infiltration value between 8 and 22 percent, according to the results of the tritium tagging technique, which was used to evaluate the level of infiltration from the dumpsite. Analyzed groundwater samples show levels of NO_2, DO, Pb_2+, magnesium, and cadmium that are higher than what the NSDWQ has approved. Overall analysis of the results from the above-described methodologies shows that the study area's aquifer system is located within the depth of 24.2 to 75.1, it is porous and that contaminants will circulate through it quickly if they are contaminated.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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