<u>Original Research Article</u>

POTENTIAL IMPACTS OF OKPUNO EGBU DUMPSITE ON GROUNDWATER RESOURCES IN PARTS OF NNEWI, SOUTHEASTERN NIGERIA

Abstract

The study area, Nnewi is one of the most populated, commercial and industrialized cities in Anambra State. Geophysical data were collected from 15 vertical electrical sounding (VES) points and hydrogeochemical analysis of 15 groundwater samples collected from 15 locations were analyzed for their chemical composition and used to assess the impact of the dumpsite at Okpunoegbu on groundwater in the study area. The results of the vertical electrical sounding indicate that most of the aquiferous units fall within the fourth layer at most of the Relocations with an average resistivity of 1340.25Ωm, an average thickness of 41.75m and average depth of 51.25m. The range of the regional water table is from 25.41m to 99.42m. The Dar-Zarrouk parameters; longitudinal conductance and transverse resistance, s and t were determined from the geophysical data to be 0.007mho and 55966.9Ω respectively. The results of s indicate that the protective capacity of the overburden layers to underlying aquifer is low. which implies easy transmission of pollutants to the aquifers making them vulnerable to pollution. The results of water analysis show that the range of pH in the samples is between 5.73 to 6.95 indicating that 20% of the water samples are slightly acidic and 80% to alkaline. TDS, TSS and EC were found to be within the permissible limits of WHO and NSDWQ standard guidelines. COD and BOD were above the permissible limits indicating the water samples to be severely polluted. DO_1 and DO_5 range between 22.78 - 65.40 mg/L and 48-358.96 mg/L respectively. The major cations and anions were within the permissible limits.. However, the heavy metals range in samples were cadmium (0.04-0.37mg/L), chromium (0.01-0.10mg/L), mercury (0-0-07mg/L) and lead (0.1-0.93mg/L), exceed the permissible limits in some samples. The geospatial distribution maps of the heavy metals implicate the dumpsite and other sources as contributors of the increased concentrations of cadmium and lead. while indicating the dump as a major contributor of chromium and mercury to groundwater in the study area. The calculated quality indices, WQI and HMPI rate the groundwater as highly polluted and unsuitable for drinking, and the CD and HMEI as moderately to highly polluted, respectively. The identified hydrochemical facies classify the water as Ca-Cl and Ca-Mg –Cl – SO_4 water type. The Cl – SO_4 facie indicate end water usually with increased age found in the discharge areas. The Okpunoegbu dumpsite is an important source of groundwater contaminants and pollutants especially the heavy metals such as cadmium, mercury, chromium and lead. The protective capacity of the overburden is enhancing the vulnerability of the aquifers to pollution as they are rated as low. It is recommended that some remediation measures be carried out to restore the groundwater quality and prevent further pollution being initiated and appropriate water treatment be carried before use for drinking purposes.

Keywords: *Protective cover, Dumpsite, Groundwater, Okpunoegbu*

INTRODUCTION

The study area, Nnewi a metro city in Anambra state, southeastern Nigeria, is known as a commercial hub with the large motor cycle markets, industries such as paint, battery, cable to mention but a few. It is the second largest and second most populous city in the southern part of the country (http://dbepia.org). Nnewi as a metropolis has a population of 1,177,465 as at 2023 (Population Stat, 2017 – 2023). The first indigenous car manufacturing plant in Nigeria is located in the city while the first wholly made-in-Nigeria motorcycle was manufactured in Nnewi. All these businesses The study area, Nnewi is known as a commercial hub with the large motor cycle markets, industries such as paint, battery, cable to mention but a few. All these businesses generate massive quantities of different kinds of waste materials including those generated daily from domestic sources. These wastes require proper management. However, improper management and disposal of wastes often create adverse environmental and societal challenges such as high risk of pollution to both surface water and groundwater. Most of the solid waste materials produced in the study area end up at surface dumpsites without separating domestic and municipal wastes from industrial wastes. The creation and location of dumpsites require adequate planning and important environmental considerations. There is several government-approved minor refuse collection points located across the major roads in Nnewi. Some common ones are those at Nnobi Road close to Nnewi High School, Ibeto Jjunction, Okigwe Road, Izuchukwu Junction, Anglican Girls Junction, Emecourt Junction among others. The dumpsite of interest for this study is the permanent dumpsite located at Okpunoegbu in Umudim Nnewi (Figure 1).

The impact of a dumpsite as a potential point source of pollutants or contaminants is a function of the vulnerability of underlying aquiferous units to pollution in relation to its protective cover. This is often studied and assessed using vulnerability maps which can be derived from various methods (Kirsh et al., 2003). They observed that aquifer vulnerability maps provide an assessment of the vulnerability of groundwater to pollutants. The parameters that are often shown on these maps are generally an indication of cation exchange capacity or clay content of the near surface layers, or quantities related to the infiltration time of surface water (a property indicated by the transmissivity). The modern conventional technique is to determine these parameters using geophysical methods rather than traditional geological means of investigation and drilling. The obvious advantage is the non-invasiveness and the capacity to cover large areas at relatively low cost. The geophysical quantity which is closely related to the parameters highlighted is the electrical conductivity. Hence, the electrical resistivity method offers a means for a quick and reliable assessment of an aquifer's vulnerability to pollution or the protective capacity of the overlying layers using the Dar-Zarrouk parameters (longitudinal conductance s,) first introduced by Maillet (1947).

Aquifer vulnerability maps, when used together with hydrogeochemical maps can offer great insights into potential zones of high aquifer vulnerability or low protective capacity and an indication of distribution of groundwater pollution and areas that are most affected. Hydrogeochemical maps can also show the impacts of point sources of pollution and hence can serve as a great tool for assessing the impacts of such utilities as dumpsites and landfills (Ogungbemi et al., 2013.

The climate of Nnewi is the equatorial type essentially warm and humid with the resultant effect of prevailing seasonal wind, and the relatively flat topography (Egboka, 1993). A humid tropical wind from across the sea leads to longer wet season (April to October) and a drier tropical continental air brings about the dry season (November to March). Around December, it culminates in a very dry and foggy harmattan (Igbozurike, 1995). The average annual minimum and maximum temperature are 25^{o}C and 32^{o}C respectively while the annual rainfall is above 2000mm.

Under the prevailing circumstances there is need to investigate the influence and implication of the Okpunoegbu dumpsite on groundwater resources using geophysical and hydrochemical methods.

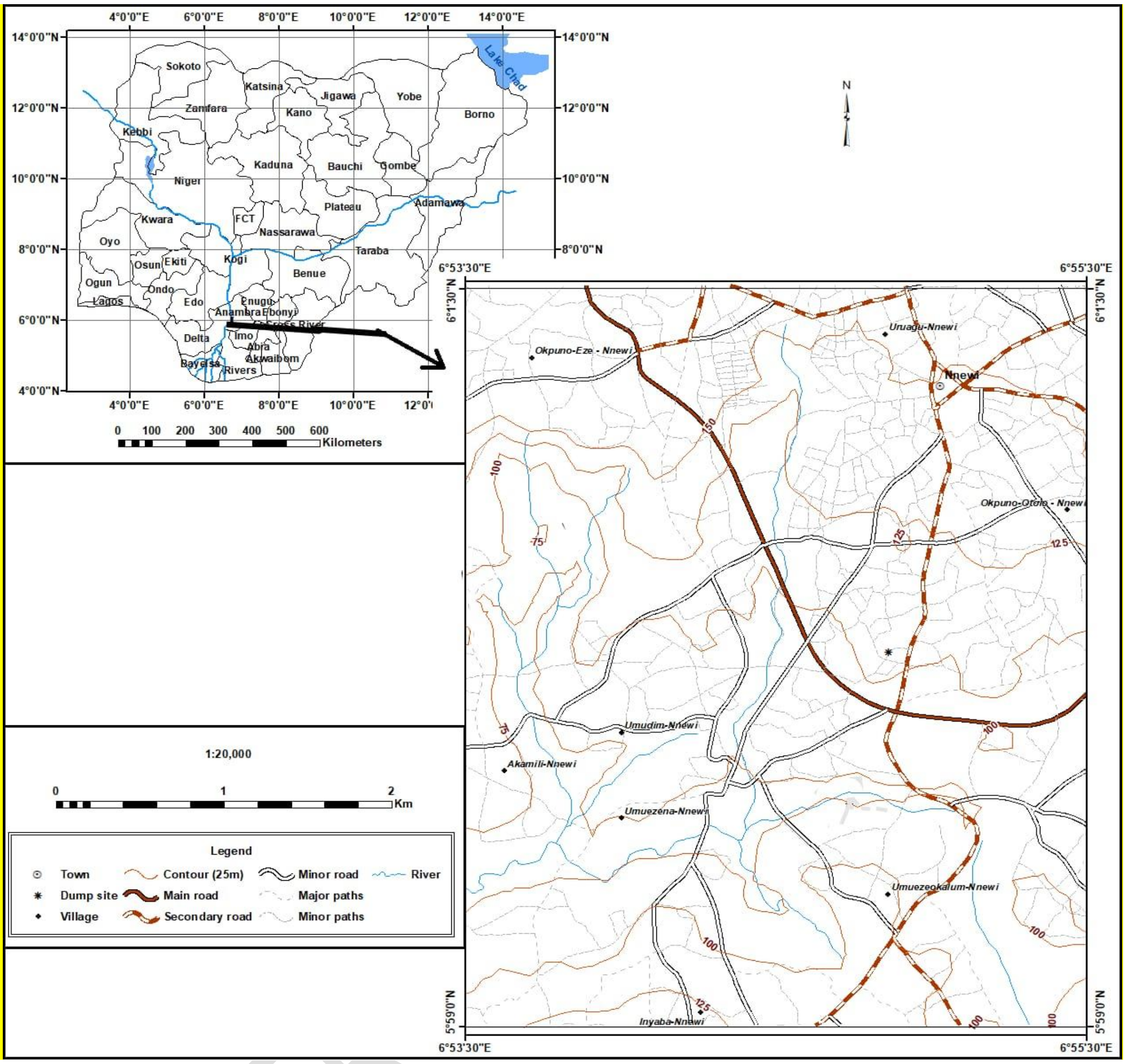


Figure 1: Location map of the study area

Hydrogeology

Eocene Nanka Formation (Ameki Group) and the Quaternary Ogwashi-Asaba Formation (Nwajide, 2013) are the stratigraphic units that underlie the study area (Figure 2). The Nanka Formation is a sequence of lowly accumulated, poorly sorted, friable, medium to coarse sand, thin clay stone, siltstone, and shale bands (Nwajide, 2013). Furthermore, the Ogwashi-Asaba Formation overlies the Nanka Formations and consists of lignite and clay intercalation, with sand (Okezie et al., 1985). Groundwater forms the major domestic water supplies in the area. The Nanka and Ogwashi-Asaba are prolific aquifers. The depth to the aquifers in the region ranges from 134 m to 237 m below the ground (Ifeanyichukwu *et al.*, 2021). Anakwuba et al, 2021, carried out the hydrogeological and water quality evaluation of parts of River Mamu sub-basin and estimated the average depth to aquifers and their thicknesses to be 109.9 and 11.8m respectively. K and T values range from 0.04-0.09m/s and 0.72-1.53m2/s respectively depicting aquifers with enhanced specific storage, and material transport (Okoyeh et al 2018).

Hydrochemistry

The physicochemical parameters in Nnewi are season dependent though they are within the WHO permissible standard though cadmium exceeded the limit (Morah et al, 2013). It has been noted that high concentrations of dissolved constituents especially the heavy metals reduce the quality of groundwater. Most of these heavy metals are from natural and anthropogenic sources (Okolo et al, 2017, Akudinibi and Okolo 2013, Okolo et al 2020).

Obasi and Akudinobi, (2013), conducted a hydrochemical investigation of Okposi and Uburu Areas of Ohaozara and Environs of Ebonyi State and concluded that chloride and magnesium were elevated in water source which may be attributed to NaCl mineralization in the area. Okoyeh et al, (2018), evaluated the water resources potential of part of Benin formation, Niger Delta, Nigeria using vertical electrical sounding method and hydrogeochemical method which indicated good yield and permeability, the water was slightly acidic, with lead, iron and cadmium exceeding the standard values. Okolo et al., (2020), evaluated the water resources of some satellite towns in Awka and observed the water sources to be slightly acidic, the major ions were within the WHO desirable limit. However, they noted the enrichment of the water sources by heavy metals such as mercury, chromium, cadmium, and iron. The calculated WQI values show the water ranged from unsuitable to excellent. Also, the Heavy Metal Pollution Index indicated the water ranged from very poor to very good. Anakwuba et al, 2021, carried out the hydrogeological and water quality evaluation of parts of River Mamu sub-basin, southeastern Nigeria and observed that the concentration of the major ions, TDS and EC were within the WHO permissible guidelines for drinking water, while heavy metals concentrations exceeded the permissible guideline values. They also found the dominant geochemical processes to be rock-water interaction in groundwater, which they suggest accounted for the major contribution of dissolved ions and precipitation in the surface water.

Impacts of Waste Dumping on Rivers

Considerable amounts of waste in developing countries end up in open dumps or drainage systems, threatening both surface water and groundwater quality and provide a breeding ground for pests (Okeke *et al.*, 2018). The adverse effect of inadequate waste management on the environment, water resources and living organism is very significant. In developing countries open dumpsites are common, due to the low budget for waste disposal and non-availability of trained manpower. The contamination of water and soil by heavy metal could be attributed to solid waste dump and could cause adverse effects on human health, animals, and soil productivity (Arimoro, 2009, Omole and Longe, 2008). River pollution is becoming a central issue in water management in Nigeria, as many streams and rivers are polluted because of the discharge of untreated wastewater and other organic wastes directly into them (Jaji, *et al.*, 2007, Obire *et al.*, 2008, Osibanjo *et al.*, 2011). The case of Nnewi area is not different, most industries in the area discharge their untreated waste effluents either directly or indirectly into water bodies as well as in open pit surface dumps (Momoh *et al.*, 2013, Okeke *et al.*, 2018). Hence, this research will employ the use of geophysical and geochemical methods to assess the protective capacity of the aquifers found in the study area and determine the extent and distribution of contaminants and pollutants from Okpunoegbu dumpsite on groundwater resources.

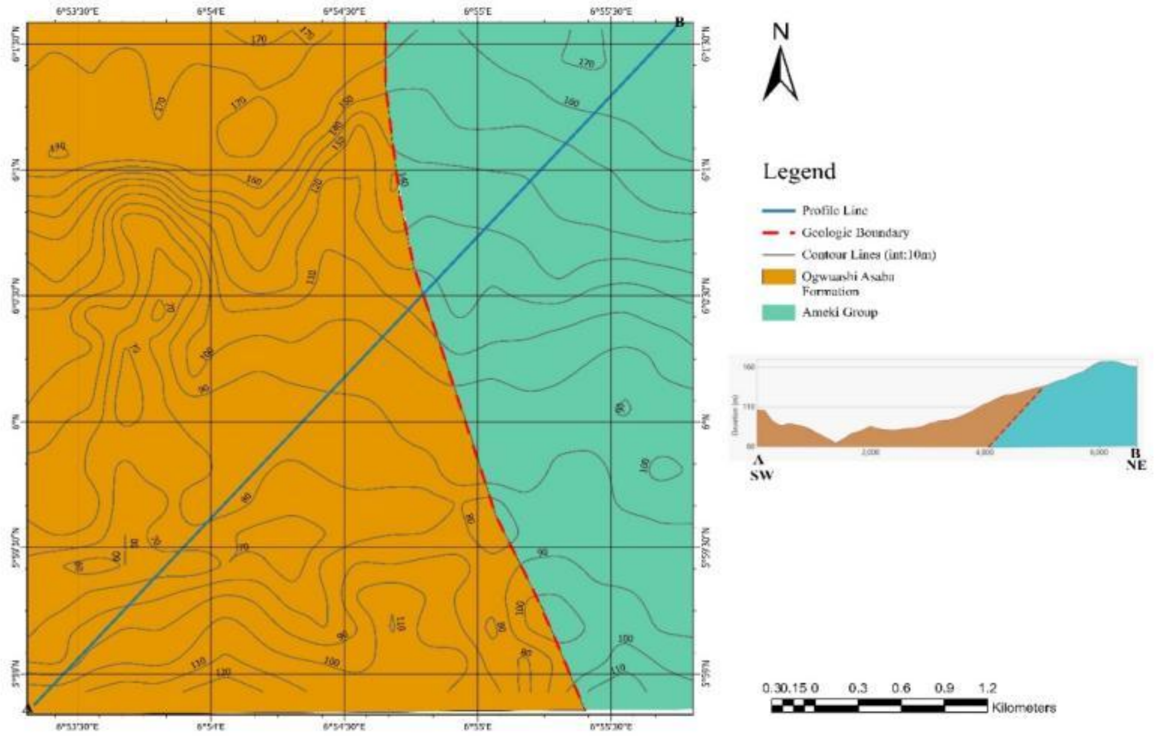


Figure 2: Geology map of study area.

METHODOLOGY

A simple schematic diagram of the methodology for this research is shown in Figure 3. The procedure for this research involved the integration of two distinct tools in the form of interpretation of vertical electrical resistivity sounding (VES) curves gotten from geophysical survey and hydrogeochemical analysis of water samples from geological survey. Aquifer parameters were determined from VES results using equations that have been sufficiently described by Heigold et al. (1979) and Todd, 1980. Also, the determination of the Dar-Zarrouk parameters from VES results and its application to water pollution studies as first proposed by Mailet, (1947) has been extensively described by Henriet, (1976). However, the correlation of aquifer parameters: hydraulic conductivity K and transmissivity T to the Dar-Zarrouk parameters longitudinal conductance s and transverse resistance t has been observed by Duprat et al., (1970). Furthermore, the identification of aquiferous zones or units and estimation of depth to groundwater table from VES curves has been proven by Henriet, (1976). Aquiferous intervals were identified from the VES results and the depth to water table determined for the study area. Therefore, the aquifer protective capacity (APC) was estimated using the Dar-Zarrouk parameters.

Fifteen groundwater samples were collected from carefully selected locations around the dumpsite (Figure 4). The samples were collected using pre-washed plastic containers which were rinsed three times with the water sample before collection. The boreholes were flushed by allowing the water run for 5 – 10 minutes before collection. This is to ensure that only representative samples from the aquifer were collected. The samples were preserved according to APHA (2005) methods. The pH, electrical conductivity, and TDS were analysed in the field using a multi-meter (Hanna, model HI991300). The heavy metals were analysed using Varian AA 240 Atomic Absorption Spectrophotometer (AAS) while anions were analysed using uv-spectrophotometer and the others using titration methods according to the specification of APHA (2005). The water quality for drinking purposes was assessed by comparing with WHO (2010) and NSDWQ (2015) guideline values. Various indices, water quality index (WQI), heavy metal evaluation index (HEI), heavy metal pollution index (HPI) and degree of contamination (Cd) were used to determine the extent of pollution. The parameters used in calculating WQI include BOD, COD, chloride, nitrate, carbonate, sulphate, sodium, calcium, magnesium and pH. However, the HEI, HPI and Cd were calculated using cadmium, chromium, copper, mercury, and lead. The steps of determining each water quality indices have been described and demonstrated by various researchers (Horton, 1965, Vasanthavigar et al, 2010, Mohan, 1996, Prasad and Jaiprakas, 1999, Okolo et al 2018, and Udegbunam et al., 2021). The results were put in a GIS environment and interpolated using the inverse distance weighting method and made into maps that were then interpreted.

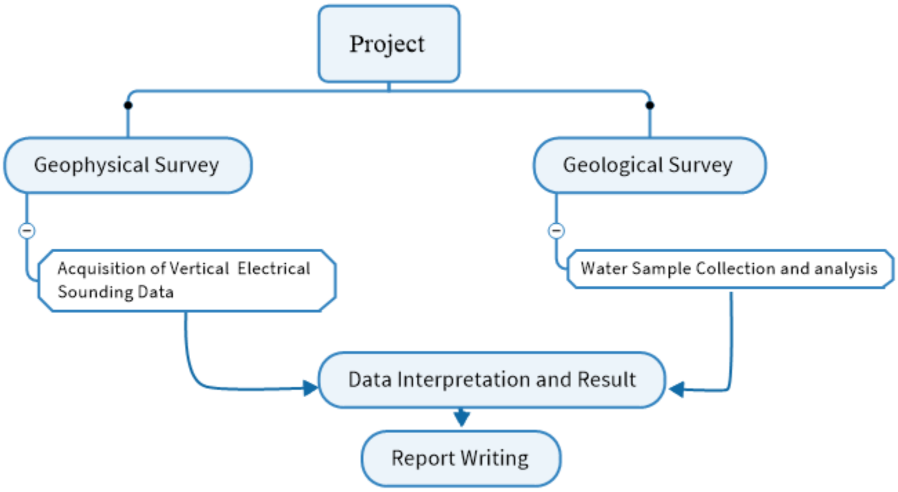


Figure 3 Schematic Representation of a simplified workflow used during the study

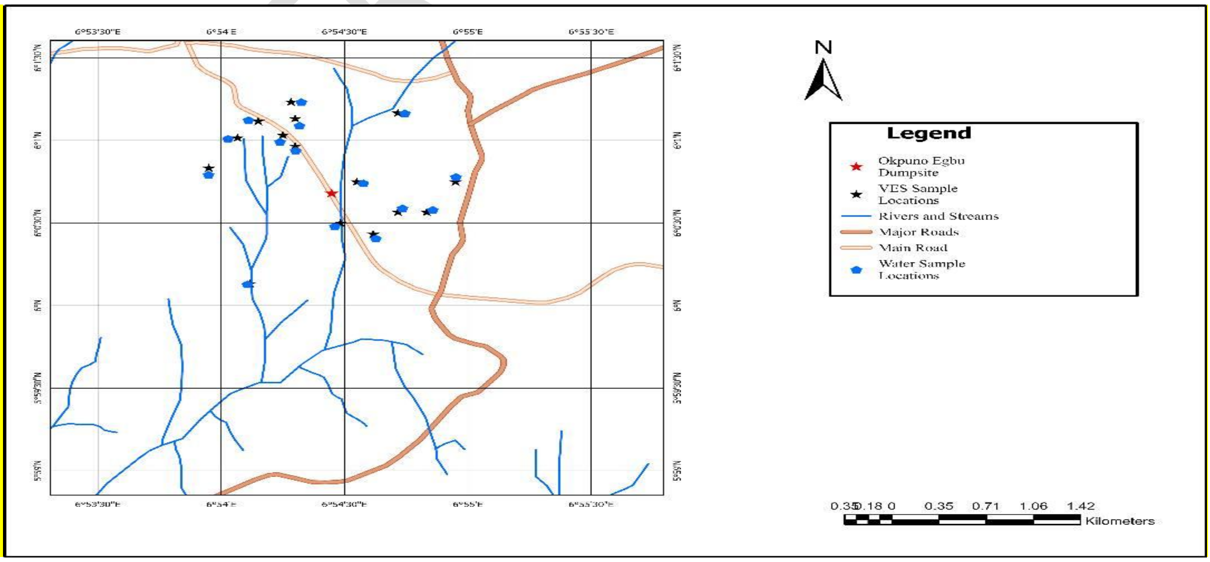


Figure 4: VES points and groundwater sample locations.

RESULTS AND DISCUSSSION

Identification of Aquiferous Units and Regional Water Table from Vertical Electrical Sounding using Curvertical Electrical Method

The strip logs and curves generated from the VES are shown in Table 1. Five-layer and six-layer models were used to represent the data observed in the field. At all the VES locations, a low resistivity top layer and base layer (deepest unit sampled by the VES survey) was interpreted, with the middle layers of average to moderate electrical resistivity with occasionally high resistivity units. This was the general trend found in the area except for location C which showed anomalously very low resistivity for the entire column of geo-electric units interpreted. This may be attributed to the presence of contaminants or lithologic changes. The aquiferous unit was interpreted as the fourth layer or unit at most of the locations with an average resistivity of 1340.25Ωm, average thickness of 41.75m and average depth of 51.25m (figure 3). The regional water table ranges from 25.41m to 99.42m, these values are also indicative of the total thickness of the overburden. It was observed that areas with lowest elevations have shallower depth to water table while areas with higher elevations have greater depth to water table. Hence, the northern parts of the study area have greater depth to water table. This implies that the water table were observed to mimic the topography of the area (Anakwuba et al., 2021).

Furthermore, in areas underlain by the Ogwashi-Asaba Formation the aquifers occur at higher depth than in areas underlain by the Nanka Formation (Figure 3). The thicknesses of the sand and clayey sand that constitute the overburden materials also affect the aquifer thickness. Areas where these lithologic units are thick have lower aquifer thickness and vice versa. Majority of the aquifers occur in the southern part of the study area (Figure 4). It was noted that areas underlain by the Nanka Formation has shallower water table and higher aquifer thickness indicating that the Nanka Formation is the more prolific aquifer in the study area. It was observed that topography, lithology, and geology are the major factors that control depth to water table and aquifer thickness in the study area. The present result is agreement with other studies carried out in other locations (Obasi and Akudinobi, 2013, Okoyeh et al., 2018, and Anakwuba et al., 2021).

Table 1: Result of Vertical Electrical Sounding curve interpretation

Station ID/ Layers	**App Res (Ωm)**	**Thickness (m)**	**Depth (m)**	**Description**
VES A (rms: 8.6%)				
1	870.3	1.91	0	Top layer/weathered sediments
2	1168.64	3.61	1.91	Sandy Clay
3	2291.64	21.74	5.52	Clayey Sand
4	4888.93	22.47	27.25	Sand
5	3491.89	64.98	49.73	Water-Saturated Sand
6	1394.52	Undetermined	114.7	Clayey Sand
VES B (rms: 22.6%)				
1	174.05	1.32	0	Top layer/weathered sediments
2	3236.35	7.58	1.32	Clayey Sand
3	5547	52.03	8.9	Sand

4	1265.83	40.2	60.93	Water-Saturated Sand
5	5593.9	Undetermined	101.17	Sand
VES C (rms: 4.4%)				
1	107.42	1.5	0	Top layer/weathered sediments
2	425.49	4.31	1.5	Sand
3	394.44	19.6	5.82	Clayey Sand
4	359.55	23.12	25.41	Water-Saturated Sand
5	145.45	Undetermined	48.54	Clay
VES D (rms: 25.2%)				
1	342.21	1.2	0	Top layer/weathered sediments
2	1692.46	7.96	1.2	Clayey Sand
3	5099.12	30.65	9.16	Dry Sand
4	4807.3	31.9	39.81	Water-Saturated Sand
5	3961.01	Undetermined	71.73	Sand
VES E (rms: 13.4%)				
1	1276.54	1.35	0	Top layer/weathered sediments
2	4290.83	3.45	1.35	Clayey Sand
3	10832.66	35.01	4.8	Sand
4	2962.54	108.83	39.81	Water-Saturated Sand
5	505.64	Undetermined	148.65	Sandy Clay
VES F (rms: 25.3%)				
1	238.01	1.68	0	Top layer/weathered sediments
2	1012.71	13.1	1.68	Clayey Sand
3	4456.51	25.5	14.78	Dry Sand
4	2804.77	31.87	40.28	Water-Saturated Sand
5	4308.93	Undetermined	72.15	Sand
VES G (rms: 4.7%)				
1	154.93	1.71	0	Top layer/weathered sediments
2	1430.19	3.94	1.71	Sand
3	1185.38	18.89	5.65	Clayey Sand
4	1382.83	49.74	24.54	Dry Sand
5	1281.93	26.3	74.28	Water-Saturated Sand
6	987.45	Undetermined	100.58	Sandy Clay
VES H (rms: 33.9%)				
1	420.15	1.3	0	Top layer/weathered sediments
2	1582.23	4.79	1.3	Sand
3	1168.53	33.95	6.09	Clayey Sand

4	270.05	38.2	40.04	Sandy Clay
5	151.06	24.08	78.28	Water-Saturated Sandy Clay
6	69.92	Undetermined	102.36	Clay
VES I (rms: 31.9%)				
1	1087.84	1.57	0	Top layer/weathered sediments
2	24688.34	7.28	1.57	Sand
3	10832.66	18.41	8.85	Clayey Sand
4	168.9	47.46	27.25	Water-Saturated Sandy Clay
5	629.5	Undetermined	74.72	Clayey Sand
VES G (rms: 18.1%)				
1	1454.47	1.51	0	Top layer/weathered sediments
2	2106.61	4.41	1.51	Sand
3	664.77	9.03	5.92	Sandy Clay
4	4930.26	60.2	14.95	Sand
5	2622.09	26	75.15	Water-Saturated Sand
6	1986.04	Undetermined	101.17	Clayey Sand
VES K (rms: 22.1%)				
1	140.72	1.26	0	Top layer/weathered sediments
2	3520.61	7.7	1.26	Sand
3	3155.63	66.6	8.95	Clayey Sand
4	2600.1	24.4	75.59	Water-Saturated Sand
5	3927.8	Undetermined	100	Sand
VES L (rms: 29.4%)				
1	103.01	1.54	0	Top layer/weathered sediments
2	7966.72	7.89	1.54	Sand
3	3671.97	30.84	9.43	Clayey Sand
4	2106.61	59.1	40.28	Water-Saturated Sandy Sand
5	800.03	Undetermined	99.42	Clay
VES M (rms: 19.1%)				
1	213.34	1.5	0	Top layer/weathered sediments
2	2578.31	7.83	1.5	Sand
3	1841.12	40.65	9.32	Clayey Sand
4	1504.29	48.3	49.97	Water-Saturated Sandy Sand
5	1110.97	Undetermined	98.27	Sand
VES N (rms: 18.9%)				
1	401.14	1.38	0	Top layer/weathered sediments
2	2666.61	7.07	1.38	Sand

3	2291.64	41.6	8.45	Clayey Sand
4	626.72	96.8	50.04	Water-Saturated Sand
5	1083.27	Undetermined	146.83	Clayey Sand
VES O (rms: 14.7%)				
1	576.12	1.26	0	Top layer/weathered sediments
2	3182.31	4.81	1.26	Sand
3	1721.2	19.2	6.06	Clayey Sand
4	5142.23	74.15	25.27	Sand
5	2876.51	58.15	99.42	Water-Saturated Sand
6	1004.22	Undetermined	157.57	Clayey Sand

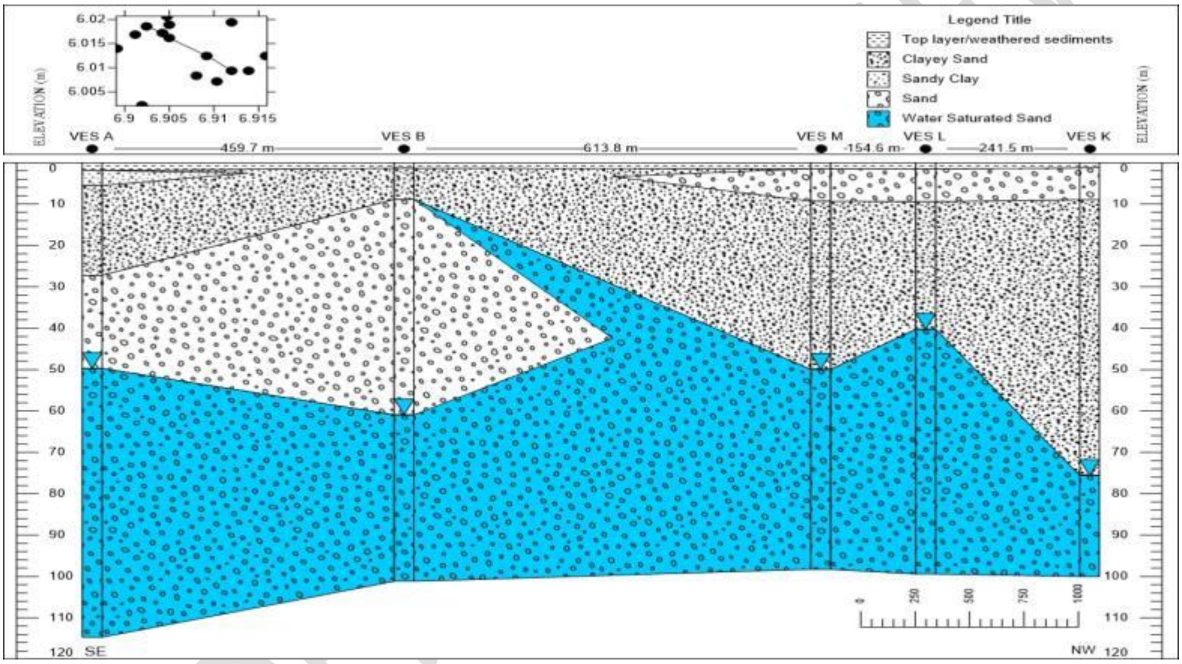
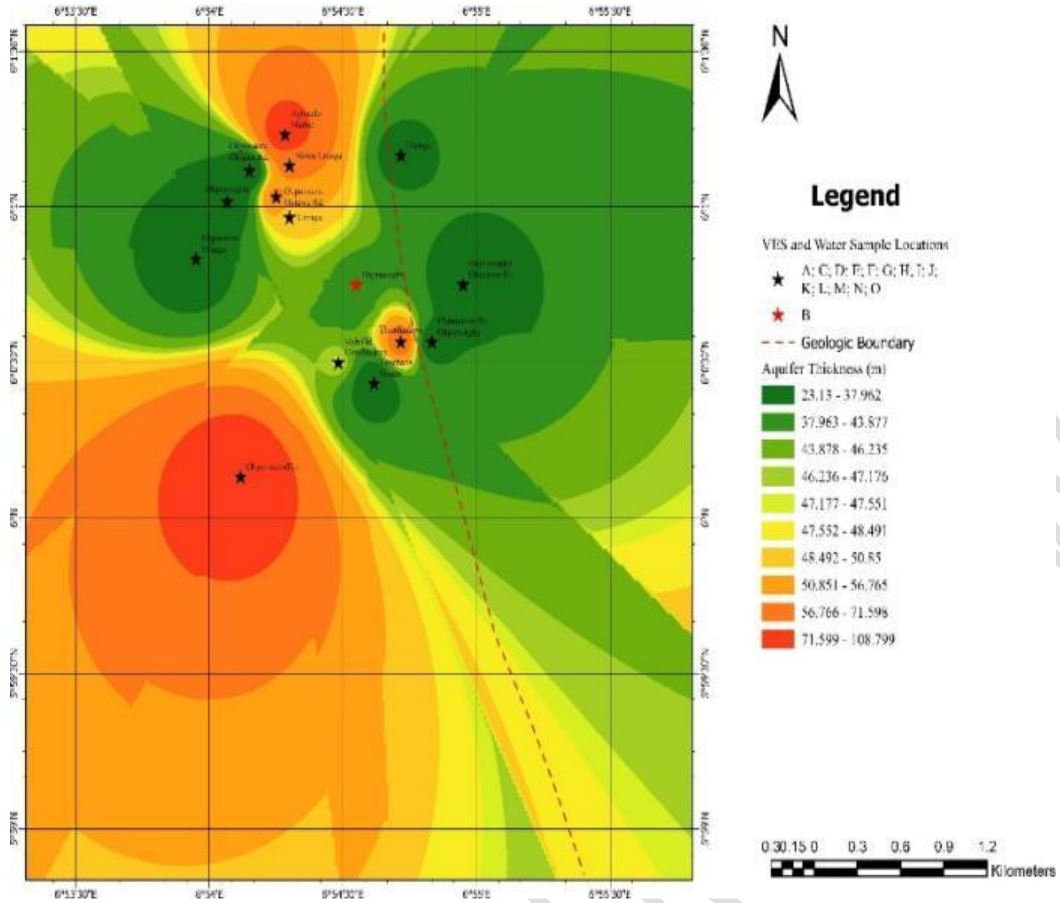


Figure 3: Section made from profile AB correlating strip logs from vertical electrical sounding A, B, M, L and K.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VES and Water Sample Locations
★ A; C; D; E; F; G; H; I; J; K; L; M; N; O
★ B
- - - Geologic Boundary
Aquifer Thickness (m)
23.13 - 37.962
37.963 - 43.877
43.878 - 46.235
46.236 - 47.176
47.177 - 47.551
47.552 - 48.491
48.492 - 50.85
50.851 - 56.765
56.766 - 71.598
71.599 - 108.799
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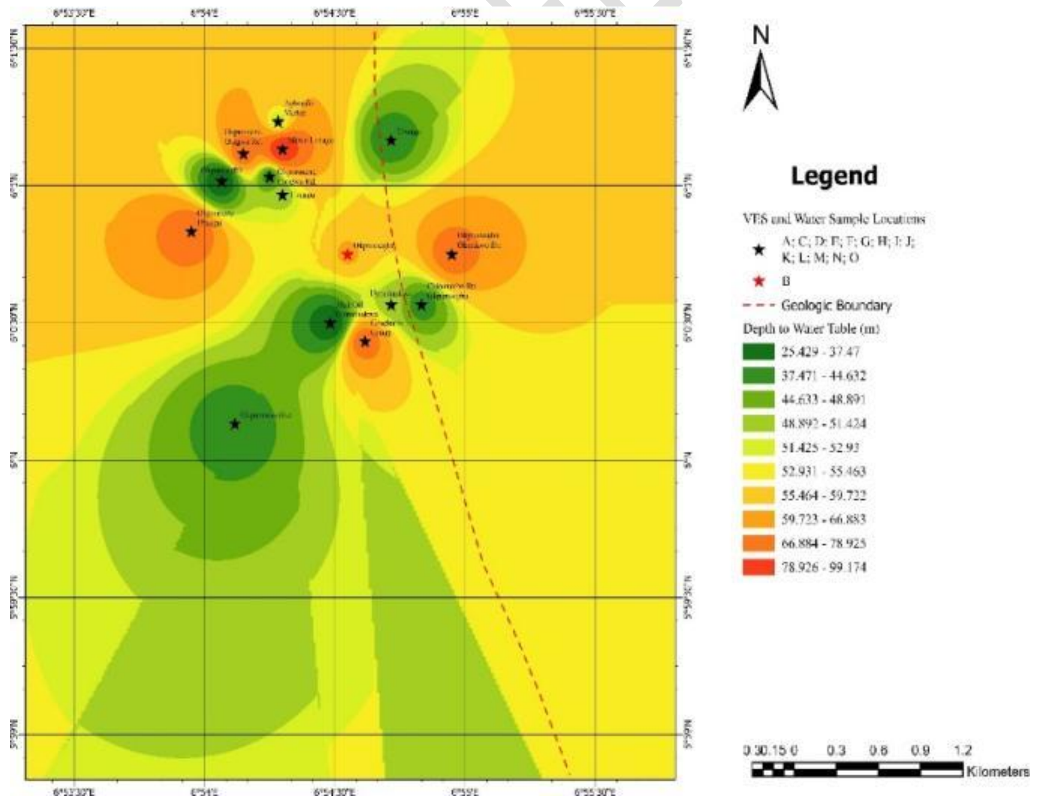
Kilometers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VES and Water Sample Locations
★ A; C; D; E; F; G; H; I; J; K; L; M; N; O
★ B
- - - Geologic Boundary
Depth to Water Table (m)
25.429 - 37.47
37.471 - 44.632
44.633 - 48.891
48.892 - 51.424
51.425 - 52.93
52.931 - 55.463
55.464 - 59.722
59.723 - 66.883
66.884 - 78.925
78.926 - 99.174
0 0.15 0 0.3 0.6 0.9 1.2
Kilometers

Figure 4 the spatial distribution of aquifer thickness and depth to water table respectively

Dar-Zarrouk and aquifer parameters

Table 2 shows the aquifer parameters (hydraulic conductivity and transmissivity) estimated from the interpretation of the VES curves. The values for the Dar-Zarrouk parameters represented by longitudinal conductance s and transverse resistivity t, and their variation in the study area are shown below (Table 2). The s and K values are positively related (Figures 5a and b) within the study area, especially in the northern portions. The greatest difference appears to be between the estimated transverse resistance t and transmissivity T (Figures 6 a and b). The study indicates that the overburden offers very low protective capacity (Ogungbemi et al., 2013) to the underlying aquiferous rock units in the area. The parameter rating indicates that even in places where good low resistive rock layers indicate clayey lithology the thickness of the units is not large enough to offer better protection to underlying aquifers from infiltrating contaminated water. The low values of T in the northern part could be attributed to the presence of the clayey sand but the variation in the north-western part could be due to the presence of more sandy units. The southern parts have higher values of T. Hence, it can be deduced that the protective capacity is poor, and the aquifers are easily susceptible to contamination and pollution. Therefore, the results indicate that two very important factors, s and t which are dependent on thickness and lithology greatly affect the protective capacity of the overburden rocks in the study area.

Table 2: Dar-Zarrouk and Aquifer parameters; S, t, hydraulic conductivity K and transmissivity T estimated from vertical electrical sounding curve.

Station ID	**Hydraulic Conductivity K (m/sec)**	**Transmissivity T (m^2/sec)**	**Average overburden longitudinal unit conductance S**	**Transverse unit resistance (t)**
A	1.91×10^{-6}	1.24×10^{-4}	4.84×10^{-3}	2.3×10^{5}
B	4.93×10^{-6}	1.98×10^{-4}	6.44×10^{-3}	5.1×10^{4}
C	1.60×10^{-5}	3.69×10^{-4}	2.46×10^{-2}	8.3×10^{3}
D	1.42×10^{-6}	4.53×10^{-5}	4.74×10^{-3}	1.5×10^{5}
E	2.23×10^{-6}	2.43×10^{-4}	1.70×10^{-3}	3.2×10^{5}
F	2.35×10^{-6}	7.48×10^{-5}	8.57×10^{-3}	8.9×10^{4}
G	4.87×10^{-6}	1.28×10^{-4}	1.64×10^{-3}	3.4×10^{4}
H	3.58×10^{-5}	8.62×10^{-4}	4.42×10^{-3}	3.6×10^{3}
I	3.23×10^{-5}	1.53×10^{-3}	1.15×10^{-3}	8.0×10^{3}
J	2.50×10^{-6}	6.50×10^{-5}	7.23×10^{-3}	6.8×10^{4}
K	2.52×10^{-6}	6.15×10^{-5}	1.08×10^{-2}	6.3×10^{4}
L	3.07×10^{-6}	1.81×10^{-4}	8.11×10^{-3}	1.3×10^{5}
M	4.20×10^{-6}	2.03×10^{-4}	1.07×10^{-3}	7.3×10^{4}

N	9.50×10^{-6}	9.19×10^{-4}	8.08×10^{-3}	6.1×10^{4}
O	2.30×10^{-6}	1.33×10^{-4}	7.32×10^{-3}	1.7×10^{5}

The Okpunoegbu dumpsite sits on top of the aquifers that outcrop in the southern parts of the study area. The aquifers immediately below the dump have shallow depth to the water table and good values of T. The least values for aquifer thickness and the protective layer which is the clayey sand were observed immediately below the dumpsite. The implication is the possibility of contaminants and pollutants infiltrating from the dump down to the groundwater zone. Further, the dumpsite is in a region where the geologic materials are very transmissive and conductive with high values of K implying that contaminants from the dumpsite will easily be dispersed in the subsurface which houses the groundwater system.

The longitudinal unit conductance (s) which is a measure of the protective capacity of the layers and the transverse unit resistance are very low in the area around the dumpsite. The values s, K, and T all favour aquifer vulnerability. Hence, it will be concluded that the groundwater in the study area is vulnerable to contamination and pollution from the Okpunoegbu dumpsite.

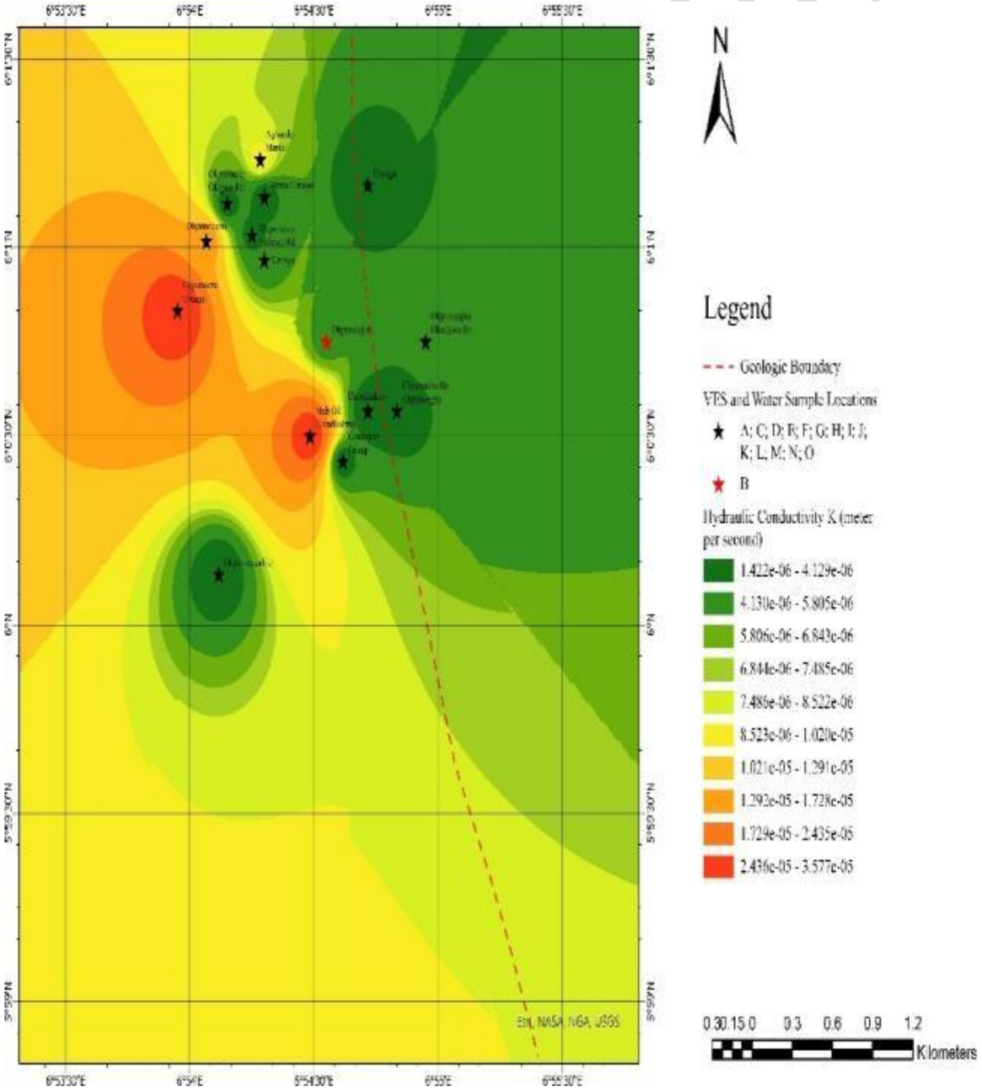
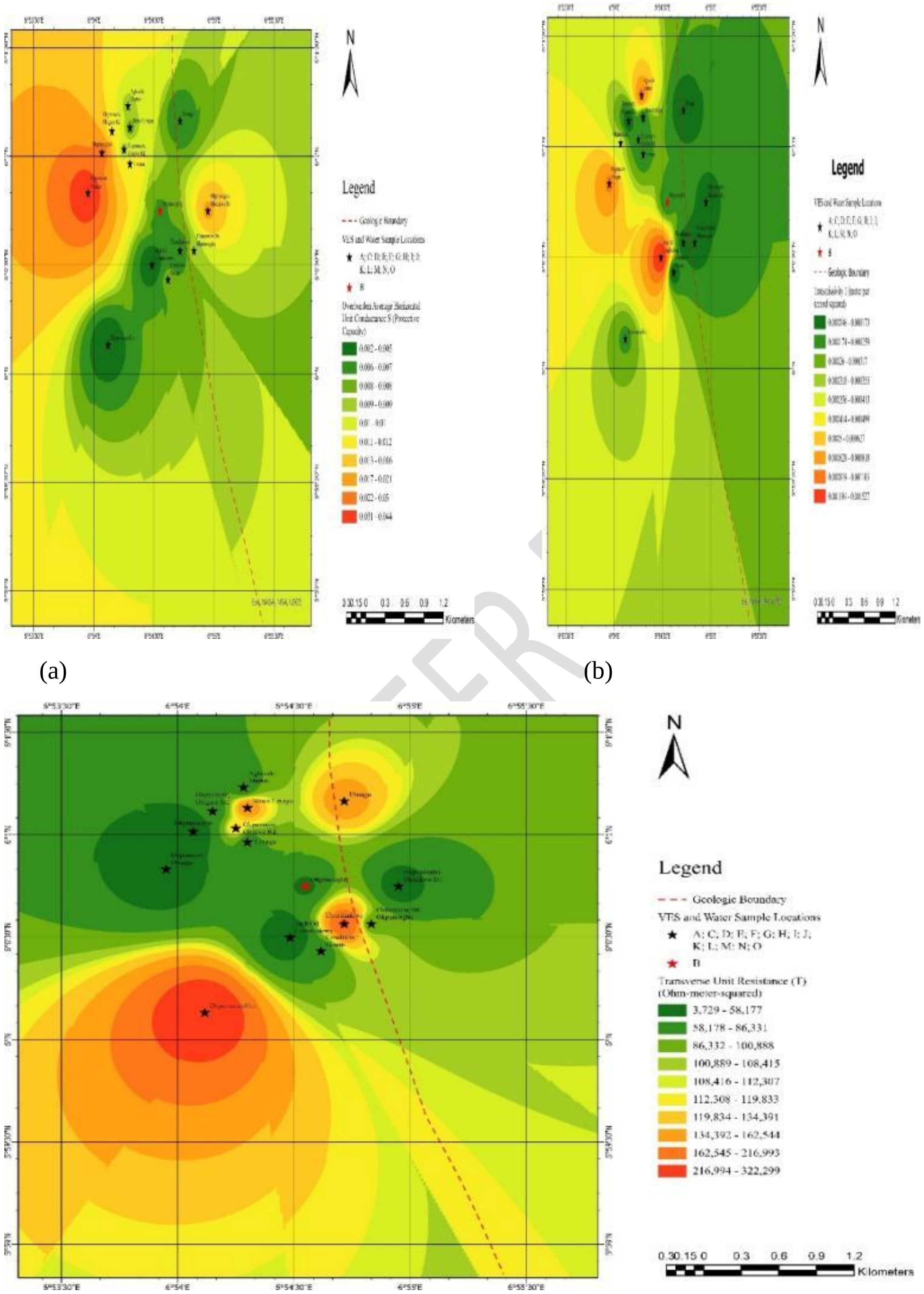


Figure 5: Distribution of K in the study area



(a)

(b)

(c)

Figure 6: The spatial distribution of T, s and t respectively

Hydrochemistry

Water Quality

The result of the 15 water samples analyzed and their chemical compositions are shown below (Table 3). The water quality will be considered under physical and chemical parameters. The concentration of the various dissolved components will be compared with WHO (2010) and Nigeria Standard for Drinking Water Quality (NSDWQ, 20015) guidelines.

Physical Parameters

The range of pH in samples is 5.73 to 6.95 with a mean value of 6.57. The water samples range from slightly acidic (20%) to alkaline (80%). Acidity in water may be attributed to the decaying of organic matter in the soil zone. It enhances the dissolution of minerals in rocks and creates conducive environment for metals to remain in solutioning.

TDS, TSS and EC are measures of the total dissolved substances in solution. These parameters have a major control on the electrical conductivity of water. The presence of high concentration of dissolved and suspended substances increases the ability of the water to conduct electricity. The concentrations of TDS, TSS and EC are within the permissible limits of the standards (Figure 7).

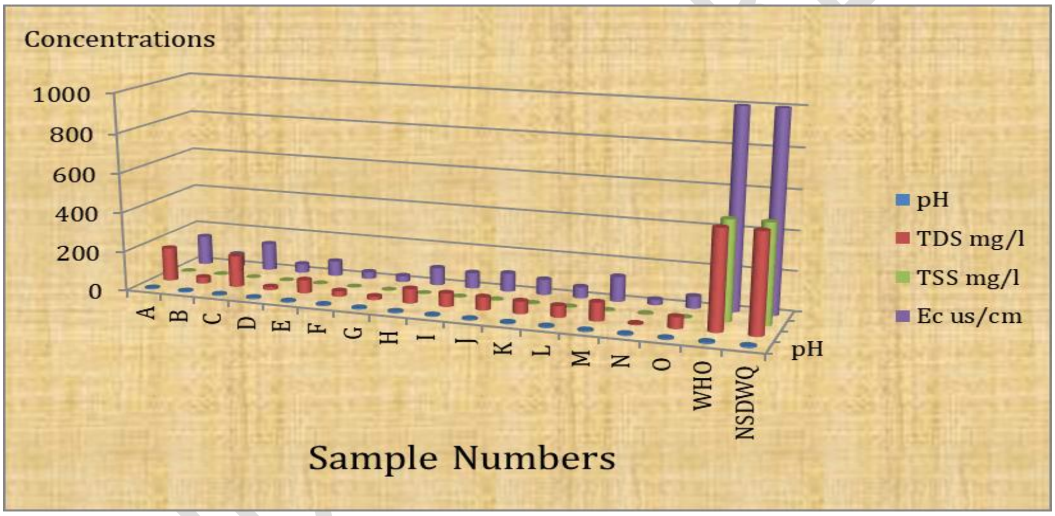


Figure 7: The distribution of the physical parameters in water samples compared with the standards

Chemical Parameters

COD is the amount of oxygen equivalent consumed in the chemical oxidation of organic matter by strong oxidation. It is used as a measure of pollutants in water. It is used to rapidly infer biodegradation especially when correlated with BOD (Srivastava et al., 2019). It is used to indirectly determine the amount of organic compounds in aquatic system. High concentration of COD indicates presence of all forms of organic matter, both biodegradable and non-biodegradable and hence, the degree of pollution in water. COD is useful as an indicator of organic pollutants in surface water (Faith, 2003; King et al., 2003). The estimation of COD along with BOD is helpful in indicating toxic conditions (Sawyer et al., 2003). Biological oxygen demand (BOD) is the oxygen needed by the organism to breakdown organic matter over a given period. BOD has been suggested as an indicator to evaluate the biodegradation of chemicals and hazardous substances (APHA, 2005). At COD level of 20mg/L and > 200mg/L the water is classified as unpolluted and severely polluted respectively (WHO, 2010). However, at BOD of 10mg/L and > 10mg/L, the water is said to be moderately and severely polluted respectively. The COD in samples range from 90.67 – 213.33mg/L and BOD, 70 -174mg/L. These values indicate that the water in the study area is severely polluted. Considering that these parameters measure both biodegradable and non-biodegradable organic matters which are components of wastes, their high concentrations in groundwater may be attributed to the influence of the Okpunoegbu dumpsite. The DO is a measure of the amount of oxygen dissolved in the water. It can have a significant effect upon groundwater pollution by regulating the valence state of trace metals and by constraining the bacteria metabolism of dissolved organic species (Rose and King, 1988). The range of DO_1 in samples is 22.78- 65.40mg/L and DO_5 is 48-358.96mg/L respectively. These values are higher than the guideline values.

Major Ions

The major cations calcium, magnesium, sodium, and potassium and anions carbonate, sulphate, chloride, and nitrate are the main contributors of the dissolved constituents in water. The distributions of the chemical parameters in water sample are shown (Fig. 8). The major cations calcium, magnesium, sodium, and potassium are within the permissible limits of the standards used in the comparison hence the low values foe TDS. The major anions carbonate, sulphate, chloride, and nitrate are also within the permissible limits of the guidelines. However, the range of chloride in samples 100-165mg/L is significant. Increased concentration of chloride has been attributed to increase in salinity, saltwater intrusion, and a signature of anthropogenic pollution (Mac Donald, 2005; Okolo et al., 2020).

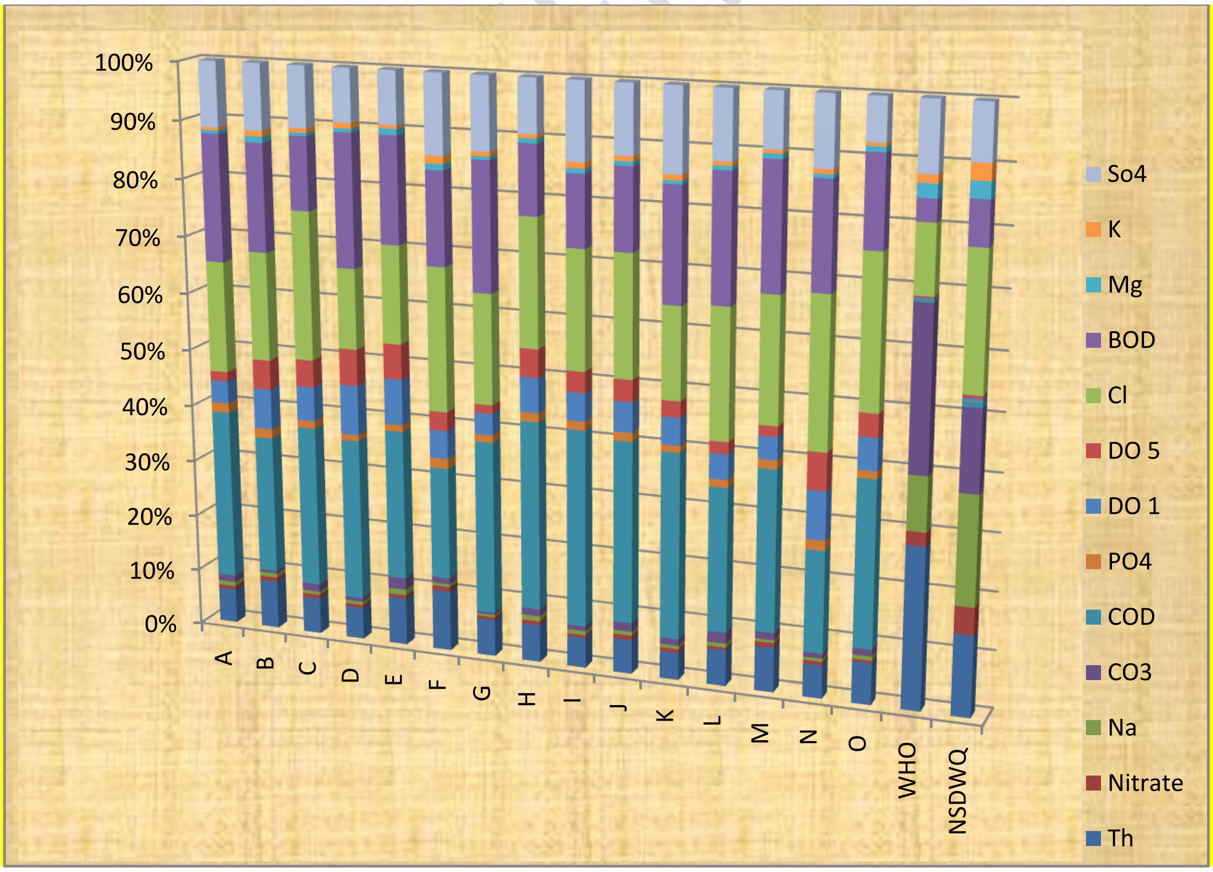


Figure 8: Distribution of the chemical parameter in the water sources with the standards

The Heavy metals

The heavy metals cadmium, chromium, zinc, copper, mercury, and lead were tested for in water samples.

However, the distribution of heavy metals that exceed the guideline values in the study area can be seen in Figure 9. The concentrations of zinc and copper in samples were within the WHO permissible and NSDWQ maximum permitted limits. Though, the range of cadmium (0.04 – 0.37 mg/L), chromium (0.01 – 0.10 mg/L), mercury (0 -0.07 mg/L) and lead (0.1 – 0.93 mg/L) in samples were above the guideline values. The concentrations of these metals are low but even at such low concentrations they are toxic and of public health concern (NSDWQ, 2015). These metals are of importance because they accumulate in human organs and most of them are carcinogenic. The heavy metals have been variously attributed to anthropogenic sources and activities (Okolo, et al., 2018, Akudinobi and Okolo, 2013). The geospatial distributions of the heavy metals are shown in maps (Figures.10 a - d) for each metal.

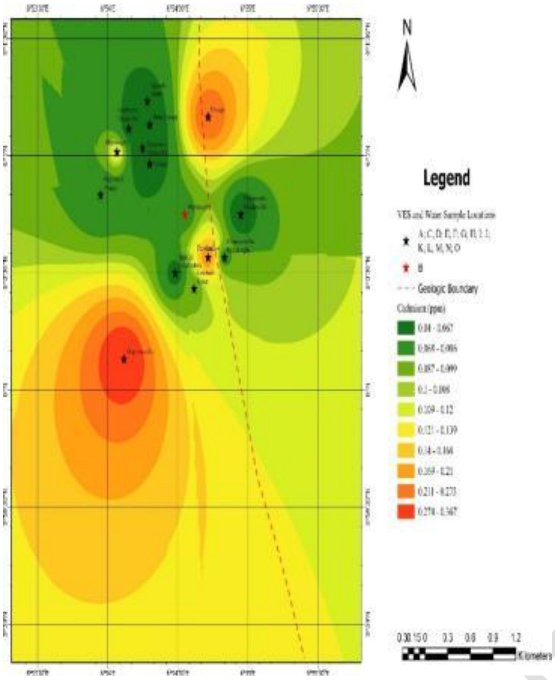
The geospatial maps indicate that the dumpsite may have contributed to the increased concentrations of cadmium, copper and lead in groundwater. It was equally observed that other input sources may exist. On the other hand, the maps depict the dumpsite as the major contributor of chromium and mercury to groundwater in the study area. The presence of these heavy metals at their present concentrations indicates that groundwater sources are polluted. The contamination of water sources in Nnewi has been previously observed by Momoh et al., 2013. To further examine the pollution status of groundwater in the study area, the WQI, the heavy metal pollution index (HMPI), the heavy metal evaluation index (HMEI) and degree of contamination (CD) were calculated.

Water Quality Index (WQI) and Degree of Contamination (CD)

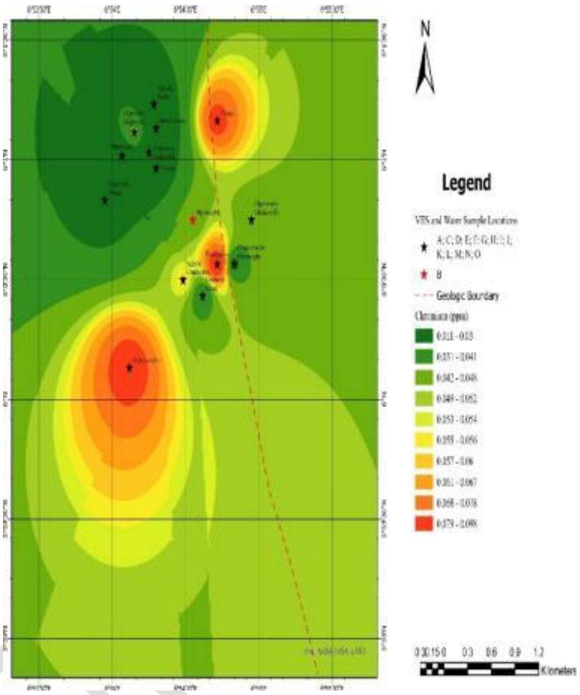
Water quality index is a mathematical technique which is used to transform large quantities of water quality data into a single number (Table 4) which is indicative of the status of the water quality. The values of the WQI indicate that 100% of the groundwater is in the range of highly contaminated and unsuitable for drinking. The result of the assessment for the degree of contamination (CD) using the heavy metals indicates 60% of the samples to be highly contaminated and 40% to be moderately contaminated, with the highest degree of contamination recorded for sample E and the element contributing most to this being cadmium whose value was highest at this station. This is consistent with results of Momoh et al., 2013. The implications of these observations are that the groundwater in study area is polluted by the chemical parameters most especially the heavy metals. The maps of their spatial distribution in the study area are shown in Figure.11 (c and d).

The spatial distributions of the CD imply that the dumpsite may not be a major contributor in this parameter. The areas around the dumpsite have low values while areas further away from the dump have higher values indicating that the input source is not the dump. This trend was also observed in the distribution of cadmium. However, the distributions of the WQI indicate that the dump is a major contributor of groundwater quality deterioration in the study area. The areas with the highest colour intensity depicting areas of highest concentrations occur around the dump and spreads towards the eastern and southeastern parts of the study area.

This depicts the contaminant/pollutant plume moving away from the dump and spreading through the aquifer system resulting in groundwater pollution.



(a)



(b)

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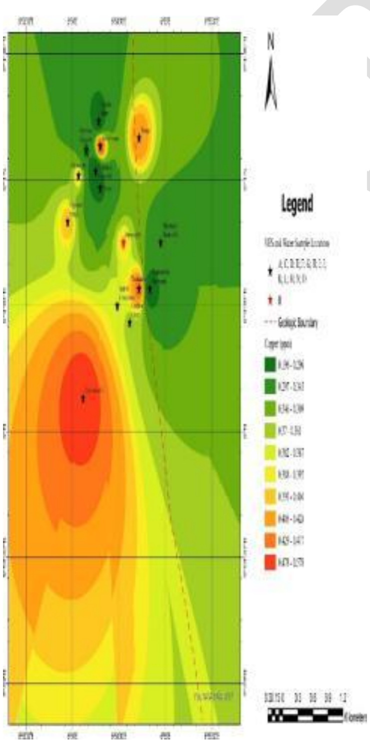
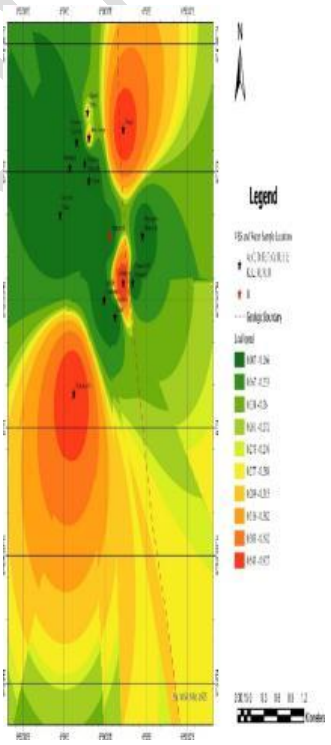
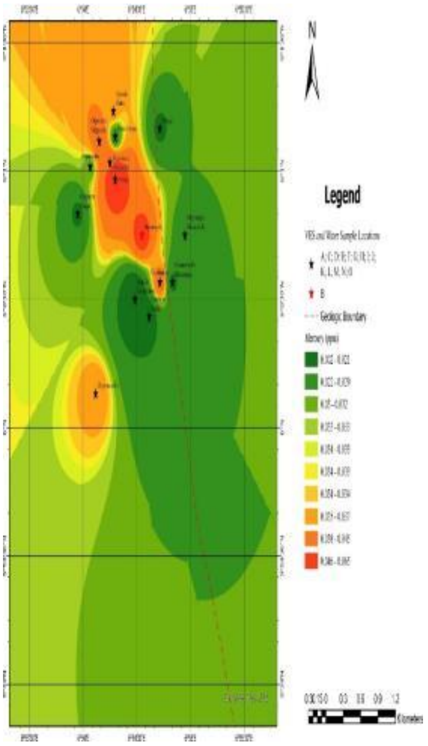
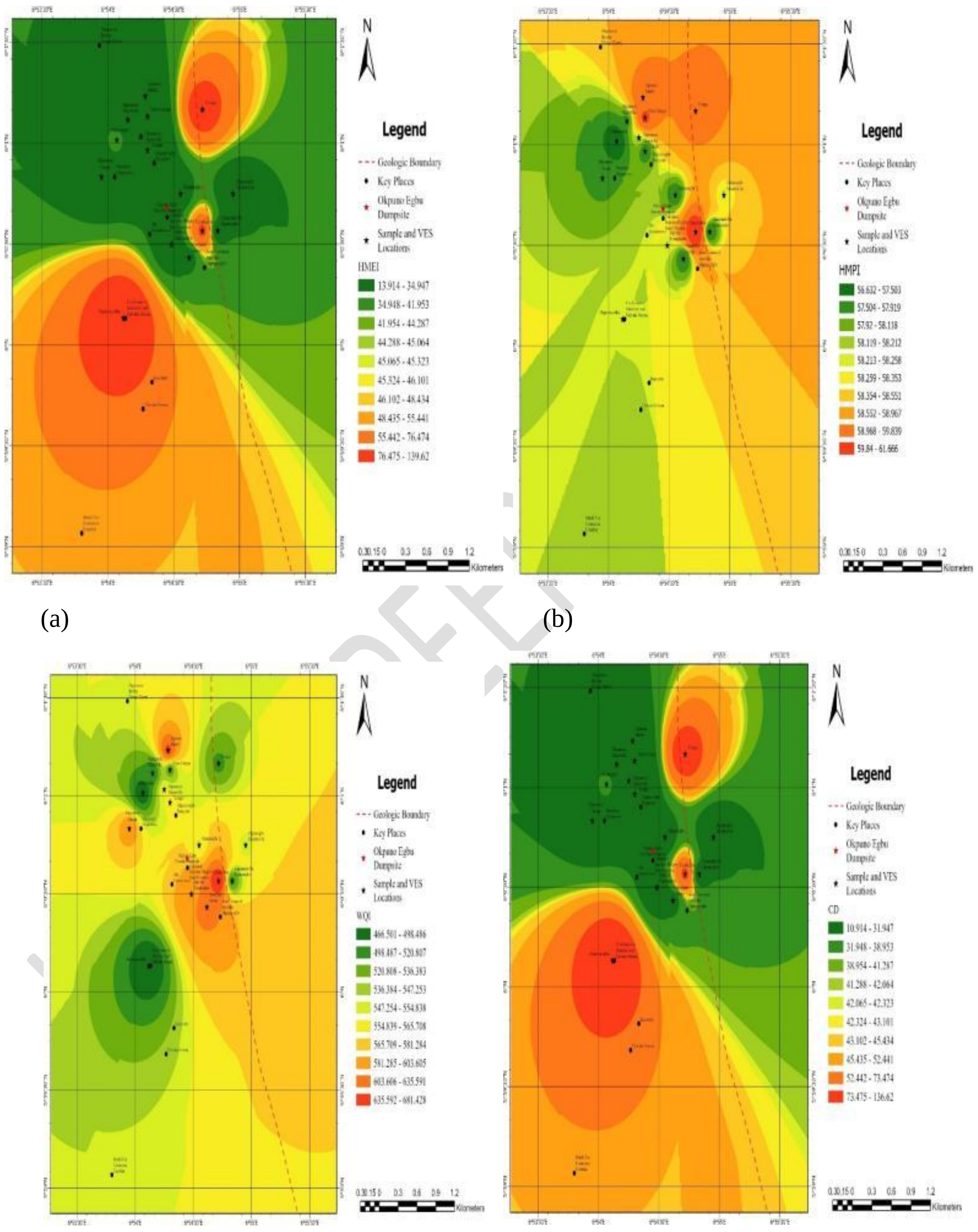






(c) **(d)** **(e)**

Figure 10: Geospatial map of distribution of (a) cadmium, (b) chromium (c) copper (d) lead and (e) mercury in groundwater samples.



(a) (b)

(c) (d)

Figure 11: Maps of spatial distribution of (a) HMEI, (b) HPI (c) WQI and (d) CD in the study area.

Heavy Metal Evaluation Index (HMEI) and Heavy Metal Pollution Index (HMPI)

The distribution of HMEI and HMPI and the value at each sample location is given in Table 4. The classifications of HMPI indicate that 100% of the water is highly polluted and unfit for drinking while HMEI indicate that 26.7% is of medium pollution and 63.3% is highly polluted.

The spatial distributions of the indices are shown in Figure 11 (a and b). There are no clear indications of any influence of the different geologic units on HMEI and HMPI distribution. For the HMPI, the distribution is reverse of HMEI with most of the areas in the southern parts indicating lower values of HMPI. The distributions of the HMEI have the same trend with the CD (Figure 11 a and d) while the distributions of HMPI have the same trend with WQI (Figure 11 b and c).

Table 4: Result of the calculated Groundwater indices for all the samples

Sample ID	WQI	HMPI	HMEI	CD
A	681.55	61.67	83.58	80.58
B	553.46	57.67	27.15	24.15
C	471.30	56.63	41.06	38.06
D	516.60	59.71	108.65	105.64
E	466.45	58.24	139.67	136.67
F	513.63	57.48	26.41	23.41
G	552.21	58.24	16.80	13.80
H	598.47	57.84	23.22	20.22
I	598.21	58.23	19.81	16.81
J	620.57	57.52	30.72	27.72
K	499.55	57.82	20.92	17.92
L	557.91	58.19	13.90	10.90
M	559.33	57.67	15.49	12.49
N	648.16	59.6	25.05	22.05
O	524.96	60.21	21.22	18.22

Hydrochemical Facies and Processes

The results of water samples were plotted using Piper diagrams to determine the dominant hydrochemical facies and processes. The diagram is used to display a large chemical data in other to interpret the bulk composition of groundwater (Freeze and Cherry, 1979). The concentrations are plotted in milliequivalents per Litre (meq/L). The size of the circle in the diamond indicates the total dissolved solid concentration for that sample. The diagram contains two triangles depicting the concentrations of cations on the left and anions on the right. The triangle for cations has 100% calcium on the left, sodium + potassium on the right and magnesium at the apex. The same separation is also in the anion triangle with sulphate at the apex, chloride to the right and bicarbonate at the left. The relative chemical composition of the water sample is indicated by a single point in the diamond. The diamond diagram forms the background for description of the chemical composition of the groundwater.

The dominant hydrochemical facies are the Ca^{2+} - Mg^{2+} - Cl^- - SO_4^{2-} type. This indicates that $Ca^{2+} + Mg^{2+} > Na^+ + K^+$ which implies that the alkaline earth metals dominate over the alkali metals. However, $SO_4^{2-} + Cl^- > CO_3^{2-} + HCO_3$ indicating the strong acids dominance over the weak acids. The dominant anion is indicated as chloride while the dominant cation is calcium. Though this is the case it is worthy of note that the concentrations of magnesium and sulphate are also significant hence, the points fall on the lines and close to the 50% line. Hence, the water is depicted as Ca^{2+}- Cl^- and Ca^{2+}- Mg^{2+} – Cl^- – SO_4^{2-} (Figures 12 and 13) which indicates water type not usually associated with recharge area but associated with the discharge area (Freeze and Cherry, 1979, Back and Hanshaw, 1965). It also indicates water with permanent hardness which will require treatment before use or it can lead to wasting of soap and scale formation in boilers and utensils. Also the dominant cation is Ca^{2+} though some percentage falls in the region of mixing water zone and the dominant anion is Cl^-.

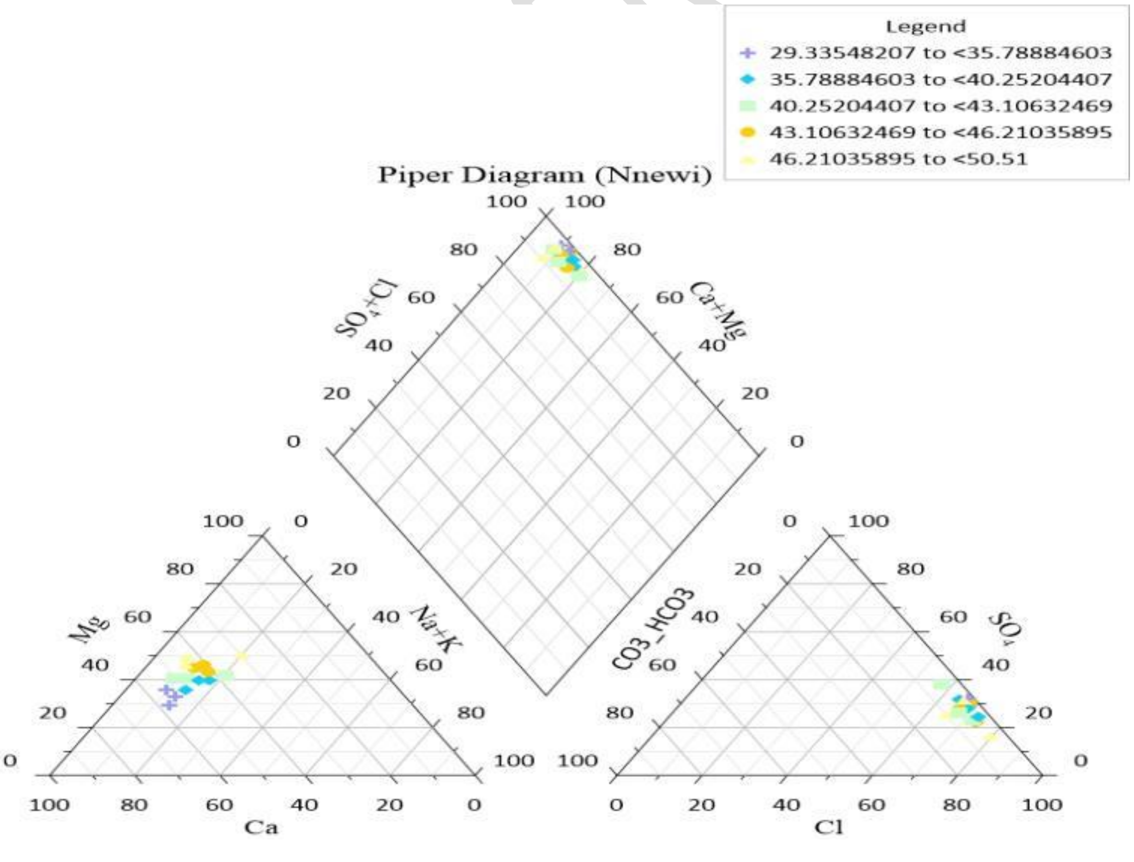
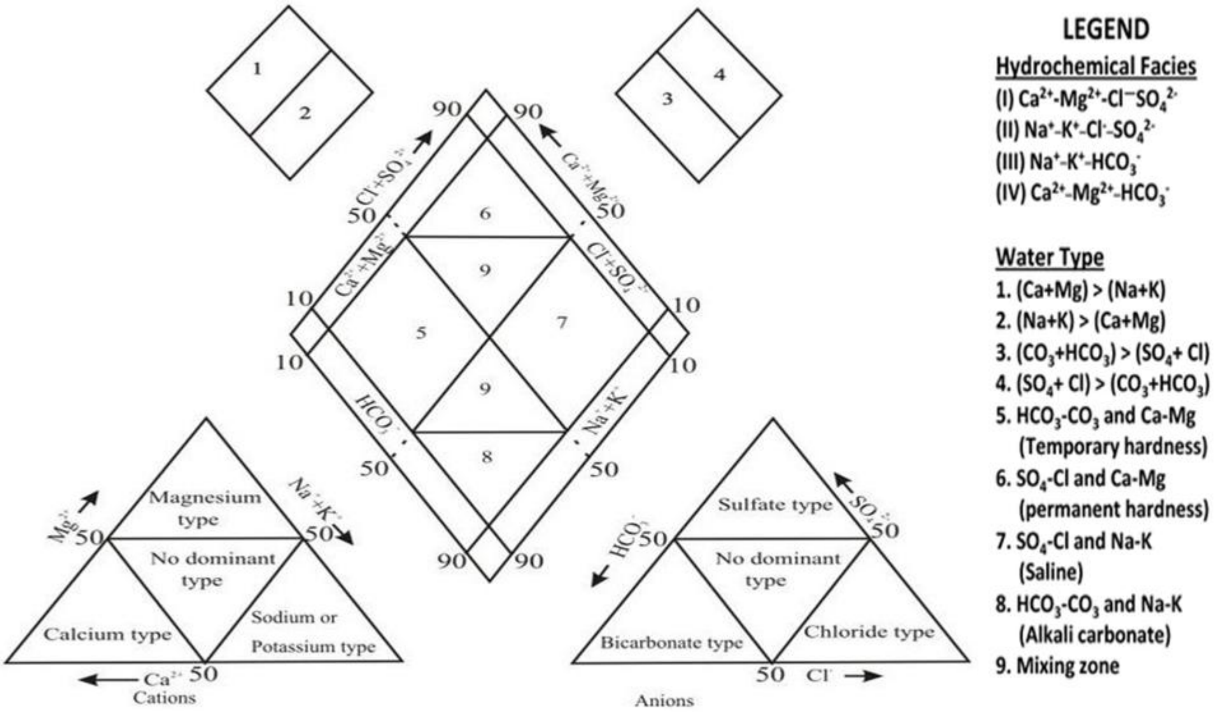


Figure 12: The classification of hydrochemical facies in Piper diagram



Hydrochemical facies according to Back and Hanshaw, 1965

Figure 13: Interpretation of the hydrochemical facies in Piper diagram (Back and Hanshaw, 1965)

CONCLUSION

Geophysical methods such as the electrical resistivity sounding method can be used in the determination of aquiferous zones or intervals, aquifer thickness, regional water level, s and t which will give an idea of aquifer vulnerability. Key aquifer parameters such as hydraulic conductivity and transmissivity were also estimated. A combination of geophysical tools and hydrogeochemical analysis was used to model the extent of the protective capacity of the geologic units on the aquifer and the influence of the Okpunpegbu dumpsite on groundwater. The distribution of contaminant/pollutants was presented in maps for an excellent picture of the pollutant plume movement. This study establishes the need for the initiation of remediation measures to reclaim and improve the quality of groundwater within the study area. The need to establish ways of proper management of waste especially in engineered landfills to prevent leachates from escaping and infiltrating to groundwater zone and to inhibit and prevent further contamination of the water resources cannot be over emphasised.

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Table 3.: Result of the Chemical Analysis of Samples

Sample	pH	TDS mg/l	TSS mg/l	CO3 mg/l	COD mg/l	Ec us/cm	DO day 1 mg/l	DO day 5 mg/l	Cl mg/l	BOD mg/l	Cd ppm	Cr ppm	Cu ppm	Ca ppm	Hg ppm	Pb ppm	Zn ppm	Mg ppm	K ppm	So4 ppm	Phosphate mg/l	Nitrate mg/l	Na ppm	Total Hardness mg/l
A	5.73	170	2.78	7.5	192	149.43	25.2	10.92	125	142.8	0.195	0.098	0.455	9.483	0.044	0.928	0.342	3.767	3.288	72.64	11.062	4.007	5.06	39.08
B	6.41	32	1.86	2.5	128	67.93	37.4	27.43	100	99.7	0.077	0.043	0.396	8.493	0.052	0.073	0.195	5.767	5.262	60.47	8.963	4.209	4.01	44.82
C	6.54	160	1.95	7.5	154.667	140.24	32.9	25.9	142	70	0.122	0.019	0.399	9.278	0.029	0.019	0.275	2.878	4.202	57.89	7.605	3.736	3.2	34.92
D	6.94	15	2.44	5	213.333	45.32	65.4	48	105	174	0.276	0.086	0.429	8.873	0.019	0.832	0.306	4.988	7.198	69.12	8.346	4.007	4.5	42.57
E	6.53	68	2.4	12.5	160	76.54	48.6	37.3	104	113	0.367	0.092	0.578	9.566	0.037	0.866	0.428	6.655	3.362	55.78	7.481	3.669	6.19	51.14
F	6.76	28	1.89	5	90.667	34.63	22.78	15.23	116	75.5	0.078	0.026	0.233	11.565	0.019	0.02	0.096	4.988	6.228	63.78	8.346	3.872	2.36	49.27
G	6.66	17	2.54	2.5	202.667	30.56	25	10	128	150	0.047	0.044	0.312	10.909	0.025	0.056	0.322	3.988	5.187	84.22	8.963	3.466	2.6	43.53
H	6.68	73	2.03	7.5	202.667	89.45	37.4	30	137	74	0.067	0.019	0.402	7.983	0.019	0.044	0.305	4.988	4.178	56.89	9.704	4.277	5.9	40.36
I	6.71	68	1.56	5	213.333	80.2	30.24	22.56	128	76.8	0.056	0.056	0.386	4.938	0.001	0.057	0.165	5.097	6.433	82.67	9.704	2.926	4.66	33.22
J	6.59	66	4.25	10	207.333	93.89	34.2	24.9	139	93	0.089	0.029	0.378	7.678	0.016	0.052	0.275	4.878	5.733	77.43	10.074	5.493	4.5	39.15
K	6.64	63	3.56	7.5	213.333	78.22	31.39	18.32	105	130.7	0.06	0.044	0.289	5.983	0.044	0.045	0.056	3.988	6.298	94.38	8.099	4.547	4	31.27
L	6.51	58	3.05	12.5	165.333	56.28	28.45	13.9	149	145.5	0.039	0.01	0.195	9.054	0.043	0.044	0.044	4.655	4.565	77.45	9.086	3.264	4.61	41.66
M	6.18	93	3.44	7.5	165.333	126.78	23.23	10.4	128	128.3	0.046	0.024	0.288	10.284	0.065	0.006	0.207	4.988	3.455	55.38	9.086	4.885	2.83	46.09
N	6.92	6	5.12	5	106.667	26.78	50.2	39.1	157	111	0.058	0.019	0.227	7.443	0.036	0.285	0.068	3.988	4.987	71.78	10.568	3.939	3.35	34.90
O	6.61	58	4.09	7.5	181.333	60.45	34.8	25	165	98	0.044	0.015	0.489	9.083	0.024	0.327	0.044	5.655	3.456	45.98	8.469	2.588	4.62	45.83