Geophysical investigation of the effects of refuse dumpsites on the quality of groundwater in some major towns in Niger state, Nigeria

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Received 15 May 2023, Revised 25 September 2023, Published 26 September 2023

Abstract: This study was carried out to investigate the effects of refuse dumpsites on the quality of groundwater in some major towns in Niger State, Nigeria. A total of sixty (60) Vertical Electrical Soundings (VES) was conducted across fifteen (15) dumpsites within the study areas; twenty (20) VES at each of the three (3) dumpsites of Lapai, Bida and Paiko using Schlumberger configuration to investigate the possibility of contamination of groundwater in the areas. The resistivity data were collected using G41 Resistivity Meter and interpreted using IPI2Win Software. The results revealed four geo-electrical layers. The resistivity values of the Aquifer layers of Lapai dumpsites ranged from 136 Ωm to 681 Ωm, with the thickness ranging between 2.82 - 8.77 m at the depth of 4.21 – 10.90 m at Engr. A. A. Kure dumpsite. At Malle dumpsite, the thickness range was (1.10 – 4.39) m and the depth at 5.27 – 12.70 m. The resistivity values of the aquifer layers at Bida dumpsites ranged from 161.10 Ωm to 223 Ωm, with the thickness ranging between 4.86 and 11.00 m at the depths of 7.65 – 12.70 m while at Mayaki Ndajiya dumpsite, the thickness range was 4.91 – 23.46 m at the depth of 6.84 – 25.57 m. Also the resistivity values of the aquifer layers of Paiko dumpsites ranged from 20.90 Ωm to 110 Ωm with thicknesses ranging from 2.33 to 14.00 m at the depth range of between 3.85 and 15.50 m at Gidan Marafa dumpsite while the thickness range was from 3.19 – 9.04 m at the depth of 6.70 – 14.14 m at Angwan Akimi dumpsite. These values were used to compute the Dar Zarrouk parameters which indicate aquifer protectivity. The protective capacity of the over burden rock materials at Lapai dumpsites ranged from 0.010 – 0.076 Siemens, while at Bida dumpsites it ranged 0.009 – 0.152 Siemens and at Paiko dumpsites it ranged between 0.025 – 0.046 Siemens. The low protective features observed in the Aquifer zones of Lapai, Bida and Paiko dumpsites indicated the possibility of leachate migration from the waste dumpsites infiltrating into the aquifers and polluting the groundwater. It is evident, from the results of this geophysical survey that the water in the study areas of Lapai, Bida and Paiko could be polluted leading to water related diseases.

Keyword : Dumpsites, resistivity, Dar Zarrouk parameters, groundwater Quality.

1. Introduction

Waste is any substance which is discarded after primary use. In Niger State, like in most other areas and cities, wastes are generated daily and most of the wastes is discarded in improperly situated dumping sites. The dumping sites are, most times, located close to residential areas, markets, farms, roadsides, and water sources. This threatens groundwater and road facilities, not sparing the aesthetics of the affected areas.

Groundwater, which is in aquifers below the surface of the earth, is one of the main and most important natural resources. About two third of the total land space in the world is covered by groundwater (Shiklomanov, 1993). Groundwater is the source of about 33 percent of the Nigeria and city water departments' supply to households and businesses (Jatau and Ajodo, 2006). It provides drinking water for more than 90 percent of the rural population of Nigeria who do not get their water delivered to them from the national water department or private company and about 42 percent of water used for irrigation comes from groundwater (Shiklomanov, 1993). The importance of groundwater as a valuable source of potable water supply cannot therefore, be overemphasized as groundwater forms the most important natural resources of any region and compliments surface sources in the provision of potable water for domestic and industrial applications.

Groundwater is reported to be a more reliable source of water for over half of the world population (Anomohanran, 2011).The populace is also dependent on its abundance and fertility of the soils for agriculture, shelter, and other economic and industrial activities (Jatau and Ajodo, 2006). Unfortunately, the quality of this natural resource has been impaired by the indiscriminate location of dumpsites without regards to the health of the people and severe damage to the environment. Wastes are generated from various sources and proper disposal mechanisms should be put in place for them.

Indiscriminate disposal of refuse without proper supervision often amounts to damage to the environment and ultimately to the human body directly or indirectly. The direct health effects arise from excessive breeding (reproduction) of vermin (difficult to control) and agents of disease such as rats, flies and mosquitoes. Improper disposal of refuse will also result to leachate contamination of groundwater and this can result to poisoning of bore holes. Other problems associated with disposal of waste include: surface water contamination, soil contamination, environmental pollution.

Toxic electrical equipment such as lamps, batteries, and switches into the trash can lead to mercury contamination in groundwater. Leachate also enters the ground through improper waste disposal are plasticizers, dioxin and chlorinated solvents used as sealants, pesticides, disinfectants and wood preservatives Lawal et. al (2014). These can cause cancer, liver, kidney and stomach damages. So, all these negative challenges led to this research with a view to mitigating them geophysically.

Electrical resistivity is an intrinsic property that quantifies how strongly a given material opposes the flow of electric current. According to Ohm's law, if a voltage is applied to two sides of a material, such as wire, a piece of rock, or an electrical appliance, electric current flows through the material. This information can be used with appropriate geometric factors to make informed decisions. Electrical resistivity studies in geophysics may be understood in the context of current flow through a subsurface medium consisting of layers of materials with different resistivities. In field studies, the resistivity of a material may be combined with reasoning along geologic lines to identify the materials that constitute the various underground layers.

Electrical resistivity surveys are commonly used for geotechnical investigations and environmental surveys (Adejumo et. al 2018). The resistivity of the subsurface is affected by porosity, amount of water in the subsurface, ionic concentration of the pore fluid and composition of the subsurface materials. Electrical resistivity survey therefore, is based on the principle that the distribution of electrical potential in the ground around a current carrying electrode depends on the electrical resistivity and the distribution of surrounding soils and rocks.

Several researches have been carried out research on groundwater contamination from solid waste disposal sites (Iyoha et. al., 2013 and Akoteyon, 2012). Oyedele (2019) carried out geochemical analyses using groundwater samples from hand dug wells around the Orita-Aperin refuse dump site in Ibadan. Bundela et. al (2012) carried out geophysical and hydro-physicochemical study of the contaminant impact of a solid waste landfill (SWL) in Port Harcourt municipality. Nwagbara et. al (2012) carried out the assessment of contamination of groundwater around two solid waste dumpsites in Lagos, Nigeria. Ogungbe et. al (2012) identified characteristics of leachates from municipal solid waste landfill sites in Ibadan, southwest Nigeria. Abdullahi et. al (2019) carried out an integrated geophysical technique in the investigation of groundwater contamination at two waste disposal sites in Kaduna Metropolis. Karijia et. al (2013) used electrical resistivity imaging to delineate contaminant transport from leachate in a basement complex terrain.

Abdourahamane et. al (2015) in their work, examined the effects of solid waste on the quality of underground water in Benin metropolis, Nigeria. Asuma, (2013) carried out an investigation on characteristics of soils and crops uptake of metals in municipal waste dumpsites in Niger State, Nigeria. Rastegari (2017) reported the effect of municipal solid waste on the levels of heavy metals in Isfahan dumpsite soil, Iran. Hasan et al. (2016) used 2D electrical resistivity imaging and vertical electrical sounding to estimate the depth to the groundwater table, identify and delineate the extent of contaminant plume and migration path below surface around landfill. Birhanu and Berisa (2015) carried out integrated geophysical surveys involving 2D electrical resistivity, very low frequency electromagnetic induction method and seismic refraction tomography on Unguwan Dosa municipal solid waste disposal site in Kaduna metropolis, northwestern Nigeria to investigate groundwater contamination. Kebede (2016) used electrical resistivity method to investigate the effects of dumpsite on the aquifer units around Giwa – Okearo area of Ogun State. Adebayo et al., (2015) used geophysical approach to delineate contaminant plumes in Ede town, southwestern, Nigeria. Olagunju et al., (2017) used geochemical and geophysical approach to investigate the impact of open dumpsite on the environment. Jegede et al., (2012) carried out integrated surveys of induced polarization and 2D resistivity tomography at open waste disposal site in Kaduna with the aim of imaging the subsurface to delineate leachate plumes and their pathways into the groundwater. Tsepav et al., (2015) studied some geoelectric characteristics of aquifer in parts of Lapai, Central Nigeria using Wenner vertical electrical sounding (VES) method.

1.1. Location and Geology of the Study Areas

1.1.1. Location and Geology of Lapai

Lapai is a local government area in Niger State adjoining the Federal Capital Territory, Abuja. Its headquarters is in Lapai town and located between latitude 9003'17".60N and 9005'07".22N and longitude 6033'49".53E and 6035'38".47E (NIPOST, 2009) with a land mass of 3,020km² and a population of 164,400 according to 2016 projection (National Population Commission of Nigeria and National Bureau of Statistics, 2016). Figure 1 shows the schematic diagram of the location of the study area indicating the VES points.

Lapai, like other areas on the same latitude, is covered by two major rock formations: The sedimentary rocks to the south which are formed by the lithification of weathered rock debris that have been transported and deposited (www.physicalgeography.net/fundamentals). The sedimentary rocks are found particularly along the Niger valley in most parts of Gulu, Muye, and the eastern parts of Lapai town and are characterized by breccia, conglomerate, sandstones, siltstone, dolomites, rock salt, iron ore, limestone and coal.

The basement area is characterized by the rocks of the Nigerian basement complex. These rocks are mainly granites of different types which includes leucocratic granite, granodiorite and biotite granite. The rocks occur as flat outcrop sometimes and form hills. Out of the three subdivisions of granites found in the study area, leucogratic granite is most abundant and occupies about 50% of the total area mapped with superficial deposits in some areas (Elias, 2017).Biotite granite forms about 35- 40% of the total mapped area and eqoahodiorite forming first 10% of the total mapped area at the North central portion (Elias, 2017).

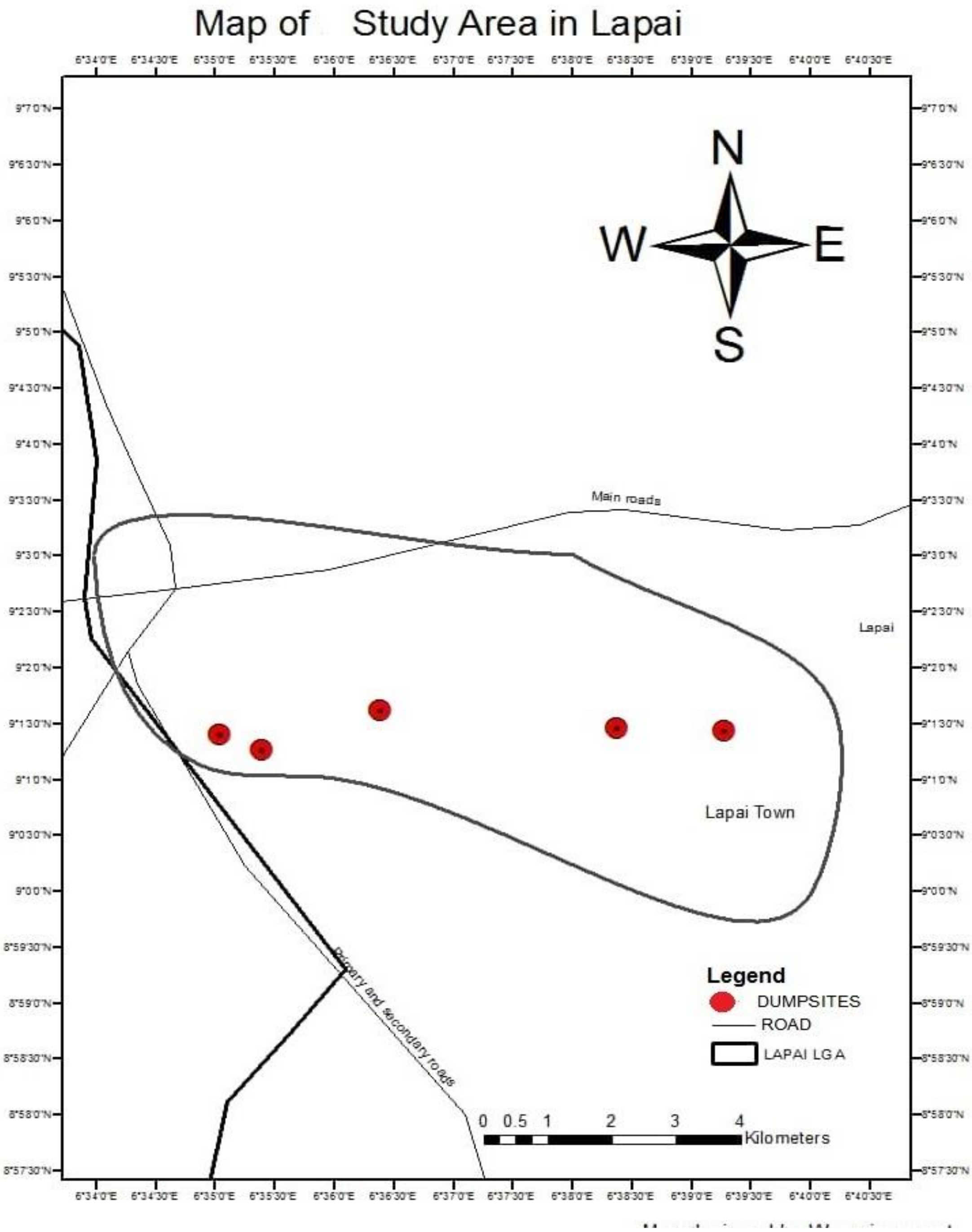

Figure 1. Map of the Lapai study area showing the VES points.

1.1.2. Location and Geology of Bida

Bida is the second largest city in Niger State with land mass of 421.6 km2 and estimated population of 260,400 according to 2016 projection by the National Population Commission of Nigeria and National Bureau of Statistics. It is located southwest of Minna, capital of Niger State, and is a dry, arid town. Figure 2 shows the sketched map of the Bida study area indicating the VES points,

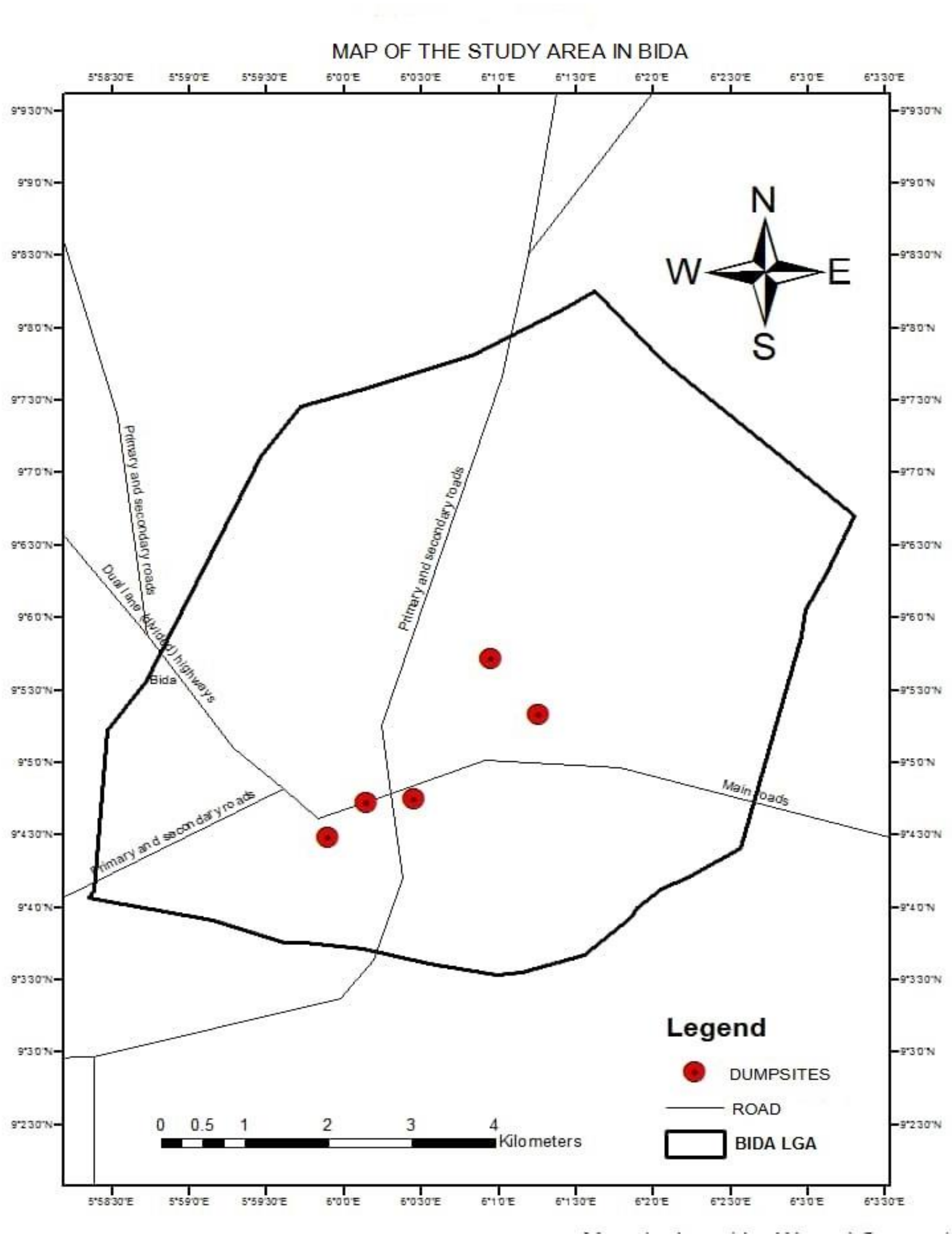

Figure 2. Map of the Bida study areas showing the VES points

Bida is filled with mainly Santonia to Maastrichtian sediments of sandstones, siltstones and superficial alluvial deposits (Obaje, 2020). The lithologies of these formations are weathered literate, sandy clay and clayey sand (Bello and Makinde, 2007). The southern part of the study area is characterized by secondary permeability with the following formations; weathered laterite, sandy clay/clayey sand, fractured basement and fresh basement rocks. Generally the rock units in this region are suggested to be highly characterized by alternating clay, siltstone, silt, and weathered bedrock (Akande et al., 2005). These geological materials are liable to form aquifer and permeable zones to the bedrocks in both the sedimentary terrain and the crystalline basement complex existing in the area. In areas underlain by crystalline rocks, presence of structures like fractures, fissures, veins, joints and such other structural deformations of the basement complex, controls the flow of groundwater and also influences the rate of recharge and discharge of the main aquiferous (Akande et al., 2005; Bello and Makinde, 2007).

1.1.3. Location and Geology of Paiko

Paikoro Local Government headquarter is located in Paiko town about 25 km south-east of the State Capital Minna. It has an area of 2,066 km2 and a population of 222,200 as at the 2016 projection by the National Population Commission of Nigeria and National Bureau of Statistics. It has its administrative headquarter situated in Paiko town. Figure 3 shows the sketched map of the study areas in Paiko indicating the VES points.

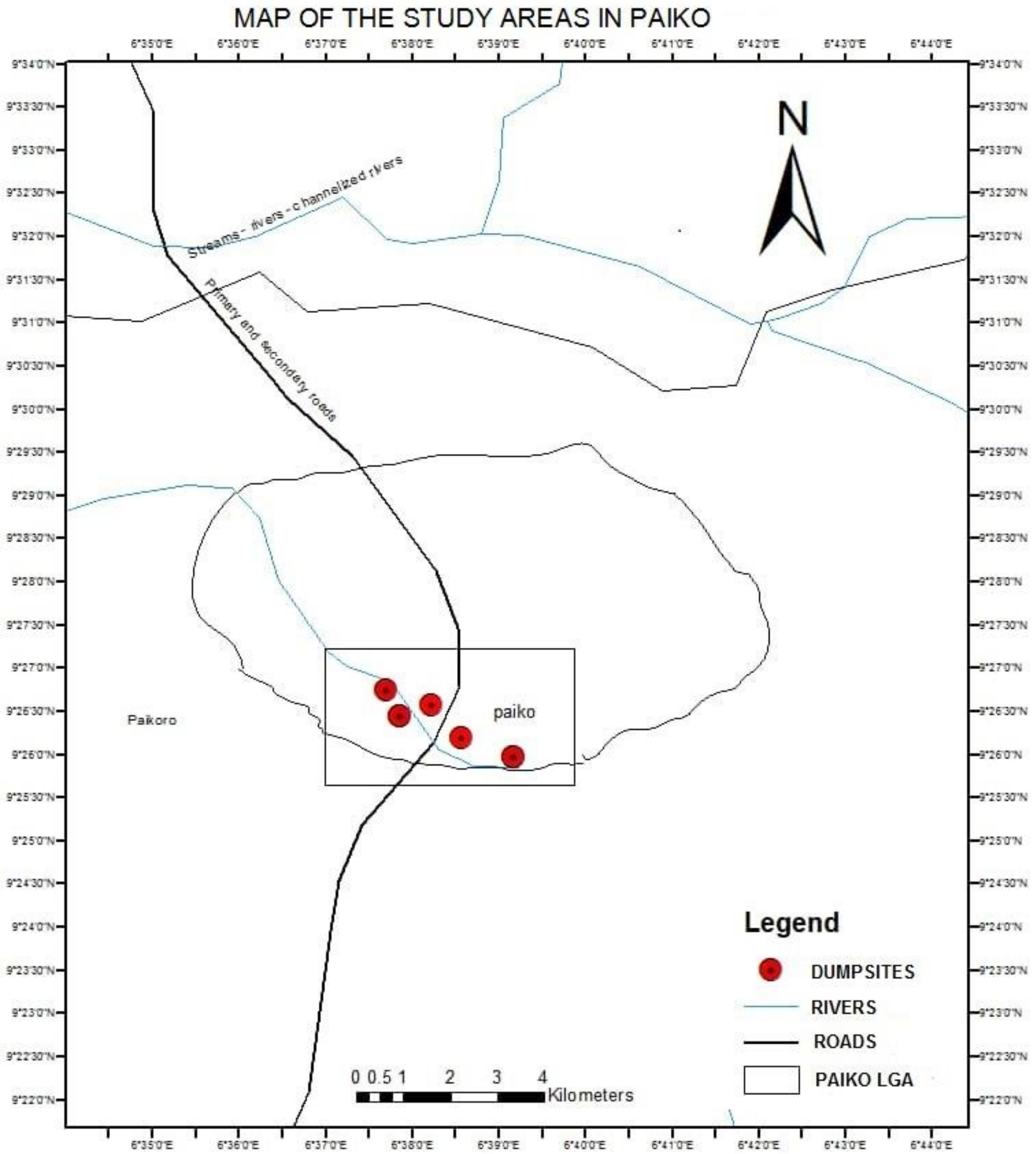

Figure 3. Map of the Paikoro Study Areas showing the VES points

Paikoro area lies within the Basement Complex Terrain of Nigeria. The Basement complex has been described by Adagunodo et al. (2017) as a heterogeneous assemblage, which includes migmatites, gneisses, schists and a series of basic to ultrabasic metamorphosed rocks. Pan African Granites and other minor intrusions such as pegmatite and aplites dykes and quartz veins have intruded these rocks. About 15% of the area in the southwestern part is covered by sedimentary rocks made up of sandstones while alluvial deposits of gravel, coarse and fine sand, silt and clay are found in the central part of the area (Adagunodo et al. (2017).

The structural elements in the area include joints, faults, foliations and minor folds. The dominant structural trend in the basement is essentially NE–SW and follows the tectonic grain of the schist belt. Subordinate directions, which are locally dominant, include E–W and NW–SE. Widespread fracturing occurs throughout the area and follows the orientation of the major faults.

2. Materials and Methods

The materials used for the field work were: G41 Geotron resistivity meter, Global positioning system (GPS) map60cx, Steel rods, Reel of calibrated cables, Hammer, electrodes, Survey tape, Cutlass and IPI2 Win Software

2.1. Theory of Resistivity Methods

The principles of electrical resistivity method of geophysical surveys are based on Ohm's law according to Barounis and Karadim (2017). In resistivity methods, artificial source of current is introduced into the ground through electrodes in order to measure potential difference at other electrodes in the neighborhood of the current flow. The resistivity ρ of material of cross sectional area A and length L is given by:

$$\rho = \frac{RA}{L} \tag{1}$$

where R is the electrical resistance, of a material which is related to its physical dimension, cross sectional area, A, and length L.

The electrical resistivity methods are based on the principles that the distribution of electrical potential in the ground around a current carrying electrode depends on the electrical resistivity and distribution of surrounding soils and rocks. This can be demonstrated on the field by applying direct current (DC) between two electrodes that are planted in the ground and also the potential difference between two additional electrodes that do not carry current. The current used is either Direct Current (DC) or Alternating Current (AC) with low frequency of about 20Hz (Kasprazak, 2015).

Since current travels in a semicircular path in the ground, the resistivity ρ is given by:

$$\rho = 2\pi r\left(\frac{V}{I}\right) \tag{2}$$

where r is the radius of the semicircle.

In the Schlumberger array, which was used for this work, the current electrodes are placed much further apart than the potential electrodes so that:

$$\rho_a = 2\pi \left| \frac{L^2 - a^2}{4a} \right| \frac{\Delta V}{I} \tag{3}$$

where a = half potential electrode spacing and L = half current electrode spacing
When L>>a, then equation (3) becomes:

$$\rho_a = \left| \frac{\pi L^2}{2a} \right| \frac{\Delta V}{I} \tag{4}$$

where $\frac{\pi L^2}{2a}$ is the array constant.

2.2. *Dar-Zarrouk Parameters and aquifer Protectivity*

Dar-Zarrouk (D-Z) parameters of conductance (S) and transverse resistance (T) play important roles in resistivity soundings. D-Z parameters are sufficient for computing the distribution of surface potential and hence an electrical resistivity graphs (Henriet 1976).

Suppose that a section consists of N fine layers with thickness h_1, h_2, ...,h_n and resistivity ρ_1, ρ_2, ρ_3,........,ρ_n for a block of unit square area and thickness then the conductance:

$$S = \sum_{i=1}^{N} \frac{h_i}{\rho_i} \tag{5}$$

and transverse resistance T, is given as:

$$T = \sum_{i=1}^{N} \rho_i h_i \tag{6}$$

The protectivity rating, according to Tsepav et al., (2021) indicates that if:

a) S > 0.7 mhos, the overburden has good protective capacity.
b) 0.69 < S < 0.2 mhos, the overburden has zones of moderate protective capacity.
c) 0.1 < S < 0.69 mhos, the overburden is classified as being of weak protective capacity
d) S < 0.1 mhos, the overburden indicates areas with poor protective capacity.
e) T > 400 Ωm^2, the overburden materials are poor and highly degraded.

2.3. *Data Collection and Interpretation*

A total of sixty (60) vertical electrical soundings (VES) points were occupied along fifteen (15) profile lines across the study areas, twenty (20) for each of the three (3) sampling areas within Lapai, Bida and Paiko using G41 Geotron resistivity meter employing the Schlumberger configuration. The equipment displayed the computed values of the resistivity using the geometric factors supplied to the meter. A global positioning system was used to ascertain the latitude, longitude and elevation at each of the vertical electrical sounding (VES) points.

Measurements were made by injecting current into the ground through two current electrodes A and B respectively, while the potential electrodes which were mounted between A and B measured the potential drop across the current electrodes. The current electrode spacing was expanded over a range of values for measurements in the field. To increase the depth of investigation, the current electrode separation was increased while the potential electrode remained constant, but over a time the potential electrodes was increased whenever loss of sensitivity was noticed due to the increase in current electrode separation.

The acquired field data was processed in form of inversion with IPI2Win Software to generate the curve sections and calculate the true resistivity distribution within the area. The VES sounding curves, upon iteration, generated the first order geoelectric parameters which were then used as inputs to compute the Dar- Zarrouk Parameters of Conductance and Transverse Resistance.

3. Results and Discussion

The measured apparent resistivity values were plotted against half electrode spacing on a logarithmic scale and interpreted quantitatively using the IPI2WIN software. This generated the first geoelectric parameters which include: subsurface stratification, layer thickness, depth to each layer as well as layer resistivities. This information is shown in Tables 1, 2 and 3 for Lapai, Bida and Paiko study areas respectively. The curve types obtained from the study areas were A, H, K, AH, AK, KH and HA.

Table 1. Sounding Geometric Parameters in Lapai Dumpsites

LOCATION	VES No.	Coordinates	Layers Thickness (m)			Depths (m)			Resistivity of Layers (Ωm)				Curve Type
			h_1	h_2	h_3	d_1	d_2	d_3	ρ_1	ρ_2	ρ_3	ρ_4	
Magaji-Badeggi Dumpsite	1	09^{0}02.794N, 006^{0}34.137E	0.3	0.1	0.1	0.3	0.4	0.5	42.0	57.2	181	1752	**HA**
	2	09^{0}02798N, 006^{0}34.140E	1.4	2.3	1.1	1.4	3.7	4.8	80.6	9.79	363	42397	**HA**
	3	09^{0}2.780N 006^{0}34.150E	0.2	0.9	2.9	0.2	1.1	4.0	38.5	29.5	23811	1.2E+5	**A**
	4	09^{0}2.782N 006^{0}34.108E	0.3	0.6	16.2	0.3	0.9	17.1	25.7	34.5	1692	1.3E+5	**H**
Engr. A A Kure Dumpsite	1	09^{0}02.160N, 006^{0}34.205E	0.2	0.4	2.2	0.2	0.6	2.8	162.0	112	295	10891	**H**
	2	09^{0}02.168N, 006^{0}34.225E	1.1	2.8	6.9	1.3	3.9	10.8	65.1	214	84.7	53130	**H**
	3	09^{0}2.140N 006^{0}34.241E	0.5	0.4	11.2	0.5	0.9	12.1	38.2	50.3	4763	1.9E+5	**HA**
	4	09^{0}2.159N 006^{0}34.213E	1.4	2.0	0.3	1.4	3.4	3.7	106.0	55.8	445	1.4E+5	**H**
Galadima Dumpsite	1	09^{0}02.410N, 006^{0}34.810E	0.4	0.7	1.9	0.4	1.0	3.0	1151.0	874	149	80738	**A**
	2	09^{0}02.536N, 006^{0}33.887E	0.2	0.8	1.6	0.2	1.0	2.6	603.0	31	6334	1.1E+5	**H**
	3	09^{0}2.533N 006^{0}33.878E	0.2	0.8	3.1	0.2	1.0	4.1	830.0	410	3904	2.3E+5	**A**
	4	09^{0}2.529N 006^{0}33.863E	0.2	0.6	0.1	0.2	0.8	4.3	1682.0	116	38.3	3.4E+5	**HA**
Market Dumpsite	1	09^{0}02.728N, 006^{0}34.471E	0.2	0.9	3.2	0.2	1.1	4.3	54.1	38.2	30982	1.4E+5	**H**
	2	09^{0}02.719N, 006^{0}34.426E	0.5	0.1	0.9	0.5	0.6	1.6	3403	414	41.4	53648	**A**
	3	090^{0}2.714N 006^{0}34.456E	0.3	1.3	1.4	0.3	1.7	3.1	4776	21.3	521	7315	**A**
	4	09^{0}2.724N 006^{0}34.462E	2.0	1.8	5.6	2.0	3.8	9.1	461	163	5571	4359	**A**
Malle Dumpsite	1	09^{0}02.434N, 006^{0}34.465E	0.5	0.8	2.7	0.5	1.2	4.0	5201	3450	71100`	770	**H**
	2	09^{0}02.442N, 006^{0}34.479E	0.4	1.2	0.6	0.4	1.7	2.3	768	225	2751	7535	**A**
	3	09^{0}02.456N 006^{0}34.476E	0.9	1.2	1.0	0.9	2.1	3.7	763	247	2150	446	**HK**
	4	09^{0}02.455N 006^{0}34.108E	2.6	8.9	2.2	2.6	11.3	13.5	1437	3968	25631	5785	**A**

Table 2. Sounding Geometric Parameters in Bida Dumpsites

LOCATION	VES No	Coordinates	Layers Thickness (m)			Depths (m)			Resistivity of Layers (Ωm)				Curve Type
			h_1	h_2	h_3	d_1	d_2	d_3	ρ_1	ρ_2	ρ_3	ρ_4	
Barije Dumpsite	1	9.0787305^{0}N, 6.0024078^{0}E	0.6	0.1	0.2	0.6	0.7	0.91	126	141	292	6.2E+5	**A**
	2	9.0746789^{0}N, 5.9983421^{0}E	0.2	0.7	0.3	0.4	0.9	1.1	71.2	79.0	157	2.9E+5	**A**
	3	9.074686^{0}N 5.998349^{0}E	1.1	0.9	1.2	1.1	2.2	3.3	270	571	351	6421	**AK**
	4	9.0781401^{0}N 6.0023033^{0}E	0.6	0.1	6.7	0.6	0.5	7.6	53.9	388	490	4.1E+5	**A**
Gbate Dumpsite	1	9.0792425^{0}N, 6.0074961^{0}E	0.9	3.1	0.3	0.9	4.0	4.3	37	115	43934	2.1E+5	**A**
	2	9.0740165^{0}N, 6.0088752^{0}E	0.5	0.4	50.8	0.54	0.95	51.8	105	144	3089	1.8E+5	**HA**
	3	9.0777953^{0}N 6.0092058^{0}E	0.21	0.22	0.51	0.21	0.43	0.93	11.25	32.6	47.8	7678	**A**
	4	9.0743695^{0}N 6.0085446^{0}E	0.21	0.48	0.33	0.21	0.68	1.02	250	35.2	52.8	2.1E+5	**HA**
Iyaruwa Dumpsite	1	9.0952846^{0}N, 6.0158419^{0}E	0.4	0.34	0.2	0.38	0.72	0.87	63.1	77	4.97	1.3E+6	**A**
	2	9.0930430^{0}N, 6.0129492^{0}E	1.0	0.15	23.8	1.02	1.17	25	84.7	151	2905	64145	**A**
	3	9.0888952^{0}N 6.0210925E	0.12	0.95	0.5	0.12	1.07	1.45	512	33	77.9	1521	**KH**
	4	9.0952917^{0}N 6.0158667^{0}E	1.57	2.4	4.1	1.57	4.33	8.43	42.2	7039	1405	31548	**A**
Ndajiya Mayaki Dumpsite	1	9.0747255^{0}N, 5.9982460^{0}E	3.1	0.1	0.3	3.11	3.16	4.41	13783	7412	1174	87151	**H**
	2	9.0792214^{0}N, 6.0101976E	0.12	0.72	2.3	0.12	0.84	3.13	292	223	81.9	47913	**HA**
	3	9.0789809^{0}N 6.0015617E	0.5	0.73	3.11	0.5	1.22	4.33	12.6	265	3819	3.4E+5	**A**
	4	9.0789817^{0}N 6.001560^{0}E	0.25	0.32	1.44	0.25	1.06	250	2410	59	7821	29324	**HA**
St. John Dumpsite	1	9.0889275^{0}N, 6.0210195^{0}E	0.15	0.42	0.32	0.15	0.48	0.87	99.2	100	123	2.1E+5	**A**
	2	9.0968514^{0}N, 6.0210195^{0}E	1.00	4.26	8.71	1.00	5.26	14	30.2	24471	1006	608	**AH**
	3	9.093794^{0}N 6.0055701^{0}E	0.2	0.7	0.4	0.2	1.0	1.3	75.5	80.7	115	9170	**HK**
	4	9.095457^{0}N 6.0022632^{0}E	1.1	1.3	2.1	1.1	2.2	4.3	141	3395	40633	75.3	**K**

Table 3. Sounding Geometric Parameters in Paiko Dumpsites

LOCATION	VES No.	Coordinates	Layers Thickness (m)			Depths (m)			Resistivity of Layers (Ωm)				Curve Type
			h_1	h_2	h_3	d_1	d_2	d_3	ρ_1	ρ_2	ρ_3	ρ_4	
Gidan Hakimi Dumpsite	1	9.4407974^{0}N 6.6309112^{0}E	0.8	0.3	1.0	0.8	1.1	2.1	445	578	8905	347	**K**
	2	9.447505^{0}N 6.6379242^{0}E	0.2	0.8	1.5	0.2	1.1	25	1723	442	7515	1.4E+5	**A**
	3	9.436937^{0}N 6.6342506^{0}E	0.2	0.7	9.5	0.2	0.9	10.4	80.7	37.4	53518	2.4E+5	**A**
	4	9.4349752^0 6.646608^{0}E	0.2	0.9	2.9	0.2	1.1	4.0	60.8	43.9	36835	1.7E+5	**A**
Gidan Marafa Dumpsite	1	9.4327954^{0}N 6.6529625^{0}E	0.6	1.3	2.0	0.6	1.9	3.9	267	438	234	962	**HA**
	2	9.4414973^{0}N 6.6315791^{0}E	0.2	0.3	2.0	0.2	0.5	2.3	21700	21577	34.8	32315	**H**
	3	9.4407911^{0}N 6.6631242^{0}E	0.3	0.4	0.7	0.3	0.7	2.2	5021	5015	88.1	41150	**H**
	4	9.4583249^{0}N 6.6352525^{0}E	0.2	0.4	10.2	0.2	0.3	10.4	18.1	52.1	110	6.6E+5	**H**
Kokorapi Dumpsite	1	9.4407974^{0}N 6.6309112^{0}E	0.7	0.2	30.8	0.7	0.9	31.7	263	320	30304	7026	**A**
	2	9.4449279^{0}N 6.6315791^{0}E	0.7	1.6	0.1	0.7	2.3	10.4	89.2	109	57690	2.6E+5	**A**
	3	9.4400755^{0}N 6.6325809^{0}E	0.4	0.6	24.4	0.4	1.0	25.0	54.8	259	1705	37559	**A**
	4	9.4397742^{0}6 6.6302434^{0}E	0.9	1.5	0.2	0.9	2.5	2.7	104	63	579	1.9E+5	**H**
Angwan Marafa Dumpsite	1	9.4458306^{0}N 6.628295^{0}E	0.2	0.8	3.3	0.2	1.1	4.3	603	25.1	105.7	2.1E+5	**HA**
	2	9.4407974^{0}N 6.6309112^{0}E	0.3	0.5	0.4	0.3	0.6	25.0	55.5	59.7	77.3	52042	**HA**
	3	9.4449279^{0}N 6.6315791^{0}E	0.3	0.2	0.4	0.1	0.4	0.9	297	61.2	77.3	6141	**K**
	4	9.4400755^{0}N 6.6325009^{0}E	0.2	0.5	0.3	0.2	0.6	25.0	81.3	66.1	95.6	11014	**K**
Wadata Dumpsite	1	9.4327954^{0}N 6.6529625^{0}E	0.5	0.7	14.3	0.5	1.2	15.5	237	241	9363	2.1E+5	**HA**
	2	9.432417^{0}N, 6.6542907^{0}E	0.2	0.1	6.0	0.2	0.3	6.12	34.9	49.6	144	9.8E+5	**HA**
	3	9.4327874^{0}N 6.6529545^{0}E	0.1	1.2	2.9	0.2	1.4	4.3	78.2	82.8	4526	4197	**A**
	4	9.433811^{0}N 6.6934136^{0}E	0.2	0.9	3.2	0.2	1.1	4.3	23.6	18.3	16219	72683	**H**

3.1. Discussion of Results

All the VES points in the study areas: Lapai, Bida and Paiko showed four layers of different curve types with geological sequence. The Lapai Dumpsites of Magaji-Baddegi, A.A Kure,Galadima, Market and Malle had four layers corresponding to topsoil, clay, clay sandstone and basement rocks. The VES points in Bida Dumpsites showed four layers corresponding to top lateritic soil, silty clay fractured/weathered basement and basement rocks while the geological sequence in Paiko revealed lithologies equivalent to topsoil, clay, laterite and basement rocks.

The first order geometric parameters of layer thickness and resistivities as shown in Tables 1,2 and 3 were used in equations 5 and 6 to calculate the Dar Zarrouk parameters of longitudinal conductance and Transverse Resistance. The result of these computations are shown in Tables 4, 5 and 6 for Lapai, Bida and Paiko areas respectively.

At the Magaji Dumpsite in Lapai, the Longitudinal conductance (S) had values ranging from 0.01 to 0.256 Siemens. These values fall within the category of weak to poor protective capacity according o the ratings of Tsepav et al., (2021). This result could mean that there is probability of leachate contamination of aquifer. The transverse resistance (R) and hence the transmisivity of the aquifer zone vary from 3.6 x 10^1 to 6.9 x 10^5 Ωm^2. Since these high transmisivities are greater than 400 Ωm^2 it suggest that the aquifer materials could be highly permeable to movement of fluid within the aquifer, which may possibly increase the migration and circulation of contaminants in the aquifer system. The control, VES 4 which was chosen 700 m away from the dumpsites for the purpose of comparison showed that the longitudinal conductance (S) was 1.039 Siemens which is greater than 1.0 Siemens, an indication of good protectivity. The high value of transverse resistance (R) which is 2.7 x 10^4 Ωm^2, however is indicative of the fact that the overburden materials could be of degraded content.

The Engr A A Kure and Galadima areas of Lapai present a similar scenario as the Longitudinal conductance (S) at the Engr. A A Kure Dumpsite had values ranging from 0.012 to 0.038 Siemens while that of Galadima had a range of values from 0.001 to 0.013 Siemens. Both indicate that the areas have poor protective capacities. The transverse resistance (R) of the areas varied respectively from 5.7 x 10^2 to 53.3 x 10^4 Ωm^2 and from 1.3 x 10^3 to 12.39 x 10^3 Ωm^2. Since these high transmisivities are greater than 400 Ωm^2 it suggest that the aquifer materials could be highly permeable to movement of fluid within the aquifer, which may possibly increase the migration and circulation of contaminants in the aquifer system. At the control site, the longitudinal conductance (S) was 1.173 Siemens for A A Kure and 1.021 Siemens for Galadima area, while the transverse resistance (R) values were 394 Ωm^2 and 397Ωm^2 respectively, indicating that the areas appear to be well protected on the account of having conductance values greater than 1.0 Siemens, and transverse values less than 400 Ωm^2.

Table 4. Dar Zarrouk Parameters for Lapai Dumpsites

LOCATION	VES Points	Coordinates	Long. Conductance (Siemens)				Transverse Resistance (ohm.m^2)			
			S_1	S_2	S_3	TLC	T_1	T_2	T_3	TTR
Magaji-Badegi Dumpsite	1	09^{0}02.794N, 06^{0}34.137E	0.007	0.002	0.001	**0.010**	12.6	5.7	18.1	**36.4**
	2	09^{0}02798N, 006^{0}34.140E	0.017	0.236	0.003	**0.256**	112.8	22.4	399.3	**534.5**
	3	09^{0}2.780N, 006^{0}34.150E	0.005	0.031	0.001	**0.037**	7.6	26.6	69051.9	**690553.2**
	4	09^{0}2.782N, 006^{0}34.108E	0.012	0.117	0.910	**1.039**	7.7	20.7	27410.0	**27438.4**
Engr. A A Kure Dumpsite	1	09^{0}02.160N,006^{0}34.205E	0.001	0.004	0.007	**0.012**	32.4	44.8	495.0	**572.2**
	2	09^{0}02.168N,006^{0}34.225E	0.017	0.013	0.008	**0.038**	71.6	599.2	5844.3	**6515.1**
	3	09^{0}2.140N006^{0}34.241E	0.013	0.008	0.002	**0.023**	19.1	20.1	533456.0	**533477.2**
	4	09^{0}2.159N006^{0}34.213E	0.013	0.36	0.800	**1.173**	148.4	111.6	133.5	**393.5**
Galadima Dumpsite	1	09^{0}02.410N,006^{0}34.810E	0.001	0.001	0.013	**0.015**	460.4	611.8	278.6	**1350.8**
	2	09^{0}02.536N,006^{0}33.887E	0.001	0.026	0.001	**0.028**	120.6	24.8	10134.4	**10279.8**
	3	09^{0}2.533N,006^{0}33.878E	0.012	0.002	0.001	**0.015**	166	328	12102.4	**12596.4**
	4	09^{0}2.529N,006^{0}33.863E	0.211	0.500	0.310	**1.021**	326.4	63.6	3.83	**396.83**
Market Dumpsite	1	09^{0}02.728N,006^{0}34.471E	0.004	0.024	0.001	**0.029**	10.8	34.4	99142.4	**99187.6**
	2	09^{0}02.719N,006^{0}34.426E	0.001	0.002	0.022	**0.025**	1751.5	41.4	37.3	**1830.2**
	3	090^{0}2.714N,006^{0}34.456E	0.001	0.061	0.003	**0.065**	1432.8	27.7	729.4	**2189.9**
	4	09^{0}2.724N,006^{0}34.462E	0.004	0.011	0.001	**0.016**	922	302.4	31197.6	**32422**
Malle Dumpsite	1	09^{0}02.434N,006^{0}34.465E	0.001	0.001	0.001	**0.003**	2600.5	2760	191970	**197330.5**
	2	09^{0}02.442N,006^{0}34.479E	0.005	0.005	0.002	**0.012**	307.2	270	1650.6	**2227.8**
	3	09^{0}02.456N,006^{0}34.476E	0.001	0.005	0.004	**0.010**	686.7	296.4	2150	**3133.1**
	4	09^{0}02.455N,006^{0}34.108E	0.002	0.001	0.001	**0.004**	35315	56388.2	56388.2	**148091.4**

Table 5. Dar Zarrouk Parameters for Bida Dumpsites

LOCATION	VES Points	Coordinates	Long. Conductance (Siemens)				Transverse Resistance (ohm.m^2)			
			S_1	S_2	S_3	TLC	T_1	T_2	T_3	TTR
Barije Dumpsite	1	9.0787305^{0}N, 6.0024078^{0}E	0.005	0.001	0.001	**0.007**	75.6	14.1	58.4	**148.1**
	2	9.0746789^{0}N, 5.9983421^{0}E	0.003	0.009	0.001	**0.013**	14.2	553	31.4	**598.6**
	3	9.074686^{0}N, 5.998349^{0}E	0.004	0.002	0.003	**0.009**	297	628.1	421.2	**1346.3**
	4	9.0781401^{0}N, 6.0023033^{0}E	0.011	0.001	0.014	**0.026**	32.3	38.8	3430	**3501.1**
Gbate Dumpsite	1	9.0792425^{0}N, 6.0074961^{0}E	0.024	0.022	0.001	**0.047**	33.3	446.4	4396.4	**4876.1**
	2	9.0740165^{0}N, 6.0088752^{0}E	0.040	0.003	0.017	**0.060**	5.3	57.6	15621.2	**15684.1**
	3	9.0777953^{0}N, 6.0092058^{0}E	0.001	0.006	0.010	**0.017**	225	69.5	238.9	**533.4**
	4	9.0743695^{0}N, 6.0085446^{0}E	0.710	0.300	0.006	**1.016**	50	14.1	15.66	**79.79**
Iyaruwa Dumpsite	1	9.0952846^{0}N, 6.0158419^{0}E	0.006	0.004	0.001	**0.10**	25.2	23.1	99.4	**147.7**
	2	9.0930430^{0}N, 6.0129492^{0}E	0.011	0.001	0.008	**0.020**	84.7	15.1	69139	**69238.8**
	3	9.0888952^{0}N, 6.0210925E	0.001	0.029	0.005	**0.035**	51.2	31.4	31.0	**113.6**
	4	9.0952917^{0}N, 6.0158667^{0}E	0.038	0.002	0.003	**0.043**	67.52	16893.6	5760.5	**22721.62**
Mayaki Ndajiya Dumpsite	1	9.0747255^{0}N, 5.9982460^{0}E	0.001	0.001	0.001	**0.003**	42727.3	7412	352.2	**8191.5**
	2	9.0792214^{0}N, 6.0101976E	0.001	0.003	0.028	**0.032**	29.2	156.1	188.4	**373.7**
	3	9.0789809^{0}N, 6.0015617E	0.063	0.002	0.001	**0.066**	10.1	1855	11838.9	**13704**
	4	9.0789817^{0}N, 6.001560^{0}E	0.001	0.014	0.001	**0.016**	723	47.2	10949.4	**11719.6**
St. John Dumpsite	1	9.0889275^{0}N, 6.0210195^{0}E	0.002	0.004	0.002	**0.008**	19.2	40	36.9	**96.1**
	2	9.0968514^{0}N, 6.0210195^{0}E	0.033	0.001	0.009	**0.043**	30.2	100331.1	8752.2	**109113.5**
	3	9.093794^{0}N, 6.0055701^{0}E	0.003	0.009	0.003	**0.015**	15.1	56.5	46	**117.6**
	4	9.095457^{0}N, 6.0022632^{0}E	0.008	0.001	0.001	**0.010**	155.1	3734.5	85329.3	**89218.9**

Table 6. Dar Zarrouk Parameters for Paiko Dumpsites

LOCATION	VES Points	Coordinates	Long. Conductance (Siemens)				Transverse Resistance (ohm.m^2)			
			S_1	S_2	S_3	TLC	T_1	T_2	T_3	TTR
Gidan Hakimi Dumpsite	1	9.4407974^{0}N,6.6309112^{0}E	0.002	0.001	0.012	**0.015**	356	173.4	8905.0	**9435.4**
	2	9.447505^{0}N, 6.6379242^{0}E	0.011	0.018	0.020	**0.049**	344.6	35.4	11272.5	**11652.5**
	3	9.436937^{0}N, 6.6342506^{0}E	0.002	0.019	0.017	**0.031**	16.4	26.2	508421.0	**508463.6**
	4	9.4349752^{0}N, 6.646608^{0}E	0.003	0.810	0.700	**1.513**	12.2	39.5	106821.5	**106873.2**
Gidan Marafa Dumpsite	1	9.4327954^{0}N,6.6529625^{0}E	0.002	0.003	0.009	**0.014**	14520.6	569.4	468.0	**15558**
	2	9.4414973^{0}N, .6315791^{0}E	0.001	0.002	0.060	**0.063**	4340	6473.1	69.6	**10882.7**
	3	9.4407911^{0}N, .6631242^{0}E	0.001	0.002	0.008	**0.011**	1506.3	2006	61.8	**3574.1**
	4	9.4583249^{0}N, .6352525^{0}E	0.011	0.008	0.092	**0.111**	3.62	20.8	1122.0	**1146.42**
Kokorapi Dumpsite	1	9.4407974^{0}N, .6309112^{0}E	0.003	0.006	0.001	**0.010**	184.1	64	9363.2	**9611.3**
	2	9.4449279^{0}N, .6315791^{0}E	0.007	0.015	0.008	**0.030**	624.4	174.4	467289	**468087.8**
	3	9.4400755^{0}N, .6325809^{0}E	0.007	0.002	0.014	**0.023**	21.9	155.4	40920.0	**41097.3**
	4	9.4397742^{0}N, .6302434^{0}E	0.100	0.930	0.003	**1.033**	93.6	93.5	114.6.0	**301.7**
Angwan Marafa Dumpsite	1	9.4458306^{0}N, 6.628295^{0}E	0.003	0.032	0.003	**0.038**	120.6	20.1	34881.0	**35021.7**
	2	9.4407974^{0}N, .6309112^{0}E	0.005	0.008	0.004	**0.017**	16.7	29.9	23.2	**69.8**
	3	9.4449279^{0}N, .6315791^{0}E	0.001	0.003	0.005	**0.009**	29.7	12.2	30.9	**72.8**
	4	9.4400755^{0}N, .6325009^{0}E	0.002	0.700	0.300	**1.002**	16.3	33.1	28.7	**78.1**
Wadata Dumpsite	1	9.4327954^{0}N,6.6529625^{0}E	0.002	0.003	0.002	**0.007**	118.5	168.7	133890.9	**134178.1**
	2	9.432417^{0}N, 6.6542907^{0}E	0.006	0.002	0.042	**0.050**	6.98	4.96	864.0	**970.38**
	3	9.4327874^{0}N, .6529545^{0}E	0.003	0.014	0.001	**0.018**	15.6	99.4	13125.4	**13240.4**
	4	9.433811^{0}N, 6.6934136^{0}E	0.008	0.049	0.001	**0.058**	4.7	16.5	51900.8	**51922**

The Longitudinal conductance (S) values for Lapai market and Malle dumpsites ranged from 0.025 to 0.065 Siemens and 0.003 to 0.010 Siemens respectively. These values put the overburden protection capacity at a very poor rating according to Tsepav et al., (2021) indicating that there is a high probability of leachate contamination of aquifers in the areas. The transverse resistance (R) in the areas vary from 2.1 x 10^3 to 99.1 x 10^3 Ωm^2 in the Market Dumpsite to 2.2 x 10^3 to 19.7 x 10^4 Ωm^2 in Malle Dumpsites. Since these high transmisivities are greater than 400 Ωm^2 there is possibility that the aquifer materials could be highly permeable to movement of fluid within the aquifer, which may possibly increase the migration and circulation of contaminants in the aquifer system. The control VES points had longitudinal conductance (S) values of 0.016 and 0.004 Siemens for the Market and Malle Dumpsites respectively. The transverse resistance (R) values are respectively 3.2 x 10^4 Ωm^2 and 14.8 x 10^4 Ωm which are > 400 Ωm^2. These results indicate that the areas are prone to contamination leading to high permittivity of aquifer materials which could allow easy movement of fluid within the aquifer and increase the migration and circulation of leachate contaminants in the aquifer system.

All the Dumpsites in Bida portrayed similar trends of protectivity, as they all showed very poor protection capacity, occasioned by very low conductance values and high resistance values. Bida- Barije Dumpsite had Longitudinal conductance (S) values ranging from 0.007 to 0.013 Siemens and transverse resistance (R) from 1.4 x 10^2 to 13.4 x 10^2 Ωm^2. The Gbate Dumpsite had Longitudinal conductance (S) values ranging from 0.017 to 0.060 Siemens and transverse resistance (R) values ranging from 5.3 x 10^2 to 15.6 x 10^3 Ωm^2. Iyaruwa Dumpsite and Mayaki Ndajiya Dumpsite had longitudinal conductance (S) values ranging from 0.010 to 0.035 Siemens and 0.003 to 0.066 Siemens respectively. The transverse resistance (R) and hence the transmisivity of the aquifer zones varied respectively from 1.4 x 10^2 to 69.3 x 10^3 Ωm^2 and 3.7 x 10^2 to 13.704 x 10^3 Ωm^2. In a similar manner, the St John Dumpsite had Longitudinal conductance (S) values ranging from 0.008 to 0.043 Siemens and transverse resistance (R) values from 9.6 x 10^1 to 109.1 x 10^3 Ωm^2. These results suggest that the aquifers are poorly protected and could be highly permeable to movement of fluid and contaminants.

At the control site however, the longitudinal conductance (S) for Barije, Gbate, Iyaruwa, Maiyaki and St. Johns areas were 0.014 Siemens, 1.016 Siemens, 0.043 Siemens, 0.016 Siemens and 0.010 Siemens respectively, while the respective transverse resistance (R) values were 3.5 x 10^3 Ωm^2, 9.7 x 10^1 Ωm^2, 22.7 x 10^3 Ωm^2, 11.7 x 10^3 Ωm^2 and 892 x 10^2 Ωm^2. These results indicate that apart from the Gbate control which shows the likelihood of having a good protective capacity with a low conductance value of 1.016 Siemens and low transverse resistance (R) value of 97 Ωm^2, the rest had very poor aquifer protective capacity with conductance values far less than 1.0 Siemens and transverse resistance (R) values all greater than 400 Ωm^2, an indication that the aquifer materials could be highly permeable to movement of fluid within the aquifer, which may possibly increase the migration and circulation of contaminants in the aquifer system.

The Dumpsites in Paiko also showed very poor protectivity as the range of values for the conductance were far less than 1.0 Siemens and fell within the poor rating category. For the Gidan Hakimi Dumpsite the Longitudinal conductance (S) had the values ranging from 0.015 to 0.049 Siemens, Gidan Marafa had values ranging from 0.011 to 0.063 Siemens, the values in Angwan Marafa varied from 0.017 to 0.038 Siemens, while Kokorapi and Wadata Dumpsites had values ranging from 0.010 to 0.030 and from 0.007 to 0.050 Siemens respectively. These values were less than 1.0 Siemens and fall within the very poor protectivity rating according to Tsepav et al., (2021). The transverse resistance (R) values also corroborated the assertion of poor protectivity as most of the values were greater than 400 Ωm^2. The transverse resistance (R) varied from 9.4 x 10^3 to 50.8 x 10^4 Ωm^2 in Gidan Hakimi, 15.5 x 10^3 to 108 x 10^3 Ωm^2 in Gidan Marafa, 7.2 x 10^1 to 35.0 x 10^3 Ωm^2 in Angwan Marafa, 9.6 x 10^3 to 46.8 x 10^4 Ωm^2 in Kokorapi and 9.7 x 10^2 to 134.1 x 10^2 Ωm^2 for Wadata Dumpsites.

Three of the control sites generally showed high protectivity as evidenced in the Longitudinal conductance (S) values. Gidan Hakimi had 1.513 Siemens, Angwan Marafa had 1.002 Siemens, Kokoropi had 1.033 Siemens which were both greater 1.0 Siemens, an indication of high protectivity. While Gidan Marafa with 0.111 Siemens could be rated as being weakly protected, Wadata control with 0.056 Siemens could be rated as being poorly protected. The transverse resistance (R) values at the control sites were 106 x 10^3 Ωm^2 at Gidan Akimi, 114.6 x 10^3 Ωm^2 at Gidan Marafa, 7.8 x 10^1 Ωm^2 at Angwan Marafa, 30.1 x 10^1 Ωm^2 at Kokorapi and 51.9 x 10^3 Ωm^2 at Wadata. These results indicate that while the areas around Gidan Marafa and Angwan Marafa were less prone to contamination, on account of having the values of Transverse Resistance less than 400 Ωm^2, Gidan Hakimi, Kororapi and Wadata with values of Transverse Ressistance greater than 400 Ωm^2 implied that the areas are highly prone to migration of contaminants to underground water sources.

4. Conclusion

Electrical resistivity method of geophysical prospecting employing the Schlumberger array method was used to obtain the various stratifications of the subsoil, layer thicknesses and depths as well as layer resistivities. This information was used to compute the Dar Zarrouk parameters which are the indicators of aquifer protectivity. The analysis of the results indicated that the aquifers were prone to contamination as the protective capacity of the overburden rock material in most of the VES points were very low with values less than 1.0 Siemens. This means that there is possibility of leachate from the solid waste dumpsites infiltrating the aquifers and contaminating the groundwater resources. The low ranges of resistivity values over the aquifers were observed at Lapai, Bida and Paiko dumpsites which could be attributed to leachates contamination from the dumpsites. The presence of the contaminants in the groundwater was identified by a decrease in the resistivity values and also low protective capacity of the aquifer. It is evident, from the results of the geophysical survey that the water in the study areas might be polluted and it might cause water related diseases common in the area.

Recommendations

The following recommendations are proferred:

i. Deeper drilling and proper casing of boreholes is encouraged.
ii. Government should enforce environmental protection laws that will prohibit indiscriminate disposal of solid waste material from domestic and industrial effluents.
iii. Adequate geophysical investigation should be carried out to understand the nature of the aquifer in areas where boreholes are to be sited for drinking water.
iv. The consumption of water from hand dug wells and shallow boreholes should be discouraged.
v. Sensitization workshops and public awareness Programmes on dangers of consumption of contaminated water should be carried out.

Conflict of Interest

The authors declare no conflict of interest

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