

Full Length Research Paper

Geoelectrical mapping of the groundwater regime around the Federal Polytechnic Ado-Ekiti, South Western Nigeria

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This paper presents the use of electrical resistivity survey technique in mapping the bedrock relief, and detection of the near surface groundwater regime around the new administrative block of the Federal Polytechnic, Ado-Ekiti, Ekiti State. Twelve vertical electrical soundings using the Schlumberger configuration were acquired. Also, groundwater samples were obtained at selected locations and subjected to both the chemical and microbial analyses accordingly. The resistivity dataset were processed using computer interaction interpretation of the sounding curves. A maximum of four subsurface geologic units were delineated from the VES-curves. These subsurface geoelectric layers correspond to loose sandy/clayey topsoil, sandy/gravel layer, clayey weathered basement forming the shallow unconfined aquifer in the area, and the underlying fresh bedrock of charnokite and migmatite gneiss. The resistivity values for each layer range from 29 to 514 Ω m (layer one), 87 to 115 Ω m (layer two), 10 to 45 Ω m (layer three), and 187 to 27863 Ω m (layer three) respectively for the these layers. The thickness of the regolith materials vary between 3.4 and 13.9 m. Also, the geophysical survey revealed bedrock depressions and low resistivity values of the weathered basement which may suggest possible groundwater contamination and/or accumulation likely associated with loose sandy topsoil, shallow water table and/or recharge from surface runoff into the subsurface aquifers. The water analysis of the water sample from the hand dug well depict the presence of high level of Coliforms (160 Coliforms per 10^2 ml) in the subsurface water, which points to the presence of high concentration of nitrogen compounds and pollution of animal origin, clearly indicates that the zone of water saturation is directly in contact with the surface runoff. Further, the total dissolved solids (TDS) is 684.83 mg/L. Generally, the chemical constituents of some of the major and minor elements fall considerably below the World Health Organization (WHO, 1963) permissible levels.

Key words: Geoelectric mapping, microbial analysis, coliform, total dissolved solids.

INTRODUCTION

Electrical resistivity surveys are sensitive to groundwater quality and water content in porous formations. As a result, it has often been used to map areas of groundwater pollution or soil contamination. Increase in total dissolved solids (TDS) leads to lower resistivity in various types of aquifers (Olasehinde et al., 1998; Oyegun and Ibikunle, 1998; Telford et al., 1976; Benson

et al., 1997). In this study an electrical resistivity survey and hydrochemical analyses were carried out to evaluate groundwater resources around the new administrative block of the Federal Polytechnic, Ado-Ekiti. Groundwater abstraction in the area has been restricted to a shallow unconfined aquifer, which comprises unconsolidated porous material. Overburden materials, which are made up of loose sand and clayey deposits directly overlies the aquifer unit characterized by weathered/loose sand. This makes the aquifers unit liable to continuous recharge from surface water runoff. Evidence of this is a hand-dug well dugged in the vicinity of the surveyed are that has

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been abandoned due to the poor quality of the groundwater.

The thrust of the paper is to apply the electrical resistivity survey technique and water analysis to provide information on the geoelectric parameters (depth and resistivity) and physiochemical properties of the fluid content of the aquifer in the subsurface of the investigated area.

Geological setting

Geographically, the study area is situated within the Ado-Ekiti Local Government Area of Ekiti State, bounded by Longitude 7° 40' E and 7° 35' E, and Latitudes 5° 10' N and 5° 15' N (Figure 1). Geomorphologically, it lies within a gently undulating surface. The regional geology of Ado-Ekiti where the study area is situated reveals rock of various units of the geological succession ranging in age from the precambrian to the quaternary.

The Precambrian rocks form part of the Western Nigerian Basement Complex predominantly composed of migmatite gneiss complex, slightly migmatized to unmigmatized paraschist and metaigneous rocks, Charnockitic rocks, older Granites, and unmetamorphosed dolerite dykes (Rahaman, 1998; Kuye 1996; Cooray, 1970; Oyawoye, 1970). The main lithological units in the study area are Quartzite, Gneiss and dark colored Charnockite. Although these rocks are concealed in most parts of the study area, few isolated outcrops exist around the school premises.

METHODOLOGY

Geophysical survey

Twelve (12) vertical electrical soundings survey was conducted using an ABEM-SAS 300C Terrameter. A schlumberger array was employed with electrode separations (AB/2) ranging from 1 to 120 m. The resistivity data collected were presented as sounding curves at given electrode spacing and contoured apparent resistivity data and qualitatively and interquantitative interpretations of the resistivity sounding curves obtained were by manual interpretation and partial curve matching technique and further refined by computer iteration procedure based on Marquadt type algorithm to identify the type curve and corresponding number of layers and resistivity of the layers (Verma and Pantula, 1990). Also, the quantitative determination of the depth to bedrock from inspection of the curve types involved the use of partial curve matching technique.

Water chemistry

Two water samples of 500 ml were collected in conical flasks from the only hand dug well in the area for chemical and microbial analyses, in order to determine the quality and characteristics of the groundwater from the well. These water samples were immediately transported to Chemistry and Microbiology Laboratories of the Federal University of Technology, Akure for both chemical and microbial analyses.

The chemical analyses were conducted using standard laboratory techniques involving wet analysis to determine both anion and cation concentrations. Parameters determined included hydrogen ion concentration (pH), specific conductance of the water, hardness, total dissolved solids (TDS), secondary and minor elements such as Iron (Fe), Zinc (Zn), and Nickel (Ni). Others are alkali-ions: potassium (K) and sodium (Na), the alkaline earth metals: calcium (Ca) and manganese (Mn), sulfate (SO_4^{2-}), chloride (Cl⁻) and nitrate (NO_3^-) constituents.

Panno et al. (1994) have interpreted groundwater of mixed cation- carbonate with low levels of total dissolved solids and concentration of chloride with fairly low sulphate to indicate rapid recharge taking place primarily from the surface.

Bacterial were isolated from the water sample using plate technique. Standard methods of microbial loads determination have been well documented by several authors (Fawole and Oso, 2001; Todd, 1980; Sawyer and McCarty, 1967). The microbial test conducted involves standard laboratory determination of the plate count of the aerobic mesophilic heterotrophic viable bacteria and most probable number of coliforms (MPN) per 10^2 ml of the water samples.

RESULTS AND DISCUSSION

Geoelectric study of the area

Curve types and geoelectric sections

In the study area, KH - curve is the predominant curve type that prevail (Table 1). This curve types categorically depict a four-layer subsurface geoelectric lithologic profile (Figure 2). The geoelectric parameters of the subsurface substratum provide information on the nature of superficial deposits overlying the bedrock, and the qualitative prediction of the fluid content in the aquifer unit. Table 2 The geoelectric units start with topsoil that exhibits resistivities values that range between 35 and 514 Ωm . The changes in resistivity correspond to grading from clayey to sandy to lateritic material (second layer). The thickness of this unit varies between 0.4 and 1.4 m. The intermediate layer is characterized by resistivity values between 89 and 520 Ωm diagnostic of sandy clay to gravelly sand or lateritic soil. Its thickness ranges from 0.2 to 1.0 m was obtained for this layer. The third unit corresponds to highly saturated clayey sand to sandy aquifer having resistivity values varying from 10 to 45 Ωm , suggesting possible high content of dissolved chemical constituents within the aquifer. The fourth layer has resistivity values that range between 186 and 27853 Ωm . The lower end of the range is diagnostic of highly decomposed weathered or fractured bedrock, while upper end of the range is characteristic of crystalline fresh bedrock. Generally in the area, thickness of the weathered layer is greater than 7 m.

Isoresistivity maps and bedrock topography

Figure 3 shows the spatial distribution of the apparent resistivity at half-electrode spacings (AB/2) of 1, 10, 40,



Figure 1. Geological map of the southwestern basement complex and location map of the study area. (a) Simplified geological map of Southwestern Nigeria showing the location of Ado-Ekiti. (b) Site location map of the New Administration area of the Federal Polytechnic, Ado-Ekiti.

60, 90 and 120 m. In addition, a bedrock topography map (Figure 4) of the underlying bedrock was made from the inferred geoelectric parameters and the observed surface topography of the area.

A general NW-SE variation in apparent resistivity at

shallow depth (corresponding to electrode separation of $AB/2 = 1$ m), with high a local high (above 500 Ω m) around VES 5 depicting a sandy topsoil is noted. This confirms the clayey to clayey sand topsoil in the area. There are pockets of clayey soil at several locations

Table 1. Estimated geoelectric parameters from the observed resistivity data.

VES station	Curve types	Layer no.	ρ_a (Ωm)	h (m)	Depth (m)	Lithological characteristics
1.	KH	1	110	0.7	0.7	Clayey top soil
		2	154	0.8	1.5	Clayey sandy
		3	34	12.4	13.9	Weathered/ highly decomposed layers
		4	333	--	--	Fractured/ fresh basement
2.	KH	1	174	0.6	0.6	Sandy top soil
		2	244	1.0	1.6	Sand
		3	45	14.2	15.8	Weathered/ highly decompose layer
		4	952	--	--	Fractured/ weathered basement
3.	KH	1	55	0.6	0.6	Clayey top soil
		2	109	0.4	1.0	Clay
		3	21	8.6	9.6	Weathered/ highly decomposed layer
		4	333	--	--	Fractured/ weathered basement
4.	KH	1	52	0.8	0.8	Clayey top soil
		2	408	0.5	1.3	Sand
		3	10	2.1	3.4	Weathered/ highly decomposed layer
		4	186	--	--	Fractured/ weathered basement
5.	KH	1	514	0.6	0.6	Sandy top soil
		2	1115	0.5	1.1	Laterite
		3	25	9.8	10.9	Weathered/ highly decomposed layer
		4	530			Fractured/ weathered basement
6.	KH	1	164	0.4	0.4	Clayey top soil
		2	281	0.3	0.7	Sand
		3	10	7.2	7.9	Weathered/ highly decomposed layer
		4	750	--	--	Fractured/ weathered basement
7.	KH	1	35	0.6	0.6	Clayey top soil
		2	142	0.2	0.8	Clayey sand
		3	16	5.4	6.2	Weathered/ highly decomposed layer
		4	1089	--	--	Fractured/ weathered basement
8.	KH	1	29	0.6	0.6	Clayey Top Soil
		2	89	0.3	0.9	Clay
		3	17	9.5	10.4	Weathered/ highly decomposed layer
		4	27863			Fractured/ weathered basement
9.	KH	1	67	0.5	0.5	Clayey top soil
		2	233	0.5	1.0	Sand
		3	17	8.5	9.5	Weathered/ highly decomposed layer
		4	1383	--	--	Fractured/ weathered basement
10.	KH	1	202	0.6	0.6	Sandy top soil
		2	520	0.3	0.9	Sand/ laterite
		3	14	7.8	8.7	Weathered/ highly decomposed layer
		4	745	--	--	Fractured/ weathered basement
11.	KH	1	362	0.5	0.5	Sandy top soil
		2	469	0.5	1.0	Sand/ laterite
		3	17	10.4	11.4	Weathered/ highly decomposed layer
		4	1010	--	--	Fractured/ weathered basement
12.	KH	1	83	1.4	1.4	Clayey top soil
		2	108	0.6	2.0	Clay
		3	15	10.2	11.2	Weathered/ highly decomposed layer
		4	488	--	--	Fractured/ weathered basement

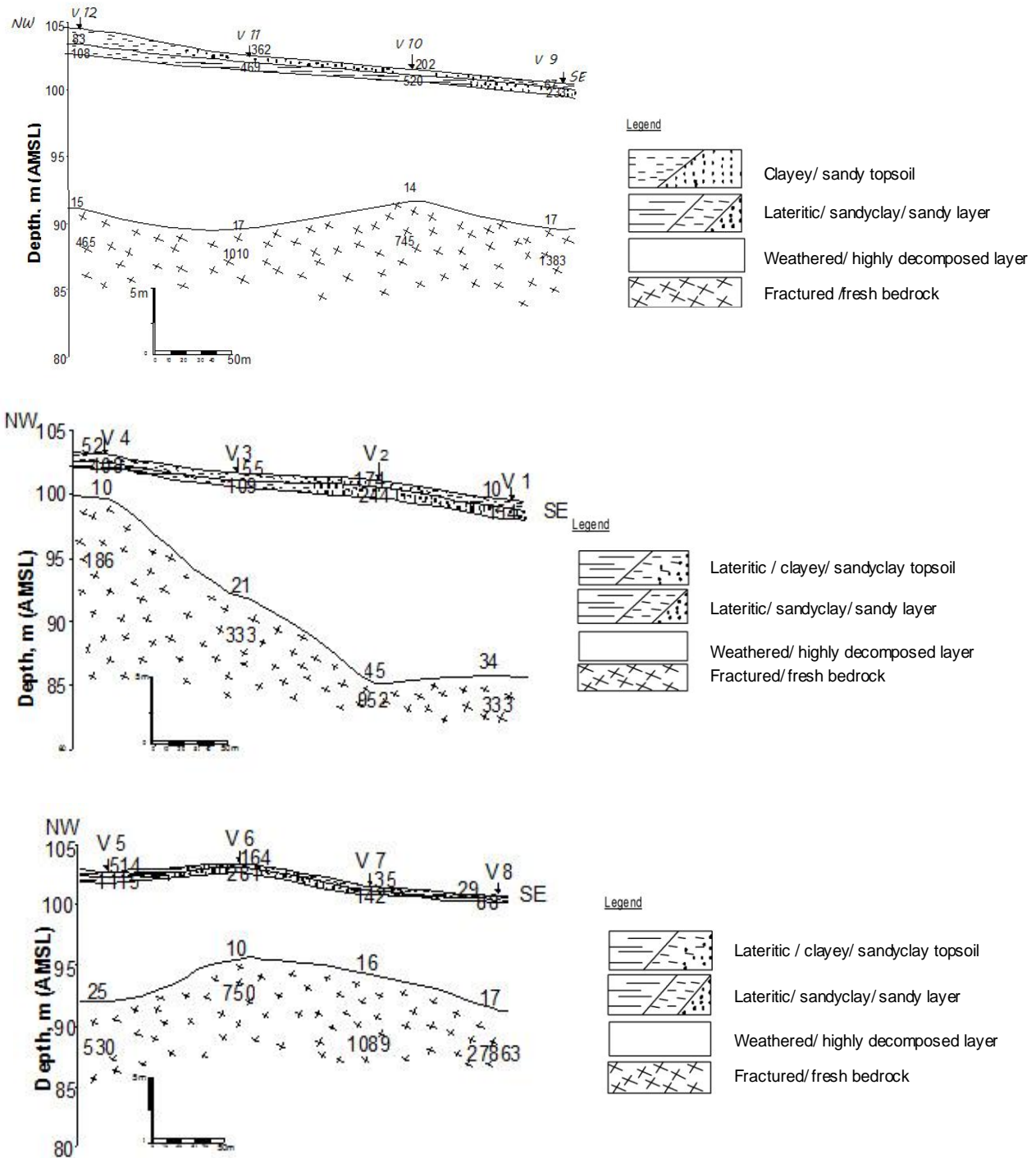


Figure 2. Typical geoelectric profiles across the study area.

within the study area, specifically along the depressed region towards the southwestern part of the area. It is observed that the resistivity value of the topsoil material ranges between 31 and 514 Ωm .

At intermediately levels ($AB/2 = 10, 40$ and 60 m), there is a general low resistivity value that correspond a possible shallow aquifer, and/or indication of dirtiness

of the clayey sand or high concentration in chemical constituents of the unit. The apparent layer resistivity for the intermediate horizon range from 29 to 176 Ωm .

At greater electrode separation ($AB/2 = 90$ and 120 m), relatively high resistivity values between 103 and 321 Ωm are observed at these horizons. However, at greater electrode separation ($AB/2 = 120$ m) there are localized

Table 2. Geoelectric Parameters and inferred lithologic profile from the VES Curves

Layer		Lithologic characteristics
Topsoil		
Range of thickness (m)	0.4-1.4	Clayey to gravelly sand to lateritic soil.
Range of layer resistivity (Ωm)	35-514	
Intermediate		
Range of thickness (m)	0.2-1.0	Sandy clay to gravelly sand to laterite.
Range of layer resistivity (Ωm)	89-520	
Weathered basement		
Range of thickness (m)	2.1-14.2	Highly saturated clayey sand to sandy aquifer.
Range of layer resistivity (Ωm)	10-45	
Bedrock		
Range of bedrock resistivity (Ωm)	186-27863	Highly decomposed/ weathered to fractured bedrock to crystalline bedrock.
Range of overburden thickness (m)	3.4-15.8	

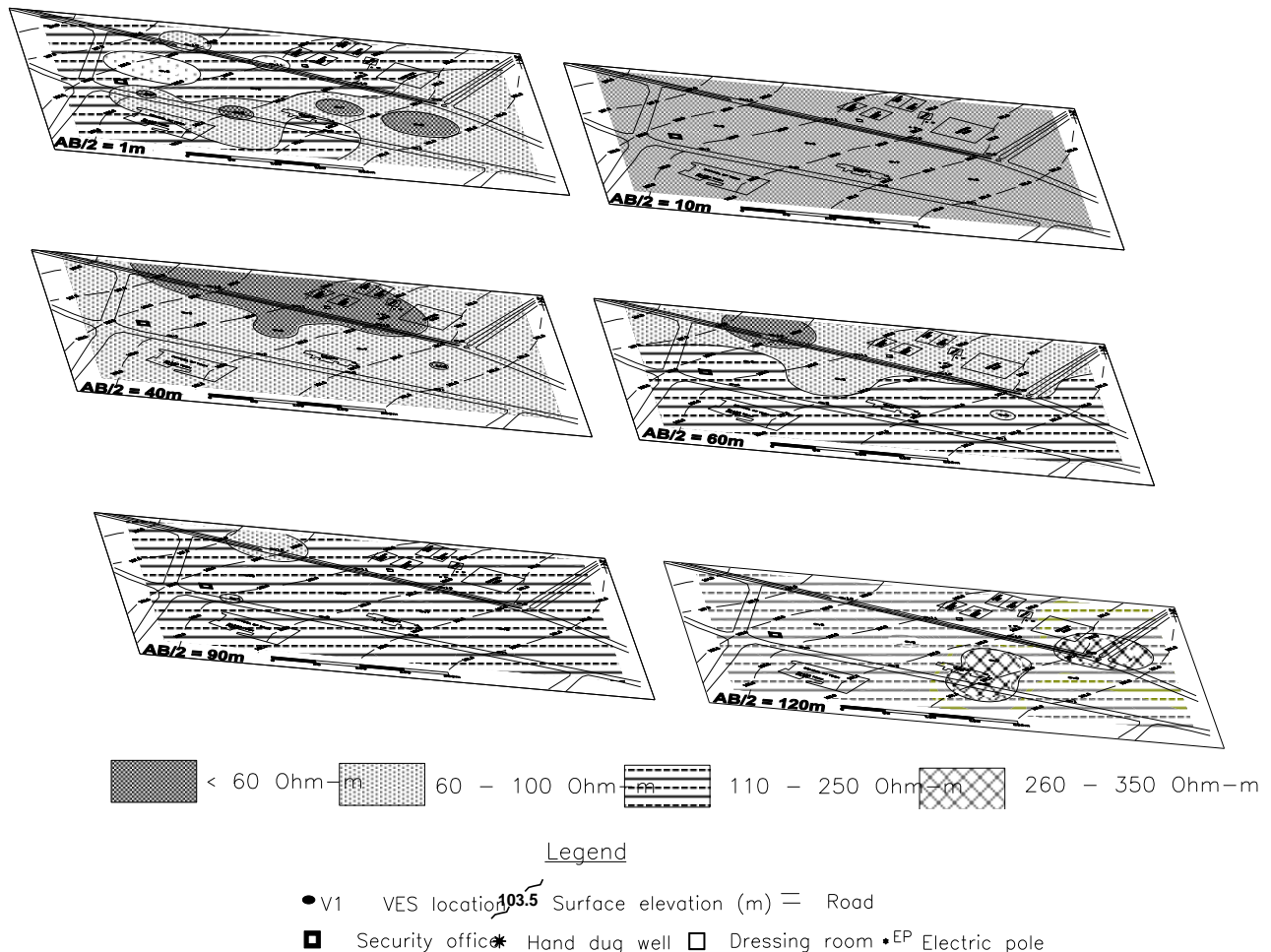


Figure 3. Spatial variation of apparent resistivity at half-electrode spacing, AB/2 = 1, 10, 40, 60, 90 and 120 m.

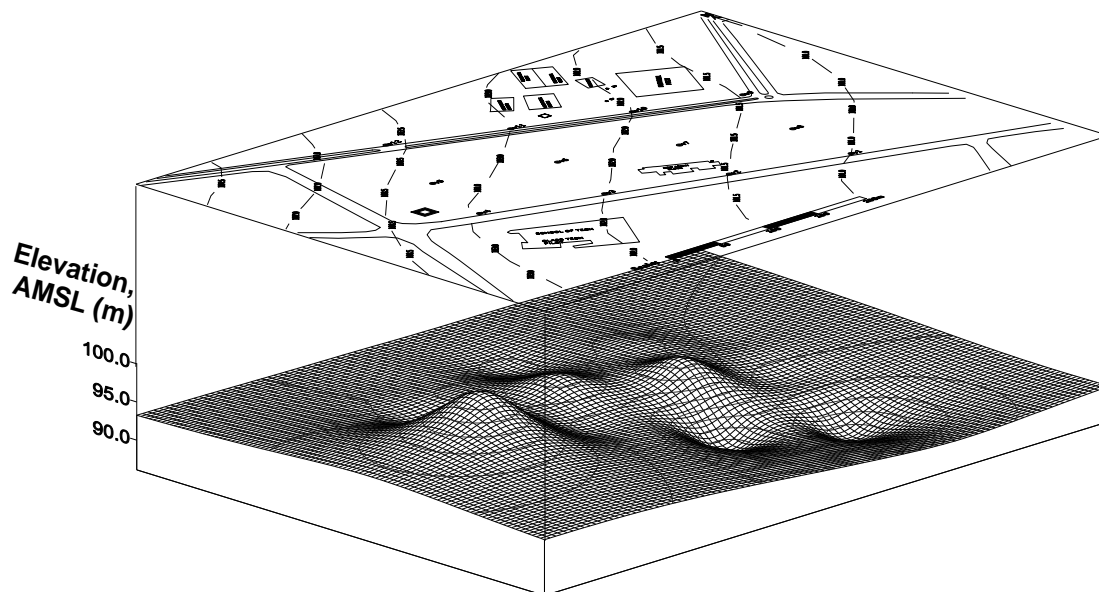


Figure 4. Bedrock relief (topographic) map.

Table 3. Analysis of water sample from the hand dug well in the study area.

Chemical constituents (mg/L)															
Anions										Cations					
Fe	Cu	Zn	Pb	Co	As	Mn	Ni	Mg	K	Cr	Na	Ca	Cl ⁻	SO ₄ ²⁻	NO ₃ ⁻
0.3	-	0.4	-	-	-	1.1	0.1	85.1	70.3	-	90.1	81.2	291.1	55	18.5
TDS = 684.83 mg/L					pH = 8.15			Hardness = 38.8 mg/L			Conductance = 950 μ S/cm				

high values (greater than 300 Ω m) centered on the VES 2 and 9 locations respectively. These zones, which fall within the bedrock depression at greater depth, will support good quality and high groundwater yield in the study area.

The bedrock relief map (Figure 4) shows both bedrock depression and highs superimposed on a general NW-SE trending dip in the underlying bedrock. The axis of the depression may represent a possible ancient buried river channel. The bedrock relief map shows a similar trend to the surface relief map implying that depositions of sediment were structurally controlled by various tectonic activities at greater depth.

Hydro-chemical analysis

Physical examination of the water sample reveals that the water is colourless without any offensive odour. The chemical analysis carried out shows that the pH recorded is 8.15 showing slightly alkaline water with specific conductance of 950 μ S/cm. The estimated value of total dissolved solids (TDS) is 684.83 mg/L. This value is

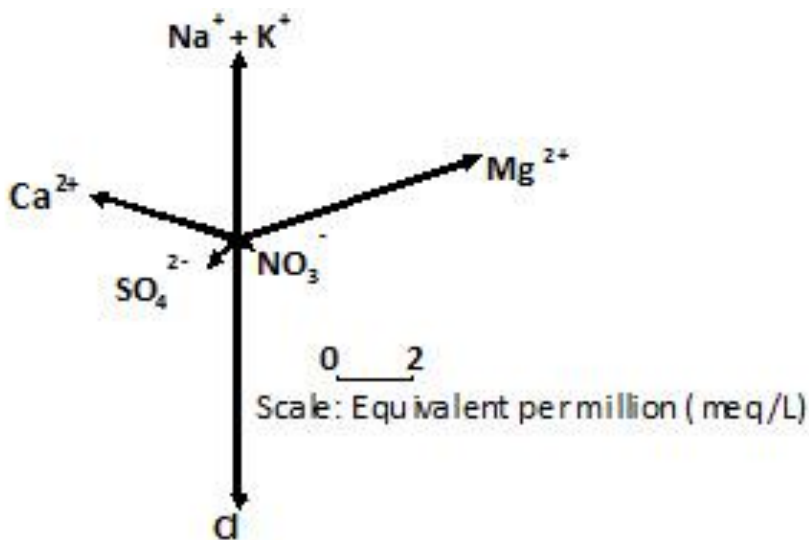
simply an indication of high concentrations of soluble minerals in the water sample. The degree of hardness of 38.8 mg/L indicates that the water is soft (Todd, 1980; Sawyer and McCarty, 1967). Generally, the chemical constituents of some of the major and minor elements such as Fe, Zn, and Ni fall considerably within the World Health Organization (WHO, 1963) permissible levels (Tables 3 and 4). Mn (1.1 mg/L) on the other hand is above 0.5 mg/L recommended maximum allowable limit. This suggests a shallow source of sediments rich in manganese, which makes the groundwater undesirable for domestic and industrial use.

Figures 5 and 6 are the vector and piper diagrams of the major cations and anions concentrations in the water sample. The vector diagram shows the chemical concentration of the principal elements in mg/L, while the piper diagram shows the elements' concentration as percentage of total component. From these diagrams, it was observed that there is considerable amount of chlorides and alkali earth metals and ions.

In Figure 5, the level of the alkali-ions: potassium (70.3 mg/L) and sodium (90.1 mg/L) are essentially high with potassium being above the recommended WHO

Table 4. WHO (1963) International standards for drinking water.

Substance	Min. acceptable concentration mg/L	Max. acceptable concentration mg/L
Total dissolved solid (TDS)	500	1000
pH	7.0 - 8.5	<6.5 or >9.5
Taste	unobjectionable	-
Odour	unobjectionable	-
Iron (Fe)	0.3	1.0
Copper (Cu)	1.0	1.5
Zinc (Zn)	5.0	15
Manganese (Mn)	0.1	0.5
Nickel (Ni)	0.3	1.0
Magnesium (Mg)	50	150
Potassium (K)	5	10
Sodium (Na)	45	100
Calcium (Ca)	75	200
Chloride (Cl ⁻)	200	600
Sulphate (SO ₄ ²⁻)	250	400
Nitrate (NO ₃ ⁻)	50	100

**Figure 5.** Vector diagram illustration of major chemical constituents in the water sample.

maximum allowable limit of 10 mg/L, these elements represent about 49% of the principal cation constituents, which have their source from feldspars and clay minerals. The alkaline earth metals: calcium and magnesium constituents are 81.2 and 85.1 mg/L respectively as shown in Figure 5, which are below the WHO recommended maximum allowable limits of 200 and 150 mg/L. These elements represent 26 and 25% of total principal cations as shown in Figure 6. At 291.1 mg/L, the chloride concentration as shown in Figure 5, from the well in the study area is a little bit above the WHO maximum

acceptable cut-off of 200 mg/L indicating a high concentration of soluble salts present in the groundwater. The chloride concentration is presented as 80% of total anions.

On the other hand, both the sulphate and nitrate constituents' obtained are 55 and 18.5 mg/L (Figure 5). These values fall below the WHO recommended maximum acceptable limits of 250 and 50 mg/L in both cases. These two elements represent 15 and 5% of total anions in the water sample respectively as shown in Figure 6. In general, the alkali-ions and metals form

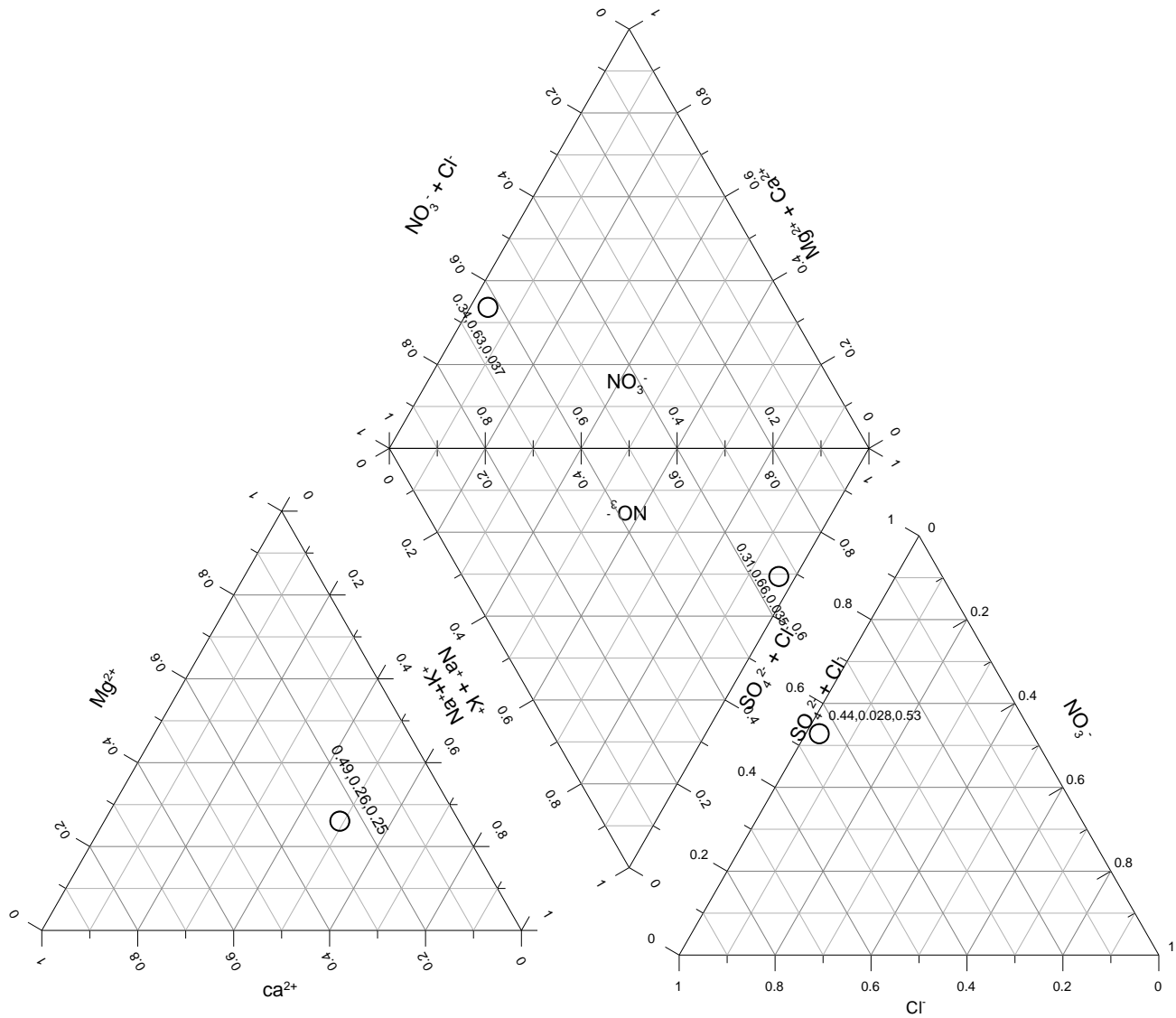


Figure 6. Piper diagrams of groundwater chemical constituents.

between 31 and 34% of principal chemical constituents of the water sample which have their source from feldspars and clay minerals from soils in the area. The chloride and phosphate concentration form close to 66%, while the nitrates are least abundant with concentration below 45% (Figure 6).

On the other hand, the microbial tests revealed a plate count of the viable bacteria reveals 18 in 0.1 ml (1.8×10^2 cfu/ml) and most probable number of coliforms (MPN) indicated 160 coliforms in 10^2 ml of the water sample. Although the plate count falls within the acceptable WHO standard, the MPN value was however above the upper limit of 10 coliforms in 10^2 ml of potable water for Africa (Todd, 1980). These results suggest possible concentration of nitrogen compounds and pollution of human origin.

Conclusions

From the results of the electrical resistivity survey and hydrochemical analysis of the water sample obtained from the study area, it was discovered that there is significant high concentration of soluble salts in the underground water. This is directly reflected by the observed low resistivity values for the aquiferous zones. This implies predominant high contents of dissolved chemical solutes within the aquifer. Likewise, the unconsolidated nature of the overlying regolith rich in chloride, magnesium and potassium elements means that recharge from the surface runoff and low-lying elevations possibly contribute to the poor quality of the vast groundwater resource in the area.

In addition, the basement troughs delineated possibly

represent an ancient buried river channel; also, the underlying moderate to thick regolith, with layer resistivity values above 200 Ω m at greater depth, showed that groundwater development is promising in the area.

High level of most probable number of coliforms (160 coliforms per 10^2 ml) in the subsurface water, which points to the presence of high concentration of nitrogen compounds and pollution of animal origin, clearly indicates that the zone of water saturation is directly in contact with the surface runoff. This perhaps eventually leads to poor quality of the groundwater, which makes it undesirable for domestic purpose except further treatment is done.

It is therefore desirable to carry out proper water treatment in order to suppress the biochemical and chemical constituents in the groundwater. Proper borehole design involving screening of the regolith materials and an efficient water treatment program will ensure maximum utilization of the groundwater resource in the area. A borehole depth of about 60 to 80 m would ensure a good water quality with minimal water treatment in the area, while screening of the upper troublesome shallow saturated zone is also desirable.

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