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Prospects and quality indices for groundwater development in Ibadan metropolis, southwestern Nigeria

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Abstract

An integrated geophysical and hydrogeochemical studies were conducted in part of Ibadan metropolis, Southwestern Nigeria to investigate the groundwater potential and quality for sustainable development. Interpreted results of vertical electrical sounding data revealed three to four geo-electric layers; top soil (22.1-441.4 Ωm), lateritic horizon (402.1-712.2 Ωm), clayey/sandyclay layer (2.95-66.0 Ωm) and weathered/fractured bedrock (66.3-1056.7 Ωm). Stacked overburden isopach and basement isoresitivity maps revealed few areas with thick overburden and fractured basement, hence of apparently high groundwater prospect. Hydrogeochemical study indicates that groundwater in the study area is generally fresh, soft- moderately hard, slightly acidic and dominated by Na, Ca, Mg, Cl and HCO_3 ions. The dominant hydrochemical facies is Na-Cl type with minor mixed Ca-Na-Cl and Ca-Cl types. Many of the analyzed parameters fall within recommended limits and thus, most of the groundwater in the study area are chemically suitable for drinking. A few however, recorded TDS, pH, NO_3, Al, Mg and Cl concentrations above permissible levels, suggesting some concern in terms of potability. The groundwater quality for agricultural purposes was assessed using Sodium absorption ratio, permeability index and electrical conductivity values along with USSL and Wilcox diagrams, all indicating that most of the samples are excellent to good for irrigation.

Keywords: Prospects, Isoresistivity, Hydrogeochemistry, Groundwater quality, Ibadan

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1. Introduction

Water resources are one of the most important materials in community development. Understanding the hydrogeological and hydrochemical characteristics of an area is crucial for groundwater planning and development. Groundwater had immensely become important water supply in urban and rural areas in both developed and developing nations for domestic, industrial and agricultural purpose (Ramkumar et al., 2010). Groundwater is replenished with precipitation and surface run-off. In Basement terrains like Ibadan, it is generally believed to occur within the overlying, weathered, unconsolidated material derived from the in-situ weathering of rocks, and within the fractured/faulted bedrock (Clark, 1985; Acworth, 1987; Bala and Ike, 2001).

There has been a rapid increase in aerial expansion of Ibadan in recent years, growing rapidly with increased residential buildings and industries being constructed at a very fast rates making demand for potable water to have increased tremendously. Municipal water supply is largely inadequate and scarce with many depending on rainwater, streams and hand-dug wells for their domestic uses. Also, few individuals and corporate bodies indiscriminately sink tube wells and boreholes within unconsolidated overburden materials, with glaring lack of concerns for the vulnerability status of aquifer and possible environmental and social risks. Hence, for sustainable development, it is necessary to subject groundwater to a comprehensive quantitative and qualitative evaluation in order to assess its potential and suitability for consumption and industrial purposes.

Geoelectrical resistivity method is a popular and successful exploration technique for groundwater conditions around the world. It probes deeper into the subsurface giving clues to the occurrence or otherwise of groundwater with the quality being determined from the measured resistivity values. Resistivity method is suitable to map the thickness and delineate the extent of the aquiferous overburden, and also to estimate depth to fractured bedrock. Many authors have attested to the efficiency of vertical electrical sounding (VES), not only in exploration but also in the determination and mapping of groundwater quality and pollution (Koefoed, 1989; Parasnis, 1997; Atekwana et al., 2003; Ayolabi et al., 2009).

Hydrochemical evaluation of groundwater systems is usually based on the availability of a large amount of information concerning groundwater chemistry (Aghazadeh and Mogaddam, 2010) which in turn, depends on the physical and chemical soluble parameters due to weathering from rocks and anthropogenic activities resulting in a complex groundwater quality. In general, groundwater quality depends on the composition of recharge water, the interaction between the water and the rock with which it comes into contact with, and the residence time and reactions that take place within the aquifer (Hem, 1989; Fetter, 1990; Appelo and Postma, 2005). The importance of water quality in human health has continually attracted a great deal of interest. In developing countries like Nigeria, around 80% of all diseases are said to be directly related to drinking water of poor quality and unhygienic conditions (Prasad, 1984; Olajire and Imeokparia, 2001). An appropriate assessment of groundwater potability requires determining the concentrations of some important physico-chemical parameters and make comparison with the guideline values set for potable water. In this study, an integrated electrical resistivity and hydrochemical methods was used to determine prospect and quality of the groundwater in part of Ibadan metropolis.

2. Materials and methods

2.1. Location and geology of the study area

Ibadan is located in southwestern Nigeria, 160km inland northeast of Atlantic coast of Africa, favorably situated between rainforest and savanna. The study area is northeastern part of Ibadan, it lies on latitudes 7^0 20^l N and 7^0 24^l N and Longitude 3^0 54^l E and 3^0 59^l E (Figure 1). The climate of the study area is tropical wet and dry, with the wet season from mid-March to October and dry period from November to March.

The study area lies within the Precambrian Basement Complex terrain of southwestern Nigeria (Rahaman, 1988). Migmatite gneiss, amphibolite schist, quartz schist, granite and pegmatite occur in the area in varying proportions. However, quartz schist dominate, occurring as low lying outcrops covering a larger part of the study area along the central to the northwestern part of the region (Figure 2). The rocks are highly weathered and fractured in most cases and possess various visible structures. Amphibolite schist occurs at the northeastern part as low lying outcrops and covers a small part of this region.

2.2. Geophysical investigation

A total of 18 Vertical Electrical Soundings (VES) were conducted at different locations with ABEM SAS-1000 Terrameter using the Schlumberger electrode configuration, with the current electrode spacing (AB/2) having a maximum spread of 200m. The data obtained were plotted against the electrode spacing and a preliminary interpretation was carried out using partial curves matching (Koefoed, 1979), engaging two-layer master curves and the appropriate auxiliary point charts (Orellana and Mooney, 1966). The interpreted layer earth model is iterated using WINRESIST computer software, to reduce the interpretation error to acceptable levels (Baker, 1989). Geo-electric sections were deduced from the interpreted data. Each geoelectric layer corresponds to a layer of uniform geological properties. The subsurface condition varies from one geoelectric layer to another.

2.3. Hydrochemical investigation

Groundwater samples were collected from hand-dugs wells and few boreholes at different locations (Figure 1) in precleaned polythene containers for the assessment of physical and chemical parameters and groundwater contamination. Temperature, pH, TDS and electrical conductivity (EC) were measured using appropriate digital meters immediately after sampling. A part of the water samples collected was acidified for cation determination using Inductively Coupled Plasma – Mass Spectrometry (ICP-MS) at ACME Laboratories, Canada while the anion was determined with Inductively Coupled Plasma–Optical Emission Spectrometry (ICP-OES) at Petroleum Trust Development Fund laboratory, Nigeria.

3. Result and discussion

3.1. Geophysical Interpretation

The quantitative and qualitative interpretation of the resistivity data revealed a range of three to four geo-electric layers: topsoil, lateritic horizon, sandyclay/clayey horizon and weathered/fractured/fresh bedrock (Table 1). The electrical resistivity contrast across the lithologic units is used to delineate the geoelectric layers (Schwarz, 1988). The topsoil has a resistivity values range from 22.1 to 441.4 Ωm, with layer thickness varying between 0.4 and 5.3 meters. Higher resistivity values (266.9, 355.5, 441.4, and 284.4 Ωm) of top soil in VES stations 3, 8, 10 and 14 could be due to imbedding of boulders at such points. The lateritic horizon has resistivity values in the range of 402.1 to 712 Ωm. Layer thickness ranges from 1.2 to 3.1m. The sandyclay/clayey horizon has a resistivity values range from 2.95 to 66.0 Ωm and layer thickness ranges from 0.9 to 30.0 meters. This horizon is the target of most hand-dug wells. The bedrock zone has resistivity in the range of 66.3 to 1056.7 Ωm.

An isoresistivity map of the bedrock zone shows areas with relatively low resistivity values corresponding to weathered or fractured bedrock and areas with relatively high resistivity values interpreted as fresh bedrock. The isopach map of the overburden, specify areas with high and low overburdens thicknesses which correspond to basement ridges and basement highs respectively. The stacked isoresistivity and isopach maps (Figure 3) were used to produce the groundwater potential map of the study area (Figure 4). Highest groundwater yields are believed to be in areas where thick overburden overlies fractured zones (Olorunfemi and Olorunniwo, 1985) whereas areas with either thick overburden or weathered/fractured basement are delineated as having medium yield while areas with thin overburden and high bedrock resistivity (fresh basement) as low groundwater potential zones. In order to ensure maximum and perennial yield, boreholes are best sited in areas where the regoliths could be maximally penetrated (Lenkey et al., 2005).

3.2. Hydrogeochemistry

The statistics of different physico-chemical parameters of the analyzed groundwater samples (N=31) revealed (Table 2), EC ranging from 14 to 864 µS/cm, temperature 25.2 - 31.3 ^{o}C, pH 5.4 - 6.93, TH 26 - 149, TDS 50 - 1240, HCO_3 26 - 149 mg/l, Cl 10 - 440 mg/l, SO_4 3 - 98 mg/l, PO_4 0 - 2.39 mg/l, NO_3 4.2 - 50.4 mg/l, F 0 - 0.86 mg/l, with a mean of 207.21 µS/cm, 27.57 ^{o}C, 6.16, 70, 349.39, 69.82, 79.52, 29.46, 0.24, 13.98, and 0.31 mg/l respectively. Ca, Mg, Na, K and Al range from 5.09 to 56.59, 1.1 to 34.38, 2.98 to 17.03, 13.47 to 92.17 and 0.002 to 0.829 mg/l with mean of 19.51, 12.46, 9.13, 37.52 and 0.12 mg/l respectively. The abundance of major ions is in the order of Na > Ca > K > Mg > Al and Cl > HCO_3 > SO_4 > NO_3 > PO_4 > F.

3.3. Hydrogeochemical facies

The evolution of hydrochemical parameters of groundwater can be understood by plotting the cations and anions in the Piper (1944) diagram (Figure 5). Facies are recognizable parts of different characters belonging to any genetically related system. The plot shows that most of the groundwater samples analysed fall in the field of Na-Cl type with minor mixed Ca-Na-Cl and Ca-Cl types. From the plot, it is observed that alkalinity (Na and K) exceeds alkaline earth (Ca and Mg) and strong acids exceed weak acids. In general, water chemistry is dominated by alkali and strong acids.

3.4. Groundwater quality assessment

Groundwater quality assessment was carried out to determine its potability for drinking, agricultural and industrial purposes. Groundwater quality for drinking water purposes was analyzed based on recommended permissible limits of WHO (2004), NIS (2007) and USEPA (2009) guidelines (Table 3). Majority of the samples were within the permissible limits while there are few exceptions in TDS, pH, NO_3, Al, Mg and Cl. TDS in all the samples are within the permissible limit with exception in sample from Olorunsogo. All water samples fall within fresh water category (< 1000mg/l) irrespective of location where they were taken with slightly saline water representation (1000-3000mg/l) from Olorunsogo. Spatial distribution of TDS demarcated on the basis of excellent (> 300mg/l) to poor (< 900mg/l) indicates majority of the study area having lower TDS which are safe for drinking purposes (Figure 6). High TDS in water may produce bad taste, odour and colour, and may also induce unfavourable physiological reactions in the consumer (Spellman and Drinan, 2000). The pH of groundwater in the study area varied from 5.4 to 6.93 which is generally lower than the permissible limit. 68% of groundwater samples recorded slightly acidic condition. Low pH levels have a potential to enhance corrosion of pump parts but may not affect its use for domestic purpose. Slightly acidic groundwater may also enhance dissolution of trace elements from country rocks (Brady, 1984). This might be responsible for the high concentrations in Mn, Zn, and Sr recorded from groundwater in the region in previous studies (Ajibade et al., 2011). Low pH values may be as a result of the production of CO_2 from microbial respiration (Pelig-Ba et al., 1991). Nitrate concentration is below the WHO and NIS recommended limit for virtually all the samples except for groundwater sample at Alarere but higher than the USEPA permissible limit at majority of the study area except for samples from Anu-Oluwa, Old-Ife, Adesanmi, Isebo and Wakajaiye (Figure 7). Higher nitrate concentration in the northwestern and southeastern regions indicates groundwater contamination with infiltrating surface water mainly derived from organic effluents, nitrogen bacteria, leaching of animal dungs, sewage and septic tanks through water and soil matrix to groundwater (Srinivasamoorthy et al., 2009). High level of nitrate in drinking water may cause methemoglobinemia in infants under four years, as well as in adults with particular enzyme deficiency (Baird, 1999). Chloride concentration is low and fall within the limit of all the guidelines for all samples in the study area except in Old-Ife (440mg/l) and slightly concentrated in Elelu II and Olorunsogo (248 and 205 mg/l respectively) (Figure 8). High chloride in water above permissible limit would impart delectable taste to water. Chloride in groundwater is due to weathering of rocks, infiltration from anthropogenic sources and industrial applications. Water hardness is caused primarily by the presence of cations such as calcium and magnesium, and anions such as carbonate, bicarbonate, chloride and sulfate in water (Sadashivaiah et al., 2008). Ca is within the permissible limit at all locations while Mg exceeds the NIS guideline in all the locations. The concentration values of Ca and Mg indicate weathering from primary mineral sources. Total Hardness refers to reaction with soap and scale formation, ability of water to readily form lather with soap and increase in boiling point of water. The hardness values obtained from the majority of the samples when compared with Todd's 1980 classification (Tables 3 and 4) show moderately hard water which may be due to leaching of Ca and Mg ions into groundwater.

The suitability of groundwater for irrigation purposes depends upon its mineral constituents. The most important criteria for judging the quality are total salt concentration as measured by electrical conductivity (EC), permeability index (PI) and sodium/alkali hazard typically expressed as Sodium Absorption Ratio (SAR) and percent sodium (% Na). Richard (1954) classified groundwater on the basis of electrical conductivity (Table 4), 74% of the samples belong to excellent, 22.5% are good while 3.5% are doubtful. WHO (1989) used PI as a criterion for assessing the suitability of water for irrigation. The PI of the water samples range from 37.6% to 98.7% with an average value of 71.12%. According to PI values, the groundwater in the study area is mainly designated as class II (25-75%) which is good for irrigation purposes with few representation of class III (> 75%) which are doubtful for irrigation. SAR quantifies the proportion of Na to Ca and Mg ions in a sample and its utility for agricultural purposes. When sodium concentration is high, it tends to be exchange for Ca and Mg in clay particles thereby reducing the soil permeability and eventually results in soil with poor internal drainage (Srinivasamoorthy et al*.,* 2009). Hence, sodium concentration plays an important role in evaluating the groundwater quality for irrigation. The SAR values for the groundwater samples in the study area range from 3.51 to 27.54 and according to Wilcox (1955) classification ten samples represent excellent, fourteen samples are good, six samples are permissible, while one samples is doubtful for irrigation purposes which is sample from Olorunsogo implying that the groundwater in the study area could be harnessed for irrigation except for groundwater around Olorunsogo. The analytical data plotted on the US salinity diagram (Richard, 1954) illustrates that 71% of the groundwater samples fall in the fields of C1S1 and C1S2, indicating low salinity and low – medium sodium water, which can be used on all soil types without danger of exchangeable sodium (Figure 9). The Wilcox (1955) diagram relating sodium percentage and total salt concentration (EC) shows that majority of the groundwater samples fall in the field of good to permissible for irrigation (Figure 10).

The quality requirements for industrial water supplies range widely and almost every industrial unit has its own standards. Industries suffer from incrustation and corrosion, which are chemical reactions caused by poor quality of waters. Water quality criteria of Subba et al*.* (2005) for defining incrusting and corrosive properties of waters is adopted in this study: waters having more than 300mg/l of TH or 100mg/l of SO_4 or 400mg/l of HCO_3 may cause incrustation and water with pH less than 7 or TDS more than 1000mg/l or Cl more than 500mg/l may cause corrosion. Groundwater in the study area is generally below the permissible limits for TH, SO_4 and HCO_3 and may not cause incrustation. The pH range is generally less than 7 in all the study locations which may cause corrosion. Higher concentration of TDS (<1000 mg/l) is represented in Olorunsogo whereas Cl content is less than 500mg/l in all the locations. Corrosion can create adverse effects on processing, steaming and cooling units if such waters are used by industrial sectors.

4. Conclusion

An integrated geophysical and hydrogeochemical investigations was carried out in part of Ibadan metropolis, southwestern Nigeria to determine the potential and quality characteristics of groundwater within the area.

VES interpretation revealed the area to be underlain with three to four geo-electric layers; topsoil, lateritic layer, clayey/sandyclay horizon and weathered/ fresh bedrock. Groundwater potential within the study area is influenced by the overburden thickness, degree of weathering and the presence of fractures in the bedrock. Areas where relatively thick overburden overlies weathered or fractured basement were identified as having highest potentials for groundwater. Northwestern and eastern parts of the study of the study area have been delineated for highest groundwater yield.

Hydrogeochemical study reveals the groundwater in the study area to be fresh, slightly acidic, moderately hard and dominated by sodium, calcium, potassium, chloride and bicarbonate ions. The hydrochemical evolution plot indicates alkalinity exceeds alkaline earth and strong acid exceed weak acid. Major ions concentration in most of the groundwater samples in the study area are within the permissible limits of WHO, NIS and EPA with few exceptions in TDS, pH, NO_3, Al, Mg and Cl indicating the influence of weathering and anthropogenic impacts. The suitability of the groundwater in the study area for agricultural purposes is evaluated based on salinity hazard, PI, %Na and SAR. Most of the samples fall in suitable range for irrigation purposes. The low pH values in all the locations and higher TDS at Olorunsogo indicating an industrial water quality that will result in corrosion of pipes.

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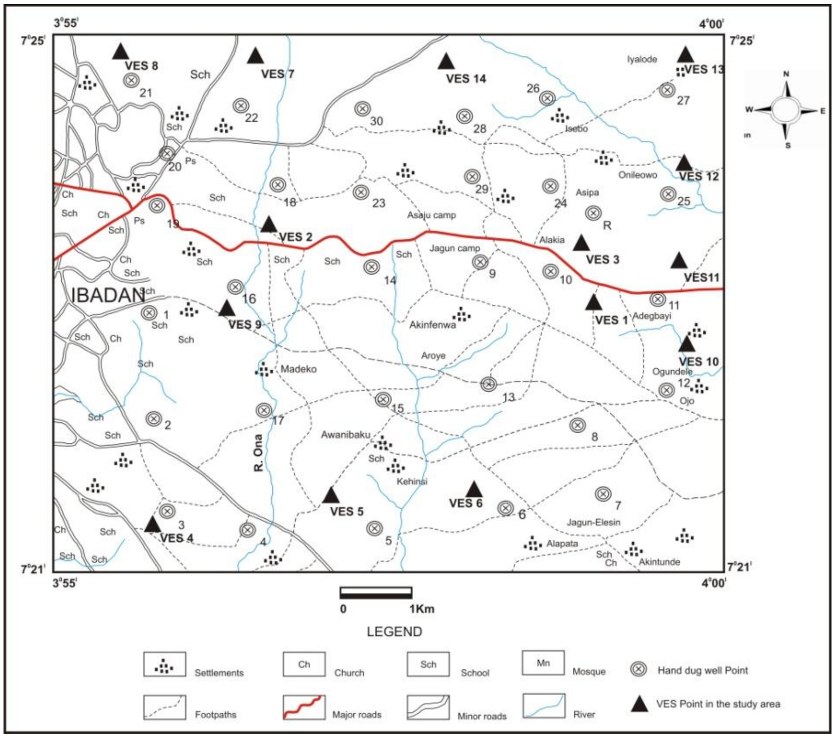

Figure 1. Map of the study area showing sample locations

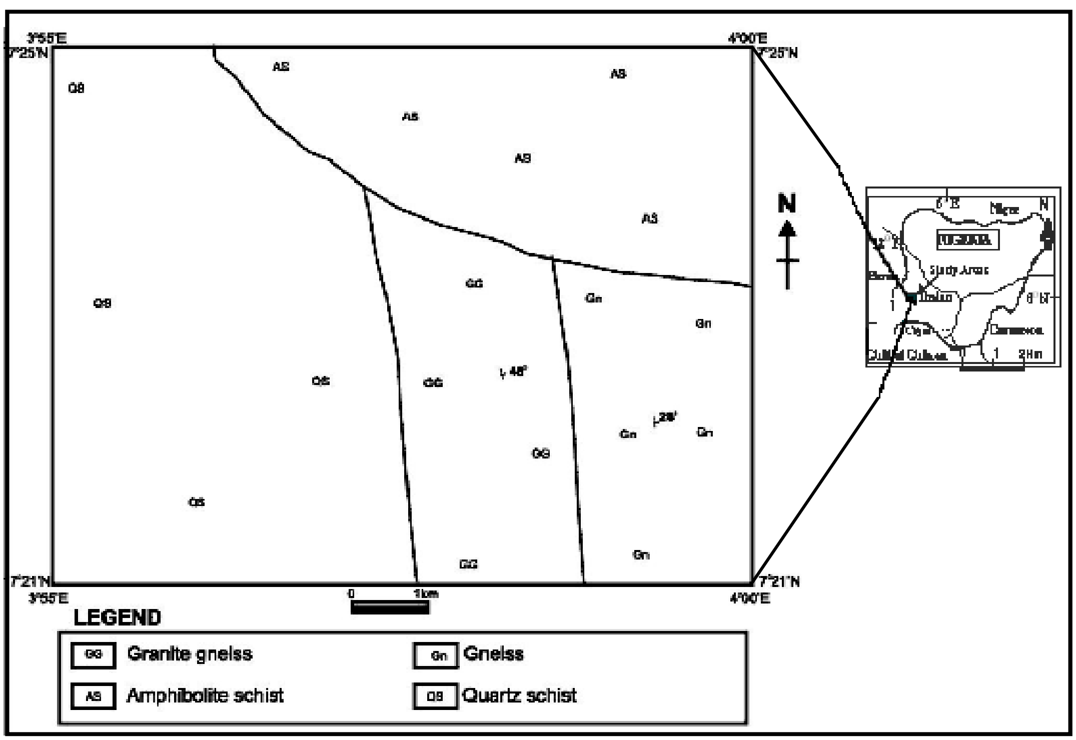

Figure 2. Geologic map of study area

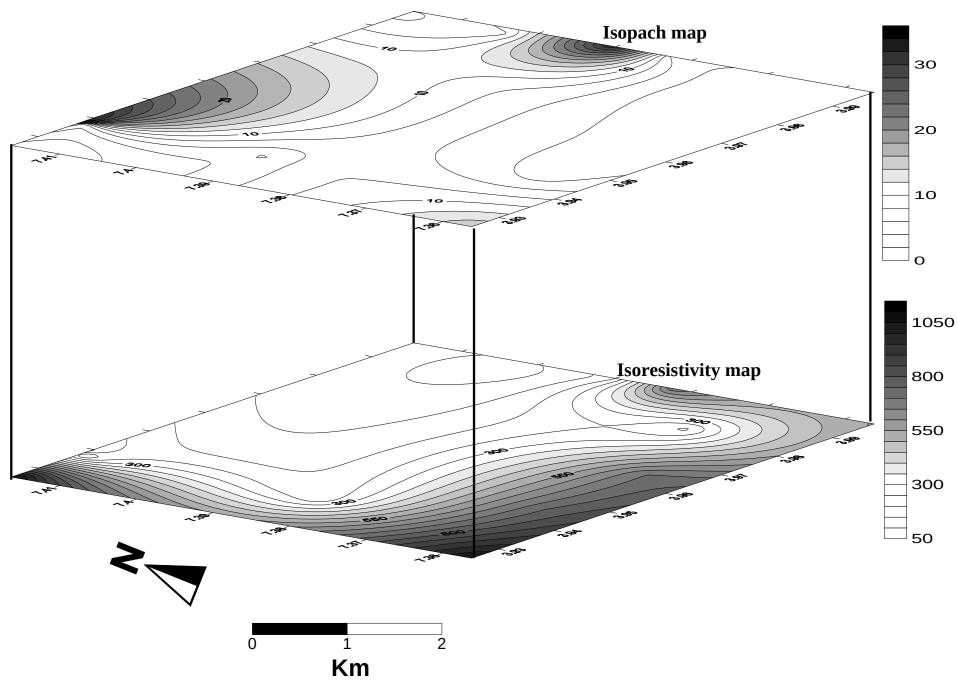

Figure 3. Stacked isoresistivity and isopach map of the study area

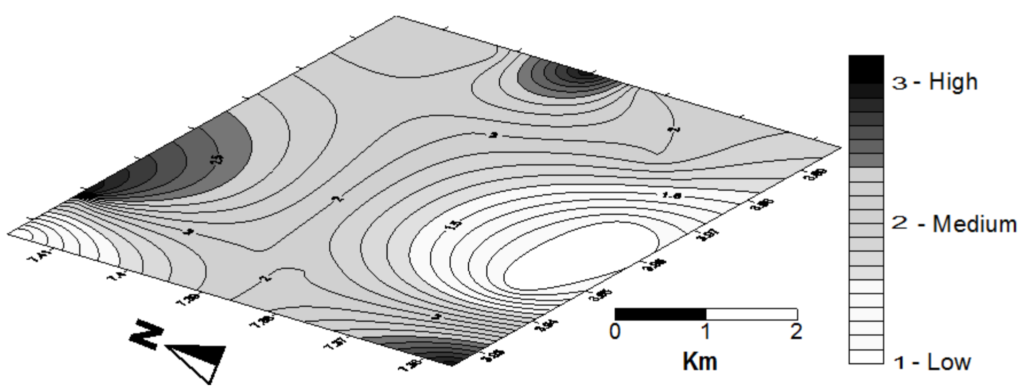

Figure 4. Combined basement resistivity and overburden thickness map showing areas of high, medium and low groundwater potentials.

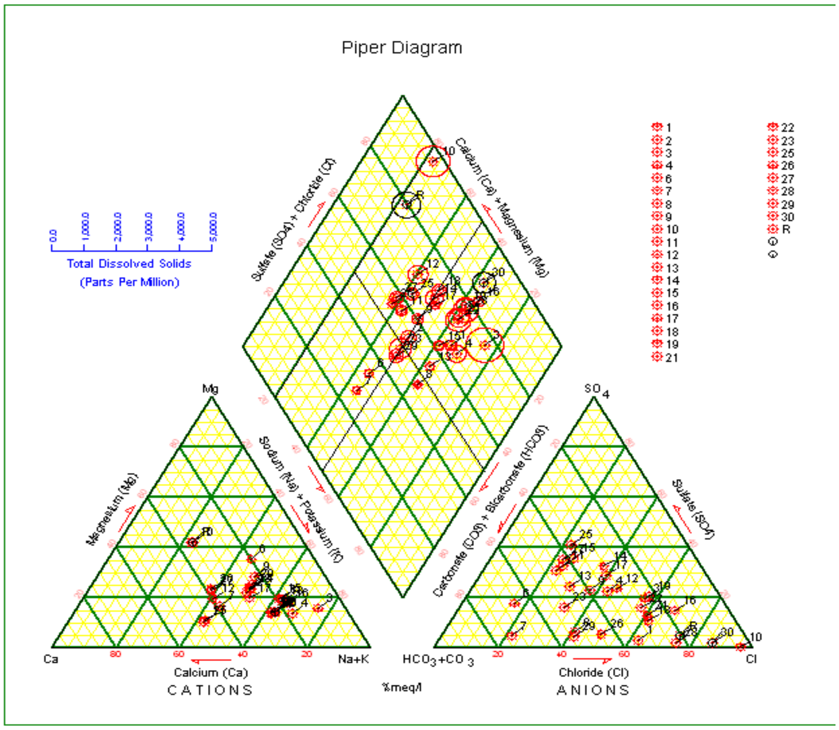

Figure 5. Piper diagram for relative percentage of major ions of analysed groundwater

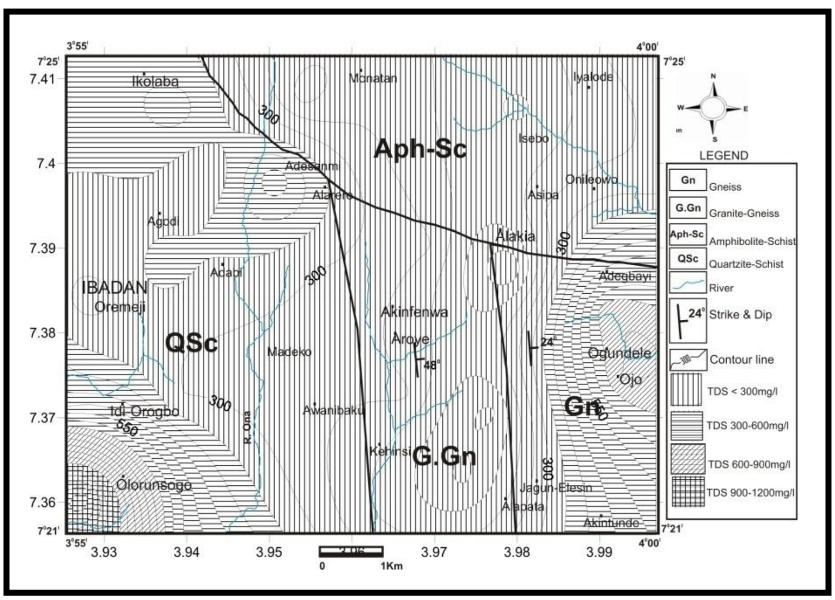

Figure 6. Spatial distribution of TDS from study area

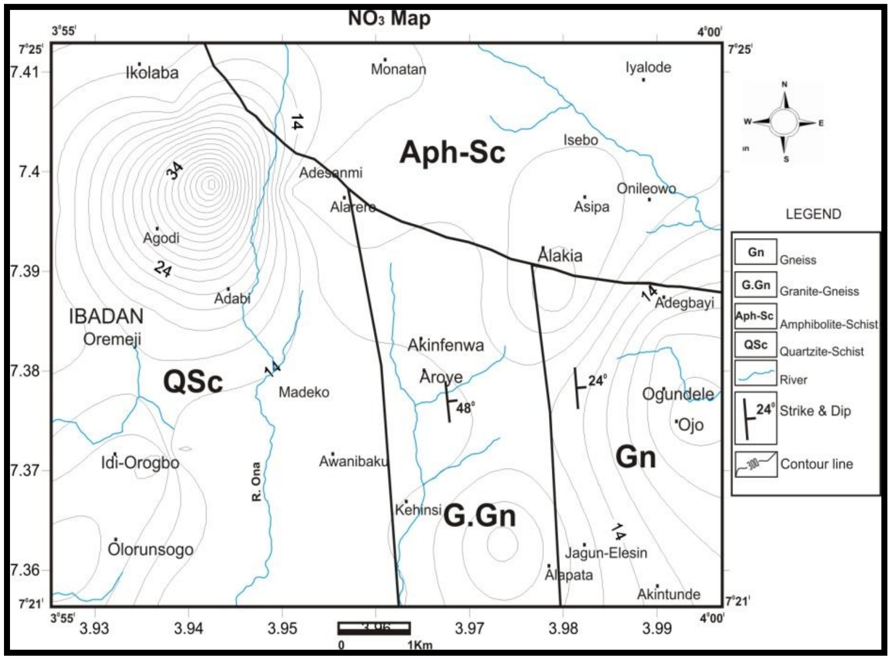

Figure 7. Spatial distribution of NO_3 from the study area

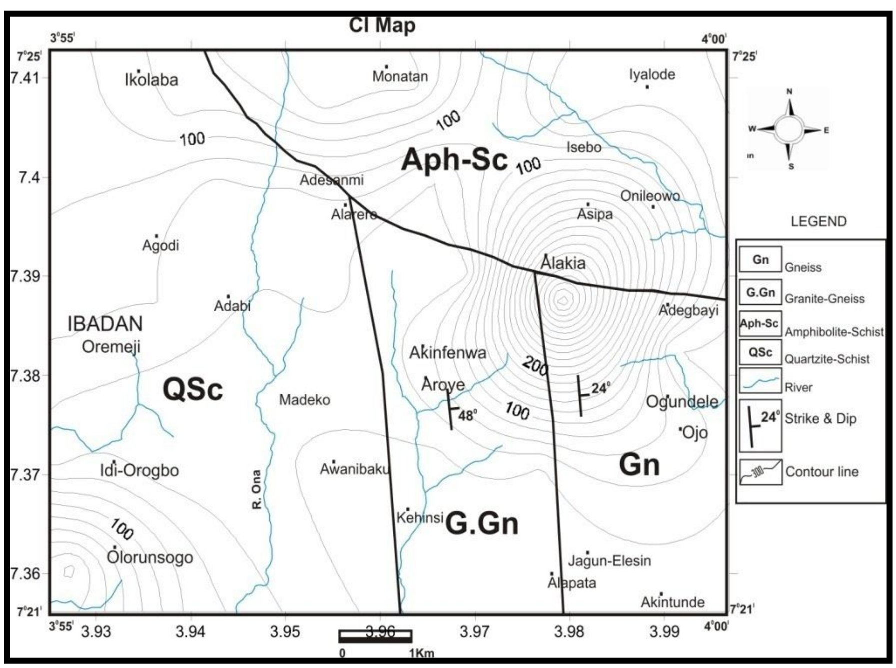

Figure 8. Spatial distribution of Cl from study area

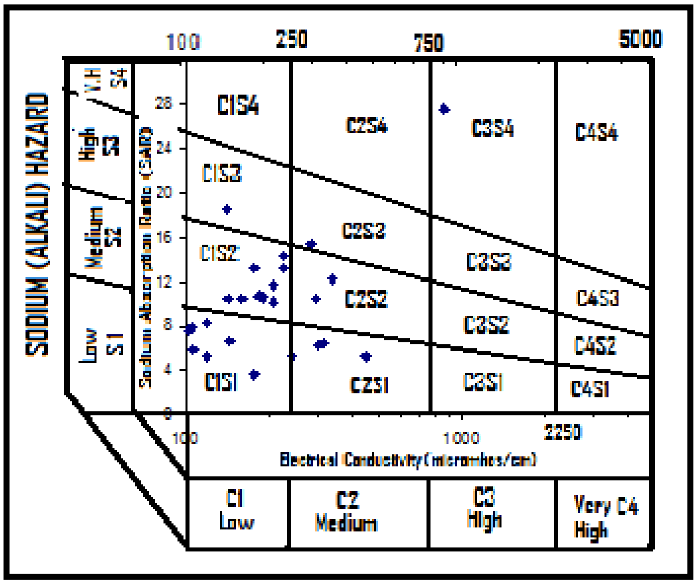

Figure 9. US salinity diagram showing rating of groundwater samples in relation to salinity and sodium hazard (after Richard, 1954).

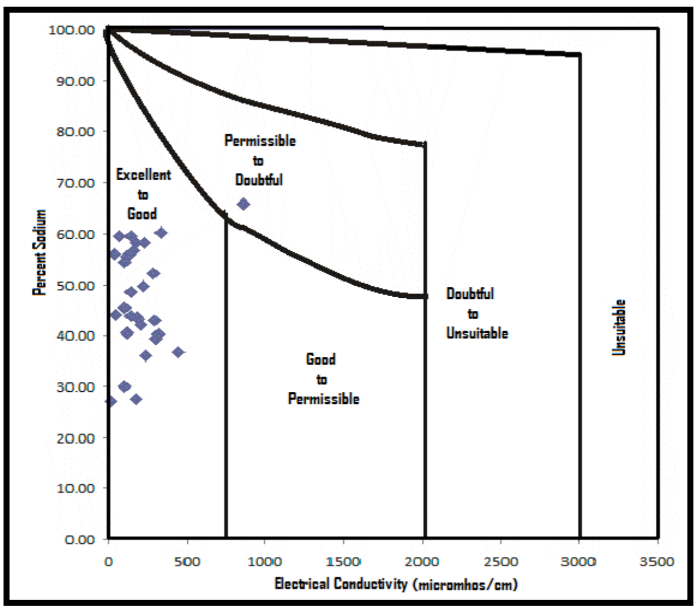

Figure 10. Groundwater quality in relation to electrical conductivity and percent sodium (after Wilcox, 1955)

Table 1. Geoelectric Parameter

VES No	Layers	Resistivity	Thickness	Depth	Lithology
	1	60.6	1	1	Top soil
1	2	62.9	1.4	2.5	clayey Horizon
	3	186.4	---	---	Weathered bedrock
	1	24.7	1.8	1.8	Top soil
2	2	432.4	2	3.8	Lateritic zone
	3	255.1	1.3	5.1	Weathered bedrock
	4	403	---	---	Fractured bedrock
	1	266.9	1.1	1.1	Top soil

3	2	29.2	7.6	8.7	Clayey Horizon
	3	179.8	---	---	Weathered bedrock
	1	43.7	0.9	0.9	Top soil
4	2	414.4	2.1	3	Laterictic zone
	3	59.1	12.6	15.6	Clayey Horizon
	4	1056.7	---	---	Fresh bedrock
	1	78.5	0.9	0.9	Top soil
5	2	29.4	0.1	1	clayey Horizon
	3	49.3	2.2	3.1	sandyclay zone
	4	742.1	---	---	Fractured bedrock
	1	69.5	0.7	0.7	Top soil
6	2	10.8	2.7	3.4	Clayey Horizon
	3	697.4	---	---	Fractured bedrock
	1	73.6	1.2	1.2	Top soil
7	2	37.4	3.6	4.8	clayey Horizon
	3	130.1	10.6	15.4	Weathered bedrock
	4	558.4	---	---	Fractured bedrock
	1	355.5	0.4	0.4	Top soil
8	2	17.9	0.9	1.3	Clayey Horizon
	3	1025.4	---	---	Fresh bedrock
	1	146	0.8	0.8	Top soil
9	2	402.1	3.1	3.9	Lateritic zone
	3	48.9	4.1	8	Clayey Horizon
	4	212.7	---	---	Weathered bedrock
10	1	441.4	1.1	1.1	Top soil
	2	66	4.5	5.5	Clayey Horizon
	3	690	---	---	Fractured bedrock
11	1	120.5	0.9	0.9	Top soil
	2	712.2	1.2	2.1	Lateritic Horizon
	3	50.8	30.3	32.4	Clayey Horizon
	4	172.1	---	---	Weathered bedrock
12	1	22.1	1	1	Top soil
	2	4.42	6.55	7.55	Clayey Horizon
	3	66.3	---	---	Highly Weathered zone
13	1	29.5	1	1	Top soil
	2	2.95	4.5	5.5	Clayey Horizon
	3	147.5	14.5	20	Weathered bedrock
	4	1475	---	---	Fresh bedrock
14	1	284.4	5.3	5.3	Top soil
	2	41.7	27.7	33.1	Clayey Horizon
	3	307.6	---	---	Weathered/Fractured bedrock

Table 2. Statistical parameters or groundwater

Parameters	Maximum	Minimum	Mean	Std-dev
Ca	56.59	5.09	19.51	11.05
K	34.38	1.1	12.46	9.69
Mg	17.03	2.98	9.13	4.86
Na	92.17	13.47	37.52	22.86
Al	0.829	0.002	0.12	0.18
NO_3	50.4	4.2	13.98	8.62
HCO_3	149	26	69.82	32.38
SO_4	98	3	29.46	23.61
PO_4	2.39	0	0.24	0.44
Cl	440	10	79.52	93.96
F	0.86	0	0.31	0.24
EC	864	14	207.21	162.72
Temp	31.3	25.2	27.57	1.42
TH	149	26	70	32
pH	6.93	5.4	6.16	0.4
TDS	1240	50	349.29	236.45

TDS = Total dissolve solids, TH = Total hardness, EC = Electrical conductivity, Temp = temperature

Table 3. Comparison of groundwater with guidelines

Parameter	Range	Guidelines		
	This study	WHO (2004)	NIS (2007)	USEPA (2009)
Ca	5.09 - 56.59	200	-	75
K	1.1 - 34.38	200	-	-
Mg	2.98 - 17.03	150	0.2	50
Na	13.47 - 92.17	200	200	200
Al	0.002 – 0.829	-	0.2	0.05 – 0.2
NO_3	4.2 - 50.4	45	50	10
HCO_3	26 – 149	240	-	-
SO_4	3 – 98	250	100	250
PO_4	0 - 2.39	-	-	-
Cl	10 – 440	250	250	250
F	0 - 0.86	1	1.5	2
EC	14 - 864	1500	1000	-
pH	5.4 - 6.93	6.5 - 9.2	6.5 - 8.5	6.5 – 8.5
TDS	50 - 1240	1000	500	500
TH	26 – 149	500	150	-

TDS = Total dissolve solids, TH = Total hardness, EC = Electrical Conductivity

Table 4. Statistical parameters or groundwater

TDS (mg/l)	W C (Todd, 1980)	n=31
<1000	♀	30
1000-3000	☼	1
3000-10,000	♂	-
10,000-35,000	♦	-
>35,000	♠	-
TH (mg/l)	**W C (Todd, 1980)**	**n=31**
<60	○	12
60-120	θ	17
121-180	Φ	2
>180	●	-
EC (µS/cm)	**W C (US Salinity Lab, 1954)**	**n=31**
<250	Δ	23
250-750	◊	7
750-2000	▲	1
2000-3000	▼	-
SAR	**W C (Wilcox, 1955)**	**n=31**
0-10	Δ	10
18-Oct	◊	14
18-26	▲	6
>26	▼	1

Fresh = ♀, Slightly Saline = ☼, Moderately Saline = ♂, Very saline = ♦, Brine = ♠, Excellent = Δ, Good = ◊, Permissible = ▲, Doubtful = ▼, Soft = ○, Moderately Hard = θ, Hard = Φ, Very Hard = ●