Preliminary Assessment of Groundwater Potential and Water Facie Classification in Parts North-Central Nigeria

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Abstract
A total of fifty-four (54) vertical electrical soundings were carried out across nine randomly selected communities within Kogi and Kwara State using ABEM SAS 2000 Terrameter. Thirty-seven (37) water samples were collected for major ions' concentration determination and their suitability for drinking and irrigation purposes were evaluated using World Health Organization (WHO) and Standard Organization of Nigeria (SON) standards. Results of Vertical Electrical Sounding showed that the area is underlain by 4-5 geoelectric layers consisting of top soil, clayey layer, partly weathered/fractured basement and the fresh basement with resistivity values. HA is the dominant curves. Overburden thickness deduced from the VES revealed about 55.5% of the area have overburden thickness less than10m, about 31% fall within 10-20m, 9.3% in the range of 20-30m and 3.7% have overburden thickness greater than 30m. 2D Aquifer thickness map reveal that the aquifers thicken towards the east. Bedrock topography reveals a southwestern groundwater flow. The bedrock resistivity distribution in agreement with the overburden thickness shows a small percentage of the area with high saturation of groundwater. Hydrochemical investigation revealed that the water is suitable for both drinking and irrigation purposes when compared to WHO and SON standards.

Keywords: *Groundwater potential, Vertical Electrical Sounding, Basement Complex, Curve types, Hydrochemical investigation*

INTRODUCTION

The importance of water in life's existence cannot be overemphasised. The health of humans is to a high degree dependent on the quality of water it consumes. In recent decades, it has become very paramount to determine the quality of water consumed by humans by comparing certain water quality parameters with international standards (Ige *et al*., 2017). Water for basic needs (households, services) represents a relatively small amount of the total quantities withdrawn for other uses. Although many fortunate people throughout the world are able to take water for granted where it is available, for an estimated 1.1billion people – water ruled their daily lives with the cruel irony that it is often both the most precious and sought after of commodities, requiring grinding daily labour to acquire (WHO/UNICEF, 2000). With population growth, demand for the world's finite supply of fresh water is rising, putting strains even on the industrialized countries. Global population projections suggest that the world population of over 6 billion people in 2000 will increase by 20% to over 7 billion by 2015, and to 7.8 billion by 2025, a 30% rise (WHO/UNICEF,2000). Enormous strains will be put on existing services, and substantial increases in the provision of water and sanitation will be needed to meet the needs of the evergrowing population. Quantitative and qualitative data on groundwater occurrence, unfortunately scarce in Nigeria, are vital for groundwater development, policy formulation, and environmental auditing (Oloruntola *et al*., 2019). Compared to other parts of Nigeria, groundwater potential appraisals conducted in Southwestern Nigeria is at the forefront. Some include excellent works of Olorunfemi and Fasuyi (1993); Ako *et al* (2005); Bayewu *et al* (2017); Aluko *et al* (2017); Oloruntola *et al* (2019) and Ige *et al* (2018, 2019, 2020). Some works on water quality include Edet *et al* (2011); Ige *et al* (2019, 2020); Oloruntola *et al* (2018). The studies of Oloruntola *et al* (2014), Ige *et al* (2019) have shown the importance of combining geophysical method with hydrogeochemical investigation for holistic groundwater appraisal. Most studies conducted have however focused on either of these two. Thus, this present study is aimed at integrating geophysical and hydrogeochemical methods for groundwater investigation. This study is therefore in agreement with Okagbue (1988) who opined that a comprehensive groundwater assessment should involve integration of geophysical and hydrogeochemical studies. The aim of this study is to evaluate potential groundwater availability based on overburden thickness, aquifer thickness, bedrock topography, bedrock resistivity and fracture attribute and also to carry out assessment of the suitability of water for drinking and irrigation purposes.

THE STUDY AREA

The study area is located between latitude 9° 37'N and 7° 32'N and longitude 3° 56'E and 6° 43'E occupying parts of Kwara and Kogi States in the North-Central Nigeria. The study area covers nine local government areas and span through different Geological Formation namely Obangede, Gada, Adavi, Kabba, Agbamu, Ira, Obehira, Agodo, and Kaiama (Figure1). The topography of the study area is of low to moderate relief with a few scattered hills where elevations rarely exceed 400m above the sea level. The hills are residual of granite gneiss and migmatites forming low-lying outcrops. The geology of the study area is a typical representation of the migmatite-gneiss complex. The migmatites are most extensive and represent about two-third of the area. They are extensively weathered and lateritized which support the assumption that places without exposure are underline by migmatite. Granite gneiss component occur as isolated domes and low ridges. Their contacts with other rocks are obscured by thick vegetation cover. The mineral constituents include microcline, quartz, biotite, muscovite, hornblende, apatite. The extensive nature of these rocks is principally responsible for dissolution of major soluble salts (anion and cation) which alter the chemistry of groundwater. The area experiences two distinct seasons: the wet season which extends from April to October and a dry season between November and March. The rainy season is characterized by heavy downpours accompanied by groundwater infiltration and percolation. Average annual rainfall ranges between 1000 to 1500 mm (Areola, 1983). The area is generally well drained. A regional dendritic pattern is most prominent; however rectilinear patterns are occasionally exhibited by the short tributaries. Thus, the inhabitants depend mainly on groundwater abstraction through hand dug wells and motorized boreholes.

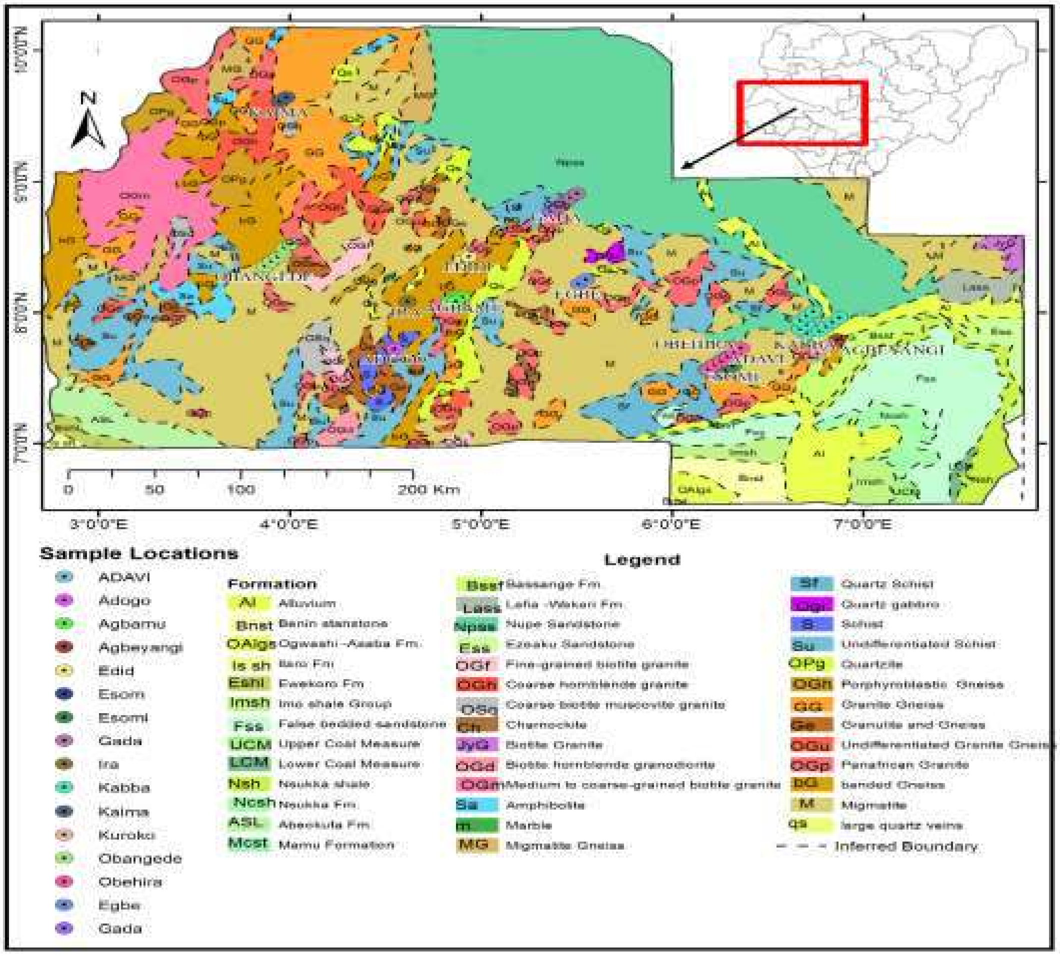

Figure 1: Selected Communities and their respective Geological Formation

MATERIALS AND METHODS

Vertical Electrical Sounding (VES)

A series of measurements of resistivity are made by increasing the electrode spacing in successive steps about a fixed point. This method of vertical exploration is known as the expanding electrode method, "Resistivity sounding" or "Depth probing" or Vertical Electrical Sounding (VES). Fifty-four (54) VES were acquired in nine (9) localities shown in Figure 1. The half-current spacing (AB/2) ranges between 0.5 – 256 m. Current was injected into the ground through two internal current electrodes (I) and the potential difference (ΔV) measured was measured through outer electrodes. The terameter displayed the resistance (R= ΔV/I), which was converted into apparent resistivity (ρa) by multiplying with appropriate geometric factor (K) using this relationship:

$$\rho a = \frac{\pi R\left(\frac{AB}{2}\right)^2}{MN}$$

The apparent resistivity values and corresponding AB/2 values were fed into IPI2WIN software which performs iteration process. When the field and model curves closely matched, the true resistivity values, thickness, and depth values displayed by the software were taken as reliable geo-electric parameters for the VES location. Generally, the

Root Mean Square Error (RMS) was not more than 4% for all the generated curves. The interpretation of the geo-electric parameters was done based on the knowledge of the geology of the area.

Water Chemistry

Thirty-three (33) groundwater samples were collected from wells at various locations across the nine local government areas. Physical parameters (pH,EC, Temperature, Static water level) of the water samples were measured on the field with handheld pH-Conductivity meter while samples for cations and anions determination were taken to the laboratory.For collection, preservation and analyses of the samples, the standard methods of American Standard for Testing Materials (ASTM, 1969), American Public Health Association (APHA, 1989) and Standard Organization of Nigeria (SON, 2007).were adopted.

Piper's diagram (1944) was used to classify the waters into respective water facies. The concentrations of the ions were compared with WHO (2011) and SON (2007) standards in order to evaluate their potability for drinking. Also, Kelley's ratio (KR)(1951), Sodium Adsorption ratio (SAR), Soluble Sodium Percent (SSP) were used to determine their suitability for irrigation.

$$KR = Na+ / Ca^{2+} + Mg^{2+;}$$

$$SAR = Na+ / \{(Ca^{2+} + Mg^{2+})\}1/2$$

$$SSP= (Na^{+}+ K^{+})/(K^{+}+Na^{+}+Ca^{2+}+Mg^{2+}) \times 100$$

RESULTS AND DISCUSSION

The area is underlain by 4- 5 layers of earth materials consisting of top soil, clayey soil/hardpan, clay/weathered/partly weathered layer, Fractured/Fresh basement, Fresh basement representing,1 – 5, respectively with varying thickness and depths.

Overburden thickness

Overburden thickness is an important indication of the presence of favourable groundwater availability in an area. In crystalline rocks such as granites, gneisses and schists, the groundwater reservoir is mainly determined by thickness of overburden material and to a lesser extent by the fractures in fresh rock. The area under study is summarised in Table 1, using Olayinka *et al* (1997) classification of aquifer potential as a function of depth to bedrock.The class of overburden thickness <10m (Kabba 3, Kabba1, Agbamu5, Agbamu4, Edidi1, Ira3, Ira1, Adogo1, Obehira1, Obehira5, Obehira4, Obehira3, Kuroko3, Kuroko4, Kuroko2, Esomi2, Esomi1, Kaima1, Adavi3, Adavi2, Adavi1, Gada4, Gada2, Gada1, Egbe2, Egbe1**)** accounts for 55.5% of the acquired VES points in the area and have poor aquifer potential. About 31% of the area falls within the low groundwater potential range, that is, the overburden thickness is between 10-20m. 9.3% of the area falls in the moderate potential range being 20-30m. It is expected that Kuroko1 and Obangede4 have a high groundwater potential since the overburden thickness is greater than 30m.

Table 1: Aquifer potential as a function of depth to bedrock (Olayinka *et al.*, 1997)

Depth to Bedrock (m)	Weighing	VES points with equivalent percentage coverage of the area
<10	Poor	Kabba 3, Kabba1, Agbamu5, Agbamu4, Edidi1, Ira3, Ira1,Adogo1, Obehira1,Obehira5, Obehira4, Obehira3, Kuroko3, Kuroko4, Kuroko2, Esomi2, Esomi1, Kaima1, Adavi3, Adavi2, Adavi1, Gada4, Gada2, Gada1, Egbe2, Egbe1 **55.5%**
10-20	Low	Adavi4, Kaima2, Esomi3, Obehira1, Obehira2, Edidi1, Agbamu2, Agbamu3, Kabba2, Kabba5, Kaba8, Kabba10, Obangede2, Obangede5 **31%**
20-30	Moderate	Ira 2, Obangede 3, Obangede1, Kabba9, Kabba4,Gada5 **9.3%**
>30	High	Kuroko1, Obangede4 **3.7%**

A contour map of the overburden thickness (Figure 2) indicated that about 60% of the study area has overburden thickness less than 15m. However, a few areas are promising with moderate groundwater potential and very few of the study area having high aquifer potential as evidence of the high thickness of weathered layer (overburden thickness).

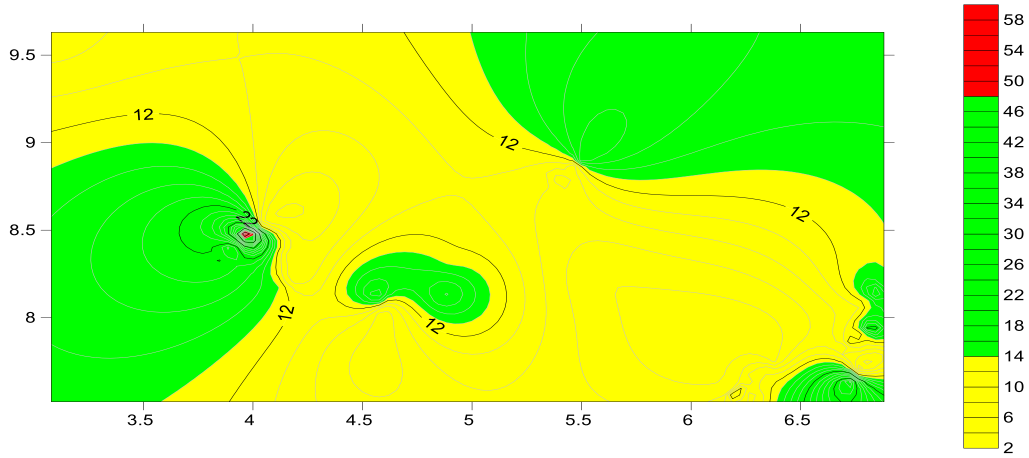

Figure 2: Overburden thickness map of the study area

Resistivity curve type

The resistivity sounding curve-types obtained from the surveyed area range from 4-5-layer curve types. HA curve type constituted 65% of the entire curve types and layers resistivity values in order of ρ1> ρ2< ρ3< ρ4 (Figure 3). The third layer and the fourth layer (where it is fractured) are the target groundwater drilling zones. Other curve types (QA, HQ, A, H) constitute the remaining 35%. Fig. 4 shows the bar chart representation of the curve types.

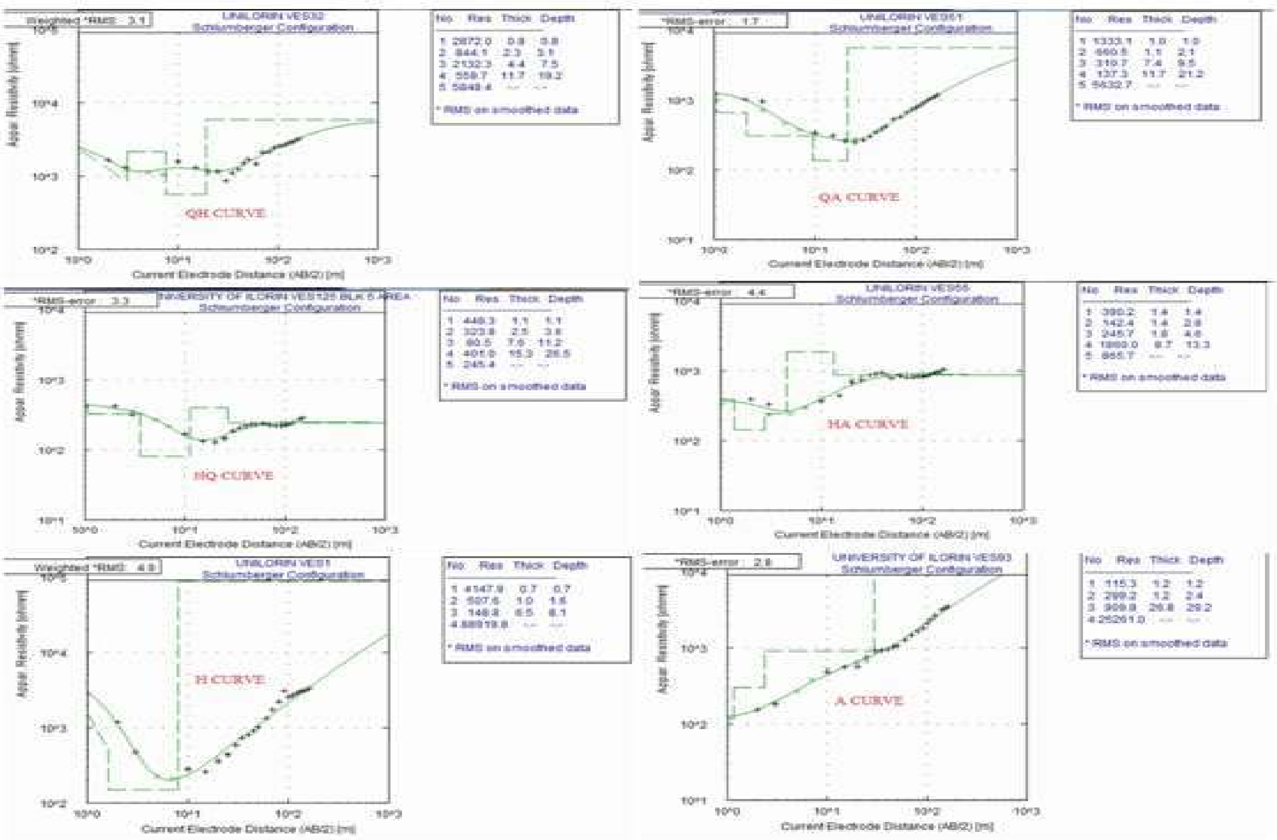

Figure 3: Typical curve types over the study area

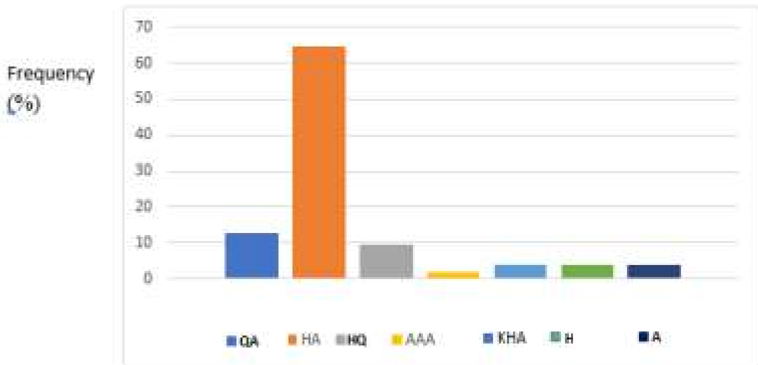

Figure 4: Bar chart showing the curve types

Aquifer thickness

The thickness of the aquifer is also an important factor in the ground system. The thickness of an aquifer may determine the quantity of groundwater that may be readily abstracted from it. Hence, good aquifer thickness is believed to be favourable for the accumulation of groundwater. Figure 5 is the 3D image of the aquifer thickness of the study area which shows that the aquifer thickens towards the East. This implies that groundwater accumulation is favourable towards the eastern part of the study area.

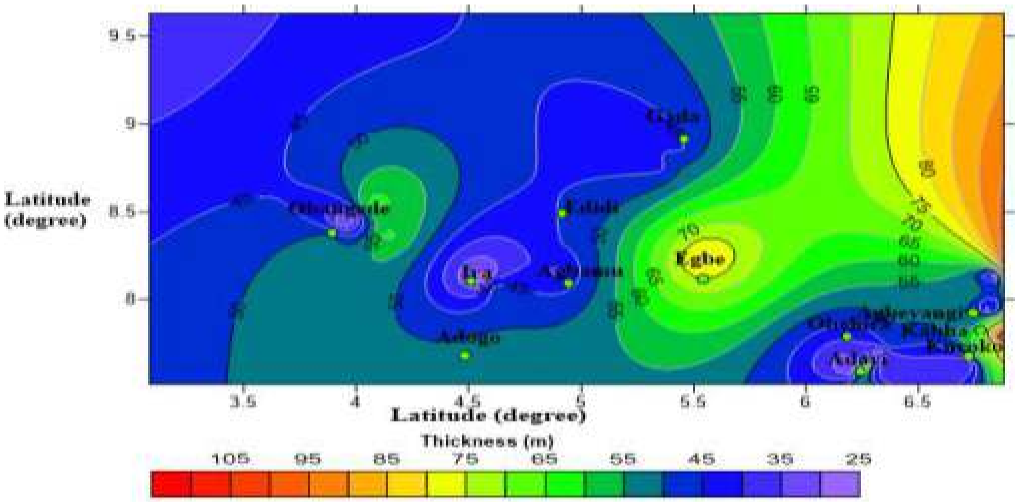

Figure 5: Aquifer thickness map

Bedrock topography of the study area

Bedrock topography helps in establishing the direction of the sideways flow of groundwater within the surface, and it is highly essential to groundwater studies. This is intended to help identify recharge and discharge regions in an area. Figure 6 is a 3-D image of the bedrock topography in the study area. The extreme eastern and mid-northern parts of the map have heights between 100-115m and are designated with blue colour.

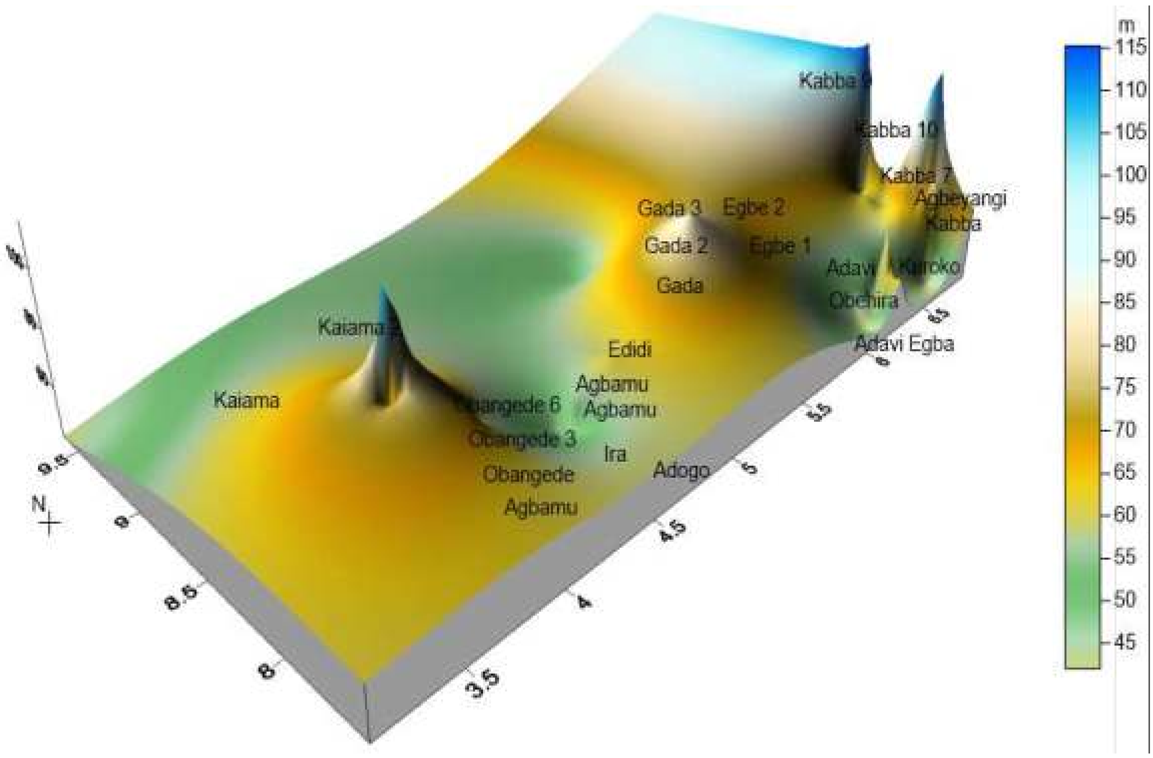

Figure 6: Bedrock topography map of the study area

Bedrock Resistivity Distribution of the study area

The bedrock resistivity map (Figure 7) of the aquifer unit depicts the manner of resistivity distribution in the study area. Resistivity values of the study area vary from 129-2303Ωm and it is expected that highly saturated regions should have characteristically low resistivity and vice versa, these areas of low resistivity values(<600Ωm) as revealed from the map cover a small percentage of the study area, which is in agreement with the groundwater potential (overburden thickness) map earlier discussed.

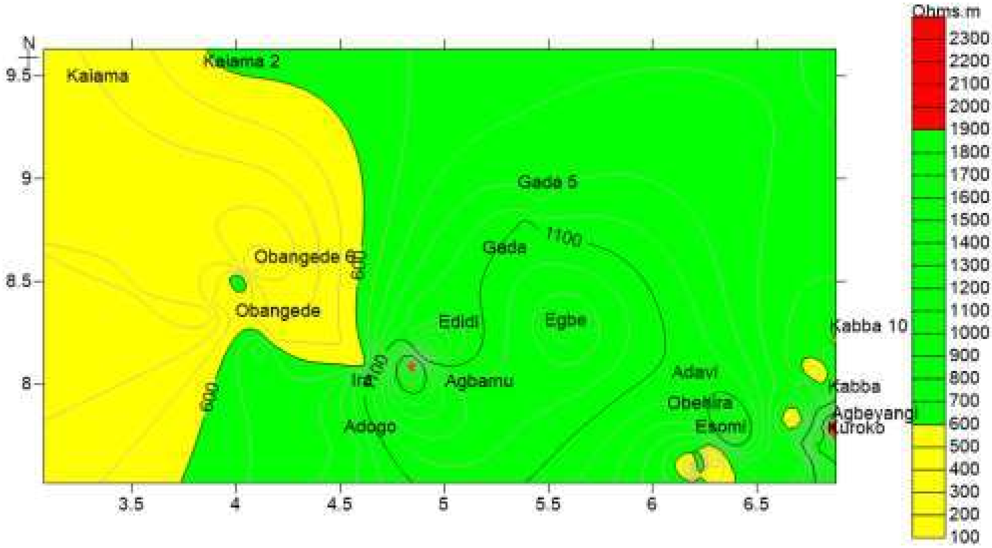

Figure 7: Resistivity distribution map of the study area

Groundwater Water Chemistry

Results of analyses of the chemical parameters at various locations are summarized in Table 2. Concentration of the cation, Ca^{2+}, Mg^{2+} and Na^{+}+ K^{+} ions ranges from 24.05-71.89, 13.39- 65.06 and 2.3-89.23mg/L respectively. While the anions, HCO_3^-, Cl^-, and SO_4^{2-} ranges from 6.67-99.53, 0.47-23.25 and 0-47.99 mg/L respectively. The hydrochemical characteristics reveal general cationic concentration in the order Ca^{2+}>Mg^{2+}>Na+K and anionic concentration in the order HCO_3^->Cl^->SO_4^2.The concentrations of cations and anions in the water samples are generally below the WHO (2011) and SON (2007) permissible limits and indicated that water across the study area is good and safe for drinking. Chemistry of groundwater is influenced by combination of atmospheric, biomass and dissolution of minerals from bedrock. However, bedrock dissolution of minerals plays the major role since contributions from atmospheric and biomass activities are negligible and ignored (Walther, 2009). Most granitic rocks contain feldspar, quartz, muscovite and biotite as major minerals. Potassium (K), Calcium (Ca), Magnesium (Mg)are common Alkaline earth metal with crustal abundance. During chemical decomposition of rocks, they go into solution more as carbonate or chloride (Kesavulu, 2014) to form Calcium Bicarbonate ($CaHCO_3$) or Magnesium Bicarbonate ($MgHCO_3$) or chloride.

Piper's diagrams (Figure 8) show dominant Ca-HCO_3 and Mg-HCO_3 water facies indicating their suitability for drinking purposes when compared with the WHO standard. The two dominant water types observed in the selected localities are shown in a water type map in Figure 9 below indicating water type per locality.

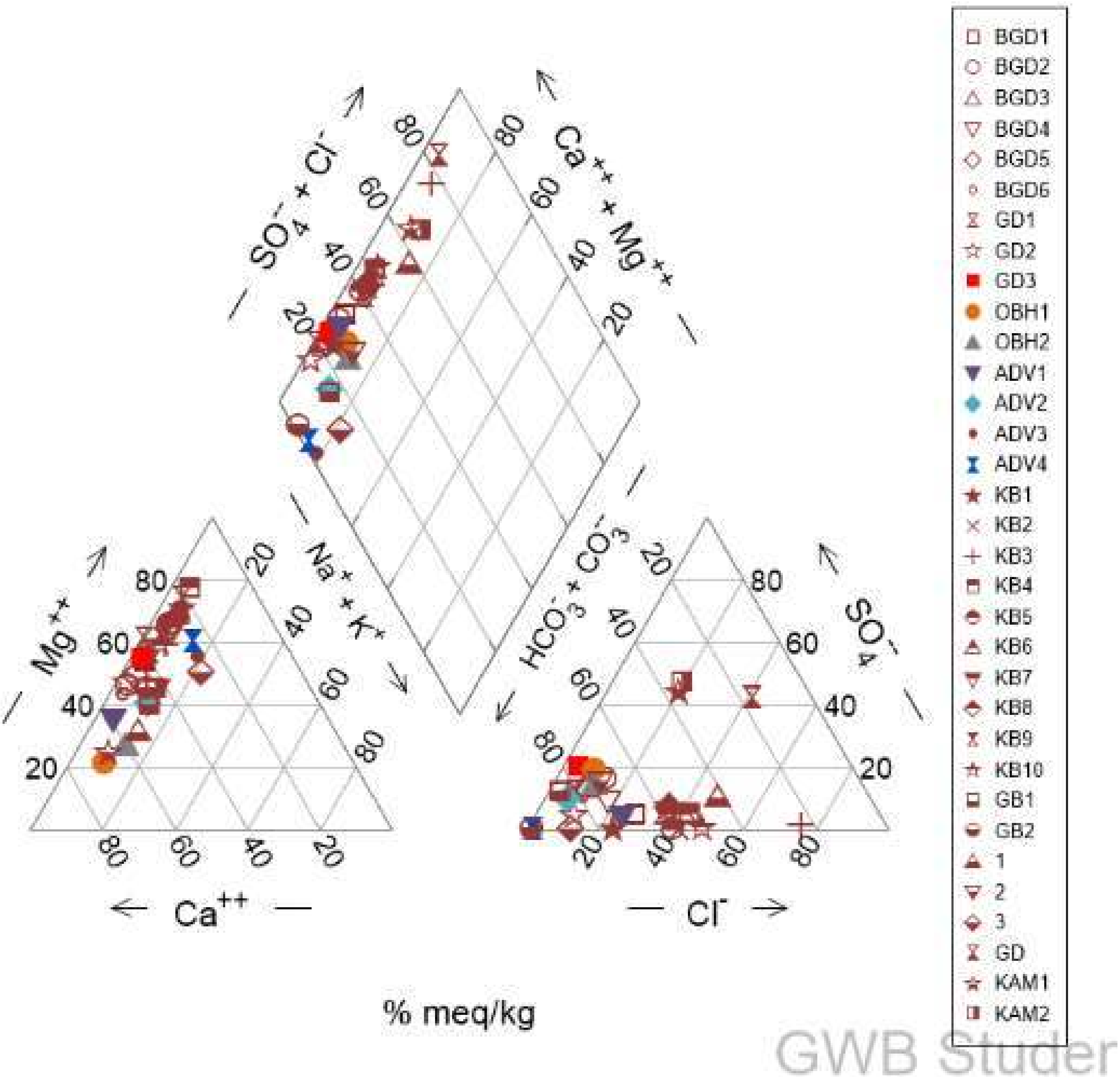

Figure 8: Positions of water samples on Pipers diagram

The concentration of hydrogen ions (pH) ranges between 6.9-7.4. All the water samples analyzed have concentrations within the safe limit of 6.5-8.5 standard set by WHO. Electrical conductivity is a good measure of salinity hazard to crops. Excess salinity reduces the osmotic activity of plants and thus interferes with the absorption of water and nutrients from the soil (Saleh *et al.*, 1999). The electrical conductivity(EC) values range from 25.3 – 142.8µs/cm while colour is generally clear. The two dominant water facies in the area are Ca-HCO_3 and Mg-HCO_3. The summary of water chemistry in the entire area is presented in Table2 below:

Table 2: Summary of Water Chemistry

Localities	Coordinates		Na+K (Mg/L)	Ca (Mg/L)	Mg (Mg/L)	$CO_3^{2-}+HCO_3^-$ (Mg/L)	SO_4^{2-} (Mg/L)	Cl^- (Mg/L)	Ca+Mg (Mg/L)	KR	SAR	SSP
	Northings	Eastings										
BGD1	N8 21' 12"	E3 52' 17"	8.55	51.34	40.11	87.24	2.41	10.34	91.45	0.047	0.632	8.55
BGD2	N8 23' 14"	E3 54' 19"	6.55	60.04	33.4	87.14	7.86	5	93.44	0.035	0.479	6.551
BGD3	N8 25' 16"	E3 56' 21"	6.6	50.4	43	90.7	6.07	3.21	93.4	0.035	0.483	6.6
BGD4	N8 27' 18"	E 3 58' 23"	7.94	50.6	41.4	89.12	4.56	6.32	92	0.043	0.585	7.945
BGD5	N8 29' 20"	E3 58' 23"	7.4	56.3	36.3	90.8	5.9	3.3	92.6	0.04	0.544	7.4
BGD6	N8 31' 22"	E3 60' 25"	6.26	62.6	31.1	87.9	8.9	3.2	93.7	0.033	0.457	6.263
GD1	N8 46' 23"	E5 22' 11"	2.32	49.4	48.3	91.9	5.38	2.7	97.7	0.012	0.166	2.32
GD2	N8 48' 25"	E5 24' 14"	4.59	60.7	34.7	94.39	2.04	3.57	95.4	0.024	0.332	4.59
GD3	N8 50' 27"	E5 26 '16"	6	52.5	41.5	89.06	9.45	1.49	94	0.032	0.438	6
OBH1	N7 33' 47"	E6 11' 34"	14.7	71.89	13.39	87.63	9.14	3.22	85.28	0.086	1.126	14.703
OBH2	N7 35' 49"	E6 13' 36"	15.42	50	13.39	89.23	6.67	4.17	63.39	0.122	1.369	19.566
ADV1	N7 33' 47"	E6 10' 47"	8.34	67.2	24.46	88.95	2.21	8.93	91.66	0.045	0.616	8.34
ADV2	N7 35' 49"	E6 12' 49"	20.1	52.91	26.98	93.71	4.18	2.09	79.89	0.126	1.59	20.102
ADV3	N7 37' 39"	E6 14' 51"	31.77	29.9	38.31	99.31	0	0.68	68.21	0.233	2.72	31.776
ADV4	N7 39' 41"	E6 16' 53"	25.89	30.21	43.88	99.39	0	0.6	74.09	0.175	2.127	25.895
KB1	N7 50' 13"	E6 42' 20"	12.66	30	57.33	91.59	0	8.4	87.33	0.072	0.958	12.661
KB2	N7 52' 13"	E6 40' 18"	12.18	31.56	56.25	82.39	0	17.6	87.81	0.069	0.919	12.181
KB3	N7 54' 15"	E6 42' 20"	13.54	41.67	44.79	50.48	1.54	47.99	86.46	0.078	1.03	13.54
KB4	N7 56' 17"	E6 40' 22"	10.88	24.05	65.06	78.44	2.97	18.59	89.11	0.061	0.815	10.881
KB5	N7 58' 19"	E6 42' 24'	10.15	38.07	51.78	83.49	0	16.5	89.85	0.056	0.757	10.15
KB6	N7 60' 21"	E6 44' 26"	11.6	33.51	54.89	79.72	2.79	17.48	88.4	0.066	0.872	11.6
KB7	N7 51' 23'	E6 46' 28"	13.57	35.33	51.1	82.37	2.43	15.19	86.43	0.079	1.032	13.57
KB8	N7 53' 25"	E6 48' 30"	11.26	38.46	50.27	81.14	3.89	14.97	88.73	0.063	0.845	11.261
KB9	N7 55' 27"	E6 50' 32"	12.81	38.99	48.19	82.91	2.85	14.2	87.18	0.073	0.97	12.811
KB10	N7 57' 29"	E6 52' 34"	11.39	43.04	45.57	77.92	0.43	21.65	88.61	0.064	0.856	11.39
GB1	N8 13' 00"	E5 31' 00"	20.53	52.63	26.84	93.71	5.24	1.05	79.47	0.129	1.628	20.53
GB2	N8 15' 02"	E5 33' 02"	16.04	52.24	31.72	99.53	0	0.47	83.96	0.096	1.238	16.04
IR1	N8 4' 59"	E4 36' 59"	21.92	57.98	20.17	70.06	6.69	23.25	78.15	0.14	1.753	21.905
IR2	N8 4' 57"	E4 36' 57"	20.57	48.39	31.05	88.59	7.67	4.62	79.44	0.129	1.632	20.568
IR3	N8 2' 55"	E4 34' 55"	35.12	30.95	33.93	96.07	0	3.93	64.88	0.271	3.083	35.12
GD4	N8 52' 29"	E5 28' 18"	10.02	28.53	61.44	7.49	7.49	5.48	89.97	0.056	0.747	10.021
KAM1	N9 36' 20"	E3 57'00"	14.23	70.07	15.69	60.83	29.38	9.79	85.76	0.083	1.087	14.231
KAM2	N9 38' 22"	E3 59'02"	19.88	48.96	31.16	57.72	32.46	9.82	80.12	0.124	1.57	19.88
WHO (2011)				75	50	500	200	200				
SON (2007)				100	50	500	150	250				

KR: Kelley's Ratio, SAR: Sodium Absorption Ration; SSP: Soluble Sodium Percent

Suitability for Agricultural Purpose

The suitability of the water for irrigation were evaluated using Sodium Adsorption Ratio, (SAR), Soluble Sodium Percentage (SSP) and Kelley's Ratio (KR) (Table 3). ***Kelley's Ratio*** (>1) indicates an excess level of sodium in water which is unsuitable and < 1 is suitable for irrigation uses. The water samples have KR value range of (0.012 – 0.23), thus in "Permissible range" and suitable for irrigation. ***Sodium Adsorption Ratio*** (SAR) indicates sodium hazard in water. It paints a clear picture of absorption of sodium by soil. If water used for irrigation is high in Na^+ and low in Ca^{2+} the ion-exchange complex may become saturated with Na+ which destroys the soil structure, due to the dispersion of the clay particles (Todd, 1980) and reduces the plant growth. The SAR for the water samples range from 0.16 – 3.08. According to Bara *et al* (2008), only water with SAR <3 has no restriction to be used for irrigation purpose hence almost all the water samples can be used for irrigation purpose. ***Soluble Sodium Percentage (SSP)*** is an important factor for studying sodium hazards. Sodium has the potential of reacting with soil thereby reducing its permeability and supports little or no plant growth. According to Hwang classification (2016), SSP <20, 20 – 40, 40 – 80 and >80 represent excellent, good, fair and poor for irrigation respectively. The SSP of the water samples range from 2.32 – 35.12, thus fall in excellent to good class for irrigation purpose.

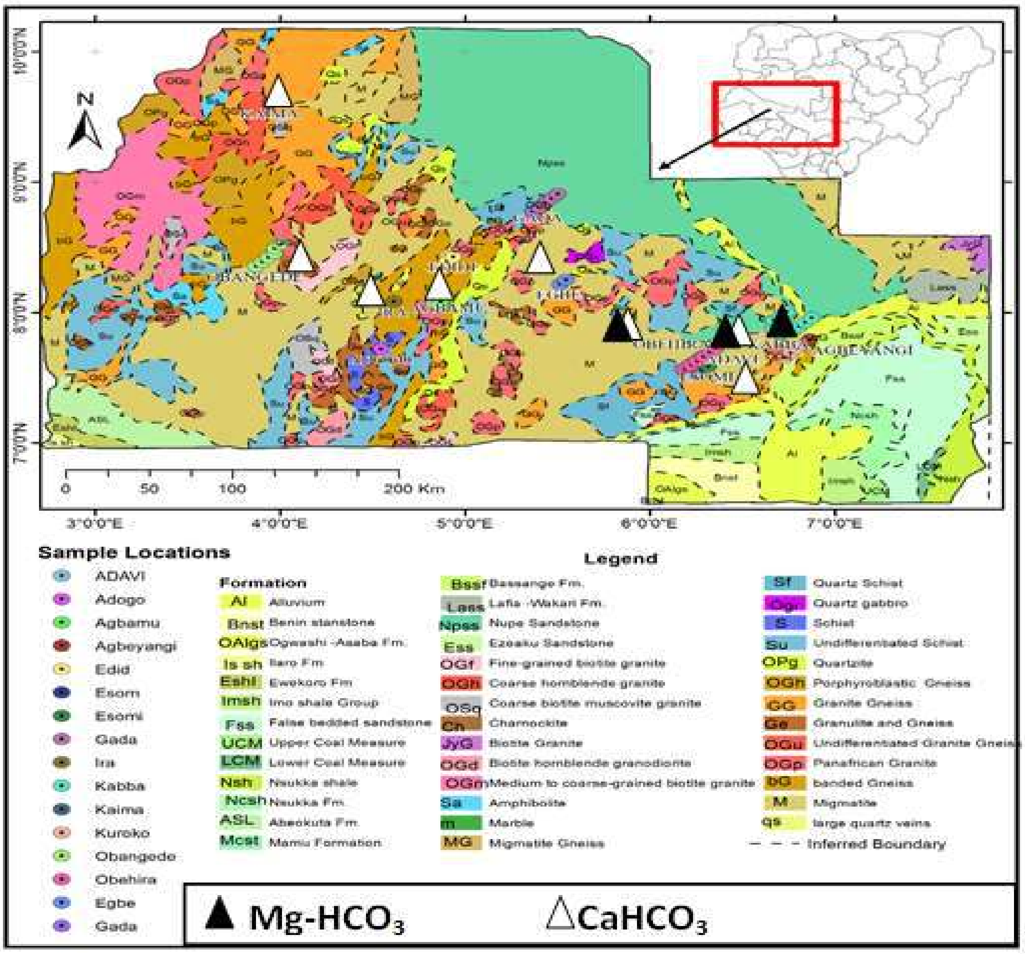

Figure 9: Distribution of the water types over the geological terrains

CONCLUSION

Preliminary assessment of groundwater availability and chemistry of some groundwater sample in the study area revealed 4-5 geoelectrical layers consisting of top-soil, lateritic clay layer, the weathered/fractured basement and the fresh basement. Thicknesses of overburden material vary spatially, with some communities having <10m (accounts for 55.5% of the acquired VES points in the area) and suggesting poor aquifer potentialwhileKuroko1 and Obangede4 have high groundwater potential because of deeper thickness of weathering. Electrical resistivity sounding curve -types obtained from the surveyed area range from 4-5-layer curve types. HA curve is the most dominant curve with about over 65% frequency while QA, HQ, HQ, A and H account for 35%. The third layer and the fourth layer (where it is fractured) are the target groundwater drilling zones. 3D image of the aquifer thickness of the study area shows that the aquifer thickens towards the East. Bedrock resistivity distribution shows that Obangede, Kabba and Kaima areas have low values (100-500Ωm) of resistivity which encourages groundwater accumulation. Chemical assessment of groundwater shows that concentration of the cation, Ca^{2+}, Mg^{2+}, Na^{+}+, K^{+} ions ranges from 24.05-71.89, 13.39-65.06, 2.3-89.23 mg/L respectively. While the anions, HCO_3^-, Cl^-, and SO_4^{2-} ranges from 6.67-99.53 ,0.47-23.25, and 0- 47.99 mg/L. Hydrochemical characteristics revealed general cationic concentration in the order Ca^{2+}>Mg^{2+}>(Na+K) while the anionic concentration is in the order of HCO^-_3>Cl->SO^2_4. Piper Trilinear diagram showed dominant Ca-HCO^-_3 and Mg-HCO^-_3 water facies that suggest principally chemical contribution from geogenic influence. Results from the assessment of Kelley's ratio (<1), Sodium Absorption ratio (<3) and Soluble Sodium Percentage (2.32 – 35.12) confirmed the suitability of analyzed water samples to be suitable for irrigation because they have values within recommended permissible limits. Thus, majority of the water samples are suitable for drinking and irrigation purpose based on some hydrochemical parameters of groundwater.

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