

The Suitability of Groundwater for Domestic and Irrigation Purposes: A Case Study of Ikere-Ekiti, SW-Nigeria

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Abstract— Shallow groundwater in Ikere-Ekiti was assessed for potability and irrigation employing chemical and bacterial analyses. Twenty two groundwater samples were collected and analyzed using Atomic absorption spectrometer for cations and ion chromatographic method for anions determinations ($^{\circ}\text{C}$), pH and electrical conductivity (EC) ($\mu\text{S}/\text{cm}$) were measured in the field using pH Testr meter. The bacteriological analysis was carried out using nutrient agar medium to obtain plate count of living bacteria. Results of the analysis revealed that all EC values were less than $1000\mu\text{S}/\text{cm}$ indicating fresh water. The pH with average values of 9.48, 7.82 and 7.44 in migmatite, granite and charnockitic terrains respectively exceeded the approved standard (6.5 – 8.5) for drinking water in two samples from migmatite, one sample from granitic terrain and none from the charnockites. Sodium was the dominant cation with average concentrations (mg/L) of 95.65, 38.33 and 6.61 in migmatite, granite and charnockite respectively while K^{+} ions in the same order of rock units have average concentrations (mg/L) of 60.49, 32.33 and 15.77. The average concentrations (mg/L) of Ca^{2+} ions in groundwater located on migmatite, granite and charnockitic terrains were 36.67, 24.63 and 10.98 respectively while those for Mg^{2+} were 9.94, 7.48 and 4.57. The order of cation abundance was $\text{Na}^{+} > \text{K}^{+} > \text{Ca}^{2+} > \text{Mg}^{2+}$. In respect of the major anions, Cl^{-} was dominant with average concentrations (mg/L) in charnockites (187.20) within approved standard of 250mg/L while the average values (mg/L) in migmatite (475.2) and granite (340.62) exceeded the standard value. Following the same sequence of rock units, HCO_3^{-} average concentrations (mg/L) were 34.6mg/L, 27.07mg/L and 25.7. Sulphate and nitrate were less dominant ions and the order of anions abundance in the groundwater was $\text{Cl}^{-} > \text{HCO}_3^{-} > \text{SO}_4^{2-} > \text{NO}_3^{-}$. Bacteria evaluation revealed that all sampled groundwater tested positive to bacteria with TBC values (CFU/100ml) ranging from 1.76×10^8 to 1.78×10^9 in migmatite, 5.3×10^5 to 8.9×10^8 in granite and 2.55×10^7 to 8.2×10^8 in charnockite. Gibb's diagram revealed that chemical weathering of rock-forming minerals has contributed to

solute source in the groundwater of the area. Water type on migmatite was mainly NaCl while granite and charnockite had NaCl and CaCl types revealing lithologic effects. Irrigation water quality assessment employing Sodium absorption ratio (SAR), Soluble sodium percent (SSP), Residual sodium bicarbonate (RSBC) and Permeability index (PI) revealed that the groundwater is suitable for irrigation purpose. Groundwater in the study area is low mineralized, chemically potable, suitable for irrigation but infected by bacteria pollutants. Differences in rock types affected the chemistry of the groundwater as reflected in their physico-chemical compositions, water facies and irrigation quality.

Keywords— Rock units, groundwater, potable, bacteria, irrigation.

I. INTRODUCTION

All over the world, population surge, industrialization and rising standards of living have put water demand on the rise; though without corresponding increase in the required quantity of the resource (Ali 2012). Records of population in Nigeria revealed that the population of the study area (Ikere-Ekiti) was 59,257 in 1963, 114,780 in 1991 and 147,355 in 2006 (NPC 2006). The population of the area will continue to increase considering the fact that the study area is the gateway to Ekiti-State and its nearness to Ado-Ekiti, the state capital has resulted into human migration into the town. With increasing population and reduction in surface water supply during the dry season and contamination by floods during the rainy season, the increase in demand for domestic water can only be met through digging of localized shallow wells that tap the small discrete bodies of groundwater present in the weathered zone of basement terrains of the area. In addition to the above crucial factors, the rock types in an area, particularly the thickness of their weathered products/fracture characteristics and rainfall contribute greatly to the chemistry of its groundwater. This in essence determines groundwater suitability for domestic, agricultural and industrial application. As groundwater migrates, it reacts with the minerals that

make up the host-rocks. These mineral may be soluble and percolate into the groundwater system thereby altering the exisisting geochemical characteristics of the groundwater. It is obvious that groundwater can be contaminated through natural processes such as chemical weathering and dissolution (Abimbola et al. 2002; Amadi et al. 2015). Thus, water- rock interactions alter greatly the chemistry of groundwater apart from contributions from anthropogenic contaminants. Groundwater is generally preferred to surface water due to natural protection from pathogenic contamination and buffer against climatic variability. At Ikere-Ekiti, access to groundwater provides the only realistic option for a sustainable safe drinking water supply. The town has sizable numbers of boreholes and wells which if properly managed will serve as recipe to safe drinking water.

Specific publications on the study area are few. Odeyemi et al. (2011) worked on Bacteriological, Physicochemical and Mineral Studies of Water Samples from Artesian bore-hole, spring and Hand dug well located at Oke-Osun of the study area and concluded that the groundwater was contaminated by bacteria. Aturamu (2012) also concluded that the groundwater at Ikere-Ekiti was contaminated bacteriologically. Similar researches in other parts of Ekiti-State (Omotoyinbo 2007; Ayodele and Aturamu 2011) as well as the work of Talabi and Ogundana (2014) covering the whole state also revealed bacterial contamination of groundwater.

Groundwater regime is dynamic and possible amelioration of bacterial contamination of groundwater in the area cannot be ruled out especially with recent health education in the state. However, according to World Health Organization (2004) about 85% of communicable diseases are water borne or water related. The quality of groundwater in an area is a function of its chemistry and the nature of the aquifer characteristics (Amadi et al. 2015). Groundwater quality appraisal is gaining importance, due to intense urbanization, industrialization and agricultural activities putting the soil and groundwater to greater risk of contamination (Sayyed and Wagh, 2011; Tiwari 2011). Water pollution also threats human health, economic development and social prosperity (Milovanovic 2007).

This study was tailored towards assessing the suitability of groundwater at Ikere-Ekiti for domestic and irrigation purposes. The research attempted deciphering the effects of rock units on the chemistry of the groundwater and discussed potential adverse chemical/health effects of the groundwater on domestic uses and irrigation.

II. LOCATION, GEOLOGY AND

HYDROGEOLOGY OF THE STUDY AREA

Ikere-Ekiti is situated in the southern part of Ekiti-State, southwestern Nigeria between latitudes 7° 29' and 7°

31'N and longitudes 5° 12' and 5° 14'E covering a total area of 346.5 km². It is a town endowed with magnificent hills, including Orole and Olosunta. The town is the gateway to Ekiti State, located between Ado-Ekiti (the capital of Ekiti State) and Akure (the capital of Ondo State) (Fig. 1). The town is situated in the humid tropical region and rugged basement terrain that is generally 250m above sea level. The mean annual rainfall is 1500mm while the annual temperature ranged from 23 - 28°C with mean annual relative humidity of 75%.

Geologically, Ikere-Ekiti is underlain by crystalline igneous and metamorphic rocks of the Precambrian basement complex. The area is made up of migmatite-gneiss quartzite complex, charnockites and Older granites. The Precambrian basement complex was affected by the Pan-African orogeny (600Ma±150Ma) thereby occupying the re-activated region which resulted from the plate collision between the passive continental margin of the West African Craton and the active Pheurasian continental margin (Burke and Dewey 1972; Dada 2006).

The migmatite-gneiss complex is the most widespread and abundant rock type in the Basement Complex into which other successions of rocks have been emplaced (McCurr 1973; Rahaman 1988).

The Older Granites and charnockites occur as intrusive bodies of various dimensions in the pre-existing basement rocks, that is, the migmatite-gneiss units and the schist belts. One striking feature of the older granites is their occurrence as picturesque inselbergs and such prominent hills rising sharply above their surrounding plains in the study area include Olsunta and Orole hills. The charnockitic rocks outcropped as oval or semi-circular hills of between five and ten meters (10m) high with a lot of boulders at some outcrops. Most of the charnockitic rocks in the study area occur along the margins of Older Granites bodies especially the porphyritic granites. Differential weathering occurs on each rock unit due to difference in mineralogical and chemical composition and consequently, groundwater occurrence is localized and these variations may result into differences in groundwater chemistry based on rock units.

The major surface water in the study area is river Osun rising from the hills at the western end of the area with highest topographical point of 598m above main sea level. River Owururu is a major tributary which along with other tributaries/streams meander through intersecting valleys. The volume of water in the streams depends on the response to wet and dry seasons. During the rainy season, there is a great increase in water volume in the major rivers while there is hardly water in some of the streams during the dry season. Rainfall is the dominant factor that determines the occurrences of groundwater. Rainy season, in the area is characterized

with high amount of uniform rainfall with the pick in August and the lowest in November. Differential weathering occurs on each rock unit due to difference in mineralogical and chemical composition and consequently, groundwater occurrence is localized which may result into differences in groundwater chemistry based on rock units.

III. METHODOLOGY

The sampling of groundwater in this research was based on the three major rock units (migmatite, granite and

charnockite) in the study area. Prior to groundwater sampling, reconnaissance survey of the study area was carried out to decide on the number of samples per rock unit and the number was based on the spread of a specific rock outcrop in the area. Granite predominates with 13 water samples, followed by charnockites with 5 samples while migmatite has the least with only 4 samples. Three set of groundwater samples put in one liter pre-washed polyethylene bottles) were obtained per location following standard sampling procedure (Stednick 1991).

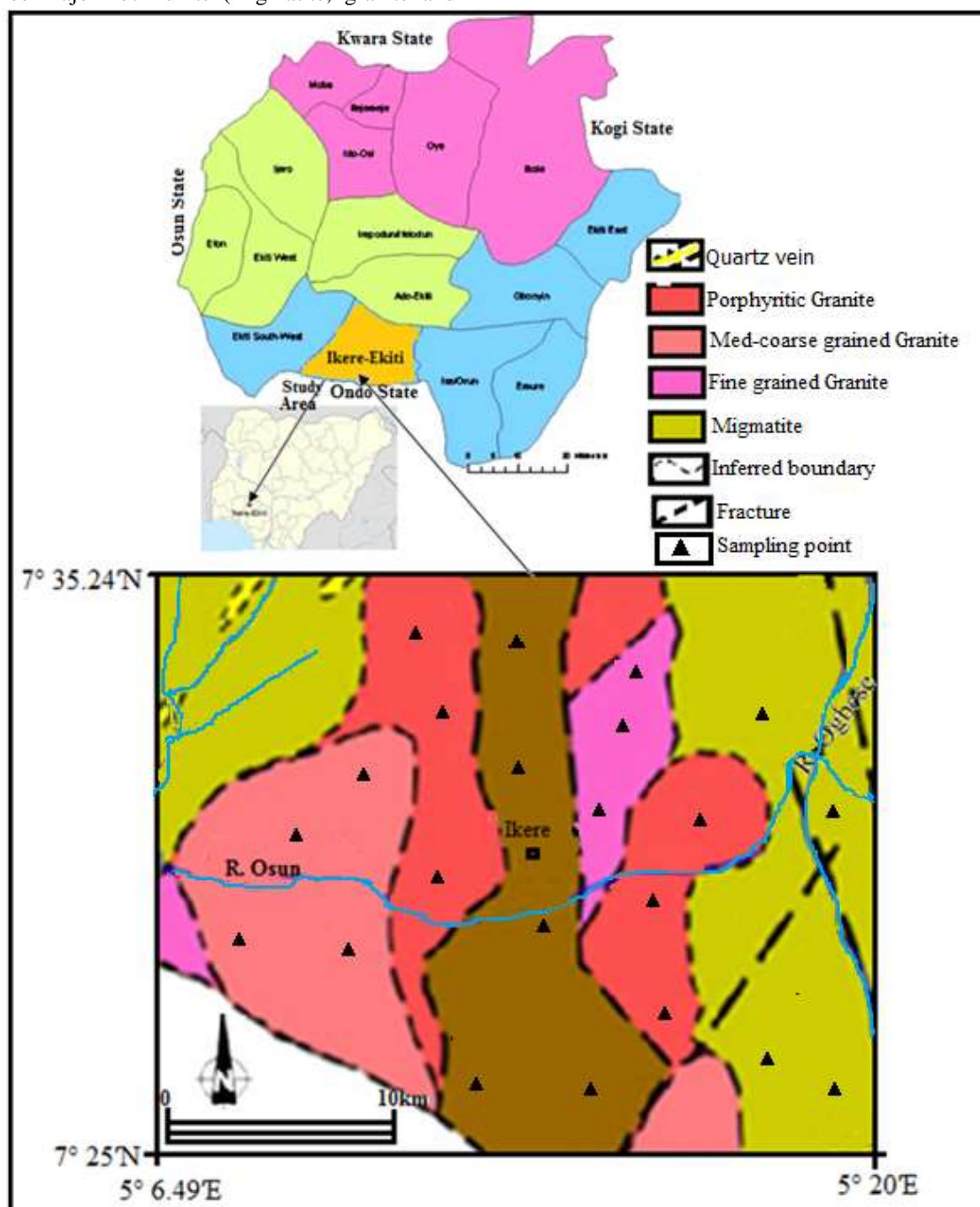


Fig.1: Location and Geology of the of Study Area

The three set of samples were for cations, anions and bacterial analyses respectively. Water samples for cations

determination were acidified to a pH<4 using concentrated Nitric acid and all samples were preserved (refrigerated) prior to analyses.

Temperature, pH and EC of water samples were measured in-situ employing portable pH Testr meter. In addition, water level and depth of sampled wells were measured using dip-meter. TDS was estimated in this research employing the relationship that:

$$\text{TDS} = \text{EC} * 0.75. \quad (1)$$

While total hardness (TH) was calculated using the relation:

$$\text{TH} = 2.5\text{Ca}^{2+} + 4.1\text{Mg}^{2+} \text{ (Fournier, 1981)} \quad (2)$$

In this research all laboratory analyses were carried out at Fatlab Nigeria Company limited, Ibadan Nigeria. Ions analyses were carried out using Atomic absorption spectrometer for cations and ion chromatographic method for anions determinations.

The basic criterion by which the sanitary quality of water may be judged is the kind and number of bacteria present in it. The presence of the coliform group of bacteria in water is accepted traditionally as an indication of pathogenic content particularly *Escheria coli* which are normal inhabitants of the large intestine of human beings and other animals and are consequently present in faeces. The samples were analyzed for bacteria count employing nutrient organ medium to obtain plate count of living bacteria.

Furthermore, the data from the hydrochemical analysis were subjected to evaluation for irrigation purpose employing sodium adsorption ratio (SAR) (Richard 1954), soluble sodium percentage (SSP) (Todd 1980), residual sodium bicarbonate (RSBC) (Gupta 1983), Kelly's ratio (KR) (Kelly 1963), permeability index (PI) (Doneen 1964) and magnesium adsorption ratio (MR) (Raghunath 1987). The irrigation parameters in this study were estimated employing:

$$\text{SAR} = \frac{\text{Na}^+}{\sqrt{(\text{Ca}^{2+} + \text{Mg}^{2+})/2}} \quad (3)$$

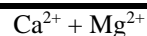
$$\text{SSP} = \frac{\text{Na}^+ + \text{K}^+}{\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+} \quad (4)$$

$$\text{RSBC} = \text{HCO}_3^- - \text{Ca}^{2+} \quad (5)$$

$$\text{KR} = \frac{\text{Na}^+}{\text{Ca}^{2+} + \text{Mg}^{2+}} \quad (6)$$

$$\text{PI} = \frac{\text{Na}^+ + \sqrt{\text{HCO}_3^-} \times 100}{\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+} \quad (7)$$

$$\text{MAR} = \frac{\text{Mg}^{2+} \times 100}{\text{Ca}^{2+} + \text{Mg}^{2+}}$$



Furthermore, the sodium in irrigation waters denoted as per cent sodium was determined using the following formula (Wilcox 1995);

$$\% \text{Na} = (\text{Na}^+) \times 100 / (\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+) \quad (8)$$

where the quantities of Ca^{2+} , Mg^{2+} , Na^+ and K^+ are expressed in milliequivalents per litre (epm). Data obtained from the analysis were subjected to statistical evaluation employing Microsoft excel software.

IV. RESULTS AND DISCUSSION

The results of the physical parameters of sampled groundwater from the study area are presented in Table 1 while those for the chemical concentrations are in Table 2. Wells depths revealed average values of 6.03m, 7.35m and 5.5m in wells located on migmatite, granite and charnockite respectively. The depth values showed that all the wells are shallow and the depth is a reflection of the degree of weathering in the study area. The physical parameters (EC, TDS and TH) have low values that are within WHO (2004) approved standard for drinking water. The pH values signified alkaline water. The pH concentrations were greater than 7 in all the groundwater samples and exceeded the approved WHO standard of 6.5 – 8.5 in two samples from migmatite. Only one sample from granitic terrain exceeded the standard value of WHO while all samples from charnockite fell within the value. In similar trends, all measured chemical parameters have concentrations within WHO (2004) approved standard. Water in the area is chemically potable. EC ($\mu\text{S}/\text{cm}$) on migmatite gneiss, granite and charnockite ranged from 598 – 650, 83 – 998 and 76 – 347 while TH (mg/L) on the same rock units was from 111 – 256, 33 – 268 and 16 – 87 respectively. These trends clearly revealed that rock units affected the chemistry of groundwater in the study area. Migmatite gneiss appeared to have more dissolved constituents with an average EC value of 629.5 ($\mu\text{S}/\text{cm}$) while this was followed by granite (av. 383.62 $\mu\text{S}/\text{cm}$) and charnockite (195.20 $\mu\text{S}/\text{cm}$) respectively (Fig.2A). The relatively high value of dissolved substances in migmatite gneiss reflects the mixed nature of the rock. All EC and TDS values irrespective of rock units were less than 1000 $\mu\text{S}/\text{cm}$ and 500 mg/L . Water can be classified into fresh (TDS <1,000 mg/L), brackish (TDS >1,000 mg/L), saline (TDS >10,000 mg/L) and brine (TDS >100,000 mg/L) categories on the basis of TDS concentrations (Freeze and Cherry, 1979). Based on this classification, the groundwater of the study area belongs to fresh water.

The total hardness (TH) represents the properties of water that prevents the lather formation with soap and causes increase in the boiling point of water. 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. Hard water is not suitable for domestic purpose. Water hardness has no known adverse effects; however, some evidence indicates its role in heart disease (Schroeder 1960). McGowan (2000) indicated that water containing calcium carbonate at concentrations below 60 mg/L is generally considered as soft; moderately hard (60–120 mg/L), hard (120–180

mg/L) and very hard (>180 mg/L). Thus groundwater on migmatite gneiss was in the moderately hard to very hard category while the groundwater from granite and charnockite fell into soft to very hard and soft to moderately hard classes respectively. Sixty percent (60%) of groundwater from charnockitic terrain fell into the soft water category while the remaining 40% were in moderately hard class.

Table.1: Physical parameters of groundwater from the study area.

| Code | Rock type | EC ($\mu\text{S/cm}$) | TDS (mg/L) | Temp ($^{\circ}\text{C}$) | pH | TH (mg/L) | Water | Depth (m) |
|--------------|-------------|-------------------------|------------|-----------------------------|-----------|-----------------|-----------|-----------|
| | | | | | | CaCO_3 | level (m) | |
| ID 1 | Mig. gneiss | 640 | 480 | 25.7 | 9.7 | 154 | 2.75 | 6.2 |
| ID 2 | Mig. gneiss | 598 | 448.5 | 26.4 | 9.6 | 111 | 3.3 | 5.1 |
| ID3 | Mig. gneiss | 630 | 473 | 25.8 | 9.2 | 256 | 4.2 | 5 |
| ID4 | Mig. gneiss | 650 | 488 | 26.2 | 9.4 | 219 | 2.6 | 7.8 |
| | Min | 598 | 448.5 | 25.7 | 9.2 | 111 | 2.6 | 5 |
| | Max | 650 | 488 | 26.4 | 9.7 | 256 | 4.2 | 7.8 |
| | Mean | 629.5 | 472.38 | 26.03 | 9.48 | 185 | 3.21 | 6.03 |
| | Stdev | 22.53 | 17.06 | 0.33 | 0.22 | 65.03 | 0.72 | 1.3 |
| ID5 | Granite | 84 | 63 | 27.6 | 8.2 | 154 | 6.3 | 9.9 |
| ID 6 | Granite | 315 | 236.25 | 25.9 | 7.8 | 111 | 10.95 | 11.3 |
| ID 7 | Granite | 106 | 79.5 | 27.1 | 7.3 | 256 | 6.45 | 7 |
| ID 8 | Granite | 180 | 135 | 26.4 | 7.3 | 219 | 10.1 | 14.2 |
| ID 9 | Granite | 83 | 62.25 | 26.1 | 7.3 | 111 | 5.2 | 6.2 |
| ID 10 | Granite | 261 | 195.75 | 28.4 | 7.2 | 154 | 4.5 | 10.9 |
| ID 11 | Granite | 998 | 748.5 | 27.8 | 8.2 | 268 | 2.9 | 5.9 |
| ID 12 | Granite | 817 | 612.75 | 27.4 | 7.3 | 172 | 7.7 | 8.3 |
| ID 13 | Granite | 876 | 657 | 27.4 | 8.6 | 155 | 1.45 | 2.65 |
| ID 14 | Granite | 187 | 140.25 | 28.1 | 8.3 | 33 | 4.3 | 5.25 |
| ID 15 | Granite | 285 | 213.75 | 28.6 | 7.9 | 101 | 4.2 | 4.7 |
| ID 16 | Granite | 621 | 465.75 | 28.7 | 7.8 | 147 | 2.7 | 6.6 |
| ID 17 | Granite | 174 | 130.5 | 27.7 | 8.5 | 56 | 2.1 | 2.6 |
| | Min | 83 | 62.25 | 25.9 | 7.2 | 33 | 1.45 | 2.6 |
| | Max | 998 | 748.5 | 28.7 | 8.6 | 268 | 10.95 | 14.2 |
| | Mean | 383.62 | 287.71 | 27.48 | 7.82 | 149 | 5.3 | 7.35 |
| | Stdev | 325.94 | 244.45 | 0.91 | 0.51 | 69.69 | 2.94 | 3.45 |
| ID 18 | Charnockite | 283 | 212.25 | 26.6 | 8.1 | 74 | 3.2 | 4 |
| ID 19 | Charnockite | 347 | 260.25 | 26.7 | 7.5 | 87 | 6.9 | 7 |
| ID 20 | Charnockite | 134 | 100.5 | 26.9 | 7 | 18 | 6 | 6.5 |
| ID 21 | Charnockite | 136 | 102 | 26.6 | 7.6 | 37 | 2.5 | 5.3 |
| ID 22 | Charnockite | 76 | 57 | 27.4 | 7 | 16 | 3.58 | 4.7 |
| | Min | 76 | 57 | 26.6 | 7 | 16 | 2.5 | 4 |
| | Max | 347 | 260.25 | 27.4 | 8.1 | 87 | 6.9 | 7 |
| | Mean | 195.2 | 146.4 | 26.84 | 7.44 | 46 | 4.44 | 5.5 |
| | Stdev | 114.25 | 85.69 | 0.34 | 0.46 | 32.57 | 1.91 | 1.24 |
| | WHO (2004) | 1500 | 1000 | - | 6.5 – 8.5 | 500 | - | - |

Table.2: Chemical parameters of groundwater from the study area.

| Code | Ca ²⁺ (mg/L) | Mg ²⁺ (mg/L) | K ⁺ (mg/L) | Na ⁺ (mg/L) | Cu (mg/L) | NO ₃ (mg/L) | SO ₄ ²⁻ (mg/L) | HCO ₃ ⁻ (mg/L) | Cl ⁻ (mg/L) | TBC (CFU/100ml) |
|--------------------|----------------------------|----------------------------|--------------------------|---------------------------|--------------|---------------------------|---|---|---------------------------|----------------------|
| Migmatite | | | | | | | | | | |
| ID1 | 43.21 | 11.23 | 62.53 | 97.84 | 0.1 | 1.86 | 2.8 | 36.6 | 475.2 | 1.78X10 ⁹ |
| ID2 | 30.12 | 8.65 | 58.45 | 93.45 | 0.02 | 0.71 | 2 | 32.6 | 475.2 | 1.4X10 ⁹ |
| ID3 | 67.6 | 21.2 | 64.4 | 98.8 | 0.06 | 1.6 | 3.2 | 34.6 | 485.2 | 1.62X10 ⁹ |
| ID4 | 58.6 | 17.8 | 60.4 | 94.8 | 0.01 | 2.8 | 2.8 | 36.2 | 464.5 | 1.76X10 ⁸ |
| Min | 30.12 | 8.65 | 58.45 | 93.45 | 0.02 | 0.71 | 2 | 32.6 | 475.2 | 1.76X10 ⁸ |
| Max | 43.21 | 11.23 | 62.53 | 97.84 | 0.1 | 1.86 | 2.8 | 36.6 | 475.2 | 1.78X10 ⁹ |
| Mean | 36.67 | 9.94 | 60.49 | 95.65 | 0.06 | 1.28 | 2.4 | 34.6 | 475.2 | 1.03x10 ⁹ |
| Stdev | 9.26 | 1.82 | 2.88 | 3.1 | 0.05 | 0.81 | 0.57 | 2.83 | 0 | 7.92x10 ⁸ |
| Granite | | | | | | | | | | |
| ID5 | 6.54 | 1.13 | 2.2 | 3.01 | 0.01 | 0.05 | 0.25 | 28.5 | 122.4 | 1.56X10 ⁸ |
| ID6 | 37.65 | 1.57 | 31.12 | 7.42 | 0.02 | 1.77 | 0.17 | 24.4 | 302.4 | 1.46X10 ⁸ |
| ID7 | 2.3 | 3.11 | 10.01 | 2.34 | 0.05 | 0.59 | 0.68 | 18.3 | 100.8 | 1.08X10 ⁸ |
| ID8 | 6.78 | 1.78 | 23.65 | 9.7 | 0.07 | 0.13 | 0.03 | 20.3 | 158.4 | 2.56X10 ⁸ |
| ID9 | 2.97 | 0.86 | 5.04 | 2.31 | 0.06 | 0.15 | 0.06 | 19.4 | 122.4 | 2.56X10 ⁸ |
| ID10 | 23.14 | 8.12 | 16.35 | 4.22 | 0.05 | 1.94 | 0.05 | 21.2 | 216 | 2.77X10 ⁸ |
| ID11 | 79.84 | 16.63 | 61.12 | 172.53 | 0.12 | 5.37 | 5.33 | 42.7 | 734.4 | 8.9X10 ⁸ |
| ID12 | 40.4 | 17.36 | 56.57 | 137.06 | 0.02 | 10.76 | 1.54 | 12.2 | 626.4 | 8.8X10 ⁸ |
| ID13 | 37.43 | 14.97 | 82.35 | 100.57 | 0.03 | 1.53 | 1.82 | 61 | 655.2 | 5.4X10 ⁶ |
| ID14 | 5.56 | 4.78 | 15.43 | 8.01 | 0.04 | 2.1 | 1.38 | 24.4 | 180 | 6.2X10 ⁷ |
| ID15 | 24.56 | 9.64 | 38.65 | 14.96 | 0.06 | 0.52 | 0.94 | 27.7 | 374.4 | 2.27X10 ⁸ |
| ID16 | 39.78 | 11.66 | 68.42 | 31.23 | 0.13 | 5.12 | 1.43 | 26.4 | 619.2 | 5.3X10 ⁵ |
| ID17 | 13.25 | 5.68 | 9.43 | 4.98 | 0.06 | 0.26 | 0.48 | 25.4 | 216 | 6.9X10 ⁷ |
| Min | 2.3 | 0.86 | 2.2 | 2.31 | 0.02 | 0.05 | 0.03 | 12.2 | 100.8 | 5.3x10 ⁵ |
| Max | 79.84 | 17.36 | 82.35 | 172.53 | 0.13 | 10.76 | 5.33 | 61 | 734.4 | 8.9x10 ⁸ |
| Mean | 24.63 | 7.48 | 32.33 | 38.33 | 0.06 | 2.33 | 1.09 | 27.07 | 340.62 | 2.56x10 ⁸ |
| Stdev | 22.3 | 6.06 | 26.7 | 58.48 | 0.36 | 3.09 | 1.42 | 12.43 | 234.29 | 2.94x10 ⁸ |
| Charnockite | | | | | | | | | | |
| ID18 | 16.57 | 7.83 | 28.25 | 3.63 | 0.23 | 1.364 | 2.35 | 30.2 | 295.2 | 8.2X10 ⁸ |
| ID19 | 21.33 | 8.22 | 24.63 | 23.64 | 0 | 1.855 | 3.79 | 31.8 | 216 | 8.09X10 ⁷ |
| ID20 | 4.66 | 1.45 | 14.32 | 2.92 | 0.03 | 2.263 | 0.08 | 24.4 | 194.4 | 1.40X10 ⁸ |
| ID21 | 8.35 | 3.96 | 7.92 | 1.75 | 0.03 | 0.05 | 1.36 | 18.3 | 122.4 | 3.6X10 ⁷ |
| ID22 | 3.97 | 1.41 | 3.75 | 1.1 | 0.04 | 0.241 | 0.04 | 23.8 | 108 | 2.55X10 ⁷ |
| Min | 3.97 | 1.41 | 3.75 | 1.1 | 0 | 0.05 | 0.04 | 18.3 | 108 | 2.55x10 ⁷ |
| Max | 21.33 | 8.22 | 28.25 | 23.64 | 0.23 | 2.263 | 3.79 | 31.8 | 295.2 | 8.2x10 ⁸ |
| Mean | 10.98 | 4.57 | 15.77 | 6.61 | 0.07 | 1.15 | 1.52 | 25.7 | 187.2 | 2.2x10 ⁸ |
| Stdev | 7.65 | 3.32 | 10.52 | 9.57 | 0.09 | 0.98 | 1.59 | 5.42 | 75.86 | 3.38x10 ⁸ |
| WHO 2004 | 200 | - | 200 | 200 | 1.00 | 50.00 | 250.00 | 240.00 | 250.00 | 0.00 |

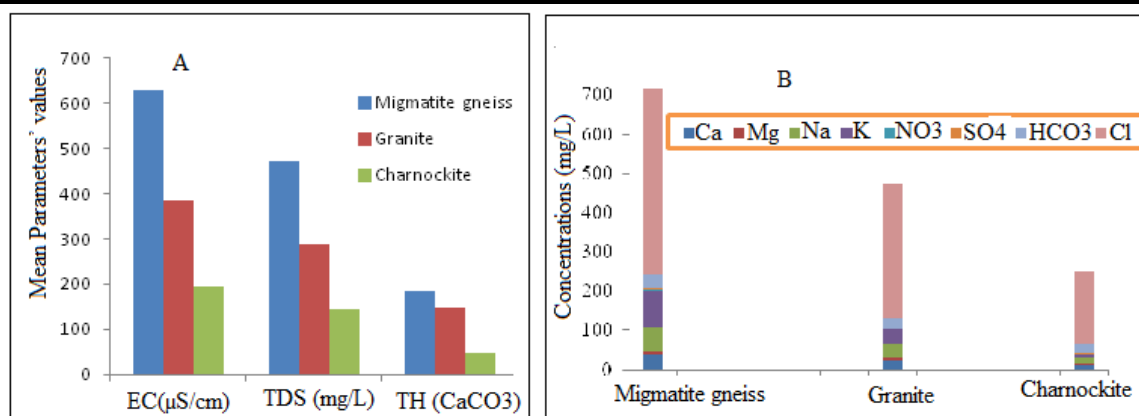


Fig.2: Variations in the concentrations of physical parameters from the study area

Effects of rock units on the chemistry of groundwater in the area were further exemplified with 50% of groundwater from migmatite gneiss terrain in the very hard category while moderately hard and hard categories each had 25% representation (Table 1). The chemical parameters (Table 2) revealed generally low chemical values that fell within approved WHO (2004) standard. Among major cations, Na⁺ was the dominant ions with an average values (mg/L) of 95.65, 38.33 and 6.61 in migmatite gneiss, granite and charnockite respectively. Following the same order of rock units, this was closely followed by K⁺ ions having average concentrations (mg/L) of 60.49, 32.33 and 15.77. Ca²⁺ ions have appreciable concentrations compared with Mg²⁺ ions. The average concentrations (mg/L) of Ca²⁺ ions in groundwater located on migmatite, granite and charnockitic terrains were 36.67, 24.63 and 10.98 respectively while those for Mg²⁺ were 9.94, 7.48 and 4.57. The order of cations abundance was Na⁺ > K⁺ > Ca²⁺ > Mg²⁺ (Fig.2B). Among the major anions, Cl⁻ was generally dominant with average concentration of 475.2mg/L in migmatite, 340.62mg/L in granite and 187.20mg/L charnockite. The second dominant anion was HCO₃⁻. Its concentrations (migmatite (av. 34.6mg/L), granite (av.27.07mg/L) and charnockite (av. 25.7mg/L)) clearly showed that rock units have significant influence on the chemistry of groundwater. Sulphate and nitrate were less dominant ions and the order of anions abundance in the groundwater was Cl⁻ > HCO₃⁻ > SO₄²⁻ > NO₃⁻. The chemical concentrations of ions in the groundwater of the study area indicated soft mineralized water that is chemically potable except in few locations where Cl⁻ exceeded the approved WHO (2004) standard. However, the results (Table 2) revealed that the groundwater was contaminated by bacterial as all sampled groundwater tested positive to bacteria with e-coli values (CFU/100ml) ranging from 1.76X10⁸ to 1.78X10⁹ in migmatite, 5.3x10⁵ to 8.9x10⁸ in granite and 2.55x10⁷ to 8.2x10⁸ in charnockite.

4.1 Characterization of groundwater from the study area

Variations in the concentrations of the different hydrogeochemical constituents dissolved in groundwater determine its usefulness for domestic, industrial and agricultural purposes (Obiefuna and Sheriff 2011). In order to gain better insight into hydrochemical processes of groundwater chemistry in the study area, Gibbs's diagrams representing the ratios of Na⁺+K⁺/ (Na⁺ + Ca²⁺) and Cl⁻/(Cl⁻ + HCO₃⁻) as a function of TDS was employed (Sivasubramanian et al. 2013). Gibbs's diagrams are widely used to assess the functional sources of dissolved chemical constituents, such as precipitation-dominance, rock-dominance and evaporation-dominance (Gibbs 1970). The chemical data of groundwater in this study were plotted in Gibbs's diagrams (Fig. 3). The distribution of sample points revealed that the chemical weathering of rock-forming minerals have influenced the groundwater quality. Furthermore, rock units have no significant influence on the Gibb's Diagrams as virtually all groundwater samples irrespective of rock type plotted in the rock dominance portion of the diagrams. Furthermore, to buttress the assertion that ions in the groundwater of the study area were derived from rock weathering, few bivariate plots of (a) Ca²⁺ + Mg²⁺ vs HCO₃⁻, (b) Ca²⁺ + Mg²⁺ vs HCO₃⁻+SO₄²⁻, (c) Ca²⁺ + Mg²⁺ vs total cation, (d) Na⁺ + K⁺ vs. Cl⁻, (e) Na⁺ vs Cl⁻ and (f) Na⁺ + K⁺ vs total cation were made as presented in Fig. 4. From Fig. 4, it is clear that rock units have effects on the groundwater chemistry of the study area. For example, in Figs 4a and 4b, the data points fell mostly away from the equiline. However, Fig. 4b has a peculiarity in which all samples from the granitic terrain fell below the 1:1 line. In addition, all samples from migmatite were above the 1:1 line in Figs.4b and 4d. Fig. 4a signified that the data point irrespective of rock units fell away from equiline 1:1 to 2:1 and 1:2.

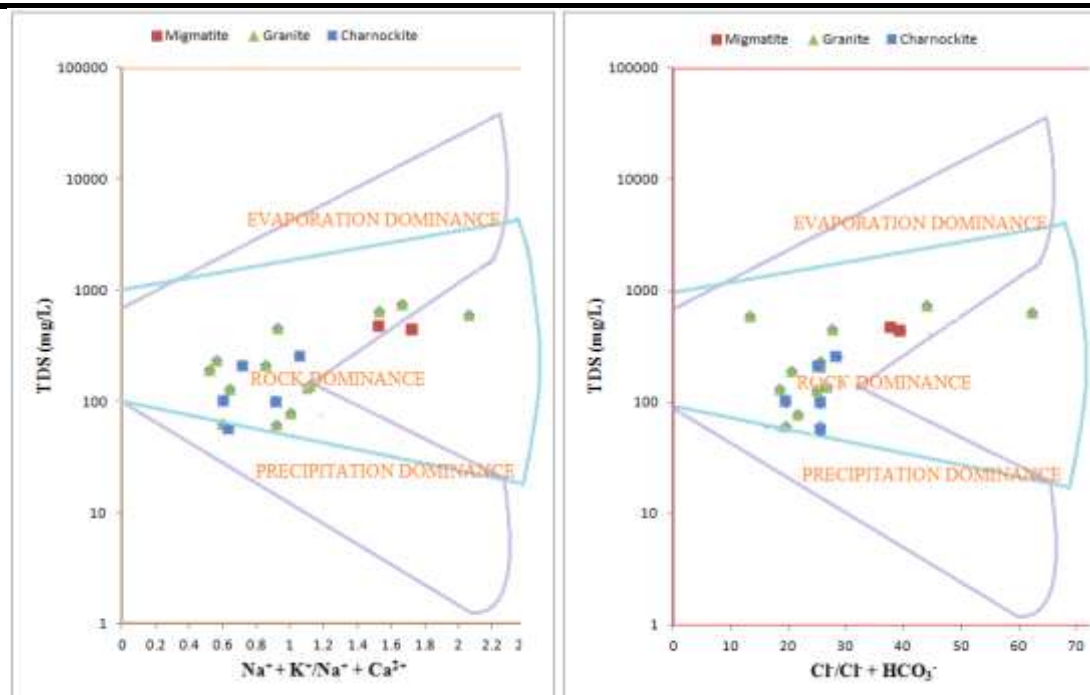


Fig.3: Gibbs Diagrams of groundwater samples from the study area.

Sixty four percent (64%) of the groundwater samples fell below the equiline indicating predominance of bicarbonate zone due to the reaction of the feldspar minerals with carbonic acid in the presence of water, which releases HCO_3^- . The remaining 36% of the groundwater samples fell above the equiline indicating silicate weathering by alkali earth (Elango et al. 2003). In figs. 4d and 4e most data fell above the equiline indicating weathering process of both alkali and alkali earth from feldspars (Jeelani and Shah 2006). In addition contribution of ions to groundwater of the study area could be from alkali/saline soil and reaction process (cation exchange) irrespective of rock units as exemplified in Fig. 4f.

Piper-Hill diagram is used to infer hydro geochemical facies (Piper 1953). Chemical data of samples from the study area were plotted on a Piper-Tri-linear diagram (Fig.5). The diagram revealed the analogous, dissimilarities and different types of waters in the study area which include NaCl water type (dominant, 72%), CaCl water type (23.5%) and mixed CaMgCl type (4.5%). Water could be categorized into distinct zones depending on the dominant ions. This concept of hydrochemical facies came up in order to understand and identify the water composition in different classes (Back 1966). Facies represent recognizable parts of different characters belonging to any genetically related system. Hydrochemical facies are zones with distinct ions concentrations. Hydrochemical properties of groundwater vary with lithology, modalities and time tracking in the different aquifers. Effects of rock units were manifested as indicated in the Piper diagram (Fig. 5) as all water

samples from migmatite terrain fell into the NaCl water type whereas those samples from granitic and charnockitic rocks fell mainly in the two major water facies (NaCl and CaCl) of the area.

Main ionic constituents of groundwater (SO_4 , HCO_3 , Cl, Mg, Ca, Na and K) in the study area in milli equivalents per liter of solution (meq/L) were plotted on a Schoeller diagram (Schoeller, 1965). The Schoeller diagram (Fig. 6) represents a semi-logarithmic diagram of the concentrations of the groundwater samples of the study area. Concentrations of each ion in each sample are represented by points on six equally spaced lines and points are connected by a line. The diagram in this study supporting the Piper diagram revealed Na and Cl as dominant cation and anion respectively (Fig. 6).

4.2. Bacteriological Evaluation of groundwater of the study area

Pollution of groundwater occurs when contaminants are discharged to, deposited on, or leached from the land surface above the groundwater. Ground water contaminated with bacteria, chemicals, pesticides, gasoline or oil can result in various human health problems, ecological imbalance etc. Specifically total bacteria counts of all groundwater samples from the study area were carried out to unveil the presence or otherwise of bacteria pollutants in the water. The results of the bacteriological analysis (Table 1) suggested that all the groundwater samples have been contaminated due to human activities and closeness to pit latrines/soak away and other domestic refuse dumps.

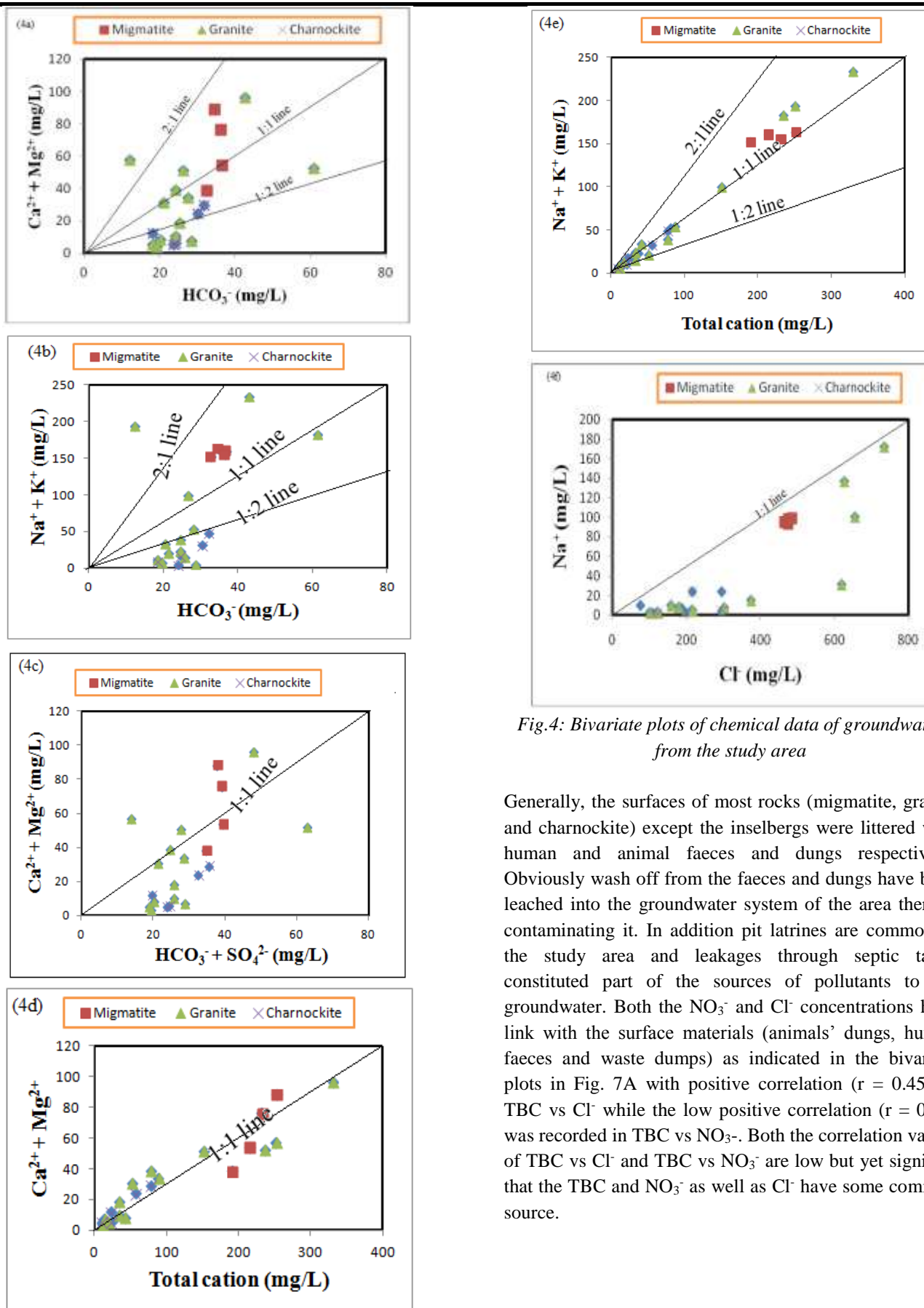


Fig.4: Bivariate plots of chemical data of groundwater from the study area

Generally, the surfaces of most rocks (migmatite, granite and charnockite) except the inselbergs were littered with human and animal faeces and dungs respectively. Obviously wash off from the faeces and dungs have been leached into the groundwater system of the area thereby contaminating it. In addition pit latrines are common in the study area and leakages through septic tanks constituted part of the sources of pollutants to the groundwater. Both the NO_3^- and Cl^- concentrations have link with the surface materials (animals' dungs, human faeces and waste dumps) as indicated in the bivariate plots in Fig. 7A with positive correlation ($r = 0.45$) of TBC vs Cl^- while the low positive correlation ($r = 0.22$) was recorded in TBC vs NO_3^- . Both the correlation values of TBC vs Cl^- and TBC vs NO_3^- are low but yet signified that the TBC and NO_3^- as well as Cl^- have some common source.

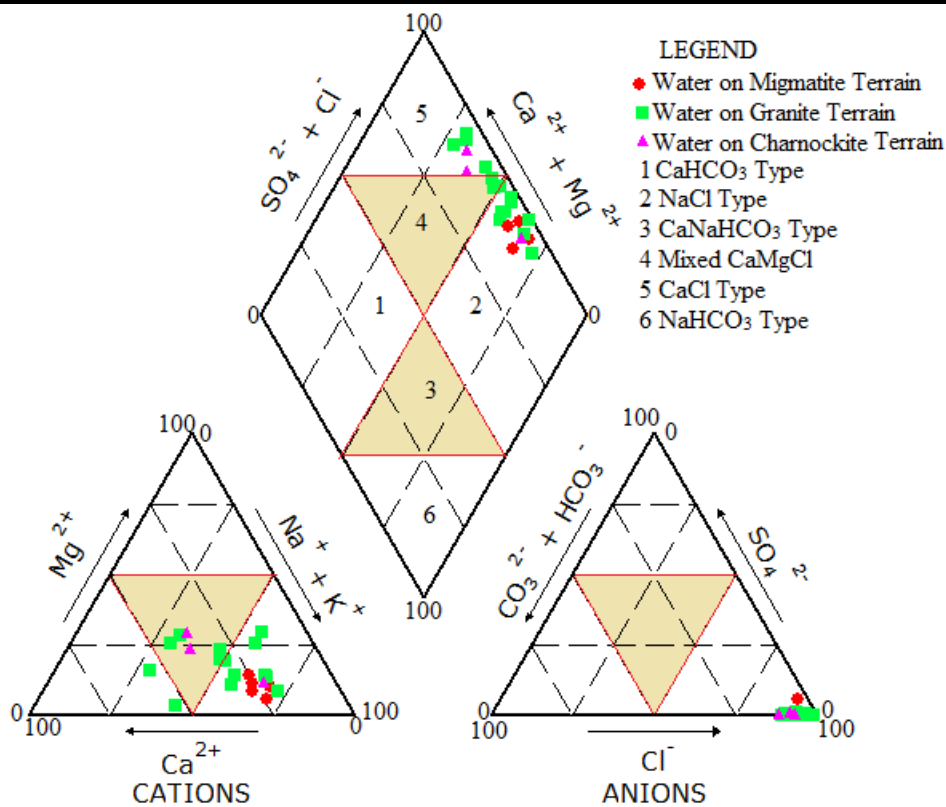


Fig.5: Piper Trilinear diagram of groundwater samples from the study area.

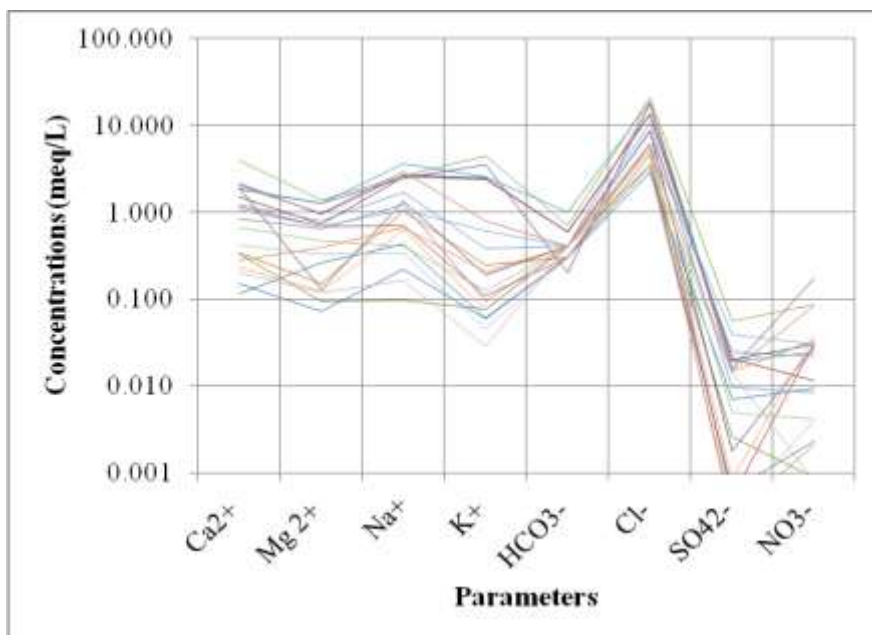


Fig.6: Schoeller Diagram of Groundwater samples from the study area.

4.3 Irrigation Quality Assessment of Groundwater of the study area.

Water is considered as an important resource which is required for the plant growth in agricultural production (Tiwari et al., 2011). The suitability of groundwater for irrigation depends on how its mineral constituents affect both the plant and the soil. High salts contents in groundwater can be highly harmful. Growth of plants can

be physically affected as taking up of water is reduced through modification of osmotic processes. Also, plant growth may be damaged chemically by the effect of toxic substance arisen from metabolic processes. Use of poor water quality can create four types of problems such as toxicity, reduction in water infiltration rate, salinity and miscellaneous (Ayers and Westcot, 1985). Assessment of water quality for irrigation could be carried out

employing EC, sodium adsorption ratio (SAR), chemical concentration of elements like Na^+ , Cl^- and/or B^- and residual sodium carbonate (RSC) (Raghunath 1987; Raju 2006). In the present study, irrigation water quality assessment were carried out employing the individual chemical parameters, SAR, SSP, RSBC, KR, PI and MR. The results of some of the essential irrigation parameters are presented in Table 3 while the USSL (1954) classification of irrigation quality assessment based on electrical resistivity of groundwater is in Table 4.

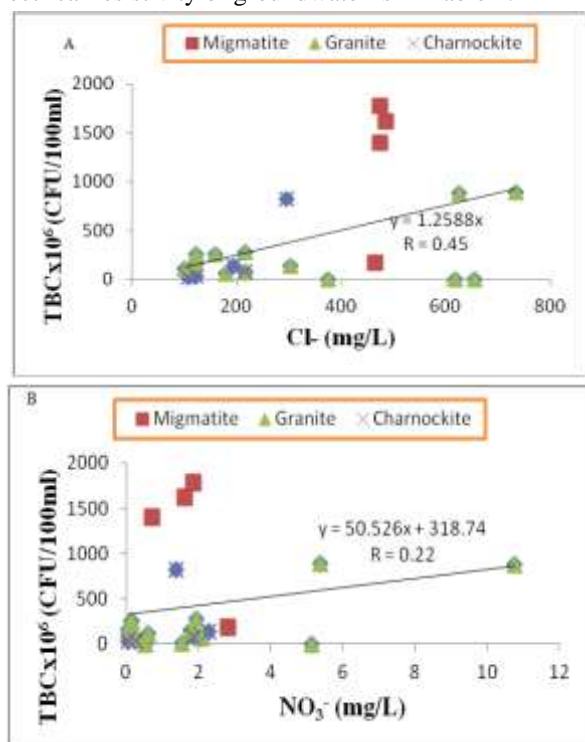


Fig.7: Bivariate Plots of TBC vs Cl^- and NO_3^-

The results in Table 3 showed $\text{SAR} < 10$ for all groundwater samples from the study area indicating water of low sodium hazard. Sodium absorption ratio (SAR) is an important parameter for determining the suitability of groundwater for irrigation because it is a measure of alkali/sodium hazard to crops (Subramani et al. 2005). The SAR values ranged from 0.04 – 1.62 and all samples are in the excellent irrigation water category (Richards 1954). However, classification based on electrical conductivity revealed that eight (8samples) (5 from granite and 3 from charnockite) out of the 22samples had $\text{EC} < 250 \mu\text{S}/\text{cm}$. Thus, only 36% of the groundwater fell into excellent irrigation class (Table 4). Fifty percent of the samples (11 samples) are in the good irrigation quality category. Three (3) samples (14%), all from granitic terrain fell into the doubtful irrigation class. Based on the

USSL (1954) classification, the groundwater from the study area is suitable for irrigation and the effects of rock units on irrigation is equally justified as only granite has samples in the doubtful class (Table 4).

Table.3: Summary of Irrigation parameters of groundwater from the study area

| Parameters | Min | Max | Mean | Stdev |
|------------|-------|--------|-------|-------|
| SAR | 0.04 | 1.62 | 0.51 | 0.56 |
| SSP | 6.68 | 54.79 | 26.48 | 16.21 |
| RSBC | -3.29 | 0.19 | -0.84 | 1.04 |
| KR | 0.30 | 4.40 | 1.72 | 1.24 |
| PI | 29.62 | 68.15 | 51.29 | 11.32 |
| MAR | 7.08 | 225.62 | 66.17 | 43.73 |

Table.4: Classification of groundwater for irrigation based on EC, SAR

| Quality of water | Electrical conductivity (S/cm) | Sodium adsorption Ratio (SAR) |
|------------------|--------------------------------|-------------------------------|
| Excellent | < 250 | < 10 |
| Good | 250–750 | 10–18 |
| Doubtful | 750–2250 | 18–26 |
| Unsuitable | > 2250 | > 26 |

Replacement of adsorbed Ca^{2+} and Mg^{2+} by Na^+ through cations exchange process can be dangerous to plants and such constitute hazard as soil structures are damaged and the soil may be compacted and becomes impervious. The analytical data plotted on the US salinity diagram (Richards, 1954) illustrates that 86% of the groundwater samples fall in the field of C1S1 and C2S1, indicating low to medium salinity and low sodium water, which can be used for irrigation on all types of soil without danger of exchangeable sodium (Fig. 8). Residual sodium bicarbonate (RSBC) calculated to determine the hazardous effect of carbonate and bicarbonate on the quality of water for agricultural purpose revealed that RSBC values ranged from -3.29 to 0.19. According to the US Department of Agriculture, water having $\text{RSBC} < 1.25$ is good for irrigation, those with RSBC between 1.25 and 2.5 are in the doubtful category while any water with $\text{RSBC} > 2.5$ is unsuitable for irrigation purpose. Based on this classification, all the groundwater samples in the area are in the good irrigation quality category.

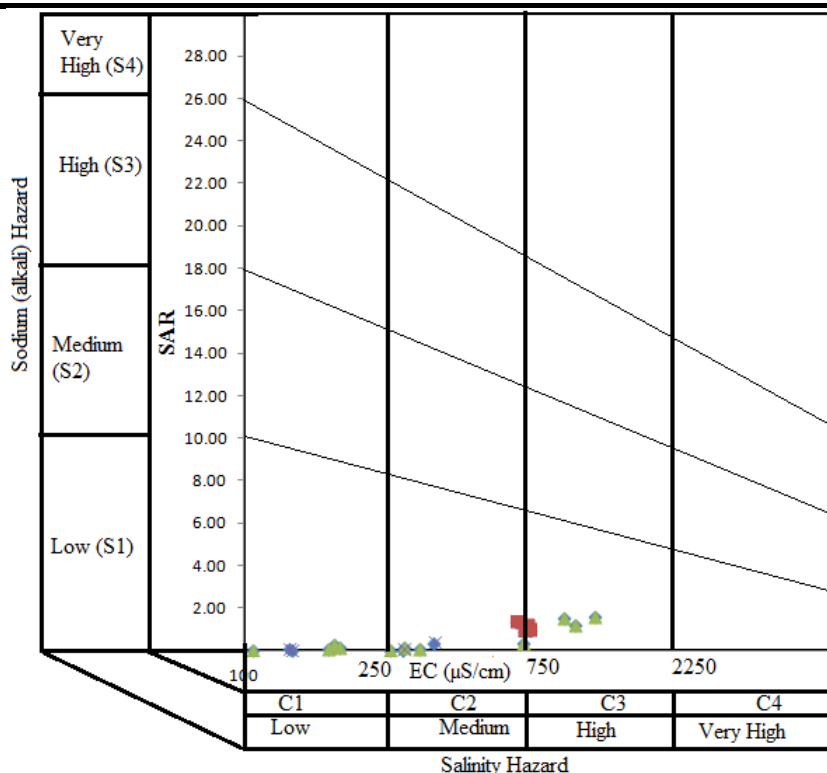


Fig.8: USSL Classification of Groundwater from the Study area

According to Paliwal (1972), $MAR > 50$ is unsuitable for irrigation. MAR values of groundwater samples in this study varied from 7.08 – 225.62 with an average of 66.17 (Table 3). Only 7 samples (31.81%) of the groundwater have $MAR < 50$ and as such suitable for irrigation. Higher levels of TDS, Na^+ , HCO_3^- , Cl^- etc in irrigation water can affect the permeability of soil. Doneen (1964) developed a criterion to assess the suitability of water for irrigation based on permeability index. PI values for groundwater samples in the area ranged from 29.62 - 68.15 %. According to Doneen's (1964) chart (Fig. 9) all the well waters fell under Class-I & II (Good Water). Furthermore all samples from migmatite terrain fell under Class-1 while samples from the other rocks (granite and charnockite) cut across Class-I and II, signifying the effects of rock units on the chemistry of the water and inadvertently on the irrigation quality of the water. Further assessments of irrigation quality of groundwater

in the study area were carried out using KR and SSP. The KR for groundwater samples from the study area ranged from 0.3 – 4.4 (av. 1.72) while the SSP varied between 6.68% and 54.79% (av. 26.48%) (Table 3). Kelly (1963) suggested that the ratio for irrigation water should not exceed 1.0meq/L. The estimated mean value of KR for groundwater samples from the study area exceeded 1.0meq/L. However, nine (9) samples (6 from granite, 3 from charnockite) have $KR < 1.0meq/L$. Thus KR values clearly indicate that the groundwater is moderately suitable for irrigation. The effects of rock units are again demonstrated as all samples from migmatite terrain have $KR > 1.0meq/L$. As for the Soluble Sodium Percentage (SSP), irrigation water with an SSP greater than 60% may result in Na^+ accumulation and possibly a deterioration of soil structure, infiltration, and aeration (Scianna et al., 2007). All groundwater samples from the study area are suitable for irrigation based on SSP values.

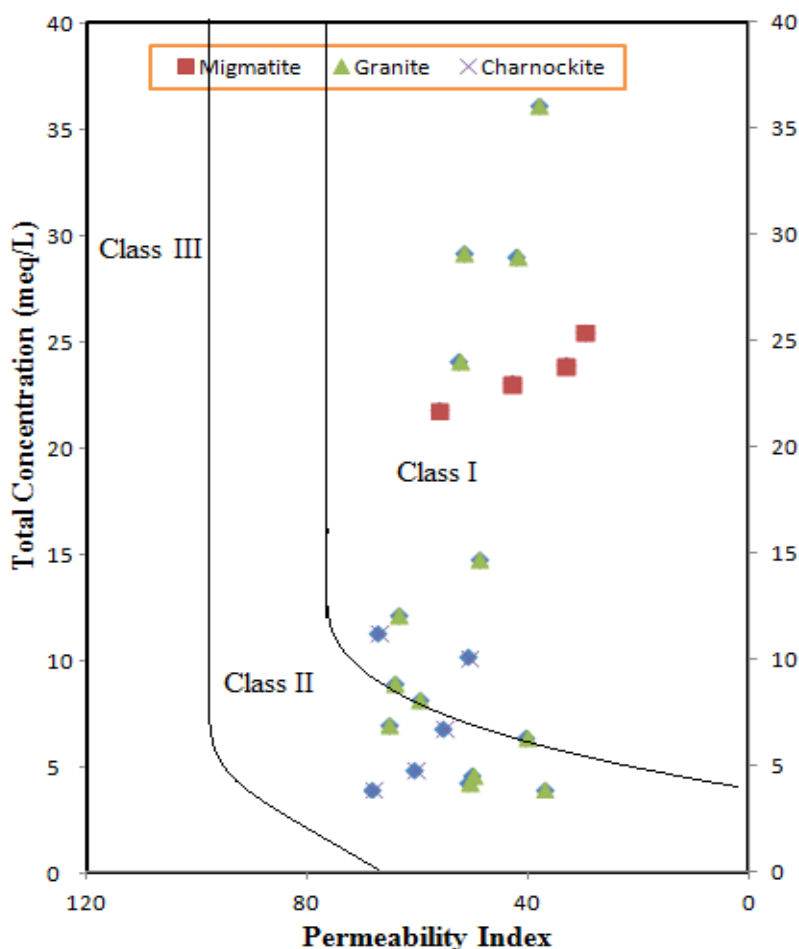


Fig. 9: Classification of irrigation water based on toatal concentration and permeability index (Doneen, 1964)

V. CONCLUSIONS

This study assessed the impacts of lithology on the chemistry of groundwater in shallow wells at Ikere – Ekiti. The study area is characterized by three major rocks; migmatite, granite and charnockite. The physico-chemical parameters of groundwater in the area have low values that are within WHO (2004) approved standard for drinking water except for pH that exceeded the standard (6.5 – 8.5) in two samples from migmatite and one sample from granite. All EC ($\mu\text{S}/\text{cm}$) values of groundwater samples irrespective of rock units were less than 1000 $\mu\text{S}/\text{cm}$ indicating fresh water. All groundwater samples were polluted by bacteria. Groundwater in the area is chemically potable but bacteriologically infected. Total hardness of groundwater from migmatite gneiss was in the moderately hard to vey hard category while the groundwater from granite and charnockite fell into soft to very hard and soft to moderately hard classes respectively. In general, the order of cation abundance was $\text{Na}^+ > \text{K}^+ > \text{Ca}^{2+} > \text{Mg}^{2+}$ while that of the anion was $\text{Cl}^- > \text{HCO}_3^- > \text{SO}_4^{2-} > \text{NO}_3^-$ though this order varied in the individual rock units of the area. Gibb's diagram revealed that chemical weathering of rock-forming minerals has contributed to solute source in the groundwater of the

area. Two water facies (NaCl and CaCl) were identified in the study area. All water samples from migmatite terrain fell into the NaCl water type whereas those samples from granitic and charnockitic rocks cut across the two facies (NaCl and CaCl) revealing lithologic effects. Irrigation water quality assessment employing the individual chemical parameters, SAR, SSP, RSBC, PI and MR revealed that the groundwater is suitable for irrigation purpose except for the KR and MR that indicated 41% and 31.5% suitability respectively. Classification of irrigation water based on toatal concentration and permeability index showed that all samples from migmatite terrain fell under Class-1 while samples from the other rocks (granite and charnockite) cut across Class-I and II, signifying the effects of rock units on the chemistry of the water and inadvertently on the irrigation quality of the water.

Groundwater in the study area is low mineralized, chemically potable but infected by bacteria pollutants. The water is suitable for irrigation purpose. Differences in rock types affected the chemistry of the groundwater as reflected in their physico-chemical composition, water facies and irrigation quality.

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