Evaluation of the Hydrogeochemical Properties of Hand-Dug Wells in Yelwa Area of Bauchi, Northeast Nigeria

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ABSTRACT

An evaluation of the hydrogeochemical properties of hand-dug wells around Yelwa metropolis was carried out. The objectives of this study were to determine and evaluate its chemical characteristics and heavy metals content of groundwater, its hydrogeochemical controls and suitability for drinking. A total of ten (10) water samples (250 ml each) were collected from hand-dug wells in the Yelwa area. The groundwater has pH ranging from 7.10 to 7.90 implying that the groundwater sources are alkaline. The value for chloride, sulphate and iron ranges between 60.10 to 414.70 mg/l, 0.10 to 2.80 mg/l and 0.03 to 0.80 mg/l respectively. While the values for hardness is between 42.00 to 236.00 mg/l.

These parameters indicate presence of mineral sulphate, corrosion and very hard water therefore should be treated before use. Human activities amongst other things that are likely to contribute to pollution of well water in the study area include the proximity to pit latrines/septic system to usable wells, laundry activities close to wells, refuse disposal in dumps adjacent to wells, as well as poor construction of some wells. The study reveals in accordance with the accepted national and international standards (WHO, USEPA, and NIS) that the water is chemically good for drinking. However, two water wells are high in sodium and chloride content, thus giving rise to salty taste and are not recommended for drinking.

(Keywords: *hydrogeochemistry, groundwater wells, pollution, Yelwa*)

INTRODUCTION

The study area Yelwa and its environs is situated in the Pre-Cambrian crystalline basement rocks of Nigeria and falls within latitudes 10º11ʹ and 10º20ʹ N and longitudes 9º43ʹ and 10º52ʹE (Figure 1). It is bounded in the south by Wurogwabbo and Bayara, south-east by Bigi, in the south-west by Gandu, in the north by Miri and Shadowanka and north-east by Bauchi. It is easily accessible by the Bauchi – Jos link road, Bauchi – Kano link road, Bauchi - Tafawa Balewa link road, Bauchi – Gombe link road and Bauchi – Maiduguri link road. The physiography and geomorphology of the study area is indicative of high relief, high surface water run-off and low infiltration rate. The groundwater storage which is already limited by geological factors is further reduced by adverse climatic conditions.

Crystalline rocks weather more easily and deeply under humid conditions. More water is available for storage under favorable rainy environments. Hence, in the Yelwa area underlain by crystalline formation, groundwater and surface water are scarce and problematic to explore / exploit. Experience all over the World has shown that the rate of failure of boreholes is usually highest in the basement complex terrains. This is due mainly to an inadequate knowledge of shallow aquifers which results from in-situ weathering (weathered mantle) and/or denudation of basement rocks.

Weathering mantles are products of in-situ rock weathering accumulating through time to form thick bodies of altered parent rock (soil formation), they play significant roles in forming of aquifer and are of considerable interest in the study area. It is only around the late 1950's that geophysical techniques have been realized as a very reliable tool to solve this sort of exploration problem (Hazell, *et al*., 1988; Uzoegbu, 2018; Amoke and Uzoegbu, 2018; Levshina and Matyushkina, 2021; Qui, *et al*., 2021; Shimamura and Yamada, 2021; Wang, *et al*., 2021).

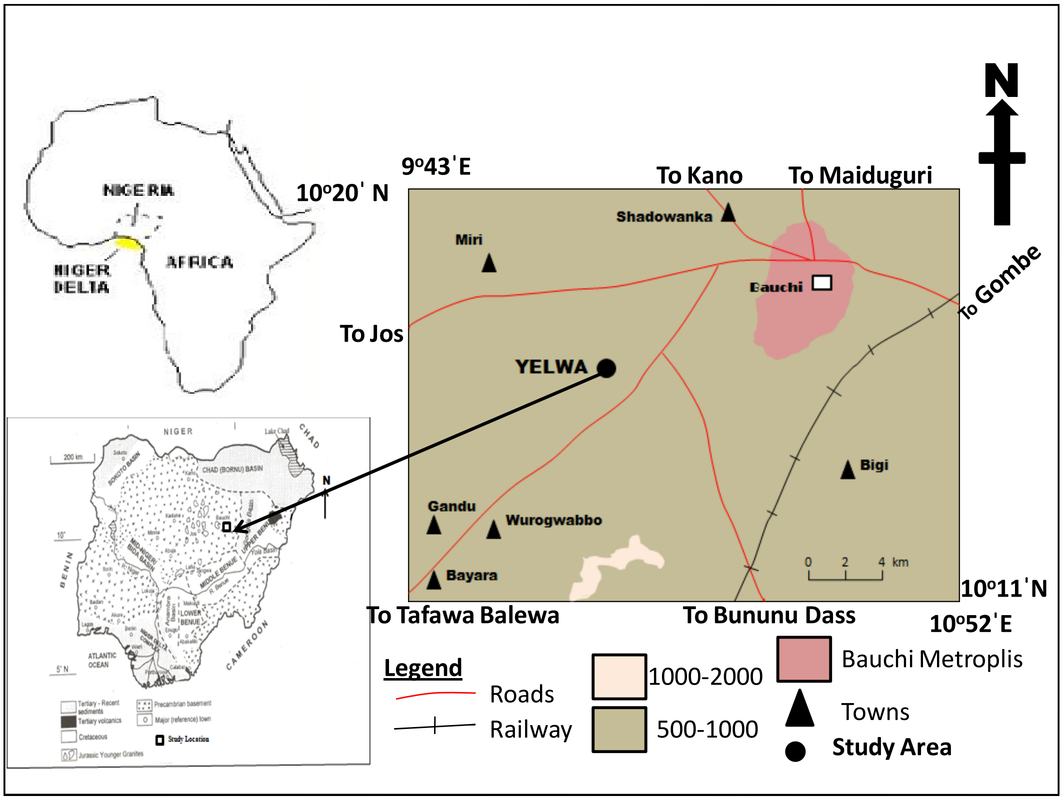

Figure 1: Map Showing Location of the Study Area (In-set: Geological map of Nigeria and Africa). (After Uzoegbu, 2018).

The hydrogeochemical properties of the hand-dug wells (W) are very important in determining the chemical characteristics and content of heavy metals in the groundwater.

Hand-dug wells are shallow ground excavations of large diameter man-made pit or hole from which groundwater can be accessed. They are the oldest methods for abstracting groundwater and are relatively inexpensive and best used for areas with high water tables; however, their shallow nature makes them prone to contamination and seasonal variations in water availability.

Previous works in the study area dates back to 1928 with the commencement of hydrogeological investigations in Nigeria by the Geological Survey of Nigeria with the exploitation of groundwater for rural communities by means of hand-dug and concrete-lined wells. In 1947, the exploitation aspect of the water supply work was handed over to the Public Works Department but the responsibility for making systematic studies of the distribution of groundwater remained with the Geological Survey.

Carter, *et al*. (1963), published maps and description of the geology of parts of Northeastern Nigeria including the then Adamawa, Bauchi, and Borno provinces, thus forming the basis for further groundwater studies around the area. Detailed study on the chemical quality of groundwater of the old Northern Nigeria have been carried out (Du Preeze and Barber, 1965, Kiserz, 1968, and Levshina and Matyushkinaz, 2021).

Ali, *et al.* (1993) also carried out a geophysical study of the Basement structure of Barkumbo Valley of Bauchi area of Nigeria. Dike, *et al.* (2008) created the awareness on the effects of groundwater pollution on the health of the residents, and basic information was provided for organizations interested in the development of groundwater resources in the Railway area of Bauchi.

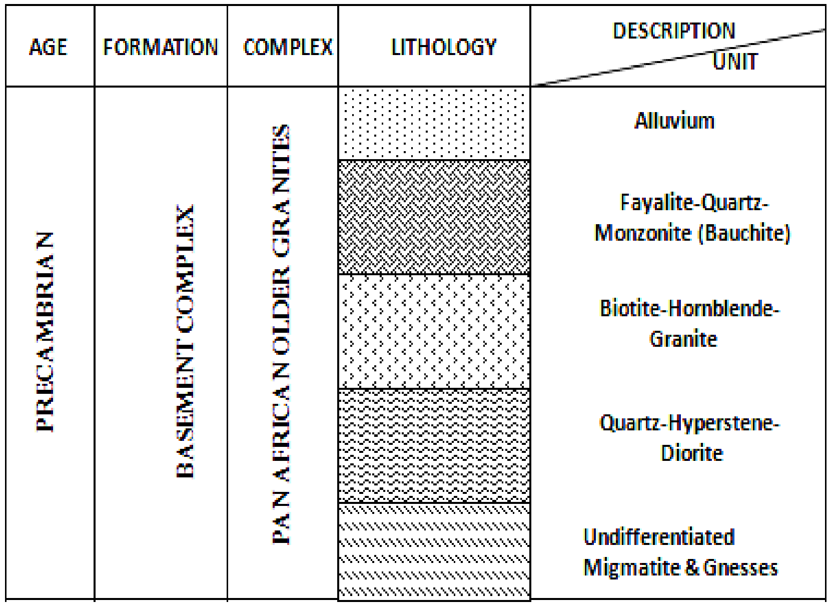

Figure 2: Sediments formed from the Weathered Basement Rocks in the Study Area.

An investigation on the erodibility of soils in the weathered basement around Bauchi metropolis has been carried out (Uzoegbu, 2018).

The occurrence of two aquiferous units (the unconsolidated weathered overburden and the fractured basement) in the Bauchi area has been observed (Amoke and Uzoegbu, 2018). While geotechnical and geophysical studies revealed the erodibility of soils and the formation of three layers, namely the topsoil, weathered/fractured basement and fresh basement (Agbo, *et al.*, 2018).

Yelwa area of Bauchi State has a population of over 4,000 people residing in the area. The traditional sources of drinking water in the area are chiefly shallow hand-dug wells, rainfall harvesting, boreholes and pipe-borne water. This study will provide the basic information on the chemical characteristics of the major ions in the groundwater of the hand-dug wells in Yelwa area.

GEOLOGY OF THE STUDY AREA

The study area is underlain by rocks of the Precambrian crystalline Basement Complex of Nigeria. The major lithologic units are the Bauchite (Fayalite-quartz-monzonite); the biotite-hornblende-granite; the porphyroblastic biotite-granites, granulites, and undifferentiated migmatites and gneisses (Figure 2). In most part of the area, these rocks are covered by the unconsolidated weathered overburden materials consisting of laterites, clays, sands and gravels.

The unconsolidated weathered overburden materials are of two types namely; the Alluvium and the Elluvium. However, outcrops of fayalite-quartz-monzonite (Bauchite) and biotte-hornblende-granite occur at two locations such as Idi and Lush hills.

Outcrops of these rocks show that they have been fractured due to tectonism. Thus fractures, fissures, joints and fracture-zones exist in places. The prominent fault zones trend towards the NE-SW and N-S zones (Oyawoye, 1970).

River Course Alluvium

The low-lying plains of the study area are essentially mantled by lateritic pebbly soils resulting from in-situ weathering of the crystalline rocks. Wherever exposed by erosion, the soil profile consists of a laterite topsoil underlain by a clay horizon which in turn is underlain by partially weathered parent rock materials. Talus and deposits of alluvial pebbles and sands are abundant. The talus is found on the alluvial deposits of river channels and the river banks.

The Hadejah valley around the northern part of the study area and its tributaries have alluvial flood plains and also the Gongola valley around the eastern part which are underlain mainly by unconsolidated coarse to medium grained sandy materials, clays and silts. From the observation it was found that at higher altitudes these sediments are coarse-grained and fine towards the low-lying plains.

Elluvium

The elluvium consists essentially of gravels and sands which are very good aquifers and have given very high yields to wells. The processes in the formation of deep weathering which led to the development of lateritic profiles as the overburden form the elluvium.

The parent materials – migmatites, gneisses which are cut by pegmatite, aptite, and quartz veins are weathered to varying degrees and depths. The depth of weathering varies from 34 to 129m. It was found that water-bearing zones are mainly found in the fractures of the poorly decomposed rock; intergranular permeability in moderately decomposed coarse-grained igneous and metamorphic rocks; and fractured pegmatites, aptite, and quartz veins within highly and moderately decomposed gneisses and migmatites.

Fayalite – Quartz – Monzonites (Bauchite)

Fayalite – bearing quartz- monzonites have been described in Bauchi area (Oyawoye, 1970). It contains quartz (72%), K- feldspar (14-72%) and plagioclase (4-52%). This unit is characterized by almost equal amount of alkali feldspars and plagioclase. It has dominant accessory minerals such as biotite and hornblende. In others, augites are present and are normally accompanied by hyperstene and olivine. The K- feldspars in monzonite is usually orthoclase (rarely microcline). Quartz occur in minor amounts. This unit is found around Guni, Wambai, Idi and Dumi hills in the central and northeastern area and some to the western portion.

Biotite-Hornblende-Granite

In this rock unit the dominant minerals are biotite and hornblende. Other minerals found associated with them are muscovites, augites, sodium-rich amphiboles, pyroxenes and minor quartz or olivine. The biotite is often dark-colored and hornblende is green-colored. This can be found in Lush and Inkil hills. It covers parts of southeastern area and also outcrops at North and northwestern area.

Quartz - Hyperstene – Diorite

This unit contains mostly of quartz in association with hyperstene and olivine. It has as sub-hedral granular texture. It outcrops at the Northeastern extreme.

Undifferentiated Migmatite and Gneisses

These are mixed rocks of mainly two sources – the pre-existing host rock and a rather indefinite diffusion of other rock materials which are granitic in composite on through the host rock. The host rock is usually the meta-sedimentary schists and the intruded materials include mostly granites, pegmatites and quartzite. They occur also mostly around the northwestern and southeastern portions and are less weathered than the schists.

HYDROGEOLOGY

The groundwater in the study area like other parts of Bauchi metropolis occurs in the overburden aquifer which is developed on the fractured crystalline rocks. The thickness of the overburden aquifers varies from place to place as depth of the weathering which is usually enhanced by the process of fracturing and also the type of rock present (Mustafa and Adamu, 1991, Uzoegbu, 2018, Levshina and Matyushkina, 2021, Van Beynen, 2021). The product of the weathering is mainly a mixture of sand and clay predominating (Schroeter, 1974) hence high porosity and low permeability of the rocks.

Boreholes reports (BH 117 and BH 120) north-east to the study area indicate that at shallow depths weathered mantle are brown silty clay with gravel interbeds and lateritic (Dike, *et al*., 2008).

Basement Complex generally forms a poor source of groundwater. The decomposed mantle is often too thin to contain quantities of water and is usually too clayey to be sufficiently permeable. Shallow-dug wells if carefully sited however will normally provide adequate supply for few residents (Dike, *et al*., 2008, Levshina and Matyushkina, 2021).

The yields of shallow hand-dug wells and boreholes in this aquifer depend largely on the amount of recharge and depth of weathering. Meanwhile, below the weathered mantle lies fractured rocks which are usually good aquifers although at depths over 100m, fractures will normally disappear.

By means of geological and geophysical techniques (electromagnetic and resistivity) the fractures can be easily and cheaply detected. Fractures are mapped on geological maps using aerial photographs and include electromagnetic profiling and resistivity depth probes (VES). The slightly weathered granites occur in the fractured zones (Dike, *et al*., 2008, Uzoegbu, 2018, Levshina and Matyushkina, 2021).

Mustafa and Adamu (1991) reported hydraulic conductivity (k) in Bauchi town basement aquifers varying between 0.09 and 0.46 meters per day (moderate). The transmissivity was found to be less than 2 meter square per day. The average borehole depth in most part of Bauchi metropolis is 32 meters and present are areas with reliable yield of about 0.8 liters per second and small drawdown. The increasing water requirement of the capital is fulfilled by the Bauchi urban pipe supply scheme from Gubi dam.

Water Table

The measurements indicate that the water table in the area is generally shallow below ground surface and range from 1.40 meters to 5.10 meters (Table 1). The shallowness of the wells leads to easy contamination and pollution by pit latrines and septic tanks which in some places are almost of the same depth with the wells.

Table 1: Water Table Depths of the Hand-dug Wells in the Study Area.

Well Number	Water Table Depth (Meters)
W1	5.10
W2	3.20
W3	3.30
W4	4.50
W5	2.40
W6	1.60
W7	2.30
W8	1.40
W9	3.10
W10	1.40

MATERIALS AND METHODS

Ten (10) water samples (250 ml each) were collected from hand dug wells (W) in the Yelwa area. The parameters Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sulphate ($SO4^{2-}$), total alkalinity and total hardness were determined by titration using EDTA titrant and murexide indicator for Ca^{2+} and Mg^{2+}, and methyl indicator for the rest. Sodium (Na+) and Potassium (K+) were determined by AAS (Atomic Absorption Spectrophotometry).

Ferrous / Ferric compounds (Fe^{2+}/Fe^{3+}) and Silicon (IV) oxide (SiO_2) were determined by calorimetry (the values were estimated from calibration curve). Chloride (Cl^-) and Bicarbonate (HCO_3^-) were determined by titration using Silver nitrate ($AgNO_3$) titrant and Potassium chromate (K_2CrO_4) and methyl orange indicators respectively. Carbonates (CO_3^{2-}) was determined by titration using standard Hydrochloric acid (HCl) titrant and methyl orange indicator. Fluorine (F-) was determined with the aid of pH meter and standard fluoride electrode. The Total Dissolved Solids (TDS) was determined by weighing and evaporating method of known volume of sample with a precision analytical balance.

All the collected water samples of the study area were pre-treated in the laboratory by filtering process using preconditioned filter device before analysis were done. Certain on-the-spot measurement was done for unstable parameters like ambient (air) temperatures. The pH, SiO_2, color, odor, and the taste of the wells water were determined in the laboratory.

RESULTS AND DISCUSSION

The results of the chemical analyses of the selected wells (W) from Yelwa area are generally within limits recommended by WHO (1958 and 1971), USA and WHO (1963), and USEPA (1975) and European and Nigerian standards for drinking water (Table 2, Table 3).

Sodium (Na^+) values in wells W3 (226 ppm) and W4 (241 ppm) are higher than that of the rest of other wells. High sodium in well water can be a concern for people on low sodium diets. These concentrations contribute to the saltiness of the ground water in wells W3 and W4 (Dike, *et al*., 2008, Uzoegbu, 2018, Levshina and Matyushkina, 2021).

The source of sodium in the ground water might be due to the dissolution (weathering) of sodium plagioclase or from sewage.

$NaAlSiO_3O_8$ (Na-plagioclase) + 11/2 $H_2O \rightarrow Na^+ + OH^-$ +$2H_4SiO_4$ + ½ $Al_2Si_2O_5(OH)_4$(Kaolinite)

or

$NaCl(s)\ H_2O \rightarrow Na^+(aq) + Cl^-(aq)$.

Potassium (K^+) in wells W3, W4, W5, W6 and W8 is in low concentration (1 ppm each). The highest concentration, 11ppm was obtained in well W2.

Deficiency in potassium intake will cause hypokalemia in human though not common to most people because deficiency of potassium is rare because it can be found in animal and vegetable foods. Hypokalemia is when the amount of potassium is too low in the blood. Potassium is an electrolyte, and excessive intake of potassium as present in well W2 (11 ppm) will minimize elevated blood pressure.

The source of potassium ions in groundwater is perhaps due to weathering of orthoclase, microcline, or biotite.

$4KAlSi_3O_8$ (Orthoclase) + $22H_2O \rightarrow 4K^+ + OH^-$ + $Al_4SiO_4O_{10}(OH)_8 + 8H_4SiO_4$

Magnesium (Mg^{2+}) concentrations are high in wells W6 and W8 as 37.7 ppm and 48.1 ppm respectively, but are within the WHO acceptable maximum limits.

Table 2: Results of Chemical Analysis of Well Water in Yelwa Area.

Parameters	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
Na^+	75.00	119.00	226.00	241.00	13.00	6.00	64.00	76.00	126.00	21.00
K^+	3.00	11.00	1.00	1.00	1.00	1.00	2.00	1.00	2.00	2.00
Mg^{2+}	15.00	6.60	7.30	13.90	13.10	37.70	8.30	48.10	14.80	22.00
Fe^{2+} & Fe^{3+}	0.05	0.10	0.03	0.10	0.12	0.04	0.01	0.10	0.80	0.03
Ca^{2+}	18.00	15.00	21.00	10.00	7.00	42.00	29.00	38.00	18.00	14.00
Cl^-	93.80	60.10	403.10	414.70	68.10	70.10	97.70	81.10	92.60	62.30
F^-	0.30	0.20	0.20	0.40	0.10	0.30	0.20	0.40	0.10	0.30
HCO_3^-	72.00	93.00	102.00	94.00	56.00	62.00	52.00	36.00	63.00	83.00
SO_4^{2-}	2.40	0.60	0.10	0.80	1.30	0.20	0.30	2.80	0.90	0.10
SiO_2	136.00	110.00	73.00	60.00	66.00	115.00	98.00	115.00	114.00	148.00
Total Alkalinity	138.00	148.00	60.00	58.00	40.00	138.00	150.00	140.00	32.00	61.00
Total Hardness	82.00	42.00	51.00	67.00	61.00	197.00	63.00	236.00	80.00	75.00
TDS	244.00	235.00	160.00	189.00	247.00	423.00	336.00	305.00	230.00	615.00
pH	7.10	7.40	7.80	7.90	7.20	7.50	7.30	7.20	7.50	7.10

NB: All values are in ppm.

Table 3: Recommended Drinking Water Standard Limits.

Parameter	WHO (1958)	U.S and WHO (1963)	WHO (1971)	USEPA (1975)	NIS (2007)
Na^+	-	-	-	-	200.00
K^+	-	-	-	-	-
Mg^{2+}	50.00	50.00	-	-	0.20
Ca^{2+}	75.00	-	75.00	-	-
Cl^-	200.00	150.00	-	250.00	250.00
F^-	0.50	-	-	1.40	1.50
HCO_3^-	-	-	-	-	-
SO_4^{2-}	200.00	250.00	-	-	-
SiO_2	-	-	-	-	-
Total Alkalinity	-	-	-	-	-
Total Hardness	-	-	-	-	-
Total Fe	0.30	3.00	0.50	0.30	0.30
TDS	500.00	-	500.00	500.00	500.00
pH	7.00-8.50	-	7.00-8.50	-	6.50-8.50

Note: WHO = World Health Organization Standard for Drinking Water
USEPA = United State Environmental Protection Agency Standard for Drinking Water
NIS = Nigerian Industrial Standard for Drinking Water

It is a mineral that's crucial to the body's function; and helps in keeping bones strong, blood pressure normal and the heart rhythm steady. Consumption of water from such wells with relatively high concentration might not have any serious health implication.

However, where the intake is deficient (low) as well W2 (6.6 ppm), W3 (7.3 ppm) and W7 (8.3 ppm) will likely cause cardiac arrhythmias (irregular heart rhythms) and pathogenesis of cancer in human and animals (Dike, *et al*., 2008, Amoke and Uzoegbu, 2018, Uzoegbu, 2018, Levshina and Matyushkina, 2021).

Though, no such illness has been reported from the owners of the wells. The source of the magnesium may be from weathering of olivine, biotite and hornblende.

$$Mg_2SiO_4 + 4H_2O \longrightarrow 2Mg^{2+} + 4OH^- + H_4SiO_4$$

Total Fe concentration in all the wells fall within the maximum acceptable limit of 0.3ppm.The values in wells W3 and W7 are low as 0.03 ppm and 0.01 ppm, respectively.

The low concentration of Fe in the groundwater is perhaps due to the inability of groundwater to dissolve iron bearing mineral like biotite and pyrite (Dike, *et al*., 2008, Amoke and Uzoegbu, 2018, Uzoegbu, 2018, Levshina and Matyushkina, 2021, Shimamura and Yamada, 2021).

$$2FeS_2 \text{ (Pyrite)} + 7O_2 + 2H_2O \rightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+$$

Calcium (Ca^{2+}) content obtained from all the selected wells in the Yelwa area are below the International recommended average limits of 75 ppm. Well W6 has the highest value of 42 ppm, followed by W8 with 38 ppm. The lowest value of 7 ppm was observed in Well W5 and also a low value of 10 ppm in W4 was observed. According to WHO standards, the average calcium content in drinking water is 75 mg/L, and the maximum allowed limit is 200 ppm. Water with calcium levels of 10 ppm or less are usually oligotrophic, and can support only sparse plant and animal life. The effects of low calcium levels of Wells W5 and W4 on human life in the area have not been reported or observed. Calcium concentration in the groundwater is likely due to the dissolution of amphibole (actinolite).

$$Ca_2Mg_5Si_8O_{22}(OH)_2\text{(Actinolite)} + H_2O + H_2CO_3 \longrightarrow Ca^{2+} + Mg^{2+} + HCO_3^- + 8H_4SiO_4$$

Chloride (Cl^-) content in the wells of the study area varies slightly from well to well. However, wells W3 and W4 show exceptionally abnormal high concentration of 403.1 ppm and 414.7 ppm respectively. Perhaps the wells are being polluted from sewage; source rich in NaCl. $NaCl \rightarrow Na^+ + Cl^-$. The values obtained in the two wells exceeded the recommended international standards for drinking water such as WHO and USEPA. Excessive consumption of chloride has no human health implication as long as a salt diet is available except to individuals restricted to a low salt diet as in the case for some cardiovascular disorders.

Fluoride (F-) content was within acceptable limits notwithstanding, the concentration is not enough to cause dental decay in children; therefore, fluorosis is not expected in the area. The source of fluoride in the area may be from weathering of fluorine-bearing minerals: example fluorite (Dike, *et al*., 2008, Amoke and Uzoegbu, 2018, Uzoegbu, 2018, Levshina and Matyushkina, 2021, Van Beynen, 2021).

CaF (Flourite) $\rightarrow Ca^{2+}(aq) + F^-(aq)$.

Bicarbonates (HCO_3^-) concentration in the wells ranges from 52 to 102 ppm. The highest bicarbonate content was obtained in well W3 (about 102 ppm). This occurs perhaps in the groundwater as a result of decay of plants, animals and organic matter or from weathering of orthoclase. Also, such concentration may result from infiltration of rainwater.

$$2AlSi_3O_8 + 2H_2CO_3 + 9H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 4H_4SiO_4 + K^+ + 2HCO_3^-$$

Carbonates (CO_3^{2-}) concentration in the wells ranges from 0.03 to 0.20 ppm. The lowest CO_3^{2-} content of 0.03 ppm in wells W1, W4, W7 and W10. The source of carbonate in the groundwater is probably due to decay of plants and animals and organic matters as in the case with bicarbonate.

Sulphate (SO_4^{2-}) content obtained from the selected wells samples is very low. The content varies from 0.1ppm (wells W3 and W10) to 2.80 ppm (well W8). The source of the sulphate in the groundwater might be attributed to the dissolution of iron bearing mineral example (Dike, *et al*., 2008).

$$FeS_2 + 7O_2 + 2H_2O \rightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+$$

Silica (SiO_2) concentration is lowest in well W4 (60 ppm) and highest in well W10 (148 ppm). The deficiency of silica can affect foetal life in women`s womb, infancy and childhood; also runny nose or mucus and phlegm might occur. Prolonged silica deficiency causes delayed bone growth, atrophy of many organs, premature aging of skin, nails and hair and loss of tissue elasticity. The source of the silica in the groundwater in wells is due to the weathering of silica minerals other than quartz in the granite and gneissic rocks (Dike, *et al*., 2008, Amoke and Uzoegbu, 2018, Uzoegbu, 2018, Levshina and Matyushkina, 2021, Wang, *et al*., 2021).

$$Mg_2SiO_4 + 2H_2O \rightarrow 2Mg^{2+} + 4OH^- + SiO_2$$

Total alkalinity content in well W1, W2, W7 and W8 show high concentration of 138 ppm, 148 ppm, 150 ppm and 140 ppm, respectively. The total alkalinity content is relatively high. This is undesirable because its association with waters have excessive hardness or high concentration of sodium salts. Low contents of total alkalinity were obtained in wells W5 (40 ppm) and W9 (32 ppm). The total alkalinity is almost entirely due to the presence of bicarbonate.

High values of 197 ppm and 143 ppm for total hardness were recorded in samples from wells W6 and W8 respectively. These high values are capable of rendering the water undesirable for human consumption and domestic use (Dike, *et al*., 2008, Amoke and Uzoegbu, 2018, Uzoegbu, 2018, Levshina and Matyushkina, 2021, Wang, *et al*., 2021). The total hardness in these samples is due to Mg^{2+} and Ca^{2+}.

Total dissolved solids (TDS) are highest in well W10 (615ppm). The amount exceeds WHO, USEPA and NIS acceptable maximum limit of 500ppm. TDS is obtained as a result of the dissolution of mineral in water.

pH of the water is the measured degree of acidity or basicity. The pH of the water is more basic in wells W3 and W4 (7.80 and 7.90, respectively) than in other wells water. All the values obtained however lie within the recommended limits of WHO, USEPA and NIS.

The Trilinear plot, revealed two types of water: sodium chloride rich water and sodium chloride deficient water type (Figure 3). The sodium rich water type can be found in wells W1, W2, W3, W4, W7, W8 and W9. The sodium deficient water type is found in wells W5, W6 and W10 (Dike, *et al*., 2008, Amoke and Uzoegbu, 2018, Qui *et al*., 2021).

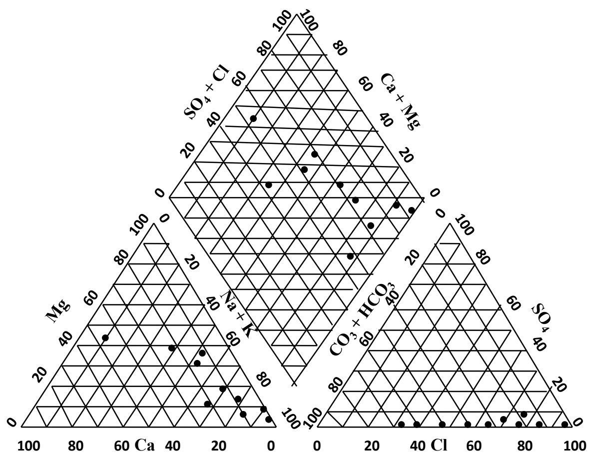

Figure 3: Piper Trilinear Diagram showing the Major Cations and Anions.

The physical properties test of the groundwater samples indicates that they are colorless and odorless. Wells W3 and W4 are salty while well W9 is slightly salty; others are unobjectionable The temperature of the water and the air are fairly close to each other in values (Between 26.0°C and 29.1°C). The ambient temperature seems to be higher in the morning period.

CONCLUSION

Yelwa and its environs derive water for use from the shallow hand-dug wells sunk in the weathered mantle aquifer of the Basement Complex, as well as from urban pipe supply scheme. Water quantity and quality can be affected by both natural and human factors, but it is interesting to note generally that the chemical and physical quality of drinking water available from the study area is satisfactory. This could be attributed to the fact that natural factors such as the origin and composition of the host rock have remained the determinant of the hydrogeochemical constituents of the groundwater in the study area. Therefore, it is worthy to conclude that the shallow hand-dug wells are physically and chemically free of pollution stress, though few individual wells have values which approach or exceed the known WHO, USEPA and NIS permissible standards for drinking water.

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