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GROUNDWATER QUALITY IN AWE AND ENVIRONS, MIDDLE BENUE TROUGH, NIGERIA

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ABSTRACT

Groundwater quality is an important thing to be determined; because it is commonly used as a source of clean water for domestic, agricultural and industry purposes. Fifty three groundwater samples (seventeen from wells, five from springs and thirty one from boreholes) were sampled for this research work. Inductively Coupled Plasma Mass Spectrophotometer (ICP-MS) was used to analyze for the major cations while titration was used for SO_4 and HCO_3. Cl was analyzed using the Ion Chromatographic Method (IC). From the results obtained, Total dissolved solids (TDS), Electrical conductivity (EC), and Strontium (Sr) classified the groundwater in the study area into three as fresh, brackish and saline water. The concentrations of major ions in all the fresh water and some of the brackish water in the study area met the World Health Organization (WHO) Standard for drinking water while the concentrations of the major ions in the saline water are above the WHO permissible values for drinking water. This indicates that the saline water from the study area are not good for domestic, agriculture and industrial uses. Four types of water are obtained from the groundwater based on Total Hardness (TH) as: 75 mg/l as soft; 75–150 mg/l as moderately hard; 150–300 mg/l as hard; and >300 mg/l as very hard. Both extreme degrees of very soft (<75 mg/l) and very hard (>300 mg/l) are considered as undesirable features in water. About 90% of the groundwater in the study area are suitable for domestic, livestock and irrigation purposes but only about 51% of the groundwater samples can be used by industries without being treated.

KEYWORDS: Groundwater, quality, Awe, Benue Trough, Nigeria

INTRODUCTION

As water needs for the various water uses such as industrial, agricultural, domestic and recreational use by human population throughout the world is increasingly becoming threatened due to the contamination through anthropogenic activities; groundwater has become very vital to water budgets throughout the world especially for potable uses. This is because groundwater is well suited to meet the dispersed demand inherent in settlement patterns of rural populations and therefore, plays a very significant role as source of water for supply systems throughout the world especially in Africa (Tay et al., 2018). Nigeria as a country in West Africa is no exception. Understanding the quality of water is as important as its quantity because it is the main factor determining its suitability for domestic, drinking, agricultural and industrial purposes (Samuel and Dibal, 2021).
Groundwater supply systems development and management as rural water supply is relatively cheaper compared to surface water supply systems. In view of the problems associated with alternate sources of water and the fact that groundwater is often considered one of the most economically feasible sources of potable water supply, groundwater resources are being increasingly utilized in order to meet the upsurge of water supply needs (Tay et al., 2018). Offodile (2014), Edet, (2017) gave empirical figures which suggest high groundwater resources potential for Nigeria. Groundwater potential in Nigeria is far greater than the surface water resources, estimated to be 224 trillion l/year.
Nearly all groundwater originates as rain or snowmelt that infiltrates through soil into flow systems in the underlying geologic materials (Gusikit, 2021). The soil zone has unique and powerful capabilities to alter the water chemistry, as infiltration occurs through this thin, biologically active zone. In recharge areas the soil zone

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undergoes a net loss of mineral matter to the flowing water. As groundwater moves along flowlines from recharge to discharge areas, its chemistry is altered by the effects of a variety of geochemical processes (Freeze and Cherry, 1979). In natural hydrological cycling, the groundwater interacts with the surrounding rocks causing a variety of hydrogeochemical processes that alter groundwater chemical components on local or regional scale. The hydrogeochemical processes that are responsible for altering the chemical composition of groundwater vary with respect to space and time (Gusikit et al., 2021, Phyu *et al.,* 2018). The chemistry of groundwater is an index of its complex history, providing important clues to geological environment, indication of groundwater recharge, discharge, movement and storage (Afsin, 1997).

Eyankware (2019) established factors that influence chemical quality of groundwater within Aptian-Albian aquifer, Ebonyi state southeastern Nigeria. From the analysis, it was observed that TDS ranges from 68 - 602 mg/L, the value range shows that groundwater is of fresh water category. Total dissolved solids (TDS) values greater than 1000 implies that the water quality is poor. TH ranges from 2.8 - 73.5 mg/L, sampled points were classified as soft water category, EC ranges from 72 -1042 us/cm. Based on total hardness values, four types of water are classified: < 75 mg/L $CaCO_3$ as soft; 75–150 mg/L $CaCO_3$ as moderately hard; 150–300 mg/L $CaCO_3$ as hard; and >300 mg/L $CaCO_3$ as very hard (Nguyet *et al.,* 2016). Both extreme degrees of very soft (<75 mg/L as $CaCO_3$) and very hard (>300 mg/L as CaCO3) are considered as undesirable features in water. Waters with hardness in excess of 500 mg/L are not suitable for most domestic purposes. The total hardness values of Tam Diep groundwater samples indicated the high amount of Dong Giao carbonate rock taken into solution (Nguyet *et al.,* 2016). Gusikit et al., (2019) and Saxena, *et al.,* (2004) established that Sr content could be linked to various water types. They suggested Sr values of < 1.6 mg/L indicates fresh groundwater, 1.6 – 5.0 mg/L for brackish water, and >5.0 mg/L for saline groundwater.

Lower SO_4 concentrations in groundwater indicate lack of industries because high SO_4 concentrations indicate anthropogenic sources and industrial process (Mostafa et al. 2017). Groundwater with very high concentration of Cl is not feasible to be used as source of domestic water (Dayal and Chauhan 2010).

Many researchers have worked on the water quality for domestic and agricultural uses in Lower, Middle and Upper Benue Troughs but little or no work done on water quality for industrial purposes in these areas. This research work seek to determine water quality for domestic, agriculture and industrial purposes in the study area.

GEOLOGY OF THE STUDY AREA

The study area lies on longitudes 9°0'0" - 9°20'0"E and latitudes 8°0'0" - 8°30'0"N and is part of the Middle Benue Trough. Five formation constitute the study area; Asu River Group, Awe-Keana Formations, Ezeaku Formation and Agwu Formation (Figure 2). The Asu River Group is the oldest marine formation in the study area. The lithologic composition of this formation comprises mainly limestones, shales and calcareous shales, micaceous siltstones, mudstones and clays. This formation is very fossiliferous. The Asu River Group in the study area was encountered both in the northeastern and southeastern as while as in the southwestern part of the study area.

The Awe Formation overlies the Asu River Group. The formation consists of flaggy, whitish, and medium to coarse-grained calcareous sandstones, carbonaceous shales and claystone. The sandstones become fine-grained and more micaceous towards the base with fine current beddings. The Awe Formation is generally not fossiliferous, however, a few gastropods and pelicypods occur in the formation. The Keana Formation consists mainly of cross-bedded, coarse-grained feldspathic sandstones. The sandstones are poorly sorted, and occasionally contains conglomerates and bands of shales and limestone’s towards the top. The Awe-Keana Formations were found in the northeastern, northwestern, and southeastern parts of the study area.

The Ezeaku Formation sediments are made up mainly of calcareous shales, micaceous fine to medium friable sandstones and beds of limestones which are in some places shelly. The Ezeaku Formation consist mainly of intercalations of shelly limestones and black shales, with brownish fine to coarse grained feldspartic sandstones at the top. The Ezeaku Formation was encountered in northwestern and southeastern parts of the study area but only in a small portion of the southeastern parts of the study area. The Awgu Formation conformably overlies the Ezeaku Formation. The formation is composed of bluish-gray to dark-black carbonaceous shales, calcareous shales, shaley limestone, limestones sandstones, siltstones, and coal seams. Agwu Formation was encountered in northwestern and southeastern parts of the study area.

MATERIALS AND METHODS

Fifty three groundwater samples were collected using 250ml plastic bottles which were previously soaked in acidified water, washed and rinsed with distilled water. At every sampling point, the sample containers were further rinsed with the sampled water before sampling. Two samples were collected at every sampling point, one was acidified with two (2) drops of concentrated nitric acid for homogenization and prevention of absorption/adsorption of elements to the walls of the plastic container while the second sample is not acidify. At each sampling point, the sample containers were rinsed with the sampled water three times before sampling. At every sampling point, coordinate readings were taken using the Global Positioning System (GPS) instrument. The electrical conductivity (EC µS/cm) and Total Dissolved Solids (TDS mg/l) were directly measured using a portable meter in the field, also alkalinity (HCO_3 mg/l) was also measured in the field using titration method. The acidified water samples were transferred into 60mls plastic bottles and sent to ACME-Laboratories in Canada where Inductive Coupled Plasma Mass Spectrophotometer (ICPMS) was used for major cations analysis. For the non-acidified water sampled, titration method was used for HCO_3 (in the field) and SO_4 while Cl was analyzed using the Ion Chromatographic Method (IC) in the laboratory of Geology Department, University of Jos.

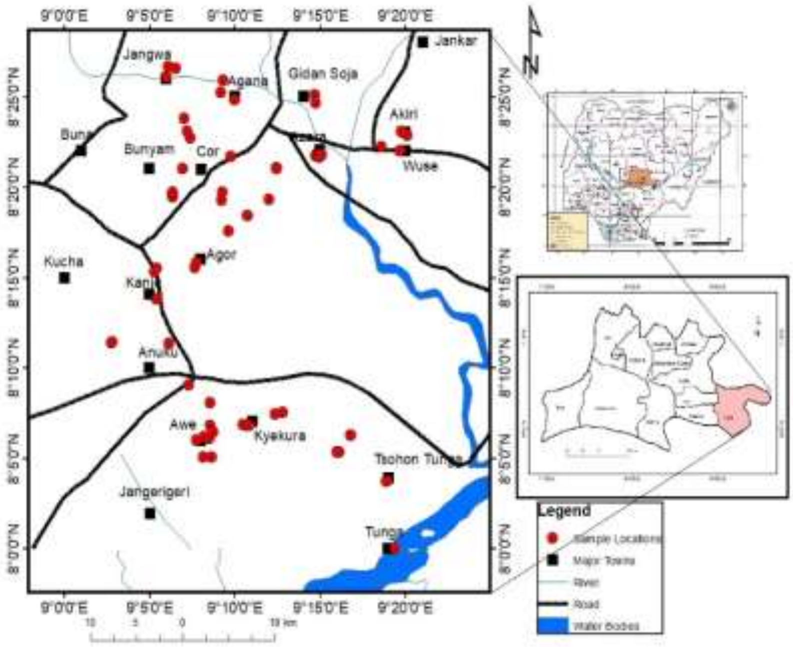

Figure 1: Location Map of the Study Area (Source: Gusikit et al, 2022)

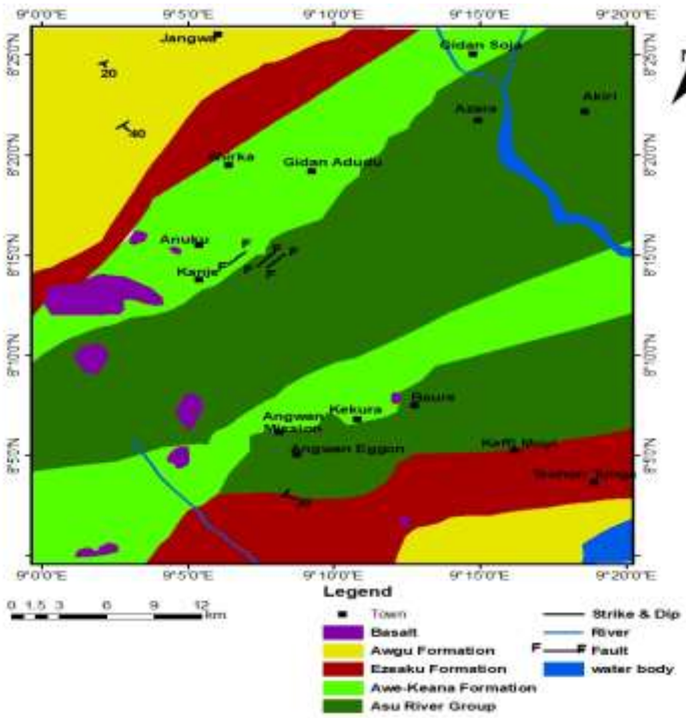

Figure 2: Geological Map of the Study Area (Source: Gusikit et al, 2022)

Presentation of Results

The concentrations of physical and chemical parameters in groundwater of the study area are presented in Table 1 and their variations in Figure 3. Figures 4 to 7 gave the water types of groundwater in the study area based on TDS, EC, TH, and Sr. Tables 2 to 4 gave the concentrations of major elements in groundwater for livestock, irrigation and industrial purposes while Figures 8 and 9 showed the classification of the groundwater of the study area for irrigation purposes.

Table 1: Concentrations of physical and chemical parameters (mg/l) in groundwater water

Parameter	Number of samples	Min.	Max.	Mean	Std. Deviation	Variance	WHO
Temp	53	23.00	46.00	30.48	3.61	13.05	—
pH	52	5.05	7.77	6.68	0.64	0.41	6.5 – 8.5
TDS	53	10.00	10000.00	936.43	2271.4	5159323.36	500
EC	53	20.00	20000.00	1864.11	4537.80	20591635.91	500
HCO_3	53	8.08	113.12	61.07	28.04	786.40	—
SO_4	53	8.50	95.00	34.82	25.16	632.76	100
Cl	53	5.00	4600.00	320.19	968.54	938067.27	250
Ca	53	2.00	215.74	39.31	39.80	1584.22	250
K	53	0.48	90.00	12.59	20.27	411.01	20
Mg	53	0.47	82.88	25.58	19.50	380.20	20
Na	53	1.13	3770.00	273.83	776.02	602212.18	200

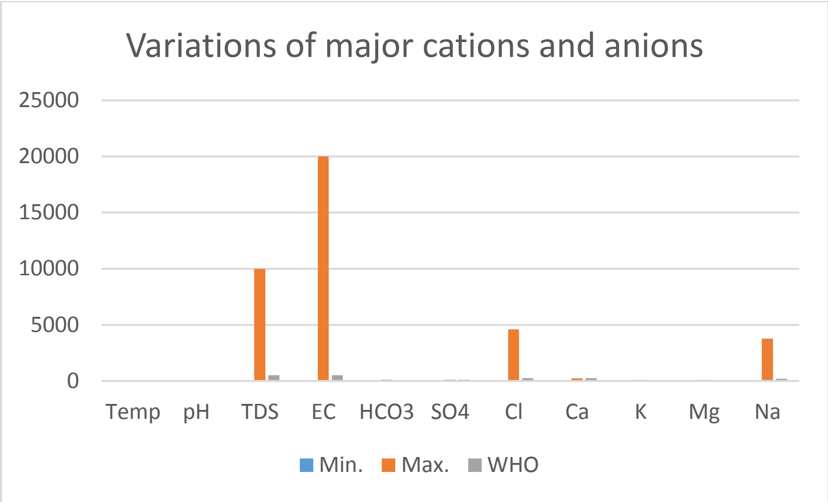

Figure 3: Variations of major cations and anions in groundwater of the study compared with WHO values

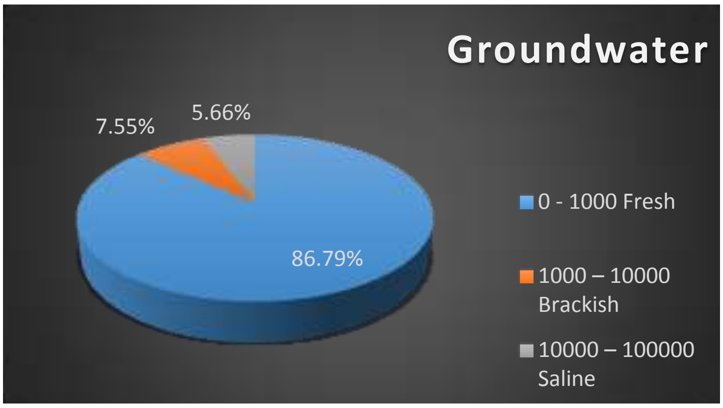

Figure 4: Water types based on concentration of TDS in groundwater of the study

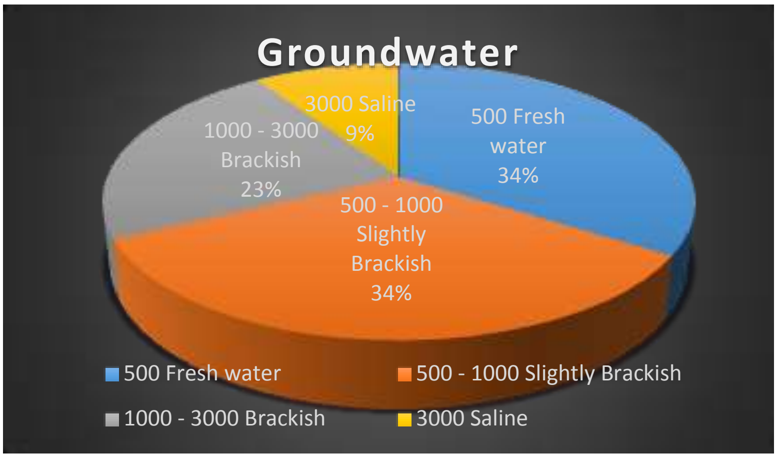

Figure 5: Water types based on concentration of Ec in groundwater of the study area

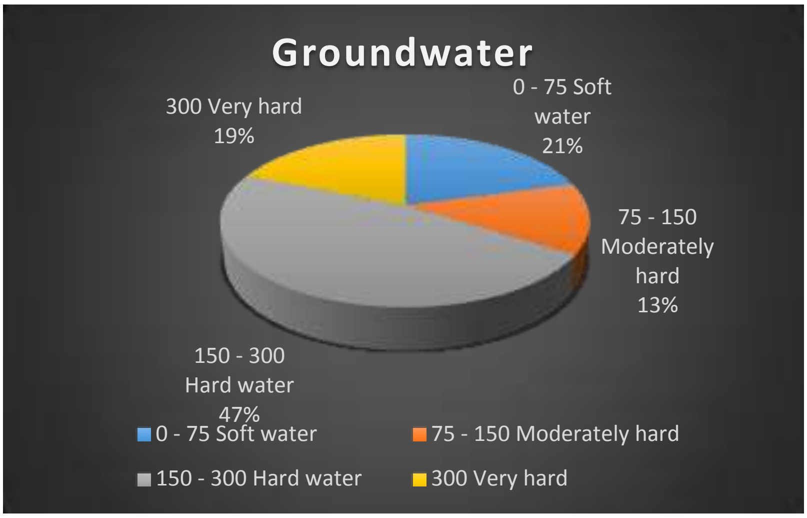

Figure 6: Water types based on concentration of TH of groundwater in the study area

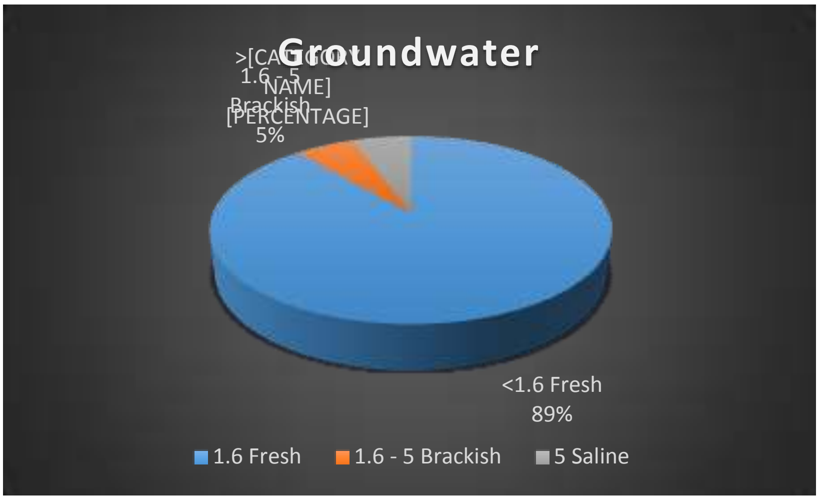

Figure 7: Water types based on concentration of Sr in groundwater of the study area

Table 2: TDS for Livestock

Livestock consumption	Upper limit of TDS (mg/l) (Sudip, 2019)	Comments	
		Groundwater	
Poultry	2860	50	suitable
Pigs	4290	50	suitable
Horses	6435	50	suitable
Dairy cattle	7150	50	suitable
Beef cattle	10,000	50	suitable
Lambs	12,900	53	Suitable

Table 3: Irrigation water classification

Purpose	Parameter	Units	Class range (Edet, 2017)	Classification (Edet, 2017)	Groundwater samples (Present study)	Groundwater Samples %
Irrigation	Electrical conductivity (Ec)	µS/ cm	<250	Excellent	11	20.75
			250 - 750	Good	22	41.51
			750 - 2000	Permissible	13	24.53
			2000 - 3000	Doubtful	4	7.55
			>3000	Unsuitable	3	5.66
	Total hardness (TH)	mg/l	<75	Soft	12	22.64
			75 - 150	Moderately hard	7	13.21
			150 - 300	Hard	24	45.28
			>300	Very Hard	10	18.87
	Sodium adsorption ratio (SAR)		<10	Excellent	49	92.45
			10 - 18	Good	-	-
			18 - 26	Doubtful		
			>26	Unsuitable	4	7.55
	Na%	%	<20	Excellent	2	3.77
			20 - 40	Good	20	37.74
			40 -60	Permissible	17	32.08
			60 - 80	Doubtful	9	16.98
			>80	Unsuitable	5	9.43
	Magnesium Hazard(MH)	%	<50	Suitable	53	100
			>50 Unsuitable		-	-
	Cl	mg/l	<142	Excellent	42	79.25
			142 - 249	Good	5	9.44
			249 - 426	Permissible	1	1.87
			426 - 710	Precaution usable	-	
			>710	Unsuitable	5	9.44
	SO_4	mg/l	<192	Excellent	53	100
			192 - 336	Good	-	
			336 - 575	Permissible	-	
			575 - 960	Precaution usable	-	
			>960	Unsuitable	-	

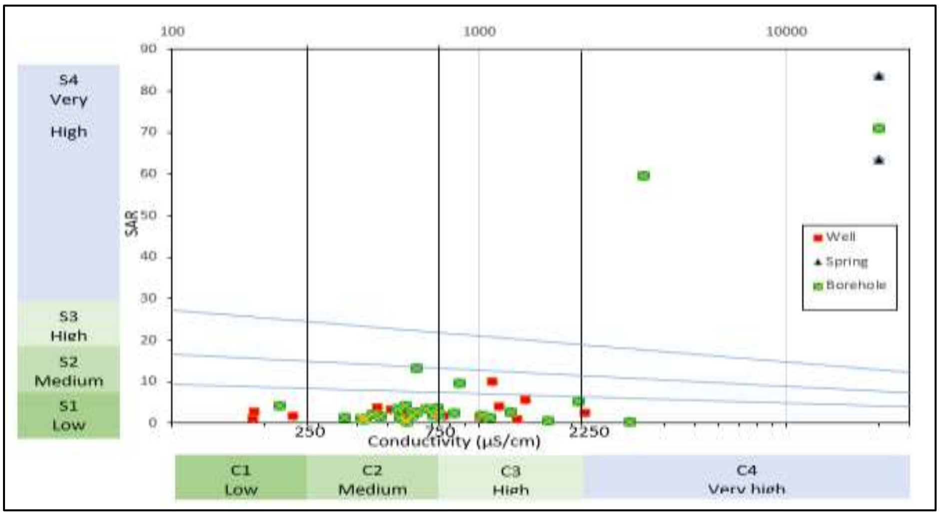

Figure 8: Classification of groundwater of the study area for irrigation using U.S. salinity diagram.

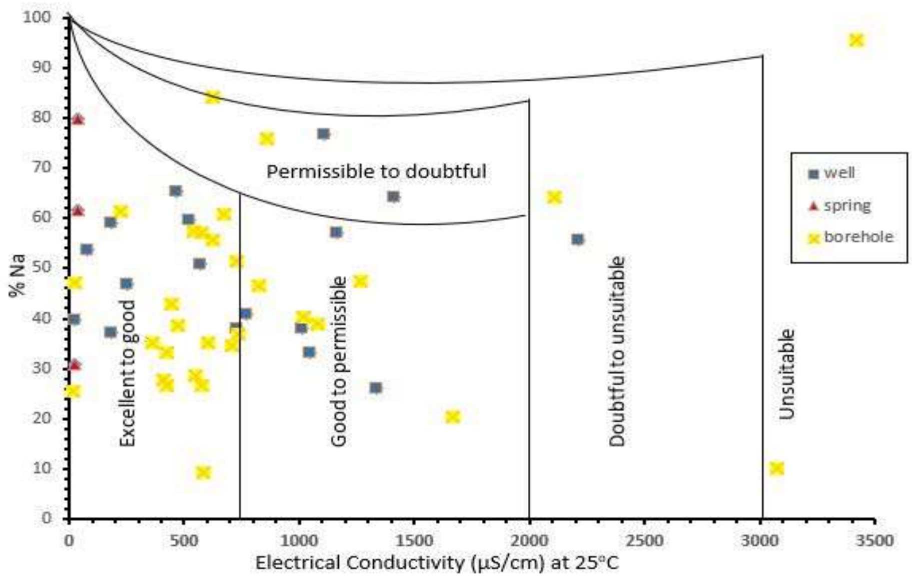

Figure 9: Wilcox (1955) diagram for groundwater of the study area classification based on EC and Na%.

Table 4: Water Quality for Industrial Purpose (Incrustation).

Sources	TH	HCO_3	SO_4
Groundwater	<300–43 samples (81%) >300 – 10 samples (19%)	<400–53 samples (100%) >400 - Nil	<100 – 53 samples (100%) >100 – Nil

Table 5: Foaming action (F) for groundwater in the study area (F=62*Na+78*K**) for Industrial Purpose**

Sources	F<60	F= 60 - 200	F>200
Groundwater	9 samples (16.98%)	18 samples (33.96%)	26 samples (49.06%)

DISCUSSION

Water Quality for Domestic Use

The pH of groundwater in the study area varies from 5.05 to 7.77 with an average of 6.68 (Table 1 and Figures 3). The lowest value is from a spring and the highest value from a well. This indicates slightly acidic to slightly alkaline nature of the groundwater. From the 53 groundwater samples, seven samples show TDS values greater than 1000 (one from well, two from springs and four from boreholes) (Figure 3). Out of the fifty three (53) groundwater samples only six (6) samples (three from well, one from spring and two from borehole) are sub-thermal with temperature values ranging from 23°C - 26°C while the remaining forty seven (47) are thermal with temperature values ranging from 27°C - 46°C (Table 1 and Figure 3). Major cations dominance in groundwater of the study area is in the order of Na>Ca>Mg>K while anions is in the order of Cl>HCO_3>SO_4. The hydrogeochemical parameters show wide variation, indicating the complex hydrogeochemical processes occurring in the study area (Gusikit et al., 2021). Na values are from 1.13 (spring) to 3770.00 mg/l (spring). Values of Ca varies from 2 (borehole) to 215.74 mg/l (borehole). Magnesium (Mg) has a range of concentration between 0.47 (borehole) and 82.88 mg/l (borehole). Concentration of K is relatively lower and shows a range from 0.48 (well) to 90.00 mg/l (spring) Table 1 and Figure 3. Chloride (Cl) ranges between 5.00 (one from well and three from borehole) to 4600.00 mg/l (spring and artesian borehole*)* while HCO_3 and SO_4 are within the WHO (2011) permissible values for drinking water (Table 1 and Figure 3).

Relative to the Ravikumar and Somashekar (2017) TDS values <1000 mg/l for freshwater, 1000–10,000 for brackish water, and 10,000–100,000 as saline water). About 86.79% of the groundwater samples in the study area are classified as freshwater, 7.55% as brackish and 5.66% as saline (Figure 4). Based on EC, four types of groundwater namely: fresh water (34%), slight brackish water (34%), brackish water (23%) and saline water (9%) are identified (Figure 5). Using Nguyet *et al.,* (2016) TH classification (< 75 mg/l for soft; 75–150 mg/l for moderately hard; 150–300 mg/l for hard; and >300 mg/l for very hard), 21% of the groundwater samples are soft, 13% are moderately hard, 47% are hard; and 19% are very hard (Figure 6). According to Saxena et al., (2004), and Gusikit et al, (2019), Sr content scheme, groundwater types in the study area are fresh water (89%), brackish (5%) and saline water (6%) Figure 7.

The high level of TDS and EC and high concentrations of Na and Cl in the hot springs and artesian borehole in Akiri and Tsohon Awe are associated with the oldest rocks (Asu River Group and Awe Formation) in the study area. This is an indication that depth and temperature play a vital role in the distribution of major ions in groundwater of the study area. Thus, groundwater with very high concentration of Cl is not feasible to be used as source of domestic water. The lower SO_4 concentrations in groundwater indicates that the study area lacks industries because high SO_4 concentrations indicate anthropogenic sources and industrial process. Based on this, the distribution of major ions in groundwater of the study area is therefore linked to geogenic (natural) processes. The concentrations of the major ions in most of the groundwater are good for domestic use with the exception of the two hot springs in Akiri and Tsohon Awe and the artesian borehole in Tsoho-garin Awe. All the fresh water and most of the brackish water in the study area are suitable are suitable for domestic use while the saline water are not suitable.

Water Quality for Agricultural Use

Water for agricultural use may be divided into livestock and irrigation purposes. Water is an essential second only to oxygen in importance to sustain life and optimum growth, lactation and reproduction of dairy cattle (Gusikit and Lar, 2014, Sudip *et al.,* 2019). Water is a medium for transportation of nutrients, waste products, hormones and other electrolytes, and aids in the movement of food through the gastrointestinal tract (Sudip *et al.,* 2019). For the livestock, high-quality water should be provided in order to prevent them from different diseases, salt imbalance and poisoning from toxic components (Bhardwaj and Singh 2011).

Fifty of the groundwater samples in the study area are within the allowable limit and suitable for livestock consumption with the exception of three samples (A13, A35a, A35b) from the hot springs and artesian borehole (Table 2) which are within the upper limit for Lambs. Water is very important for all forms of life.

Most of the water quality variables for livestock are same as for human drinking water, although the total permissible levels of total suspended solids and salinity may be higher (Bhardwaj and Singh 2011). The total dissolved solids (TDS) are the main parameter usually used to assess the suitability of any water for livestock farming. Based on a research by Sudip *et al.,* (2019), the TDS value for some livestock are listed as follows (poultry – 2860mg/l, pigs – 4290 mg/l, horses – 6435mg/l, dairy cattle – 7150 mg/l, beef cattle – 10, 000 mg/l, lambs – 12,900 mg/l). In this present research, most of the groundwater in the study are good for poultry, pigs, horses and diary cattle because their TDS ranged from 10 - 1851 mg/l. The groundwater from the two hot springs and artesian borehole with TDS >10,000mg/l will only be suitable for beef cattle and lambs productions.

Most of the groundwater in the study area are suitable for irrigation in terms of Ec, TH, SAR, MH and Cl (Table 3) with the exception of the three saline water (Akiri salt farm, Tsohongari Awe artesian borehole and Tsohon Awe spring). In terms of SO_4, all the groundwater are suitable for irrigation. The suitability of water for irrigation is based on effects of mineral constituents of the water for both the plants and soils. In general, excessive amount of dissolved ions in water used for irrigation will affect both plants and soils thus reducing productivity (Edet, 2017).

Most natural waters are between pH 5 and 8. The generally accepted pH for irrigation water is in-between 5.5 and 7.5 (Sudip *et al.,* 2019), this is an indication that the pH of the groundwater in the study area are suitable for irrigation purpose. Electrical conductivity (EC) is a good measure of salinity hazard as it reflects the total dissolved solids (TDS) in water. Eleven groundwater samples fell under excellent water for irrigation, twenty two groundwater samples fell under good water for irrigation, and thirteen groundwater samples fell under permissible water for irrigation, four and three groundwater samples fell under doubtful and unsuitable water for irrigation respectively (Table 3). The doubtful and unsuitable types of groundwater are not important for irrigation in the study area. Excess EC may physically harm plant growth by limiting the uptake of water and nutrients through modification of osmotic processes (Edet, 2017) and chemically by metabolic reactions such as those caused by toxic constituents (Edet, 2017). The total hardness (TH) according to the classification of Edet (2017), twelve groundwater samples fell under the category of soft water. Seven groundwater sample came under moderately hard category, while twenty four groundwater samples are in the hard class. Ten groundwater samples fell under very hard water for irrigation and they are not suitable for irrigation.

Sodium adsorption ratio (SAR) was also used to assess the groundwater for irrigation. SAR is used as a better measure (alkali) hazard in irrigation as SAR of water is directly related to the adsorption of Na by soil and is a valuable criterion for determining the suitability of water for irrigation (Edet, 2017). Almost all the groundwater samples are excellent for irrigation and just few fell in the unsuitable category using SAR calculation. None of the groundwater sample fell in the good or doubtful categories. Classification of groundwater of the study area for irrigation using U.S. salinity diagram (SAR/conductivity) indicates that most of the well and borehole water are good for irrigation and only water from the two hot springs and Tsohogari Awe artesian borehole are unsuitable for irrigation (Figures 8).

Sodium percentage (% Na) is very important for classifying the irrigation water because Na by process of ion exchange replaces Ca in soil thereby destroying the soil structure resulting in reduced permeability (Edet, 2017). The Na % data for groundwater indicates that few fell under excellent zone, many fell within good and permissible zone and few fell under doubtful and unsuitable respectively for irrigation purpose (Figure 9).

In terms of magnesium hazard (MH), water has no adverse effect on crop yield with MH <50 % (Edet, 2017). The MH values from the present research showed that all of groundwater are suitable for irrigation purpose (Table 3). Chloride (Cl) and SO_4 have also been used for assessment of suitability of water for irrigation (Edet, 2017). Chloride is an essential element for plants and also an important criterion for agriculture water. Sulphate is necessary for plant nutrition, but water containing more than 1000 ppm of SO_4 is not good for plants with respect to adsorbing Ca (Edet, 2017). From the results obtained, many of the groundwater samples from the study area are in excellent zone while few fell within good, permissible and unsuitable with respect to Cl for irrigation purposes (Table 3).

Water quality for industrial purposes

Three well water samples (A25, A29 and A30a), one spring sample (A35a) and six borehole water samples (A10a, A16b, A28, A37b, A38b and A41) are not suitable for industrial use based on TH (Table 4). Boiler scale attached to the boiler wall is adverse to heat transfer, hence wastes fuel, even melts boiler or causes an explosion. It is formed by precipitation of calcium salt, magnesium salt, SiO_2, Al_2O_3, Fe_2O_3, and suspended solids dissolved in water. Three parameters can be adopted to decide the properties of incrustation. The concentrations of TH, HCO_3, and SO_4 are greater than 300 mg/L, 400 mg/L and 100 mg/L, respectively, may cause incrustation (Hao *et al.,* 2015). Total hardness (TH) results showed that forty three (43) of the groundwater samples are suitable for industrial use while the remaining 10 samples are unsuitable.

Nine of the groundwater samples have foaming action less than 60 (F < 60). Eighteen of the groundwater samples have marginal forming action (F 60 – 200). Twenty six of the groundwater samples have foaming action greater than 200 (F > 200). Water bubbled up to the surface when boiled. While bubbles cannot break open in time, thick and unstable bubbles are formed. Too many bubbles elevate the water table resulting in boilers not working. This is a result of the saponification reaction related to sodium (Na), potassium (K), grease, and suspended solids (Hao *et al.,* 2015). The foaming coefficient is a measure of foaming action: $F = 62 \times Na + 78 \times K$. Where the concentrations of sodium and potassium are expressed in meq/l. The water of no foaming action is $F < 60$, and that of foaming action is $F > 200$. While F is in the range of 60–200, the water is marginal.

As per the value of calculated F, 17 samples of the groundwater have the values of F ranged from 60 to 200, which all belong to marginal range (Table 5). It means that locomotive water boiler needs to be refreshed at least two or three days. As for no foaming action, 9 groundwater samples with F < 60, refreshing once a week is required. The remaining 27 groundwater samples (Table 5) are unsuitable for industries that use boilers because bubbles cannot break open in time and this can result to thick and unstable bubbles. Too many of this bubbles elevate the water table resulting in boilers not working (Hao *et al.,* 2015).

CONCLUSION

The distribution of major ions in the groundwater water of the study area is geogenic in nature as indicated by low level of SO_4. Fifty samples of groundwater in the study area are suitable for domestic and agricultural purposes with the remaining three saline water not suitable for any of these purposes.

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