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Research Paper

Groundwater Quality Assessment in the Upper Denkyira Districts of Ghana

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Abstract: The Upper Denkyira East and West Districts heavily rely on groundwater for all of their various water needs. The rising levels of surface water pollution brought on by mining, farming, improper waste disposal, and galamsey activities necessitate evaluating the quality of the groundwater for drinking, domestic use, and irrigation. The goal of the study was to assess the suitability of groundwater for drinking, domestic use, and irrigation purposes. Groundwater in the area can be classified as mixed water, NaCl, $CaHCO_3$, and $CaMgSO_4$. Three processes including rock mineral dissolution, ion exchange, and the effects of anthropogenic activities are major factors influencing the chemistry and overall quality of the groundwater in the area. The water quality index indicates that 38%, 38%, 3%, and 21% of the water samples are of excellent, good, poor, and very poor quality respectively for drinking. The groundwater is unfit for drinking without prior treatment due to its low pH, high pH, high Fe, high Mn, and high PO_4^{3-} levels. The quality of groundwater is impacted by both geological processes and anthropogenic activities like improper agrochemical application, galamsey, and improper waste disposal. The study discovered that 48% of the groundwater types were excellent, 34% were good, 14% were moderate, and 3% were poor based on IWSI. The IWSI was calculated using EC, SAR, Na%, RSC, KI, PI, MH, and CR. The IWSI results and the USSL and Wilcox diagrams demonstrated that the groundwater falls within the excellent to good categories. The study has shown that the IWSI method is a reliable technique for assessing water quality irrigation.

Keywords: *Upper Denkyira Districts, Groundwater Quality index, Irrigation Water Suitability Index, Anthropogenic Activities, Birimian*

Introduction

Water is a natural resource essential for human survival, socioeconomic development, factory operation, aquatic life survival, etc. The quality of water is determined by its intended usage; however, for water to be useful the physical, chemical, and biological parameters should have concentrations within a certain limit as approved by the right authority. Increasing or decreasing the centration of a water parameter may render water unfit for its intended usage. Therefore, the definition of water quality is complex since it depends on its desired use and other factors (Babiker et al., 2007). The challenge of not meeting water supply demand calls for effective techniques that serve as keys to the sustainability of water resources. Hence, there is a need for data collection, analysis, and interpretation to make informed decisions on water resources. This is needed for groundwater resource protection and the overall management of water resources.

In modern days the increasing growth of the global population size and advancement in all areas of technology including agriculture, mining, road construction, etc. have impacted water bodies such that some are unsafe for human consumption without treatment. The rate at which this contamination is occurring is so alarming that the whole environmental contamination is globally seen as a major issue for human survival. For example, in Ghana, the recent outbreak of illegal small-scale mining has destroyed the environment and strongly impacted water bodies. This impact includes the introduction of heavy metals and other poisonous substances into water bodies through runoff from agrochemical applications on farmland, improper disposal of domestic and industrial waste, etc.; making them unfit for human consumption (Raju *et al.*, 2011). This calls for effective groundwater quality monitoring for early detection of contamination and this involves continuous groundwater quality assessment. Therefore, a lot of researchers have conducted research in this field of study in different parts of the globe. This is to help address the increasing challenges affecting groundwater management due to geogenic processes and human activities. For example, the studies of Baba and Tayfur in Turkey and Li *et al.* in China helped

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reveal the groundwater quality issues in the respective study areas and their possible public health effects (Li *et al*., 2010a; Baba & Tayfur, 2011).

Different authors have successfully applied the GIS technique in groundwater studies to integrate different parameters for effective decision-making (Goodchild, 2000). The technique also bridges the gap between water professionals and other professional groups when it comes to communication about water quality issues (Twigg, 1990). For instance, the application of GIS successfully revealed public exposure to polluted water, the spatial distribution of the degree of contamination, and the affected communities (Aral & Maslia, 1996).

Most developing countries like Ghana heavily depend on groundwater due to its availability and relatively low treatment cost. Groundwater is used for drinking, domestic, and agricultural purposes in most developing countries (Margat *et al*., 2013). This has resulted in increasing demand for the resource globally (EEA, 1999; UNECE, 1999). This shows the importance of groundwater and the need to protect it from contamination. This calls for data collection, analysis, and interpretation for effective decision-making. Ghanaians primarily use groundwater resources for drinking, domestic use, and agriculture, according to Gyau-Boakye *et al*. (2008). This is partly because Ghana Water Company Limited (GWCL) serves only the urban areas. Groundwater is the main source of water for the majority of rural water supplies developed by the Community Water and Sanitation Agency (CWSA), non-governmental organizations, faith-based organizations, etc., according to Gyau-Boakye *et al.* (2008). Like many other districts in Ghana, the Upper Denkyira East and West Districts heavily rely on groundwater for the majority of their water needs.

Most of their activities, like improper agrochemical application, galamsey, and improper waste disposal have the potential to contaminate groundwater, endangering the ability of the groundwater resource to remain pure. These towns are primarily agricultural, and the gold minerals in their lands are abundant. The suitability of groundwater for drinking, domestic use, and agricultural use, as well as any potential anthropogenic effects on the chemistry of the groundwater, are important to understand. This will contribute to the public's access to potable water and the efficient management of water resources.

The groundwater resource of the aquifers in the districts, however, is not well known. The purpose of the study was to characterize the chemical parameters, identify the factors influencing groundwater chemistry, and assess the suitability of the groundwater for irrigation, domestic use, and drinking. This is essential to meet Sustainable Development Goal Number Six mainly on clear water and sanitation. The hydrogeology of the Districts is mainly controlled by the underlying Birimian and Tarkwaian formations. These rocks have limited primary porosity and permeability; hence, their hydraulic properties are controlled mainly by the secondary hydraulic properties. Therefore, the flow of groundwater occurs mainly through the fracture zones and other discontinuities instead of interstitial flow (CAGL, 2010). While Coffey observed that the groundwater flows toward the Offin River, (CAGL, 2010) observed a radial flow of groundwater within the Districts. Also, while JMSL (1993) noticed aquifer recharge of 3-5% of the total precipitation CAGL (2010) observed 15% of total precipitation.

Materials and Methods

Study area

Situated on a forest-cut plateau, the study area features undulating steep-sided hills and valley topography. The highest rise is about 250 m high. The primary drainage sources for the region are the Offin and Dia Rivers and their tributaries, Ninta, Subin, and Afiefi. The area is in the semi-equatorial zone, with mean annual temperatures of 30°C for the hottest month and 26°C for the coolest month during the wet and dry seasons, respectively (GSS, 2021). With an average yearly rainfall of 1,200 mm to 2,000 mm, the region experiences two different rainfall regimes (GSS, 2021). The first rainy regime starts in May or June, the second begins in September or October, and the dry season starts in November or February. Plantains, cocoa, cassava, and other crops are common in the districts. The districts rank among the top cocoa-producing districts in the Central Region of Ghana, which is significant. Due to the large gold reserves within the districts, many mining companies and small-scale illegal miners, known locally as galamsey, have been drawn to the area. The primary geological components of the region are the Tarkwaian and Birimian Formations (Fig. 1).

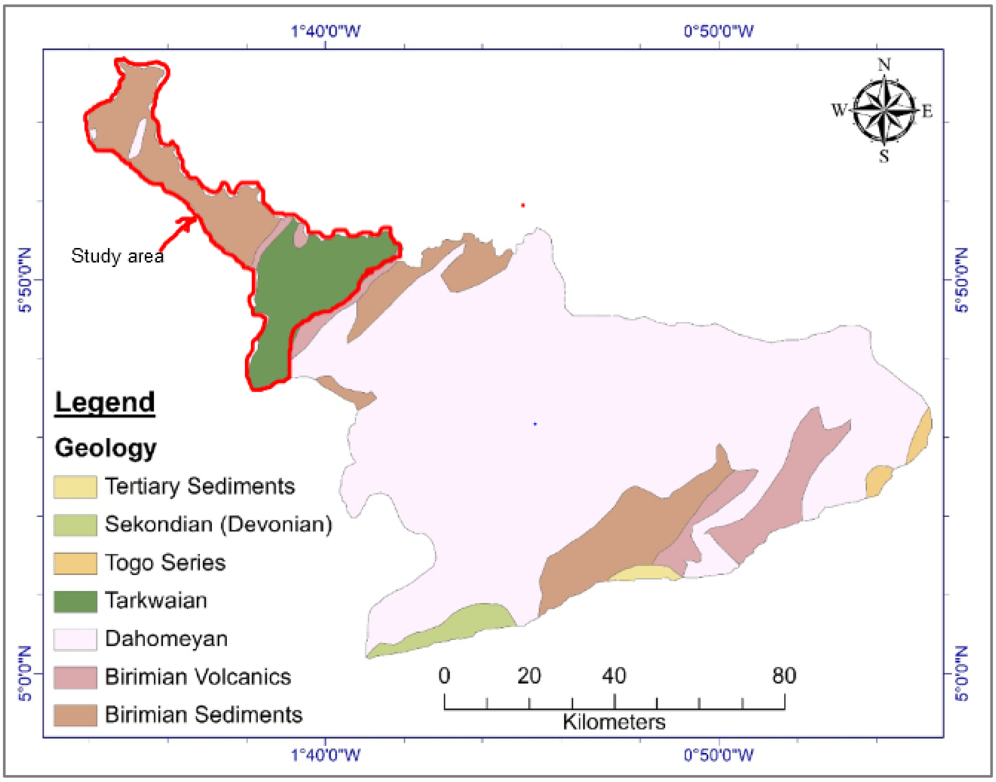

Figure 1. Geological Map of Central region showing the study area (Modified after Osiakwan *et al*., 2022)

Hydrogeology

The study area is underlain by the northeastern and southwest-oriented Middle Precambrian Birimian and Tarkwaian Formation hydrogeological units (Fig. 1). Despite having distinct dates, phyllite may be found in relative abundance in both the Tarkwaian and Birimian Formations. The Birimian formation contains metamorphosed volcanic and sedimentary rocks. Granitoid invasion, folding, and transformation under the greenschist-facies condition occurred during the Eburnean (Junner, 1935; Leube *et al*., 1990). The folded and foliated rocks of the Birimian formation enhance the permeability of the rocks for groundwater storage and flow in conjunction with the faults, folds, foliations, and joints (Junner, 1935). Because of the considerable shearing, schists are more common where the rocks and granitic intrusives of the Birimian Sedimentary Basin meet.

Because the Dixcove granite (G2) is a complex rock that intrudes into the Birimian metavolcanic, the volcanic belts are granitoid. These rocks are frequently tonalitic, consisting of granodiorites, biotite granite, or soda-rich hornblende that grade into hornblende diorite and quartz diorite. The study area has a variety of rocks, including granite, sandstones, mudstones, siltstones, phyllites, slates, schists, tuffs, conglomerates, and greywackes. Thus, the minerals commonly discovered in the area include orthoclase, plagioclase, quartz, biotite, muscovite, amphibole, hornblende, calcite, silica, and chlorite. The Birimian rocks have poor correlations between borehole production and depth, according to Anornu et al. (2009). The transmissivity of boreholes ranges from 0.12 to 125 m2/day based on the results of pumping tests conducted by Anornu *et al.* (2009).

Different sandstones, conglomerates, and argillites make up the Tarkwaian Formation. Griffiths et al. (2002) claim that after deposition in alluvial fans, the conglomeratic units of the Tarkwaian Formation were modified by braided stream channels. In the latter, concentrated fine gold particles are considered present in the channel conglomerates. The northeastern folding of the Tarkwaian increases the groundwater potential (Kesse, 1985). Additionally, according to the CSIR-WRI Database (2007), the presence of a buried river channel (Dickson and Benneh, 1988), substantial weathering, and the availability of quartz veins are characteristics of the Birimian and Tarkwaian Formations that contribute to the comparatively high groundwater potential of the area (Kortatsi, 1994). Figure 2 shows the directions of groundwater flow within the study area. The groundwater flows into the Offin River within the study area.

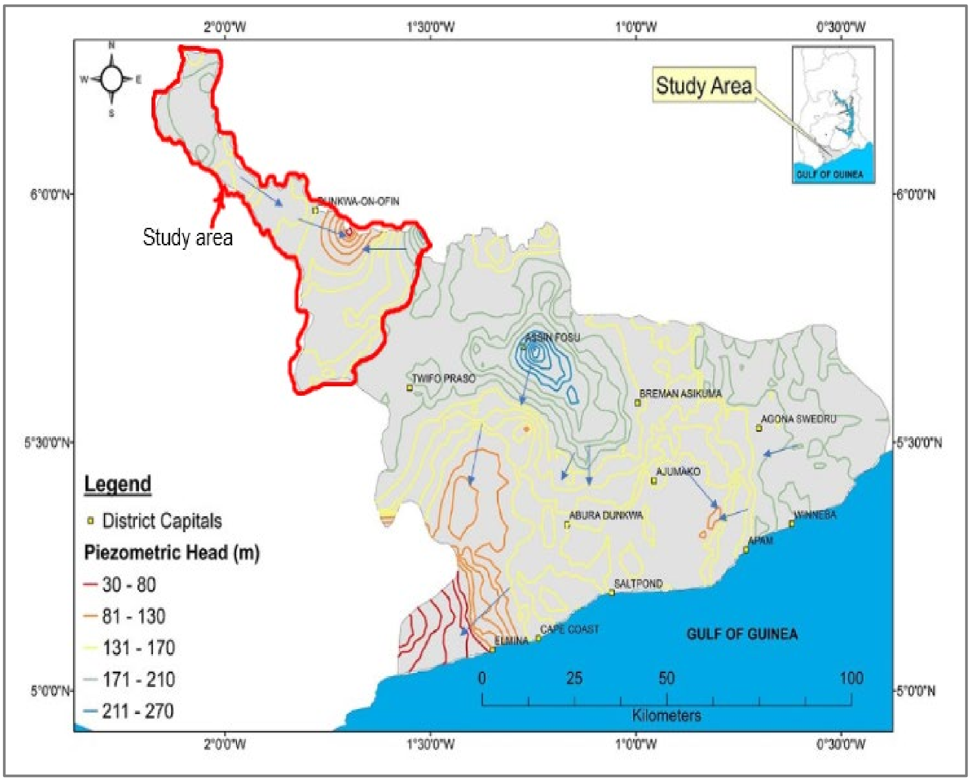

Figure 2. Groundwater flow directions of Central Region showing the study area (Modified after Osiakwan *et al.*, 2022)

Method

The data used in this study was provided by the Central Regional Office of Community Water and Sanitation Agency (CWSA) in Cape Coast. Physico-chemical parameter data from 29 boreholes were obtained from CWSA in November 2020. The data was gathered as part of several initiatives to provide the target communities with potable water. The Geographic Positioning System (GPS) was used to record the coordinates of the boreholes where the samples were taken. Groundwater samples were taken in 500 ml high-density polyethylene sampling bottles for in-lab testing. Typically, the samples were taken after a long pumping session or a pumping test. The samples were preserved for heavy metal analysis, and 10 ml of 69% nitric acid was used to prepare them for the analysis. The bottles were labeled to identify the samples while the necessary field observations and other data were being recorded in the field notebook. Physical parameters such as pH, Total Dissolved Solids (TDS), and Electrical Conductivity (EC) were measured in situ using a portable meter (Hanna instrument), using the guidelines of the World Health Organization (WHO, 2008) and American Public Health Association (APHA, 1995). The samples were kept in an ice chest with ice packs during transportation to the Ghana Water Company Limited (GWCL) Laboratory in Cape Coast for additional analysis.

The recommended standards from APHA (1995) were used to analyze the groundwater samples. TDS, EC, temperature, and pH were among the physical parameters examined using the probe method. Chemical parameters F^-, Cl^-, SO_4^{2-}, NO_3^-, NO_2^-, PO_4^{3-}, and CO_3^{2-} were examined using ion chromatography, while Fe, Mn, and Ca^{2+} were examined using Atomic absorption spectrometry (AAS). $CaCO_3$ mg/L was changed into HCO_3^- using the formula proposed by Hem (1985). The measurement of Total Suspended Solid (TSS) was done using photometric method 8006, the measurement of Total Hardness (TH) was done using titrimetric method, the measurement of alkalinity was done using titration method, the measurement of turbidity was done using absorptiometric method, the measurement of color was done using cobalt standard method, the measurement of salinity was done using electrical conductivity method, measurement of sodium and potassium was done using flame photometer. The calculated Charge Balance Error (CBE) of the samples was used to evaluate the accuracy of the laboratory data, and it was found that the samples were accurate to within ±10% (Celesceri *et al.*, 1998) as shown in Table 1.

Table 1. Calculated results of charge balance error

No	Community	Na	K	Ca	Mg	NH_4	Cl	SO_4	NO_2	HC_3	CO_3	TZ^+	TZ^-	CBE (%)
1	Subinsu	2.91	0.19	1.00	1.33	0.00	1.76	1.31	0.00	2.69	0.00	5.44	5.75	-2.84
2	Barrier	0.57	0.06	0.17	0.41	0.00	0.45	0.33	0.00	0.49	0.00	1.20	1.28	-3.00
3	Sobroso	0.83	0.07	0.46	0.09	0.00	0.28	0.17	0.00	0.05	1.08	1.45	1.59	-4.60
4	Zion Camp	0.76	0.07	1.20	0.17	0.00	0.68	0.52	0.00	1.04	0.00	2.20	2.24	-0.90
5	Achiase	0.53	0.01	0.08	0.16	0.00	0.14	0.11	0.00	0.44	0.00	0.78	0.69	6.45
6	Fosu Dankwa	0.07	0.02	2.41	1.03	0.02	0.17	0.36	0.00	3.10	0.00	3.53	3.64	-1.58
7	Zion 2	0.65	0.09	0.32	0.15	0.00	0.34	0.05	0.00	0.37	0.40	1.21	1.15	2.62
8	Akyerekrom	0.20	0.03	0.70	0.10	0.00	0.40	0.02	0.00	0.53	0.00	1.02	0.95	3.45
9	Zion 1	0.30	0.06	0.12	0.20	0.00	0.33	0.00	0.00	0.24	0.00	0.67	0.57	8.38
10	Congo 1	0.24	0.03	0.20	0.33	0.00	0.17	0.13	0.00	0.56	0.00	0.80	0.86	-3.55
11	Gyampokro1	0.37	0.06	0.12	0.20	0.00	0.34	0.02	0.00	0.36	0.00	0.75	0.72	2.16
12	Konaboe	0.37	0.06	1.49	0.48	0.00	0.37	0.16	0.00	1.84	0.00	2.41	2.37	0.78
13	Abudukrom	0.75	0.06	0.44	0.20	0.88	0.03	0.00	0.00	0.74	0.00	1.45	1.66	-7.90
14	Imbrain Clinic	0.37	0.03	0.40	0.16	0.00	0.28	0.34	0.00	0.40	0.00	0.96	1.02	-3.14
15	Kruwa	0.52	0.08	1.03	0.17	0.00	0.31	0.52	0.00	0.81	0.00	1.80	1.64	4.81
16	Kyebi	2.04	0.35	2.69	3.28	0.00	3.83	2.02	0.00	1.75	0.00	8.35	7.60	4.68
17	Tegyamoso	0.73	0.04	0.43	0.56	0.00	0.28	0.22	0.00	1.09	0.00	1.75	1.59	4.84
18	Betease	0.80	0.13	0.24	0.13	0.00	0.62	0.02	0.00	0.68	0.00	1.29	1.32	-1.18
19	Adedietem	0.44	0.07	0.91	0.36	0.00	0.45	0.57	0.00	0.91	0.00	1.78	1.94	-4.27
20	Amobaka	0.81	0.02	0.20	1.09	0.00	0.68	0.18	0.00	1.40	0.00	2.12	2.26	-3.08
21	Adeade	0.80	0.01	0.04	0.37	0.00	0.28	0.23	0.00	0.60	0.00	1.22	1.11	4.66
22	Kyerepo	0.99	0.02	0.56	0.85	0.00	0.20	0.22	0.00	2.00	0.00	2.42	2.41	0.06
23	Ampabeng	1.11	0.05	0.16	0.29	0.00	0.14	0.08	0.00	1.24	0.00	1.62	1.46	6.14
24	Aniantetem	1.23	0.02	0.24	0.41	0.00	0.88	0.17	0.00	0.76	0.00	1.90	1.81	2.34
25	Ntomfom	0.13	0.02	0.87	0.73	0.00	0.43	0.27	0.00	1.24	0.00	1.74	1.94	-5.52
26	Kotedaso	0.43	0.07	0.42	0.55	0.01	0.28	0.18	0.00	0.88	0.00	1.48	1.35	4.60
27	Ananekrom	0.22	0.03	0.34	0.83	0.00	0.28	0.20	0.00	0.80	0.00	1.41	1.29	4.49
28	Bethlehem	0.65	0.05	0.15	0.18	0.00	0.51	0.12	0.00	0.45	0.00	1.02	1.08	-2.52
29	Amoaman	0.10	0.02	0.40	0.22	0.00	0.17	0.07	0.00	0.42	0.00	0.73	0.66	5.07

Water Quality Index (WQI)

The WQI was assessed using the following parameters pH, TH, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-, TDS, F^-, NO_3^-, SO_4^{2-}, Fe, Na^+, Mn and PO_4^{3-} and following steps below;

a. Assignment of Weights (w_i) to the various groundwater parameters based on their potential impact on human health (Table 2). The weights to the various parameters were assigned based on literature review and public health experts input.

b. Calculation of Relative weight (W_i);

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (1)$$

c. The Quality rating (q_i) calculation;

$$q_i = 100 * \left(\frac{C_i}{S_i}\right) \quad (2)$$

d. Calculation of sub-index (SI) of various parameters;

$$SI_i = W_i * q_i \quad (3)$$

e. Calculation of Water Quality Index (WQI);

$$WQI = \sum SI_i \quad (4)$$

Where SI is the sub-index for the different parameters, S_i is the WHO value in mg/L, C_i is the lab concentration in mg/L, W_i is the relative weight, W_i is the assigned weight, and n is the number of parameters (Couillard & Lefebre, 1985).

Irrigational Water Suitability Index (IWSI)

To assess the suitability of the groundwater for irrigation use, an effort was made to integrate the effects of eight parameters frequently used to evaluate irrigational water to create IWSI. The creation of IWSI involved the computation of the eight irrigational water quality assessment parameters including EC, Sodium Absorption Ratio (SAR), Sodium Percentage (Na%), Residual Sodium Carbonate (RSC), Kelly Index (KI), Permeability Index (PI), Magnesium Hazard (MH) and Corrosivity Ratio (CR) using equations (5) to (11) and expressing all the ionic concentrations in meq/L. After that, an equal weight of 5 was assigned to all eight parameters. The parameters were classified based on their existing classification, and a rate of 1-5 was assigned to the classes based on their impact on water quality. Equation (12) was used to calculate the IWSI after the weights and ratings for each factor were assigned. Higher values achieved through this method indicate a greater likelihood of suitable groundwater quality for irrigational purposes.

Table 2. Groundwater quality parameters used for calculation of water quality index

Parameter	Weight (w_i)	Relative weight (W_i)	WHO (2012)
pH	4.00	0.09	6.5-8.5
TH	3.00	0.07	500.00
Ca^{2+}	2.00	0.04	75.00
Mg^{2+}	2.00	0.04	150.00
Na^{+}	3.00	0.07	200.00
Cl^{-}	4.00	0.09	250.00
TDS	4.00	0.09	1500.00
F^{-}	4.00	0.09	1.50
NO_3^{2-}	5.00	0.11	50.00
SO_4^{2-}	4.00	0.09	250.00
Mn	3.00	0.07	0.10
Fe	3.00	0.07	0.30
PO_4^{3-}	4.00	0.09	0.10
TOTAL	**45.00**	**1.00**	

$$SAR = \frac{rNa^{+}}{\sqrt{(rCa^{2+}+rMg^{2+})/2}} \tag{5}$$

$$\mathrm{Na\%} = 100 * \frac{\mathrm{rNa^{+}}}{\mathrm{rCa^{2+}+rMg^{2+}+rNa^{+}+rK^{+}}} \tag{6}$$

$$\mathrm{MH} = \frac{\mathrm{rMg^{2+}}}{\mathrm{rCa^{2+}+rMg^{2+}}} * 100 \tag{7}$$

$$\mathrm{PI} = 100 * \frac{\mathrm{rNa^{+}} + \sqrt{\mathrm{rHCO_3^{-}}}}{\mathrm{rCa^{2+}+rMg^{2+}+rNa^{+}}} \tag{8}$$

$$\mathrm{RSC} = (\mathrm{rCO_3^{2-}} + \mathrm{rHCO_3^{-}}) - (\mathrm{rCa^{2+}} + \mathrm{rMg^{2+}}) \tag{9}$$

$$CR = \left(\frac{\frac{rCl^{-}}{35.5} + 2\left(\frac{rSO_4^{2-}}{96}\right)}{2\left(rHCO_3^{-}+rCO_3^{2-}\right)}\right) * 100 \tag{10}$$

$$\mathrm{KI} = \frac{r\mathrm{Na^{+}}}{\mathrm{rCa^{2+}+rMg^{2+}}} \tag{11}$$

$$IWSI = \sum_{j=1}^{m}\sum_{i=1}^{n}(W_i * r_j) \tag{12}$$

Where n is the total variables, m is the total variable classes, W_i is the weight of the i^{th} desired variable, r_j is the weight of the j^{th} variable class, and IWSI is the irrigation water suitability index. Table 3: presents the weights assigned to the different parameters and rating of their subclasses

Table 3. Weights assigned to different parameters and rating of their subclasses

Parameter	Weight (W)	Classes	Rate (r)	W*r
EC (Wilcox, 1955)	5	<1000	5	25
		1000-2000	4	20
		2000-3000	3	15
		3000-4000	2	10
		>4000	1	5
SAR (USSL, 1954)	5	<2	5	25
		2-10	4	20
		10-18	3	15
		18-26	2	10
		>26	1	5
Na% (Wilcox, 1955)	5	< 60	5	25
		>60	1	5
RSC (Raghunath, 1987)	5	<1.25	5	25
		1.25-2.5	3	15
		>2.5	1	5
KI (Kelley, 1940)	5	<1	5	25
		>1	1	5
PI (Doneen, 1962)	5	<25	1	5
		25-75	3	15
		>75	5	25

MH	5	<50	5	25
(Paliwal, 1972)		>50	1	5
CR	5	<1	5	25
(Ryzner, 1944)		>1	1	5

To show the spatial distribution of the WQI and IWSI values, numerical weight were assigned to the various classes as codes as shown in Table 4.

Table 4. Computed values of WQI, IWSI and their assigned codes

WQI			IWSI		
Classes	**Interpretation**	**Code**	**Classes**	**Interpretation**	**Code**
0-50	Excellent	1	90-100	Excellent	1
50-100	Good	2	80-90	Good	2
100-200	Poor	3	70-80	Moderate	3
200-300	Very poor	4	60-70	Poor	4
>300	Unsuitable	5	<60	Unsuitable	5

Results

A statistical breakdown of the hydrochemical data used in this study is shown in Table 5. The table shows that, according to WHO (2012), some samples are below the parameters' upper permissible limits while others are above them. The pH of the groundwater ranged from 5.24 to 9.40, with a mean of 6.17. The dissolution of minerals in groundwater is impacted by pH, which also affects the chemistry and overall quality of the groundwater for a range of intended uses. (Freeze, 1979; Langmuir, 1997) The majority of groundwater samples have pH values that range from neutral to acidic. The pH range for drinking water is 6.5 to 8.5, as per the WHO (2012). The low pH levels of groundwater are attributed, in part, to CO_3^{2-}charged precipitation (Anku *et al*., 2009; Chegbeleh *et al*., 2020). The EC ranged from 54.10 to 758.00µS/cm, with a mean of 198.18µS/cm. The EC values meet the 2500µS/cm drinking water standard recommended by the WHO. The TDS values, which ranged from 29.80 mg/L to 501 mg/L with a mean of 127.21 mg/L, were all below the recommended level of 1000 mg/L.

Table 5. Statistical summary of the groundwater data

Parameter	Unit	Minimum	Maximum	Mean	Std. Deviation	WHO (2012)
Alkalinity	mg/L	9.80	155.00	48.32	35.29	
HCO_3^-	mg/L	3.17	189.00	59.07	43.85	
Ca^{2+}	mg/L	0.80	53.70	12.25	13.00	75.00
Ca^{2+} Hardness	mg/L	2.00	134.00	29.86	32.74	
Cl^-	mg/L	0.00	32.50	1.53	6.36	250.00
CO_3^{2-}	mg/L	1.00	134.00	18.11	24.97	
Colour	PCU	2.50	50.00	10.10	12.67	15.00
EC	µS/cm	54.10	758.00	198.18	150.25	2500.00
F^-	mg/L	0.01	1.32	0.27	0.31	1.50
Fe	mg/L	0.01	1.59	0.39	0.46	0.30
PO_4^{3-}	mg/L	0.00	0.81	0.33	0.28	0.10
K^+	mg/L	0.40	13.50	2.44	2.61	30.00
Mg^{2+}	mg/L	1.10	39.30	6.37	7.49	150.00
Mg^{2+} Hardness	mg/L	0.01	162.00	25.99	31.64	
Mn	mg/L	0.01	2.78	0.29	0.53	0.10
Na^+	mg/L	1.50	67.00	15.49	13.67	200.00
NH_4^-	mg/L	0.00	15.90	0.56	2.95	
NO_2^-	mg/L	0.00	0.26	0.03	0.05	3.00
NO_3^-	mg/L	0.00	42.00	4.32	8.35	50.00
pH	pH unit	5.24	9.40	6.17	0.89	6.50-8.50
SO_4^{2-}	mg/L	0.00	96.90	14.15	20.16	250.00
TDS	mg/L	29.80	501.00	127.21	109.27	1500.00
TH	mg/L	12.00	296.00	56.86	57.77	500.00
TSS	mg/L	1.00	321.00	25.72	65.38	500.00
Turbidity.	mg/L	1.00	64.00	23.01	11.55	5.00

Hydrochemical facies of the groundwater

According to the Piper (1944) diagram, the main groundwater types in the study area are mixed, NaCl, $NaHCO_3$, $CaMgSO_4$, and $CaMgHCO_3$ (Fig. 3). Plotting Cl^- versus Na^+ reveals that there is no obvious linear relationship between the two variables (Fig. 4).

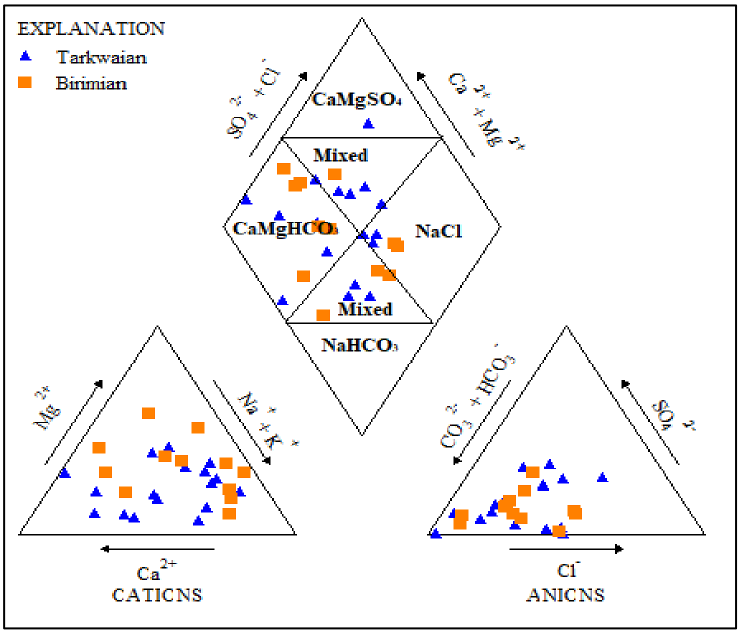

Figure 3. A Piper (1944) diagram showing the groundwater types

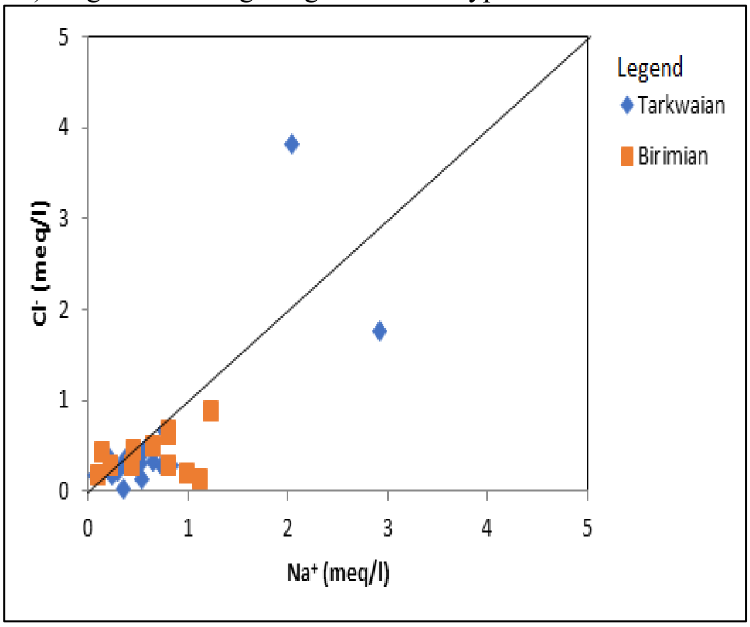

Figure 4. A plot of Cl^- against Na^+ of groundwater in study area.

Hydrogeological Processes

The plot of Gibbs (1970) diagrams (Fig. 5) illustrates how the weathering of rocks has a significant impact on the chemistry of groundwater. Because most samples were below the equiline and few samples were above it, the plot of (HCO_3^- + SO_4^{2-}) vs. (Ca^{2+} + Mg^{2+}) revealed an excess of (HCO_3^- + SO_4^{2-}) over (Ca^{2+} + Mg^{2+}) as shown in Fig. 6. Figure 7 shows a plot of (Ca^{2+} + Mg^{2+}) versus the total cation (TZ^+) and all the samples have more TZ^+ than (Ca^{2+} + Mg^{2+}). The CAI 1 and CAI 2 plots show that only a small fraction of samples have positive values for either index (Fig. 8). Equations 13 and 14 were used to calculate the CAI 1 and CAI 2, respectively.

$$CAI\ 1 = \frac{rCl-(rNa+rK)}{rCl} \quad (13)$$

$$CAI\ 2 = \frac{rCl-(rNa+rK)}{rSO_4+rHCO_3+rC0_3+rNO_3} \quad (14)$$

(All values are measured in meq/L)

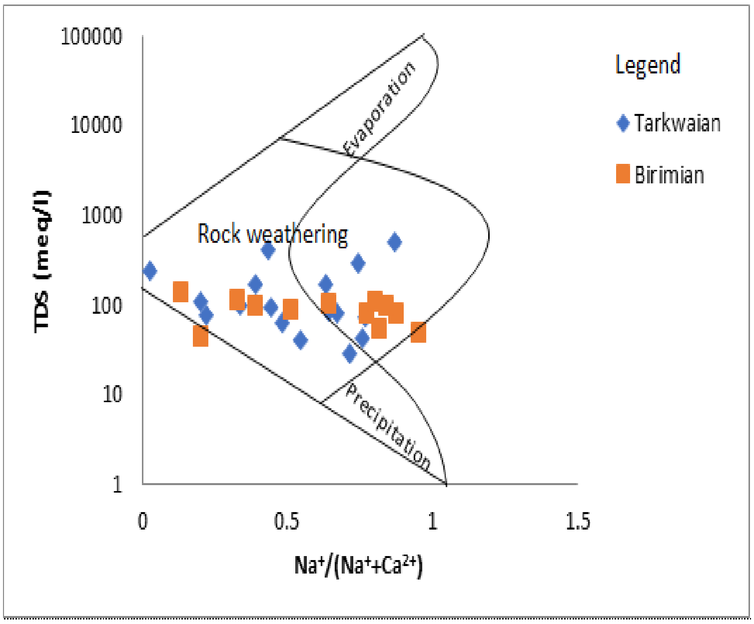

Figure 5. A plot of TDS vs. Na^+/ (Na^++Ca^{2+}) of groundwater in the study area

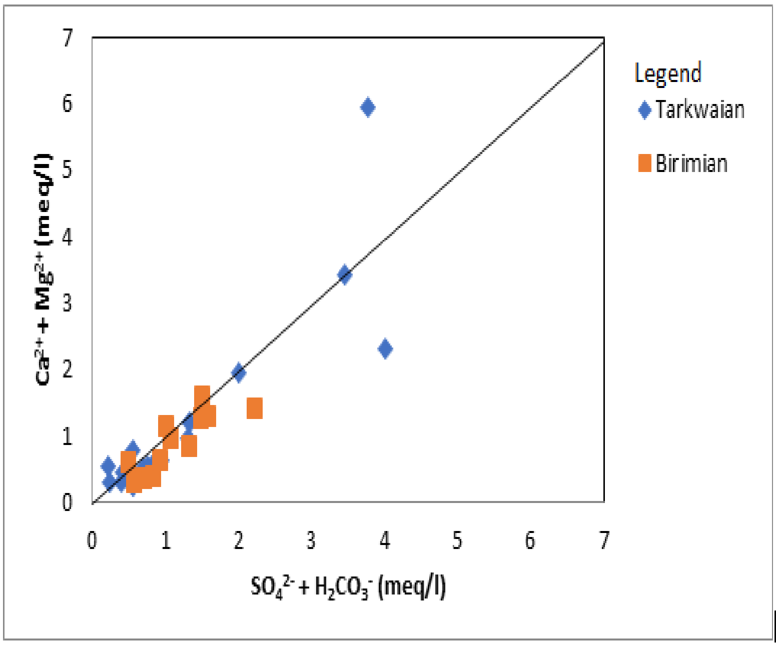

Figure 6. A plot of (Ca^{2+}+Mg^{2+}) vs. (SO_4^{2-}+HCO_3^-) of groundwater in the study area

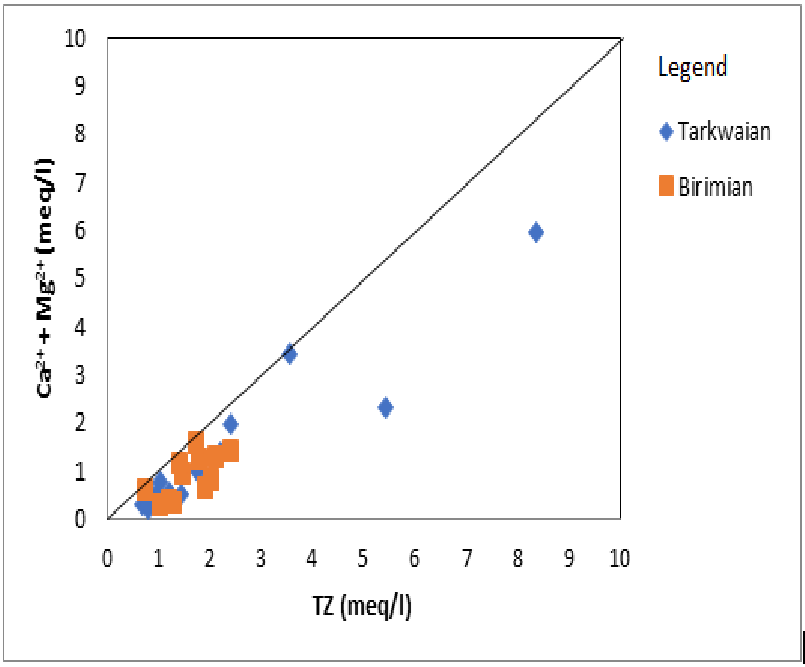

Figure 7. A plot of (Ca^{2+}+Mg^{2+}) vs. TZ^{+} of groundwater in the study area

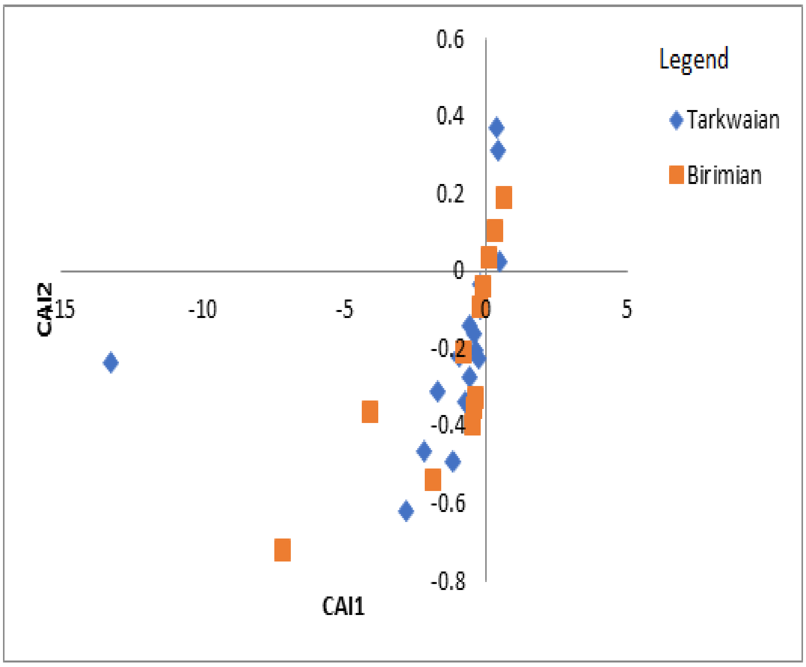

Figure 8. CAI1 vs. CAI2 of groundwater in the study area.

Groundwater suitability

For holistic management of groundwater resources, the recharge zone, discharge zone, and flow paths should be identified. The recharge zones must be protected against potential contamination of the groundwater. For example, the application of fertilizers and manure, improper disposal of waste, and galamsey activities which are common in the study area and have the potential to contaminate the groundwater should be avoided at the recharge zones. This will help in the prevention of contaminating the aquifer system through the flow path from the recharge zone to the discharge zone. Therefore, the study applied the WQI and IWSI techniques to assess the quality of the groundwater for drinking and irrigational purposes respectively. The calculated results of WQI and IWSI are presented in Table 6. About 38% excellent water type, 38% good water, 21% poor water and 3% very poor water based on the WQI (Fig. 9). It also shows 48% excellent water type, 34% good water, 14% moderate water type and 3%

poor water type based on IWSI (Fig. 10). The irrigational water suitability index was divided into the following ranges using the overall maximum potential value of 200 (i.e. 5×5×8=200). Excellent (>90%), Good (80–90%), Moderate (70–80%), Poor (70–80%), and Unsuitable (<70%) are the five categories. The spatial variation of the water quality index and the irrigational water quality index are depicted in Figures 9 and 10. The USSL (1954) and Wilcox (1955) diagrams are shown in Fig. 11 and Fig. 12.

Table 6. Calculated results of WQI and IWSI

			WQI		IWSI										
No	Latitude	Longitude	%	Code	EC	SAR	Na%	RSC	KI	PI	MH	CR	IWSI	%	Code
1	5.888823	-1.75399	108.61	3	149	3.81	53.59	0.36	1.25	86.78	57.14	10.32	140	70	3
2	5.978427	-1.7778	74.65	2	544	1.49	47	-0.09	0.98	110.55	70.61	0.48	180	90	1
3	5.888823	-1.75399	102.73	3	137	2.22	57.09	0.58	1.5	76.5	16.62	0.65	180	90	1
4	5.873235	-1.64606	90.71	2	157	1.3	34.56	-0.32	0.56	83.79	12.2	1.56	160	80	2
5	5.933146	-1.86322	53.37	2	309	2.19	68.27	0.2	2.24	154.91	66.43	0.14	160	80	2
6	5.92318	-1.6077	93.25	2	209	0.07	1.85	-0.34	0.02	52.03	30.01	1.9	170	85	2
7	5.855725	-1.6152	19.61	1	91	1.9	53.7	0.3	1.39	112	31.91	0.4	180	90	1
8	5.887208	-1.62935	18.36	1	203	0.44	19.2	-0.26	0.25	93.43	12.58	0.31	200	100	1
9	5.859436	-1.64566	34.39	1	89	1.05	43.82	-0.08	0.92	127.49	62.5	0.08	180	90	1
10	5.847507	-1.64911	245.13	4	194	0.65	29.77	0.03	0.45	127.89	62.5	0.21	180	90	1
11	5.874987	-1.70158	26.16	1	150	1.31	49.04	0.04	1.15	140.68	62.5	0.18	160	80	2
12	5.815628	-1.6914	37.36	1	181	0.53	15.54	-0.13	0.19	73.81	24.56	1.27	170	85	2
13	5.817042	-1.71869	23.01	1	399	0.87	33.23	0.3	0.54	133.33	31.25	0.04	200	100	1
14	5.811346	-1.76584	82.94	2	232	0.99	38.45	-0.16	0.66	107.99	28.36	0.3	200	100	1
15	5.798412	-1.76106	65.74	2	134	0.95	28.94	-0.39	0.44	82.68	13.93	0.79	200	100	1
16	5.768424	-1.7943	102.96	3	131	1.67	24.47	-4.21	0.34	42.08	54.95	13.15	150	75	3
17	5.766016	-1.84052	53.03	2	153	1.47	41.75	0.11	0.74	103.5	56.78	0.68	180	90	1
18	6.153626	-2.04054	124.35	3	167	2.65	61.86	0.32	2.19	139.47	34.25	0.61	160	80	2
19	6.184009	-2.09068	159.61	3	91.5	0.79	24.95	-0.36	0.35	81.68	28.25	1.12	180	90	1
20	6.199853	-2.17885	66.75	2	76.2	1.42	38.13	0.11	0.63	94.84	84.52	1.6	160	80	2
21	6.182736	-2.09267	31.57	1	54.1	2.51	65.74	0.19	1.97	130.49	90.16	0.38	140	70	3
22	6.234641	-2.10499	98.37	2	74.5	1.67	41.02	0.59	0.7	100.18	60.28	1.01	160	80	2
23	6.14823	-2.04018	115.53	3	78.8	2.41	55.14	0.39	1.31	113.31	81.21	0.35	160	80	2
24	6.088327	-2.10479	50.47	2	202	3.07	65.04	0.11	1.9	111.89	62.98	1.08	120	60	4
25	6.204763	-2.12468	46.05	1	162	0.21	7.51	-0.35	0.08	72.29	45.6	1.1	170	85	2
26	6.099691	-2.14141	79.1	2	116	0.88	29.45	-0.09	0.45	97.74	56.7	0.51	180	90	1
27	6.078153	-2.05409	87.97	2	185	0.4	15.41	-0.36	0.19	80.56	70.82	0.49	180	90	1
28	6.231055	-2.11934	44.49	1	758	2.29	63.73	0.12	2.01	135.2	53.85	0.38	140	70	3
29	6.27263	-2.06824	33.97	1	320	0.26	13.66	-0.19	0.16	105.61	35.42	0.13	200	100	1

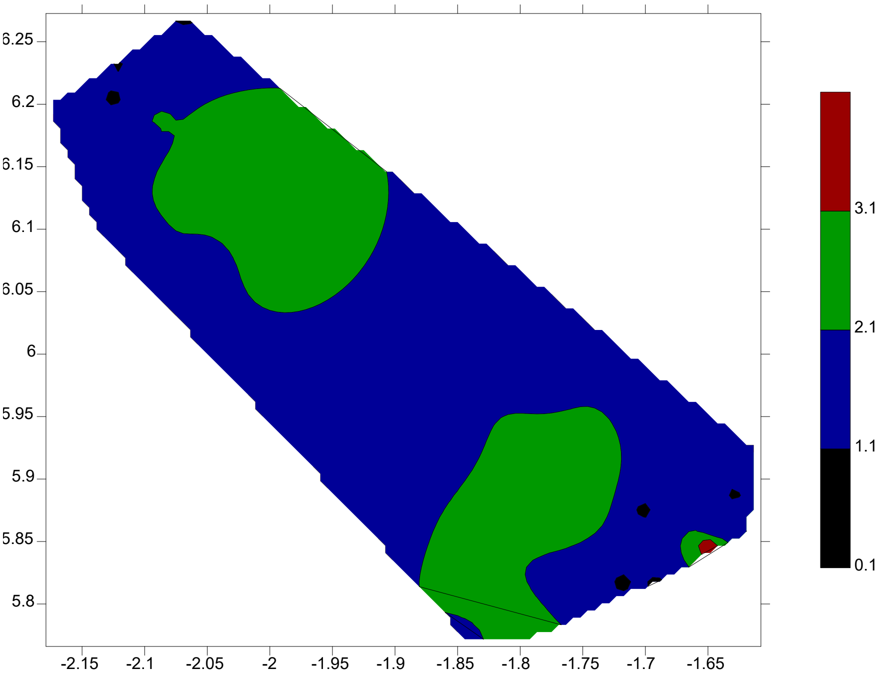

Figure 9. Spatial distribution of WQI of groundwater in the study area

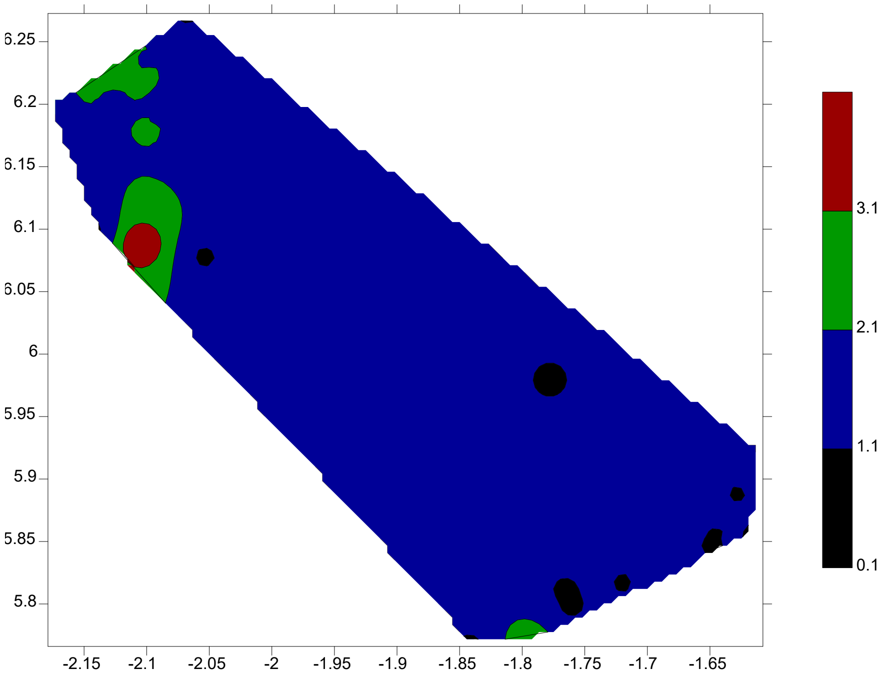

Figure 10. Spatial distribution of IWSI of groundwater in the study area

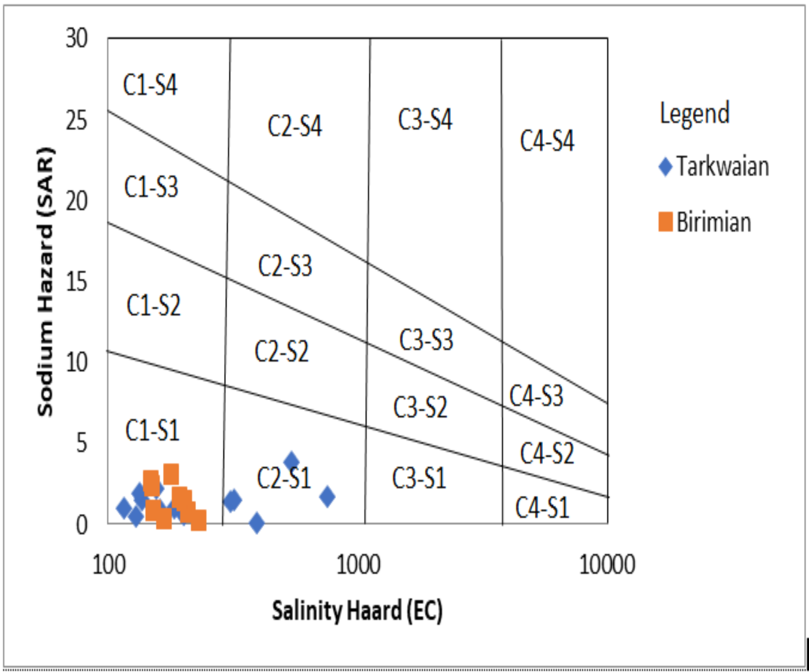

Figure 11. A plot of EC vs. SAR (After USSL, 1954) of groundwater in the study area

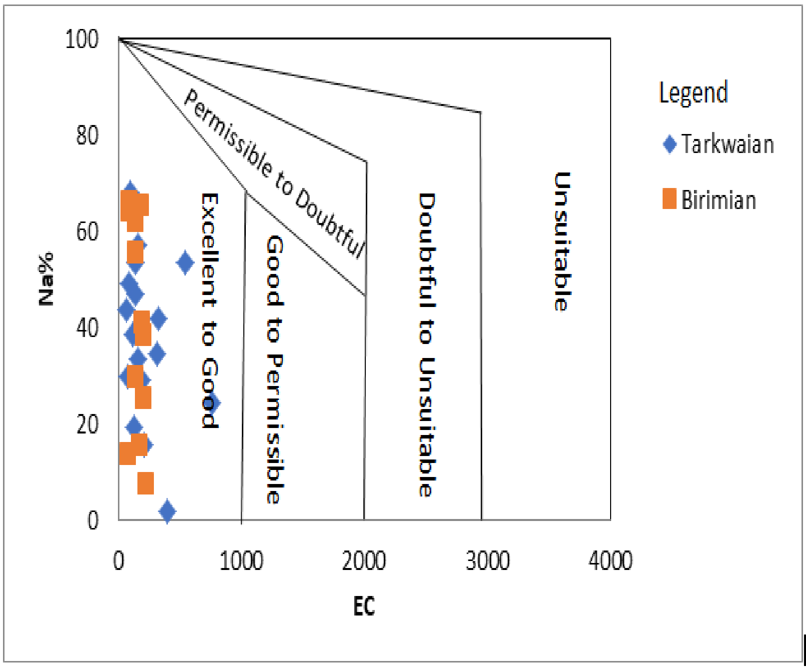

Figure 12. A plot of EC vs. Na% (After Wilcox, 1955) of groundwater in the study area.

Discussion

The generally low EC and TDS show that the study area is a recharge zone. Since fewer rock-water interactions have occurred, the concentration of various constituents in freshwater that enter the water table has not increased. The concentrations of the various groundwater parameters are lowered by the freshwater due to the frequent rainfall in the study area. All parameters are within the recommended limits of the WHO (2012) for drinking water, apart from pH, Mn, Fe, and PO_4^- of some samples. The Mn concentration was greater than the recommended level of 0.10 mg/L, ranging from 0.01-2.78 mg/L with a mean of 0.29 mg/L (WHO, 2012). With a mean of 0.39 mg/L and a recommended value of 0.30 mg/L, the range of Fe concentrations was 0.01 to 1.59 mg/L. The concentration of PO_4^{3-} ranged from 0 to 0.81 mg/L, with a mean that was 0.33 mg/L higher than the recommended value of 0.10 mg/L.

Hydrochemical facies of the groundwater

The major groundwater types in the districts are NaCl, $NaHCO_3$, $CaMgSO_4$, $CaMgHCO_3$, and mixed water types. The formation of NaCl water may be influenced by the dissolution of minerals such as halite. However, the lack of a well-defined relationship between the Cl^- and Na^+ reveals that their entry into the water is not by dissolution of rocks like halite (Hem, 1985). $NaHCO_3$ groundwater type may be produced from the dissolution of Na-bearing silicates as meteoric water charged with carbonic acid dissolving Na^+ (Garrels and Mackenzie, 1967). However, the dissolution of albite and augite rich in Na+ and the presence of CO_2 may have also contributed to the occurrence of $NaHCO_3$ in the study area.

Considering the occurrence of $CaHCO_3$ and NaCl in the study area the $NaHCO_3$ may have also occurred through the ion exchange reaction whereby $CaHCO_3$ evolve to $NaHCO_3$ by interacting with NaCl water types. This occurs when the Na increases along the flow path of the groundwater and gains dominance over the Ca^{2+} through an ion exchange process. Through this process, the NaCl water within the aquifer system is diluted by fresh water to form a mixed water type before the formation of the $NaHCO_3$ water type. The mixing of various types of water has a significant impact on the chemical composition of the groundwater in the study area. Mixed water types have no single ion that shows dominance; hence, they do not have any specific feature that is particular to them. The mixed water could result from the weathering of different minerals and/or the mixing of two chemically distinct groundwater types.

Hydrogeological Processes

The moderate TDS and moderate $Na^+/(Na^+ + Ca^{2+})$ ratio in the Gibbs (1970) diagram demonstrate that the primary factor regulating groundwater chemistry is the dissolution of rock minerals through rock-water interaction. There was an excess of (HCO_3^- + SO_4^{2-}) over (Ca^{2+} + Mg^{2+}) as seen in the (HCO_3^- + SO_4^{2-}) vs. (Ca^{2+} + Mg^{2+}) plot. According to Tiwari and Singh (2014), the effects of silicate mineral weathering, carbonate weathering, and potential ion exchange processes on groundwater chemistry were identified. However, silicate weathering dominates, especially within the Birimian Supergroup. The minerals quartz, hornblende, biotite, and other materials may be responsible for the high SO_4^{2-} + HCO_3^- concentration. Silicate weathering produces secondary minerals like clays such as kaolinite, and iron oxides since the Al-compounds are insoluble (Appelo and Postma, 2005). The process increases the cation and silica concentrations of the groundwater. However, the secondary data used for this study did not have silica concentration.

The amount of silica in groundwater is controlled by the weathering of silicate minerals and the presence of multivalent ions like Al^{3+}, Ca^{2+}, Mg^{2+}, and Fe^{3+} that affect the solubility of silica (Hem, 1985; Hann, 1993; Jansen et al., 2010). The results of the study suggest that silicate weathering is a significant process influencing the chemistry of the groundwater because the concentrations of alkalis are higher than the concentrations of the major ions (Fig. 7). Under specific conditions, groundwater can exchange ions with the host aquifer system, particularly with clay particles (Schoeller, 1965). Generally, Mg^{2+} or Ca^{2+} from aquifer material exchanged with Na^+ or K^+ in groundwater results in negative values for the two indices (Schoeller, 1965). Na^+ or K^+ from aquifer material exchanged with Mg^{2+} or Ca^{2+} in groundwater results in positive values for the two indices. Reverse ion exchange consequently has a significant impact on the chemistry of the groundwater in the districts.

Groundwater suitability

Factors that affect groundwater quality include the composition of recharge water, mineralogy of the aquifer system, climatic conditions, topography, possible impacts of anthropogenic activities, etc. These factors may cause the concentrations of certain minerals to increase above the recommended permissible limits. This causes groundwater contamination affecting environmental and human health (Kumar and Riyazuddin, 2008).

Suitability of groundwater for drinking and domestic purposes

The people of the study area hugely depend on groundwater for their water needs including drinking, domestic, agriculture, and industrial purposes. The overdependence on groundwater in the area is partly due to the high pollution of the existing surface water bodies due to galamsey activities. This has resulted in the outbreak of waterborne and related diseases such as diarrhea, dysentery, cholera, and guinea worm in the area (Ganyaglo *et al*., 2011). This means that the groundwater resource in the districts is prone to anthropogenic contamination. Unfortunately, monitoring of groundwater quality has not been effective in Ghana even though most people in the rural areas use groundwater without prior treatment. One of the major challenges associated with the overdependence on the groundwater resources in the area is the insufficient knowledge of the aquifer system, the groundwater quality, and the possible impact of anthropogenic activities on the groundwater quality in the area.

The study found that 38% of the groundwater in the districts is of excellent quality for domestic and drinking purposes; 38% has good quality; 21% has poor quality and 3% has very poor quality. This indicates that the groundwater is generally suitable for drinking, but certain parameters that are above the recommended values should be treated. The generally high groundwater quality may be attributed to the low concentrations of the groundwater parameters. On the other hand, the groundwater in some communities is unfit for drinking without prior treatment due to its low pH, high pH, high Fe, Mn, and PO4- levels. Both natural/geogenic processes and anthropogenic activities, such as the use of agrochemicals, pit latrines, and improper waste disposal, have an impact on the quality of groundwater in the districts. Considering Figure 2, the groundwater flows toward the Offin River, accounting for the relatively pure groundwater compared to the contaminated surface water bodies in the area.

The groundwater quality in the Birimian and Tarkwaian geological formations is similar. The high Fe, Mn, and PO4- consecrations of the groundwater in the districts are due to the dissolution of Fe and Mn-containing minerals of the host aquifer systems and anthropogenic activities. The poor groundwater quality for drinking was seen at Subinsu, Sobroso, Fosu Dankwa, Congo 1, Kyebi, Betease, and Ampabeng in the southern part of upper Denkyira east. This shows the impact of anthropogenic activities on the groundwater quality in those communities at the local scale. In their studies of heavy metals in drinking water, their effects on human health, and their treatment techniques Jamshaid et al (2018) observed that both Fe and Mn have essential roles to play in the normal functioning of the body when their concentrations are within a certain recommended range.

However, inadequate supply and excess of the two can affect the normal functioning of the body. High concentrations of Fe and Mn in drinking water can cause an increased risk of certain diseases in consumers. Fe and Mn may be found naturally in groundwater in low concentrations. They cause taste and staining problems with groundwater (Jamshaid et al., 2018). Mn has a very essential role to play in the human body when the concentration is low (Jamshaid et al., 2018). However, the excessive intake of Mn can cause different diseases such as nervous system disorder and Parkinson's disease (Jamshaid et al., 2018). Also, Fe is one of the essential elements needed for the proper functioning of the human body. It helps in the production of haemoglobin which is the protein responsible for carrying oxygen from the lungs to the other parts of the body. However, excess Fe may cause hypothyroidism, heart failure, osteoarthritis, depression, osteoporosis, infertility, and abdominal pain (Jamshaid et al., 2018).

Irrigational water suitability assessment

It is crucial to remember that figuring out the quality of groundwater is difficult because it depends on a variety of factors, such as the intended use of the water and the specific water quality parameters involved. Due to this complexity, it is challenging for researchers and water professionals to communicate their research findings with decision-makers who might not be technically savvy in water science. In this case, the water quality index method can bridge the communication gap. It provides values of the overall water quality at a particular time and location based on selected water quality parameters (Yogendra and Puttaiah, 2008). The study discovered that 48% of the groundwater types were excellent, 34% were good, 14% were moderate, and 3% were poor based on IWSI. This shows that the quality of the groundwater is good for irrigation use. To verify the accuracy of the new method, USSL and Wilcox diagrams were also employed. Groundwater falls into the C1-S1 and C2-S1 categories in the USSL diagram, but the Wilcox diagram places it in the excellent to good category. This indicates that the two diagrams also show 'excellent to good' groundwater types for irrigation use, just as the IWSI method had shown. This demonstrates the dependability of the IWSI technique. The groundwater quality of the Tarkwaian and Birimian geological formations is comparable.

Conclusion

Groundwater suitability for drinking, domestic use, and irrigation purposes in the Upper Denkyira East and West Districts has been assessed. Groundwater types in the districts are mixed water, NaCl, $CaHCO_3$, and $CaMgSO_4$. Rock weathering, ion exchange, and impacts of anthropogenic activities like improper agrochemical application, galamsey, and improper waste disposal are the major processes affecting groundwater quality. The study found that 38% of the groundwater in the districts is of excellent quality for domestic and drinking purposes; 38% has good quality; 21% has poor quality and 3% has very poor quality. The groundwater is generally suitable for drinking but the low pH, high pH, high Fe, high Mn, and high PO_4^{3-} levels of some samples make them unsuitable for drinking without prior treatment. These observations agree with the findings of early studies. The study discovered that 48% of the groundwater types were excellent, 34% were good, 14% were moderate, and 3% were poor based on IWSI. The IWSI was calculated using EC, SAR, Na%, RSC, KI, PI, MH, and CR. The USSL diagram and the Wilcox diagram confirmed that the groundwater falls within the excellent to good categories. This revealed the IWSI agrees with USSL and Wilcox diagrams; the technique is effective for groundwater suitability assessment for irrigational use. The groundwater quality of the Tarkwaian and Birimian geological formations is comparable.

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Availability of data: *All data used for this study are included within the manuscript.*

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