Assessment of Groundwater Quality and Health Risk of Heavy Metals: A study from the Tarkwa Mining Area, Ghana*

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Abstract

This study seeks to evaluate the hydrogeochemical characteristics of water in the Tarkwa mining area using the Piper and Chadha plots and to carry out a health risk assessment using the US Environmental Protection Agency (USEPA) health risk assessment model. A total of 39 groundwater sample points were used for this study. Results from the Piper and Chadha diagrams show that the dominant water types in the study area are Ca-HCO3 and Mixed Ca-Mg-Cl water types which indicates that groundwater in the area can be classified as fresh water. The hazard quotient (HQ) value for heavy metals estimated, suggested an acceptable level of noncarcinogenic inimical health risk. In relation to the HQ value, the Hazard Index (HQ) calculated was less than 1 suggesting that inhabitants will not be exposed to a potential health risk for the injection of heavy metals. Carcinogenic risk estimated for As (1.80×10^{-4}) was higher than the acceptable risk. The carcinogenic risk estimated therefore indicated that, drinking of groundwater over a long period will increase the probability of cancer. It can be concluded that currently the groundwater in the Tarkwa area is safe for domestic purposes.

Keywords: Hydrochemical Characteristics, Human Risk Assessment, Tarkwa Mining Area

1 Introduction

Groundwater has been identified as the best option for drinking water as well as other uses like irrigation and industrial purposes, especially in areas where surface water is scarce (Ghalib, 2017; Delgado *et al.*, 2010). The chemistry of groundwater is the determining factor for its consumptive use: either domestic, agricultural or industrial purposes (Krishna Kumar *et al.*, 2014, Sajil Kumar, 2012). In recent years, due to population increase and industrialisation, groundwater resources have come under intense stress which has in some cases rendered the water unwholesome for human consumption (Khan and Jhariya, 2017; Tiwari *et al.*, 2015). It has therefore become imperative that groundwater must be treated before use. Tarkwa, has a concentration of both large scale and small scale mining activities in its environs. These mining activities especially the illegal mining activities always bring about deterioration of the quality of water. River bodies that were the main source of water for drinking, household chores and other activities have all been destroyed by these activities of illegal small scale mining of gold. Subsequently, the small scale mining industry of gold is getting more damaging and has become the second largest pollution after agriculture in Africa (Kessey and Arko, 2013).

Groundwater development in Tarkwa has often been hampered among other problems by contaminants from mining activities, improper waste disposal, leakage of underground storage tanks, and seepage of agrochemicals from municipal and agricultural fields (Akabzaa, 2000). The provision of groundwater has become the most effective means of water supply in Tarkwa due to the contamination of its main source of drinking water, Bonsa River. This has led to drilling of numerous boreholes and hand-dug wells in the area for domestic water supply. In spite of its various importance, with the increase in demand, this resource is being overexploited in many areas resulting in a permanent depletion of the aquifer system and associated environmental consequences like water quality deterioration. Cases of loss of borehole yields and circulation have been reported around the University of Mines and Technology (UMaT) campus where there is a concentration of illegal small scale mining activities who pump out the groundwater so as to keep the mining area dry for their operations.

Much as groundwater can be seen as the best source of water supply, its quality must always be evaluated. Hydrogeochemical facies evaluation provides a tentative idea about the chemical processes that the groundwater has undergone. Hydrogeochemical diagrams have been used by researchers to understand water chemistry over the years (Stamatis *et al.*, 2011; Srivastava and Ramanathan, 2007). The method is able to provide information on the chemistry of water, especially its origin (Sajil Kumar, 2012) and evolutional trends (Chadha, 1999). Hill (1940) first attempted to create a trilinear diagram to describe water chemistry. This was modified by Piper (1944). A new diagram by Durov (1948) was a modification of the Piper plot. One underlining weakness in all these diagrams, is that, specific software packages are needed to plot them (Sajil Kumar, 2012; Chadha, 1999). Sajil Kumar, (2012) used Piper and Chadha diagrams for

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hydrogeochemical analysis in Tamil Nadu state, India. In the current study, the Piper and Chadha diagrams are being used to understand groundwater chemistry in the Tarkwa gold-mining area, Ghana.

An assessment of the water has also been carried out using the USEPA health risk assessment model to identify and determine the potential of heavy metals in the water.

1.1 Study Area

Tarkwa is a gold mining town located in the Western Region of Ghana. It is accessible by road about 85 km from Takoradi the regional capital, about 233 km from Kumasi and 316 km from the national capital, Accra (Seidu *et al.*, 2019). The Tarkwa area falls within the south-western equatorial climate zone with season's primary influenced by moist south-west monsoon winds from the South Atlantic Ocean and dry dust-laden north-east trade winds known as the Harmattan which blows over the Sahara desert from the northern sub-tropical high pressure zone. The Inter Tropical Convergence Zone (ITCZ) crosses over the Tarkwa area two times in a year which results in two peaks in the rainfall figures. The two wet seasons stretch from April to July (with a peak in June) and October to November. The area is dominated by series of ridges and valleys which are parallel to one another with a general strike of northeast-southwest (NE-SW) of the underlying geology. Whitelaw, (1929) reported that transverse to the ridges and valleys are smaller valleys and gaps determined by faulting and jointing. Elevation in Tarkwa ranges from approximately 45 m to 330 m above mean sea level. The study area falls within the Ankobra River Basin which is an extensive drainage basin. The area is drained by a large number of streams including Huni and Bonsa Rivers. These rivers are perennial even though during dry months their flows decrease significantly (Kuma and Ewusi, 2009). Also, flooding during the rainy season is very common occurrence.

1.2 Geology and Hydrogeology

Tarkwa is hosted on the unconformable contact between the younger Tarkwaian rocks to the west and Birimian rocks to the east. The Tarkwaian Group comprises a sequence of coarse, clastic, fluviatile meta-sedimentary rocks consisting of the Kawere conglomerates, Banket Series (host of gold mineralisation), Tarkwa Phyllite, Huni Sandstones and Dompim Phyllite in the direction of younging (Fig. 1). About 20 % of the total Tarkwaian within the Tarkwa area is made up of intrusive igneous rocks (Kuma and Younger, 2001). These rocks range from hypabyssal felsic to basic igneous rocks, which form conformable to slightly trangressive sills with small number of dykes. The Tarkwa area is faulted and jointed with the most prominent joints trending in an east-southeast-west-northwest direction (Hirdes and Nunoo, 1994).

Groundwater occurrence is associated with the development of secondary porosity through fissuring and weathering. The rock underlying the area lack primary porosity since they are consolidated. Kuma, (2002) stated that aquifers in the Tarkwa area possess dual and variable porosity and heterogeneous permeability with limited storage properties. Within an aquifer, folding of the whole area with the widespread presence of fractures, faults, fissures and dykes enhances this variability (Kuma and Younger, 2000). Two types of aquifers occur in the study area: the weathered and fractured zone aquifer. The weathered aquifer occurs mainly above the transition zone between fresh and weathered rocks. Due to the presence of clay and silt, these aquifers have high porosity and storage but relatively low permeability. The fractured zone aquifer occurs below the transition zone. They have high transmissivity but low storativity (Kortatsi, 2004). Seidu, (2017) reported that, in the Tarkwa stratigraphy, groundwater occurrence is favourable in the Tarkwa Phyllite and Banket Series, whereas the Huni Sandstone and Kawere Conglomerate have difficult hydrogeological conditions and do not have appreciable yields. Conceptual groundwater flow directions show that the two ridges of the Tarkwa Phyllite and Banket Series form a water divide and partition the area into the northern and southern sectors. On the assumption that both surface and groundwater are hydraulically connected, groundwater flow in the southern sector divide is due south and south-southwest. In the northern sector, however, groundwater flow directions are generally to the northwest, but inferred to be near the nose of the Huniso syncline (Kuma and Younger, 2000).

2 Resources and Methods Used

2.1 Hydrogeochemistry

A total of 54 data points were initially gathered for this study and 39 samples passed the reliability check using ±10 in the local context. This was done using the Charge Balance Equation (CBE) as shown in Equation 1. Physico-chemical parameters were analysed using the standard method suggested by the American Public Health Association (APHA) (Anon., 2012). Physical parameters like pH, TDS, EC, turbidity and temperature were taken in situ using pH meters and multiprobe meter. Chemical parameters were analysed in the laboratory. The 39 samples were used for further Hydrogeochemical analysis. Piper and Chadha diagrams were constructed to determine the hydrogeochemical facies and water types in the area.

$$CBE = \frac{\sum cations - \sum anions}{\sum cations + \sum anions} \times 100 \qquad (1)$$

In the Piper diagram, major cations and anions are plotted on two base triangles as milliequivalent percentage. Each apex of the triangles represent 100 % concentrations of the cations and anions. The points in the two triangles are projected and plotted onto the diamond shaped field, which represent total concentration. The water types are determined on the basis of the position of the plot in the cation and anion fields and the diamond shape gives the overall character of the water.

Chadha, (1999) proposed a modified version of the Piper diagram. In the proposed diagram, the difference in milliequivalent percentage between alkaline earths (Ca^{2+} + Mg^{2+}) and (Na^+ + K^+), expressed as percentage reacting values, is plotted on the x-axis, and the difference in milliequivalent percentage between weak acidic anions (CO_3^{2-} + HCO_3^-) and strong acidic anions (Cl^- + SO_4^{2-}) is plotted on the y-axis). The milliequivalent percentage differences between alkaline earths and alkali metals, and between weak acidic anions and strong acidic anions, would plot in one of the four possible sub-fields of the proposed diagram. The advantage Chadha diagram has over Piper diagram is that, it can be plotted using any spreadsheet software package (Sajil Kumar, 2012; Chadha, 1999).

Chadha, (1999) divided his diagram into 8 fields (Fig. 3):

(i) Alkaline earth exceeds alkali metals

(ii) Alkali metals exceed alkaline earths

(iii) Weak acidic anions exceed strong acidic anions

(iv) Strong acidic anions exceed weak acidic anions

(v) Alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions, respectively. Such water has temporary hardness. The positions of data points in the diagram represent Ca^{2+}-Mg^{2+}-HCO_3^--type, Ca^{2+}-Mg^{2+}-dominant HCO_3^--type or HCO_3^--dominant Ca^{2+}-Mg^{2+}-type.

(vi) Alkaline earths exceed alkali metals and strong acidic anions exceed weak acidic anions. Such water has permanent hardness. The positions of data in the diagram represent Ca^{2+}-Mg^{2+}-Cl^--type, Ca^{2+}-Mg^{2+}-dominant Cl^--type, or Cl^--dominant Ca^{2+}-Mg^{2+}-type waters.

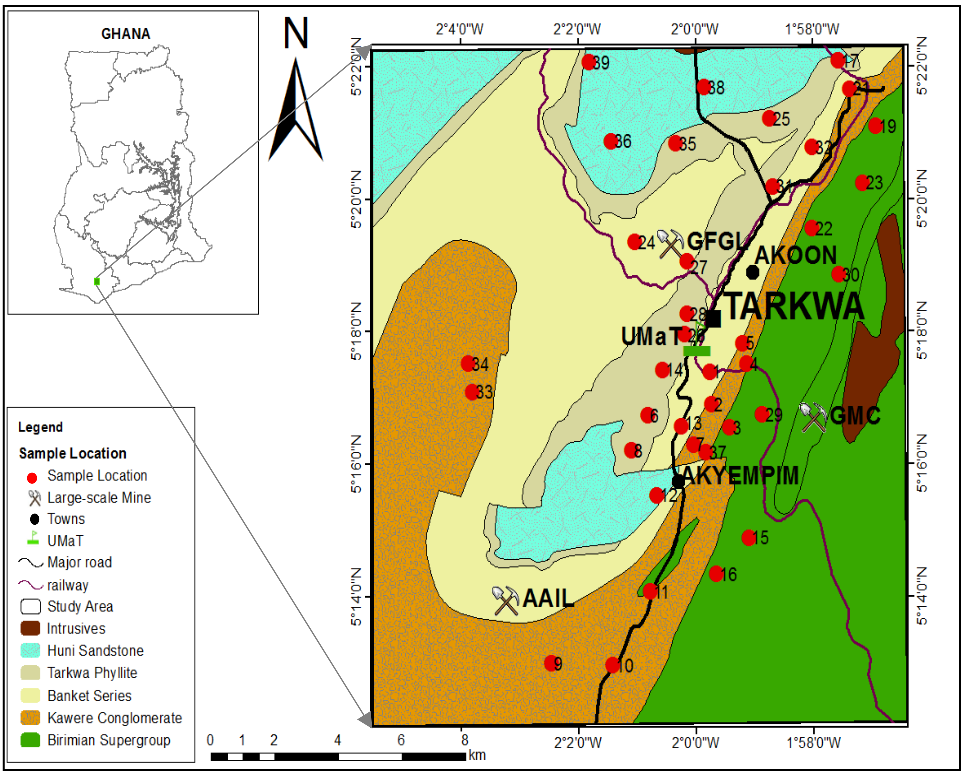

Fig. 1 Simplified Geological Map of the Tarkwa Mining Area with Sample Locations

(vii) Alkali metals exceed alkaline earths and strong acidic anions exceed weak acidic anions. Such water generally creates salinity problems both in irrigation and drinking uses. The positions of data points in the diagram represent Na^+-Cl^--type, Na_2SO_4-type, Na^+-dominant Cl^--type or Cl^--dominant Na^+-type waters.

(viii) Alkali metals exceed alkaline earths and weak acidic anions exceed strong acidic anions. The position of data points in the diagram represent Na^+-HCO_3^--type, Na^+-dominant HCO_3^--type, or HCO_3^--dominant Na^+-type waters.

Health risk is defined as the potential hazard to human health due to environmental contaminations. As regards the heavy metal toxicity, human exposure to heavy metals in the soil occurs in three ways: a) direct contact or ingestion b) skin contact or skin absorption of heavy metals by soil contact c) inhalation of soil particles from the mouth or nose. In order to assess the risk of carcinogenic and non-carcinogenic in children and adults living in the Tarkwa region, the health risk assessment model presented by the US Environmental Protection Agency (USEPA) has been used.

2.2 Human Health Risk Assessment

Risk assessment is the processes of determining the probable occurrence of any magnitude of adverse health effects over a specified time period. It is a function of hazard and its exposure over the specified period of time. At the specified time, it is necessary to assess the human health risk by determining the level of human exposure to that metal by tracing the path of exposure of pollutant to the human body. The exposures routes for heavy metals that depend upon a contaminated media such as groundwater, soil and vegetables on the recipients. Li *et al.* (2014) highlighted that, heavy metals in contaminated drinking water, food, and soils, ingestion plays the key roles among the potential exposure pathways.

The health risk assessment of each potentially toxic metal is mostly based on the weight of the risk level (Wongsasuluk *et al.*, 2013). It is expressed in terms of carcinogenic and noncarcinogenic health risk by USEPA, which have proven successful and has been adopted in several research. The general exposure equations used are based on recommendations provided by USEPA (Anon., 1991, 2000, 2002). To calculate levels of human exposure to heavy metals in groundwater, the average daily intake (ADI) (mg/kg-day) is defined as (Equation 2):

$$ADI = \frac{C \times IR \times EF \times ED}{BW \times AT} \qquad (2)$$

where *C* is the chemical concentration in a particular exposure medium (mg/L, mg/kg, mg/m^3) and *IR* is the ingestion rate (L/day, kg/day, m^3/day). According to USEPA (Anon., 2000), *IR* for drinking water is 2.0 L/day (Anon., 2004). *EF* is the exposure frequency (day/per year), which in the case of water, it is 350 days/year. *ED* is the exposure duration (30 years); *BW* is the body weight of the exposed individual (70-kg adult, average; age-specific values); and *AT* is the time period over which the dose is averaged (day), and it is derive by using pathway-specific period of exposure for noncarcinogenic effects (ED × 365 days/year) and 70-year lifetime for carcinogenic effects (70 years × 365 days/ year), averaging time.

2.3 Risk Characterisation

2.3.1 Carcinogenic risk assessment

Carcinogenic risks represent the individual probability of developing cancer over a lifetime as a result of exposure to the potential carcinogen. The slope factor (SF) converts the estimated average daily intake of a toxin averaged over a lifetime of exposure directly to the incremental risk of an individual developing cancer (Anon., 1989; Li *et al.*, 2014).

$$Risk = ADI \times SF \qquad (3)$$

where *Risk* is the unitless probability of an individual developing cancer over a lifetime and SF is the carcinogenicity slope factor (per mg/kg-day). The toxicity indices of each potentially toxic metal are shown in Table 1. Risks surpassing 1×10^{-4} are viewed as unacceptable; risks below 1×10^{-6} are not considered to pose significant health effects; and risks lying between 1×10^{-4} and 1×10^{-6} are generally considered an acceptable range, depending on the situation and circumstances of exposure (Li *et al.*, 2014).

2.3.2 Noncarcinogenic Risk Assessment

It is the maximum daily allowable dose for human per its life cycle. To determine quantification of noncarcinogenic risks, the hazard quotient (HQ) is estimated by dividing the ADI of hazardous substances with the corresponding reference dose (RfD). HQ of a single chemical is determined by:

$$HQ = \frac{ADI}{RfD} \qquad (4)$$

where RfD is the chronic RfD for the chemical (mg/kg/day). If HQ > 1, there is an unacceptable risk of adverse noncarcinogenic effects on health, while if the HQ < 1, it is at an acceptable level (Anon., 2001a). Considering risk assessment of a mixture of chemicals, the individual HQs are combined to form the hazard index (HI).

$$HI = \sum HQ \tag{5}$$

where an HI >1 means an unacceptable risk of noncarcinogenic effects on health, while an HI <1 means an acceptable level of risk (Anon., 2001b)

Table 1 Toxicity Responses to Heavy Metals as the Oral reference Dose (RfD) and Oral Slope Factor (SF) (Bempah and Ewusi, 2016)

Heavy metals	Oral RfD (mg/kg/day)	Oral Sf^{a} (mg/kg-day)$^{-1}$
As	0.0003	1.5
Cd	0.0005	n.d
Cr	0.003	n.d
Cu	0.04	n.d
Pd	0.0035	n.d
Hg	0.0004	n.d
Ni	0.02	n.d
Fe	1.6	n.d
Mn	0.14	n.d
Zn	0.3	n.d

n.d = not determine

3 Results and Discussions

3.1 Water Quality Analysis

Results of water quality analysis are presented in Table 2. The results show that pH ranges from mildly acidic to neutral with a minimum, mean and maximum values of 5.19, 6.23 and 7.23 respectively. All samples were within the World Health Organisation (WHO) drinking water standards (Anon., 2011) except sample 21 which recorded EC and TDS values of 1152 and 771 respectively. The outliers recorded in sample 21 is attributed to the presence of anthropogenic activities close to the well location. The dominant cations are Na (2.89-108.12 mg/L) and Ca (1.65-90.51 mg/L): the dominant anions are HCO_3- (2.00-278.4 mg/L) and Cl (2.15-156 mg/L).

3.2 Hydrogeochemical Facies

Piper's trilinear diagram showing chemical relationship between groundwater constituents is shown is Fig. 2. In the study area, two main hydrogeochemical facies are observed in the order Ca^{2+}-Mg^{2+}-Cl^{-}-SO_4^{2-} > Ca^{2+}-Mg^{2+}-HCO_3^{-}. These two facies collectively constitute 92 % of the total samples. Six different water types are observed on the plot with Ca-HCO_3^{-} being the most dominant water type. The results from the Piper plot is summarised in Table 3.

Results from the Chadha diagram (Fig. 3) show that the data points were plotted in regions 5, 6, 8 and 7 in a decreasing order. The study area is dominated by mixed Ca^{2+}-Mg^{2+}-HCO_3^{-} water type which constitute 77 %. The second most dominant water type in the study area is Ca^{2+}-Mg^{2+}-Cl^{-} type which also constitutes 15 %. The data plots in the Chadha diagram show the study area is dominated by fresh water type. Unlike the Piper plot, one sample in the area is classified as Na-Cl water type.

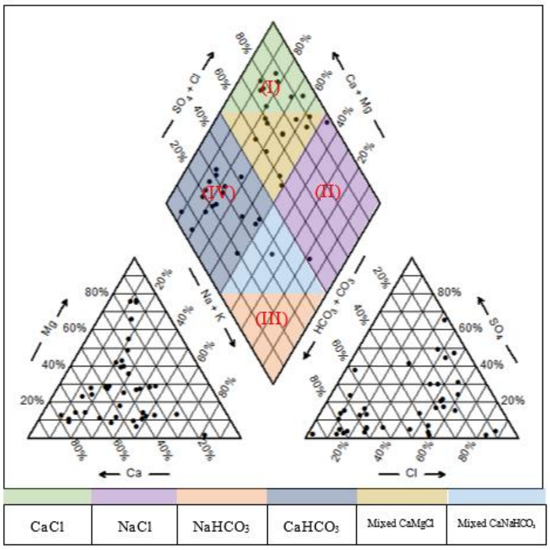

Fig. 2 Piper Plot of Groundwater Samples

Table 2 Results of Physico-Chemical Parameters

ID	pH	EC	TDS	DO	Turb	Temp	Na	K	Ca	Mg	Cl-	SO_4^{2-}	HCO_3	NO_3^-
1	6.9	196	127	6.07	3.0	25.4	6.59	2.06	14.44	4.95	4.34	5.39	69.42	2.54
2	6.22	154	100	6.97	2.0	25.4	7.17	0.40	3.55	2.41	6.83	2.57	23.40	0.01
3	6.84	191	124	6.80	3.0	25.4	7.05	0.29	12.07	4.43	8.74	1.34	53.22	1.05
4	5.85	105	68	6.26	1.5	24.7	4.78	0.13	6.72	0.57	4.55	4.13	19.89	0.01
5	6.34	229	148	4.72	3.0	24.9	6.92	0.73	12.93	4.33	2.44	4.34	65.42	0.77
6	5.43	225	146	6.17	4.2	24.9	2.97	1.05	3.61	2.24	3.45	4.63	15.40	2.97
7	5.85	150	97	6.81	2.0	24.5	5.96	0.36	7.81	1.02	5.50	2.79	19.87	3.13
8	6.53	104	67	6.71	1.0	24.7	6.60	0.37	2.17	0.71	3.79	2.89	31.24	3.45
9	5.59	191	122	3.23	1.5	25.6	4.80	3.02	6.55	14.23	6.77	4.87	18.00	2.54
10	5.95	185	118	4.87	0.9	25.7	4.88	3.08	4.75	20.10	7.22	3.79	20.00	3.92
11	5.81	197	126	4.64	0.0	25.5	4.51	3.10	7.04	22.98	8.93	2.84	24.00	1.49
12	5.89	193	123	4.87	1.8	26.4	4.24	3.21	6.52	6.65	4.13	1.72	16.00	1.03
13	6.02	189	121	3.24	0.6	26.4	3.96	3.04	6.18	8.04	7.00	2.88	18.00	3.44
14	5.65	174	111	4.12	1.4	25.7	4.36	3.05	4.33	17.36	4.39	3.66	22.00	2.77
15	5.76	288	184	6.22	0.0	25.1	5.35	0.73	15.33	3.81	24.99	0.62	36.00	0.43
16	5.19	739	471	5.80	2.0	25.3	8.55	7.84	14.70	5.27	3.91	0.61	76.00	0.10
17	6.11	351	235	6.22	1.0	26.1	22.14	0.89	12.83	7.59	46.20	2.55	21.22	0.43
18	6.37	551	269	7.01	31.0	26.1	21.37	0.69	27.99	18.01	50.20	3.58	120.56	2.77
19	6.54	423	283	4.12	25.0	26.2	17.84	0.60	23.06	17.60	14.20	12.23	140.02	3.44
20	6.39	300	359	3.24	47.0	26.3	11.04	0.30	17.27	11.58	5.90	0.99	113.42	2.77
21	7.23	1152	771	2.56	6.0	26.2	108.12	36.71	87.13	16.49	156.00	4.22	212.50	0.10
22	6.76	380	246	4.19	2.0	26.5	7.00	0.39	26.56	5.89	6.07	10.57	94.00	0.00
23	5.79	182	118	5.96	2.0	25.4	4.93	0.48	6.16	1.39	7.90	10.64	8.60	0.88
24	5.78	129	84	6.10	1.0	25.2	4.47	0.21	5.44	3.75	3.28	6.32	29.20	1.56
25	5.48	52	34	6.60	2.0	25.8	2.89	0.18	1.65	0.37	2.15	5.72	2.00	1.22
26	5.75	142.5	97	3.46	5.2	28.0	10.30	0.55	8.59	3.92	15.00	8.00	34.80	4.00
27	7.15	507	357	2.79	14.0	30.7	19.34	0.98	86.75	6.09	31.00	8.00	261.90	0.00
28	5.75	95.7	67	5.58	2.4	29.9	8.03	2.09	8.05	1.00	7.00	12.00	20.80	7.00
29	6.88	615	351	5.50	1.0	31.7	19.60	0.82	90.51	7.59	16.00	51.00	242.60	6.00
30	6.75	449	255	4.15	2.7	31.6	15.52	0.66	61.32	7.42	16.00	7.00	219.70	0.00
31	6.91	422	264	3.52	13.1	26.6	10.90	0.33	74.80	7.08	4.00	3.00	278.40	0.00
32	6.02	123.3	73	5.79	1.0	29.9	4.23	0.21	13.03	3.86	4.00	1.00	57.00	2.00
33	5.93	124.1	85	8.00	4.0	21.5	18.37	0.33	3.11	0.14	7.50	1.00	49.70	0.50
34	6.35	261	178	8.40	3.4	21.7	15.38	0.46	13.00	1.02	6.50	7.00	71.30	0.50
35	6.12	139.4	94	6.90	5.0	22.7	7.96	0.19	5.89	0.90	4.60	1.00	39.10	0.20
36	6.91	481	322	6.60	6.2	24.4	31.51	1.08	23.81	11.49	25.60	7.00	144.80	0.20
37	6.68	250	169	6.60	3.2	23.7	14.09	0.72	10.24	2.21	5.50	1.00	66.20	0.40
38	6.87	498	334	6.70	7.1	23.4	18.84	0.82	54.82	6.99	3.30	3.00	231.50	0.60
39	6.47	447	300	6.80	6.4	23.6	25.36	0.66	47.43	5.15	5.00	48.00	164.70	0.80
Min	**5.19**	**52**	**34**	**2.56**	**0**	**21.5**	**2.89**	**0.132**	**1.647**	**0.14**	**2.151**	**0.611**	**2.00**	**0.00**
Mean	**6.23**	**297.05**	**194.82**	**5.49**	**5.63**	**25.87**	**13.02**	**2.12**	**21.49**	**6.84**	**14.10**	**6.77**	**80.82**	**1.67**
Max	**7.23**	**1152**	**771**	**8.4**	**47**	**31.7**	**108.12**	**36.71**	**90.51**	**22.98**	**156.00**	**51.00**	**278.4**	**7.00**
SD	**0.52**	**215.85**	**141.91**	**1.49**	**9.29**	**2.31**	**17.18**	**5.87**	**25.64**	**6.14**	**25.82**	**10.55**	**80.27**	**1.73**

Table 3 Classification of Groundwater Samples using Piper Diagram

Class	Groundwater	Sample Statistics	
		No. of samples	%
Hydrogeochemical facies			
I	Ca^{2+}- Mg^{2+}-Cl^{-}-SO_4^{2-}	19	48.72
II	Na^{+}-K^{+}-Cl^{-}-SO_4^{2-}	2	5.12
III	Na^{+}-K^{+}-HCO_3^{-}	1	2.56
IV	Ca^{2+}-Mg^{2+}-HCO_3^{-}	17	43.59
Water types			
Ca-HCO_3		18	46.15
Mixed CaMgCl		10	25.64
CaCl		8	20.51
NaCl		2	5.13
Mixed CaNaHCO_3		1	2.56

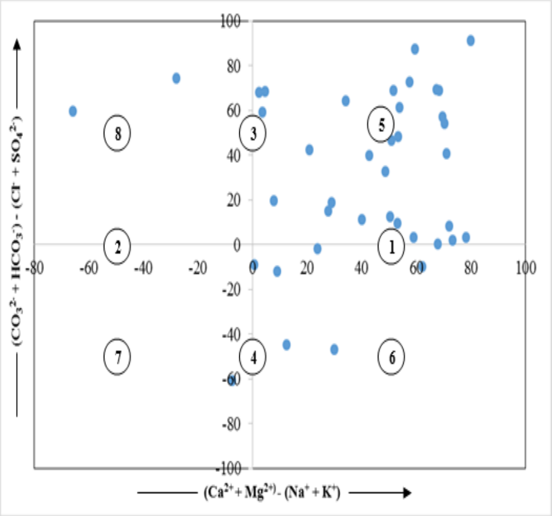

Fig. 3 Chadha Diagram for Groundwater Samples

3.3 Human Health Risk Assessment

3.3.1 Exposure assessment

A summary of the estimated average daily intake (ADI) of heavy metals for adults in Tarkwa is presented in Table 4. The results indicate that ADIs concentration for the heavy metals in groundwater ranges from Zn 3.759×10^{-3} for Zn mg/kg/day to 2.658×10^{-6} mg/kg/day for Cr, which is ordered as Zn>Mn>Fe>As>Cu>Ni>Pb>Cd>Cr.

3.3.2 Carcinogenic Risk

Carcinogenic risk of arsenic (As) was only estimated due to the unavailability of carcinogenic SFs for the other heavy metals (Table 4). Carcinogenic risk estimated for As (1.80×10^{-4}) was higher than the acceptable risk. Thus, drinking of groundwater will pose significant health problems. The carcinogenic risk estimated indicated that, drinking of groundwater over a long period will increase the probability of cancer.

3.3.3 Noncarcinogenic risk

The hazard quotient (HQ) value for heavy metals estimated, suggested an acceptable level of noncarcinogenic inimical health risk. In relation to the HQ value, the Hazard Index (HQ) calculated was less than 1 (Table 5). This suggest that inhabitants will not be exposed to a potential health risk for the injection of heavy metals.

Table 4 Summary of the Average Concentrations of Heavy Metals found in Groundwater

Community	**Cd mg/L**	**Cu mg/L**	**Zn mg/L**	**As mg/L**	**Pb mg/L**	**Ni mg/L**	**Cr mg/L**	**Mn mg/L**	**Fe mg/L**
UMaT Campus	1.30E-05	7.97E-02	4.90E-02	5.56E-04	2.12E-03	1.25E-03	1.85E-04	3.18E-02	2.56E-02
Brahabobome	1.27E-05	7.78E-03	3.67E-02	5.38E-03	1.33E-03	8.13E-04	9.83E-05	1.99E-01	5.93E-01
Kamponase	3.93E-05	3.49E-04	1.78E-02	7.77E-05	4.68E-04	9.84E-04	2.07E-04	5.93E-02	1.71E-02
Efuanta	2.43E-05	2.87E-03	5.29E-02	7.46E-04	2.97E-04	2.30E-03	4.56E-04	2.37E-01	5.18E-01
Tamso	9.53E-05	4.64E-03	1.99E-02	1.58E-03	5.92E-04	7.15E-03	3.48E-04	4.66E-01	1.18E-02
Nsuta	2.77E-05	8.52E-04	6.05E-02	2.65E-04	2.90E-05	6.50E-04	5.43E-05	2.16E-01	7.73E-02
Bonsaso	9.00E-06	1.23E-03	9.03E-03	1.26E-03	5.58E-05	1.56E-03	2.25E-04	4.93E-01	4.79E-01
Bogoso Junction	3.88E-05	3.22E-03	1.30E-02	8.71E-04	3.60E-04	2.11E-03	1.19E-04	2.18E-01	2.56E-02
Huniso	1.97E-03	5.64E-03	2.46E+00	3.58E-03	1.51E-02	1.09E-02	5.54E-04	4.53E-01	7.61E-02
Akyempem	5.29E-04	4.27E-03	7.53E-01	8.15E-04	5.62E-04	5.80E-03	2.45E-04	6.53E-01	5.95E-01
Gold Fields	0	0	0	9.71E-02	0	0	0	1.86E-01	0

Table 5 Estimated Exposure of Heavy Metals via Drinking of Groundwater and the Health Hazard Index

Heavy Metals	ADI (mg/kg/day)	HQ	Car_Risk
Cd	2.948E-06	0.0059	0
Cu	1.180E-04	0.0029	0
Zn	3.709E-03	0.0124	0
As	1.198E-04	0.3994	1.797E-04
Pb	2.227E-05	0.0064	0
Ni	3.582E-05	0.0018	0
Cr	2.658E-06	0.0009	0
Mn	3.428E-03	0.0245	0
Fe	2.582E-03	0.0016	0
Hazard Index (HI)		**0.456**	

*Car_Risk: Carcinogenic Risk

4 Conclusions and Recommendation

Results from the water quality analysis showed that groundwater in the area is slightly acidic to neutral in nature. Most of the physico-chemical parameters are within the WHO drinking standards. The Piper plot show that a combined Ca-HCO$_3$ and mixed Ca-Mg-Cl water types which are fresh water types constitute 72 % whereas the Chadha diagram showed that fresh water constitute 92 %. Even though there is a variation between the fresh water types in both diagrams, the results revealed that the study area is dominated by fresh water. The advantage of using the Chadha diagram is that it can be plotted using any spreadsheet software, however, it is recommended that it is always used along with other hydrogeochemical diagrams for analysis.

The current intake of groundwater in the area is satisfactory according to the non-carcinogenic assessment of the health risk. However, the carcinogenic assessment points to the fact that drinking groundwater over a long period of time will results in increase in the probability of cancer. Additionally, the results for this study can offer a benchmark for the design and monitoring of arsenic in groundwater in the Tarkwa area.

It is recommended that:

(i). Diagnostic testing for metal toxicity (preferably hair or urine test) should form an integral part of the daily clinical services so as to detect as early as possible, any incidence of metal intoxication to forestall detrimental consequences.

(ii). Periodic analysis of groundwater sources in the Tarkwa area be carried out to ascertain the concentration levels of heavy metals so that the local inhabitant could be advised accordingly.

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