



# **Groundwater Quality Characterisation of Selected Hand-dug Wells and Geological Implications in the Assin North Municipality, Ghana**

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## **Authors' contributions**

*This work was carried out in collaboration among all authors. Author GMT designed the study. Author PDB performed the sampling and analysis while author ROD was guided by author GMT to analyse the data and write an initial project report as a requirement for an undergraduate programme. Author GMT did further literature review and wrote the manuscript. All authors read and approved of the final manuscript.*

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## **ABSTRACT**

Water from ten hand-dug wells from Assin North Municipality in Ghana were analysed at Ghana Water Company Limited Quality Assurance Laboratory, Ho in Ghana for various physico-chemical parameters. The analyses used standard methods with chemicals of AR grade; pH was measured with the Horiba Compact B-122 and Inolab 7300 Conductivity/TDS portable meter. Colour, turbidity, aluminium, copper, sulphate and total iron were analysed by spectrophotometry using Hach DR/2500 following standard methods. Flame photometer was used for determination of metal ions Na<sup>+</sup>, K<sup>+</sup> and Ca<sup>2+</sup>. Silver nitrate method was used to estimate chloride, sulphate was determined by turbidimetric method. Total hardness was calculated by complexometric titration using EDTA. The results of the analyses show pH 6.0 to 7.2 with a mean of 6.5, conductivity from 300 to 800 µS/cm, TDS range from 90 to 400 mg/l. Piper Trilinear diagram revealed three main water types - calcium bicarbonate (Ca+Mg-HCO<sub>3</sub>) possibly sourced from Ca-plagioclase, biotite and amphibole; sodium chloride (Na-Cl) from Na-plagioclase, muscovite and chlorite; and mixed water types which may be

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due to the combined effect of Birimian metasedimentary rocks, Belt granitoid and pegmatites that released into the water through cation exchange and accounted for Na<sup>+</sup> in the Na-Cl water type. Chloride in a few hand-dug wells may be linked to mineralogy crystallised from marine deposited sediments and infiltration of rainwater along fractures in the rocks. Hence most of the water samples have Na/Cl ratios < 0.86. The rainwater in the area with weak acidity possibly infiltrated into the soil to cause appreciable concentration of HCO<sub>3</sub><sup>-</sup> in the studied water. The total coliform values in water were less harmful as there was no faecal coliforms, though total microbial values in hand-dug wells X4 and X10 with total coliform values of 2.2 and 5.1 MPN/100ml respectively exceed the WHO guidelines. Hand-dug wells X4 and X6 in the study probably ended in aquifers in the weathered zone with the rest of the wells in fresh fractured horizons of the granitoids. Na/Cl ratios > 1 (for water samples X1, X7 and X8) might have been due to contamination from anthropogenic sources. Pearson correlation indicates strong and positive correlation of TDS < Mg < Na with conductivity. All the water samples were safe for human consumption.

*Keywords: Groundwater; physico-chemical parameters; water types; birimian rocks; mineralogy.*

## 1. INTRODUCTION

Generally, the quality of groundwater is dependent on the physico-chemical and biochemical parameters. In Ghana, the quality of groundwater in most of the hydrogeological province has been found to be influenced strongly by its interactions with lithology [1]. The physico-chemical parameters are used to assess the suitability of groundwater for domestic purposes based on the concentrations of inorganic elements, as well as biogenic parameters compared with the World Health Organisation (WHO) guidelines for potable water [2].

Digging the ground with a pick and shovel when the ground is soft and the water table is shallow produces hand-dug wells which have large area exposed to the aquifer to obtain water from less-permeable earth materials such as very fine sand, silt, or clay. Hand-dug wells are shallow making them subject to contamination from surface run-off and become dry during periods of drought when the water table drops below the well bottom [3].

Most communities in the Assin North Municipality with an estimated population of about 155,000 people depend on groundwater as the main source of water for domestic and other general purposes [4,5].

The concentrations of the chemical constituents in groundwater are controlled by elements in the soil and rocks through which the water flows. This paper sought to assess the contributions of geology to groundwater composition. It investigated the water quality, types or hydrochemical facies from the various sampled hand-dug wells in the Assin North Municipality.

### 1.1 Study Area

The area falls within the moist tropical forest, mainly deciduous forest and has an annual rainfall between 1500 to 2000mm; annual temperatures are high and range between 30°C from March to April and 26°C. Rainfall pattern is bi-modal as the major rainy season starts from April - July corresponding with the major farming season and the minor rainy season starts from November – September [5].

The District is characterised by undulating topography and has an average height of about 200m above sea level. Flood-prone plains of rivers and streams occur at low lying areas. The municipality has numerous small rivers and streams. The main rivers include the Pra, Offin, Betinsin and Fum; swamps also abound and are used for fish farming and dry season vegetable and rice farming [5].

The land area is underlain by basin granitoids belonging to the Precambrian terrain. It comprises basically of granites, granodiorites, adamellites and migmatites. The predominant mica minerals are muscovite and biotite. The geology also comprises mainly of phyllites and schists [4].

The Basin granitoids are rarely foliated, often migmatitic, potash rich granitoids which take the form of muscovite-biotite granite, granodiorite, porphyroblastic biotite gneiss, aplites and pegmatites. The granites are characterised by the presence of many enclaves of schists and gneisses. They are generally associated with Birimian metasedimentary rocks. The sedimentary Basin granitoids are believed to represent a multiphase intrusion consisting of

four separate magmatic pulses [6]. There is usually a large metamorphic aureole associated with the sedimentary Basin granitoids [6]. Table 1 shows the elemental composition of the sedimentary Basin granitoids.

Small intrusive bodies related to the sedimentary Basin granitoids are found at coastal areas e.g. near Saltpond, over 80 pegmatite bodies occur and are clearly related to the margin of the batholith from which they radiate for about 12 km. General mineralogical composition includes quartz, muscovite, biotite, microcline, tourmaline, albite, garnet and kaolin [6]. The total iron oxide concentration of the rocks makes the soils concentrate total iron likely to pose risk to the water quality.

The composition of water by World Health Organisation guidelines and most of national authorities, are to ensure maximum admissible concentrations. Arsenic is associated with sulphides and so high concentrations can sometimes be found in rocks containing sulphides. The Birimian Basin granitoids contain sulphides as their associated metasedimentary rocks [6]. During weathering, there is dissolution of carbonates, silicates or evaporate minerals to release elements into water and soil. The minerals dissolve slowly and have conspicuous effect on the water chemistry [6].

Correlation matrices of physico-chemical parameters of water is used to develop mathematical relationship for comparison of the parameters [7,8].

The present study was undertaken to assess groundwater quality of hand-dug wells located in various parts of the Assin North Municipality using physico-chemical parameters. The study

was necessary to monitor water quality deteriorations and to assess bacteriological quality and chemical characteristics using Piper Trilinear diagrams.

## 2. METHODOLOGY

Ten hand-dug wells at elevations of 144.0 m to 190.4m above sea level, at depths of 12-23m and located within 5 to 20m from the houses at Assin North Municipality (Juaso Transformer, Juaso M/A School, Bantema, Akrofuom, Foso Habitat, Atonsu, Dompim JHS, Dompim Habitat, Adiembra and Fosu Station) were collected in clean sterilised plastic containers of 2L capacity and labelled X1 –X10(Fig. 1, Table 2). Some water of each of the hand-dug wells was used to rinse the containers for 3 minutes prior to collection. The rock floats around the hand-dug wells show that the wells are located on the Basin granitoid (Fig. 2). The samples were transferred immediately to the Ghana Water Company Limited Quality Assurance Laboratory, Ho (Ghana) and analysed for various physico-chemical parameters using standard methods [9] (Table 3). All the chemicals used were of AR grade; pH was measured with the Horiba Compact B-122 and Inolab 7300 Conductivity/TDS portable meter. Colour, turbidity, aluminium, copper, sulphate and total iron were analysed by spectrophotometry using Hach DR/2500 following standard methods [10]. Flame photometer was used for determination of metal ions: Na<sup>+</sup>, K<sup>+</sup> and Ca<sup>2+</sup>. Silver nitrate method was used to estimate chloride present in water samples, sulphate was determined by turbidimetric method [11]. Total hardness was calculated by using complexometric titration using EDTA. The results of the analyses are shown in Table 3. The various chemical evolution of groundwater was deduced using the Piper

**Table 1. Elemental composition of the sedimentary Basin granitoids in Ghana (after [6])**

Oxides	Mean wt. (%)	Standard deviation
SiO <sub>2</sub>	69.24	5.86
TiO <sub>2</sub>	0.32	0.14
Al <sub>2</sub> O <sub>3</sub>	15.05	2.08
Fe <sub>2</sub> O <sub>3</sub>	2.73	1.24
MnO	0.04	0.03
MgO	0.97	0.53
CaO	2.19	0.81
Na <sub>2</sub> O	4.37	1.05
K <sub>2</sub> O	2.58	1.08
P <sub>2</sub> O <sub>5</sub>	0.09	0.04
SO <sub>3</sub>	0.06	0.19
LOI	0.77	0.34

Trilinear diagram generated by Groundwater Chart (GW-Chart) software (Fig. 3). Multivariate Correlation and regression were calculated using Excel and SPSS respectively to identify highly correlated parameters [5,6].

### 3. RESULTS AND DISCUSSION

Majority of the elements analysed in water from hand-dug well in the study area fall within the WHO guidelines for groundwater [9]. The pH values vary from 6.0 to 7.2 with a mean of 6.5. Conductivity values from 300 to 800  $\mu\text{S}/\text{cm}$  were recorded while TDS range from 90 to 400 mg/ (Table 3).

The groundwater hydrochemical facies in the various aquifers shows three main water types (Fig. 3). Calcium bicarbonate ( $\text{Ca}+\text{Mg}-\text{HCO}_3$ ) water type at hand-dug wells X2, X7 possibly sourced from Ca-plagioclase, biotite and amphibole (waters of this type have temporary hardness, carbonate hardness exceeds 50% and usually fresh water. Sodium chloride (Na-Cl) water type occurs in hand-dug wells X3, X4, X6, X8, and X10 and likely to be associated with Na-plagioclase, muscovite and chlorite. The waters are of non-carbonate alkalis exceeding 50%, high Na+K and  $\text{Cl}+\text{SO}_4^-$ . Mixed water types in hand-dug wells X1, X5, X9 have no cation-anion pair exceeding 50%, and of intermediate chemical character (Fig. 3).

The possible rocks that could produce these groundwater types are the Birimian metasedimentary rocks and Belt granitoid; the mixed water types possibly intersected a combination of these rocks [6,7].

Most of the water samples have Na/Cl ratios < 0.86 showing that the groundwater has been contaminated by seawater whereas those with Na/Cl ratios > 1 (X1, X7 and X8) might have been contaminated by anthropogenic sources [12]. According to Kortatsi [13], the source of Na-Cl water type is usually attributed to seawater intrusion for aquifers located along the Accra plains. Similarly, the high chloride concentration found in groundwater in the coastal aquifers at *Ekumfi Akwakrom and Ekumfi Asokwa in the Mankessim Municipality of the Central Region of Ghana* was attributed to dissolution of soluble salts ( $\text{Cl}^-$ ) accumulated in the unsaturated zone

[13]. The study area is located inland where there is minimal influence of seawater in the absence of major faults. Other possible sources of chloride is feldspars and micas in the granite and granodioritic gneiss (Fig. 3).  $\text{Cl}^-$  could be associated with sediments which were deposited in marine environment and halite fluid inclusions in minerals. Oberg [14], suggests that organic- $\text{Cl}^-$  pool occurs in soils naturally through the chlorination of carbon compounds by micro-organisms, plants and fungi. Additional source of chloride from production of  $^{36}\text{Cl}$  at the earth's surface due to cosmic radiation is a function of exposure time, latitude, of target elements with slow production rates from spallation of  $^{39}\text{K}$  and  $^{40}\text{Ca}$  in terrestrial rocks [15]. The source of  $\text{Cl}^-$  in the groundwater could be associated with the infiltration of rainwater to the groundwater zone. Possibly halite from farm used aerosols might have concentrated NaCl in the soil zone. This is possible in the tropics, as the area studied, where rainfall season is followed by prolonged dry season during which period halite precipitates in the soil [16]. Also,  $\text{Cl}^-$  could be released from fluid inclusions in minerals found in the granitoid rocks [17]. Since the Birimian metasedimentary rocks and Basin granitoids were possibly deposited in marine environment, the  $\text{Cl}^-$  in marine water might still be available in the weathered granitoid.

$\text{Ca}^{2+}$  can be found in plagioclase feldspar, amphiboles, epidote whiles K-bearing minerals are potassium feldspars, biotite and muscovite. Hence the higher concentration of  $\text{Ca}^{2+}$  and  $\text{Na}^+$  in the groundwaters may be due to the dissolution of plagioclase feldspars within the rocks.  $\text{Na}^+$  ions, usually from minerals such as sodium rich plagioclase feldspar (albite to oligoclase found in the rocks) might have been released through cation exchange reactions into water to account for  $\text{Na}^+$  in the Na-Cl water type.  $\text{HCO}_3^-$  in the water may be from organic matter, which releases carbon dioxide that reacts with water in the soil zone to form weak carbonic acid that aids in the breakdown of the minerals. Though rainwater in a major mining town in Ghana, Obuasi, according to Akoto et al. [18] had a mean pH range from 4.0 to 5.6 probably influenced by local mining activities has ionic species in the order,  $\text{SO}_4^{2-} > \text{Cl}^- > \text{Ca}^{2+} > \text{K}^+ > \text{Na}^+ > \text{NO}_3^- = \text{Mg}^{2+} > \text{NH}_4^+$ . Rainwater in the area could infiltrate into the soil to cause such appreciable concentration of  $\text{HCO}_3^-$  in water from poorly constructed borehole and hand-dug wells.

**Table 2. Results of geocentric coordinates and depths of the hand-dug wells in the study area**

Hand-dug Well ID.	X	Y	Z	Depth (m)
X1	689323.5877	634127.7203	183.2148596	19
X2	689414.7016	633770.347	191.4476409	17
X3	689652.2863	631164.9503	190.3736004	18
X4	698856.7667	617546.043	152.4143766	12
X5	690927.7616	631021.4872	188.3235571	22
X6	692162.7266	627735.5386	162.5405277	15
X7	688835.9883	628103.1503	162.9161874	21
X8	688796.2204	628260.5743	162.3355446	23
X9	684567.0895	625516.7378	143.993416	19
X10	690846.9455	630087.9145	185.6133462	22

**Table 3. Results of various water parameters from the hand-dug wells in the study area**

Parameters	units	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	WHO [19]
Temperature	°C	27.7	28.1	28.1	27.8	28.2	27.7	28.2	27.9	27.9	28.2	NA
pH		6	6.4	6.2	7.2	6.9	6.4	6.4	6.4	6	7.1	6.5-8.5
Turbidity	NTU	0.4	0.25	0.45	7.4	23	0.15	3.7	0.55	0.15	0.6	0-5
Conductivity	µS/cm	544	440	401	756	360	766	500	572	485	580	1000
TDS	mg/l	292	221.9	231.6	373.0	95.15	397.4	265.8	245.5	255.8	314.7	1000
TSS	mg/l	0	0	0	4	23	0	3	0	0	0	NA
Total hardness	mg/l as CaCO <sub>3</sub>	70	30	50	120	40	120	100	50	50	120	0-500
Colour (Apparent)	HU	0	0	0	20	99	0	0	0	0	4	0-15
Total Alkalinity	Mg/l as CaCO <sub>3</sub>	90	50	70	150	70	120	130	60	60	150	NA
Magnesium	mg/l	10.2	11.5	6.6	29.6	9.0	22.2	9.8	16.8	5.4	10.4	NA
Bicarbonate	mg/l as CaCO <sub>3</sub>	167.4	125.2	85.2	143.5	73.0	207.4	50.9	118.4	72.2	146.2	NA
Calcium	mg/l	12.6	21.3	20.8	16.7	32.2	36.9	27.7	21.1	22.7	33.4	0-200
Chloride	mg/l	46.1	55.3	54.6	110.9	31.7	104.2	11.4	69.6	56.2	104.9	0-250
Potassium	mg/l	1.6	2.7	2.7	2.7	2.4	4.3	4.3	1.5	2.4	4.4	0-30
Sulphate	mg/l	32.3	4.8	18.7	55.0	43.0	39.5	20.9	52.2	18.02	15.2	0-250
Sodium	mg/l	65.3	31.3	45.2	83.5	14.2	79.9	19.9	70.5	28.0	54.8	0-200
Total iron	mg/l	0	0	0	0.26	0.3	0	0.05	0	0	0.06	0-0.3
Manganese	mg/l	0.15	0	0.01	0.02	0.24	0.06	0.02	0.03	0	0.1	0-0.1
Fluoride	mg/l	0	0.6	0.2	0.4	0.6	0.6	0	0	0.2	0.9	0-15
Faecal coliform	cfu/ml	0	0	0	0	0	0	0	0	0	0	0
Total coliform	MPN/100ml	0	0	0	2.2	0	0	0	0	0	5.1	0

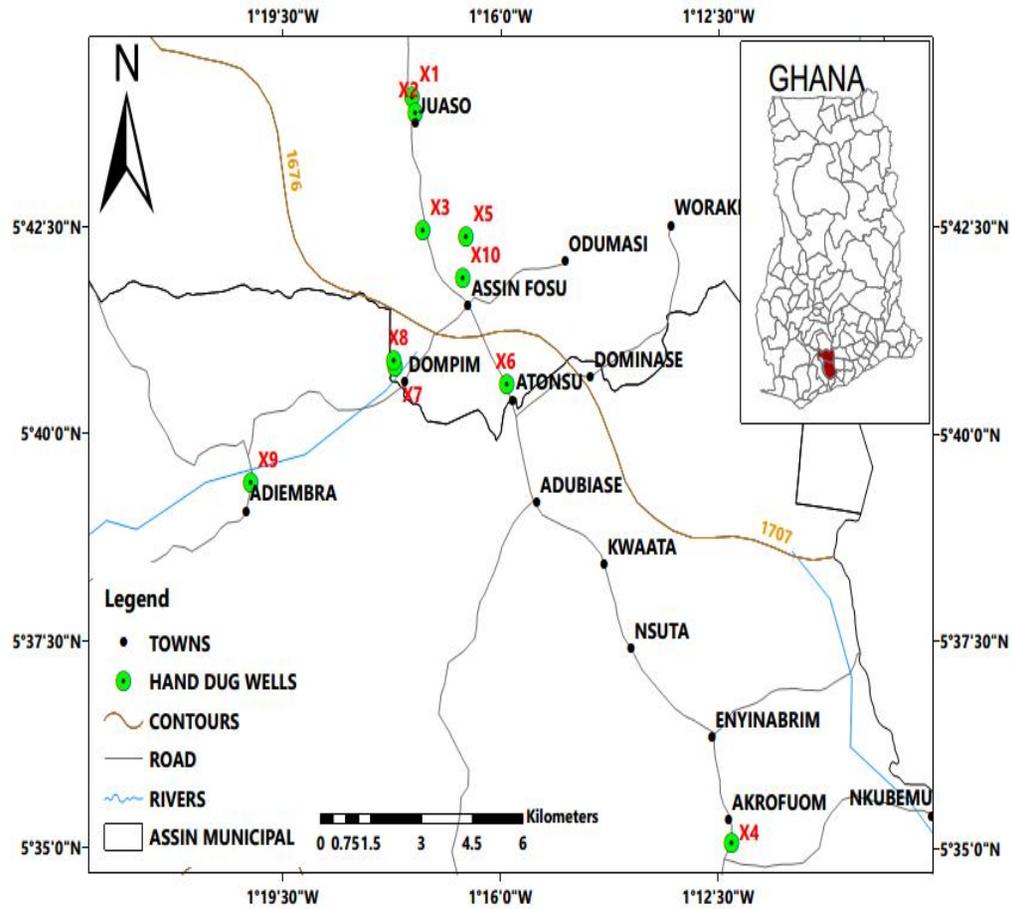


Fig. 1. Topographical map of the study area

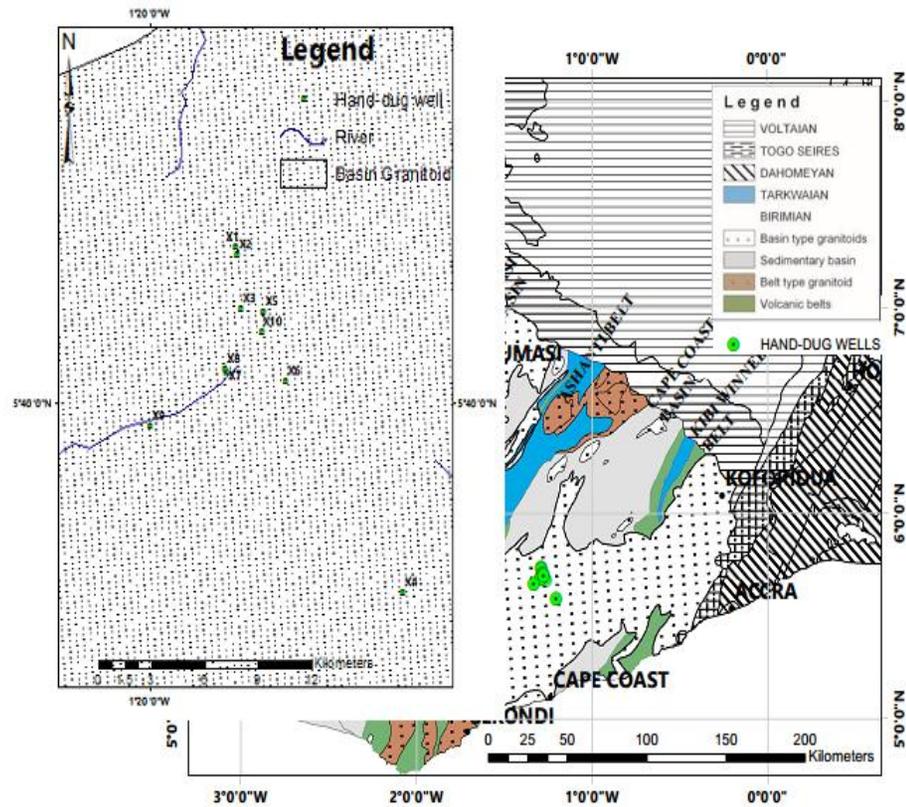


Fig. 2. Geological map of southwest Ghana showing the study area (after [20])

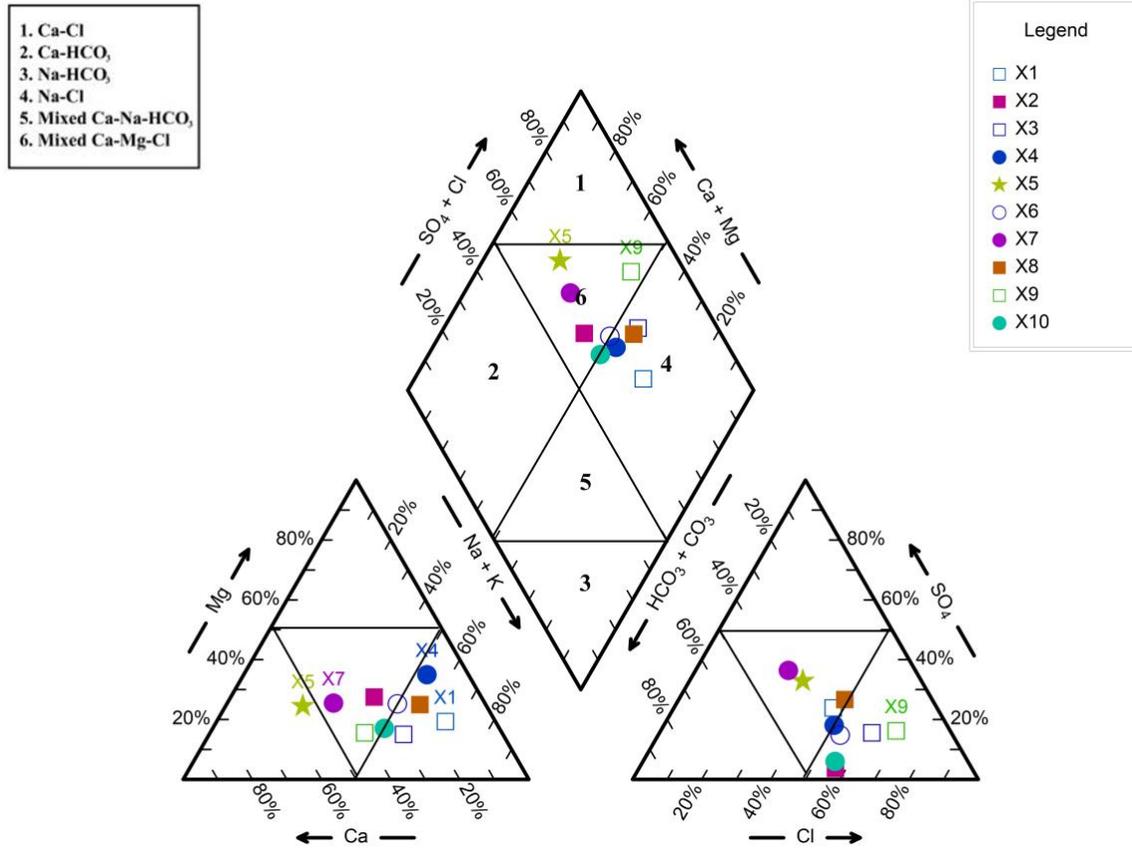


Fig. 3. A Piper plot showing the various hydrochemical facies of the study area

Table 4. Correlation matrix of the physicochemical parameters

	Temperature	pH	Turbidity	Conductivity	TDS	Total hardness	Total Alkalinity	Magnesium	Bicarbonate	Calcium	Chloride	Potassium	hSulphate	Sodium
Temperature	1.000													
pH	0.306	1.000												
Turbidity	0.344	<b>0.502</b>	1.000											
Conductivity	<b>-0.678</b>	0.303	-0.310	1.000										
TDS	<b>-0.624</b>	0.097	<b>-0.592</b>	<b>0.913</b>	1.000									
Total hardness	-0.240	0.481	-0.165	<b>0.799</b>	<b>0.809</b>	1.000								
Total Alkalinity	-0.056	<b>0.608</b>	-0.020	<b>0.662</b>	<b>0.671</b>	<b>0.963</b>	1.000							
Magnesium	<b>-0.544</b>	<b>0.507</b>	0.020	<b>0.860</b>	<b>0.650</b>	0.582	<b>0.513</b>	1.000						
Bicarbonate	<b>-0.680</b>	0.116	-0.347	<b>0.736</b>	<b>0.698</b>	0.482	0.338	<b>0.591</b>	1.000					
Calcium	0.364	0.336	0.254	0.077	-0.007	0.333	0.282	-0.032	0.056	1.000				
Chloride	-0.433	0.485	-0.275	0.776	<b>0.714</b>	<b>0.587</b>	0.482	<b>0.683</b>	<b>0.728</b>	0.151	1.000			
Potassium	0.323	0.338	-0.118	0.298	0.410	<b>0.688</b>	<b>0.675</b>	0.094	0.114	<b>0.735</b>	0.230	1.000		
Sulphate	-0.493	0.342	0.405	<b>0.503</b>	0.171	0.244	0.202	<b>0.689</b>	0.261	-0.082	0.299	-0.328	1.000	
Sodium	<b>-0.750</b>	0.172	-0.395	<b>0.851</b>	<b>0.785</b>	<b>0.545</b>	0.411	<b>0.768</b>	<b>0.817</b>	-0.201	<b>0.789</b>	-0.060	<b>0.555</b>	1.000

Total microbial values in hand-dug wells X4 and X10 at Akrofuom and Fosu Station with total coliform values of 2.2 and 5.1 MPN/100ml respectively exceed the WHO guidelines (Table 3) [19]. A shallow well such as X4 at a depth of 12m is prone to contamination (Table 2) usually from agricultural sources, organic wastes, infiltration of irrigation of water, septic tanks, proximity to pit latrine, biofilm development within the sources and personal hygiene accumulating total coliforms and *E-coli* [18,21]. Also, particulate contaminants such as bacteria can very rapidly be transported in fracture systems [22]. The hand-dug wells in the study were situated in valleys which could be along fracture/fault zones (Fig. 1). These hand-dug wells are within five to 20m from the houses and so prone to contamination from seepage of septic tanks. Though total coliforms in water include bacteria that are found in soil and in human or animal waste; faecal coliform presence is an indication of animal or human waste [23]. The total coliform values in water in the wells is therefore less harmful as there were no faecal coliforms which could have been due to faecal contamination, especially, some rare strains of *E-coli* (O157:H7) that may lead to lethal disease conditions [24]. The water in the study is, therefore, safe for human consumption. If the groundwater in Birimian Basin granitoid terrain at Sekyere area in the Ashanti Region of Ghana occurs at a relatively shallow depth with potential water bearing zones between depths of 8 - 15m in weathered rock aquifers and 20 - 30m for fractured non-weathered aquifers [25], then the hand-dug wells X4 and X6 in the study probably ended in aquifers in the weathered zone with the rest of the wells in fresh fractured horizons of the granitoids.

Pearson Correlation study was carried out to establish the relationship between the physico-chemical parameters (Table 4). In the present study, there was strong and positive Mg and conductivity ( $r = 0.860$ ), Na and conductivity ( $r = 0.851$ ), total hardness and conductivity ( $r = 0.799$ ), TDS and conductivity ( $r = 0.913$ ). These results indicate that these parameters have direct relationship with each other. Moderate positive correlation was for the following: total alkalinity - magnesium ( $r = 0.513$ ), total alkalinity - potassium ( $r = 0.675$ ), magnesium - bicarbonate ( $r = 0.591$ ), magnesium - chloride ( $r = 0.683$ ), magnesium sulphate ( $r = 0.689$ ), magnesium - sodium ( $r = 0.768$ ), pH - alkalinity ( $r = -0.608$ ). Low correlation include pH - turbidity ( $r = 0.502$ ), pH - magnesium ( $r = 0.507$ ). The parameters

which showed correlation coefficient less than 0.5 are indication of poor correlation. A few parameters also showed moderate negative correlation these are temperature - conductivity ( $r = -0.678$ ), temperature - bicarbonate ( $r = -0.680$ ) temperature - sodium ( $r = -0.750$ ) (Table 4).

#### 4. CONCLUSION

Parameters of water from hand-dug wells from the Assin North Municipality fall within the WHO guidelines and so the water is safe for domestic and other general purposes. The main hydrochemical facies are Na-Cl and Ca+Mg-HCO<sub>3</sub> and mixed water types, with Na-Cl water type being the dominant one. These water types were influenced by the geology of the area which are the Birimian Belt granitoids and metasedimentary rocks or both.

There is strong to moderate and positive correlation decreasing from total dissolved solids, magnesium, sodium with conductivity with correlation coefficients of  $r = 0.913$ ,  $0.863$  and  $0.851$  respectively; bicarbonate -potassium, magnesium -sodium, temperature - conductivity, magnesium - chloride, total alkalinity - potassium, magnesium - bicarbonate, alkalinity - bicarbonate. Absence of *E-coli* in the hand-dug wells suggest less infiltration and contamination of human and animal faeces along fractures in the rocks. The water is therefore safe for human consumption.

#### DISCLAIMER

The products used for this research are commonly and predominantly used products in the country. There is absolutely no conflict of interest between the authors and the laboratory because the results are for advancement of knowledge. Also, the research was not funded by the company that performed the analyses rather it was funded by personal efforts of the authors.

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#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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