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Research Paper

Spatial Patterns of Groundwater Trace Elements Concentration in Northern Ghana Basement Aquifer.

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Abstract
Elements, for example, the groundwater minor components can be fundamental and destructive relying upon openness and portion that can be impacted by the normal land and ecological variables concerning their fixations and conveyances. A few elements add to changes in groundwater hydrochemistry, including environment, precipitation, mineralogy of the fundamental geography with which the water communicates, spring properties and geology. These elements add to the spatial and fleeting changes in the water synthesis. The spatial fixation and appropriation of groundwater minor components from Northern Ghana spring (storm cellar) was thusly explored in the study. What's more, a correlation of the supplement fixation with suggested everyday admission (RDI) was led to comprehend the job and commitment of groundwater to dietary requirements. Water quality data of 184 wells from the Northern Ghana were utilized in the study. The contextual analysis regions in Northern Ghana are described by storm cellar springs. The consequence of the investigation directed tracked down Northern Ghana to have a Blend Calcium-Magnesium-Chloride-Sulfate water type and Calcium-Bicarbonate water type separately. The geochemical controls inside the review regions were found to change with spring type and the cellar springs were portrayed by rock enduring and rock-water association because of delayed contact with translucent rocks. This anyway doesn't meet the RDI values for these supplements. Consequently, this study infers that drinking of groundwater from the Northern Ghana might add to supplement admission; it should be expanded by nutritious nourishment for the dietary should be met.

Keywords: Spatial, Concentration, Trace Elements, Basement, Aquifer

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I. Introduction

The utilization of groundwater as a significant wellspring of consumable water in non-industrial nations has shown to be an important asset for neighborhood populaces. The capacity to securely involve this water for drinking, notwithstanding, relies upon its substance quality, an element basically constrained by different spring credits like geography and geochemistry. On a worldwide scale, groundwater is essentially obtained from either sedimentary or cellar springs (Nwankwo *et al.,* 2020). Groundwater is shielded from defilement by anthropogenic contaminations because of the filtering limit of the overburden material and is in this manner generally liked to surface water (Yidana *et al.,* 2012). In any case, the quality might disintegrate relying upon the neighborhood ecological circumstances (Zhang *et al.,*2007; Wang *et al*., 2014; Liu *et al.,*2018). A few elements add to changes in groundwater hydrochemistry, including environment, precipitation, mineralogy of the fundamental geography with which the water cooperates, spring properties and geology. These variables add to the spatial and fleeting changes in the water creation. Understanding the hydrochemical attributes of groundwater in this manner gives knowledge into the components and geochemical processes that drive groundwater synthetic advancement. Groundwater is respected, in many region of the world, as a dependable and versatile water asset because of its disseminated, subsurface capacity and perpetual accessibility. The geographical developments which briefly store this water and permit it to stream, are known

as springs. Lithologically, these can be facilitated inside one or the other storm cellar (old, glasslike rocks of transformative as well as nosy beginning (Nwankwo *et al.*, 2020).

These components especially the minor components can be fundamental and destructive relying upon openness and portion and can be affected by the normal land and ecological elements with regards to their fixations and disseminations (Salinus *et al.,.*2005). The pathways, openings and degree of ingestion can effect on the dispersion of medical issues in people and creatures (Arhin *et al*.,2015). Addressing ecological medical problems owing to effects of the common habitat on General Wellbeing falls inside a multidisciplinary logical field where geoscience can possibly help clinical and general wellbeing networks all around the world chasing answers for an extensive variety of natural and normally incited medical problems (Centeno *et al*.,2016). The minor components in the regular habitat comprise the wellsprings of numerous sicknesses and the focuses and overflows influence on wellbeing in various ways (Arhin *et al.,* 2016)

In most non-industrial nations of the world, groundwater is viewed as an important asset to the neighborhood populace who rely upon it for drinking water. Aside from its capability of keeping the human body hydrated, research by Hoque and Butler (2015) recognized that the supplements in the groundwater in three Asian Deltas met the suggested everyday admission (RDI) and were answerable for the wellbeing status of the neighborhood populace in view of the sum drank each day. In any case, a few examinations (Rosborg, 2015; Hoque and Butler, 2015; Hoque and Butler, 2016) have shown that food consumption gives the greater part of the large scale and miniature supplements required by the body. For the most part, in drinking water, there is a scope of focus in supplement accessibility, which can measure up to the WHO's RDI esteem (Table 1).

Table 1: Normal concentration of nutrients available in drinking water versus WHO's recommended daily intake (RDI) values

Mineral Nutrient		Normal availability in water (mg/L)	WHO's RDI value (mg/day)
Macro-nutrients	**Ca**	10 - 100	800
	Mg	1-50	300
	Na	2-20	2000
	K	<1-5	3000
Micro-nutrients	**Fe**	<1-1	14
	F	<1-2	4
Pollutant	**As**	<0.01	-

For example, large scale supplements, for example, calcium and magnesium will have a rising impact with expanding measurements up to a specific level where any longer consumed will be irrelevant to the body. Though, poisons like arsenic; which is here and there present in groundwater, might be decent up to a specific portion, yet will become harmful on the off chance that any longer is polished off.

In the review region, concentrate on the hydro substance portrayal of surface water and groundwater is extremely scanty and the couple of ones that exist (Tay *et al.,* 2017; Loh *et al*.,2022) are inadequately organized to give a territorial outline to better preparation and the board of the springs in the bowl. The intricacy describing the fundamental geography and the gigantic land-use changes make it very difficult to comprehend the cycles that decide the nature of surface water and groundwater in a provincial setting (Manu *et al.,* 2023).

Various examinations in the space have utilized different customary ways to deal with evaluate the nature of water assets for drinking (Zhang *et al.*, 2012; Xia *et al.,* 2022) and water system (Loh *et al.,* 2021; Panneerselvan *et al.,*2023) purposes. The Water Quality Record (WQI)has been utilized widely in different land territories to concentrate on surface water and groundwater quality for drinking (Loh *et al*., 2020; Okofo *et al.,*2021). Others have been utilized to concentrate on water system water quality, including the USSL, % Na and Wilcox outline (Yidana *et al.,*2012; Loh *et al.,* 2021; Panneerselvan *et al.,*2023). In the Pra Bowl, Loh *et al.* (2021) utilized the WQI, % Na, Wilcox and the US Saltiness Level graph to evaluate groundwater quality in the Lake Bosumtwi region of the Pra Bowl and presumed that the groundwater is of good quality for drinking and water system and exhibited the utility of these methodologies in concentrating on water quality in the territory (Manu *et al.,* 2023). In this current review, significant cation and anions are utilized to give information about spatial appropriation and grouping of groundwater minor components in Northern Ghana cellar spring.

II. STUDY AREA

2.1 Description of the Study Area

There are three significant geological locales in Northern Ghana; Upper East District, Upper West Area and the Northern Locale. Because of openness of data, the contextual analysis region is focused on the Upper East

Locale, arranged in the Ghanaian North-eastern district, what imparts a typical boundary to Burkina Faso in the North and Togo along the East (Figure 1). The region falls inside scopes 10°30′N and 11°N and longitudes 0° and 1°W, spreading over an area of around 8,842 km2. Bolgatanga is the significant city around here and the region is mostly urban. Bolgatanga is the major city in this area and the area is mainly rural.

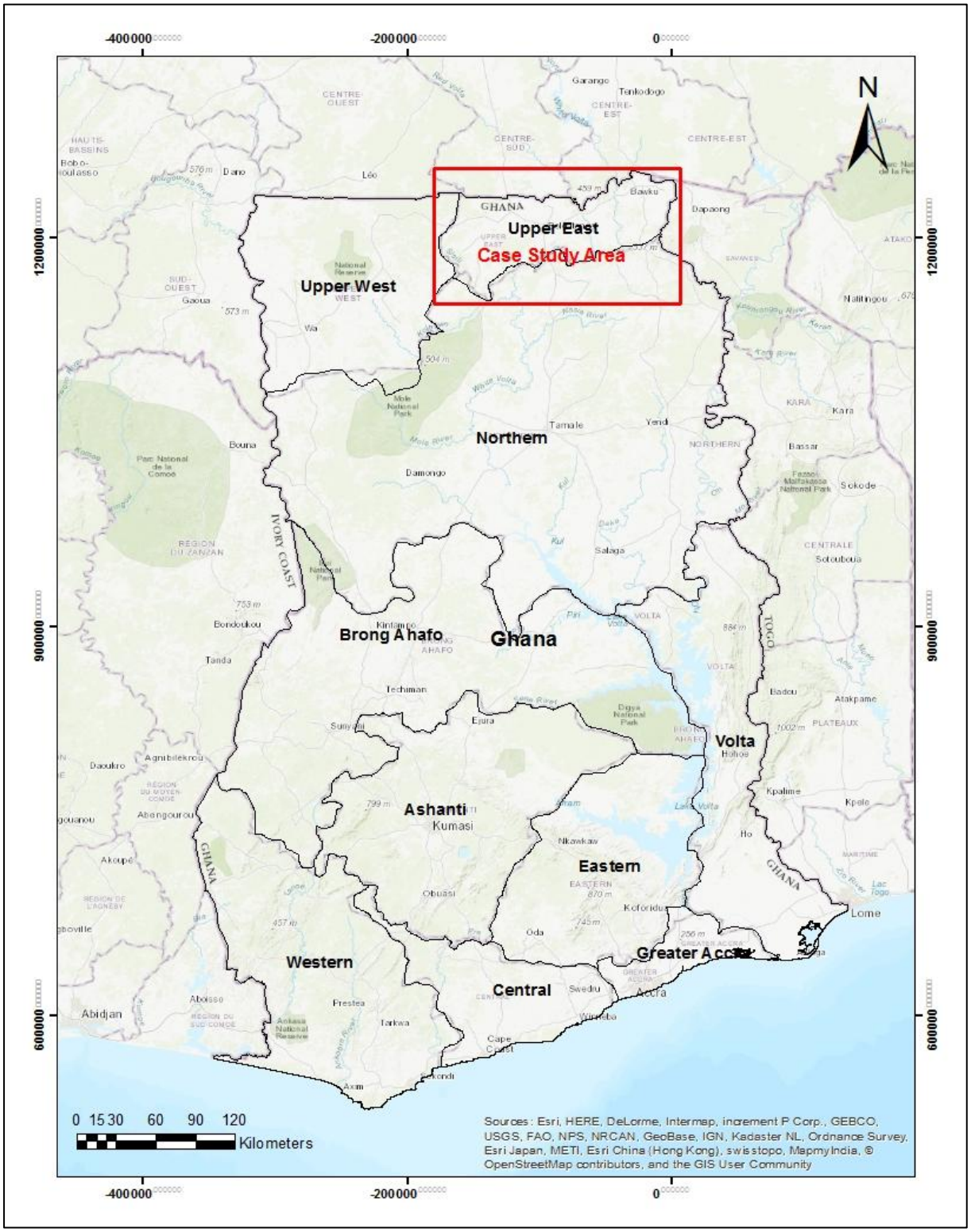

Figure 1: Topographic map showing the location and extent of the case study area in the Upper Eastern Region of Northern Ghana.

2.2.1 Physiography

The region of the country, Ghana in general range at around 238,539km2, and lies on the south-focal shoreline of West Africa, containing inland water bodies. Around 10% of the complete expanse of land is covered by wetlands, including marine and beach front wetlands, inland wetlands, and counterfeit wetlands like weirs and lakes (FAO, 2005). The wetlands incorporate three significant stream frameworks which are Volta Waterway, South Western Stream and Beach front Waterway (EPA, 2005).

The landed areas of Ghana are generally under 600m with unequivocally couple of regions arriving at rises around 1000m. The region of the land higher than 300m is under 10%. The least regions are tracked down along the coast and in the center Volta Bowl. There are six expansive physiographic districts in Ghana; the Gambaga ledge, the savanna high fields, the southern Voltaian level, the woods dissected level, the Buem-Togo ranges and the waterfront fields (USAID/Ghana, 2006). The contextual analysis region in northern Ghana lies between the savanna high fields and the Gambaga slope.

2.2.2 Environment and Vegetation

Ghana traverses a few climatic zones, from the semi-bone-dry Sahel locale in the far north to the jungles in the southern piece of the country. The typical yearly temperature in Ghana is ordinarily above 25°C, most likely because of the low scope of the district and absence of high-height locales. Precipitation in Ghana commonly tumbles from the southern to northern regions. In the far north (around the contextual analysis region), the yearly rainfalls are under 1100mm (Government of Ghana, 2017).

The normal vegetation inside the contextual analysis region (north-eastern piece of Ghana) is that of the savannah (Guinea) forest, portrayed by wide leaved, deciduous and fire open minded trees dispersed in a ground vegetation of significantly grass, some of the time above 1.5m in level (Government of Ghana, 2017).

2.2.3 Topography

Structurally, northern Ghana possesses the southern piece of the West African Craton, which is in the eastern piece of the Man Safeguard (Nwankwo , 2017). It is encircled in the eastern part by the Dish African Belt and is underlain by two fundamental topographical regions, the Voltaian Territories and Precambrian Cellar.

There gives off an impression of being a great deal of conflict among researchers in regards to the stratigraphic units of northern Ghana, as the land guide of the area is right now under survey by the Geographical Review of Ghana. Be that as it may, an overall lithology of the stones in view of chronostratigraphic units of, Kesse (1985) is introduced in Table 2 and displayed in Figure 2.

Table 2: General lithology of the major geological provinces of northern Ghana (After, Carrier et al., 2008).

System	Series	Dominant lithology
Voltaian System	Upper Voltaian	Massive sandstone, conglomerate with mudstone and thin beds of shale locally
	Middle Voltaian	Obosum beds - Sandstone, shale, mudstone, conglomerate, some limestone
		Oti beds - Arkose, conglomerate, sandstone, limestone, shale, mudstone
	Lower Voltaian	Basal quartz sandstone with pebbly grits and grits
-	Buem Series	Sandstone, shale, lava and tuff with some limestone, grit, conglomerate
Tarkwaian System	Huni, Tarkwa, Banket, Kawere	Shale, sandstone, conglomerate, phyllite, quartzite, schist
Birimian System	Granitoid intrusions	Mainly granite, gneiss and granodiorite
	Upper Birimian	Metamorphosed tuff and lava (basaltic and andesitic)
	Lower Birimian	Phyllite, schist, slate with sandstone and greywacke

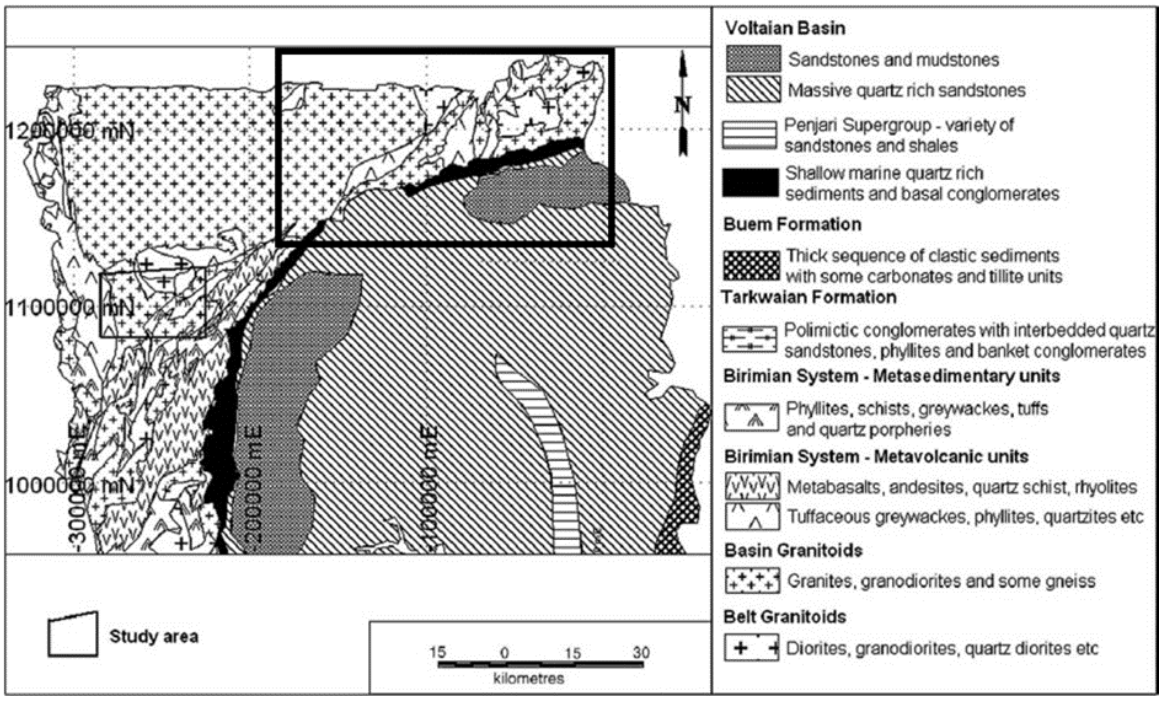

Figure 2: Simplified geological map showing the general lithology of the rocks found in Northern Ghana (After, Nude & Arhin, 2009).

An overlay of regolith containing in-situ artificially endured material and a few moved surface materials are run of the mill of most topographical developments in Northern Ghana (Kwei, 1997). This regolith ordinarily superimposes a saprock district, which is gradually recharged by fluidly cracked and non-endured, bedrock. This enduring profile may anyway be fractional in certain areas on account of disintegration and profundity of the enduring front may not generally be obvious (Nwankwo*.,* 2017).

Around the contextual analysis region (Upper East Locale), the regolith created over Tarkwaian and Birimian rocks differ from 12m to 33m averaging 23m, while fluctuating from 3m to 37 m averaging 20m over granitoid interruptions (Dapaah-Siakwan and Gyau-Boakye, 2000).

2.2.4 Hydrogeology

There are two significant hydrogeologic regions in northern Ghana; Voltaian and Precambrian Storm Cellar Territories. By and large, hydrogeological regions of Ghana have been fundamentally separated in light of geography (Figure 3.), which influences accessibility and event of groundwater (Gill, 1969; Nwankwo*.,* 2017).

Low essential porosity and penetrability are generally shown by rocks of the Precambrian Storm Cellar Territory (Nwankwo, 2017). Consequently, stream and event in this territory are generally controlled by optional porosity coming about because of substance enduring, blaming and breaking. Enduring impacts the putting away capacity of translucent rocks. In any case, hydrogeological properties of springs in such regions are extremely conflicting, basically because of the anisotropic idea of break organizations and the different force and intricacy of enduring cycles that partake in regolith advancement (Kwei, 1997; Dapaah-Siakwan and Gyau-Boakye, 2000). In the voltaian territory, rocks are distinctively impermeable and all around solidified. Cracking, blaming and enduring have in any case expanded the penetrability of these stones on a more limited size (Nwankwo., 2017).

The principal uses of water in Ghana are animals, water system and homegrown water supply. Water supplies in provincial regions are gotten exclusively from groundwater sources as on account of the review region. Nonetheless, modern and homegrown metropolitan water supplies depend for the most part on surface water, either redirected by dams in streams or put away behind little dams (Howard, 2002).

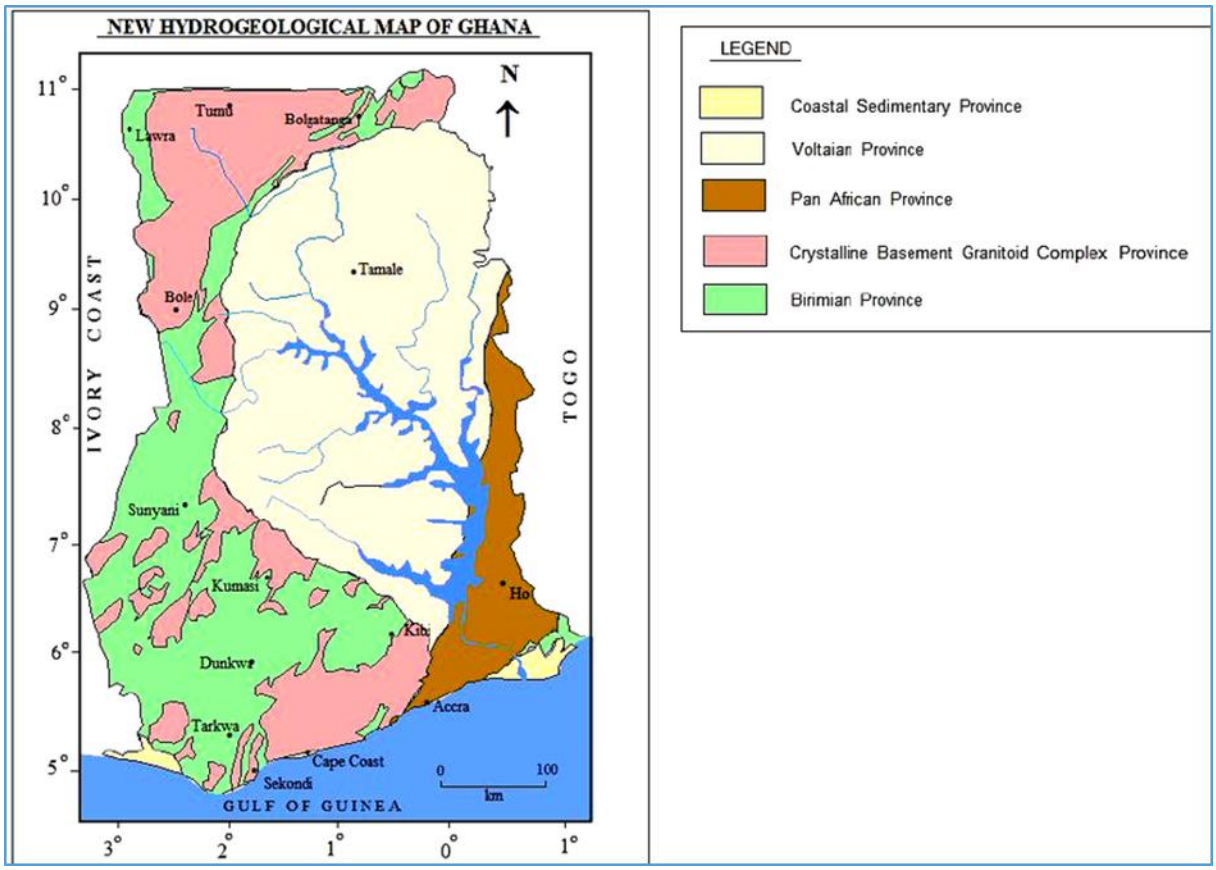

Figure 3: Map of Ghana showing the various hydrogeological provinces (Yidana et al., 2011).

III. MATERIALS AND METHODS

3.1 DATA

A broad water quality dataset has been assembled from tube wells, Northern Ghana [n = 184]; note that the terms wells and cylinder wells are utilized reciprocally in this work) utilizing the distributed writing (BGS/DPHE 2001; Smedley et al. 2002). The vast majority of the wells have recorded a full scope of substance investigation, including minor components. The scope of grouping of minerals in drinking water can measure up to the WHO's RDI values, but this study will be restricted to the large scale minerals (calcium, Ca; magnesium, Mg; sodium, Na; potassium, K) and miniature minerals (iron, Fe) and the degrees of components of conceivable concern [i.e., fluoride (F) and arsenic (As)] ordinarily found in groundwater in changing fixations.

3.2 Diagram OF Information Investigation

Coming up next were chosen for this near study: calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), iron (Fe), bicarbonate (HCO3), fluoride (F) and arsenic (As). Subtleties on the logical techniques directed, too as the real information, can be tracked down in the referred to sources (BGS/DPHE 2001; Smedley et al. 2002). The RDI for the different mineral supplements' changes relying upon the age bunch, as well concerning any unique groupings (e.g., pregnant ladies). For effortlessness a proper moderate worth, as characterized by Hoque and Steward (2016a, b), was utilized for every mineral supplement: Ca (800 mg/d), F (4 mg/d), Fe (14 mg/d), K (3000 mg/d), Mg (300 mg/d) and Na (2000 mg/d). The focus levels for different minerals and poisons found in the two spring types were thought about by adjusting the fundamental hydrogeochemical processes. What's more, the centralizations of different particles (e.g., Na, Ca, Fe) were contrasted with the poisons with decide any conceivable regulating impacts. For the RDI estimation, it was expected an individual hydrates from a similar water-well consistently (Hoque and Steward 2016a; WHO 2011), in spite of the fact that it ought to be noticed that this figure can change. Between spring RDIs for different minerals (Ca, Mg, Na, Fe) found in two liters of water were looked at by normalizing utilizing the accompanying condition.

% Rx = (CxX2) X 100 … … … … (1)

Rx

Where %Rx is rate RDI (as %) of 'x' (x being Ca, Mg, Na or Fe), Cx is fixation (in mg/l) of x in 1 liter of water, Rx is RDI sum in mg/day lastly duplicated by 100 to have the result in rate.

IV. RESULTS AND DISCUSSION

4.1 Northern Ghana

Altogether, information from 184 wells were examined for this contextual analysis region. Albeit, the investigated information did exclude well profundity, the mid-screen or well profundity is accepted to be between 5m to 40m (Smedley et al., 2002). These wells were undeniably situated in the Upper East area of Ghana, near the line with Burkina Faso.

4.2.1 Major cations

Four significant cations were examined; Calcium (Ca2+), Magnesium (Mg2+), Sodium (Na+) and Potassium (K+).

Calcium (Ca2+) - Fixation goes from 4.9 mg/L to 71.1 mg/L, with a normal of 30.9 mg/L (Figure 4.). Focus is equitably conveyed inside the review region, with higher qualities happening more at the limit regions among Ghana and Burkina Faso.

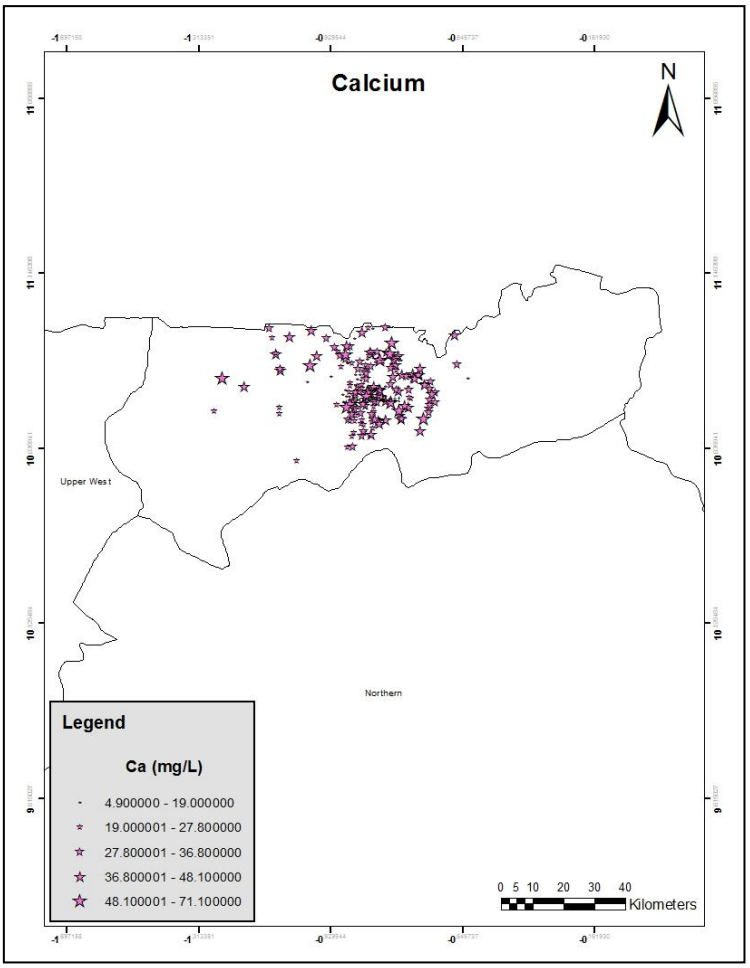

Figure 4: Distribution and concentration of Calcium in Upper East Region, Ghana (decimal points are insignificant).

Magnesium (Mg2+) - Focus goes from 1.5 mg/L to 43.1 mg/L, with a normal of 13.0 mg/L (Figure 5). The conveyance inside the review region is described by geological fixations; regions with high qualities happening near each and those with lower esteems likewise being inside close distance (e.g., regions around the far north having high qualities while those around the south having brings down values, despite the fact that with few extraordinary events).

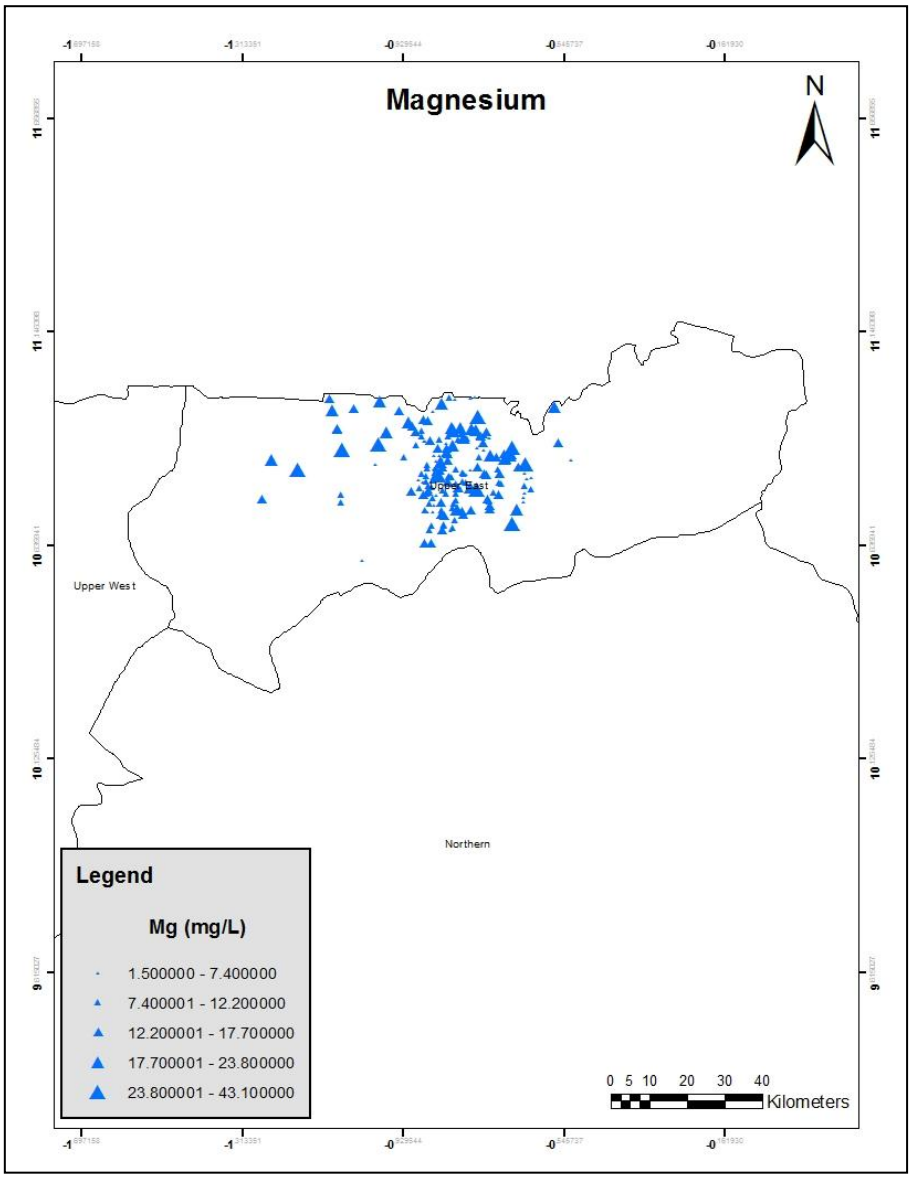

Figure 5: Distribution and concentration of Magnesium in Upper East Region, Ghana (decimal points are insignificant).

Sodium (Na+) - Fixation is profoundly factor and ranges from 6.3 mg/L to 107.8 mg/L, with a normal of 23.7 mg/L (Figure 6). The dispersion is described by nearby fluctuation, where both high and low qualities were distinguished in exceptionally close distances (inside towns).

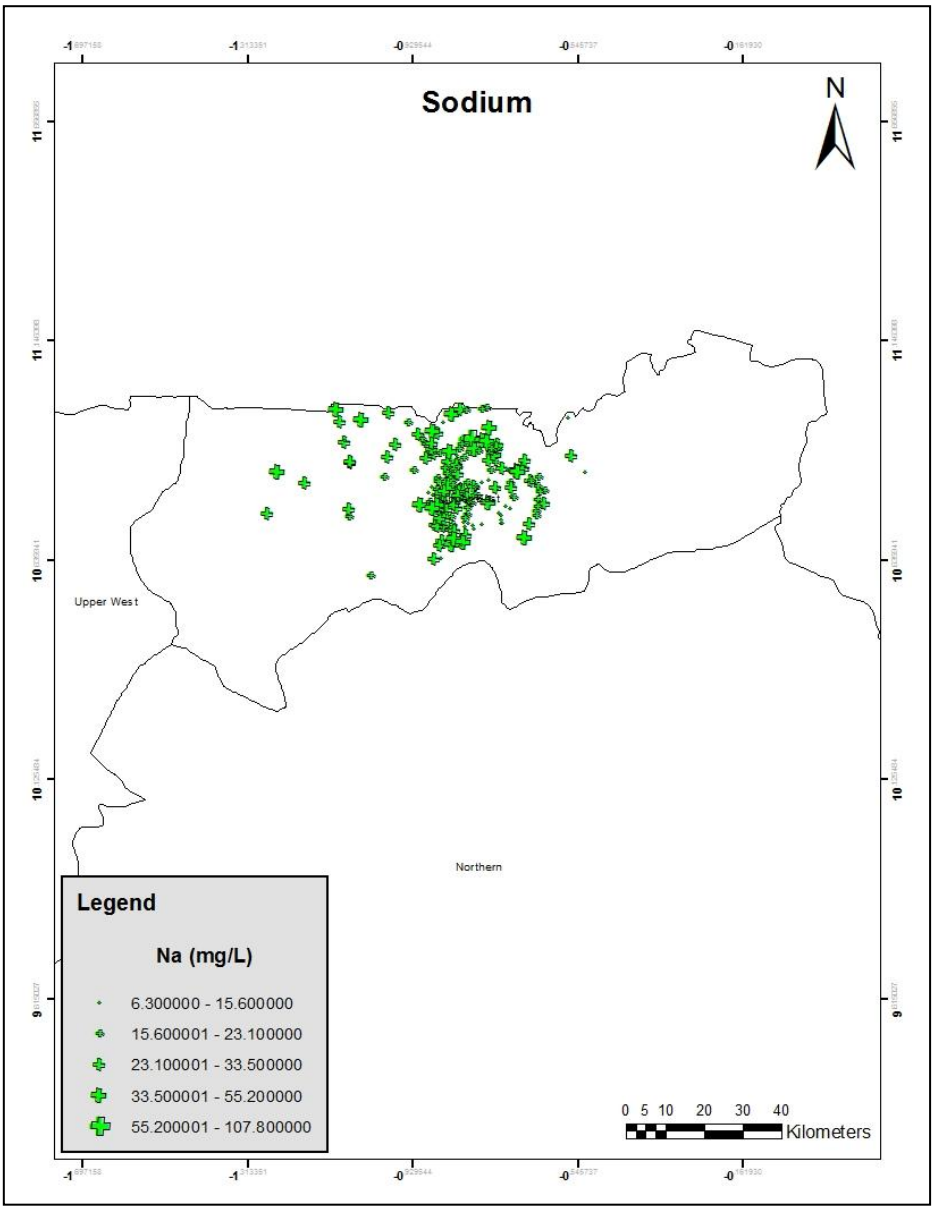

Figure 6: Distribution and concentration of Sodium in Upper East Region, Ghana (decimal points are insignificant).

Potassium (K) - Focus goes from 0.015 mg/L to 15.8 mg/L, with a normal of 2.24 mg/L (Figure 7). Higher upsides of potassium were recognized inside the focal regions, with focus commonly becoming lower as it gets away from the focal.

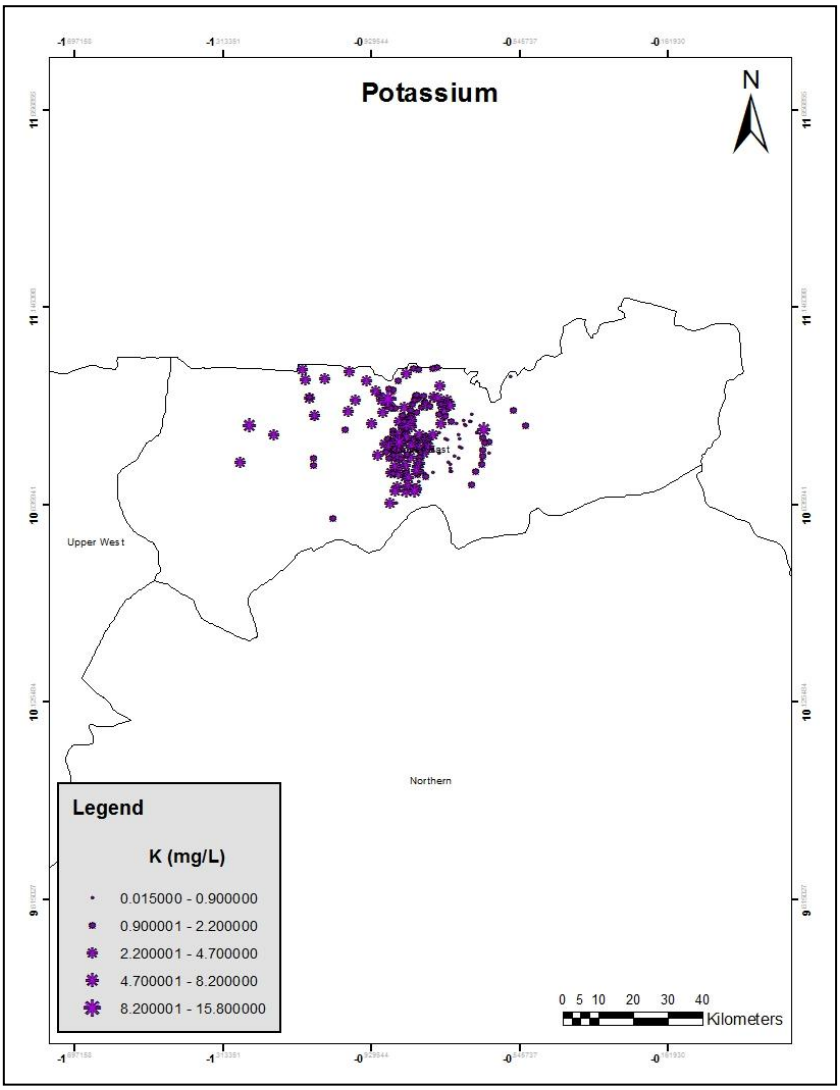

Figure 7: Distribution and concentration of the Potassium in Upper East Region, Ghana (decimal points are insignificant).

4.2.2 Major anions

Because of information accessibility, two significant anions were examined for this contextual investigation region; sulfate (SO42-) and chloride (Cl-).

Sulfate - Fixation goes from 0.1 mg/L to 73.1 mg/L with a normal of 3.0 mg/L (Figure 8); in any case, just few wells with recognized high focuses, with under 3% having focus more noteworthy than 10 mg/L.

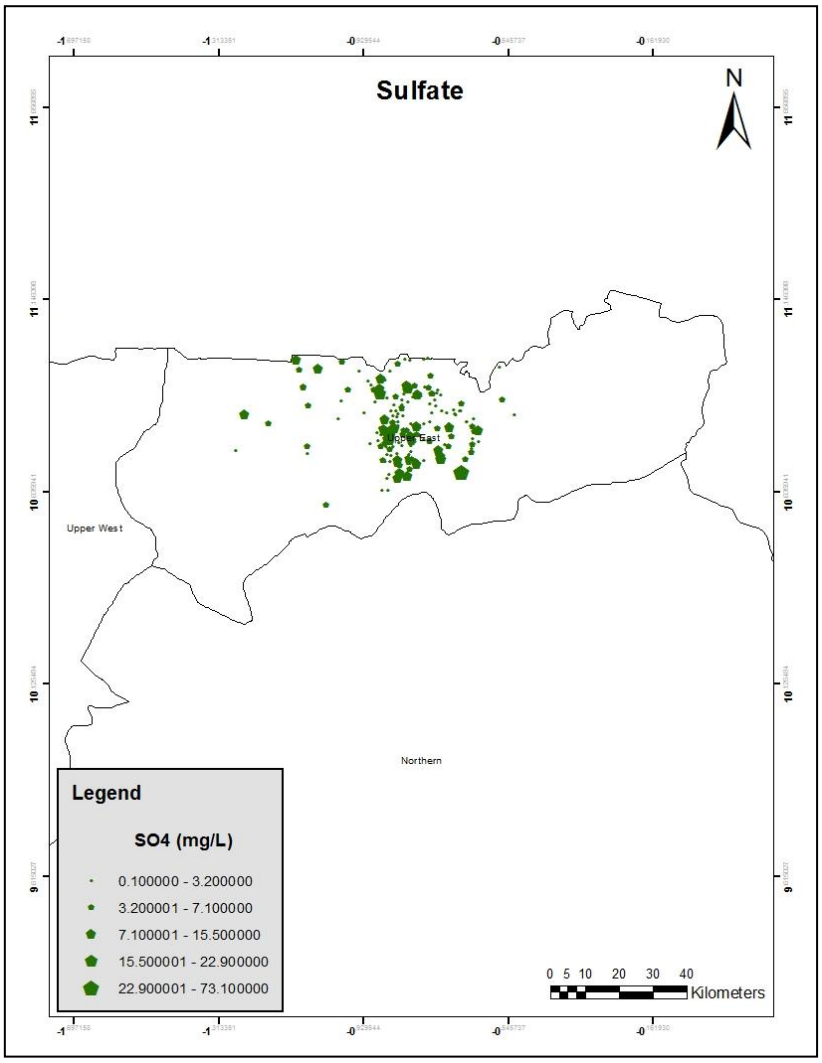

Figure 8: Distribution and concentration of Sulfate in Upper East Region, Ghana (decimal points are insignificant).

Chloride - Fixations goes from 0.015 mg/L to 51.50 mg/L, with a normal of 7.2 mg/L (Figure 9). The low centralization of chloride can be credited to the spring property being essentially of glasslike silicate rocks with almost no cooperation with ocean water; subsequently low saltiness and low chloride fixation.

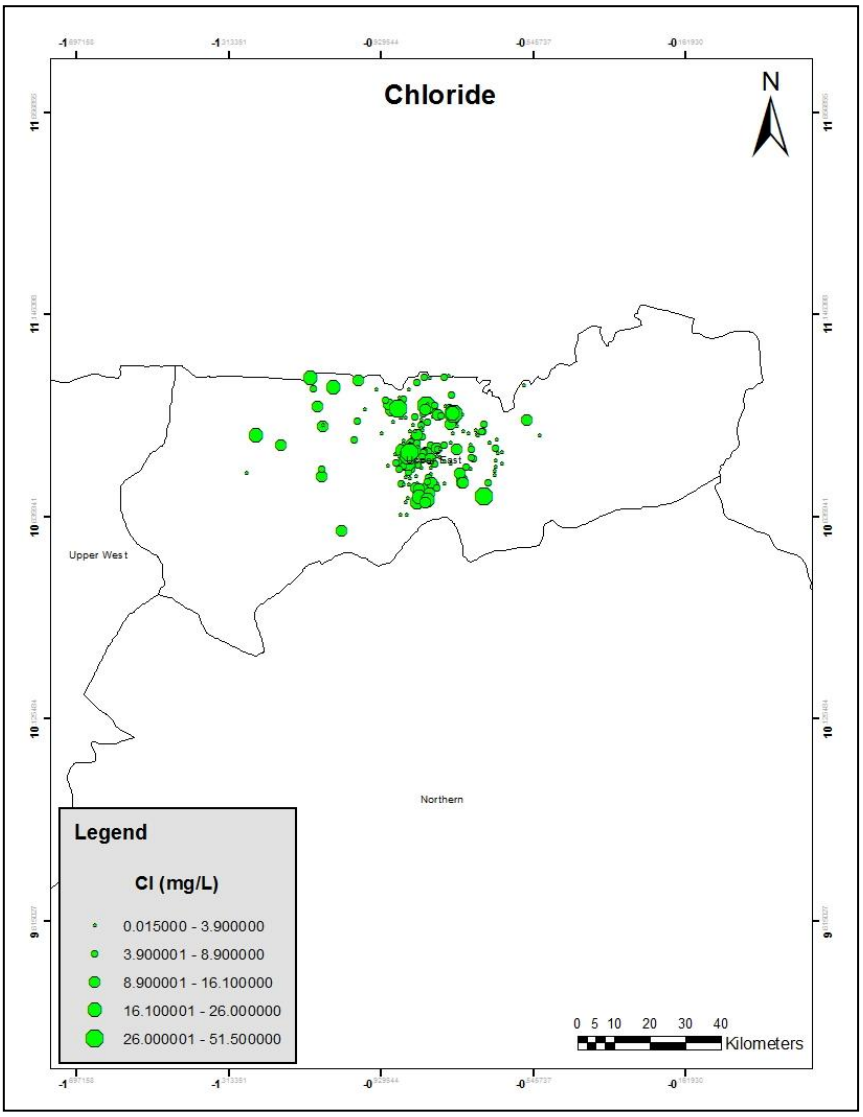

Figure 9: Distribution and concentration of Chloride in Upper East Region, Ghana (decimal points are insignificant).

4.3. Other elements

Two different components were investigated; Iron (Fe) and Fluoride (F). High groupings of iron have been portrayed as one of the head groundwater quality issues in Ghana; for the most part accepted to be related with anaerobic groundwater conditions (Smedley *et.al.,* 1995). Fluoride event in groundwater is firmly connected to geography (granitic rocks), which are dominating around here. Dental fluorosis, which means that high fluoride fixation in this space was accounted for by (Smedley *et al* 1995).

Iron - Fixation goes from 0.001 mg/L to 2.51 mg/L, with a normal of 0.18 mg/L (Figure 4.22). The low focus saw in this space were in accordance with past review (Smedley et. al., 1995). The low focus can likewise be credited to the spring being for the most part glasslike as high fixation will be probable related with sedimentary springs.

Fluoride - Fixation goes from 0.09 mg/L to 4.37 mg/L, with a normal of 1.0 mg/L (4.22). High convergence of this component in concentrate on region is related with the focal regions (around Bolgatanga), where the spring is essentially portrayed by granitic rocks. See figure 10, beneath for their focus and spatial appropriation.

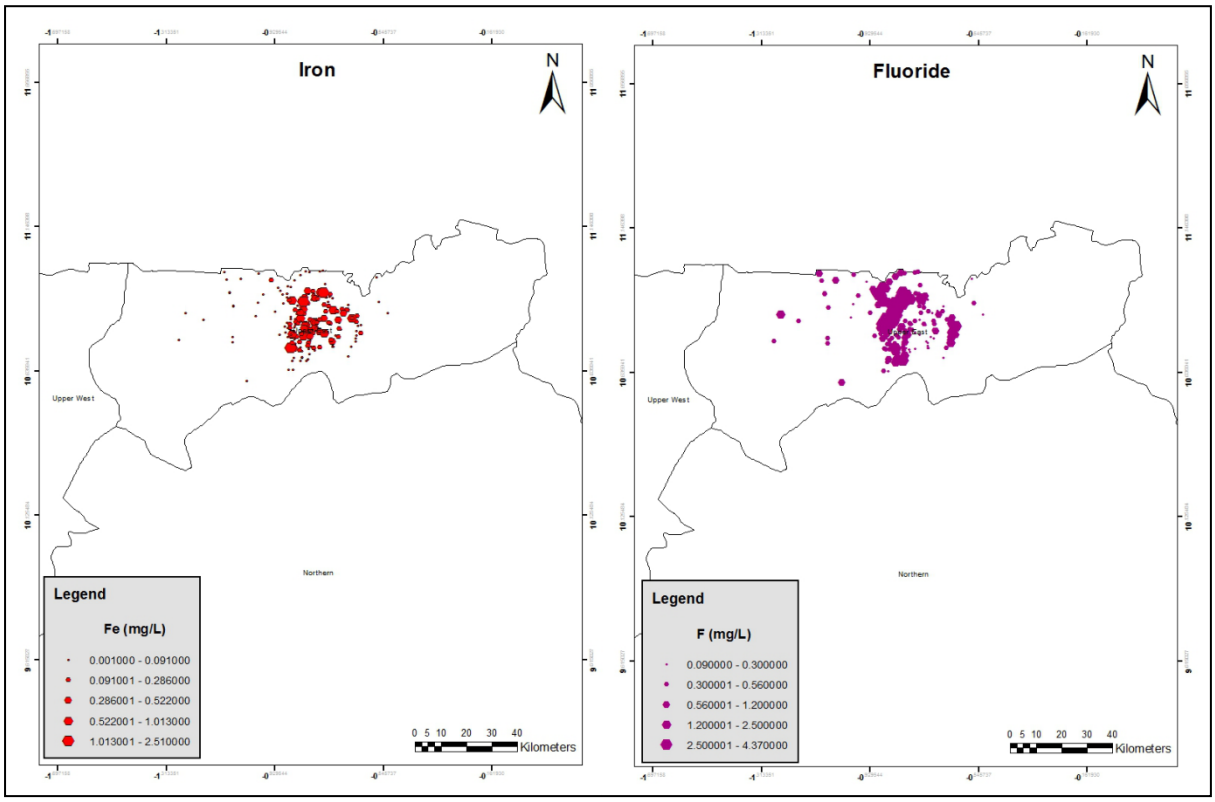

Figure 10: Distribution and concentration of Iron and Fluoride in Upper East Region, Ghana (decimal points are insignificant).

4.4 Case Study Areas and Recommended Daily Intake (RDI) Values

The nature of water in a district have been as of late connected to wellbeing results of the neighborhood populace in the review region. This was finished by examining the groundwater science and relating the supplements present in the water to suggested everyday admission (RDI).

Calcium - Around 75% of the wells in Northern Ghana have a fixation higher than 21 mg/L. Thusly, for an ordinary grown-up that hydrates a day, the supplement feasible will be 42 mg of calcium. When contrasted with a RDI worth of 800 mg/day, the contextual investigation regions couldn't generally depend on drinking of water alone to meet the nourishing admission of calcium.

Magnesium - Around 75% of the wells in Northern Ghana have a fixation higher than 8.3 mg/L. Thusly, for an ordinary grown-up that hydrates a day, the supplement feasible will be 16.6 mg of calcium. When contrasted with a RDI worth of 300 mg/day, the contextual investigation regions couldn't generally depend on drinking of water alone to meet the nourishing admission of magnesium.

Sodium - Around 75% of the wells in Northern Ghana have a fixation higher than 17.3 mg/L. Thusly, for an ordinary grown-up that hydrates a day, the supplement feasible will be 34.6 mg of calcium. When contrasted with a RDI worth of 2000 mg/day, the contextual investigation regions couldn't generally depend on drinking of water alone to meet the nourishing admission of sodium.

Potassium - Around 75% of the wells in Northern Ghana have a fixation higher than 1.2 mg/L. Subsequently, for a typical grown-up that hydrates a day, the supplement reachable will be 2.4 mg of calcium. When contrasted with a RDI worth of 3000 mg/day, the contextual investigation regions couldn't really depend on drinking of water alone to meet the healthful admission of potassium.

Fluoride - Around 75% of the wells in Northern Ghana have a fixation higher than 0.34 mg/L. Subsequently, for a typical grown-up that hydrates a day, the supplement reachable will be 0.68 mg of calcium. When contrasted with a RDI worth of 4 mg/day, neither the contextual investigation region in Northern Ghana could depend on drinking of water alone to meet the healthful admission of fluoride.

Iron - Around 75% of the wells in Northern Ghana have a fixation higher than 0.0025 mg/L. Subsequently, for a typical grown-up that hydrates a day, the supplement reachable will be 0.005 mg of calcium. When contrasted with a RDI worth of 14 mg/day, the contextual investigation regions couldn't really depend on drinking of water alone to meet the healthful admission of iron.

CASE STUDY AREA	STATISTICAL PROPERTIES	MAJOR CATIONS				MAJOR ANIONS		OTHER ELEMENTS		
		Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	SO_4 (mg/l)	Cl (mg/l)	Fe (mg/l)	F (mg/l)	As (mg/l)
GHANA	MINIMUM	4.9	1.5	6.3	0.015	0.1	0.015	0.001	0.09	0.2
	1^{ST} QUARTILE	21.78	8.3	17.275	1.2	1.58	2.18	0.0025	0.338	0.2
	MEDIAN	30.6	11.1	22.75	1.9	2.85	4.3	0.057	0.5	0.2
	3^{RD} QUARTILE	38.75	16.15	27.725	2.73	5.75	9.63	0.228	1.41	0.5

Table.3 Summary of results for the study area showing the basic statistical property of all the elements analyzed

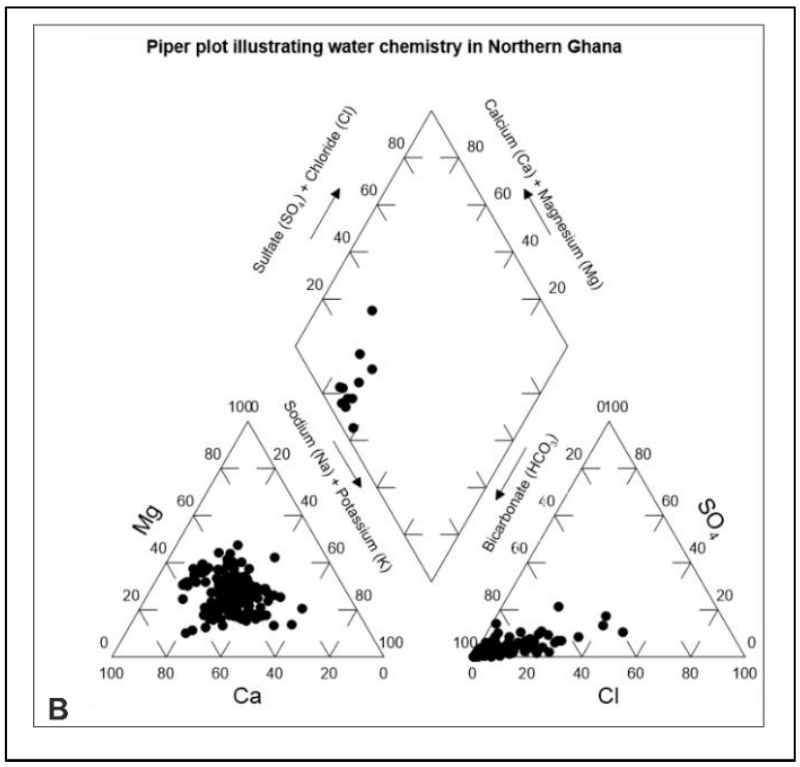

Figure 11. Northern Ghana, the piper plot

For Northern Ghana, the piper plot (Figure 11) shows the groundwater to be of Calcium-Bicarbonate (Ca-HCO_3) type. This water type is generally associated with shallow aquifers with fresh water recharge characteristics (Nazzal *et.al*., 2014), which is typical of this region.

V. CONCLUSSION

The study concludes that, the groundwater quality from Northern Ghana basement aquifer were analyzed to understand the relationship between aquifer properties and groundwater quality. The review was directed to demonstrate the speculation that; the nature of groundwater is constrained by geography and, still up in the air by the kind of spring source. Water quality information from Northern Ghana known to be portrayed by storm cellar springs were thought about, which then again, is known to be described by an alluvial spring. A portion of the components present in groundwater in the review regions were likewise contrasted with RDI values with comprehend the commitment of groundwater to dietary requirements. The aftereffect of the examination did have shown the accompanying;

i. Geology assumes a significant part in deciding the water nature of a locale. Rock-water connection in storm cellar rocks prompts groundwater with substance organization that bears mark of the source rock, which was seen on account of Northern Ghana having a Blend Calcium-Magnesium-Chloride-Sulfate water type with high convergence of sodium. This water type proposed its basaltic beginning yet in addition one which has been in touch with sodic antacid rocks at some stage in its advancement.

ii. Other factors, like hydrology, re-energize and release system may likewise assume a critical part in deciding the groundwater quality. In any case, these variables are likewise reliant upon the spring properties.

iii. Finally, the groundwater quality completed in the review region comparable to RDI, showed the review region have more centralization of supplements in calcium, magnesium, potassium and iron than Northern Ghana. In the whole outcomes it was seen that groundwater contributes simply little to a person's healthful admission day to day. Consequently, drinking of water from Northern Ghana should be expanded by food consumption for the dietary necessities of the nearby populace to be met.

REFERENCE

[1]. Arhin E, Boansi A. O, Zango M. S (2015). Trace elements distributions at Datoko-Shega artisanal mining site, northern Ghana. Environmental Geochemistry and Health. 2015; 37: 2.

[2]. Arhin E, Zango M.S (2016): Impact of Trace Elements in the Natural Environment and Public Health: A Medical Geology Perspective. Ann Public Health Res 3(4): 1051.

[3]. BGS/DPHE. (2001). *Groundwater Quality: Ghana*. [online] British Geological Survey. Available at: https://www.bgs.ac.uk/downloads/start.cfm?id=1281 [Accessed 18 Jun. 2017].

[4]. Carrier, M. A., Lefebvre, R., Racicot, J., & Asare, E. B. (2008). Northern Ghana hydrogeological assessment project. In *33rd WEDC International Conference, Accra, Ghana*.

[5]. Centeno JA, Finkelman RB, Selinus O (2016). Medical Geology: Impacts of the natural environment on Public Health. Geosciences. 2016; 6: 8.

[6]. Dapaah-Siakwan, S., & Gyau-Boakye, P. (2000). *Hydrogeologic framework and borehole yields in Ghana.* Hydrogeology Journal vol. 8, No. 4, pp. 405-416.

[7]. EPA (2005). Ghana State of Environment Report 2004, Accra: Environmental Protection Agency.

[8]. FAO (2005). Aquastat, Ghana, Food and Agriculture Organization of the United Nations, Rome.

[9]. Gill, H. E. (1969). *A ground-water reconnaissance of the Republic of Ghana, with a description of geohydrologic provinces* (No. 1757-K). US Govt. Print. Off.

[10]. Government of Ghana. (2017). *Upper East Region*. Available online: http://www.ghana.gov.gh/index.php/ about-ghana/regions/upper-east

[11]. Hoque, M. A., & Butler, A. P. (2015). Medical hydrogeology of Asian deltas: status of groundwater toxicants and nutrients, and implications for human health. *International journal of environmental research and public health*, *13*(1), 81.

[12]. Hoque, M. A., & Butler, A. P. (2016). Mineral nutrients and toxicants in Bangladesh groundwater–Do we need a holistic approach to water quality? In *Arsenic Research and Global Sustainability: Proceedings of the Sixth International Congress on Arsenic in the Environment (As2016), June 19-23, 2016, Stockholm, Sweden* (p. 416). CRC Press.

[13]. Howard, G. (2002). *Water supply surveillance: a reference manual*. WEDC, Loughborough University.

[14]. Ibrahim, H.; Yaseen, Z.M.; Scholz, M.; Ali, M.; Gad, M.; Elsayed, S.; Khadr, M.; Hussein, H.; Ibrahim, H.H.; Eid, M.H. (2023). Evaluation and prediction of groundwater quality for irrigation using an integrated water quality index, machine learning models GIS approaches: A representative case study. Water 2023, 15, 694.

[15]. International Resources Group. (2005). Progress against Desertification: Case Studies of Experience in Ghana. Washington: United States Agency for International Development.

[16]. Kesse, G. O. (1985). The mineral and rock resources of Ghana.

[17]. Kwei, C.A. (1997): *Evaluation of groundwater potential in the Northern Region of Ghana.* report for the Canadian International Development Agency, March 1997, p.66.

[18]. Liu, J.; Gao, Z.; Wang, M.; Li, Y.; Ma, Y.; Shi, M.; Zhang, H (2018). Study on the dynamic characteristics of groundwater in the valley plain of Lhasa City. Environ. Earth Sci. 2018, 77, 646.

[19]. Loh, Y.S.A.; Addai, M.O.; Fynn, O.F.; Manu, E. (2021). Characterisation and quality assessment of surface and groundwater in and around Lake Bosumtwi impact craton (Ghana). Sustain. Water Resour. Manag. 2021, 7, 81.

[20]. Loh, Y.S.A.; Akurugu, B.A.; Manu, E.; Aliou, A.S. (2020). Assessment of groundwater quality the main controls on its hydrochemistry in some Voltaian and basement aquifers, Ghana. Groundw. Sustain. Dev. 2020, 10, 100296.

[21]. Loh, Y.S.A.; Fynn, O.F.; Manu, E.; Afrifa, G.Y.; Addai, M.O.; Akurugu, B.A.;,M.(2022). surface water interactions: Application of hydrochemical and stable isotope tracers to the lake bosumtwi area in Ghana. Environ. Earth Sci. 2022, 81, 518.

[22]. Manu, E.; De Lucia, M.; Kühn, M. (2023). Hydrochemical Characterization of Surface Water and Groundwater in the Crystalline Basement Aquifer System in the Pra Basin (Ghana). Water 2023, 15, 1325. https://doi.org/10.3390/w15071325

[23]. Nwankwo, C.B; Hogue, M.A; Islam, M.A; Dewan, A (2020): Groundwater Constituents and Trace Elements in the Basement Aquifers of Africa and Sedimentary Aquifers of Asia: Medical Hydrogeology of Drinking Water Minerals and Toxicants. Earth Systems and Environment.https://doi.org/10.1007/s41748-020-00151-z

[24]. Nwankwo, C.B (2017): Disparities in groundwater quality between basement aquifers in Africa and alluvial aquifers in Asia. An unpublished M.Sc. Dissertation submitted to the School of Earth and Environmental Sciences, University of Portsmouth, United Kingdom/ Institutional Repository.

[25]. Nazzal, Y., Ahmed, I., Al-Arifi, N. S., Ghrefat, H., Zaidi, F. K., El-Waheidi, M. M., ... & Zumlot, T. (2014). A pragmatic approach to study the groundwater quality suitability for domestic and agricultural usage, Saq aquifer, northwest of Saudi Arabia. *Environmental monitoring and assessment*, *186*(8), 4655-4667.

[26]. Nude, P. M; & Arhin, E. (2009): Overbank Sediments as appropriate Geochemical Sample Media in Regional Stream Sediment Surveys for Gold Exploration in the Savannah Region of Northern Ghana. Journal of Geochemical Exploration, 103 (1), pp 50-56.

[27]. Okofo, L.B.; Anderson, N.A.; Bedu-Addo, K.; Armoo, E.A. (2021). Hydrochemical peculiarities and groundwater quality assessment of the Birimian and Tarkwaian aquifer systems in Bosome Freho District and Bekwai Municipality of the Ashanti Region, Ghana. Environ. Earth Sci. 2021, 80, 818.

[28]. Panneerselvam, B.; Ravichandran, N.; Kaliyappan, S.P.; Karuppannan, S.; Bidorn, B. (2023). Quality and Health Risk Assessment of Groundwater for Drinking and Irrigation Purpose in Semi-Arid Region of India Using Entropy Water Quality and Statistical Techniques. Water 2023, 15, 601.

[29]. Rosborg, I. (2015) Drinking Water Minerals and Mineral Balance: Importance, Health Significance, Safety Precautions; Springer International Publishing Switzerland: London, UK, p. 140.

[30]. Selinus O, Alloway B, Centeno JA, Finkelman RB, Fuge R, Lindh U (2005). Essentials of Medical Geology: impacts of the natural environment on Public Health. Elsevier academic press. 2005; 812.

[31]. Smedley, P. L., Edmunds, W. M., West, J. M., Gardner, S. J., & Pelig-Ba, K. B. (1995). Vulnerability of shallow groundwater quality due to natural geochemical environment. 2, health problems related to groundwater in the Obuasi and Bolgatanga areas, Ghana.

[32]. Smedley, P. L., Nkotagu, H., Pelig-Ba, K., MacDonald, A. M., Tyler-Whittle, R., Whitehead, E. J., & Kinniburgh, D. (2002). Fluoride in groundwater from high-fluoride areas of Ghana and Tanzania.
[33]. Tay, C.; Hayford, E.; Hodgson, I (.2017). Application of multivariate statistical technique for hydrogeochemical assessment of groundwater within the Lower Pra Basin, Ghana. Appl. Water Sci. 2017, 7, 1131–1150.
[34]. USAID/Ghana (2006). USAID/Ghana environmental threats and opportunities assessment (FAA 118/9 Assessment). Accra, Ghana
[35]. Wang, R.; Bian, J.M.; Gao, Y (2014). Research on hydrochemical spatio-temporal characteristics of groundwater quality of different aquifer systems in Songhua River Basin, eastern Songnen Plain, Northeast China. Arab. J. Geosci. 2014, 7, 5081–5092.
[36]. WHO. (2011). Guidelines for Drinking-Water Quality. (4th ed.); World Health Organisation (Ed.); World Health Organisation. Geneva: Switzerland.
[37]. Xia, C.; Liu, G.; Meng, Y.; Jiang, F. (2022). Reveal the threat of water quality risks in Yellow River Delta based on evidences from isotopic and hydrochemical analyses. Mar. Pollut. Bull. 2022, 177, 113532.
[38]. Yidana, S.M.; Banoeng-Yakubo, B.; Sakyi, P.A (2012). Identifying key processes in the hydrochemistry of a basin through the combined use of factor and regression models. J. Earth Syst. Sci. 2012, 121, 491–507
[39]. Yidana, S.M.; Yidana, A. (2010). Assessing water quality using water quality index and multivariate analysis. Environ. Earth Sci. 2010, 59, 1461–1473.
[40]. Zhang, B.; Song, X.; Zhang, Y.; Han, D.; Tang, C.; Yu, Y.; Ma, Y (2012). Hydrochemical characteristics and water quality assessment of surface water and groundwater in Songnen plain, Northeast China. Water Res. 2012, 46, 2737–2748.
[41]. Zhang, G.; Deng, W.; Yang, Y.; Salama, R (2007). Evolution study of a regional groundwater system using hydrochemistry and stable isotopes in Songnen Plain, northeast China. Hydrol. Process. Int. J. 2007, 21, 1055–1065.