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Assessment of Groundwater for Dry Season Farming in the Upper East Region of Ghana-Determining the Storage Capacity

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Abstract; Groundwater is the primary source of water for domestic, agricultural and industrial uses in many countries. Demand for potable water in northern Ghana, especially during drought has raise in a short time. The Groundwater potential within the area of study was studied using critical hydrogeological factors such as; overburden thickness, groundwater geophysics, borehole successes, pumping rate and groundwater depth. Over reliance on rain-fed agriculture can threaten food security now and centuries to come due to the irregularities of rainfall patterns. This research targeted areas of high groundwater success rate so as to minimise the gap in the computation that may be affected as a result of the dry boreholes. Sites of high Static Water Level (SWL = 44.50-22.86 m) are likely to have shallow groundwater depth while sites of (SWL = 18.91-5.74 m) may have deeper depth. The Groundwater Storage and the Usable Storage were estimated to be approximately 514.6 x 10^3 BCM and 214.8 × 10^3 BCM respectively for the aquifer basement complex of the 37 boreholes. The pumping rate showed that sufficient amount of groundwater was discharged from the boreholes; hence the exploration of groundwater as an alternative water supply for irrigation and agricultural production within the Upper East Region is completely feasible.

KEYWORDS – Ghana, Birimian, geophysics, groundwater and pumping

1.0 Introduction

Globally, irrigation is the backbone of high agricultural boost to the economies of some parts of the world. Africa will remain food insecure when measures are not put in place to protect irrigated-agriculture. The rareness of water supply for irrigation is irrefutable in many parts of the SSA countries (Forkuor *et al*., 2013). Groundwater has long been trusted as resilient source of water supply for dry-season farming. Many cities in Africa have depended on groundwater-fed system over decades; it is in this light that developed countries like China and India idealised groundwater-irrigated agriculture (Adelena, 2009). However, the colossal unseen nature of groundwater has made it underdeveloped when it comes to irrigated-agriculture, despite its enormous advantages in most countries with high groundwater potential (Shah *et al.*, 2007). Groundwater is increasingly relied upon as a source of potable water for rural populations in developing countries, but the long-term sustainable yield of these resources is not always known. Demand for potable water in northern Ghana, especially during drought, places emphasis on development of rapid and efficient well-siting techniques (Apambire, 2000).

Organizations that provide potable water have started to address water supply and quality issues.The population of northern Ghana is growing rapidly, at about 2.5% per year (Martin and Van de Giesen, 2005), and groundwater is an economically viable solution to meet demands for potable water. Reasons for developing groundwater include: ease of developing hand-pumps in remote locales; availability during drought; superior chemical and biological quality (compared with surface water sources); and relatively low price compared with methods of treating surface water. In the latter case, for instance, costs of treating water derived from surface sources is approximately twice that of groundwater for communities of less than 5000 people (Dapaah-Siakwan, Gyau-Boakye, 2000).

The Northern Section (Northern Region, Upper West and East, Northeastern) of Ghana is defined by a single rainfall pattern as a result of climatic variability compared to Southern Ghana making it favourable for irrigated-agriculture. Even in the rain-forest where precipitation is maximum irrigation is essential for short term crops during the dry period. The Upper East Region generally has a favourable groundwater potential with high concentration of fluoride and other dissolve minerals around the Bongo and Talensi districts which may not be suitable for domestic, industrial and agricultural use. This survey was conducted between June – July, 2019 by the Centre for Development Partnership and Innovations (CDPI) in partnership with the Ghana Red Cross Society (GRCS) survey team. The issues of high and low fluoride concentration may be attributed to the petrogenesis and petrography of the bedrock. This paper will take into consideration areas of high fluoride concentration in order to predict viable sites for future irrigational programs.

Underground resources can be delineated using different combination of geophysical procedures; the popularly used ones are the Electro-Magnetic Induction (EMI) and Electrical Resistivity (ER) which operates using geo-electrical principles. This methods estimates areas of high fractures, degree of weathering and areas of low resistivity was desired. The drilling method preferably used in the Upper East Region was the air rotary drilling. Sustainable exploitation of groundwater for the purpose of irrigated-agriculture is imperative since irregularities in rainfall patterns have become unpredictable. In that respect, this study brings to fore the quantification of groundwater storage capacity from 37 boreholes from selected areas in the Upper East Region in making recommendations to sites of maximum groundwater gradient that may be suitable for irrigation.

The related issues on groundwater quantity and resilience answers the question on *"Modus Operandi"* and it tendency for irrigated agriculture across the world. Shaibu and Kpiebaya, (2020); Shaibu and Kpiebaya, (2020) in a similar research in the Upper West Region discovered that the quantity of groundwater available is reasonably enough to support future irrigation activities.

2.0 MATERIALS AND METHODS

2.1 Study Area

The study area is situated in the North-Eastern corner of the country, bounded to the North by Burkina Faso in the West by the Upper West Region in the south by Northern Region and in the East by the Togo. The Upper East Region covers roughly an area of 8,842km² approximately 2.7% of the total land area of Ghana. The study area lies between longitudes 0° and 1° West and latitudes 10° 30¹N and 11°N. Administratively, the Region is divided into fifteen (15) districts, which corresponds roughly with the main tribal groups, for instance People in Talensi-Nabdam District speaks Talensi, Kasena-Nankana District speaks Kasem. The total population as at 2000 to 2010 was 1,046,545 out of which 51.6% are females and 48.4% are males. The Settlement pattern in the study area in dispersed and this has high cost of implication in the provision of water and sanitation facilities, for instance a small town water system. In most cases the youth usually migrate to the southern part of Ghana in the dry season for jobs (Wikipedia, 2020).

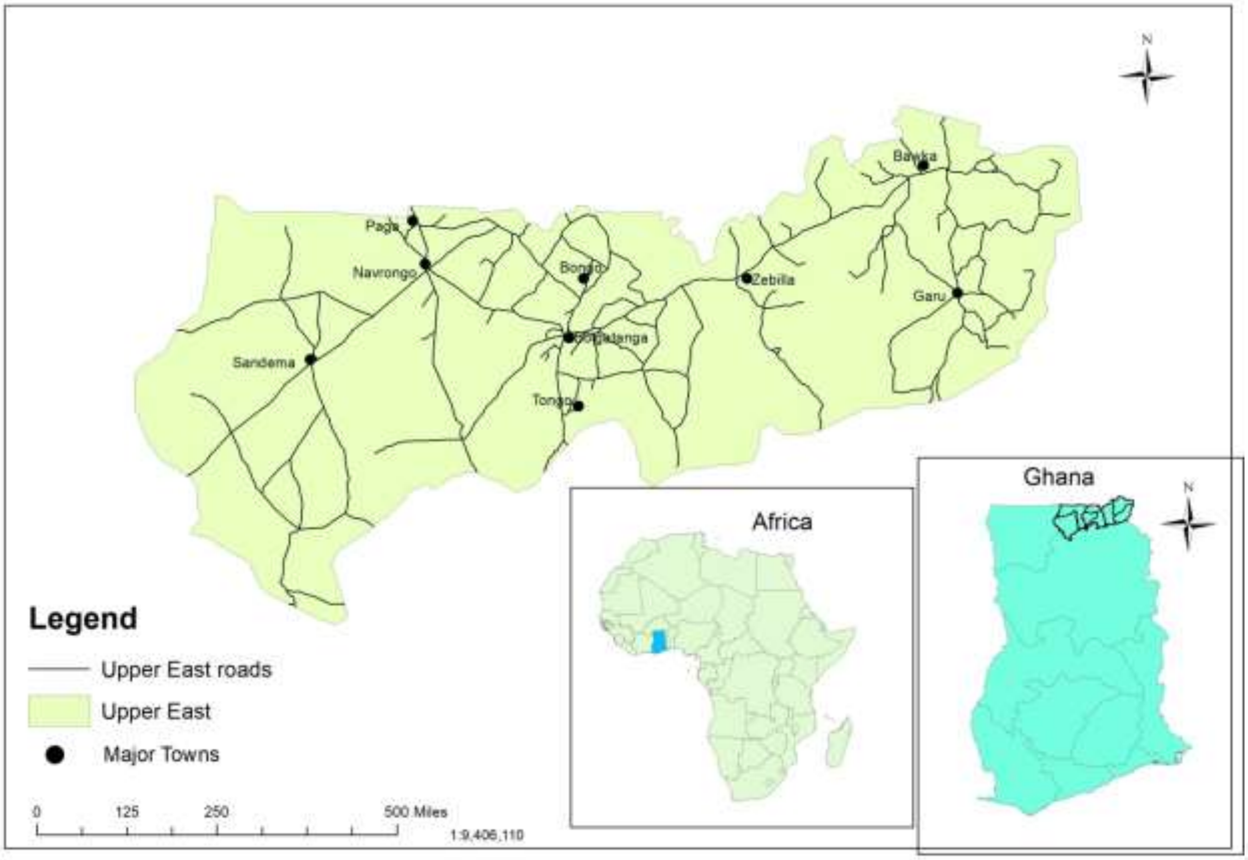

Figure 1; Detail Map of the Study Area

2.2 Geological and Hydrogeological Settings

The Upper East Region is underlain mainly with the Precambrian Base rock complex, this complexes comprises crystalline igneous and metamorphic rock which make up about 90% of the Region. However, the main units include the granitic formation which covers about 65% of the area, while the Birimian rock formation is the second largest in terms of stress in the area cover about 25%. Rocks of the Birimian series consist of phyllites, schist, shales, siltstones and greywackes. Also, there are geological units that are of less stress, some of which include; Tarkwaian formation, Voltaian and Dahomeyan. Leptosols, Cambisols and Lixisols are most dominant soils in the Upper East area. The main hydrogeological structures are; sedimentary fractured, sedimentary intergranular-fractures and the basement aquifer. Groundwater occurrence in the study area is largely characterized by (ie the availability of faults, fractures and joints), regolith thickness, nature of topography and vegetation. Research has showed that the aquifer system in the southern part of the study area is of low productivity compared to the upper half of the region (Acheampong and Hess, 1998). This conclusion can be attributed to the fact that the granities and Birimain in the Upper half of the study area has a drilling success rate of 75 – 80% whereas the Southern part is covered with the metamorphic rocks with success rate of 65%, suggesting that the overall drilling success rate is about 70%

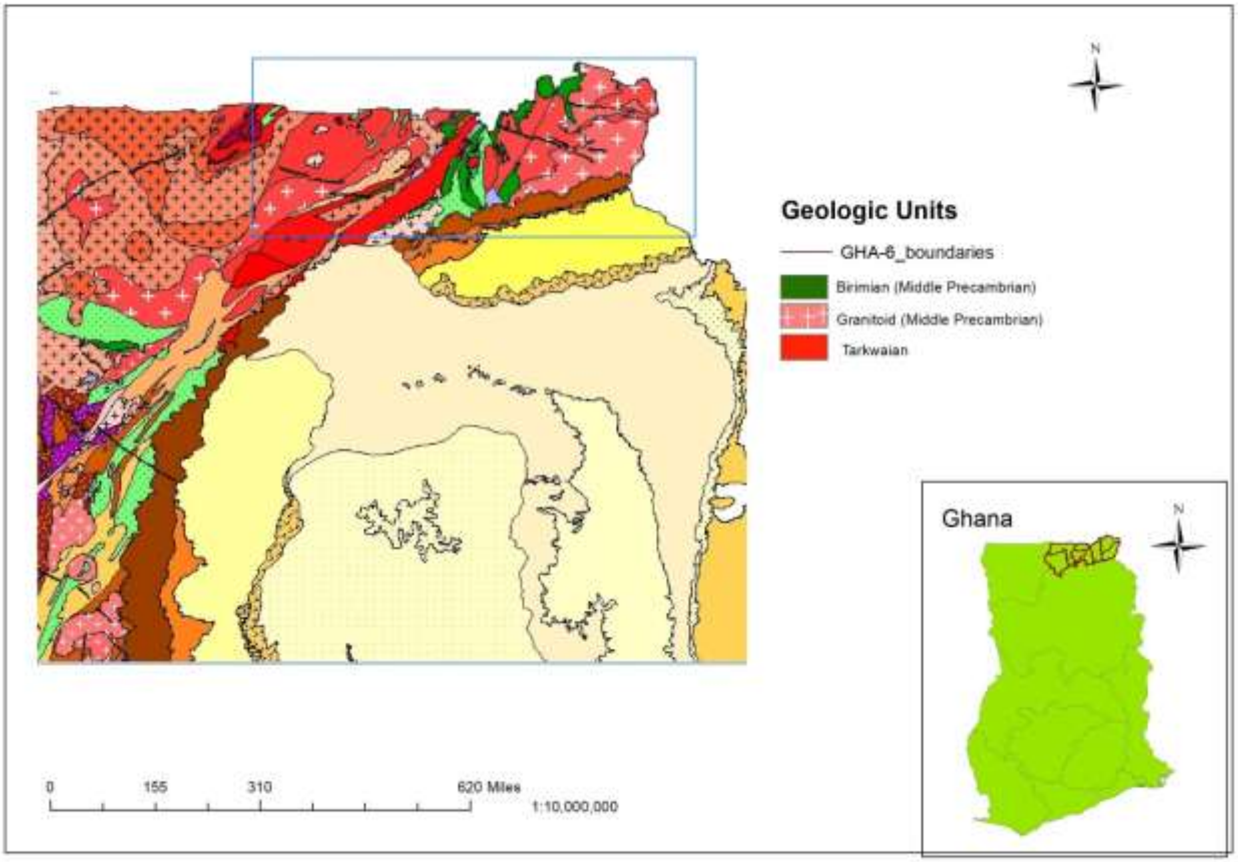

Figure 2; Geological Map of the Study Area

2.3 Methodology

The four factors that were considered in the study of groundwater as a better alternative of water supply for agricultural activities. These factors include; groundwater geophysics, borehole loggings, pumping rate of boreholes and SWL of boreholes. The methodology used for this paper includes; Vertical Electrical Sounding (VES) and Schlumberger profiling array for the groundwater geophysics, air-drilled boreholes and Constant Rate Test (CRT-6 hours) and Recovery Test for the pumping test.

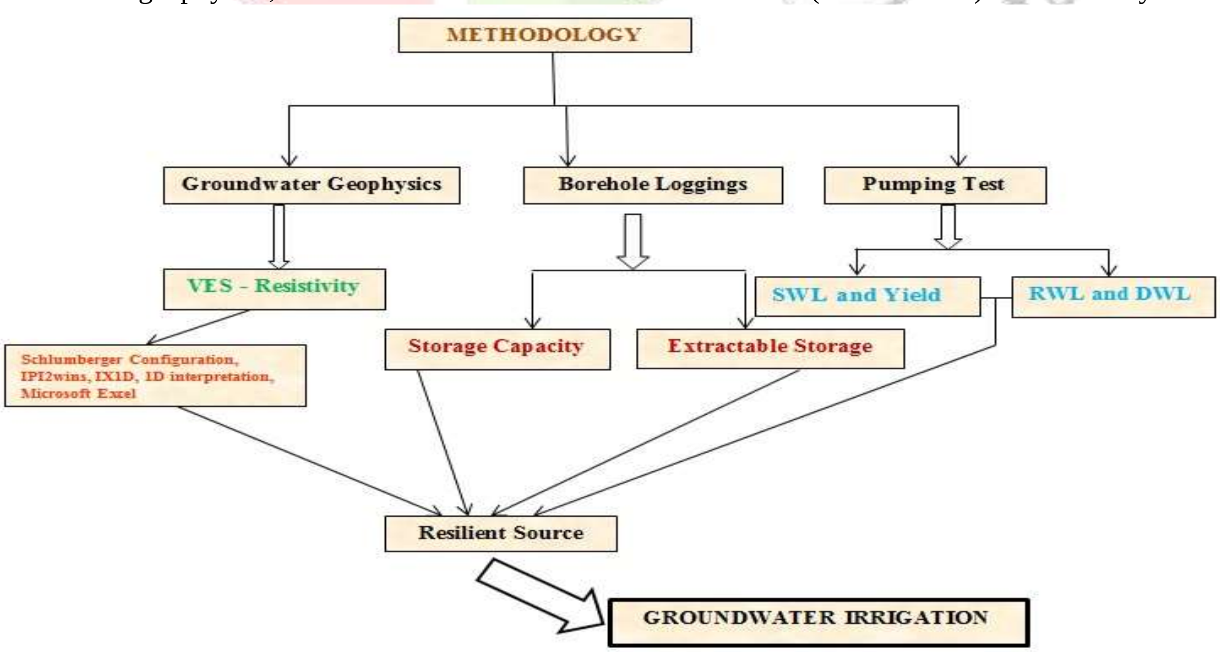

Figure 3; Theoretical Framework of the Methodology

2.3.1 Groundwater Geophysics

Some of the geophysical devices used to measure resistivity include ABEM Terameter SAS 400, 800, 1000, 4000; but SAS 1000 was used for the study because of its depth of penetration. The schlumberger configuration array was considered, because the investigation of lithology was important to this study and also, groundwater delineation as well. Maximum current electrode spacing was about 400 m. Station spacing was 10 m with a probing depth of 25 m – 35 m; also, the mean transverse length was about 800 m.

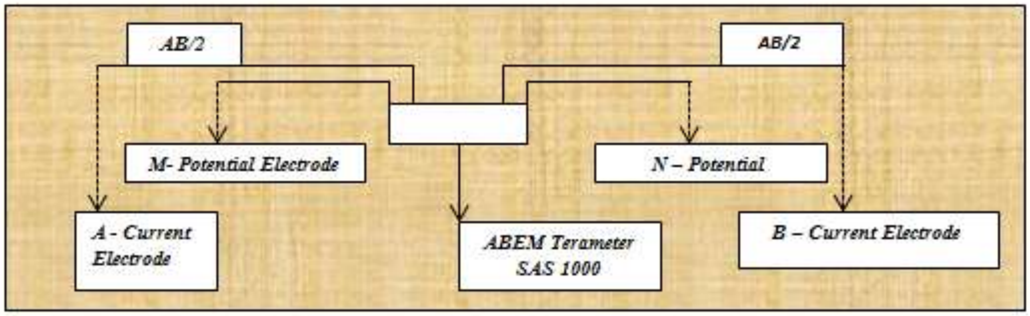

Figure 4; Schlumberger Configuration

$$\rho = \left\{ \frac{\frac{(AB)^2}{2} - \frac{(MN)^2}{2}}{MN} \right\} \Delta \frac{V}{I} \qquad (1)$$

MN = distance between potential electrodes (m), AB = distance between current electrodes (m), ΔV = Potential Difference (volts) and I = applied current.

Figure 5; Geophysical survey (on field)

2.3.2 Borehole Loggings

Over 37 borehole loggings were collected in the study area, but data from the study area suggested that there are more than 650 boreholes that exist functionally. Information on the loggings include; drilling penetration rate, depth of water-surface, lithological units, yield and airlift-yield, materials used for the development. These data gathered aided in the computation of groundwater capacity in the regolith. Air - drilling was the prefer drilling method, that is because it is widely use within the Upper East Region of Ghana (crystalline formations).

2.3.3 Pumping rate

The Constant Rate Test was used for continuous discharge of water with duration from 6 to 9 hours whereas the Recovery Test lasted for 3 hours. This consideration was to avoid large discharges in barren formations; areas of marginal wells were pumped between 10 to 13Lpm. The pumping test kits used 1.5 hp submersible pump, diesel generator, PE pipe of 100 m and a water level indicator.

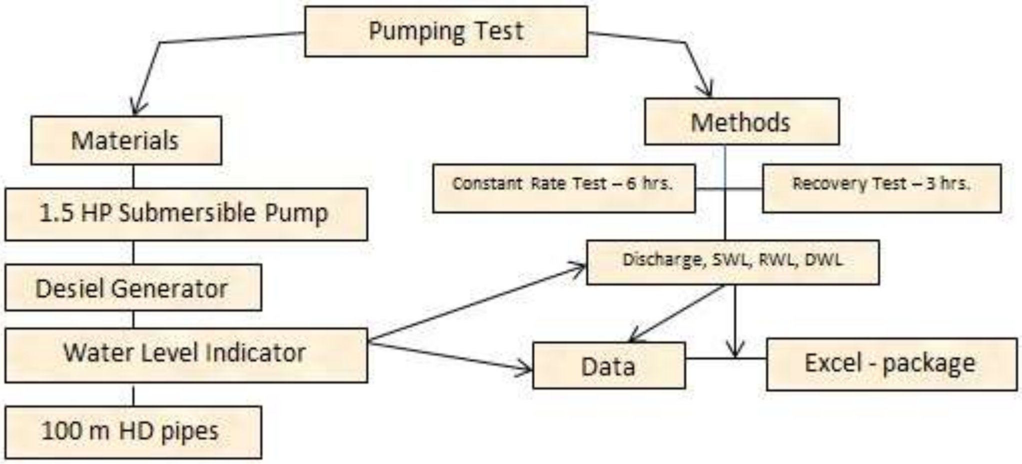

Figure 6; Materials and Methods for the pumping test

$$Borehole\ discharge = dq/dt\ \ (LPM) \qquad (2)$$

$$where \quad dq = is\ the\ drawdown \quad dt = time$$

3.0 Findings and Discussions

3.1 Geophysics and Geology

The distribution of the water-points within the study area is relatively even across different districts, this is to investigate geology, this determines the groundwater condition and environment. The Vertical Electrical Sounding (VES) data was gathered with the help of a resistivity meter SAS 1000 with AB/2 distance of 5m interval and MN distance increasing progressively. The table 1 shows the summary of the water-points with resistivity in the study area.

Table 1. Summary of VES Results and Lithological description in the Upper East region

Locations	VES points	Range (Ohm.m)	Mean (Ohm.m)	Remarks
Zebilla	21	142.44 – 47.32	94.88	Sand-clay, meta-sedimentary formation
Garu	8	103.12 – 41.97	72.545	Lateritic-clay, meta-sediments
Tempane	3	707.21 – 92.50	399.855	Laterite, clay, granitoids
Kasena Nakana	5	83.31 – 6.89	45.10	Birimian Sedimentary rocks, Clay

The Upper East Region falls under the Pre-cambrian formation popularly known as the Birimian, this geological formation is the makeup of meta-volcanics rocks, meta-sedimentary rocks, basaltic flows and metamorphosed rocks (GGS, 2010). The Tempane area is underlain with granitoids as its base-rock of quartz-boitite mineralisation, this kind of rock undergoes shear stressing resulting in faults and fractures within it. These fractures represents footprints of high groundwater occurrence, the VES values for the Garu locality depict meta-sedimentary formation; this can be evident from the 8 drill logs of boreholes around Garu Assembly. The drill log shows a formation of metamorphic sediments which accounts for the VES values of 103.12 ohm.m – 41.97 ohm.m. The VES values of 142.44 ohm.m – 47.32 ohm.m around the Zebilla market show a define geology of the Birimian; this area is predominantly of meta-volcanics and meta-sediments. The regolith has an average thickness of 18m with laterites and dry clay. The VES values ranging between 707.21 ohm.m – 92.50 ohm.m depicts crystalline formation with low groundwater success rate. Areas around the Tempane JHS exhibited a formation of meta-sedimentary, these are formed as a result of compaction and cementation of sediments over time accounting for the average VES value of 399.855 ohm.m. The VES values within the Kasena Nakana are definitive of the underlying geology (Birimian sedimentary rocks). Rock-cut around Tono, Balobia and Paga shows visible phyllite and schist which reflects the VES values ranging from 83.31 ohmm – 6.89 ohmm. The Birimian formation has an aquifer depth ranging between 6 m to 120 m (Gyau-Boakye and Dapaah-Siakwan, 2000).

3.2 Spatial variation of groundwater resistivity

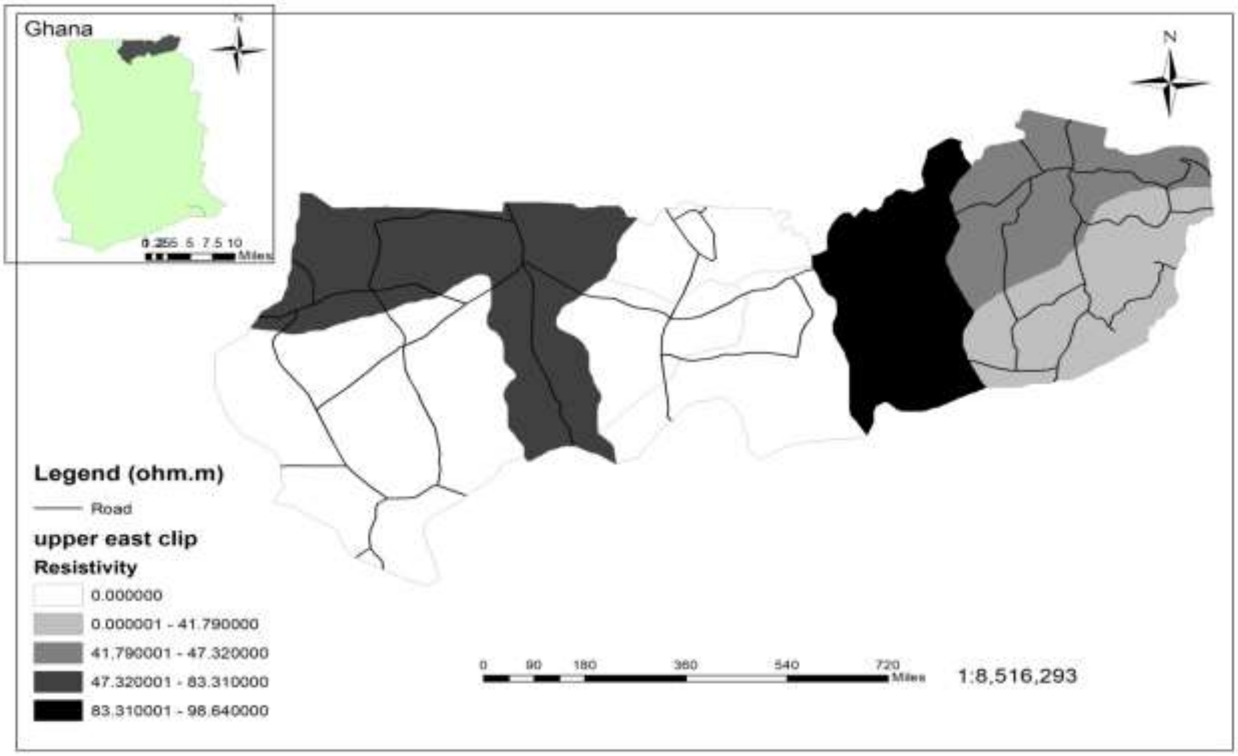

Figure 7; Spatial variation of VES

The Vertical Electrical Sounding (VES) is one of the common geophysical techniques in the search of groundwater. The essence for the Schlumberger configuration was to study the lithology as well as delineate groundwater zones. Areas of low resistivity were preferred as drilling point per this study, the groundwater resistivity values ranges from 41.79 ohm.m to 98.64 ohm.m with an average saturated depth of 12 m. Finding from a work carried out in Shalateen area around the Red Sea showed a groundwater resistivity values ranging from 38.6 ohm.m – 98.4 ohm.m and depth ranging from 1.31 m – 19.0 m (Mohamaden and Ehab, 2017. Figure 5 also represents the distribution of resistivity values within the study area as well as its relation to geology

3.3 Boreholes successes (Rate)

A numbering of thirty-seven (37) successful boreholes were considered in this research, they were drilled in both the lower and the middle Birimian. Twenty-one of the boreholes were drilled around the Zebilla area with a 99% success rate while Eight (8) of the boreholes were drilled around the Garu area with a success rate of 99%. Also, three (3) of the boreholes were drilled around the Tempane areas with a success rate of 90%. Finally, five (5) of the boreholes were drilled in the Kasena Nakana District with a success rate of 99%. It had a combine success of 97% which is more than the SSA regional average of 93% (Carter and Bevan, 2008). The 97% success rate can be authenticated by computing the groundwater storage capacity and Usable storage using the Schoeller equation (i.e Eqn 3a and 3b)

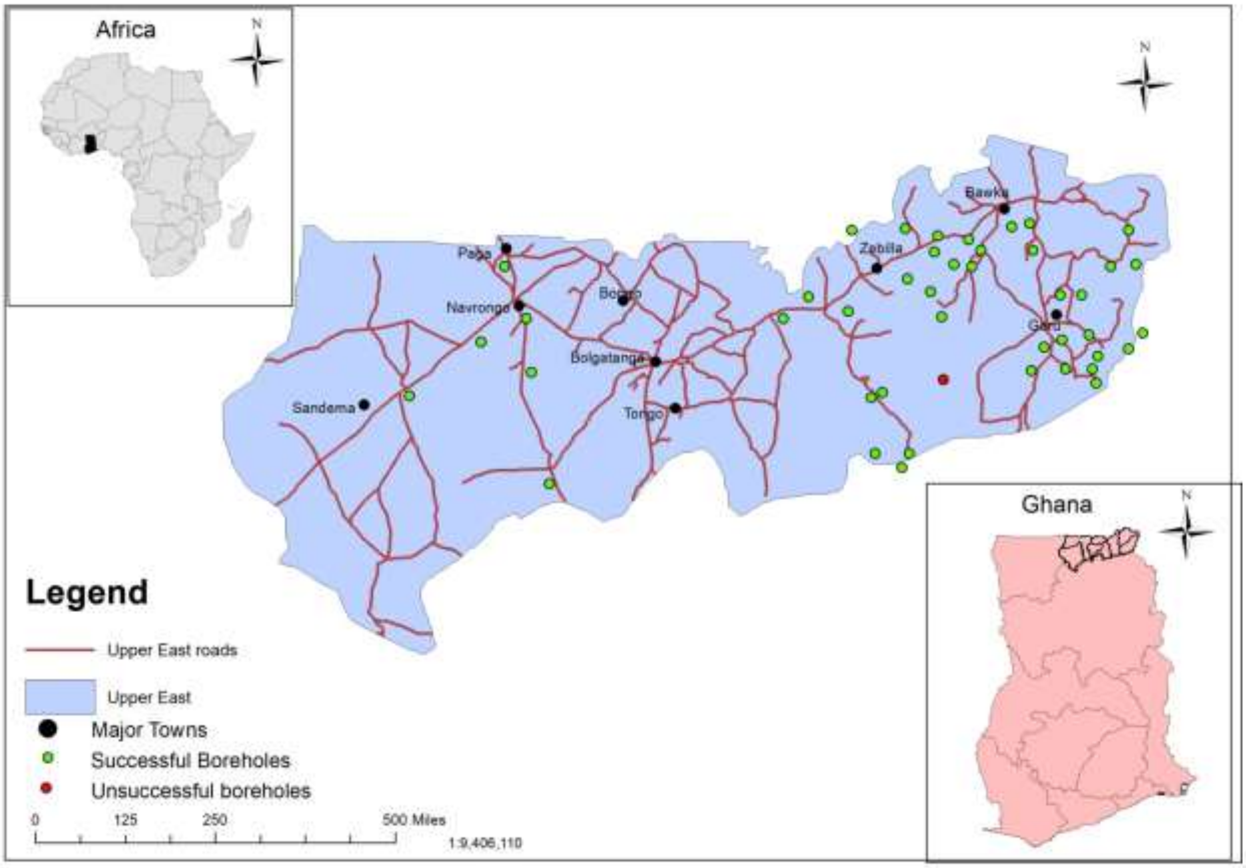

Figure 8; Borehole Location Map

$$Q_s = (C \ldots.\%) \times E_p \times D \times A \qquad 3a$$

$Where\ (Q_s)\ is\ The\ Total\ Groundwater\ Storage, (C \ldots.\%) = Groundwater\ Coverage, (E_p) = Effective\ Porosity, (D) = Saturated\ Depth, \quad (A)\ Extent\ of\ Study\ Area$

But Porosity is the measure of the void space of a rock or unconsolidated material. It can be express as Porosity $(E_p) = V_v/V_t$, where V_v is the void volume and V_t is the total volume of unconsolidated material (Bear, 1979).

$$Q_e = (C \ldots.\%) \times S_y \times D \times A \qquad 3b$$

$Where\ (Q_e)\ is\ The\ Usable\ Groundwater\ Amount, (C \ldots.\%) = Groundwater\ Coverage, (S_y) = Specific\ Yield, (D) = Saturated\ Depth, \quad (A)\ Extent\ of\ Study\ Area$

Where, $S_y = {}^{V_{wd}}/_{V_t}$ *, Where* V_{wd} *is the volume of water drained and* V_T *is the total rock or material volume (Bear, 1979).*

Table 2. Summary of Borehole Results from the Upper East Region

Parameters	Zebilla	Garu	Tempa ne	Kasena Nakana	Mean values
Weathering Front (H) m	31.5	36.5	26.5	17.5	28.00
Depth to water-strike (h) m	22.83	14.91	17.81	8.45	16.00
Depth of Saturation (D=H-h) m	8.67	21.59	8.69	9.05	12.00
Total number of boreholes drilled (T)	21	8	3	5	37
Total number of successful boreholes (S)	21	8	2	5	36
Total number of unsuccessful boreholes (U)	0	0	1	0	1
Groundwater Coverage (C….%) = S/T	0.99	0.99	0.90	0.99	0.97

Equation 3a and 3b was used to quantify the groundwater storage and Usable storage respectively; this was systematically done using the data generated from the drill logs and also the pumping test. Taking, Specific yield and interconnected-pores to be 2% and 5% respectively (Asomaning, 1993 and Acworth, 1987) for an area of 8,842km². The Groundwater Storage and Usable Storage were estimated to be approximately 514.6 x 10^3 BCM and 214.8 × 10^3 BCM respectively. A similar research was carried out in the Bawku East District with an extend area of 1166.45 km² and a saturated depth of 13.7 m considering same assumptions; the storage capacity was found to be 799.12 × 10^6m³ while the Usable storage was 319.61 × 10^6m³ for 760 boreholes (Zango *et al.*, 2014). Also, in a similar study in the Upper West and East Region the storage and Usable capacity was for to be 134.9 × 10^3 Km³ and 53.23 × 10^3 Km³ for 35 high yielding boreholes (Shaibu and Kpiebaya, 2020; Shaibu and Kpiebaya). The Usable storage is the quantity that can be drawn legally without posing any threats to the aquifer. These values reflect only areas of high groundwater potential; this is to make these areas more viable for the implementation of groundwater irrigation.

3.4 The Pumping Test (Rate)

The pumping test results shows that a substantial amount of water was pumped out from the wells, the discharges suggests there is reasonably high amount of groundwater that may be suitable for future irrigation projects (Shaibu and Kpiebaya, 2020; Zango *et al.*, 2014; Shaibu and Kpiebaya. 2020).

Table 3. Summary of Pumping test results for the Upper East Regions.

		Borehole depth (m)	Borehole Discharge (LPM)	SWL
Regions	**Boreholes Analyzed**	**Range**	**Range**	**Range**
Zebilla	21	85 – 55	290 – 110	22.58 – 12.60
Garu	8	80 – 65	230 – 84	21.45 – 16.89
Tempane	3	120 – 75	120 – 7	44.50 - 22.86
Kasena Nakana	5	75 – 40	255 – 85	18.91 – 5.74

From table 3 the values for the discharge range within Upper east shows there is enough groundwater to support the idea of using groundwater for irrigated agriculture, discharges of 290 LPM and 230 LPM are correspondingly high. Communities around the Zebilla, Navrongo and Garu had an average airlift yield of 320 LPM. The Static water level (SWL) shows areas of shallow and deep groundwater resources (Forkuor *et al.*, 2013). The meta-sedimentary formation would have moderate groundwater depth while areas around Garu will probably have deeper groundwater depth within the research area.

3.5 Spatial distribution of borehole yield (Lpm)

The necessity of Figure 5 is to show areas of high to low yield and its variation on a map, some of the areas were not assessed and hence no yield values were assigned. The map also reflects areas of high groundwater potential relating to the performance of the boreholes. Forkour *et al.* (2013) conducted a research to map groundwater potential areas using GIS and Remote sensing technique (typically showed in Figure 7). Finding from his work showed that Garu, Zebilla, Bawku areas has enormous potential of groundwater comparing to the present study in Figure 8.

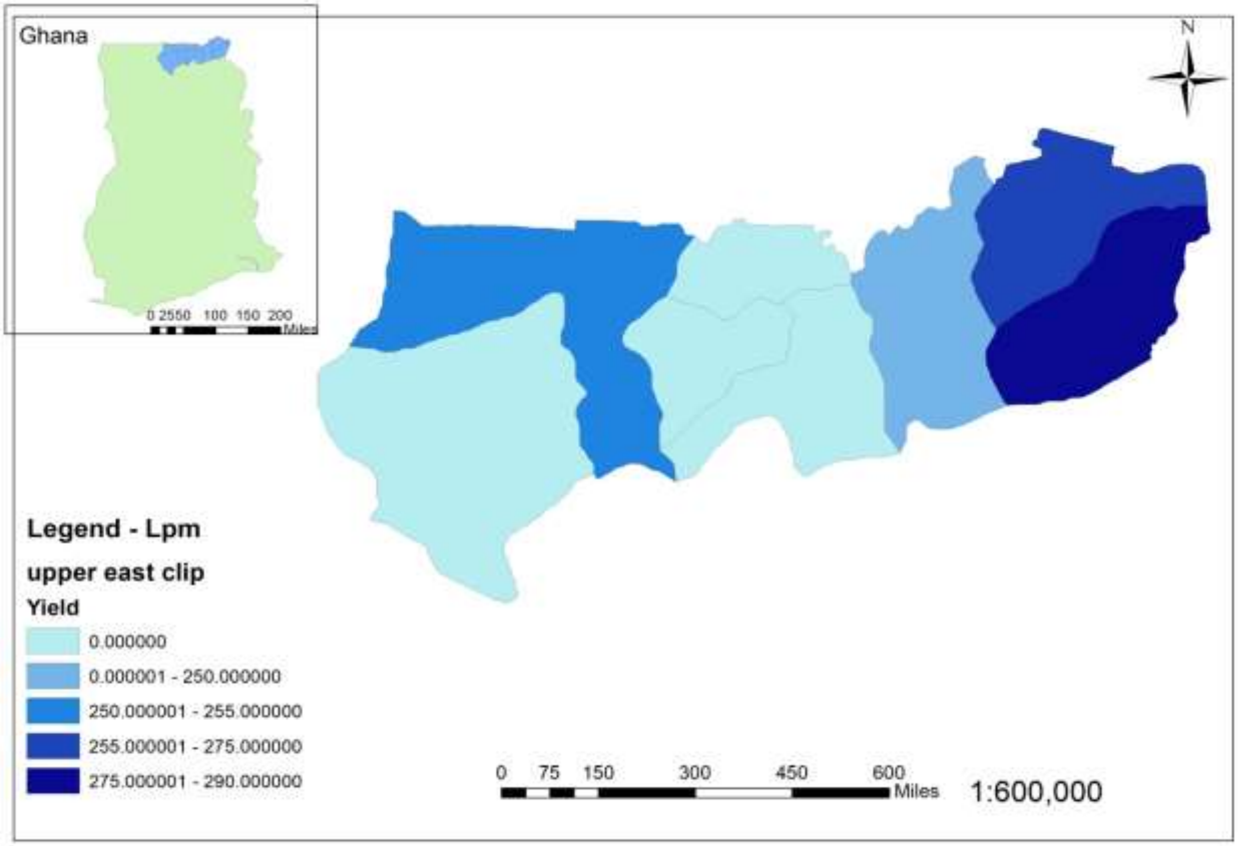

Figure 9; Spatial distribution of borehole yield

3.6 Areas of favourable groundwater Potential

The map shows areas of high groundwater potential, the demarcated area (Northern Eastern Corner of the Map) is the area of focus (Forkour *et al.*, 2013). In the future where the idea is to be manifested this map can serve as a guiding block. In the Upper East Region areas around Zebilla, Bawku, Garu, Navrongo and some few areas in Bolagatanga are promising sites that may be suitable and favourable for irrigated agricultural activities. Areas within the Bongo and Talensi districts have to review extensively in terms on fluoride concentration which may cause adverse effects on agriculture.

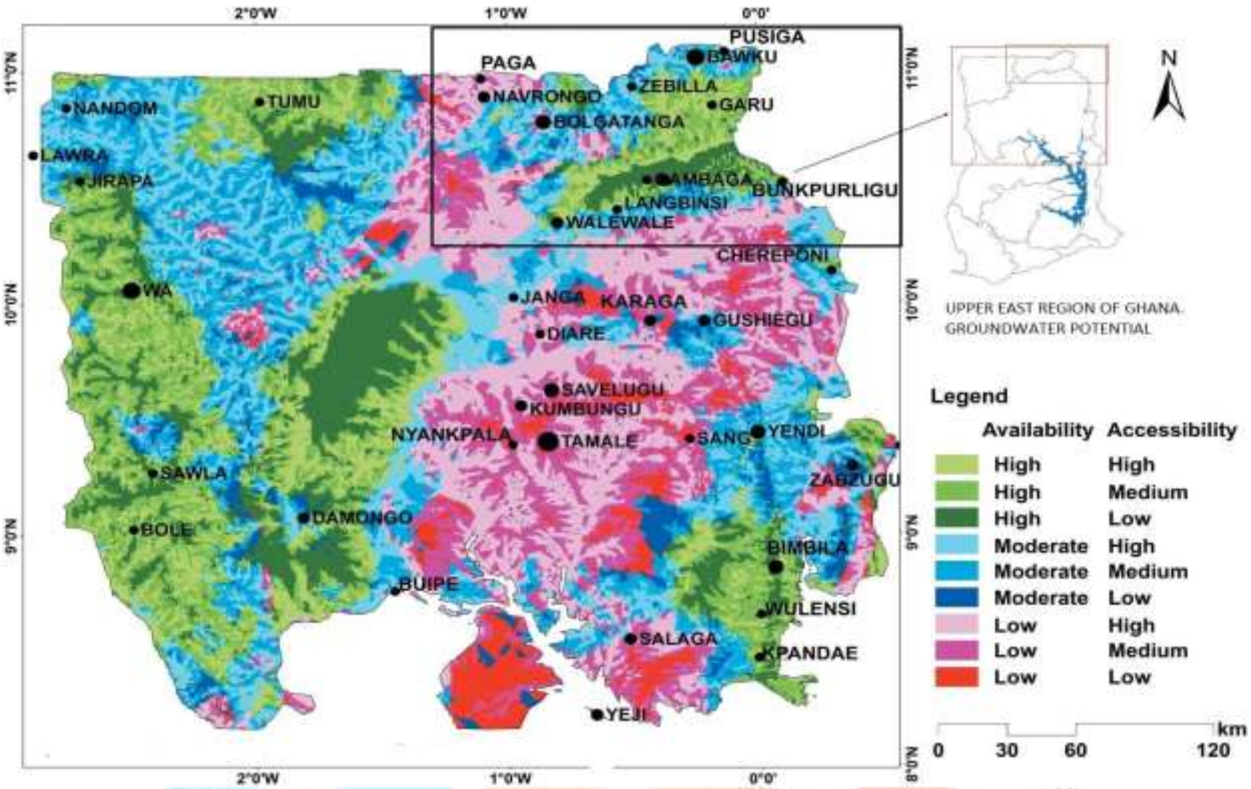

Figure 10: Areas of High Groundwater Potential (Adapted from Forkuor *et al.*, 2013).

3.7 Significance to Agriculture

Mdemu *et al.,* (2010) noticed in his research that the economic profits farmers gets from the practice of groundwater-irrigation in the dry season is substantially high. In North Africa; Algeria and Libya has the largest irrigation schemes in Africa with groundwater as the main source of supply. Thus, it is imminent to develop groundwater resources for the purpose of dry season farming. However, studies into the feasibility of the practice of groundwater irrigation are inadequate. Many organizations have put in efforts in irrigating some lands in the research area using groundwater as the source of water supply. The results from these schemes were unsatisfactory due lack knowledge to set up these schemes considering the source of water supply. The merits from this research are measures placed in establishing a solid knowledge-based background in recommending sites for possible future projects. Thus, the prediction of viable sites of high groundwater potential is important, and will inform stakeholders on fruitful sites that require immediate attention regarding groundwater exploration (i.e. areas of high groundwater reserves). It will also aid organization to pick sites that would be more suitable for irrigation taking into accounts the geology (soil-nutrients) and water source. For instance, farmers around Zebilla, Bawku, Garu and Navrongo areas irrigate relatively small areas of land during the dry-season, and hence lack the financial strength to irrigate on large scale basis sourcing water from Underground reserves. In this situation sites of high-moderate potential may be viable sites to irrigate, while farms with enough financial capability can explore deeper.

4.0 Conclusion

The data was collected from recent sited and drilled boreholes within Febuary – December 2017 and January – May 2019, it was analyzed using both qualitative and quantitative methods to estimate and predict viable sites for future groundwater-irrigated agriculture. The VES results showed that the Upper East Region is underlain with the Birimian rocks which comprises of Metamorphic sediments (Phyllite, Slate, Schist), and Meta-Volcanic (granitoids, gneiss) while the overburden has an average thickness of 18m which is made up of laterite, clay and weathered parts of the parent rock. The Groundwater Storage and the Usable Groundwater Storage in the Area of Study were estimated to be approximately 514.6 x 10^3 BCM and 214.8 × 10^3 BCM respectively. The pumping rate showed that large amount of groundwater discharged from the boreholes, hence the exploration of groundwater as a better alternative of water supply for irrigation and agricultural production within the Upper East region is completely feasible.

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