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GIS Aided Prospect Siting of Boreholes for Maximum Yield

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Abstract— *Groundwater contributes significantly to total annual water supply. Overexploitation has depleted groundwater availability at some places. Assessing the potential zone of groundwater recharge is extremely important for the protection of water quality and the management of groundwater systems. Groundwater potential zones are demarked with the help of Remote Sensing and Geographic Information System (GIS) techniques. Preliminary results indicate a high correlation between drilling success and proximity to lineaments and drainage lines where water 'pass' underground. 64 boreholes and wells were investigated. 40.6% were non-functional or dried up due to several reasons but chiefly, due to poor siting away from drainage lines in which case the water table drops during the dry season. 59.4% were functioning. 58% were found to be poorly sited away from drainage lines and lineaments. 68% of this were non-functional confirming the need for unit drainage maps to aid siting water wells and boreholes within communities. 45% of all wells and boreholes are yielding less than they ought to yield. These figures go to confirm the need to use Remote Sensing Techniques and GIS for Community Drainage Maps to aid drillers and community folks in siting wells and boreholes for maximum yield.*

Keywords— *Remote sensing, GIS, Groundwater, Community Drainage Map, Drainage Density, Lineament Density*.

I. INTRODUCTION

Globally, about 663 million people still remain without access to improved sources of water. 1.8 million has no access to any form of improved sources. The majority are in Asia (19%) and sub-Saharan Africa (38%) (WHO/UNICEF, 2015). People in developing countries especially children below five years die every year from diseases associated with lack of access to safe drinking water, (WHO 2015). Groundwater is a valuable natural resource which supports human health, economic development and ecological diversity. Due to its several inherent qualities, it has become an immensely important and dependable source of water supply. In Ghana, 62% - 71% of people in per-urban and rural communities rely on groundwater (Obiri-Danso et al., 2009) as their main source of drinking water. Increasing access to groundwater is a high priority for sub-Saharan Africa. Reducing borehole drilling costs in sub-Saharan Africa must be a high priority, if the Millennium Development Goals (MDGs) or national water supply coverage targets are to be met. Even small savings could extend services to many millions of people across the continent, (Carter et. al., 2006). An area of high drainage density also increases surface runoff more than a low drainage density area. Surface water bodies like rivers, ponds, etc., can act as recharge zones (Murugesan B. et al., 2012).

Factors that influence the siting of boreholes but are often neglected by drillers due to demographic and geographic constraints from clients mainly include;

Topography: A preferred site would be on level ground in the middle of a plain. This is not always possible. The worst location would be on the top of a steep narrow ridge. The water table would commonly follow the land surface. While valley bottoms or depressions where water accumulates after rains are generally the best places to drill, (Dijon, 1981).

Drainage Patterns: In Fig. 1 six types of drainage patterns are shown. Trellis and rectangular drainage develop where dipping, fractured sedimentary rocks are present; these are the most favourable areas for high yield aquifers (Selby, 1985). Contorted drainage develops over folded rocks. Water bearing tension fractures and gaps between layers of differing hardness sometimes develop near the top of folds. Angular drainage typically develops over volcanic or intrusive (granitic) domes, with streams flowing along water bearing fracture zones. Dendritic or branching patterns with a large number of tributaries are typical of drainage in areas of impermeable crystalline rock such as gneiss. Parallel drainage patterns may develop in areas with linear water bearing structures such as faults and dikes.

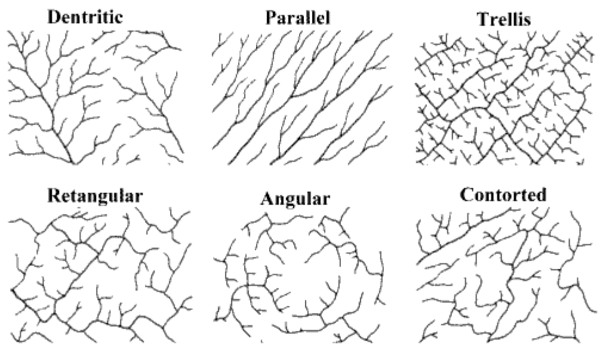

Fig. 1. Drainage patterns. Source: Selby, 1985.

As the demand for groundwater grows and the more obvious aquifers and target features become increasingly exploited, it can be expected that further development will have to consider alternative targets for significant savings in exploration and drilling costs if success rates could be improved. This study concentrates on assessing the yield capacity of existing boreholes against their siting away from

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drainage lines or, and lineaments, in which case they will be out of potential zones. This groundwater potential information will be useful for effective identification of suitable siting locations for maximum extraction of water.

The Mangu and Kambali are fast growing communities, and the increasing rate of population growth give rise to demand for food, increased urbanization and high standards of living which contribute to the need for water supply. Following the inability of government at various levels to provide portable, accessible, and quality water, citizens have resorted to providing private borehole water for domestic and agricultural usage. Currently groundwater is gaining more attention due to drought problem, rural water supply, irrigation project and low cost of development. Despite the extensive research and technological advancement, the study of groundwater has remained riskier, as there is no direct method to facilitate observation of water below the surface. Its presence or absence can only be inferred indirectly by studying the geological and surface parameters, (M.L. Waikar and Aditya P. Nilawar, 2014).

The indiscriminate siting of these boreholes without recourse to future development and other environmental considerations poses a big danger to the communities. This multiplicity of borehole water facilities also undermines the recharge capacity of underground water causing most wells to dry up. Most communities complain about less water or no water in boreholes and wells, which are then abandoned and new ones sunk. The result is a cyclic activity that tends to destroy the environment and weaken the stability of the earth within the communities. The rate of dried up wells have increased in recent times due to changing climate within the Upper West Region, which experience lots of flash floods. Thus, rate of infiltration is decreasing as the changing climate favour high intensity short duration rainfall, (Neelin, 2011).

According to Egwuonwu et al., (2012) and the Council for Geosciences, South Africa (2006), moisture changes lead to swelling and shrinkage of clays, and affect shallow boreholes. It is reported that a borehole at latitude 8°19ˡ53.10ˡˡE, longitude of 9°35ˡ46.91ˡˡN, drilled in 2005 to a depth of 42m, had a recorded yield of 15litre/min, way above the minimum guideline value for a successful borehole, (KSWB, 2006). Further studies reveal that the profile where the borehole is located has an aquifer with thickness of approximately 60m. Thus, wells and boreholes below a depth of 30m are likely to fail sooner than later irrespective of where it is sited. Preliminary studies indicated that most wells within the households fall below this minimum depth.

It is the suggestion of this study that unit (community) drainage maps can help drillers site wells and boreholes to achieve maximize yield and be sustained. These potential zones when made accessible to both customers and drillers will reduce exploration costs, the ultimate establishment costs per successful water point, and the cost of the water are dramatically reduced compared to conventional methods due to greatly improved success rates and significantly higher yields. Water scarcity is a serious problem in the area and most rely on hand-dug wells and boreholes. Groundwater is a preferred water option because of its generally availability even in drought situations and its relatively good quality. The location of high yielding boreholes may also assist in identifying targets that are potentially high yielding.

II. Objectives

The main objective of the research is to advocate the use of GIS and Remote Sensing Techniques in aiding the siting of boreholes and wells for maximum yield. Hereto it will be achieved by the following specific objectives;

- identify the primary causes of borehole failure within the study area
- identification of spatial location of water point facilities using hand-held Garmin 60 receiver.
- determine proximity of boreholes to geological structures and their yield
- provide, from remote sensing data, information on drainage network

The corresponding analysis will provide the necessary information and underscore the potential threat of the continual indiscriminate siting of these facilities to our environment.

III. Methodology

Study Area: Wa town, the capital of the Upper West Region is in the southern part of the Sahel, the semi-arid area south of the Sahara. Average annual rainfall is around 879 millimetres (34.6 in), almost all of which occurs between May and October. Following the May–October rainy season is a cool dry period called the Harmattan when a steady, often dusty, north wind blows from the Sahara. The hottest period of the year is in February and March when daytime temperatures often reach 40°C (103°F). It has a landmass of about 1,078km², which lies between latitudes 9º 55"N and 10º 25"N and longitude 1º 10"W and 2º 5"W. The population of the municipality according to 2010 population and housing census stands at 107,214 with 52,996 males and 54,218 females. Mangu and Kambali, together have an estimated population of 21,442 which is about 20% of the Wa Municipal population (GSS, 2010). It has a Birimian subgroup as the geological material of bedrock and ordinarily would support success in wells and boreholes. There exist underlain fractured bedrock aquifers where success rates and borehole yields have been historically low, yet high yielding holes are present suggesting that suitable hydrogeological target features do exist as suggested in Fig. 2. Fig. 3 is the study area.

Materials and Method: Geophysical investigations and field proofing investigations are required to identify target lineaments and to pinpoint the lineaments in the field using observation. Twenty-three boreholes and forty-one wells were investigated in order to determine the possible causes of borehole failure and the following variables were analyzed for each borehole;

- Initial recorded yield of borehole and Borehole depth.
- Season during which drilling took place.
- The recorded static water level of the area when the borehole was drilled.

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Initially the main problem was to locate topographic maps covering the whole study area, to have a uniform topographic coverage. The field team unfortunately had only the district topographic map at a scale of 1: 2500, covering scattered areas. This was not very helpful so the field team had to depend on a guide within the communities. Hand held Garmin GPS receiver was used to pick waypoints of these facilities. No records exist for the depth of wells so a lead was tied to a nylon thread and dropped down the wells and measured against a Tape measure to obtain the respective depths. Abandoned and filled (with waste) wells were not considered. However, both functional and non-functional facilities were considered.

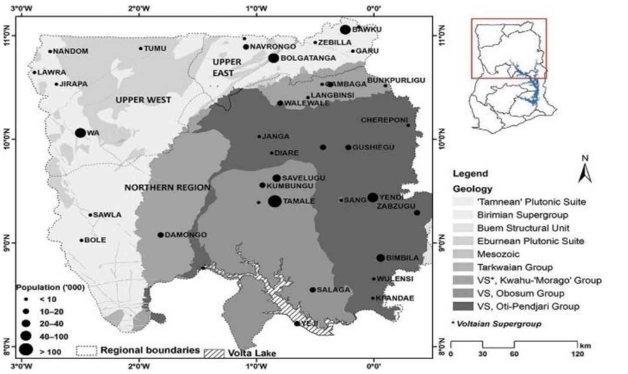

Fig. 2. Map bedrock type in Northern Ghana. Source: Forkuor et. al., 2013.

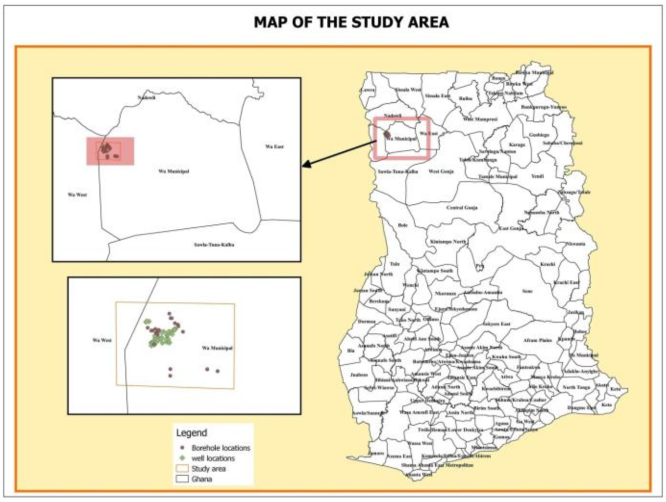

Fig. 3. Map of study area.

A satellite image of the Municipality was clipped out of a regional image from Landsat. Then having plotted the picked boundary points of the communities, the section was also clipped out in ArcGIS 10.1. Same was done with a Digital Elevation Model of the region to obtain that for the study area. Drainage and Lineament maps were produced from the DEM using ArcGIS 10.1. A point layer was produced and then superimposed on the drainage and map to determine which wells or boreholes fall away from the drainage lines. This information was compared to the raw information obtained on the dried-up facilities and yield capacity of these facilities. The purpose was to ascertain the veracity or otherwise of the assumption that wells and boreholes that sited away from drainage lines produce low yield and end up drying.

IV. Discussion of Results and Analyses

Out of the total of 23 borehole schemes inspected, 8 are mechanized with submersible pumps, while 15 were fitted with hand pumps. A total of 15 boreholes are functioning, while 8 boreholes are non-functioning. Out of 41 wells inspected, 23 are functioning and 18 non-functioning. Out of the total of 41 schemes, 18 have concrete covering and 23 have other material for cover. More details are presented in table I.

TABLE I. Status of facility inspected in the study area.

No. of Facility	Functioning	%	Non-Functioning	%	Type of Scheme
	Boreholes				
15	10	66.7	5	33.3	Hand pump
8	5	62.5	3	37.5	Motorised
23	**15**		**8**		
	Wells				
18	7	38.9	11	61.1	Concrete Covered
23	16	69.6	7	30.4	Other
41	**23**		**18**		

Slope map: The slope amount derived from contours and spot heights have shown that elevation decreases from the northern part to the southern part with slope 0º to 10º in flat and mountainous areas respectively. In the nearly level slope area (0-1) degree, has a slow surface runoff allowing more time for rainwater to percolate and is considered a good groundwater potential zone, where as strong slope area (11-14) degree, facilitate high runoff allowing less residence time for rainwater hence comparatively less infiltration and poor groundwater potential. The entire slope map is divided into five categories as in table III.

TABLE II. Drainage density category.

Class	Km/Km^2	Drainage Density Category
1	0 – 0.5	Very Low
2	0.5 – 1.0	Low
3	1.0 – 1.5	Moderate
4	1.5 – 2.0	High
5	2.0 – 2.5	Very High

TABLE III. Slope gradient category.

Class	Degree	Slope Category
1	0 – 1	Nearly Level
2	1 – 3	Very Gently Sloping
3	3 – 6	Gently Sloping
4	6 – 11	Moderately Sloping
5	11 – 14	Strongly Sloping

Lineament and Lineament density: Digitally processed images offer better interpretation, however high spatial resolution and multi-spectral data make the marking of lineaments much easier, accurate and reliable.

Lineaments, based on their length fall into two types - Minor lineaments with length < 3 km and Major lineaments with length > 3 km. The study area has both major and minor lineament, with magnitude range of 1.52 Km to 2.95 Km.

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Area with very high lineament density (2.22-2.65) have good groundwater potential whereas area with very low lineament density (0-0.12) have poor groundwater potential. The entire map is grouped in five categories; very poor, poor, moderate, good, and excellent as shown in table III.

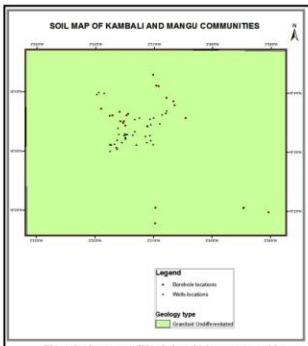

Fig. 4 Geology map of Kambali and Mangu communities

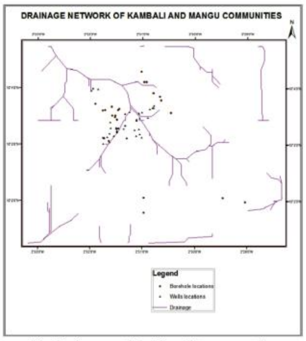

Fig. 5 Drainage map of Kambali and Mangu communities

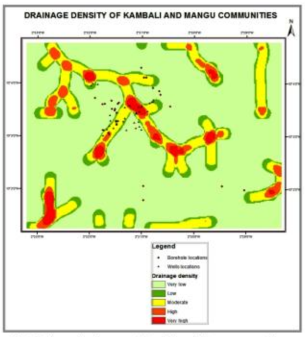

Fig. 6 Drainage density map of Kambali and Mangu communities

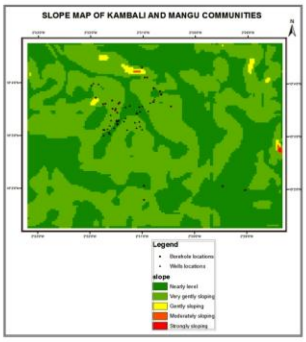

Fig 7. Slope map of kambali and Mangu communities

TABLE IV. Lineament density category.

Class	Km/Km^2	Lineament Density Category
1	0 – 0.12	Very Low
2	0.12 – 0.55	Low
3	0.55 – 1.99	Moderate
4	1.99 – 2.22	High
5	2.22 – 2.65	Very High

Assigning rank and weight: The groundwater potential zones were obtained by overlaying all the thematic maps in terms of weighted overlay method using the spatial analysis tool in ArcGIS 10.1. The slope and geomorphology were assigned higher weight, whereas the lineament density and drainage density were assigned lower weight. After assigning weights to different parameters, individual ranks are given for sub variable. The parameters were carefully analyzed and ranked after (Butler et al., 2002, Asadi et al., 2007, Yammani, 2007). Highest groundwater potential features were given maximum values but lowest potential features attracted minimum values.

As far as slope is concerned, the highest rank value is assigned for gentle slope and low rank value is assigned to higher slope. The higher rank factors are assigned to low drainage density because the low drainage density factor favour more infiltration than surface runoff. Among the various lineament density class, the very high lineament density category is assigned higher rank value as this category has greater chance for groundwater infiltration. Lower value is assigned for very low lineament density. All shown in Fig. 4 to Fig. 8.

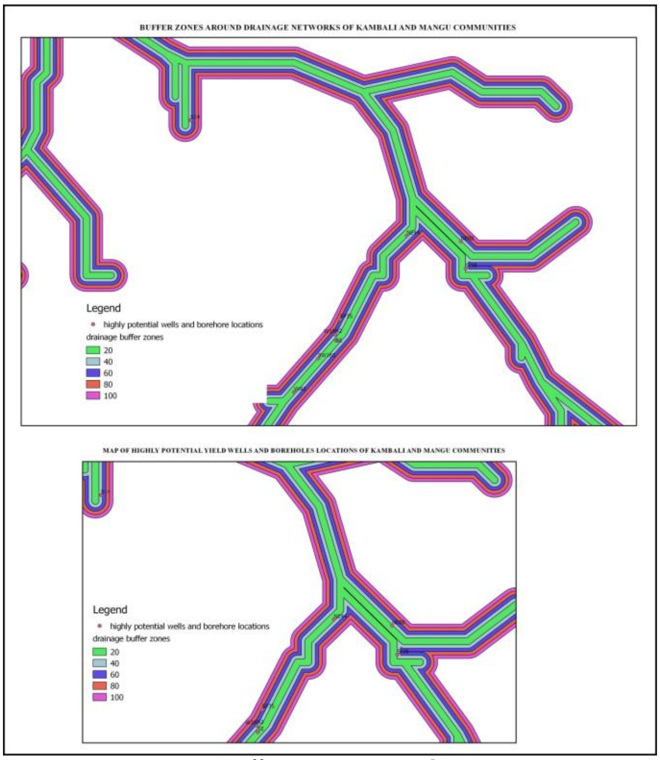

Fig. 8. Buffer zones or potential zones.

TABLE V. Rank and weight for different parameter of groundwater potential zone.

Parameter	Classes	Groundwater prospect	Weight (%)	Rank
Slope Classes	Nearly Level	Very good	15	5
	Very Gently Sloping	Good		4
	Gently Sloping	Moderate		3
	Moderately Sloping	Poor		2
	Strongly Sloping	Very Poor		1
Drainage density (km/km^2)	0 – 0.5	Very good	10	5
	0.5 – 1.0	Good		4
	1.0 – 1.5	Moderate		3
	1.5 – 2.0	Poor		2
	2.0 – 2.5	Very Poor		1
Lineament density (km/km^2)	0 – 0.12	Very Poor	10	1
	0.12 – 0.55	Poor		2
	0.55 – 1.99	Moderate		3
	1.99 – 2.22	Good		4
	2.22 – 2.65	Very Good		5

TABLE VI. Groundwater potential zones.

Sr. No	Potential Zones	Area (km^2)	Area (%)
1	Excellent	1.12	1.25
2	Good	25.56	28.60
3	Moderate	45.36	50.76
4	Poor	16.34	18.29
5	Very Poor	0.98	1.10

V. CONCLUSION AND RECOMMENDATIONS

From the results analyses it is evident that boreholes and wells that are sited along drainage and lineament lines produce high yield. It can also to be deducted that these properly sited

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water facility has a low rate of drying up. This is due to the recharge rate of the underlying material. It is therefore advised that siting and developing wells in shallow sand and gravel deposits with water table less than 3 meters below surface be avoided.

Under these conditions, waste water can easily infiltrate back down to the water table near the well and contaminate the drinking water supply. Wells constructed in silt or clay soils will have very low yields regardless of how they are constructed. To compensate for this, large diameter water wells should be carefully dug so that large volumes of water can slowly accumulate in the well casing over time and provide sufficient quantities when required. The results obtained in the study areas show that the study suggestion will results in increased borehole success rates compared to previous drilling, as recorded in the Hydrological Department as opposed to a solely geophysical approach.

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