Appraisal of the borehole drilling success rate on the Kwahu Plateau, Ashanti Region, Ghana.

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Introduction

Areas of Mampong Municipality and Sekyere Central District of the Ashanti Region, Ghana, have a poor borehole drilling success rate. Over various Government, World Bank and NGO funded drilling programmes, success rates in the area average 49%; on a community scale the success rate varies from 0 to 100%. Ashanti Development, a small, Ghana- and UK-based charity working in the area, wished to identify the reasons for the variation in success to allow better fund allocation and improve drilling success for future water resource projects.

The study area (Figure 1) was defined as being the Kwahu Plateau area of Mampong Municipality and Sekyere Central District (Ashanti Development's area of work). The Kwahu Plateau is defined geographically by an escarpment to the west and has been arbitrarily defined as the 300mOD contour to the east. There are over 70 communities within the study area and a population of approximately 100,000.

Database Population

During 2009, a database of borehole logs was created using borehole drilling records from Mampong Municipal Assembly (formerly Sekyere West District Assembly) and the Ashanti Region Community Water and Sanitation Agency (CWSA). Where possible, the database was verified and extended on visits to communities during 2009 and 2010 and with data from Coy and Neath (2008). All data was assumed to be correct unless obviously erroneous; information collected, where available, includes:

- Grid coordinates and approximate elevation;
- Resistivity sounding data (predominantly dipole-dipole array);
- Geological logs, water strikes and estimated yields;
- Six-hour pump test static water level, drawdown, yield and calculated specific capacity;
- Hydrochemistry;
- Type of pump installed;
- Field pH, electrical conductivity and temperature.

Whilst the database is known to be imperfect, it is currently the most complete record of borehole logs for the study area comprising 72 wet boreholes and 74 dry. Wet boreholes are classified as those installed with a pump after drilling and used (or in temporary disrepair) by the community to abstract water.

Data Review

Mapping of the wet and dry boreholes appeared to show a trend of increasing success rate with distance away from the escarpment. Figure 2 shows no wet boreholes (16 drilled) within 4km of the escarpment and erratic success between 4 and 11km, varying between 8% and 56% (89 boreholes). From 12km onwards 39 of the 41 boreholes drilled were successful.

The subsoil across the area is almost exclusively laterite: iron-rich, red clayey sand. Borehole logs show laterite thickness can be up to 30m or entirely absent; the mean thickness is 7m. There does not appear to be a pattern to thickness either geographically or topographically, and so it is not considered a factor in success. In addition, there are very few hand dug wells in the area, of the eleven catalogued eight were successful (72%). The most successful are dug adjacent to watercourses and so are not greatly patronised, it being easier to collect from a stream than queue for the well. Anecdotal evidence suggests that most hand dug wells are not able to meet demand and often must be allowed to recover for a few hours.

The bedrock of the Kwahu Plateau comprises three sandstone formations of the Voltaian Supergroup (GSD, 2009) which lie unconformably on biotite granitoids of the Eburnean Plutonic Suite (*c.* 2100Ma). The three formations shown in Figure 1 from youngest (*c.* 950Ma) to oldest (*c.* 1000Ma) are:

- Anyaboni Formation – medium grained, dune-bedded to cross-bedded sandstone;
- Mpraeso Formation – medium grained, thickly bedded to cross-bedded sandstone; and
- Damongo Formation – fine to medium grained, flaggy to laminated sandstone.

Inspection of outcrops in the field showed that all three formations have beds of various lithologies from mudstone and shale to coarse sand and occasional conglomerates. Analysis of the success rate by formation (Table 1) shows that the Anyaboni Formation is significantly higher than the other the Damongo and Mpraeso, 78% compared with 28% and 16%.

Table 1. Borehole success by geological formation.

Geology	Wet	Dry	Success (%)	Distance from Escarpment (km)
Damongo Formation	4	21	16%	0.0 to 7.5
Mpraeso Formation	15	38	28%	3.0 to 6.5
Anyaboni Formation	53	15	78%	6.5 to 20
TOTAL	**72**	**74**	**49%**	

The maximum elevation in the study area is 632mOD, while the minimum is the arbitrary 300mOD area definition. The topography upon the plateau is characterised by flat hilltops defined by relatively deep stream-cut valleys. Most communities are located on the hilltops and the surface water sources are down the steep valleys where elevation can fall as much as 100m within 500m of a community. The steep elevation allows boreholes to be drilled at significantly different elevations within acceptable walking distance from a community. Dividing boreholes into 25m elevation groups, no significant success pattern emerges (Table 2).

Table 2. Borehole success by elevation.

Elevation (mOD)	Wet	Dry	Success (%)
526 to 550	1	0	100
501 to 525	0	7	0
476 to 500	3	5	38
451 to 475	20	14	59
426 to 450	14	6	70
401 to 425	8	18	31
376 to 400	6	8	43
351 to 375	8	12	40
326 to 350	8	4	67
301 to 325	4	0	100

There are 117 records of borehole depth in the database: 45 wet boreholes and 72 dry. When plotted as a cumulative frequency curve (Figure 3), it shows that dry boreholes are drilled, on average, 17m deeper than wet. It also shows that 90% of wet boreholes are less than 60m deep.

Conceptual Model

The only significant factor in drilling success seen from the borehole database is distance from the escarpment. This expected because it is also the distance down the catchment area. The correlation with geological formation is assumed to be a product of distance from the escarpment. However, distance cannot be the only factors in success because there are successful boreholes within 5km of the escarpment and within both the Damongo and Mpraeso formations. Conceptually it has been assumed that:

- Groundwater flows in deep (30-50m), thin, sub-horizontal fractures or bedding planes.
- Pore flow does not occur (due to the age of the bedrock).
- Vertical fracturing is rare (little indication in rock outcrops of the area).
- There is little or no usable groundwater in the overburden.

Site Selection Technique Review

Physical Characteristics

Topography, vegetation and termite mounds are quoted by Ghanaian hydrogeologists as useful indicators of groundwater. If this is correct, it is not being exploited in the area probably because the high clay content of the laterite means it cannot be.

Geophysics

Geophysics was used as the principal site selection technique for the majority of boreholes in the database, all using the same methodology: electromagnetic profiles followed by resistivity soundings. Generally an EM-34 was used at 20m and 40m spacing with both horizontal and vertical dipoles. With no text to accompany the results it is unclear how the profiles were interpreted, but they were used to select two or three sites for resistivity soundings. The majority of the soundings were carried out using a dipole-dipole array, although a Schlumberger array was used on a few occasions. The soundings were then ranked (again it is unclear how this was done) in order of expected success.

The conceptual model would suggest that both electromagnetic profiling and resistivity soundings would be of little use in the area. This is because electromagnetic profiles are most suitable for the identification of horizontal variation (i.e. vertically orientated features), something excluded from the conceptual model. Resistivity sounding may not be appropriate because it lacks the sensitivity to identify thin layers at depth. Also, the use of a dipole-dipole array for resistivity soundings does not always give good results because data can become noisy, due to its greater sensitivity in the near surface.

Field Investigation

A four-borehole drilling programme was devised by Ashanti Development. The primary aim was to provide a water supply to villages; however, it was also used to investigate the suitability for geophysics to be used as a site selection technique. Three communities with established relationships with Ashanti Development, no wet boreholes and in different geological formations were selected for the programme: Abonkosu, Amangoase and Mprim. Database records show that Abonkosu had six dry boreholes with the most successful having an estimated yield of $0.3m^3/d$. Amangoase had never had a borehole drilled, but three wet boreholes have been drilled within 700m, in Dida, a neighbouring community. Mprim had five dry boreholes and a sixth that was in use for a short time (1999 to 2001). However, with a static water level of approximately 30mbgl and specific capacity of $0.4m^3/d/m$ extracting water by hand was difficult and it often had to be left to recover.

With the aid of Dr Ron Barker (pers. comm., 13th December 2009), two geophysical techniques were chosen to be evaluated for their effectiveness in site selection: electromagnetic (EM-34) profiling and resistivity imaging (Wenner array). These techniques were chosen because the equipment and expertise are readily available within Ghana, allowing the techniques to be reproduced easily if they are proved to work. Very low frequency (VLF) was also considered; however, there is a lack of expertise in the country and it was unlikely a suitable transmitter would be available for use.

A Wenner array was decided upon, as opposed to the dipole-dipole, because it is a better suited and simpler array for deep resistivity imaging and standard equipment (such as a Terrameter or Geopulse) does not have sufficient power output to compensate for the small measured voltage (and hence resistance) produced in a dipole-dipole array. Short and long normal borehole geophysical logging was also proposed to increase interpretation accuracy; however, logistical problems in the field prevented this from being completed.

Results

400m transect lines were selected in Abonkosu and Amangoase, and two transects in Mprim. They were chosen by community representatives, hydrogeologists and geophysicists using factors such as accessibility, topography and proximity to the community.

As anticipated, the electromagnetic profiles were of little use in site selection. Generally, the recorded conductivity varied by only a small degree (0 to 2mmho/m) between adjacent stations. This was interpreted as being the same rock type with no lateral change in properties. Any larger variations were not consistent between profiles of different investigation depths and most could be attributed to interference from surface features – usually metal roofing sheets.

The resistivity imaging generally confirmed the conceptual model of sub-horizontal zones, although potential vertical faulting was also seen in three of the images. These could not be seen (even retrospectively) in the EM-34 profiles. Further logistical problems meant that only two boreholes were logged correctly, the results from which are not sufficient to give a robust appraisal of the method. Despite this, three of the four boreholes drilled were wet, one in each of the communities.

Conclusion

The most significant factor affecting borehole success rate is the distance from the escarpment or, in other words, the distance from the catchment watershed, an expected conclusion. For areas closer to the escarpment, poor site selection methods were identified as the most significant reason for unsuccessful boreholes because no practical correlation was seen with regards to geology, site elevation or borehole depth.

While the field investigation into site selection technique was not conclusive, the study as a whole does allow some general rules to be made that should allow better use of resources during borehole drilling projects:

1. The use of geophysics was not a critical factor in achieving the current 49% success rate. This rate should be considered a baseline from which improvements can be made across the area, but not necessarily on a community-scale.
2. In the simplest scenario, geophysics may be removed from all drilling projects without significantly altering the success rate, provided that boreholes are drilled in sensible locations (e.g. not the top of hills).
3. To improve on the success rate while keeping the budget as low as possible, different approaches may be taken depending upon the distance away from the escarpment:

- Thorough background investigations should be undertaken for all projects, including community-specific reasons for previous borehole failure or success, if records exist.
- If a borehole is dry at 60m, drilling should be terminated – there is only a 10% probability of achieving a suitable strike any deeper. In addition, if the abstraction method proposed is a hand pump, then drilling deeper than 60m reduces the ability to easily extract water.
- From 0 to 4km away from the escarpment, borehole drilling should be carefully considered and, if possible, alternative water sources utilised instead.
- From 0 to 12km, all drilling locations should be chosen with the aid of resistivity imaging. Investigation depth must be at least 60m.
- For boreholes to be drilled at distances greater than 12km from the escarpment but within the study area, geophysics is not essential to get a success rate approaching 100% but may be insightful.

The use of resistivity imaging may not improve success rate in the short-term, although an electrical image of the subsurface is a far more robust and defensible methodology than electromagnetic profiling and resistivity soundings. Long-term use of imaging and accurate borehole logging will allow a greater understanding of the subsurface, expected resistivity ranges and images likely to yield water. In addition, it may answer further questions such as whether the sub-vertical features seen in this investigation are likely to act as conduits or barriers to flow.

References

Coy and Neath, 2008. *Ashanti Development Groundwater Assessment Report.* Ove Arup & Partners Ltd.

GSD, 2009. Geological Map of Ghana 1:1,000,000 scale. Geological Survey Department (eds.), Accra, Republic of Ghana.

Figure 1. Study area map and cross section.

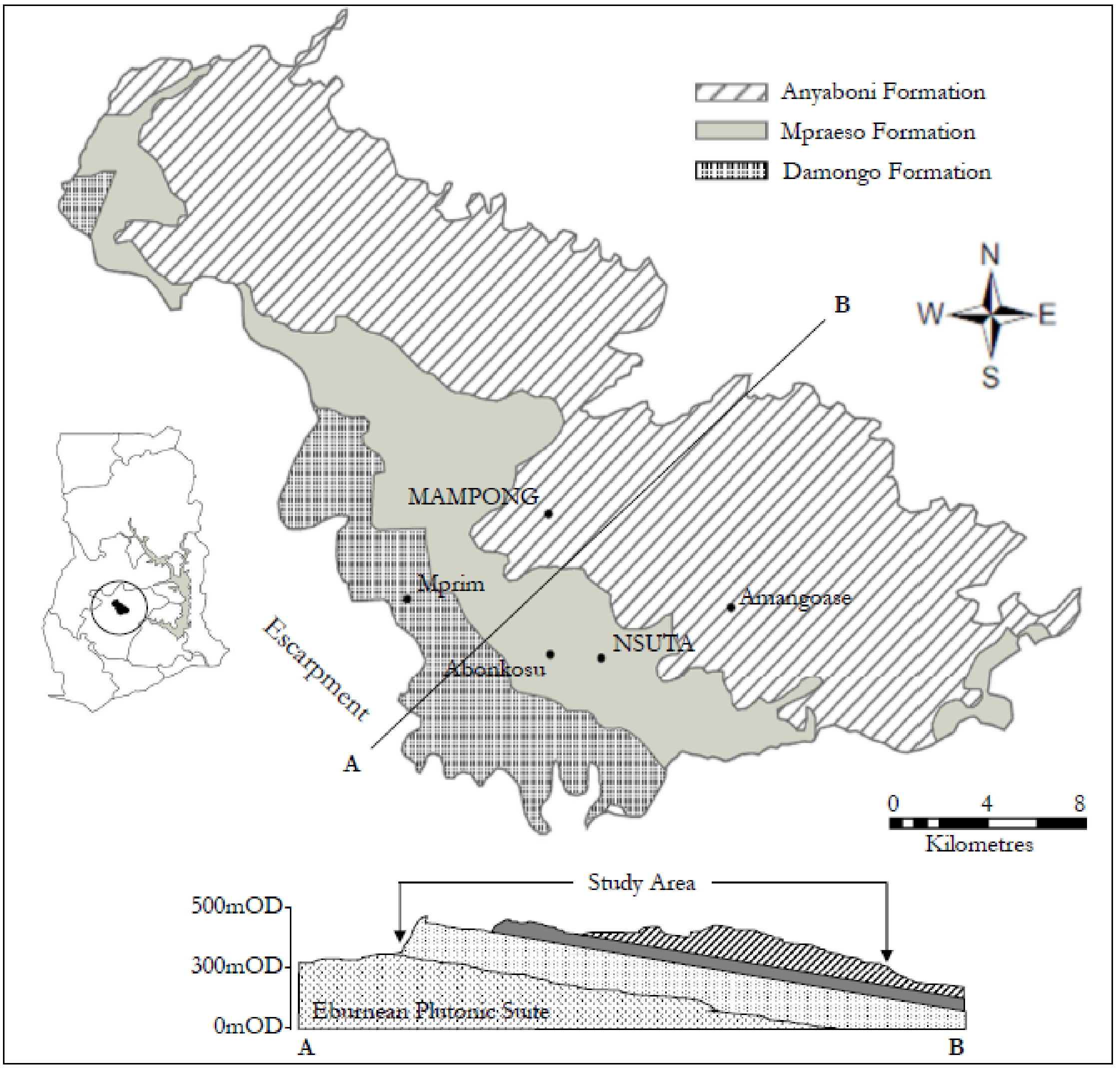

Figure 2. Borehole success by distance from escarpment.

Figure 3. Wet and dry borehole depths.