Understanding groundwater in Gyetiase and surrounding villages, Ashanti Region, Ghana.

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Hydrogeology is the study of water in rocks, otherwise known as 'groundwater'. Groundwater plays a major role in water supplies around the world being the resource which comes out of springs, wells and boreholes. It is also the water that flows in rivers during the dry season.

In 2010, James Lalor and I visited Gyetiase and surrounding villages to see whether we could get a better understanding of the groundwater in the area. This, we hoped, would have the benefit of being able to apply resources (financial and man-power) to the areas where they would be most beneficial. I have tried to summarise this study here, along with a little lesson in hydrogeology for those who would like to find out a bit more.

Where does groundwater come from?

Almost all groundwater starts its life as rain (a very tiny proportion comes from septic tanks and latrines and so on). It infiltrates through the soil and percolates down to the groundwater body or 'water table'. This process is known as 'recharge'.

In Mampong (where there is a weather station), the average rainfall is around 1,300 mm/year (comparable with wetter parts of the UK) and the recharge may be around 100 mm/year. The difference between rainfall and recharge is because there are a few obstacles between the sky and the water table.

- Evaporation – rain catches on soil, trees, leaves, buildings, etc. allowing it to evaporate. The *potential* evaporation rate in Mampong is quite high 1,340 mm/year (it can be just over 600 mm/year in the UK). The *actual* evaporation rate depends on how much water is available to be evaporated: in the dry season the potential is high, but the actual is low.
- Runoff – most of the rain in Mampong doesn't fall as drizzle, it pours down. There is so much water falling at once that it cannot all be absorbed so it must 'runoff' to streams and rivers. This is where most rainfall ends up and why catching it (rainwater harvesting or reservoirs) is so sensible – rainwater will otherwise just keep on flowing down streams and rivers to the sea.
- Soil type – the amount of runoff also depends upon the makeup of the soil. Loose soil, (sand-rich) is good at absorbing water while tight soil (clay-rich) is not. Although it may not appear it at first sight, the vegetated areas around Gyetiase have fairly loose soils, which is good for recharge. Within the villages, removal of vegetation and erosion of the upper soils has exposed deeper soils, these tend to solidify when they come into contact with the air (over a few years) which is not so good for infiltration.
- Transpiration – any rain that does get into the soil can then get sucked back up by plants. Grass roots can suck water up from as deep as 10 m (but usually 1 to 2 m) while some tree roots can reach even deeper.

After all this, a recharge rate of 100 mm/year is still quite a lot of water: one square kilometre will recharge, on average, over quarter of a million litres every day. An average Ghanaian person will use around 20 litres of water a day (an average Brit will use 45). So, in theory, every square kilometre will recharge enough water for well over 10,000 people. The trouble is getting the water back out of the ground.

How does groundwater flow?

Groundwater flow is controlled by two things: head (water level) and hydraulic conductivity. Hopefully I can explain both using the analogy of a hosepipe...

Imagine filling a short hosepipe with water, placing your thumbs over the ends and holding it in a U-shape with both ends pointing up, one end higher than the other. When you take your thumbs away, water will flow from the lowest end because it is being driven by the higher 'head' of water at the other end. Once the heads are the same, the water will remain static in the pipe. You may also notice that at the beginning the flow of water is highest and slowly reduces to a stop. This, again is because the flow is relative to the head difference: the higher the head difference the greater the flow.

Similarly, if you were to repeat the experiment but with the hosepipe filled with sand, you would notice that the flow rate would be smaller but obeys exactly the same rules. The sand is both 'porous' (has gaps between the grains) and 'permeable' (water can move from gap to gap) so water can flow through it but it must flow round each grain it comes to which slows it down. The amount a rock (or sand) affects groundwater flow is known as 'hydraulic conductivity'. In short, the more pore-space (gaps between grains) and the better connected they are, the faster water can flow and the higher the hydraulic conductivity...and vice versa.

Should Ashanti Development fund hand dug wells?

Yes, but not too many and only in the right place: there are very few hand dug wells in the area around Gyetiase for a reason. We only found eleven (we visited over 30 villages), of which only eight worked properly. The reason for this is that the overburden (the upper soils which are not rock) in the area is rich in clay. This is rock which has been chemically-weathered for a few million years. Most overburden in the UK is due to the movement/melting of glaciers in the ice age – this didn't happen much in Africa. Clay has a low hydraulic conductivity and, therefore, water does not flow through it easily. This is why you don't see many hand-dug wells in the area: water cannot physically flow into the wells fast enough to stop them drying up after a few bucket-fulls are removed. It sometimes takes days for the water level to come back up again – not very good for a thirsty village. The places where hand-dug wells are successful are where there is sandier overburden which has a higher hydraulic conductivity. Sand deposits are usually physically-weathered deposits so tend to be very close to streams and rivers (like the one in Gyetiase and on the road to Bonkron).

So are boreholes the answer?

Yes and no: you can drill a borehole anywhere on the planet and get some water (or ice). However, there are two large controlling factors on this water:

- quality – is the water chemistry suitable for its purpose? (in this case, is it safe to drink?); and
- quantity – is there enough water for its purpose?

If the water in a borehole cannot satisfactorily answer either of these questions, you cannot use the borehole to supply water.

Thankfully, the water quality in the area is pretty good – no nasty chemicals like arsenic and few or no diarrhoea/vomit causing beasties (which are plentiful even in the most natural of streams). So the main problem here is quantity.

Where do we drill a borehole to get enough water for a village?

There are a few different techniques that help to identify where to drill a borehole and; for most of our time, James and I were investigating which of these are the most suitable around Gyetiase.

1. Look at where boreholes have been successful in the past and where they haven't.
2. Look for reasons why the some boreholes are successful and some are not. For this we focused on four main areas.
    i. Geology – are some rocks better for boreholes than others? Thankfully the Ghanaian Geological Survey Department, with contributions from the Geological Survey of Denmark and Greenland the British Geological Survey, had done all the hard work for us in mapping the geology of the area.
    ii. Elevation – water is pulled down by gravity so are the more successful boreholes at lower elevations than the unsuccessful ones?
    iii. Borehole Depth – similarly, if you drill a deeper hole are you more likely to have success?
    iv. How was each of the sites chosen?
3. Carry out a small-scale drilling programme to test different theories.

What did we find out?

Where have boreholes been successful and unsuccessful?

There is no single database of boreholes for the area, so we decided to make our own. For this we had to visit the regional Community Water and Sanitation Agency (CWSA) in Kumasi, Mampong Municipality Water and Sanitation Team (MMWST), Sekyere Central District Water and Sanitation Team (SCDST) and lots of villages to double check and add any missing boreholes. We found 144 boreholes in our study area (although there are probably lots more) which covered 44 km^2, over 70 and villages and a population of approximately 100,000 people.

Has geology affected success?

The bedrock of the area can be loosely described as three types of sandstone lying on top of granite as the cross section in Figure shows. Together, the sandstones are between 150 and 250 m thick and were deposited about a thousand million years ago (1000 Ma). The 'sand' part of it is due to erosion of long-gone hills and mountains which stretched across what are now Ghana, Togo and Brazil (before the Atlantic Ocean ripped the contents apart, of course). These sands slowly cemented themselves together over time to become sandstone. The trouble is that they have cemented so much that all of the pore-space has filled in. This means they have a very low hydraulic conductivity so groundwater finds it very difficult to flow through them. Really, the only way groundwater can flow is through fractures (cracks), which are unlikely to be more than a few millimetres wide. Unusually, there are very few vertical (or nearly vertical) fractures; they are predominantly horizontal which makes finding them in the 'usual' way is quite difficult. There are signs as to how the rock is fractures if you look at cliff faces like the escarpment coming from Mampong (Figure) and the springs at Kyebi and PSK (Figure).

Figure . Kwahu Plateau escarpment from the Mampong-Kumasi Road.

The granite is too deep to be of use to for hand-pump supply, but may be of use in the future when electric pumps are more commonplace. Off the plateau (in Abasua, Atwea and Adutwem) the granite is at the surface and is used very successfully for their water supplies.

Back on the plateau, there appears to be a link between the geology and the success rate as shown in Table . Remember that geology is three dimensional and that is why a cross-section is also very useful (Figure). The success rate shows that the Anyaboni Formation has most success while the Damongo Formation does not fair so well. In addition to this, the specific capacity is also higher in the Anyaboni and worse in the Damongo. The specific capacity can be thought of as a hydrogeological measure for how good a well is at supplying water – the higher it is the more water can be supplied.

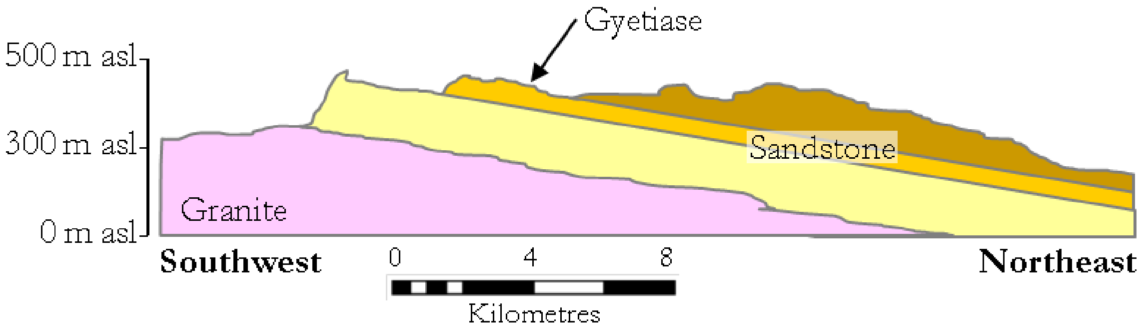
Figure . Horizontal fractures producing water at PSK.

Table . Geology and success rate.

Bedrock Geology	Successful Boreholes	Unsuccessful Boreholes	Success Rate	Specific Capacity Range (m³/d/m)
Anyaboni Formation	52	16	76%	1.6 to 40
Mpraeso Formation	16	39	29%	0.62 to 1.9*
Damongo Formation	4	19	17%	0.30 to 0.75
TOTAL	**72**	**74**	**49%**	

* excludes a fourth borehole drilled in gravely alluvium 5 m from a river which has a specific capacity of 71 m³/d/m

Figure . Geological cross section of the area around Gyetiase.



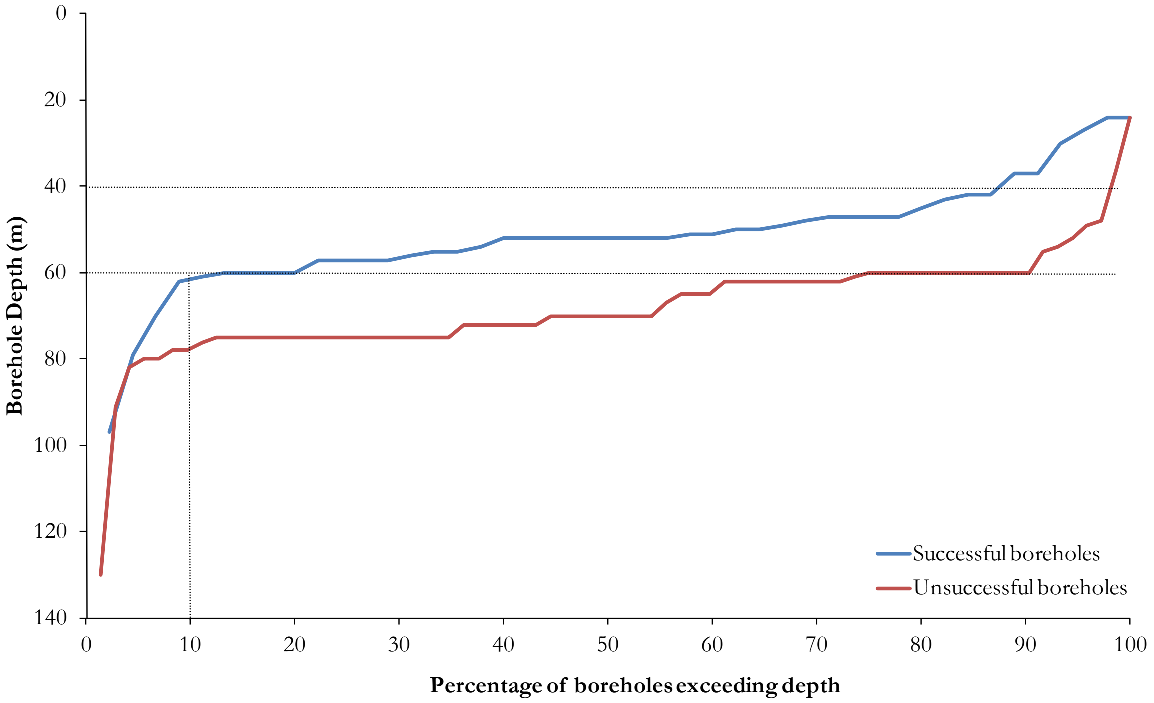
Has elevation or depth affected success?

There does not appear to be any correlation between elevation and success rate as Table below shows. Of course drilling at the top of a hill is still unwise, but it is not the primary reason not to drill there. There also appears to be no correlation between the depth of borehole and success because, on average, unsuccessful boreholes are drilled 17 m deeper than successful ones. Furthermore, 90% of successful boreholes are less than 61 m deep, most being between 40 and 60 m (Figure).

Table . Borehole success by elevation.

Elevation (mOD)	Successful	Unsuccessful	Success Rate (%)
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

Figure . Depth exceedance curves for successful and unsuccessful boreholes.



Has site selection affected success?

We must now consider what geophysics techniques were used. Geophysics is a way of sending energy pulses (e.g. electricity, magnetism or pressure) through the earth and recording the results. This gives us a bit of an idea as to what is going on underground in terms of geology and water (and gas, oil and other things, but don't expect them to turn up here). If the right techniques are used, they may be very useful at identifying where a borehole may be successful. Sadly, there was very limited information on what was used when a borehole was drilled so this is one of the reasons why we needed a small-scale drilling programme to test a few methods.

We discovered that a lot of the techniques that have been used historically were not the reason for the success (as many unsuccessful sites were chosen with exactly the same techniques). One type of geophysics, known as resistivity imaging, we believe, may be of use in difficult areas. We used this technique in Abonkosu and managed to drill the first successful well there (six previous attempts had been made by other agencies). It is definitely not the best well in the area (it is only just suitable for a water supply) and part of it was down to luck, but by using the right techniques in the right place it gave us more chance to be lucky.

What does this all mean for Ashanti Development?

I feel this work has provided a number of golden rules that will allow Ashanti Development to allocate the most suitable water supply-method to any village in the area thus saving time, money and the hopes of a few hundred villagers watching a drill rig produce nothing but dust. They are very simple...

1. A borehole or hand dug well is not always the best solution for a village and alternative supplies (such as spring protection and pumped stream water) should be considered first. This is most relevant to villages within 3 km of the escarpment where no successful boreholes have ever been drilled.
2. If a borehole or hand dug well is decided to be an option, a thorough background investigation of the selected village should be undertaken before any drilling is started. It sounds obvious but it appears that Ashanti Development are the first to ever do this in the area. To aid this, the local District Assembly or regional CWSA office should maintain an up to date record of all drilling in the area along with basic interpretation.
3. To improve borehole success rate, while keeping the budget as low as possible, different approaches may be taken depending upon which geological formation the village overlies.
    i. For boreholes to be drilled in the Anyaboni Sandstone Formation (the upper layer), geophysics is not essential to get a success rate approaching 100%, but it may be insightful.
    ii. All drilling locations for boreholes in the Mpraeso Sandstone Formation (middle layer) or Damongo Formation (bottom layer which makes up the escarpment) should be chosen with the aid of resistivity imaging and a hydrogeologist (I would say that).
4. If a borehole is dry at 60 m depth, drilling should be terminated – there is only a 10% probability of achieving a successful hole by drilling deeper so it is better to cut your losses and try elsewhere. In addition, if it is being drilled for a hand pump, then drilling deeper than 60 m reduces the ability to easily extract water.