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EVALUATING BOREHOLE PERFORMANCE IN TOLON AND WA WEST DISTRICTS OF NORTHERN GHANA

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ABSTRACT
Groundwater is a very important asset for many domestic and agricultural activities to the people of Northern Ghana, where majority are farmers. This research evaluated boreholes yields and transmissivity in Wa West (Baleofili) and Tolon Districts (Kpaligung) of Northern Ghana. Pumping tests, absolute and barometric pressures were monitored using non-vented water level sensors for one year (2015-2016). Results of the research indicate that the aquifer of the Kpaligung borehole is of Voltaian province while that of Baleofili is of Granitoid intrusions. The yield of the Baleofili borehole is 1.8 m^3/h (30 l/min), while that of the Kpaligung borehole yields 1.4 m^3/h (23 l/min). The Kpaligung borehole indicated gradual decrease in drawdown as pumping test went on, due to the borehole receiving recharge from the surrounding boreholes, as the cone of depression intercepted their aquifers. The transmissivity (T) value was therefore determined to be 0.5 m^2/d. However, the Baleofili borehole shows gradual increase in drawdown, which indicates that the aquifer properties away from the borehole are poorer than those closer to the borehole. The transmissivity (T) value was therefore determined to be 0.8 m^2/d. The yields of the two boreholes are enough for domestic water supply of the beneficiary communities. More intensive monitoring and data gathering efforts should be undertaken to understand the groundwater resources in northern Ghana especially geology, aquifer system, and flow patterns.

Keywords: *Borehole, Discharge, Pumping-test, Transmissivity, Yield*

INTRODUCTION
Fresh and clean water is vital for socio-economic development and the provision of ecological services, but this resource is gradually becoming a scarce in rural Ghana. Despite the fact that rainfall in Ghana allows for several perennial rivers to flow, clean water has been denied millions of people (Doe, 2007). Similar to the rural water sector in many developing countries, there are serious constraints for provision of adequate water supply to rural residents. The main sources of water for household use are potable water supplied by the state water company, rivers, boreholes, wells, ponds, lakes, harvested rainwater and streams. Nearly 80 % of the population is using an improved source of drinking water – 91 % in urban areas and 69 % in rural areas (GSSS, 2012).

Groundwater is frequently chosen as the most suitable source of drinking water, supplies of which are brought to the surface by rehabilitating existing boreholes or drilling new ones (Philippe, 2011). Groundwater serves as one of the most reliable sources of water for domestic and agricultural activities, especially where the yield is sustainable.

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According to Karikari (2000), the quality of groundwater in Ghana is generally good and accounts for a large share of the potable-water supply in rural communities, except in some few areas, like Bongo and Prestea, where the water contains iron, manganese and fluoride deposits.

According to Brian *et al.* (2004), groundwater-levels are the most critical information collected about an aquifer indicating its hydrologic character and stresses. Water-level data are increasingly used by agencies to calibrate groundwater models and to design, implement, and monitor the effectiveness of groundwater management and conservation efforts. However, water-level data are often limited in frequency and geographic distribution for meaningful analyses.

Groundwater levels provide critical information about the hydrologic relationships of recharge and discharge to storage within an aquifer, and the direction of groundwater flow. Long-term, systematic measurements of water-level data are essential to develop groundwater models and to design, implement, and monitor the effectiveness of groundwater management programs (Taylor and Alley, 2001).

Pumping tests are a practical way of obtaining an idea of the borehole's efficiency and its optimal production yield (Philippe, 2011). Groundwater levels and pumping rates measured during pumping tests provide some indication of the behaviour or state of 'health' of the groundwater system. These tests undoubtedly provide valuable information, help to understand the groundwater system, and inform decisions.

The research evaluated boreholes yields and transmissivity as well as the effects of absolute and barometric pressures on water level fluctuations of two boreholes in Wa West and Tolon Districts of Northern Ghana respectively.

MATERIALS AND METHODS

Study Areas

The study was conducted in two administrative districts, Wa West in the Upper West Region where Baleofili is located and Tolon in the Northern Region of Ghana, where Kpaligung is located. The districts studied are located in the Guinea Savannah belt of Ghana. The climate of the study areas follows a general pattern identified within the three regions of northern Ghana (Ghana Districts, 2006). It has a single rainy season from April to October/November, with average annual rainfall ranging between 950mm - 1,200 mm (GSS, 2014). This is followed by a prolonged dry season, from early November to March. The mean day temperatures are ranging from 33°C to 39°C, while mean night temperature range from 20°C to 26°C. Before the onset of the rainy season, temperatures rise to their maximum (40 °C) and fall to minimum (20 °C) during `harmattan` period (January-February).

The Tolon District is in the Northern Region of Ghana, latitudes 9° 15′` and 10° 02` N and longitudes 0° 53′and 1° 25′ W. It shares boundaries to the north with Kumbungu, north Gonja to the west, Central Gonja to the south, and Sagnarigu Districts to the east. The district is a particularly difficult place to find groundwater, as it is largely underlain by ancient, indurated sedimentary rocks of the Voltaian Supergroup, which were deposited in the northern part of the elongate, north to south trending Volta Basin in Neoproterozoic to early Palaeozoic times (Ó Dochartaigh *et al.,* 2011).

The rocks comprise thick sequences of continental and marine silty mudstones and sandstones, with subordinate conglomerates, limestones and glacially-derived deposits. Unsuccessful water boreholes have been drilled throughout the district, but are particularly common in areas that are underlain by mudstones, which are usually poorly fractured. Sandow *et al.* (2011) finds that the sandstone aquifers are the most prolific and offer themselves as the best lithologies for drilling successful wells in the area. Linear prediction maps suggest that the most prolific aquifers are located in the northern parts of the region, where aquifer transmissivity, specific capacity, and well yield values are quite high, due to enhanced secondary permeabilities. Representative drilling success rates, which vary by region, range from 32 % (Tolon Kumbugu) to 82 % (Bawku East) (CIDA and WRC, 2011).

Generally, the land in the district is undulating, with a number of scattered depressions. There are no marked high elevations throughout the district. The land is drained by a number of rivers and streams, most prominent being the White Volta. Among the major tributaries of the White Volta are Kulabong, Koraba, Salo, Bawa and Winibo. The major river and its tributaries exhibit dendrite drainage patterns. Most of these tributaries dry up during the dry season. There are small dams and dug-outs constructed by various agencies in some communities in the District (GSS, 2014).

The Wa West District is located in the western part of the Upper West Region, approximately between longitudes 9º 40' N and 10º 10' N and also latitudes 2º 20' W and 2º 50' W. It shares boarders to the south with Northern Region, north-west by Nadowli District, east by Wa Municipal and to the west by Burkina Faso (GSS, 2014). This study was carried out at Baleofili community, near Wichagu.

The topography of the Wa West District is gently rolling with a few hills ranging between 180 and 300 meters asl. It is drained by the Black Volta - to the west marking the boundary between the District and the Republic of Burkina Faso (GSS, 2014).

The geology of the study area is characterised by basement crystalline rocks derived from the Precambrian era and principally comprise the Birimian rocks and associated granitoid intrusions (Leube *et al.,* 1990; Taylor *et al.,* 1992; Hirdes *et al.,* 1992). The Birimian rocks include biotite and muscovite—bearing granite, granodiorite, diorite and gabbro, phyllites, schist, tuffs, basalt, sandstones, siltstones and strongly deformed metamorphic rocks (Nude and Arhin, 2009). These rocks occur in the southwest and the northeast of the study area whilst Upper Birimian rocks comprising metamorphosed lavas and pyroclastic rocks underlie the south-eastern portion of the area. Basal sandstone of the Lower Voltaian System also underlies the extreme northeast section of the study area.

The basement crystalline rocks are essentially impermeable with very little porosity. The existence of groundwater comes as a result of chemical weathering and fracturing, leading to the formation of aquifers (Obuobie and Boubacar, 2010). Aquifers in the northern part of Ghana are semi confined and have depth ranging from 10 to 60 m. The aquifer recharge has been found to be mainly through precipitation (Obuobie 2008, Martin, 2006).

Methodology

Drilling of the Boreholes and Conduction of Pumping Tests

A borehole each was drilled at Baleofili in Wa West District and Kpaligung in Tolon District in July 2015 by WATERSITES LTD in Tamale. Pumping test was carried on both boreholes using constant-rate test method, to determine their yield and hydraulic properties of the aquifers. The aquifer types for both boreholes are unconfined, in which the water table forms the upper boundary of the water bearing formation.

A suitable local datum (such as the top of the casing) from which all water-level readings were taken was 45 cm and 90 cm, respectively, for the Kpaligung and Baleofili boreholes; the static water levels were 10.17 m and 12.45 m, respectively, for the Kpaligung and Baleofili boreholes. The characteristics of the two boreholes are presented in Table 1.

***Constant-rate test*:** this was **c**arried out by pumping at a constant rate for six (6) hours using electric submersible pump, electric generator and stop watch to provide information on the hydraulic characteristics of the aquifer such as transmissivity. The valve was opened to the appropriate setting and the pump switched on, starting the stopwatch at the same time. The valve setting was not changed until it was possible to achieve the 23 l/min and 30 l/min pumping rate, respectively, for the Kpaligung and Baleofili boreholes (See Table 1).

Recovery test: this was also carried out to monitor the recovery of water levels on cessation of pumping at the end of a constant-rate test to provide a useful check on the aquifer characteristics derived from the other tests such as the transmissivity of the borehole. The recovery time for Kpaligung borehole was 2 hours, whilst that of Baleofili was 3 hours.

Monitoring Water Levels using "dipper"

The hand-held water-level monitor, commonly known as a "dipper," with dipper probe was lowered down the boreholes and when it reached the water surface, an electrical circuit is completed and a 'bleep' sound was recorded. The water level was then read off from a graduated tape, to the nearest centimetre or metre. This equipment was used to determine the static and dynamic water levels of the boreholes.

Monitoring Pumping Rates

Bucket and stopwatch: The method was used to measure the pumping rates using a graduated bucket and a stopwatch. The arrangements were made for the discharge from the pump to flow freely into the bucket and the time taken for the bucket to fill was recorded. The flow rates were then calculated by dividing the volume of the bucket by the time taken to fill it.

Other Equipment Used For the Studies

- ***Motorized pump:*** an electrical submersible pump (PEDROLLO) with 1 HP, discharge of 100 l/min and total head of 79 m was used to monitor the yields of the boreholes.
- ***Generator:*** a 6.5 HP, Tiger (TG 3700 E) petrol generator was used to provide electricity for the motorized pump.
- ***Rising main*****:** To carry the water up the borehole from a submersible pump, a flexible pipe of 100 meter long with 4.0 mm diameter was connected to the submersible pump.
- ***Manually-operated valves:*** 1`` (1 inch) manually operated valve was installed between the rising main and the discharge pipes to control the pumping rate.
- ***A stopwatch*** to measure the time of pumping and recovery

Data Analysis

Analysis of Pumping Tests and Recovery Data

The pumping tests and recovery data from the two boreholes were entered into Excel spread sheet for analysis to calculate the drawdowns and residual drawdowns, respectively, as well as time ratio (the time since pumping started, divided by the time since pumping stopped). Based on step-by-step pumping tests, the pumping rates were selected for the two boreholes to be 30l/min and 23 l/min for Baleofili and Kpaligung based on the local geology and the intended purpose of the boreholes (domestic water supply). The method of analysis used is called the Jacob (sometimes referred to as the Cooper-Jacob) straight-line method, which is based on a simplification of the Theis method (Kruseman and de Ridder, 1990). The analysis was done using Excel Spread Sheet. A semi-log graph was prepared with water levels on the (linear) y-axis, in metres below datum, and time on the (logarithmic) x-axis (time since the start of pumping, in minutes). A best fit line was drawn and from

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this line, a parameter known as *Δs*, which is the difference in water levels (in metres) over one log cycle was measured. The average pumping rate for the duration of the test, Q, in m^3/day and the values of Q and *Δs* inserted into the formula (equation 1) to calculate the transmissivity *T*.

$$T = 0.183 \times \frac{Q}{\Delta s} (m^2/d) \qquad (1)$$

(Kruseman and de Ridder, 1990)

Unlike the pumping test data, all the water levels measured during the recovery phase (in metres below datum) were converted to residual drawdowns (s') by subtracting the original rest-water level measured just before the start of the pumping phase.

The time elapsed since the start of the recovery phase (in minutes) is denoted by t'. For all the residual drawdowns, t, which is the time, elapsed since the start of the pumping phase of the test was also calculated. From these calculations, the time ratio, t/t` was determined.

A semi-log graph was prepared with the residual drawdown s' on the (linear) *y*-axis, in metres, and t/t' on the (logarithmic) *x*-axis. A best-fit line was drawn and by ignoring the early data (those on the right-hand side) and concentrating on middle to late data, a parameter known as *Δs'*, which is the difference in residual drawdowns (in metres) over one log cycle was determined.

By inserting the values of Q and *Δs'* into the formula (Equation 2) the transmissivity, T was calculated.

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$$T = 0.183 \times \frac{Q}{\Delta s`} (m^2/d) \qquad (2)$$

(Kruseman and de Ridder, 1990)

RESULTS AND DISCUSSIONS

The Characteristics of the two Boreholes

Table 1 presents the characteristics of the two boreholes. For the Kpaligung borehole, the aquifer is of Voltaian province, while that of Baleofili is of granitoid intrusions. According to Agyekum (2004), for areas underlain by granitoid intrusions, borehole depths are similar, ranging from 35 m to 55 m, for which the depth (48.25 m) the Baleofili borehole falls within. The borehole yields range from 0.3 m^3/h to 36.4 m^3/h with the average of 4 m^3/h. The yield of the Baleofili borehole is 1.8 m^3/h, implying that the Baleofili borehole yield is within the expected range. The low yield of boreholes in this formation, according to Martin (2006) could be attributed to differences in degree of weathering and fracturing. Even though the borehole yield is considered to be low, it is higher than that of the Kpaligung borehole, which yields 1.4 m^3/h.

The depth of the Kpaligung borehole is 70 m. According to Agyekum (2004), boreholes depths in the Voltaian province range from 45 m to 75 m, with the average of 55 m. However, the yield of the borehole was 1.4 m^3/d. This value is in the range of borehole yields (0.3 m^3/h to 72 m^3/h) with an average of 7.3 m^3/h indicated by Acheampong and Hess (1998) for the Votaian province.

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Table 1: Characteristics of the two studied boreholes

Community	Datum Height above ground level (m)	Borehole Depth (m)	Pump Setting (m)	Static Water Level (m)	Borehole Yield (m^3/h)
Kpaligung	0.45	70.00	50	10.17	1.4
Baleofili	0.90	48.25	45	12.45	1.8

(Field measurements, 2015)

Constant Rate Pumping Tests Results for Kpaligung and Baleofili Boreholes

Figures 4 and 6 show the relationship between times since pumping started and the drawdowns for both Kpaligung and Baleofili boreholes, respectively. With respect to Kpaligung borehole, the graph indicates gradual decrease in drawdown as pumping test went on. This phenomenon could be as a result of the borehole receiving recharge from the surrounding boreholes as the cone of depression intercepted the aquifer of the other boreholes during the pumping test. The borehole under study is surrounded by three other boreholes at its upstream, with the closest one being approximately 40 m whiles the furthest one is about 100 m (Figure 2). This findings is in line with the assertion by MacDonald *et al.* (2005) that, gradual decrease in drawdown occurs as the aquifer is gaining water from another source, either because the aquifer is leaky, or because the expanding cone of depression has intercepted a source of recharge, such as surface water. According to MacDonald *et al.* (2005) this is an encouraging sign for the borehole as a sustainable water source, and the transmissivity value should be measured using the data before the leakage is observed.

The transmissivity (T) value was therefore determined to be 0.5 m^2/d for the Kpaligung borehole. According to Acheampong and Hess (1998), generally the aquifers from this formation have a low to moderate productivity and overall transmissivity ranging from 0.3 m^2/d to 267 m^2/d with an average of 11.9 m^2/d.

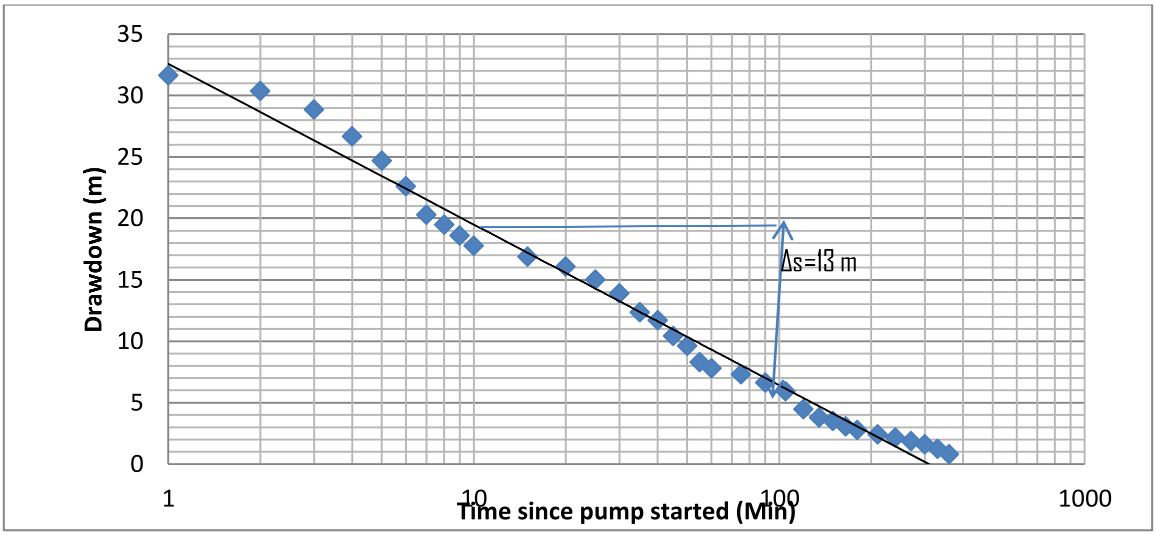

Figure 1: Time-drawdown Graph for Kpaligung borehole (Field measurements, 2015)

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Figure 2: Kpaligung network of boreholes (borehole understudy in yellow) (Field measurements, 2016)

Unlike the Kpaligung borehole, the graph of the Baleofili borehole (Figure 3) shows gradual increase in drawdown. According to MacDonald *et al.* (2005) this phenomenon indicates that the aquifer properties away from the borehole are poorer than those closer to the borehole. This could be that the aquifer is limited in extent (in other words, the expanding cone of depression has encountered a hydraulic barrier), or because shallow parts of the aquifer are being dewatered.

The geological formation of the aquifer for the borehole is the fractured rock of the granitoids. The transmissivity (T) value was therefore determined to be 0.8 m^2/d for the Baleofili borehole, while the yield was 1.8 m^3/h. According to Martin (2006), for areas underlain by granitoids, transmissivity ranges from 0.3 m^2/d to 114 m^2/d, with an average of 6.6 m^2/d. The low transmissivity of boreholes in this formation, according to Martin (2006) could be attributed to differences in degree of weathering and fracturing.

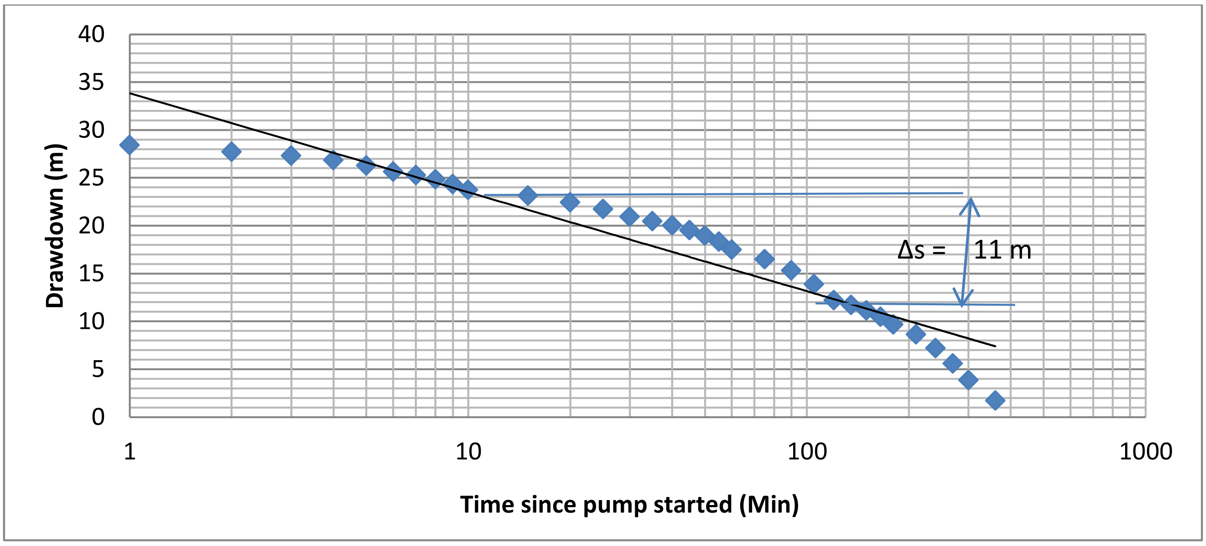

Figure 3: Time-drawdown Graph for Baleofili borehole (Field measurements, 2015)

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Recovery Tests Results for Kpaligung and Baleofili boreholes

The recovery test results of both the Kpaligung and Baleofili boreholes are presented in Figures 7 and 8 respectively. With respect to the Kpaligung borehole (Figure 4), the recovery graph confirms the fact that the borehole receives water from the aquifers of the surrounding boreholes. MacDonald *et al.* (2005) described a graph of this nature as very leaky, and the aquifer being tested is receiving water from other aquifers or aquifer layers by vertical leakage. The transmissivity of the recovery test was 0.4 m^2/d which is close to the transmissivity value (0.5 m^2/d) of pumping test.

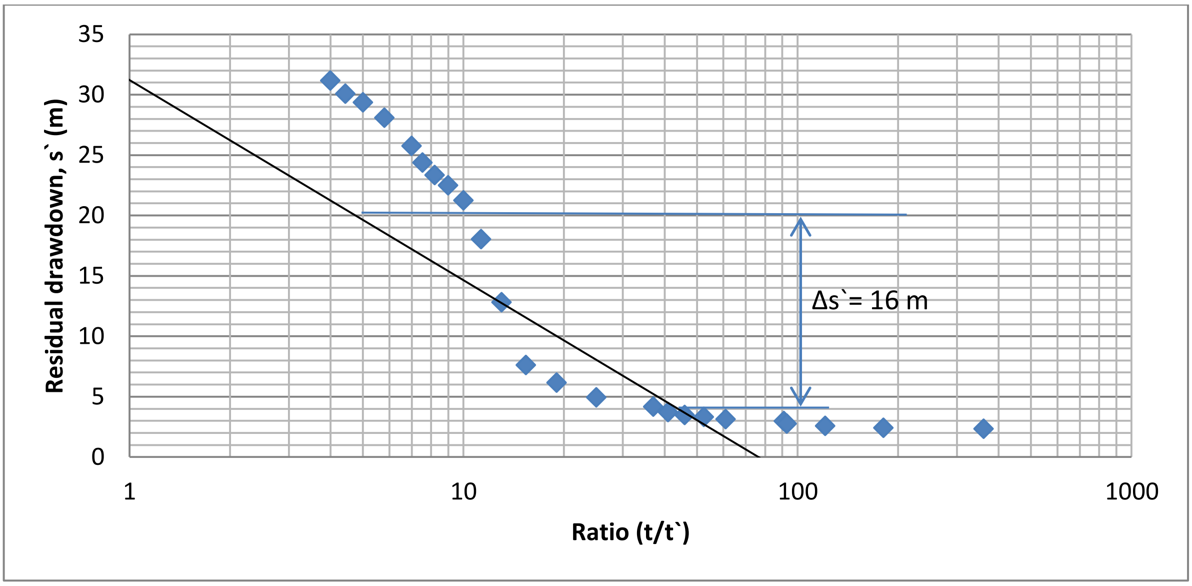

Figure 4: Time Ratio -Residual drawdown Graph for Kpaligung borehole (Field measurements, 2015)

Figure 8 depicts the graph for the recovery test conducted for the Baleofili borehole. The recovery curve deviates from the best fit line which could be the effect of cascading fracture (that is large amount of water moving into the borehole as a result of fractured rocks). MacDonald *et al.* (2005) explained that, as the water level recovers, it eventually submerges a fracture from which water was cascading (when the water level was below the fracture). However, the transmissivity from the recovery test was 0.6 m^2/d, that is 0.2 m^2/d lower than the pumping test transmissivity value. Unlike the Kpaligung, borehole which took 2 hours to recover, the Baleofili borehole took 3 hours indicating a slightly lower recovery rate as compared to the Kpaligung borehole, which received water from other aquifers during the recovery period.

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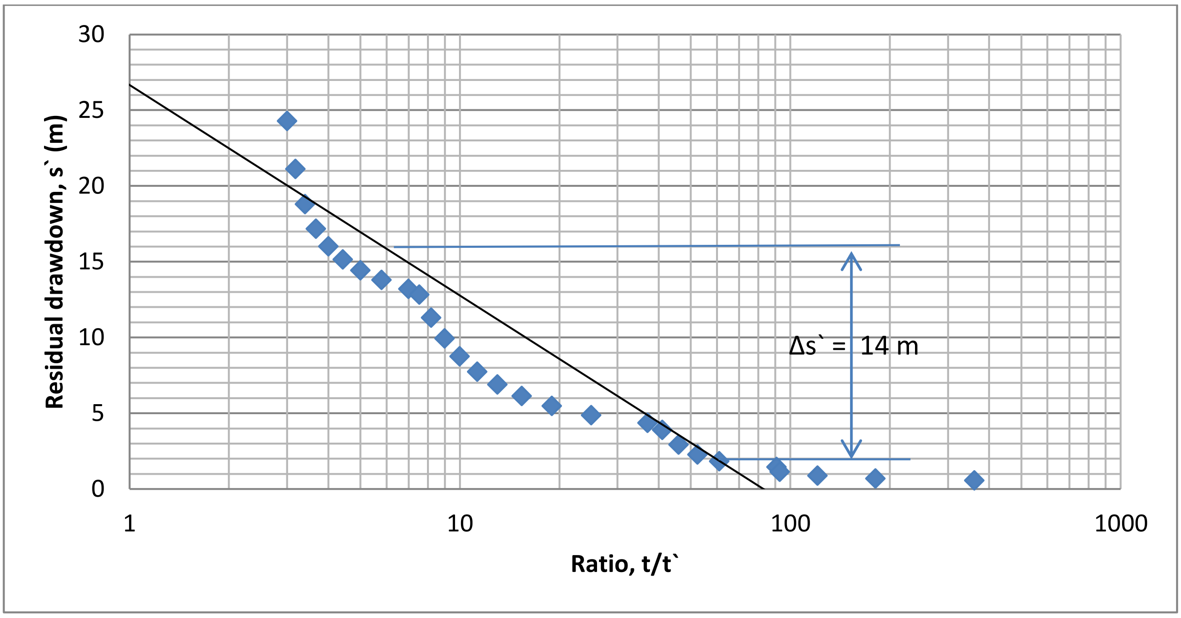

Figure 5: Time Ratio-Residual drawdown Graph for Baleofili borehole (Field measurements, 2015)

CONCLUSION

From the monitoring of the two boreholes in northern Ghana during 2015-2016, the following conclusions were drawn:

- The aquifer of the Kpaligung borehole is of Voltaian province, while that of Baleofili is Granitoid intrusions.
- The yield of the Baleofili borehole is 1.8 m^3/h, implying that the Baleofili borehole yield is higher than that of the Kpaligung borehole, which yields 1.4 m^3/h.

The Kpaligung borehole indicates gradual decrease in drawdown as pumping test went on due to the borehole receiving recharge from the surrounding boreholes as the cone of depression intercepted the aquifer of the other boreholes during the pumping test. The transmissivity (T) value was therefore 0.5 m^2/d. The Baleofili borehole shows gradual increase in drawdown which indicates that the aquifer properties away from the borehole are poorer than those closer to the borehole. The transmissivity (T) value was therefore 0.8 m^2/d.

With respect to the Kpaligung borehole, the recovery confirms the fact that the borehole receives water from the aquifers of the surrounding boreholes closer to it. The transmissivity of the recovery test was 0.4 m^2/d. For the Baleofili borehole, the recovery curve deviates from the best fit, line which could be the effect of cascading fracture. However, the transmissivity from the recovery test was 0.6 m^2/d.

RECOMMENDATIONS

- The yields of the two boreholes are sufficient for domestic water supply of the beneficiary communities
- The spatial distribution of natural recharge to the aquifer system should be studied to determine the available water resources and that consequently, groundwater development activities can be better planned.

- More intensive monitoring and data gathering efforts should be undertaken to understand the groundwater resources availability in northern Ghana, especially with regards to geology, aquifer system, and flow patterns.
- Continuous water-level data observations are critical to understanding the short- and long-term trends and stresses in an aquifer.

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