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HYDROGEOPHYSICAL INVESTIGATION OF RIVER-AQUIFER INTERACTION: A CASE STUDY OF THE BAMA-RIDGE SHALLOW AQUIFER AND RIVER NGADA, DALORI, NORTH-EASTERN NIGERIA

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Abstract
Geoelectrical depth soundings were conducted on the same area on the Bama Ridge at different times of the year, covering over three seasons. The surveys were conducted at the beginning of the rainy season and repeated at the end of it. These times corresponds to when the river bed is almost empty of water (June) and when the Ngada River is still flowing and it is at its highest stage (October) respectively. The interpreted results of the study show that the shallow aquifer of the Bama Ridge is in hydraulic connection with the Ngada River. The apparent resistivity curves also indicated that Vertical Electric Sounding (VES) could be used as a preliminary technique to explore possible river-aquifer interaction phenomena in a hydrologic system.

Keywords: River-aquifer interaction, Hydrogeophysics, Bama-Ridge, North-Eastern Nigeria

1. Introduction

Semi-arid regions are characterized by limited water resources and expanding of urban, industrial and agricultural water requirements will further increase the pressure of accessible groundwater. A quantification of groundwater recharge is therefore a prerequisite for efficient and sustainable groundwater resource management (De Vries and Simmers, 2002). In semi-arid regions the actual evapotranspiration (AET) represents a key role of the hydrological cycle. AET may account for more than 90 % of the precipitation (P) (Pilgrim *et al.*, 1988; Huxman *et al.*, 2005). A thorough understanding of the AET processes and reliable estimates of the spatial and temporal rates of AET as well as P are required to obtain reliable estimates of the available water recourses as the little difference between P and AET determines what is left for recharge and runoff. In addition the relationship between any surface water source and the existing aquifer must also be investigated. Therefore all necessary scientific methods of investigating such an area for the benefit that could be derived should be made a priority. Methods such as groundwater modeling, rainfall water harvesting, remote sensing etc are valuable tools for water resources investigations.

The Bama Ridge is a long narrow and prominent morphological feature forming part of the quaternary Chad Formation in parts of North Eastern Nigeria. It is thought to represent the ancient shoreline of Lake Chad and was formed during the late Pleistocene when it was left as a distinct sand ridge as the mega Chad receded.

This sands ridge, trends NW-SE for about 160km from the Cameroun plains extending through the tip of the Mandara mountains in Nigeria, passing through Bama and Maiduguri towards Nguru and Gashua and finally it flattens out beneath the sand dunes of the Niger plains.

The study area falls on the topographic sheet 90 (Maiduguri) and is geographically located between latitude 13°9' – 13°15'N and longitude 13°10' – 13°13'E. The area surrounding the exposed sections of the Bama ridge in the study area is relatively a flat plain, except for the ridge itself whose strandline stands at approximately 12m above the surrounding plain.

The sections studied are the exposed Ridge that runs more or less parallel to the river. Figure 1 shows the geological map of the study area, with Bama Ridge indicated.

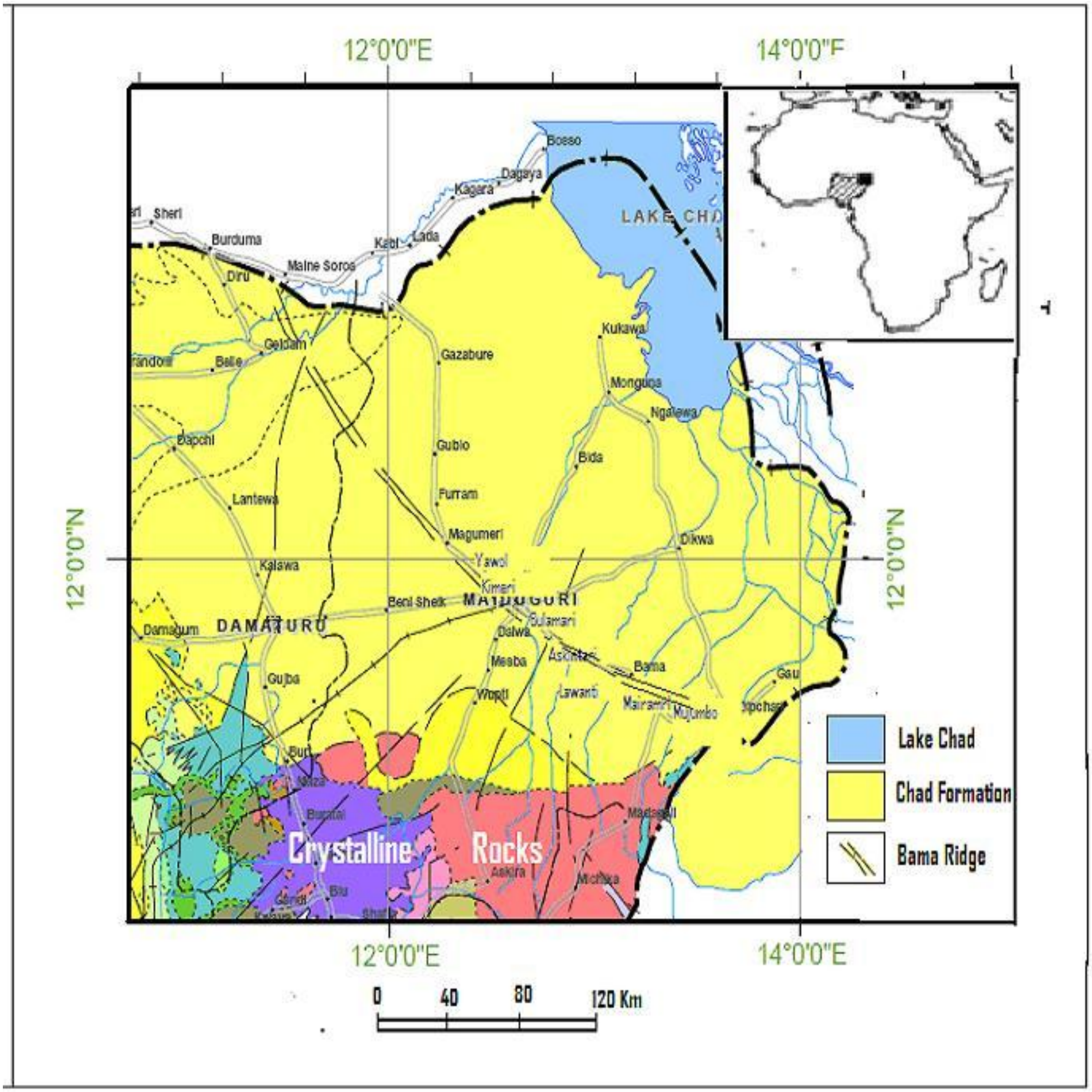

Figure 1: Geological map of a portion of the Chad Basin showing the trend of the Bama Ridge

2. Statement of the problem

Bama-Ridge occupies an economically important position around Maiduguri metropolis and it's environ. It serves as a ready- made site for residential building developments by individuals and the state government. It also provides fertile land for farming of vegetables along the shores of Lake Alau. These developments have resulted in the drilling of a lot of bore holes, locally called wash-bore holes. The consequences of these developments in general and for the groundwater reserve in particular could be far reaching, because the groundwater in the local shallow aquifer may be put under stress. One of the questions that might arise on the utilization of the groundwater in the Bama-Ridge shallow aquifer is, could it be stressed and endangered by likelihood of over exploitation?

The scenario of what happens to an aquifer interacting with a river was discussed by Hassan *et al*. (2010). In the paper it was pointed out that withdrawing water from shallow aquifers that are directly connected to surface-water bodies can have a significant effect on the movement of water between these two water bodies. Also Rushton and Tomlinson (1979) and Miles and Rushton (1983) both reported that the leakage of water between aquifers and rivers depend on the relative head difference between the two water bodies. In another paper Hassan and Carter (2004) showed that riverbed sediment could also significantly affect the leakage. These papers however approached the problem of river-aquifer interactions using numerical modeling domain.

Therefore in this paper a different approach was adopted whereby a hydrogeophysical study was carried out to investigate the hydraulic characteristics of the shallow aquifer and the likelihood of it being hydraulically connected to the perennial Ngada River. Knowledge of this type of relationship could inform stakeholders on the consequences or otherwise of any action in the management of the shallow aquifer.

3. Data collection and analysis

Direct current resistivity method is a common tool for surveying water in arid areas. It is well known that this method can be successfully employed for ground water investigations, where a good electrical resistivity contrast exists between the saturated and unsaturated layers. The vertical electrical sounding with Schlumberger array as a low-cost technique and veritable tool in groundwater exploration is more suitable for hydrogeological survey of sedimentary basin. This method is regularly used to solve a wide variety of groundwater problems. Some recent studies include: determination of zones with high yield potential in an aquifer (Ahilan and Kumar, 2011; George *et al*., 2011; Joshua *et al*., 2011; Nejad, 2009), determination of the boundary between saline and fresh water zones (Sikandar *et al*., 2010; Hodlur *et al*., 2010; Adeoti *et al*., 2010), delineation groundwater contamination (Abdullahi *et al*., 2011; Ugwu and Nwosu, 2009; Enikanselu, 2008), exploration of geothermal reservoirs (Cid-Fernandez and Araujo, 2007; El-Qady, 2006), groundwater exploration in hard rock (Nwankwo, 2011; K'Orowe *et al*., 2011; Armada *et al*., 2009), estimation of aquifer specific yield (Onu, 2003) and estimation of hydraulic conductivity and transmissivty of aquifer (Ekwe *et al*., 2010; Egbai, 2011; Majumdar and Das, 2011; Tizro *et al*., 2010).

Apparent resistivity data were collected, using Schlumberger array, from eight (8) vertical electrical sounding (VES) points. Though the points were chosen randomly, consideration was given to both economy and proximity to the community in the study area within a maximum distance of half a kilometre.

The set of data were interpreted using a resistivity inversion program IPWIN2. Figure 2 (a) and (b) show typical interpretations of the apparent resistivity data for VES-I and II which typify the data collected at other stations within the study area in June and October respectively. That is at the beginning and end of the rainy season.

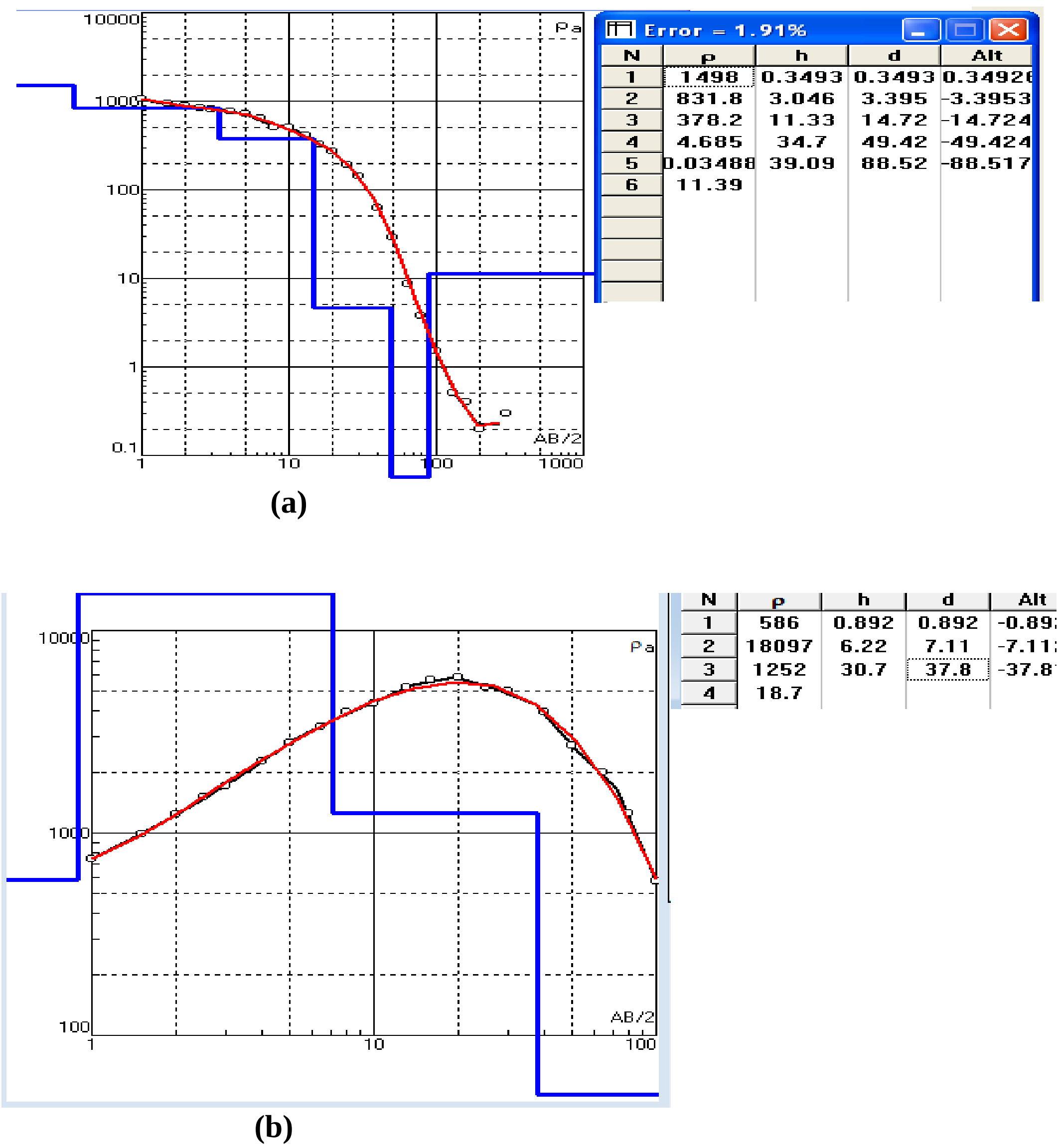

Figure 2: Typical interpreted VES curve for (a) the rainy season (Sept-Oct, 2007) and (b) the dry season (June-July 2007).

4. Discussion of results

A side-by-side comparison of the VES interpreted curves were carried out as shown by the figures for each survey for the three seasons.

Figure 2(a) and (b) are typical interpreted data for the 2007 season. The first figure suggessted that at the end of the rainy (Sept-Oct) low resisitivity layer was encountered at a depth of 14.72 meters below ground level. The value of the resistivity at this depth indicated a water bearing layer was encountered. This earth formation containing water continued for a depth of 88 meters.

Comparing the data in Figure 2(b), one can see that at the end of the dry season (June-July) low resistivity layer was encountered at a depth of 37.8 meters. This suggessts that there is a likely drying up of the formation from October-June-July before it ws replenished by rainfall and the river from July-October. This gives a difference of almost 23 meters rise in the suspected water table between the months of July and October in the shallow Bama Ridge Aquifer.

Other interpretations of the VES for the 2008 and 2009 seasons are shown in Figures 3 and 4 respectively. The curves show almost similar behaviour and therefore share same description to those from 2007 season. They however differ in their physical results.

Figure 3(a) and (b), the 2008 season results and Figure 4(a) and (b), the 2009 season results, also show that the rains and the river have strong influence on the shallow aquifer.

According these interpretations, the wet layer was encountered at a depth of 10.5 meters and 13.3 meters respectively in 2008 and 2009, October VES soundings. While during the June-July sounding data show depths of 23.3 m and 19.7 m.

These results further suggessted that the average depths to the water table in the wet season varies from 10.5 – 14.7 meters, while it varies from 19.7 to 37.8 metersin the dry season. This also implies that the average rise in water table varies from 9 to 23 meters in a typical season. Could this indicate the quantum of recharge to the shallow aquifer and also the extent of discharge due to many factors during the long dry season?

Shallow wash bore holes in the neaby settlements of Dalori GRA and the 202 Housing Estate, has shown good agreement to our results. In some of these bore holes drillers encounter water tables at different depths depending on the time of the year.

And consumers have also complain of their bore holes output falling during the dry season and measurement of the depth to the water table were in tens meters of what it was in the wet season.

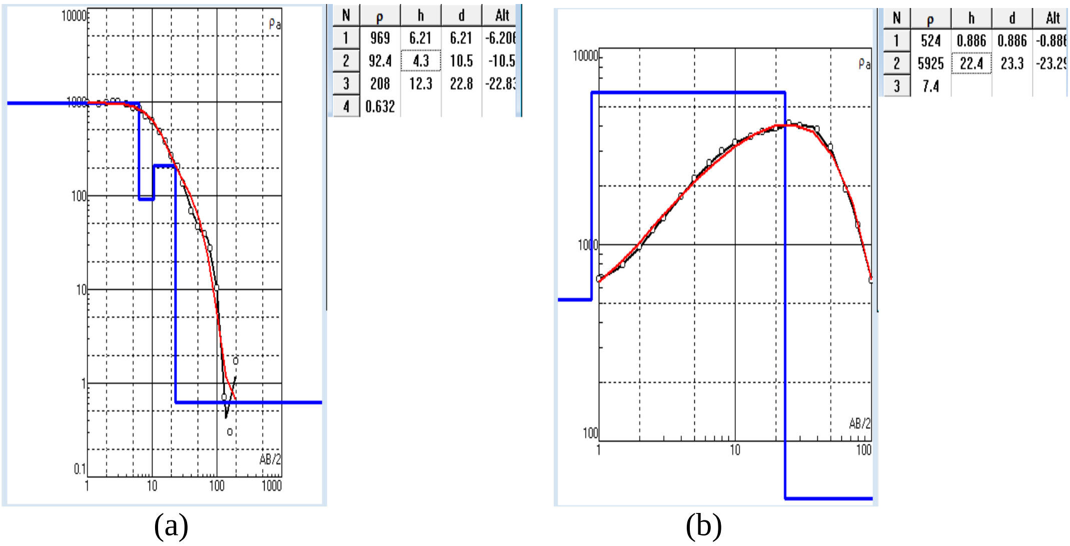

Figure 3: Typical interpreted VES curves for the (a) rainy and (b) dry season (2008)

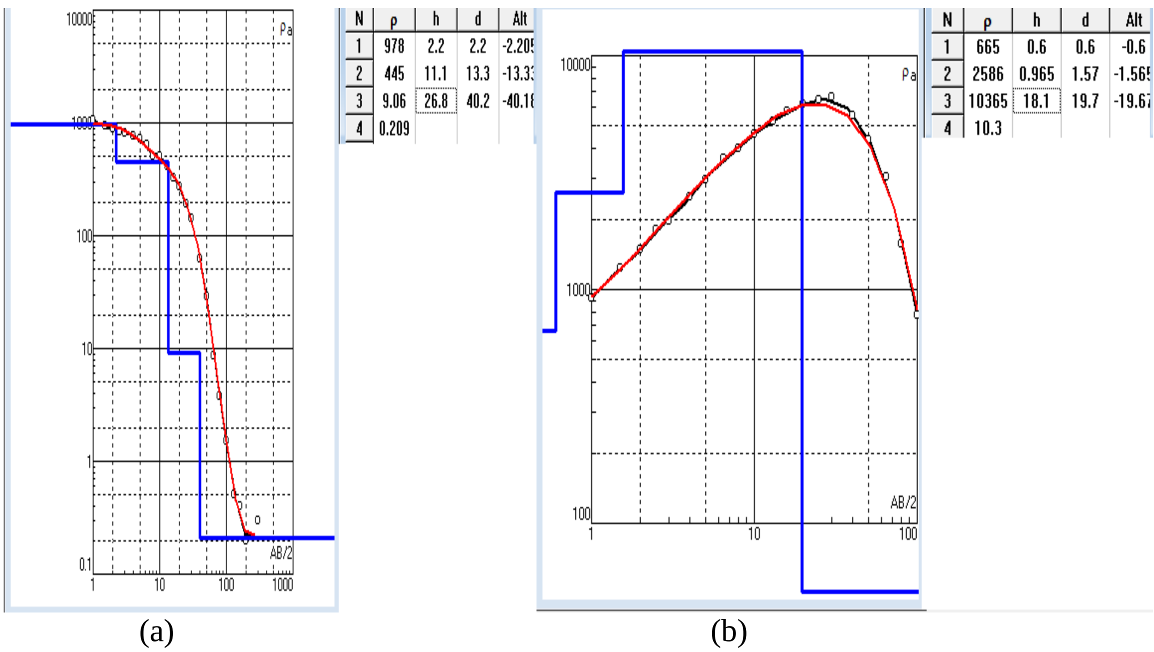

Figure 4: Typical interpreted VES curves for the (a) rainy and (b) dry season (2009)

5. Conclusions and Perspectives

Hydrogeophysical investigation of river-aquifer in a semi-arid region is more difficult than in other hydrological regimes due to more extreme hydrological conditions in combination with a large spatial variability of landscape characteristics. A further complication that hampers reliable suido-model of the system interactions is scarcity of data for such regions. In this study a vertical electric sounding has been applied to the Bama Ridge- River Ngada system, to investigate the water resources despite these complicating circumstances. The method has proved to be a valuable tool for analyzing the hydrological behavior of the catchment and for examining the water exchanges between the hydrological compartments. The method has also led to the followings:

- The Bama Ridge contains a shallow aquifer that is in hydraulic connection with River Ngada.
- The depth to the shallow aquifer varies from place to place, with an average depth of 20 meters below ground level.
- The vertical electric sounding can be used for investigation of river-aquifer interactions.

Further development and application of other methods of water resources studies needs to be considered in such regions. For example, existing distributed modeling capabilities are needed to improve the simulation of semi-arid catchments particularly with respect to flow in highly degraded lands, flow in perennial rivers with dynamic river courses and the associated loss of discharge as infiltration into the river bed, direct runoff on semi-impervious landscapes and slopes. Alongside these, new measuring technologies need to be developed for continuous and on-demand measurements of hydrological variables. A major source of uncertainty for the hydrological simulations is the regional precipitation input to the catchment. In this regard weather radar seems to offer promising opportunities.

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