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VERY LOW FREQUENCY ELECTROMAGNETIC (VLF-EM) SURVEY FOR GROUNDWATER DEVELOPMENT IN BICHI/BAGWAI AREA, NORTH WESTERN NIGERIA

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ABSTRACT

A Detailed Very Low Frequency Electromagnetic (VLF-EM) hydrogeophysical survey was undertaken to identify conductive zones and recommend potential areas for possible groundwater development in the Bichi area of Kano state northwestern Nigeria. The area is characterized by porphyritic granite, coarse grained granite and medium to fine grained granite. The VLF-Electromagnetic method was adopted as a fast reconnaissance tool to map possible linear fractures. During the survey, measurements were taken at a station interval of 20 m along each profile line ranging from 0 – 420 m, making a total of six VLF-EM traverses which were mapped in the study area. The filtered components for both real and imaginary parts of the VLF-EM data were plotted against distance for each profile using the Karous–Hjelt filter® computer software to interpret and identify the top of linear fractures. The Very Low frequency (VLF) normal and filtered component anomalies identified ten (10) major geological interfaces suspected to be faults/fractured zones (f_1 – f_{10}). These suspected zones were marked as targets for future groundwater development in the area since these anomalous zones are areas of high conductivity and this parameter is one of the physical characteristics of water saturated zones. Therefore, this work has proven that VLF method is robust in tying down good locations for groundwater development in rural areas.

Keywords: Conductive Zones, Electromagnetic, Fault, Fractures, Groundwater Development, Hydrogeophysical

INTRODUCTION

Groundwater is considered to be one of the most valuable fresh water resources to sustain life and a satisfactory (adequate, safe and accessible) supply must be available to all. Improving access to safe drinking-water can result in substantial benefits to health. Efforts should be made to achieve drinking-water that is as safe as possible (WHO 2017). The largest source of fresh water lies under the earth's surface and increase in demand for water has stimulated efforts in the development and exploration of Groundwater resources (Todd 2005). Underground water accounts for more than 95% of worldwide storage for freshwater (Shiklomanov, 1998; Healy, *et al*., 2007). Groundwater is characterized by a certain number of parameters which are determined by geophysical methods such as electrical resistivity methods, seismic methods, magnetic methods, gravity methods and so on. Several geophysical methods have been used in hydrological investigations for decades (Raji, *et al*., 2020). The communities located in the basement complex terrain are commonly associated with problems of groundwater supply due to the crystalline nature of underlying rocks which lacks primary porosity and the capacity of groundwater storage. Basement complex communities depend primarily on the depth of weathering and intensity of fracturing of the underlying rocks (Bala, 2008). The presence of groundwater in any given area depends on the thickness and lateral extent of decomposition and where both occur, the groundwater condition is usually very good (Arabi *et al.,* 2010).

(Akpaneno and Abdulwahab, 2020) investigated the contamination of groundwater at Isa Kaita college of education male hostel using DC Resistivity geophysical method and identified four layers, namely: Topsoil, weathered basement, fractured basement. The value of VES 03 and VES 04 have high electrical conductivities which showed they are contaminated, The topsoil resistivity along the profile ranges from approximately 1 Ώ to 154 Ώ. The depth to basement (basement topography) Varies from 4.94 m to 7.59 m, with aquifer thickness range of 1 m to 6.8 m.

Over the years, people of this community have really suffered enormous problems of water supply either surface or groundwater. These problems have been noticed to be much more severe at the peak of the dry season when ironically demand for water is greatest and most of the surface sources dry up completely. Before now, the greater majority in the community relied on such sources as streams and ponds especially during the dry seasons when hand-dug wells would have dried up. This situation definitely led to the outbreak of water borne diseases like cholera, diarrhea that seriously threatened lives in the community. This study is focused on evaluating the groundwater potential of the area and more importantly, providing information on the hydrogeological framework of major aquifer units, and delineation of areas suitable for groundwater development.

Study Area

The study area lies between latitudes 12° 00' 00" to 12° 00' 15"N and longitudes 8° 00' 00" to 8° 00' 15"E of the Federal Survey Sheet (Bichi Sheet 57SW) covering an area of about 770 km^2 (Figure 1).It comprises of the present Bagwai and Bichi Local Government Areas of Kano State and is located in the Northwestern part, about 50 km away from Kano metropolis. It is accessible through major roads; Kano-Katsina Road and Gwarzo-Shanono-Bichi Road and is accessible through numerous footpath networks. Mostly the populations are majorly farmers practicing rain-fed agriculture and a little irrigation agriculture in some parts. The area is noted for its climate with relatively wide and rapid changes in temperatures and humidity. Humidity at times can rise to about 100% in an area considered characteristically dry. The mean daily maximum and minimum temperatures are 15.5ºC and 33.1ºC respectively. The climate period is divided into the rainy season and the dry season. The dry season lasts from October to May. During December and January, the Harmattan is at its highest blowing with thin dust over the area from the Sahara Desert. Rainfall is concentrated from June to September. The average annual rainfall is 870.20 millimeters. About 56% of this fall in July, August and September.

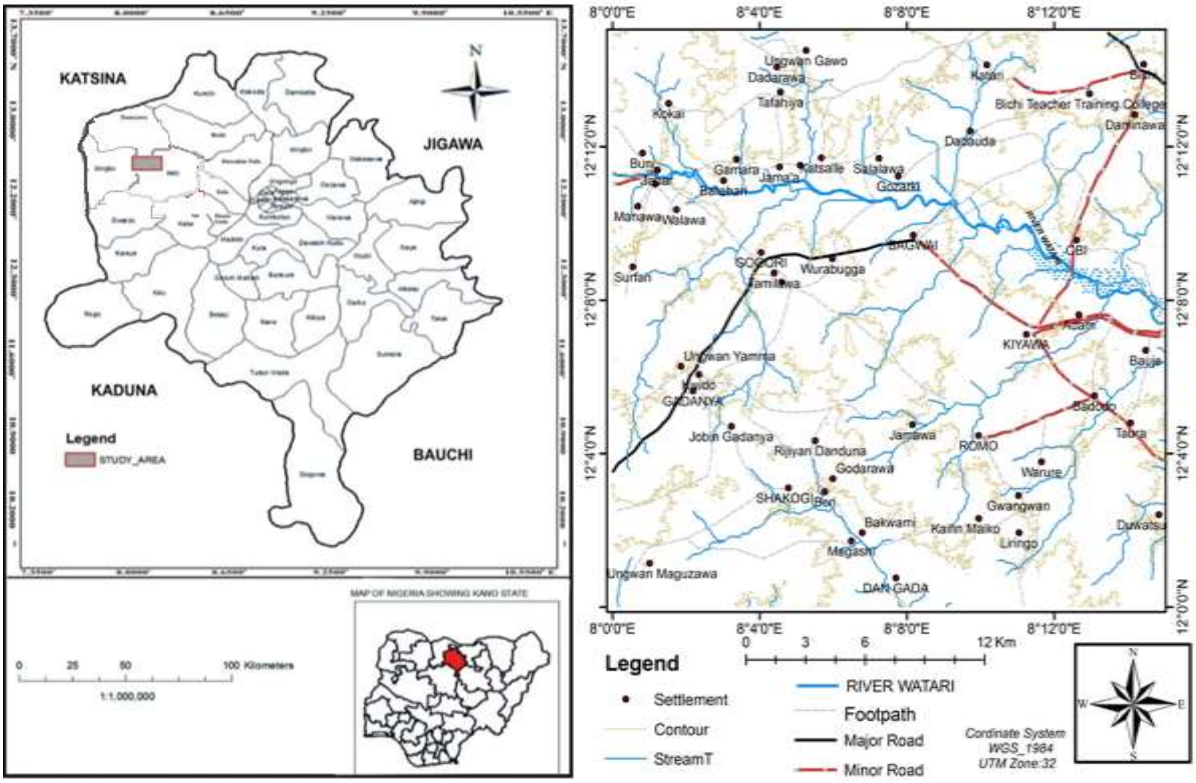


Figure 1: Location Map of the study area

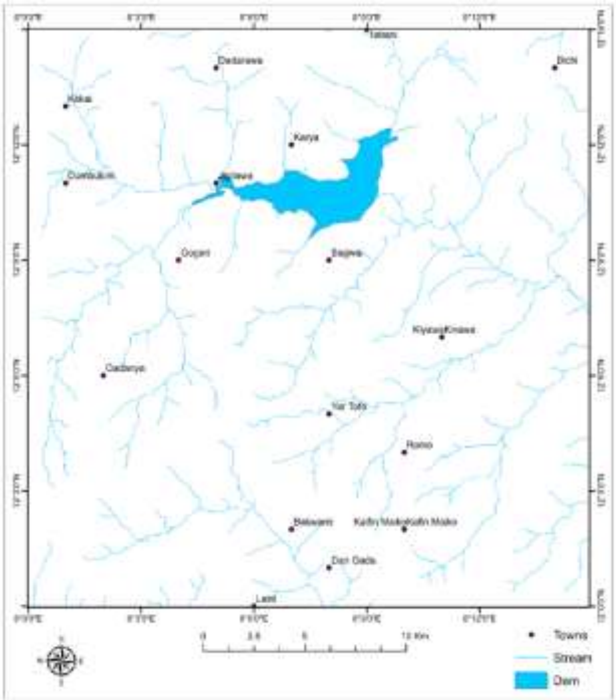


Figure 2: Drainage Map of the Study Area

Geological Setting of the Study Area

The Bichi area occurs within the Precambrian basement complex of Northwestern Nigeria and therefore should be expected to have groundwater problem unless there is/are evidence(s) of fracturing and weathering activities on the rocks constituting the area. Also, the degree or extent of these activities would determine the quality of aquifers. The area is characterized by porphyritic granite, coarse grained granite and medium to fine grained granite. Highly productive water wells are obtained by drilling in rock that is broken along joints and small fractures (Olayinka *et al.,* 2004; Dan-Hassan & Adekile 1991).

Electromagnetic (EM) profiling is a widely used geophysical method in the delineation of basement regolith and location of fissured media and associated zones of deep weathering in crystalline terrains (Beeson & Jones 1988; Hazell *et al.,* 1988; Olayinka 1990; Olayinka *et al.,* 2004). In many instances, reconnaissance EM surveys are used to located aquiferous zones such as fractures, faults and joints (Palacky *et al.,* 1981; Benard & Villa 1991; Omosuyi *et al.,* 2007). Geophysical methods play an increasingly important role in the search for these suitable and productive groundwater reservoirs. Electrical resistively method has been used routinely in exploration for groundwater. However, several other geophysical methods have been applied successfully either singly or in combination, for prospecting for groundwater resources in varying geologic situations. The very low frequency electromagnetic (VLF-EM) method is useful in groundwater investigation in basement terrain, most especially as a reconnaissance tool. Also, geophysical techniques such as gravity, seismic refraction, can be applied during the search for groundwater depending on whether the search is on a regional or local scale. This study is focused on assessing the groundwater prospect of the area and more importantly, providing information on the hydrogeological framework of major aquifer units, and delineation of areas suitable for water wells.

MATERIALS AND METHOD

Very Low Frequency Electromagnetic (VLF-EM) geophysical method was used for the geophysical investigation. The VLF-EM investigation involved mapping the terrain in terms of its conductivity distribution, which has the ability to provide salient information about some structural features such as fractures, joints or faults as well as to delineate the thickness of the weathered profile on the basis of a conductivity contrast between the saturated weathered layer and the unfractured crystalline basement rocks (Poddar and Rathor 1983). Measurements were taken along the profiles which were perpendicular to the geological structures in the field that is, NE–SW. A total of 6 VLF-EM profiles were occupied with the profile length ranging from about 0 to 420 m. Readings were taken at a station interval of 20 m each to obtain a depth measurement of up to 100 m. The VLF-EM profiles ran through the basement terrain with the aim of determining the variation in the conductivity contrast across the transition zones. The idea is to map the near surface environment across the contact zone which is expected to give the current density contrast between the weathered and the fresh basement rocks in the basement terrain and thereby map the nature of the basement rocks. The VLF-EM method does not require contact with the ground and can be deployed easily, thereby saving time as compared with some other geophysical methods. The Karous–Hjelt filter® was used in data processing to enhance the signal-to-noise ratio, such that the elipse and tilt-angle crossovers will be easier to identify. The filter also converts tilt-angle crossovers into peaks and calculates the equivalent source current at a given depth, which is known as the current density.

RESULTS AND DISCUSSION

Interpretation of VLF-EM Profiles

Representative current density plots of Karous–Hjelt filteredVLF-EM data (raw VLF-EM data were pre-filtered using a Fraser filter before Karous–Hjelt filtering) are presented in the figures below. The plots show the conductivity distribution of the subsurface along the profiled stations. Conductive zones display characteristically high current density, which range from 0to 15, while the non-conductive zones have negative values (-60–0). Three distinct zones were delineated, based on the current density distribution. The first is the highly resistive zone with a current density value of less than -20. This zone corresponds to the fresh basement rocks in the basement terrain. The second is the intermediate zone with a current density value ranging between -10 and 10, which is typical of rocks that are slightly resistive to slightly conductive, such as moderately saturated weathered crystalline rocks in the basement terrains. The third zone is highly conductive, with a current density value greater than 10. Saturated weathered profiles, clay units and saturated sandy units fall into this group. Electrical Resistivity and Very low frequency electromagnetic (VLF-EM) induction was employed in a survey of shallow hydrocarbon contamination of groundwater in Utah County, Utah, United States in 1997 (Alvin *et al.,* 1997).

Interpretation of Very Low Frequency Electromagnetic (VLF-EM) is basically qualitative and it involves visual inspection of the profile for points where the maximum peak of the Filtered Real coincides with the point of inflection of raw real as such points are usually suggestive of presence of conductive (weak) zones. Several of such points were identified on the profiles. Furthermore, the presence of multiple peak Positive filtered real anomalies (as observed on the profiles) is suggestive of inhomogeneity of near surface structures/material. The result obtained from this work is in agreement with Miranda *et al.,* (2021) who conducted a hydrogeophysical survey for the evidences of groundwater exploration potentiality in Bicudo Farm of São Gonçalo, Bahia, Brazil using a combined study of electroresistivity and VLF and identified basement and two zones of high conductivity (one shallower and the other deeper) that occur in all lines that characterized the aquifer in the study area. (Alabi *et al.,* 2021) who also investigated the groundwater potential of Moloko-Asipa, Ogun State, Nigeria using integrated geophysical methods and reported that the VLF-EM results obtained showed that the geology of the area has an average depth of 25 m, revealing that the potential for groundwater exploration in the study area is poor due to the thin nature of the weathered layer and its shallow depth to basement and the aquifer protective capacity of the area was likewise inferred to be poor. The plots of filtered real are presented as profiles (Figures 4 - 9) with their corresponding Karous-Hiljet (K-H) pseudo sections respectively. The interpretation of these profiles and pseudo sections were basically qualitative or semi quantitative. The pseudo section is a measure of conductivity of the subsurface as a function of depth. The conductivity is shown as colour codes with conductivity increasing from left to right (from negative to positive). Different features of varying degree of conductivity trending in different directions were delineated on the sections.

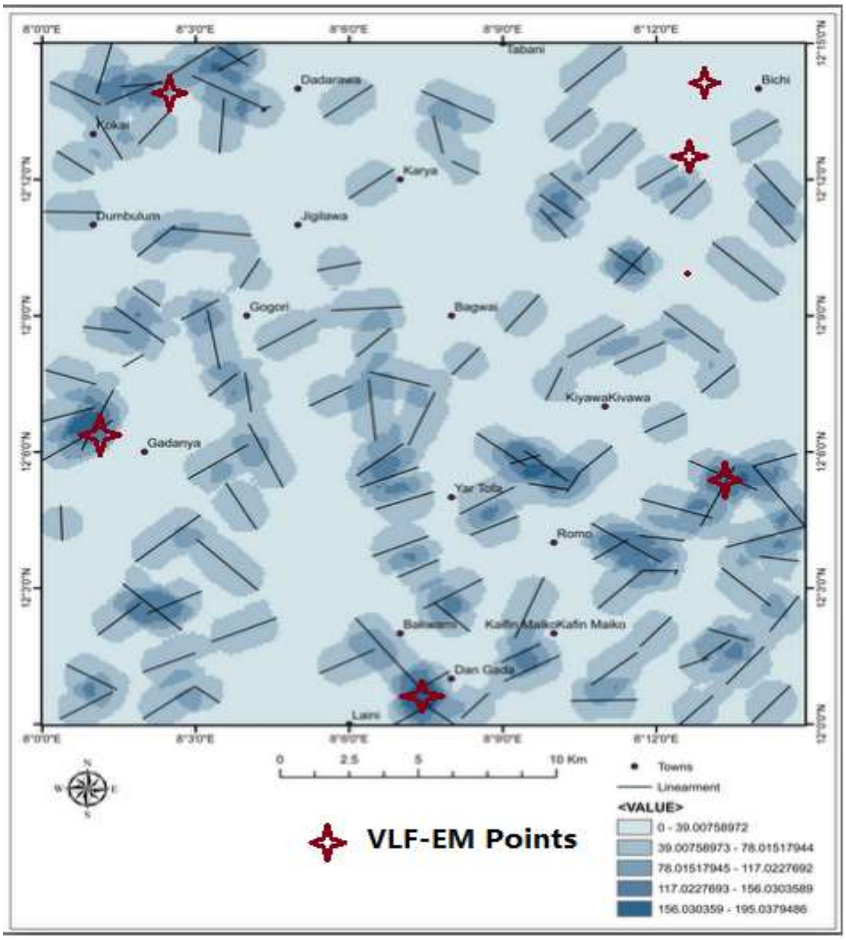
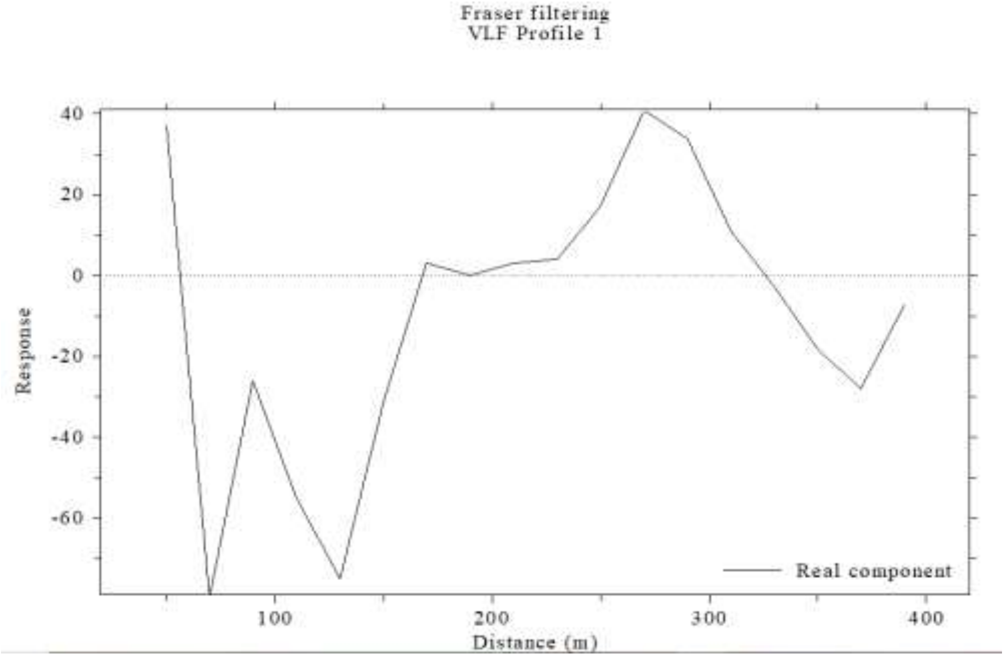


Figure 3: Lineament Density Map of VLF-EM Profiling Points

Interpretation of VLF-EM Sections



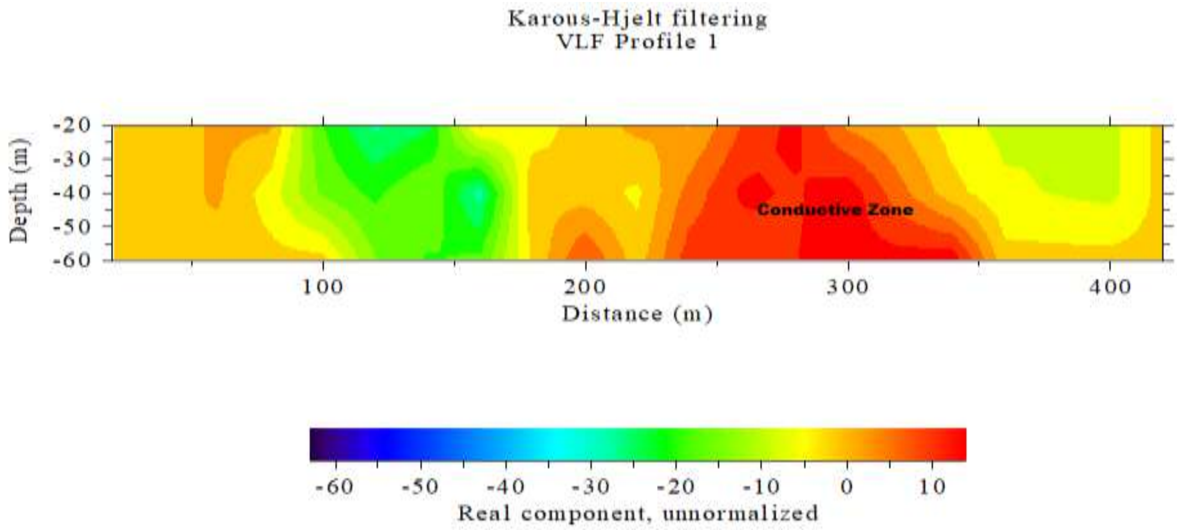


Figure 4: Current density distribution across VLF-EM Transverse 1

VLF-EM Traverse 1 shows only 1-region of high conductivities, that is, the region in which the highest peak is observed at about 300 m. (Fig. 4). The point indicates possible presence of conductive fluid within soil/rock pores, joints and fractures. The points of very low peaks are; 70 m, 130 m and 360 m at 70 m being the lowest peak indicating low conductive zones.

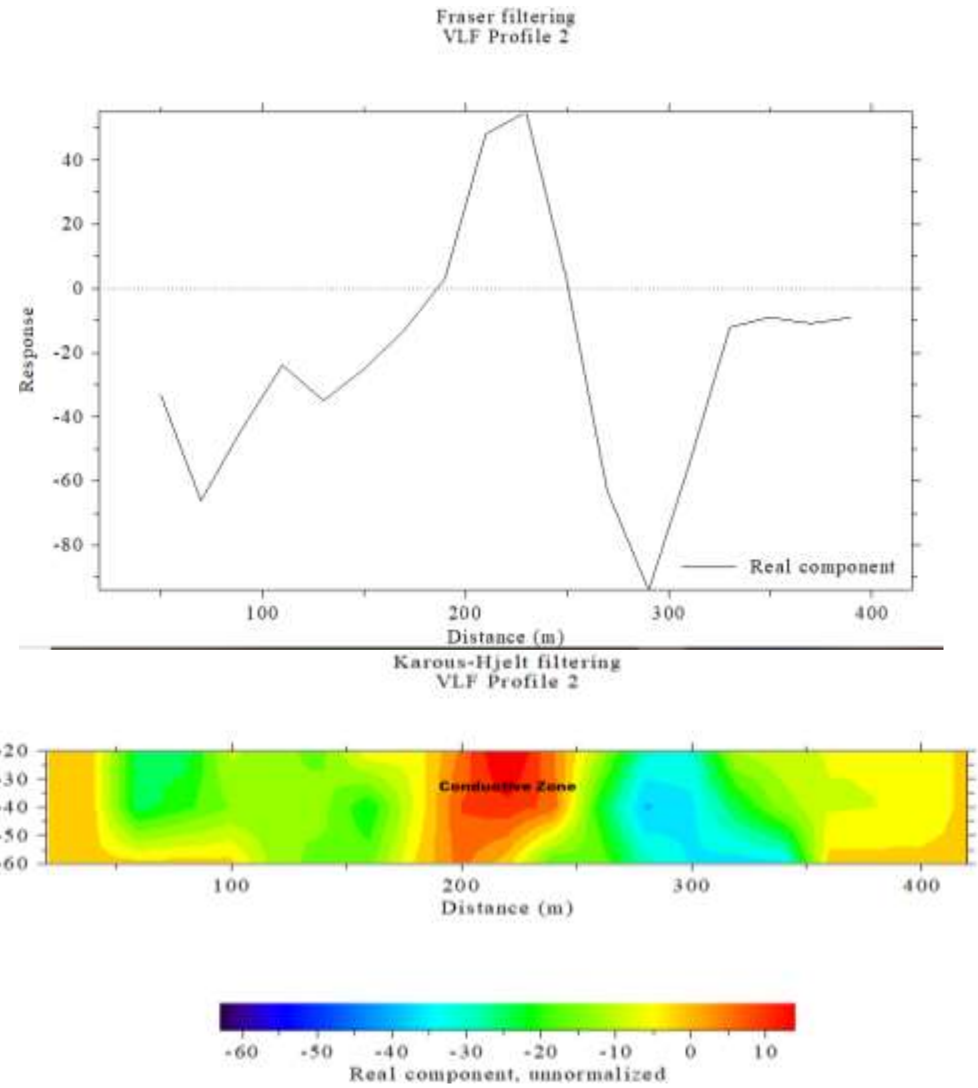


Figure 5: Current density distribution across VLF-EM Transverse 2

VLF-EM Traverse 2 has about 10 point stations with maximum distance of 420 m along which measurements are taken in the NW-SE direction (Fig. 5). It shows maximum peak at about 200 m indicating presence of a highly conductive medium, that is, conductive fluids may be located along faults/fractures. Other points on the profile show low to very low conductivity peak at 75 m and 290 m hence constitutes region of low conductive zones.

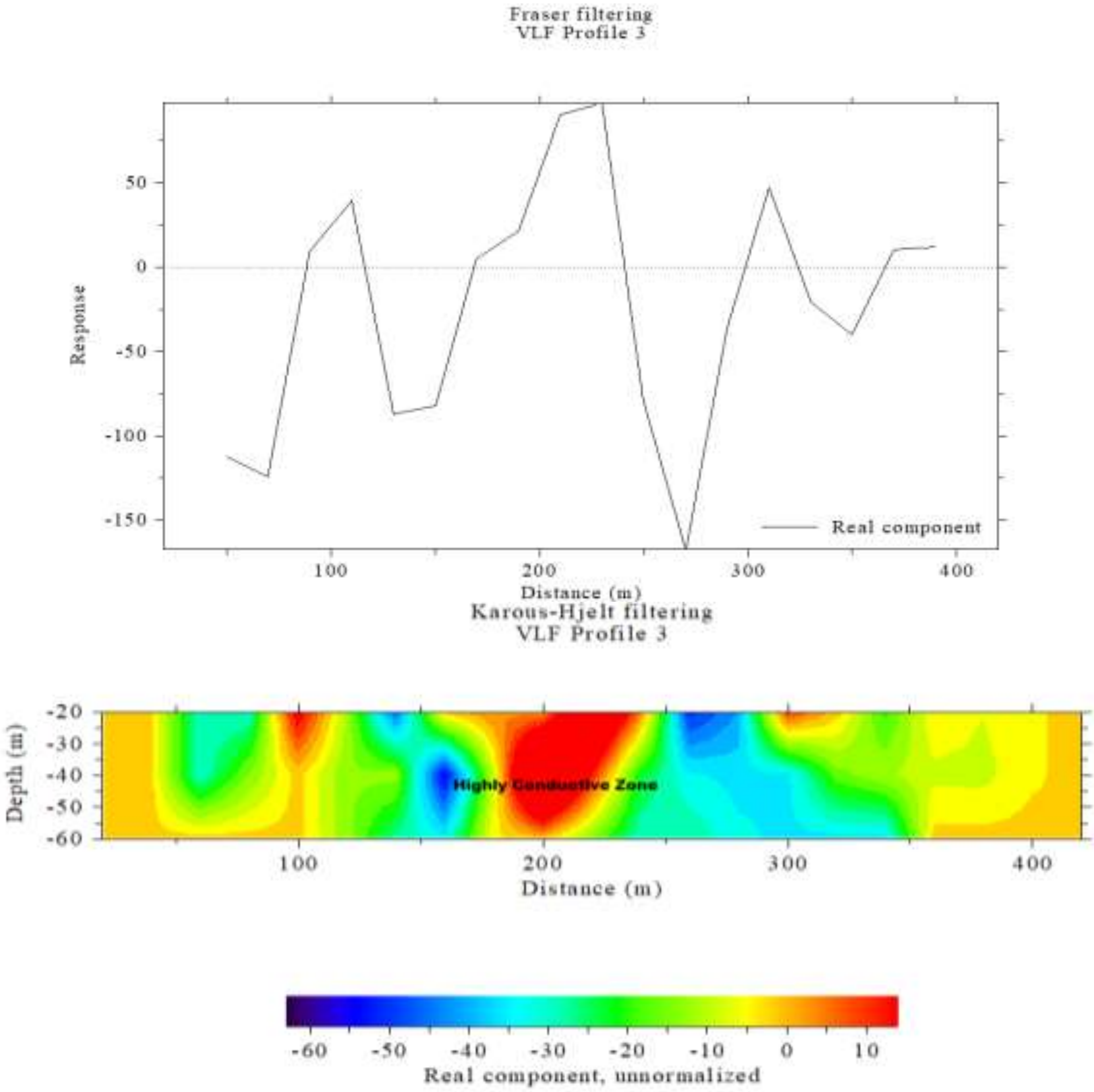


Figure 6: Current density distribution across VLF-EM Transverse 3

VLF-EM Traverse 3 is also about 420 m in length and measurement was taken in the NW-SE direction. This part of the study area has a high conductivity peak at about 200 m, 100 m and 300 m (200 m being the highest peak). The points of low conductivity peak are at 150 m, 270 m and 350 m (270 m being the lowest peak) which also indicates region of low conductivity.

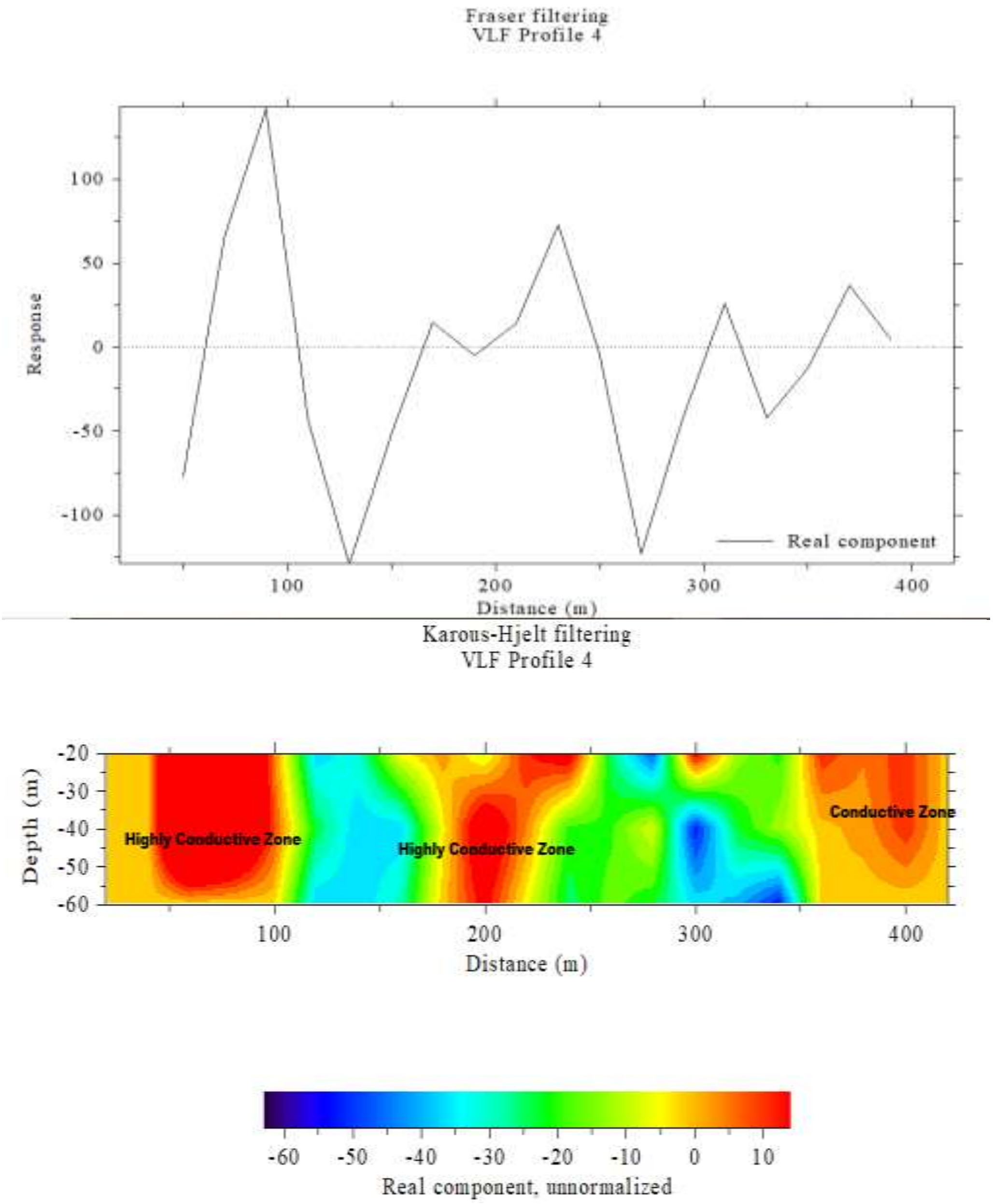


Figure 7: Current density distribution across VLF-EM Transverse 4

VLF-EM Transverse 4 is about 400 m long; the measurement was also taken in the NW-SE direction. The Karous & Hjelt filter indicates high conductivities at about 50 – 100 m, 220 m and 400 m respectively. Along the profile, low conductivity peaks were noticed at 130 m and 270 m.

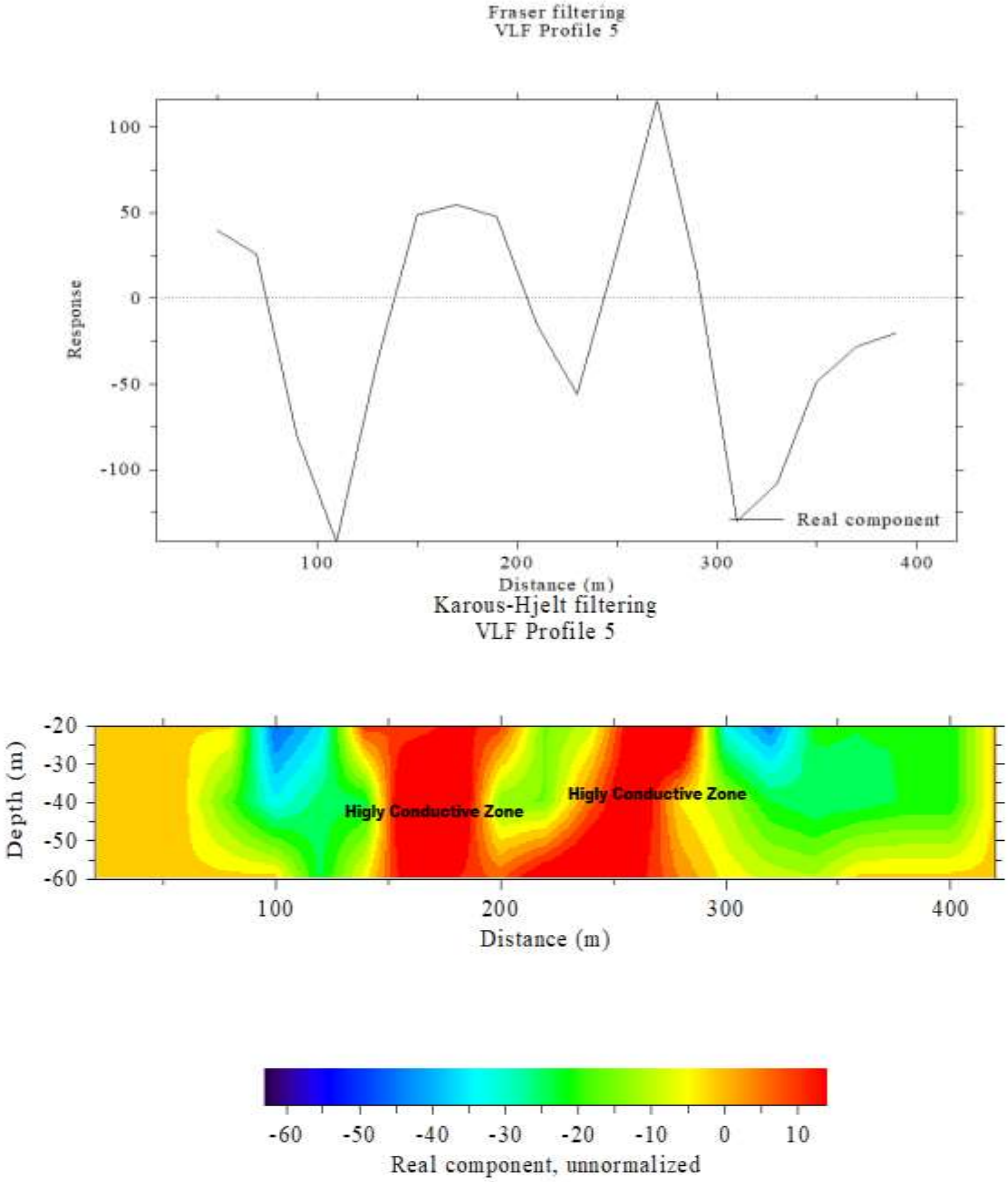
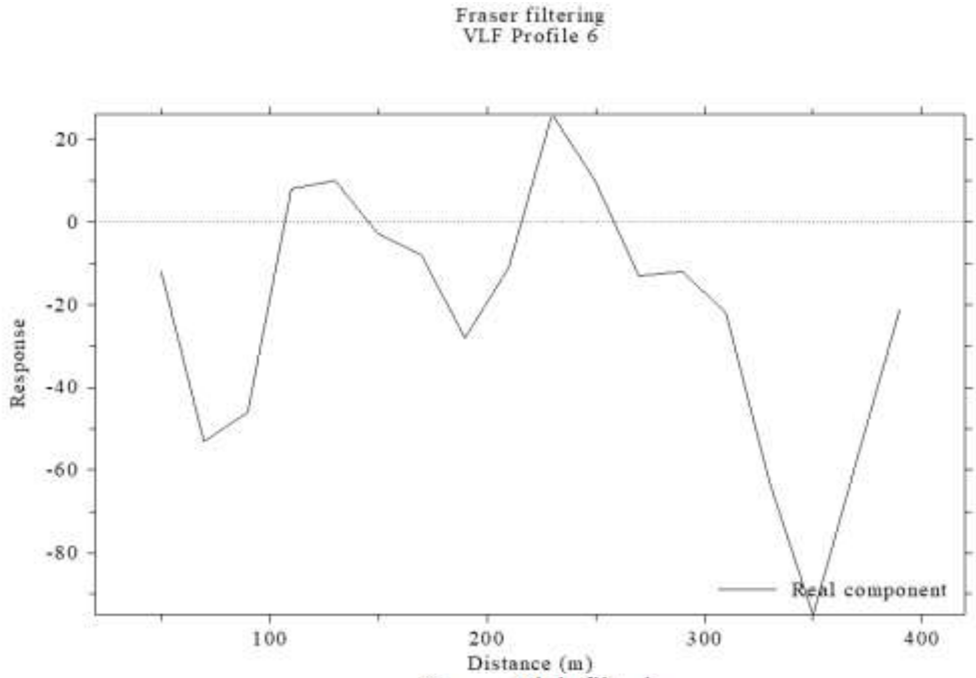


Figure 8: Current density distribution across VLF-EM Transverse 5



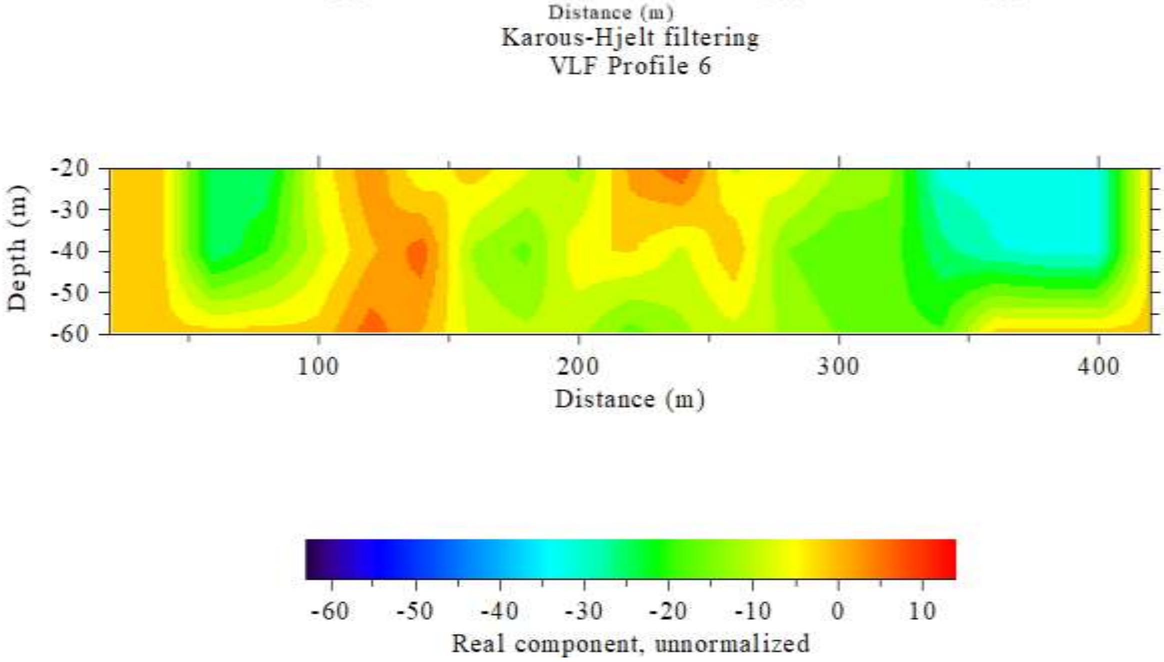


Figure 9: Current density distribution across VLF-EM Transverse 6

CONCLUSION

The electromagnetic profiling survey of the Bichi area have contributed to a better understanding of part of the basement complex of Northwestern Nigeria. Sites with high electromagnetic anomaly (high positive filtered real anomaly) can be expected to be aquifers, implying locations suitable for the development of groundwater resources. However, airfilled, altered or fissured bedrock, or predominantly clayey regolith may exhibit such anomalies and therefore proper care has to be observed during interpretation. Ten (10) major geological interfaces identified as f_1 to f_{10} were inferred from the VLF-E profiles. All interfaces are subsurface fractures or compacted overburden at greater depths. In this study, data from the VLF-EM survey has provided qualitative information on the hydrogeological framework and subsurface disposition of major aquifer units in the study area. Therefore, based on the results obtained, it can be concluded that the use of electromagnetic profiling is not efficient enough to determine the groundwater potential in the study area as it can only provide qualitative interpretation.

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