Global Journal of HUMAN-SOCIAL SCIENCE: B
Geography, Geo-Sciences, Environmental Science & Disaster Management
Volume 19 Issue 1 Version 1.0 Year 2019
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-460X & Print ISSN: 0975-587X

Detection of Fracture Zones for Groundwater Investigation from Interpretation of VLF-EM Anomalies of Kwara State Polytechnic Ilorin and its Environs

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GJHSS-B Classification: FOR Code: 050299

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I. Introduction

The VLF-EM technique was developed in the 1960s with the use of the transmitted signals of the already established powerful radio communication stations (in the 10-30 kHz band). The transmitters of these stations generate primary fields with horizontal magnetic components (H_y), and vertical electric component (E_z). Both components are perpendicular to the direction of propagation (X). At great distance, their wave front is considered uniform and plane. It is known that the induction caused by the primary magnetic field in a homogenous earth modifies the H_y component and creates a horizontal electric component E_x, and when a subsurface conductor is encountered, a secondary magnetic field will be generated (Mahemedet *al.*, 1998).In recent times, the VLF EM method has been applied successfully to map the resistivity contrast at boundaries of fractured zones having a high degree of connectivity (George *et al.*, 2013). Also VLF method yields a higher depth of penetration in hard rock areas because of their high resistivity (McNeill and Labson, 1991). VLF method is capable of delineating fractures in lateral direction effectively compared to resistivity sounding (Sharma and Baranwal, 2005), characterize aquifer structures in a complex environment (Ozeginet *al.*, 2012), underground water contamination by solid waste (Deborah and Ayobami, 2013) and examination of the fault pattern of industrial estate (Theophilus and Lukman, 2012).

The Very Low Frequency Electromagnetic (VLF – EM) method has found useful application in groundwater investigation in basement terrain, most especially as a reconnaissance tool (Amadi and Nurudeen, 1990; Olorunfemi et. al., 1995). It is an accepted fact that most of the ground VLF-EM anomalies are caused by the galvanic effect (McNeil, 1985) where the influence of frequency may be neglected (Guerin *et al.*, 1994). This method of geophysical prospecting was primarily developed for the delineation of sheet – like metallic conductors, which are often concentrated within fault and fracture zones which are known to be good groundwater aquifers, particularly when the fracture frequency is high (Olorunfemi et. al., 1995). The technique may be applied indirectly to the location of sites with appreciably thick overburden to the mapping of geological structures such as fault and fracture zones that are favourable to groundwater accumulation (McNeil, 1980; Palacky et. al., 1981; Adiat et. al., 2009).

The mapping of fracture zone which is a break in crystalline basement rock due to tectonic forces or intrusion of magmatic bodies is important for civil engineering and hydrogeological applications. In civil engineering, it helps to locate the safest depth to lay the foundation of buildings. The geological significance of fracture zones in hydrogeology is that it determines the

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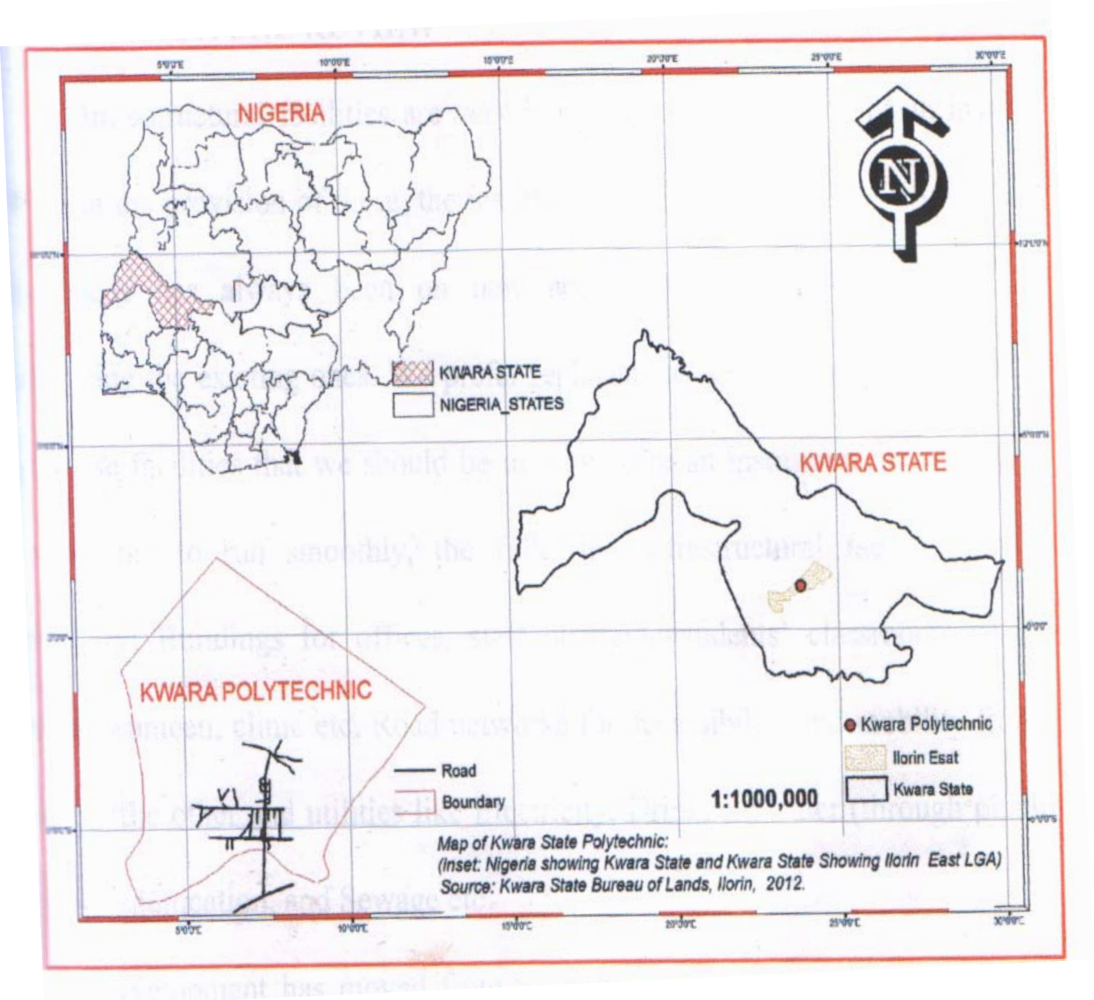
competency of the underlie rocks (George *et al.*, 2013). Areas that are extensively fractured and where the fractures are deep are considered as weak zones and considered suitable zones for groundwater development (Alagbe*et al.*, 2013);but areas that are slightly fractured and where fractures are not deep are considered as competent zones and are considered better sites for engineering purposes (Sunmonu and Alagbe, 2011). In hard rock areas, groundwater is found in the cracks and fractures of the local rock. Groundwater yield depends onthe size of fractures and their interconnectivity.

This study was driven by the desire to investigate water bearing fracture zones in the area under investigation using very low frequency (VLF) electromagnetic method. Most boreholes drilled in the past in the area are unproductive and due to this failure, it is therefore necessary to use an appropriate geophysical method to locate the fracture zones. This became important as the inhabitants of the study area depend solely on streams, lakes and groundwater for their domestic needs and otherwise.

II. THE STUDY AREA

Kwara State in its entirety is located in the North-Central part of Nigeria. It lies between the Longitude 3^0 and 6^0E and Latitude 8^0 and 10^0N respectively (Fig. 1). It covers an area of over 32,500 square kilometer and bounded by an international boundary with Benin Republic in the West, in the North by Niger, in the East by Kogi and to the south by Oyo, Ekiti and Osun.



Map of Kwara State Polytechnic:
(Inset: Nigeria showing Kwara State and Kwara State Showing Ilorin East LGA)
Source: Kwara State Bureau of Lands, Ilorin, 2012.

Figure 1: Merged geographical map of nigeria, kwara state and the study area, herein referred to as kwara polytechnic (source: kwara state bureau of lands, ilorin, 2012)

The area of study, falls in Ilorin, the capital city of Kwara State, with Kwara State Polytechnic (Fig. 2) as the central point, lies within the crystalline basement rocks of western part of central Nigeria. The area is a semi-arid region of Nigeria with vegetation mainly guinea savannah, with shrubs and undergrowth (Nwankwo, 2011). The area is drained by rivers and streams such as Oyun River and river Ile-Apa as a tributary of river Niger (Nwankwo*et. al.*, 2004).

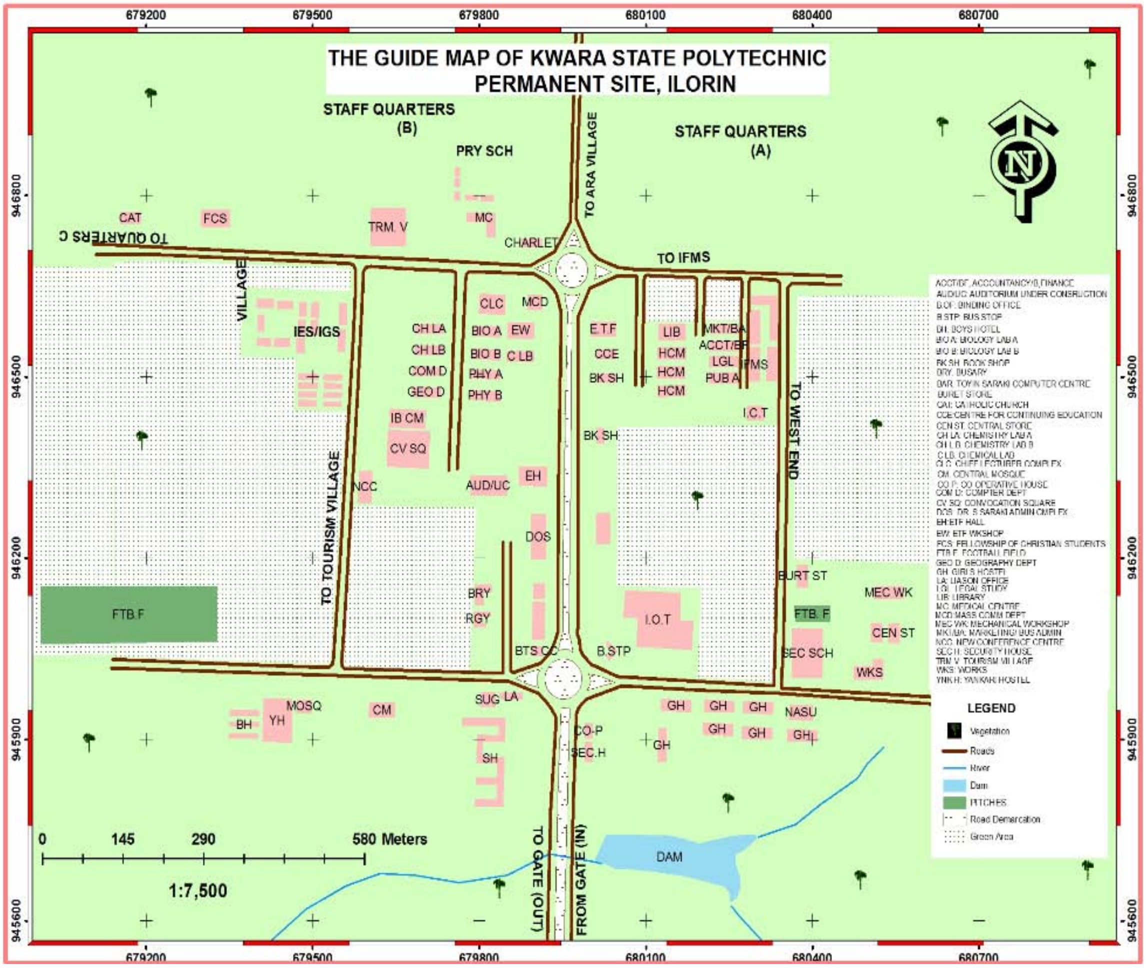


Figure 2: Guide map of the central point of the study area (kwara state polytechnic, permanent site)

The progressive population growth in Ilorin, the nearest major town to the study area, has led to severe shortage of portable drinking water for the area which poses a great challenge to both the citizens and the government. It is therefore obvious that the demand for reliable and consistent water supply is high. Certainly the use of water is beyond mere domestic as virtually all the industries, companies and governmental establishments are in dare need of water. Such high demand can only be achieved through viable boreholes. The drilling of viable boreholes can be obtained by carrying out adequate geophysical studies to empirically ascertain areas or sites where long term steady supply can be achieved.

Furthermore, rapid industrialization recently witnessed by the Ilorin metropolis has resulted in population increase and has led to the urbanization of satellite villages and settlements of which the ancient Eleko, Kwara Poly. (Permanent site), Ara and Akuo settlements, all of which fall in the study area. The people of these settlements depend solely on surface water from streams and hand dug wells for their domestic use. However, these sources of water are highly vulnerable to pollution thereby making the people to be susceptible to water borne diseases. Moreover, fast increase population growth of this region occasioned by the influx of people from nearly congested city of Ilorin, coupled with the location of government institutions such as Kwara State Polytechnic and University of Ilorin Teaching Hospital has also made these sources of water inadequate for its dwellers, and the need for good quality and readily available portable groundwater in this area forms the basis for this research.

III. MATERIALS AND METHODS

The ABEM WADI VLF-EM Instrument used to measure the EM response is a portable instrument which measures the electrical properties of the subsurface, using EM induction as detailed in McNeil (1980a). In this work, thirteen EM profiles were made using a 20m coil spacing, with an expected maximum depth of investigation of about 15m for the horizontal dipole (HD) mode (McNeil, 1983). The EM data were collected at 20m interval along thirteen profiles (Fig. 3) with lengths ranging from 300 to 1700m. The VLF-EM data were presented as profiles figures by plotting raw real (quadrature) measured on the field and the filtered real while their corresponding Karous-Hiljet (K-H) pseudo sections are shown in Figures respectively. The interpretation of both the profiles and pseudo sections was basically qualitative or semi quantitative.

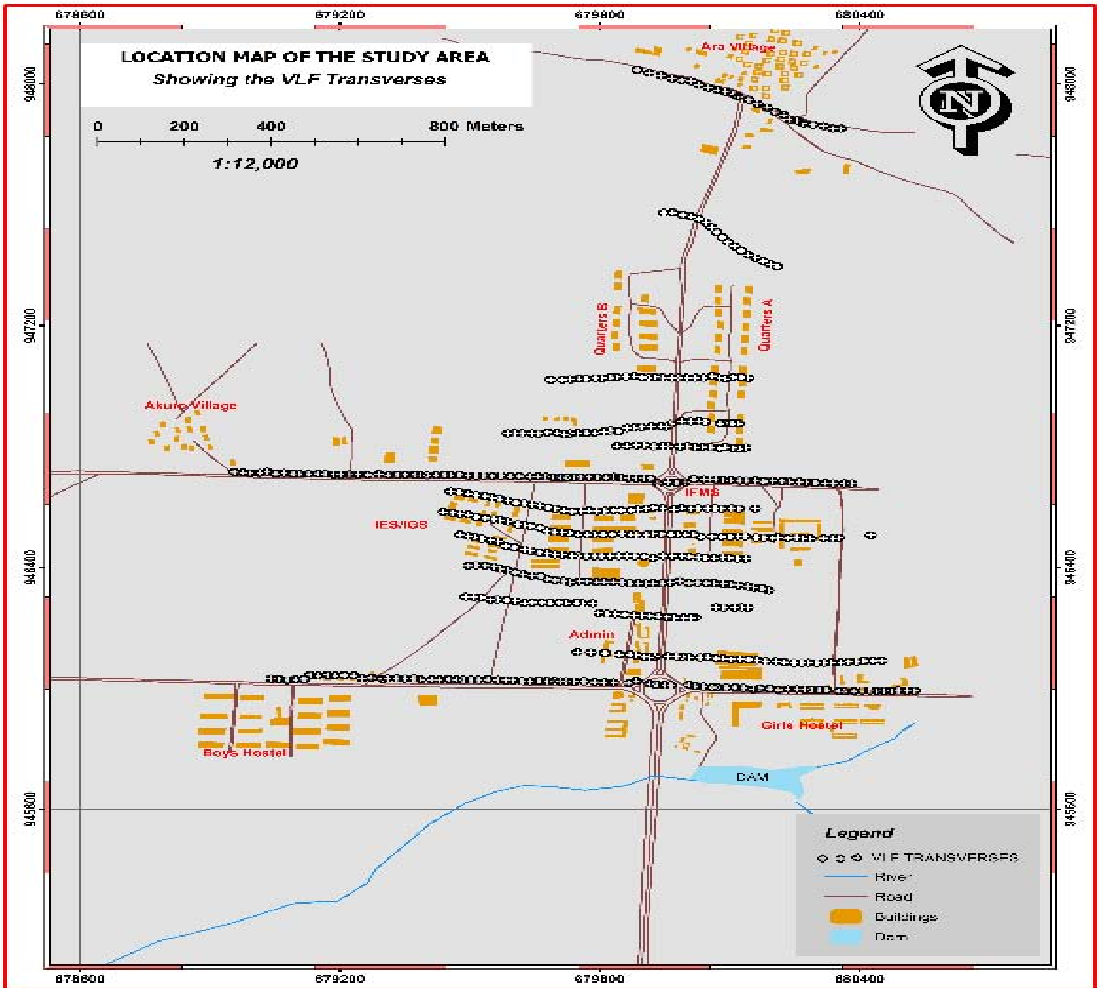


Figure 3: Location map of the study area showing vlf transverses

The VLF WADI instrument displays the filtered real anomaly on the screen, and this anomaly can be roughly interpreted on site. This feature of the instrument is used to select sounding locations for resistivity surveys. For further detailed information of the subsurface, the measured real anomalies were re-discretized at 1 m interval and filtered using the approach of Karous and Hjelt (1983). This process yields pseudo-section of relative current density variation with depth. A higher value of relative current density corresponds to conductive subsurface structures.

IV. Results and Discussions

It is observed that apparent current density cross-sections using real and imaginary anomalies show almost similar features. Therefore, for simplicity only the real component results are presented below (Fig. 4-Fig 16).

At location VLF01 with traverse oriented in the E-W direction, a plot of filtered data shows intermitent positive responses with the most prominet one between 20-30m (Fig 4a) resulting in probable fracture zone located around same region along the profile at a depth extending from 0-6moriented at NW-SE direction (Fig 4b).

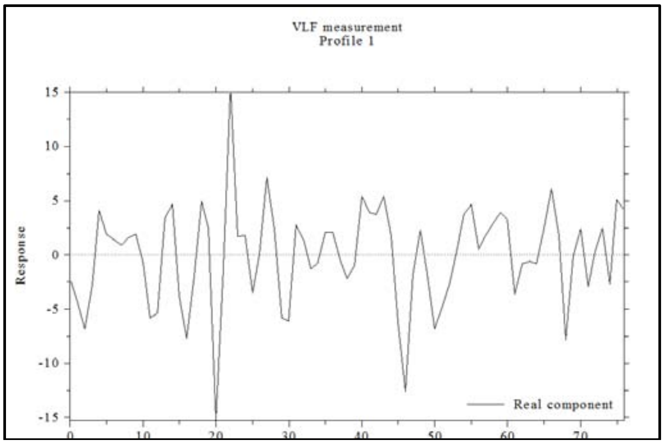


Figure 4a

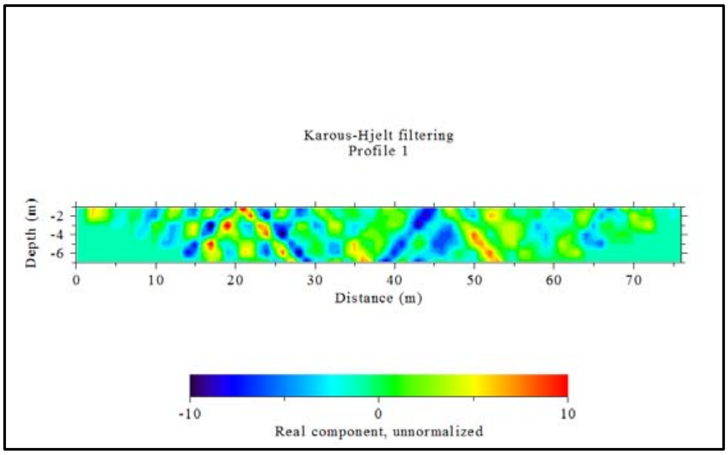


Figure 4b

Figure 4 (a): Filtered in-phase data against distance at location VLF 01 (b): Current density cross section plot in-phase data against distance at location VLF 01

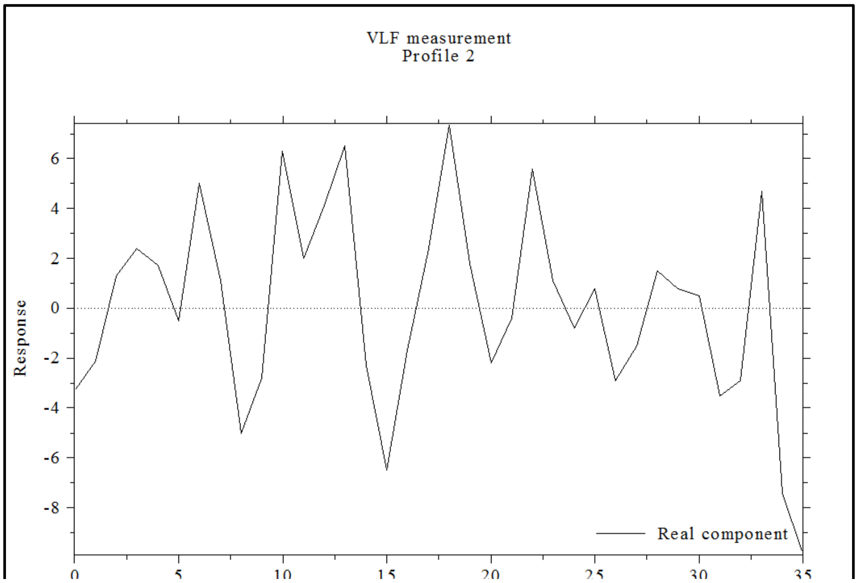


Figure 5a

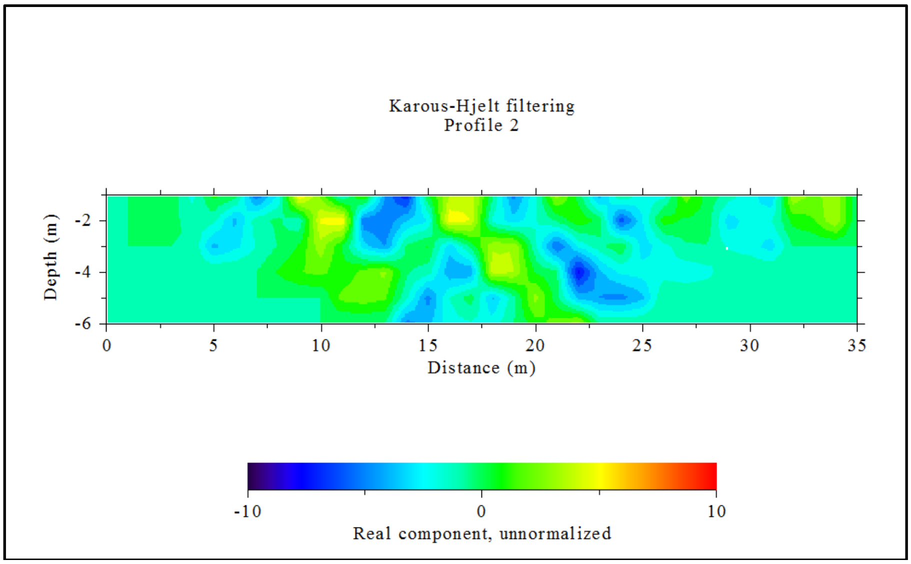


Figure 5b

Figure 5 (a): Filtered in-phase data against distance at location VLF 02 (b): Current density cross section plot in-phase data against distance at location VLF 02

At location VLF 02 with traverse oriented in E-W direction, there also intermittently well-fractured zone (Fig 5a) located at a horizontal distance of between 5-25m, along the profile at depth of between 0-6m. This zone is oriented at NW-SE (Fig 5b).

A very similar result was observed at locations VLF 03 and VLF 04 with both having same traverse orientation but 20m and 40m away respectively from Location VLF 02. They however lies along their corresponding profiles at depth between 20-60m. (Fig 6 and Fig 7).

At location VLF 05 with traverse oriented E-W direction, three (3) probable fracture zones were identified with one (the first) highly conductive. They were located between 5-7m, 15-17m and 25-27m respectively along the profile (Fig 8a). The depth of the fracture zones is between 10-40m with orientation sat NW-SE (Fig 8b).

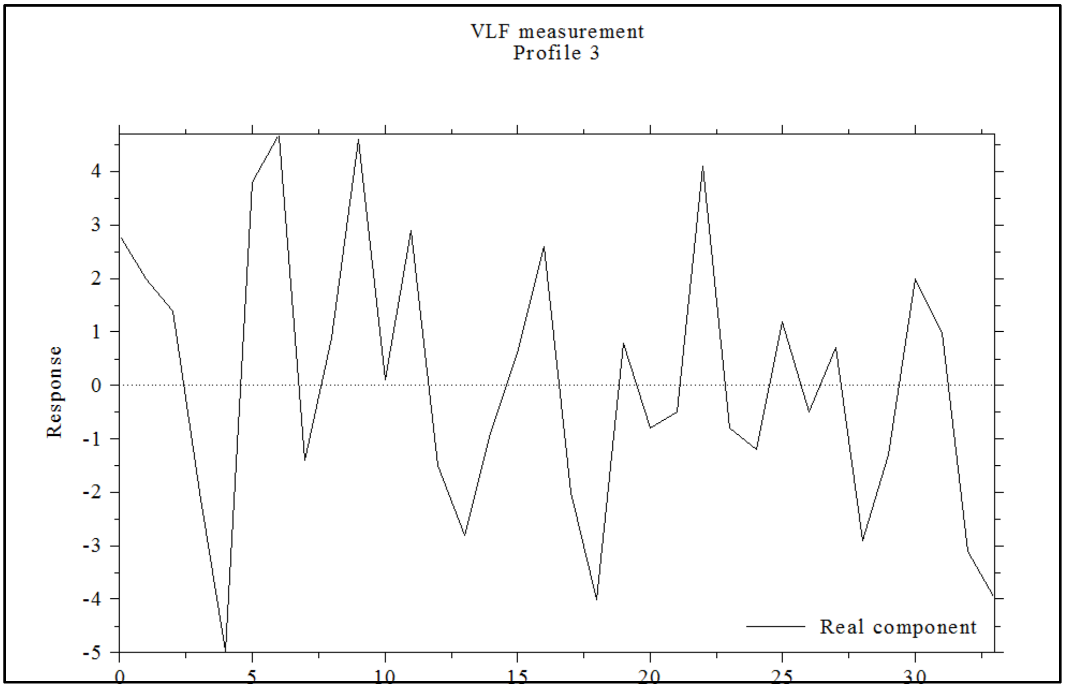


Figure 6a

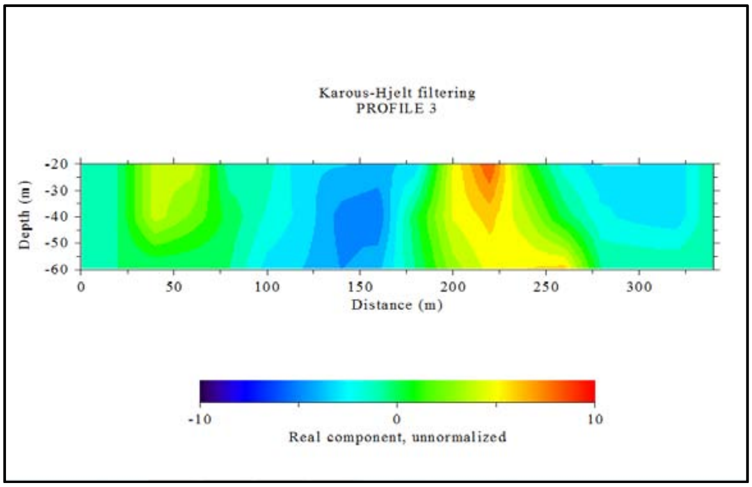


Figure 6b

Figure 6 (a): Filtered in-phase data against distance at location VLF 03 (b): Current density cross section plot in-phase data against distance at location VLF 03

At location VLF 06 with traverse oriented in the E-W direction, a well-fractured zone with positive Fraser filter was identified (Fig 9a). It is located at a horizontal distance between 11-13m, along the profile at depth of between 2-6m. Similar was the case at location VLF 07 with a prominent fracture zone located at a horizontal distance between 28-34m (Fig 10a), along the profile at depth between 2-6m.

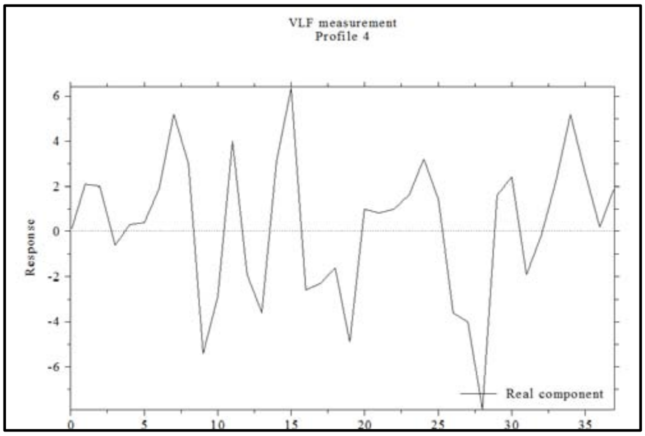


Figure 7a

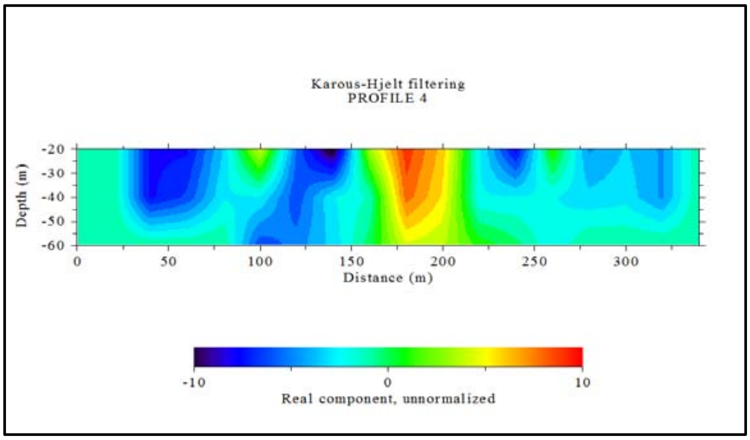


Figure 7b

Figure 7 (a): Filtered in-phase data against distance at location VLF 04 (b): Current density cross section plot in-phase data against distance at location VLF 04

At VLF 08 with traverse oriented in the N-S direction, two probable and another two not well-fractured zones were identified. They were located between 5-8m, 32-34m, 50-52m and 68-70m respectively along the profile (Fig 11a). The depth of each fracture zone was between 0-40m, 0-35m, 0-30m and 0-30m respectively all with orientation sat NE-SW (Fig 11b).

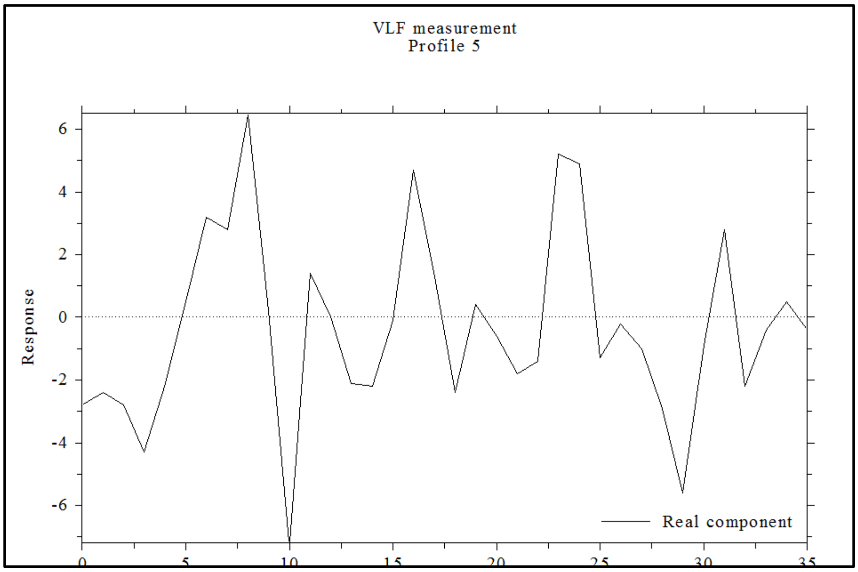


Figure 8a

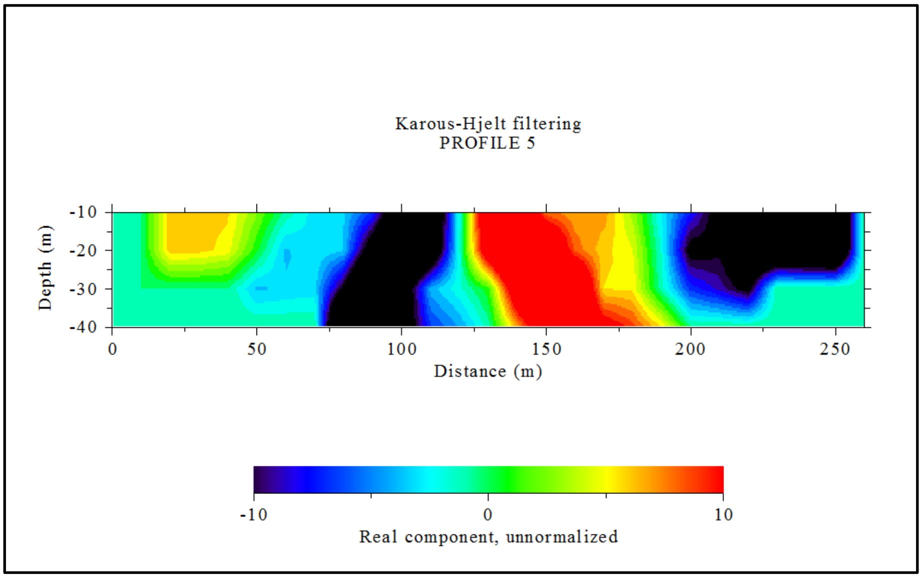


Figure 8b

Figure 8 (a): Filtered in-phase data against distance at location VLF 05 (b): Current density cross section plot in-phase data against distance at location VLF 05

At location VLF 09 with traverse oriented E-W direction, a not well-fractured zone with positive Fraser filter was identified (Fig 12a). This zone is located at a horizontal distance between 6-8m, along the profile at depth of between 20-40m (Fig 12b).

The result of VLF data collected at location VLF 10 with traverse oriented in E-W direction (Fig 13a) shows two positive fracture Fraser filter responses along the horizontal distance between 7-9m and 16-18m with depth extending from 30-40m for both. They were oriented at NW-SE and NE-SE respectively (Fig 13b).

The VLF responses at location VLF 11 with traverse oriented in the E-W direction shows positive responses along the traverse (Fig 14a) resulting in a not pronounced fracture zones located between 0-4m (Fig 14b).

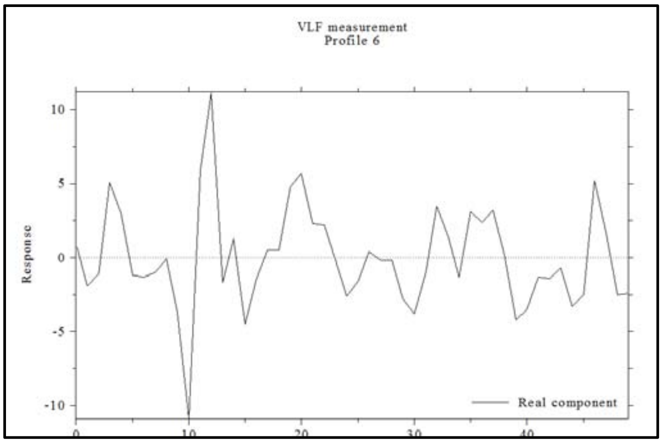


Figure 9a

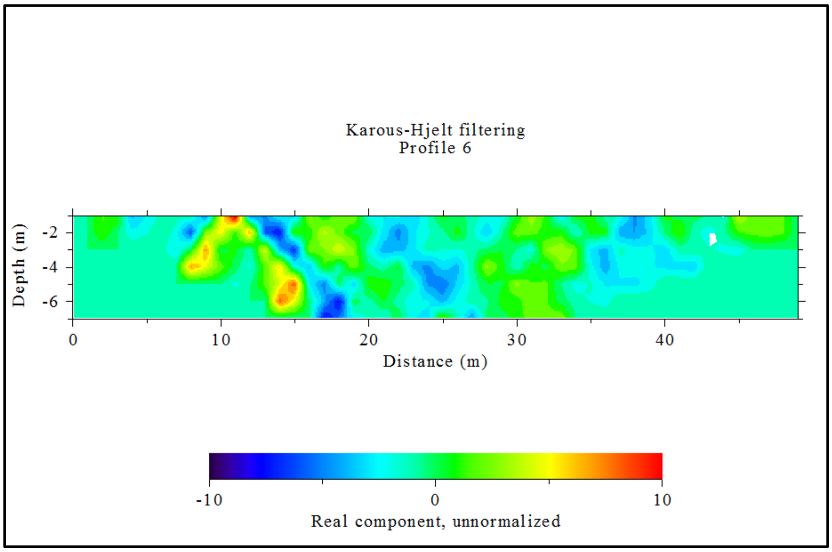


Figure 9b

Figure 9 (a): Filtered in-phase data against distance at location VLF 06 (b): Current density cross section plot in-phase data against distance at location VLF 06

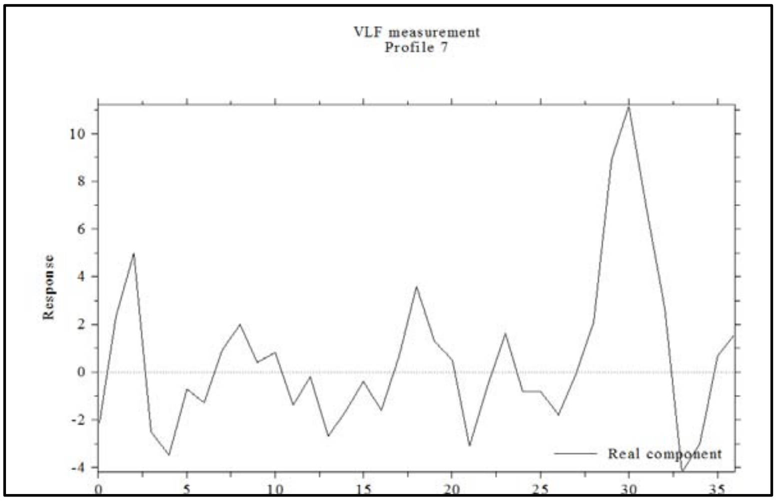


Figure 10a

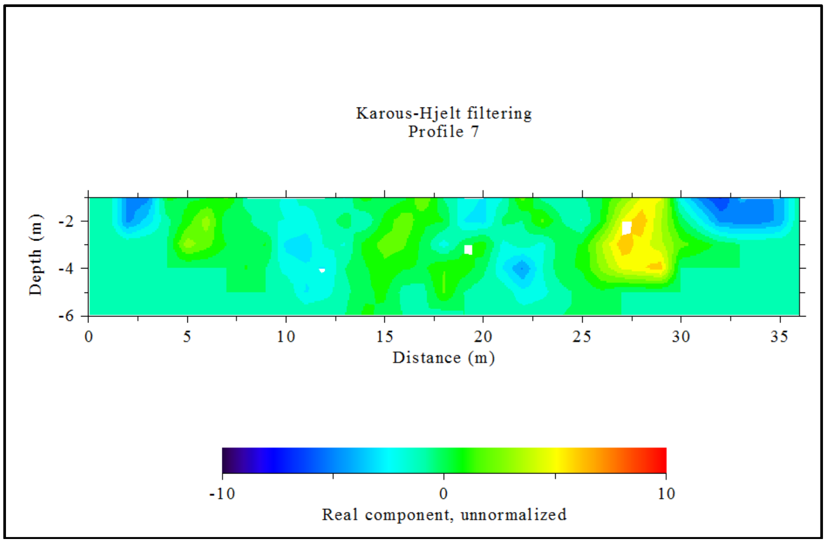


Figure 10b

Figure 10 (a): Filtered in-phase data against distance at location VLF 07 (b): Current density cross section plot in-phase data against distance at location VLF 07

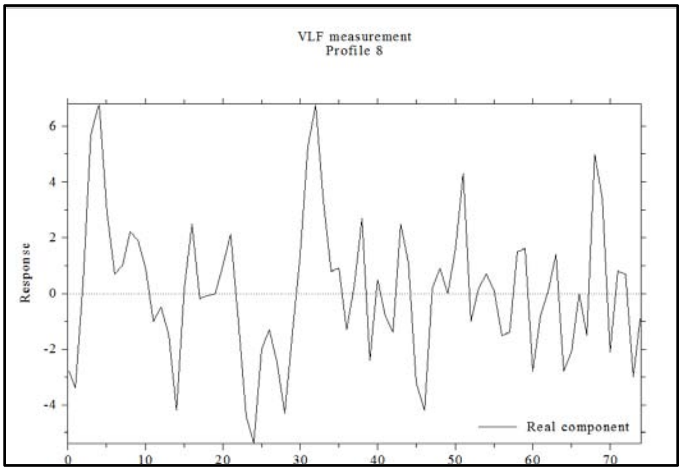


Figure 11a

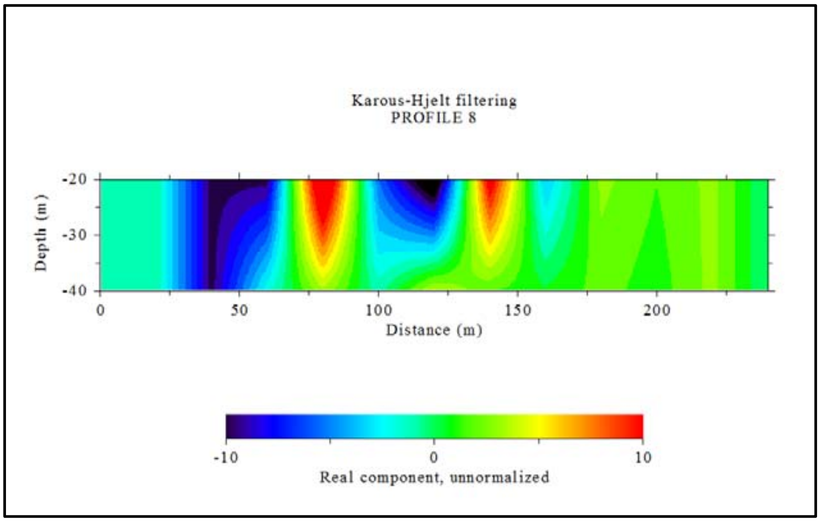


Figure 11b

Figure 11 (a): Filtered in-phase data against distance at location VLF 08 (b): Current density cross section plot in-phase data against distance at location VLF 08

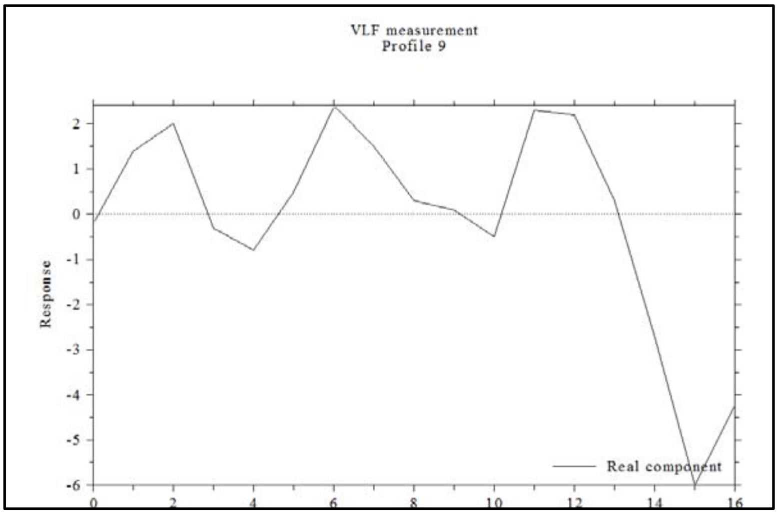


Figure 12a

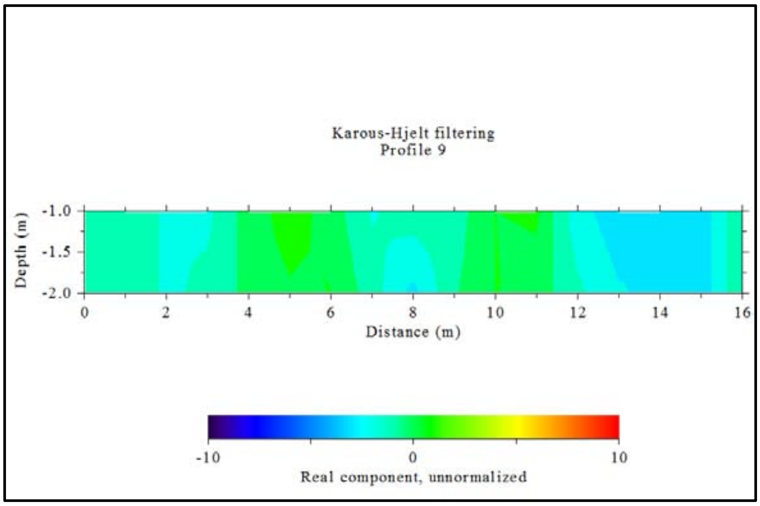


Figure 12b

Figure 12 (a): Filtered in-phase data against distance at location VLF 09 (b): Current density cross section plot in-phase data against distance at location VLF 09

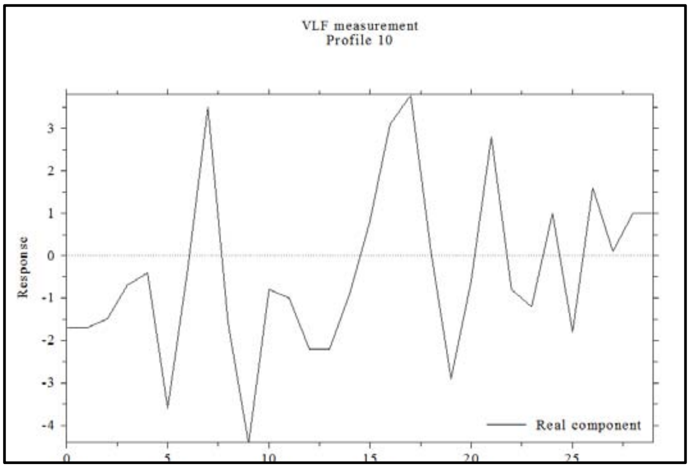


Figure 13a

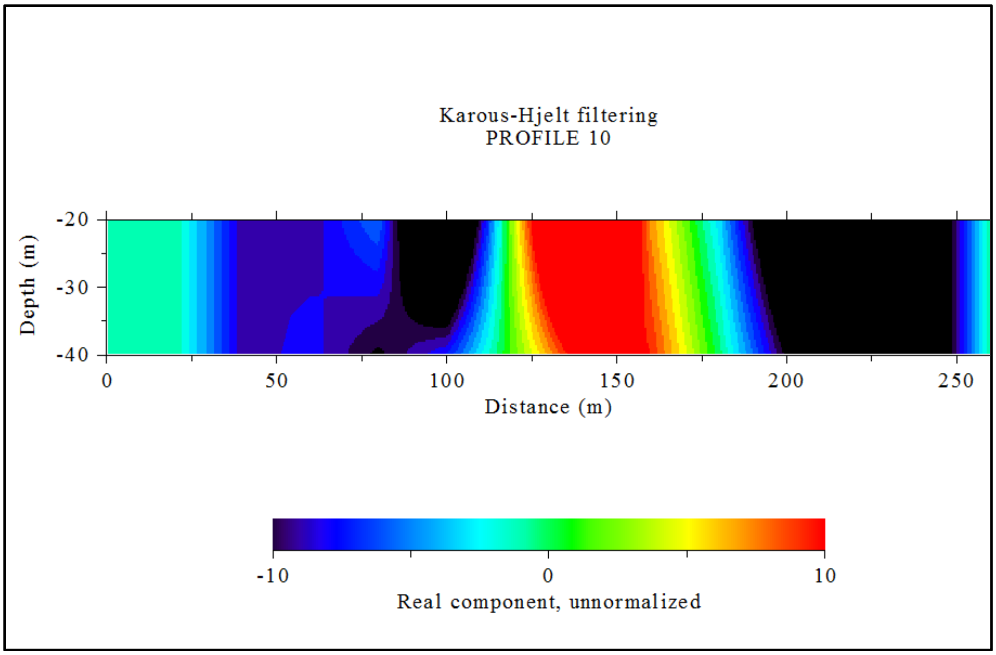


Figure 13b

Figure 13 (a): Filtered in-phase data against distance at location VLF 10 (b): Current density cross section plot in-phase data against distance at location VLF 10

VLF data at locations VLF 12 and VLF 13, both has a positive response identified each along the traverse (Figb15a and Fig 16a), these were between 17-19m and 19-22m respectively. These correspond to zones located at depth between 0-4m and 0-2m (Fig 15b and Fig 16b).

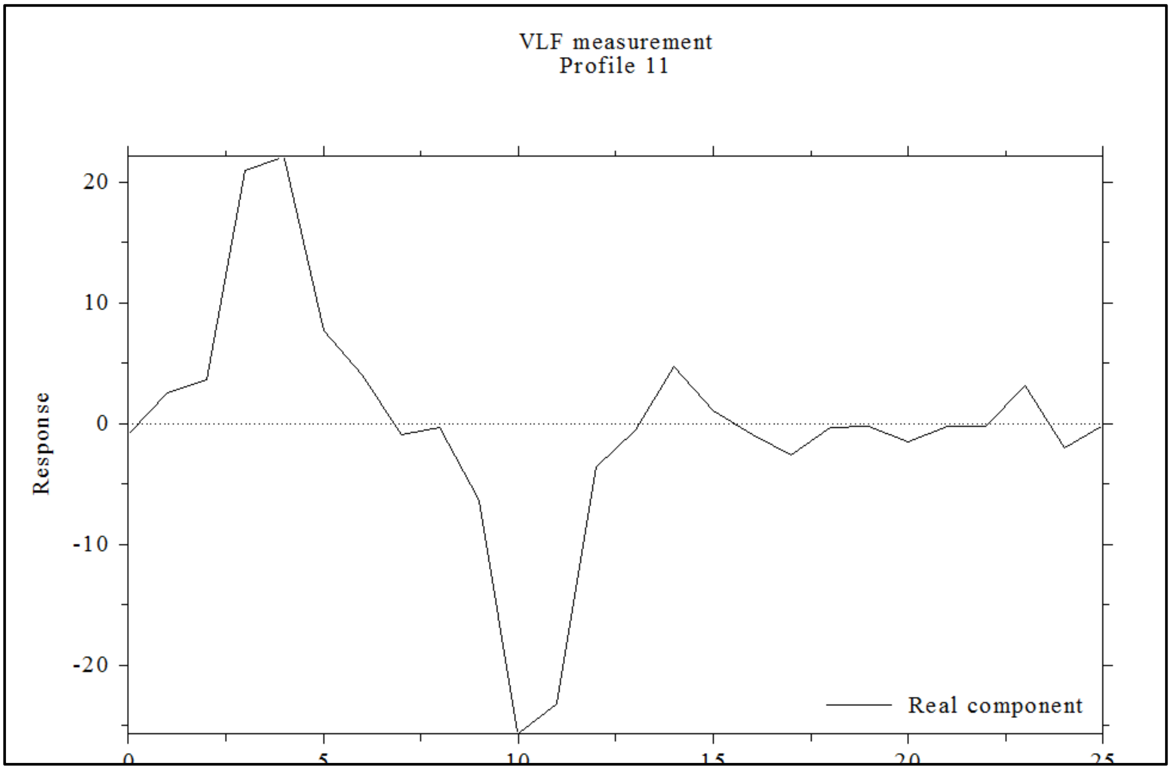


Figure 14a

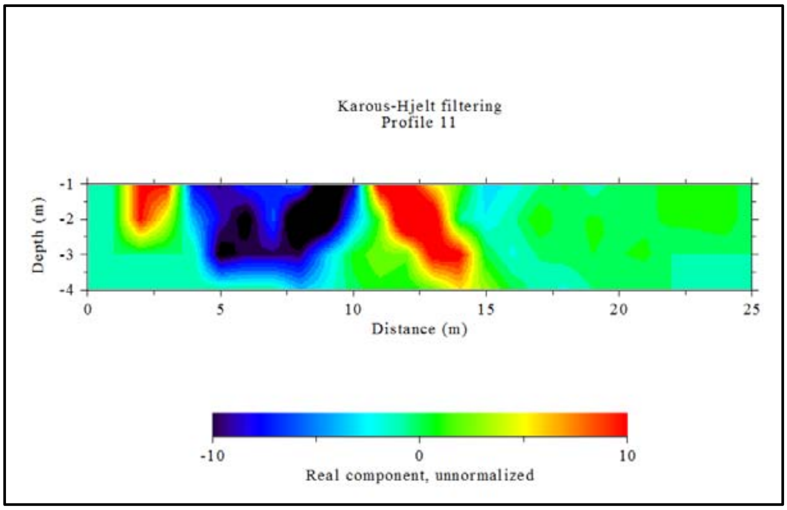


Figure 14b

Figure 14 (a): Filtered in-phase data against distance at location VLF 11 (b): Current density cross section plot in-phase data against distance at location VLF 11

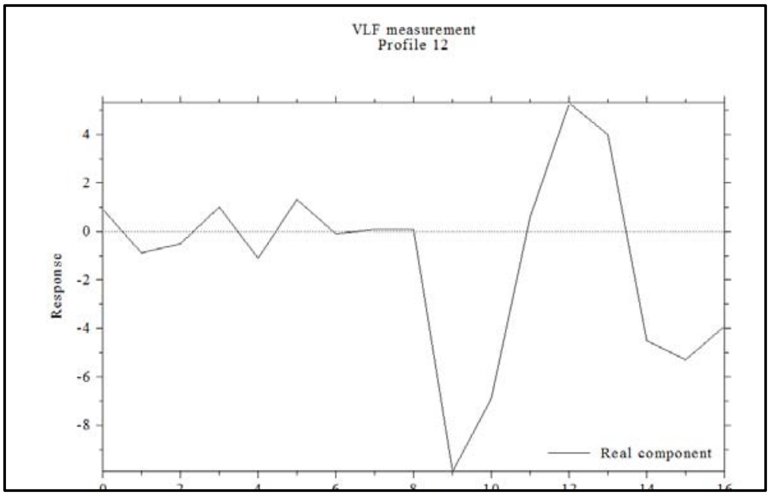


Figure 15a

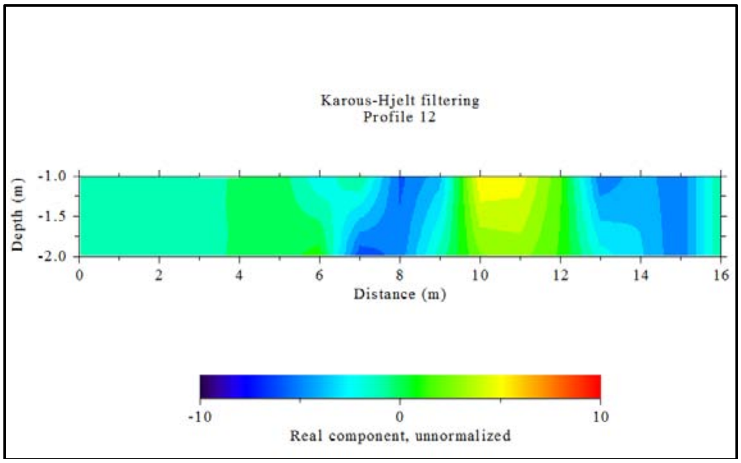


Figure 15b

Figure 15 (a): Filtered in-phase data against distance at location VLF 12 (b): Current density cross section plot in-phase data against distance at location VLF 12

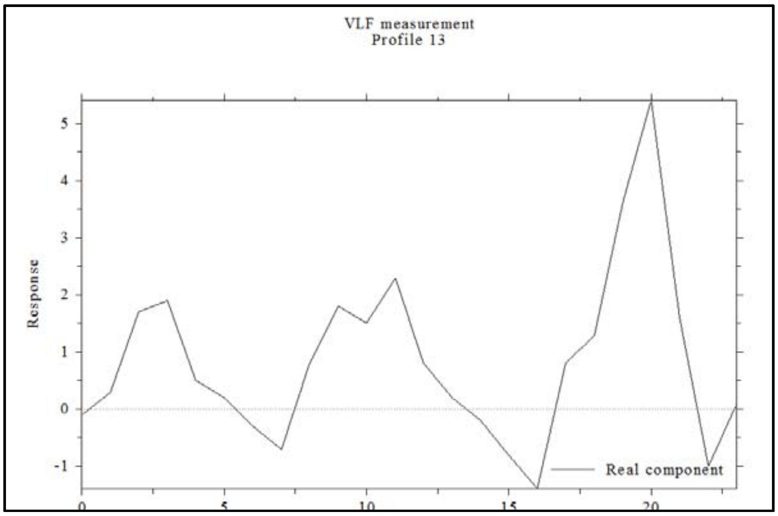


Figure 16a

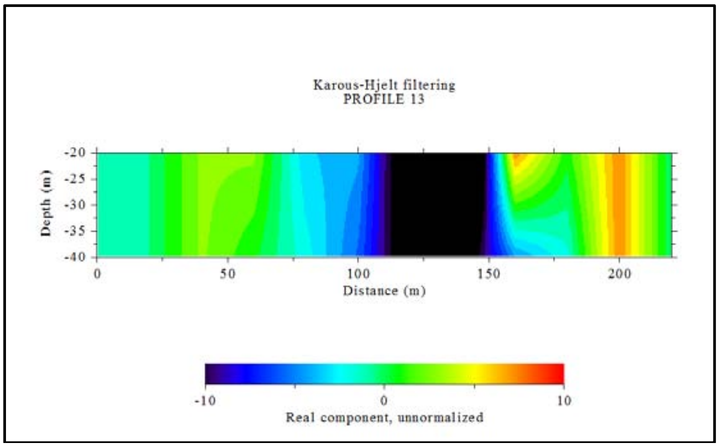


Figure 16b

Figure 16 (a): Filtered in-phase data against distance at location VLF 13 (b): Current density cross section plot in-phase data against distance at location VLF 13

The EM anomalies vary greatly. Some of the anomaly peaks are narrow, sharp while others are broad with varying width extent. The values of the filtered real range from -0.9 to 22.5 across the study area. The profiles for the EM sections contain significant maxima in the filtered real part. Zones with peak positive filtered real anomalies are considered priority areas for electrical sounding, since they often correspond to zones with high conductivity, characteristic of water-filled fractures or faults (Alvin et. al., 1997), or effect of appreciable depth to bedrock or lithological variations within the unconsolidated regolith (White et al., 1988). In other words, VLF-EM anomalies were delineated as fairly-conductive, conductive, highly-conductive, fairly-resistive and resistive responses at different locations across the study area. Positive anomaly is indicative of steeply-dipping linear features such as fractures. These features serve as channels for migrating fluids and minerals. These points are zones of interest in groundwater abstraction in basement complex terrain. These results therefore form the basis for Vertical Electrical Sounding (VES) investigation that may subesequently be carried out on any portion of the study area.

V. Conclusion

The study area has good prospects for groundwater development due to the presence of fracture zones which are interconnected in nature. Further investigations for groundwater in the study area is therefore recommended; these should however be aimed at searching for fracture zones where overburden is relatively thin and any borehole drilled in the study area should be made to pass through as many fracture zones as possible. Finally, it is recommended that for productive and sustainable boreholes to be drilled on any location in the study area, relevant electrical resistivity methods should be employed for the Vertical Electrical Sounding (VES) of all areas of interests (as suggested by the results of the present study) along each of the thirteen profiles that were traversed.

Acknowledgements

The authors are grateful to the tertiary education trust fund (tetfund) for providing research grant utilised for this study. The authors also wish to acknowledge the support of the management of Kwara State Polytechnic as well as the cooperation of the heads and youths of the communities in which this research was carried out.

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