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Delineation Of Fracture Zones For Groundwater Exploration Using Very Low Frequency Electromagnetic (VLF-EM) Method In A Sedimentary Complex TERRAIN: a Case Study of KebbiState University of Science and Technology Aliero, Northwestern Nigeria.

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Abstract: *The (Very low Frequency EM) VLF-EMmeasurements data were acquired along twelve (12) traverses on an trial basis for qualitative assessments of water bearing fractures, with the aim of locating the best point to drill for groundwater exploration, in this present research, geophysical investigation was performed to delineatesfracture zones in the some selected location of kebbi state university of science and technology Aliero sedimentary complex of Sokoto basin, interpretation of VLF-EM data is carried out qualitatively using Fraser and Karous-Hjelt filters .Anomalies associated with conductive zones such as water-bearing weathered layers and geological features such as fractured and sheared zones were delineated. The results of the study showed the presence of fracture zones which are prominently in most of investigated areas. The results also showed that most of the fracture zones are located at a depth range from 10 m to 30 m within the subsurface and extended beyond 30 m in most of the traverses, someof the traverses identified with cross over that coincide with positive and negative magnetic conductivity and signal response against distance, include traverse T_1 at 140 m (+40%), traverse T_2 at 50 m (-40%) with aquifer thickness of (15-30 m) depth, traverse T_4 at 50-100m (+50%) and 150 m withaquifer thickness of (10-30 m) depth, traverse T_6 at 50-100 m (+20%) and 140-160 m (+50%)with aquifer thickness (10-40 m) depth, meanwhile traverse T_7 at 50-100 m (-50%)with aquifer thickness (10-30 m) depth, traverse T_{10} at distance 70-100 m (+40%)with aquifer thickness (10-30 m) depth, traverse T_{11}, T_{12} indicate conductive zones at some location with low cross over signal response with aquifer thickness (10-30 m) depth.At suitable locations VLF Traverse suggest the existence of fracture zones in part of permanent site of Kebbi State University of Science and Technology Aliero, which indicate that the study area has good prospects for groundwater. Therefore, on thebasis of this studythe drilling of productive boreholessuitable for groundwater exploration are recommended attraversesidentified above.*
Key Words: Fractures, Sedimentary, Anomalies, Conductivity, Exploration.

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I. Introduction

Geophysical groundwater prospecting techniques, generally speaking, base themselves on the detection of the abnormal physical fields associated with inhomogeneities that the geological evolution has "printed" on the Earth's crust structure and geological composition (Olatunji, and Magawata, 2016).The passageway to the understanding of the earth become one of the most difficult task ever come across by man. It is based solely on what can be observed, how well the observer can perceive and deduce hisobservation. The VLF (Very Low Frequency) technique, in its most recent portable version of equipment, can summarily be characterized as the detection of electromagnetic anomalies caused by induction from a primary magnetic field of worldwide distributed military use VLF transmitters on water bearing zones, such as fracture or fault zones of high electric conductivity acting as conductors, imbedded in high electric resistivity geological formations. These features, along with the portability and low cost effectiveness use of the VLF equipment, make it the ideal tool for groundwater prospecting associated with deeper paths along sub-surface water bearing bodies (fractures and fault zones) in hard rock geological environments.

The measurements of the VLF campaign over the area were carried out with various profiles of varying length. Readings along those profiles stepwise 10 m intervals. Another important issue involved in the planning of the surveys was the necessity to maintain the orientation of the profile when taking the readings along its length but little changes occurs in orientation of some profiles. So, a system was constructed to help in this matter, consisting of a wire marked every 5 meters tightly stretched along the profiles.

The profile schematic applied on the area consist of AdministrativeBlock, Multipurpose Hall, Faculty of Science,Agriculture, Department ofElectrical Engineering, Information and Communication Department. The first aim, is the identification of fracture zone, whilesecond approach was determinationofthe spatial distribution, accordingly to thesedimentary area possibilities. Thus far, the VLF campaign over the study area has generated 12 traverses. The data of these profiles that, summarily, is analyzed on the base of the relation between the horizontal primary magnetic field and a vertical secondary magnetic field originated by induction on a sub-surface conductor, was performed automatically with ABEM's sector program. The KarousHjelt filter offers the possibility to generate current density pseudo-sections which, by showing the distribution of the apparent current density along the depth, provides a pictured image that can give an idea of the conductor's geometry that originated the anomaly.

The study area lies within the sedimentary area of Sokoto basinNorth Western Nigeria. The geophysical investigation involved the use of very low frequency electromagnetic (VLF- EM) method was carried out in the study area to investigate the groundwater prospect of the area. Very low frequency electromagnetic (VLF- EM) is said to be widely geophysical method used in delineation 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 usedto located aquifers zones such as fractures, faults andjoints (Palacky,*et al.,* 1981, Benard, and Villa, 1991., Mogaji and Oladapo., 2008.,Omosuyi.,2007., Ariyo.,2007). Geophysical methods play a progressivelyvital role in the search for these suitable andproductive groundwater reservoirs. Electrical ResistivityMethod has been used routinely in exploration forgroundwater.However, several other geophysical methods havebeen applied successfully either singly or incombination, for prospecting for groundwater resourcesin varying geologic unit. The electromagnetic(VLF) method has found useful applications ingroundwater investigation in basement terrain, mostespecially as a reconnaissance tool (De Jong., *et al.,* 1981, Amadi, and Nurudeen, 1990., Olorunfemi,*et al.,* 2001), applied thespontaneous potential (SP) and electrical resistively tounderstand the nature and groundwater developmentfeasibility of a suspected spring in Ajegunle-Igoba,Akure, Southwestern Nigeria. (Magawata, 2019), used geoelectric survey for ground water exploration at birninkebbi, Sokoto Basin Nigeria using electrical resistivity technique with view to locate confined aquifer and zone of favorableground water exploration. (Naziya, and Singh 2018), used very low frequency electromagnetic (VLF-EM) and electrical resistivity (ER) methods in hard rock area of Sangod Block, Kota District, Rajasthan, India, for Identification of fracture zones for groundwater exploration. The results of the study showed the presence of fracture zones which are prominently oriented in the NE-SW and NW-SE direction. The results also showed that most of the fracture zones are located at a depth range of 10 m to 30 m within the subsurface. The vertical electrical sounding data are collected at suitable locations corresponding to subsurface fracture zones, identified on basis ofVLF data. The interpretation of VES data also suggest subsurface fracture zone at these locations.

II. Location and Geology of the Area

The study was conducted within theKebbi state university of Science and technology Aliero permanent site in Northwestern Nigeria (Fig. 1),located between latitude 12° 18. 22.2" andlongitude 4° 29 47.6", predominantlywith sedimentary rocks of the basin range in age from Cretaceous to Tertiary and are composed mostly of interbedded sand, clay, and some limestone; the beds dip gently toward the northwest. Alluvium of Quaternary age underlies the lowlands of the River Sokoto (now Sokoto) and its principal tributaries. These rocks contain three important artesian aquifers, in addition to regional unconfined ground-water bodies in all the principal outcrop areas, and a perched water body in the outcrop of the Kalambaina Formation. Artesian aquifers occur at depth in the Gundumi Formation, the Rima Group, and the Gwandu Formation and are separated from one another by clay beds in the lower part of the Rima Group and the Dange Formation. In outcrop, clay in the Dange Formation also supports the perched water of the KalambainaFormation.BirninKebbi is dominated by two formations; Precambrian Basement Complex in the southern and south east young sedimentary rocks in the north. The Basement Complex region is composed of very old volcanic and metamorphic rocks such as granites schist's, gneisses, quaetzites and migmatites. In addition there are met sediments such as phyllites and met Conglomerates. (Henry andWilliam 1973). The sedimentary region consists of the Gwandu, Illo and Rima groups whose ages range from the cretaceous to the Ecocene. The Gwandu group consist of massive clay grits inter bedded with sand stone while the Illo and Rima groups consist of pebby grits, sand stone and clays mudstone and siltstone respectively. The Rima Group contains an extensive artesian aquifer which is economically important in the Sokoto and BirninKebbi areas. The aquifer generally provides moderate quantities of water to boreholes (average yield of 5,400 gph among 30 boreholes), but the depth to the water may be as much as 173 feet below land surface. In the Sokoto area the sand of the Rima aquifer is fine to medium; nevertheless, boreholes readily yield as much as 7,000 gph. Moreover, with drawdowns in boreholes of

10 to 65 feet, several aquifer tests have indicated transmissivities averaging about 45,000 gpd per ft. (Henryand William1973). In western Sokoto Province (now part of North Western State), the Rima aquifer is confined by clay in the Dange Formation so that in the River Sokotofadama the aquifer yields artesian flow to boreholes. At BirninKebbi, for example, where fine to coarse sand of the aquifer extends from a depth of 360 to more than 1,000 feet, single boreholes flow as much as 7,000 gph and yield by airlift as much as 18,000 gph. The Illo Group, which is in part contemporaneous with the Gundumi Formation, includes interbedded varicolored clay

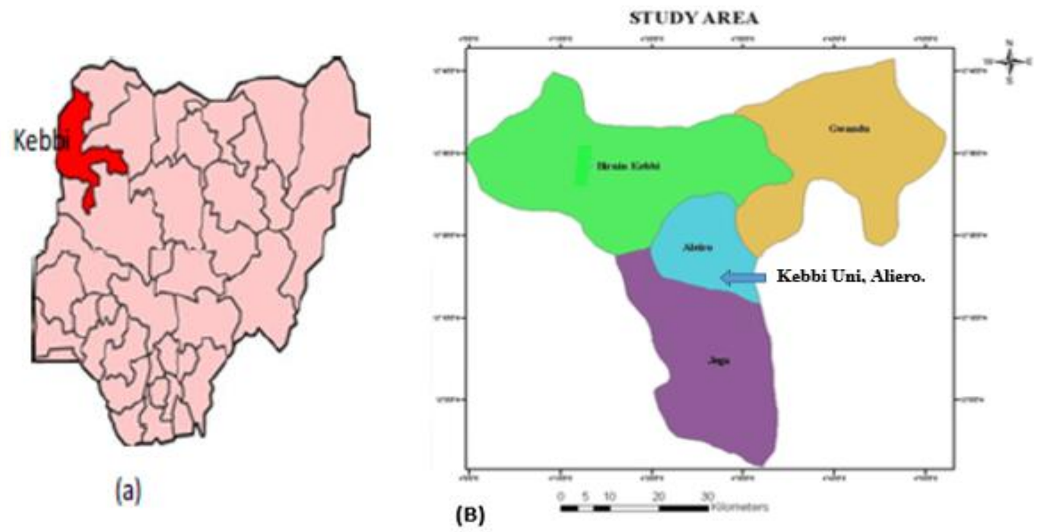


Fig. 1. Map of Nigeria
(a) Showing Kebbi State; (b) Showing study location

and grit in the southern part of the Sokoto Basin. The upper part of the Illo is known to be water-bearing; however, except for the test borehole at Mungadi, little is known of its subsurface extent and water-yielding potential.

III. Materials and method

3.1. **Instrumentation**

VLF-EM is a passive method that uses the electromagneticfield generated by military navigation radiotransmitters (there are about 42 global ground militarycommunication transmitters) operating in the VLF frequencyband (15-30 KHz) as the primary electromagneticfield. These transmitters generate primary planeelectromagnetic waves that can induce secondary eddycurrents particularly in electrically conductive elongated(2D) targets. The data are collected along Twelve 12 VLF Traverses and readingsare taken at station interval of 10 m on a particular single traverse. The VLF-EM ground survey is a rapid and powerful method for the study of geologic features within 100 m of the sub-surface. A qualitative interpretation of VLF-EM data is carried out using Fraser and Karous-Hjelt filtering techniques Although this range is very low for radiotransmission, it is higher than that used in standard lowfrequency electromagnetic methods (1-3 KHz).(Paal, 1965) observed that radio waves at VLF couldbe used to prospect for conductive mineral deposits.Since then, VLF transmitters at several locations aroundthe world have been used widely as EM sources for near surface geologic mapping. The VLF method was developed as an inductive survey technique to measure the amplitude and phase (dip angle/ ellipticity). The VLF method is very sensitive to small changes in ground conductivity. The field radiated from a VLF transmitter over a uniform or horizontally layered earth consists of a vertical electrical field component and a horizontal magnetic field component, each perpendicular to the direction of the propagation (Sinha, 1990).The real part is the part of the resultant, which are in phase with the primary field from the VLF transmitter, while the imaginary part is the one that is 90° out of phase with the primary field. The real and imaginary components consistofthe measurements recorded by the instrument.

3.2Geophysical investigation

The objective of this geophysical study is to locate where wells could be drill. Traverses were established in E-W, W-E and S-N direction. The geophysical investigations involved the Very Low Frequency

Electromagnetic (VLF-EM) method. The VLF-EM measurements were made at 10 m intervals along Twelve 12 traverses (Figure 2-7). The VLF traverses range in length from 200-240 m, while the inter traverse distance are varied. The ABEM WADI VLF-EM receiver unit was used for the data collection. The transmitter used for this study is that of ABEM WADI with frequency range of 15.0-15.1 KHz. The direction of the transmitter (T_X) is approximatelyparallel to the strike direction. The instrument measures the tangent of the tilt angle (the inclination of the major axis of the polarization ellipse) and the ellipticity (the ratio of the minorto major axis of the ellipse) of the magnetic polarization ellipse. Both these quantities are affected by lateral variations in the subsurface conductivity.

3.3Filtering procedures.

Although VLF receivers measure individually the horizontal and vertical magnetic components of the magnetic field as discussed earlier, that part of the vertical field which is in phase with the horizontal field is called the in-phase part and that which is out of phase with the horizontal magnetic field is called the out-of-phase part. In order to avoid effects of the time variation of the magnetic field due to changes in the wave-guide formed by the Earth surface and the bottom of the ionosphere, it is customary to take the ratio between the vertical and horizontalfield directly inside the VLF instrument and only the complex ratio is shown to the user. This eliminates slow temporal variations in primary field strength which produces a spurious crossover response not related to subsurface features. Further, the measured dip angle responses need to be filtered to reduce random noise and long spatial wavelengths.

However, for all practical purposes it is not generally necessary to eliminate the noise and long spatial wavelength as VLF ensures fairly accurate measurements with random errors well below an appreciable level. To overcome some of these problems, (Fraser, 1969) devised a simple numerical filter which converts crossovers of the current polarity into peaks by differencing successive values of tilt angle (the in-phase component) along the profile. The Fraser filter shifts the measured dip angle data by 90°. That is, Fraser filtering transforms the anomaly such current density with depth. Areas with high current density correspond to good conductors. This technique has found wide popularity as it provides a simple, readily implemented scheme for semiquantitative analysis and target visualization.

A qualitative interpretation of VLF-EM data is carried out on the basis of cross-over point between the real and imaginary data which appears as positive peaks in the Fraser-filtered real curve. These regions constitute anomalous zones which can be attributed to the presence of vertical conductor or lateral contacts of different resistivity beneath the surface (Srigutomo *et al.,* 2005).

4.1 Interpretation of VLF-EM data

For interpretation of VLF-EM data along the VLF profile, the KHFFILT software is used which show both positive and negative Fraser and Karous-Hjelt anomalies along the traverses are indication of the probable fracture zones. The VLF data along Twelve 12 traverses T_1 to T_{12} are collected at station interval of 10 mdepending on a traverse. The plot of the raw field data real and filtered real data plots depicting variation of apparent current density with distance for all the traverses are illustrated in (Figures 2-7).These regions could represent anomalous zones of conductivebody of different resistivity beneath the surface. The Fraser filter (Fraser, 1969) converts crossover points intopeak responses by 90° phase shifting. This process removes direct current bias that reduces the random noisebetween consecutive stations resulting from very low frequency component of sharp irregular responses (Al-Tarazi*et al*., 2008).The Fraser filter real part always show a positive peak above a conductor, while the imaginary part may show apositive as well as a negative peak depending upon the overburden layer. The imaginary part is useful while makingdecision about the quality of the conductor. In this work, the real part of the filter is used to process the pseudo sectionof relative apparent current density variation with depth because areas with stronger positive anomalies onlyon real data map show zones with presence of groundwater (Ariyo*et al*., 2009). The apparent currentdensity pseudo sections are represented in color codes with conductivity increasing from negative to positive, high positive value constitutes the conductive sub-surface and low negative value represents a resistive sub-surface.Hence, the sub-surface features of high conductivity are identified on the VLF profiles as possible fracture zones. On the basis of these VLF-EM responses, series of conductors were identified (C_1 – C_{20}), four (4) fractures (f_1-f_4) were markedfrom which (f_1-f_3) are identified as shallow depth while (f_2-f_4)were marked for further investigation due to their attitude, length of the fractures and depth extent (>30 m) as shown in Table 1.

4 .2 Result and Discussion

4.2.1 Profile 1

Along Profile T_1 (a), the plot of Fraser filtered data and apparent current density pseudo-section using Karous-Hjelt filtering of in-phase data show positive response between 90-100 m, 140-160 m respectively extending beyond 30m beneath the earth subsurface (Figure 2) indicating the major fracture zones which serve as probable ground water interface, with minor fractures located in some points with negative magnetic susceptibility, meanwhile the coincident inflection points on the positive peak of the filtered real and the Fraser peaks are diagnostic of fractures while the positive KH model is additional requirement of importance relevant in groundwater development. However along Profile T_2 (b), the plot of Fraser filtered data and apparent current density pseudo-section using Karous-Hjelt filtering of in-phase data show positive response between 50-70 m extending beyond 30m beneath the earth subsurface, other fracture appear at120-125 m.

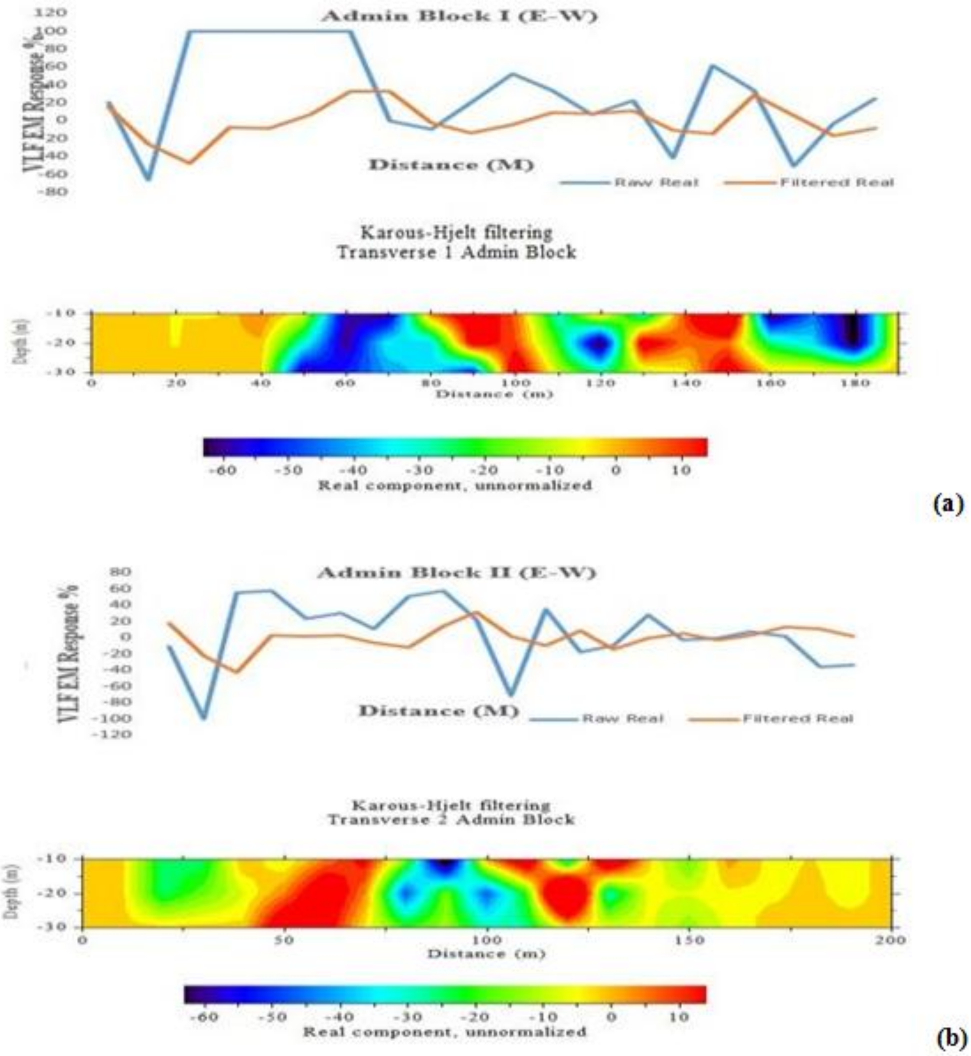
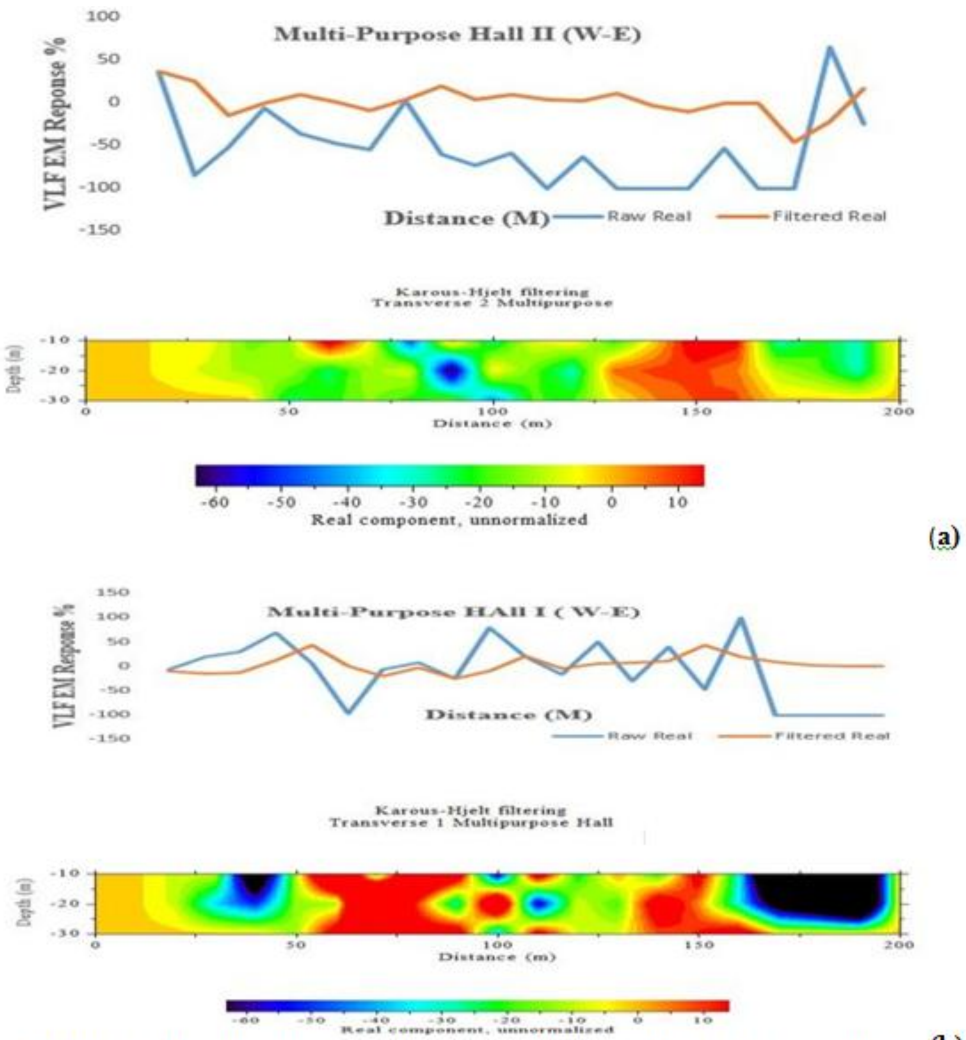


Figure 2: Plot of VLF results along the profile 1(T_1a, and T_2b), unfiltered Real component of VLF-EM data, Fraser filtered real (in-phase) data against distance, and Karous and Hjelt pseudo-section of in-phase data (apparent current density pseudo-section) against distance.

4.2.2 Profile 2

Along the Profile T_3 (a), the plot of Fraser filtered data and apparent current density pseudo-section using Karous-Hjelt filtering of in-phase data show positive response at 130-170 m,extending beyond 30m beneath the earth subsurface as shown in (Figure 3) with some signature of low magnetic response at some locations. However at T_4 (b) high positive magnetic response appear at 50- 100m and 120m with other portion with substantial resistive features revealed.



(b)

Figure 3: Plot of VLF results along the profile 2 (T_3a, and T_4b), unfiltered Real component of VLF-EM data, Fraser filtered real (in-phase) data against distance, and Karous and Hjelt pseudo-section of in-phase data (apparent current density pseudo-section) against distance.

4.2.3 Profile 3

The plot of Fraser filtered data and apparent current density pseudo-section using Karous-Hjelt filtering of in-phase data show Prominent cross-over point that depict the exact location of the subsurface fractures appear within 40-70 m and 120m from the starting point of the T_5 (a). The fracture zone appears as a negative peak, indicating a less conductive characteristic, compared with the surrounding rocks. The inferred pseudo section shows that the fracture content is conductive and extends to a depth of about 30 m. at T_6(b) indicate prominent cross over with negative conductive zone, starting from 40-100m indicating a less conductive characteristic and 130-200 m toward the end of the profile.

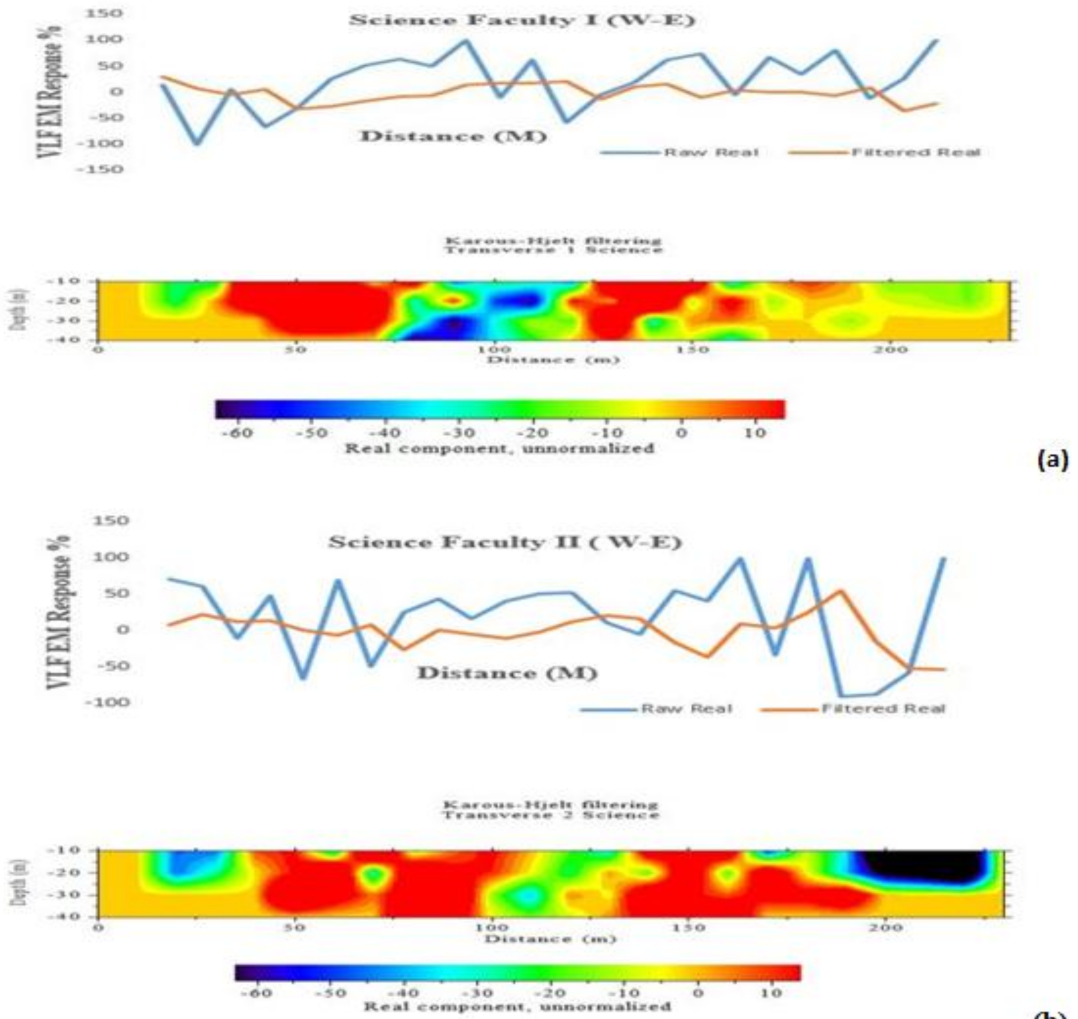


Figure 4: Plot of VLF results along the profile 3 (T_5 a, and T_6 b), unfiltered Real component of VLF-EM data, Fraser filtered real (in-phase) data against distance, and Karous and Hjelt pseudo-section of in-phase data (apparent current density pseudo-section) against distance.

4.2.4 Profile 4

Highly conductive fracture zones appear at a distance of 30 m, 50 -100 m, and 120 m), profile 4 (Fig. 5a) with a common negative signal response. The pore could be considered to contain a conductive material such as water, however conductive zone appears at the profile proved the bore hole at length of 60m. At profile 4 (Fig 5b) at distance 70-120 m on the profile, fractures whose content is less conductive appear with negative cross over response, indicating less conductive material, the fracture depths extend as far as 30 m.

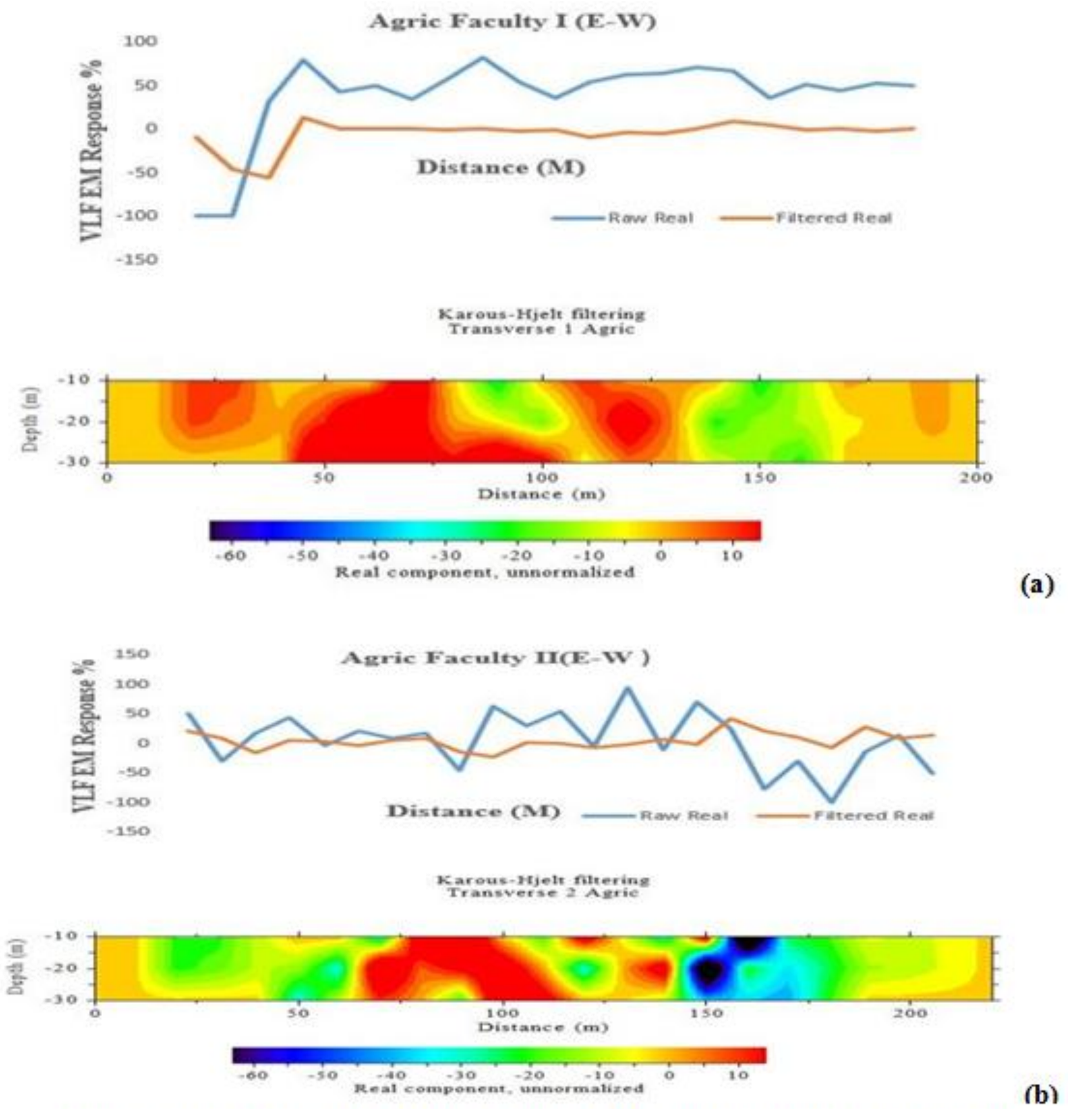


Figure 5: Plot of VLF results along the profile 4 (T_7 a, andT_8 b), unfiltered Real component of VLF-EM data, Fraser filtered real (in-phase) data against distance, and Karous and Hjelt pseudo-section of in-phase data (apparent current density pseudo-section) against distance.

4.2.5 Profile 5

Along the VLF Profile 5 ($T_{9,}$ a), the plot of Fraser filtered data and apparent current density pseudo-section using Karous-Hjelt filtering of in-phase data show positive response between 30-100 m, 180 m respectively extending beyond 30 m beneath the earth subsurface at 30-100 m (Figure **6a)** indicating the major fracture zones which serve as probable ground water bearing zone, with minor fractures located in some points as negative magnetic fractures, in other vain profile 5 ($T_{10,}$ b) indicate the fracture zone at distance of 60-120 m with positive cross over along the profile, the magnetic conductivity extend beyond the depth of 30 m, some negative conductivity appear in some distance(Appendix I).

4.2.6 Profile 6

Along the VLF Profile 6 ($T_{11,}$ a), the plot of Fraser filtered data and apparent current density pseudo-section using Karous-Hjelt filtering of in-phase data show positive response between 60-120 m,at 50-100 m other fractures appear with magnetic conductivities($T_{12,}$ b) extending beyond 30 m beneath the earth subsurface with some minor negative conductivities the cross over appear aspositive but not strong mean while it coincide with current density pseudo section as shown in (Appendix II).

Table 1. VLF-EM Interpreted Results.

Traverse no.	Distance (m) × 10	Coincident inflection points	Conductors	Fraser derivative	KH section	Geologic structure	Attitude
T1	100	Yes	C1	+ve Low	Negative	F2	Dipping deeper depth
T1	140	Yes	C2	+vePeak	Negative	F4	
T2	50	Yes	C3	-ve Peak	Positive	F2	
T3	150	Yes	C4	-ve Peak	Negative	F2	
T4	70	Yes	C5	+ve Peak	Positive	F2	
T4	150	Yes	C6	+ve Peak	Negative	F4	Dipping deeper depth
T5	50	Yes	C7	+ve Low	Positive	F2	
T5	130	Yes	C8	+ve Low	Positive	F4	
T6	70	Yes	C9	+ve Low	Positive	F2	
T6	150	Yes	C10	+ve Low	Positive	F4	
T7	50	Yes	C11	-ve Low	Positive	F2	
T7	120	No	C12	−ve Peak	Negative	F1	Shallow Depth
T8	100	Yes	C13	+ve Low	Positive	F2	
T9	50	Yes	C14	-ve Low	Positive	F2	
T10	70	Yes	C15	+ve Peak	Positive	F2	
T10	100	Yes	C16	+ve Peak	Positive	F3	Shallow depth
T11	70	Ye	C17	+ve Low	Positive	F2	
T11	100	No	C18	+ve Peak	Positive	F4	
T12	60	Yes	C19	-ve Low	Positive	F2	
T12	90	No	C20	-ve Low	Positive	F4	

IV. Conclusion

The VLF-EM measurements data were acquired along twenty (12) traverses on anexperimental basis for qualitative assessments of waterbearing fracturesor zoneand thereby to find optimum/bestlocations suitablefor groundwaterdevelopment, in this present research, geophysical study was performed to delineationto delineate fracture zonesin the selected location ofKebbi State University of Science and Technology Aliero, Sokoto sedimentary complex. Anomalies associated with conductive zones such as water-bearing weathered layers and geological features such as fractured and sheared zones were delineated.(Venuand and Linga ,2017), have identified areas with thick overburden cover as high groundwater potential zones. Consequently, areas with overburden thickness of 15m and above are priority areas for groundwater development, and majority of the areas identified from VLF-EM plot have thickness greater than this values, drilling of the productive boreholes is recommended at the locations, especially traverses identified with cross over that coincide with positive magnetic signal response against distance, include traverse 1 at 140 m, traverse 2 at 50 m, at traverse 4 at 50-100m and 150 m, traverse 6 at 50-100 m and 140-160 m, meanwhile traverse 7 at 50-100 m, traverse 10 at distance 70-100 m, and traverse 11, 12 indicate conductive zones with low cross over points that coincide with current density pseudo-section, with further analysis and evaluation four (4) fractures (f_1-f_4) were markedfrom which (F_1-F_3) are identified as shallow depth while (f_2-f_4) were marked for further investigation (Table 1)due to their attitude, length of the fractures and depthextended beyond (>30 m). Thus, a follow-up study of those site with fractures (f_2-f_4) should be carried out.

5.1 Recommendations

This work Recommend the combination of VLF-EM and VES survey to accurately delineate an area for groundwater location and exploitation to complement and confirm the present outcome.The borehole located at the vicinity of the area rated as positive conductive zone in traverse 2, 5 and traverse 7 appeared to be properly located on a confined aquifer. Thus, is suggested that it should be maintained because of its good quality.

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Appendix 1

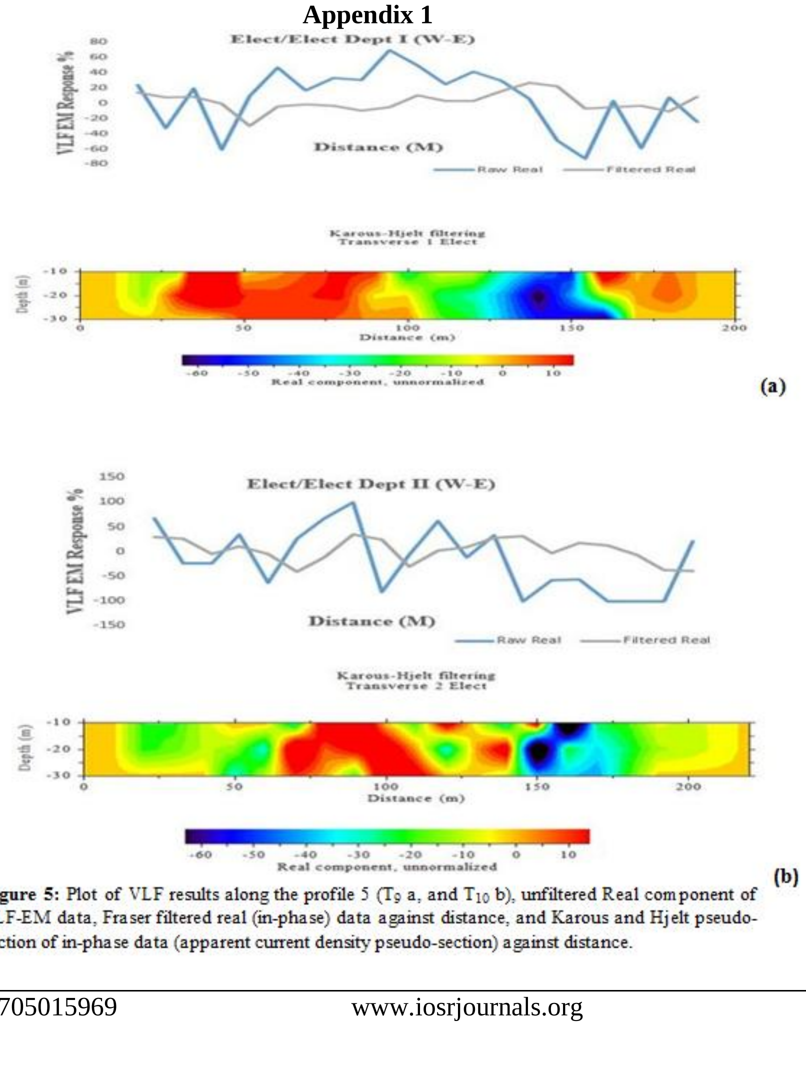

Figure 5: Plot of VLF results along the profile 5 (T_9 a, and T_{10} b), unfiltered Real component of VLF-EM data, Fraser filtered real (in-phase) data against distance, and Karous and Hjelt pseudo-section of in-phase data (apparent current density pseudo-section) against distance.

APPENDIX II

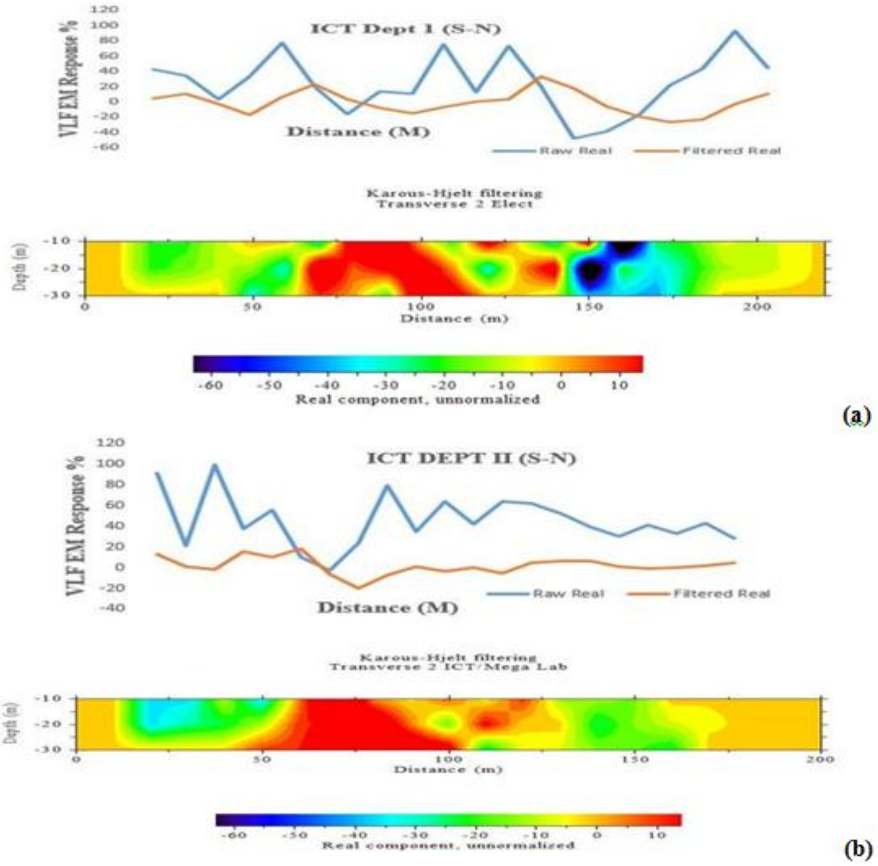

Figure 7: Plot of VLF results along the profile 6 (T_{11} a, and T_{12} b), unfiltered Real component of VLF-EM data, Fraser filtered real (in-phase) data against distance, and Karous and Hjelt pseudo-section of in-phase data (apparent current density pseudo-section) against distance.

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