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### RESEARCH ARTICLE

## A QUANTITATIVE ANALYSIS OF VLF DATA FOR GROUNDWATER EXPLORATION IN A HARDROCK TERRAIN IN OSMANIA UNIVERSITY CAMPUS, HYDERABAD, TELANGANA STATE, INDIA.

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Very Low Frequency Electromagnetic Method (VLF-EM); Aquifer zones; Pseudo-section; Conductivity; Groundwater.

#### Abstract

Groundwater exploration is reported in the hardrock terrain of Osmania University Campus, Hyderabad area, (78°31'00"E Longitude to 78°32'30"E Longitude and 17° 23'48" N Latitude to 17° 25'42"N Latitude) Telangana State. Nineteen (19) VLF traverses were conducted with 10m interval. VLF-EM is carried out using ABEM WADI equipment to locate the spatial location of the aquifer zones like fractures, faults, dykes and EM Conductors. Applications of Fraser filter for the real and imaginary components are aided in filtering the noise and refining the raw data for location of conductive zones. A Karous Hjelt filter pseudo section reveals the nature of conductive, dip and depth of these conductors and shallow linear conductors are mapped and also identified 52, subsurface fractures which are highly groundwater potential zones.

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#### Introduction:-

Very Low Frequency Electromagnetic (VLF-EM) method of geophysics utilizes very low frequency radio signals determine electrical properties of near surface and shallow bedrock features. This method is especially used for mapping steeply dipping structures such as faults, fractures and aquifer zones.

VLF method is a passive method that uses radiation from ground based military radio transmitters has the primary EM field for geophysical survey, utilizes signals from the communication stations operating in 3 to 30 KHz frequency range. These stations located around the world transmit the signals. These transmitters generate plane EM waves that can induce secondary eddy currents particularly to electrically conductive elongated two dimensional targets. EM wave propagates through the subsurface and subject to local distortions by the conductivity contacts in this medium. These variations indicate the variation in geo-electrical properties which may be related to the presence of groundwater (Satpathy, B.N. and Kanungo, B.N. 1976<sup>[1]</sup>). And also VLF method effectively applicable for studies for mapping contaminated zones, soil engineering, cultural detection, ionospheric, archeological and mineral exploration.

The theory and practice of VLF method is well documented by many authors (Omosuyi et al., 2008<sup>[2]</sup>; Oluwafemi and Oladunjoye, 2013<sup>[3]</sup>; Hazel, J.R.T., Cratchley, C.R. and Preston, A.M.1988<sup>[4]</sup>; Paterson and Ronka 1971<sup>[5]</sup>; Pedersen, 2002<sup>[6]</sup>; and Sundararajan et. al., 1996<sup>[7]</sup>).

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The present paper reports the result of the VLF-EM surveys carried out in Osmania University campus area, Telangana State are locating groundwater potential zones.

### Geology:-

The Osmania University Campus ( $78^{\circ}31'00''\text{E}$  Longitude to  $78^{\circ}32'30''\text{E}$  Longitude and  $17^{\circ}23'48''\text{N}$  Latitude to  $17^{\circ}25'42''\text{N}$  Latitude) is situated in an area of approximately 6.58 sq. km (1627.32 acres) lies in Hyderabad metro politon city (SOI). The maximum elevation observed is 535m and minimum elevation is 503m with respect to mean sea level. Here three types of granites exist—pink, grey and the leucogranites (Balakrishana and Rao, 1961<sup>[8]</sup>; Sitaramayya, 1968<sup>[9]</sup>, 1971<sup>[10]</sup>) and some pegmatite patches traversed by narrow white apatite veins, which intersect each other randomly. The granitic host rocks are (Figure: 1) intruded at places with doleritic dykes. The general geological section consists of soil layer underlain by weathered rock, which is in turn followed by the fractured rock at a few places. The basement, occurring at an average depth of 15m consists of hard impervious granite. Groundwater occurrence in the hardrock terrain can be vary irregular due to abrupt discontinuity in lithology, thickness and electrical properties of the overburden and weathered bedrock (Udaya Laxmi and Ramadass 2013<sup>[11]</sup>).

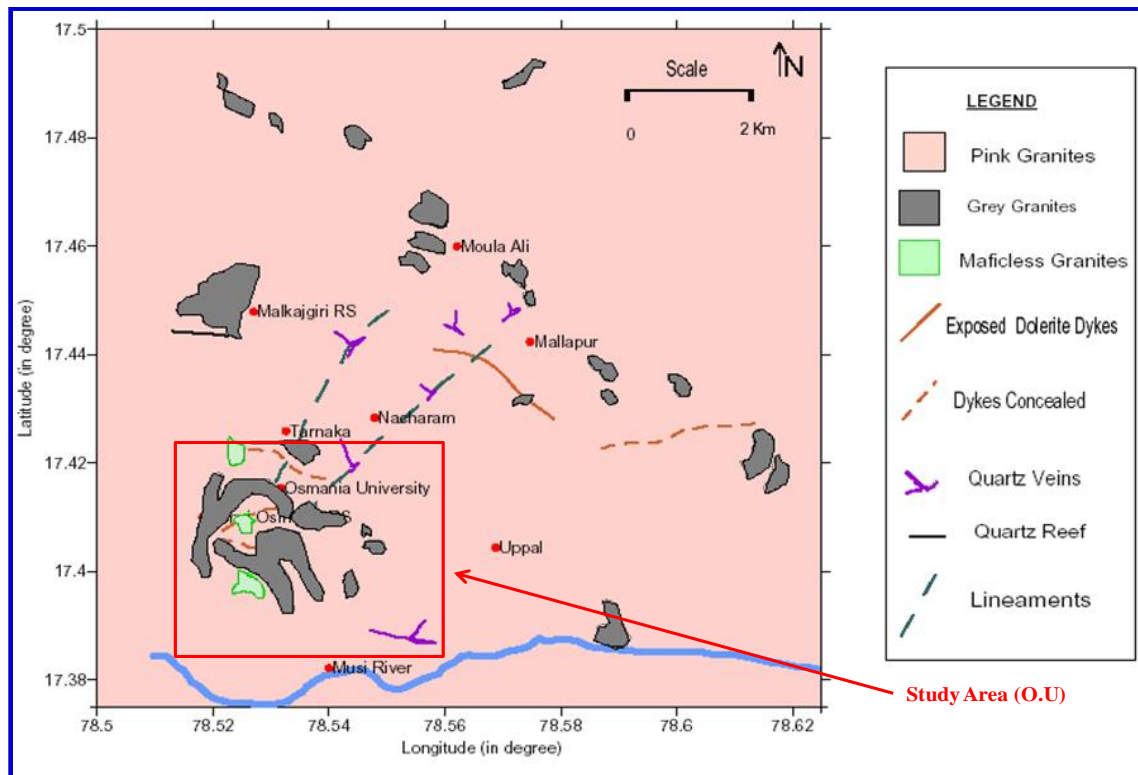


Figure 1:- Geology Map of the Study Area (After G. Udayalaxmi, 2009)

### Data base:-

Electrical, VLF (Very Low Frequency) Electromagnetic and Magnetic investigations were conducted to identifying the groundwater potential zones. These studies were then supplemented by hydrogeological data to evolve an integrated exploration strategy for groundwater. The studies as investigated thus combined reconnaissance, semi-detailed and detailed investigations. These integrated geophysical studies corresponding to a part of the map, were carried out roughly in comprising the Osmania University campus area (Figure: 2),  $78^{\circ}31'00''\text{E}$  longitude to  $78^{\circ}32'26''\text{E}$  longitude and  $17^{\circ}23'45''\text{N}$  latitude to  $17^{\circ}25'42''\text{N}$  latitude total area of 6.58 square kilometers (1627.32 acres). The surveys were directed towards tracing out and verifying the detailed geological setting and identifying different tectonic structures in the area which could have a definite bearing potential zones for groundwater.

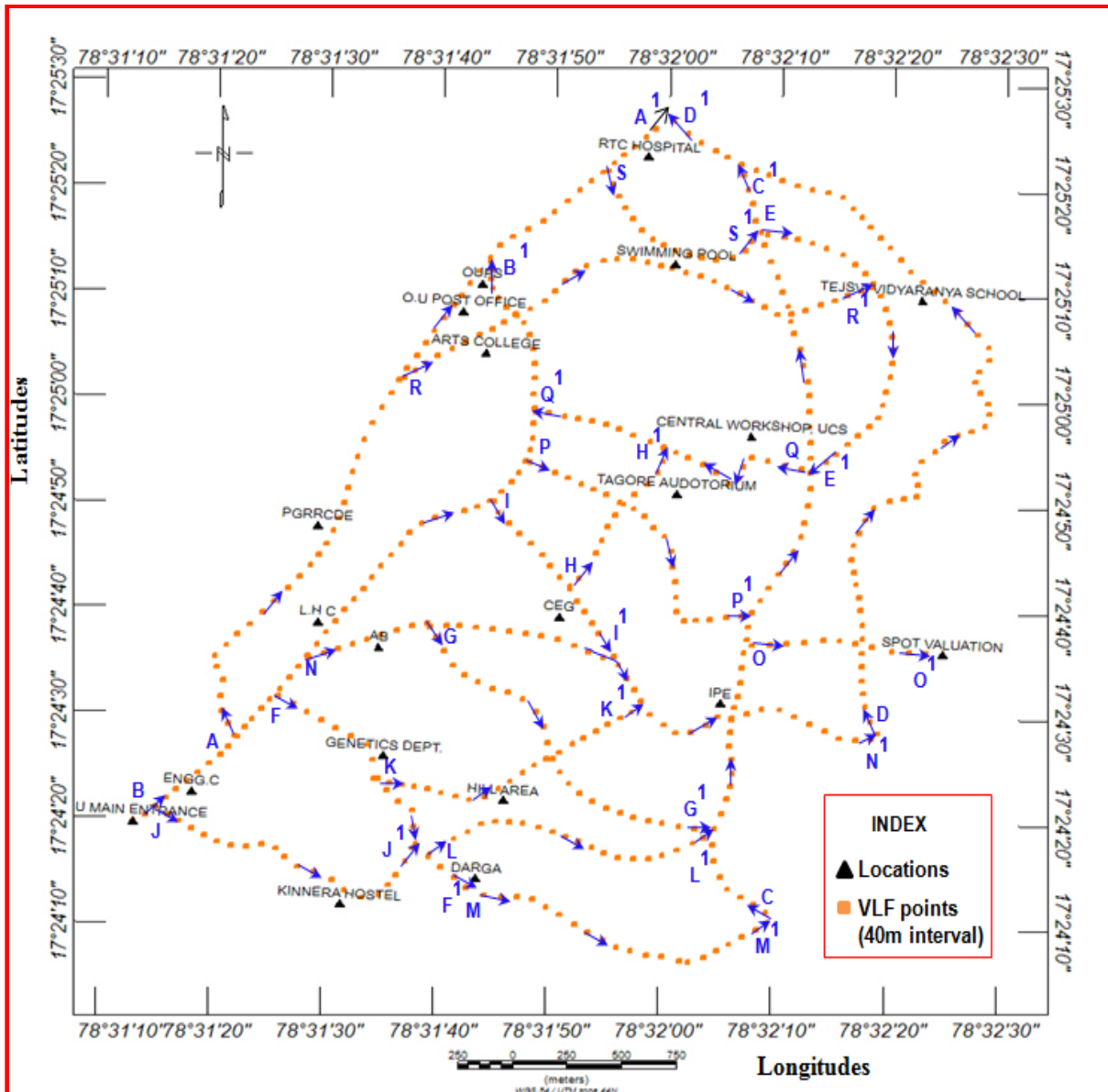


Figure 2:- Locations of VLF traverses (AA<sup>1</sup>, BB<sup>1</sup>, CC<sup>1</sup>, DD<sup>1</sup>, EE<sup>1</sup>, FF<sup>1</sup>, GG<sup>1</sup>, HH<sup>1</sup>, II<sup>1</sup>, JJ<sup>1</sup>, KK<sup>1</sup>, LL<sup>1</sup>, MM<sup>1</sup>, NN<sup>1</sup>, OO<sup>1</sup>, PP<sup>1</sup>, QQ<sup>1</sup>, RR<sup>1</sup> and SS<sup>1</sup>)

**Analysis of VLF-EM data:-**

For quantitative interpretation, it is more useful to plot the real and imaginary data. The method of estimating depth to a linear conductor based on the peak to peak width of VLF vertical in-phase data. The depth is half the peak-to-peak width, less the instrument's elevation above ground. This procedure was developed by Karous and Hjelt (K&H, 1983<sup>[12]</sup>)

The interpretation of VLF surveys in terms of buried conductors can be assisted by the application of the Karous and Hjelt, linear filter to the observed in-phase component of the vertical magnetic field. Karous and Hjelt filter technique are based on discrete linear filtering of VLF data. Starting with the Biot–Savart law to describe the magnetic field arising from a subsurface 2-D current distribution, these authors use linear filter theory to solve the integral equation for the current distribution, assumed to be located in a thin horizontal sheet of varying current density, situated everywhere at a depth equal to the distance between the measurement stations. By calculating the inverse filter at various depths (example Δx, 2Δx, 3Δx), one can study the variation of current densities with depth. This filter is expressed as;

$$\frac{\Delta z}{2\pi} I_a \left( \frac{\Delta x}{2} \right) = 0.102 H_{-3} - 0.059 H_{-2} + 0.561 H_{-1} - 0.561 H_1 + 0.059 H_2 - 0.102 H_3 \dots 1$$

### Filtering of VLF-EM data:-

#### Karous & Hjelt Filtering

Where  $\Delta z$  is the assumed thickness of the current sheet,  $\Delta x$  is the distance between the data points and also the depth to the current sheet, location of the calculated current density is beneath the center point of the six data points. The values of  $H$  are the normalized vertical magnetic field anomaly at each of six data points. Details of the filter derivation can be found in Karous & Hjelt (1983<sup>[12]</sup>).

Filtered VLF data help to locate vertical discontinuities such as hidden faults. K&H filter technique also provides a useful complementary tool for the semi-quantitative analysis and target visualization from the surface to a few ten meters. The current density maxima seem always to occur within or around the conductors. As a result of this feature, current density pseudo sections can give diagnostic information for the target (Ogilvi and Lee, 1991<sup>[13]</sup>).

#### Fraser Filtering:-

A simple filtering technique that transforms crossovers into peaks, removes regional gradients and also amplifies anomalies from near surface was suggested by Fraser, 1969<sup>[14]</sup>. The filter (Fraser) is applied to the in-phase (real), Quadrature (imaginary) component data and presented in the form of a contour map (Figure: 3 & 4). The negative contours are due to the false crossovers and are discarded. Based on the contour pattern it may be inferred that the conductive are probably a result of en-echelon-type complex fracture systems.

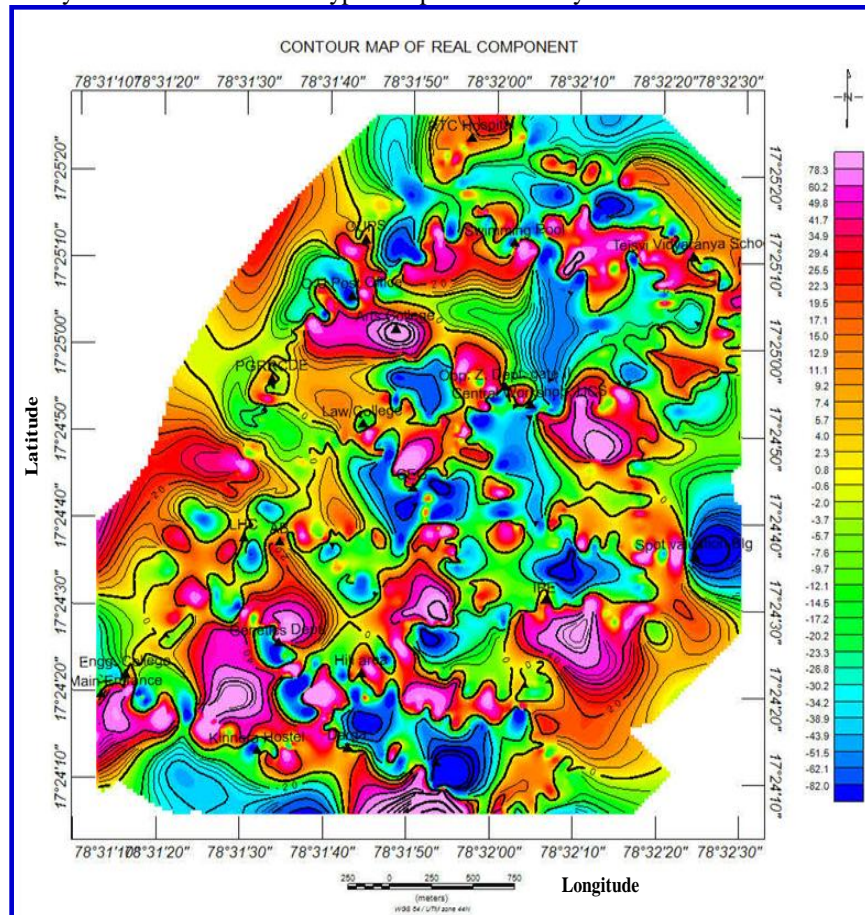


Figure 3:- Contour map of Real Component (Contour Interval 2.5)



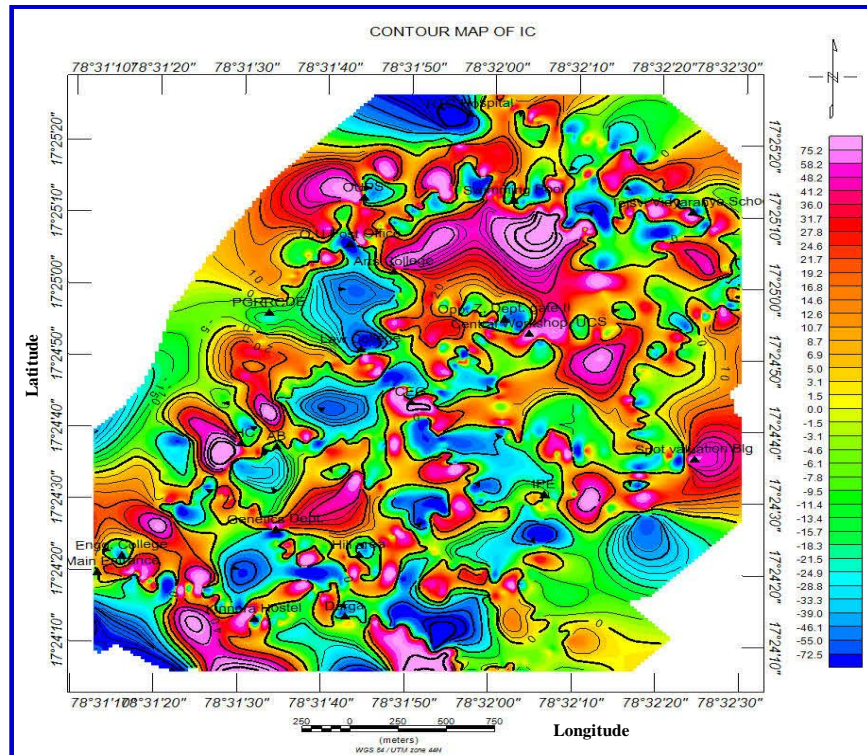


Figure 4:- Contour map of Imaginary Component (Contour Interval 2.5)

#### Fraser filtered pseudo-sections:-

An additional interpretation tool is pseudo-section obtained through filtering (Wright, 1988<sup>[15]</sup>). Such a section is produced by processing a given data profile with filters of various lengths. As the length of the filter increases, response from increasing depth is successively emphasized. Pseudo-sections are prepared for traverses AA<sup>1</sup> to SS<sup>1</sup> with two filters by normalizing each time with its filter lengths of the filtered in-phase component.

#### Interpretation of VLF-EM traverses:-

Electromagnetic VLF traverses (AA<sup>1</sup> to SS<sup>1</sup>) are carried all along parallel to the roads (10m away from the roads) in the N-S & E-W direction. Nineteen traverses in all were taken up. Plots of the filtered real and imaginary parts were produced for every traverse and they were interpreted in view of the existence of conductive zones that could be related to tectonic faults.

**Traverse-AA<sup>1</sup>** is running in the N-S direction about 2000m long towards west of the study area and it traverse from UFRO - under the Adikmet flyover – PGRRCDE – EFLU -Bed College to Tarnaka Junction.

Fraser filtering (Fraser, 1969<sup>[14]</sup>) responses ranged in value from -100 % to 98% along the traverse. Figure: 5(a) shows the Fraser filtered data (real or in-phase component and imaginary or quadrature component). The in-phase traverses show positive peaks of different values of relative current density correspond to higher values of resistivity. All the VLF-EM intensities and sharpness were suggesting the presence of shallow and deep conductors. Lower traverses in this study were processed using the Karous-Hjelt filter (Karous and Hjelt, 1983<sup>[12]</sup>). Conductors (colored red) were delineated from equivalent current density pseudo sections along traverse AA<sup>1</sup>. A higher value of relative current density is regarded as conductive subsurface structures, such as fractures, which often store groundwater in hardrock terrains. The 2-D inversion shows the variation of equivalent current density, and change in conductivity with depth. With such equivalent current density cross-section plots, it is possible to qualitatively discriminate between conductive and resistive structures where a high positive value corresponds to the conductive subsurface structure and low negative values are related to resistive materials. In addition, equivalent current density cross-section also gives an idea about the dip direction; however, exact dip angle cannot be estimated due to the vertical axis variable being a pseudo depth only.

The equivalence current density pseudo section of traverse (Figure: 5 b) reveals the presence of major anomalies at the southern side between 590m and 710m, and at the northern side between 1400m and 1490m with depth of 20 to 60m, which can be referred to as fracture zone. Furthermore, two high current density zones between 300m and 350m, and 510m along the traverse can also be referred to as indications of the potential subsurface fracture system (Figure: 5 b). Asymmetry in the observed real and imaginary anomalies suggests the dipping nature of a subsurface conductive body. The Fraser filtering data plots and the Karous-Hjelt current density plot for traverse as presented in Figure: 5 (a) reveals a number of anomalies, which reflects conductive subsurface structural trends of inferred fractures zones (at 500, 640 and 1450m) along the traverse.

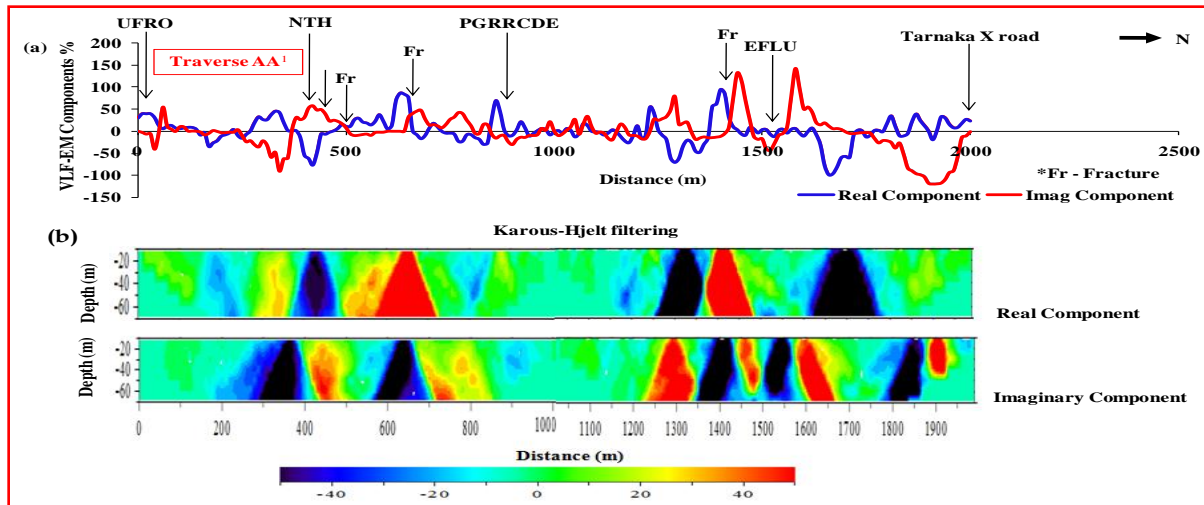


Figure: 5 (a), (b):- Fraser filtering graph and equivalent current density pseudo-section of Traverse AA<sup>1</sup>.

**Traverse-BB<sup>1</sup>** is running 2200m and trending in N-S direction, lies towards west of the study area and it traverse from O.U Main Entrance - Engineering College - Ladies Hostel - Law College - Arts College to O.U Police Station.

Figure: 6(a) shows the Fraser filtered data of in-phase and quadrature component, responses ranged in value from -100 % to 175% along the traverse.

Figure: 6(b) shows the corresponding K-H pseudo section of traverse BB<sup>1</sup>. The pseudo section is a measure of the conductivity of the subsurface as a function of depth. The conductivity shown as color codes with conductivity increasing from left to right (i.e., from negative to positive). Different features of varying degree of conductivity trending in different directions are delineated on the section, for instance, between stations 515m and 620m and between stations 1745m and 1830m, highly and major conductive bodies respectively at approximate depth of 70m are indicated. Figure: 6(a) reveals a number of anomalies, which reflects conductive subsurface structural trends of inferred fractures zones (at 490 and 1850m) along the traverse.

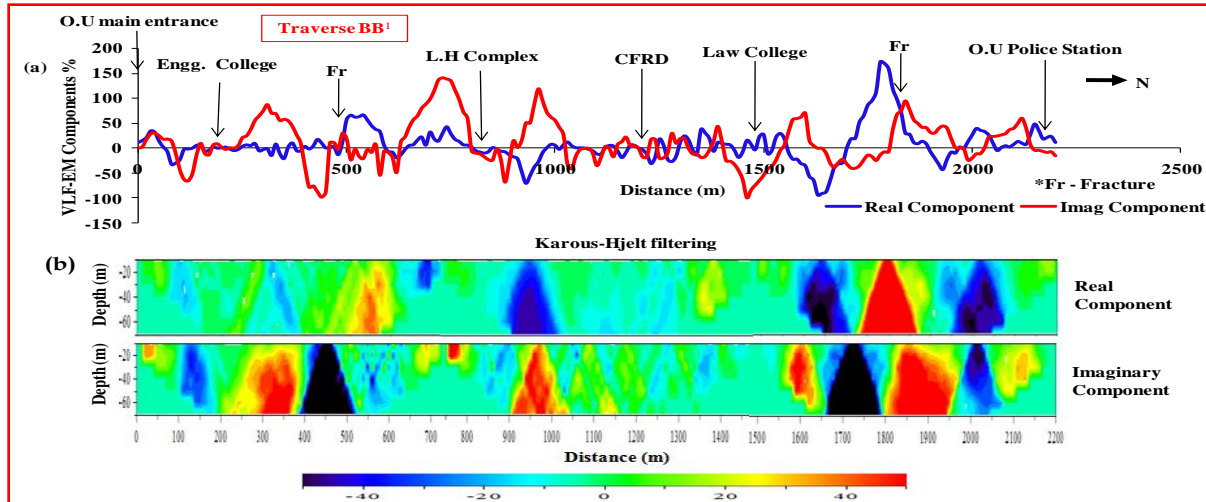


Figure: 6 (a), (b):- Fraser filtering graph and equivalent current density pseudo-section of Traverse BB<sup>1</sup>.

Traverse-CC<sup>1</sup> is situated east of the O.U Campus, about 2400m long and it runs from a point towards IPE, in N-S direction nearby Darga which is behind the Genetics Dept. – IPE - behind the residences of Maneru Hostel - Professors Quarters - Indore Stadium to Aradana Theater.

Figure: 7(a) shows the percentage of real and imaginary component of Fraser filtered data with ground distances, ranged in values from -120% to 153% along the traverse.

Figure: 7(b) shows a highly conductive body between stations 1400m and 1510m and major conductive body is indicated between stations 2035m and 2170m at an approximate depth of 70m and also a low conductive body between 1550m and 1575m with approximate depth of 30m. Figure: 7(a) reveals a number of anomalies, which reflects conductive subsurface structural trends of inferred fractures zones (at 1470 and 2070m) along the traverse.

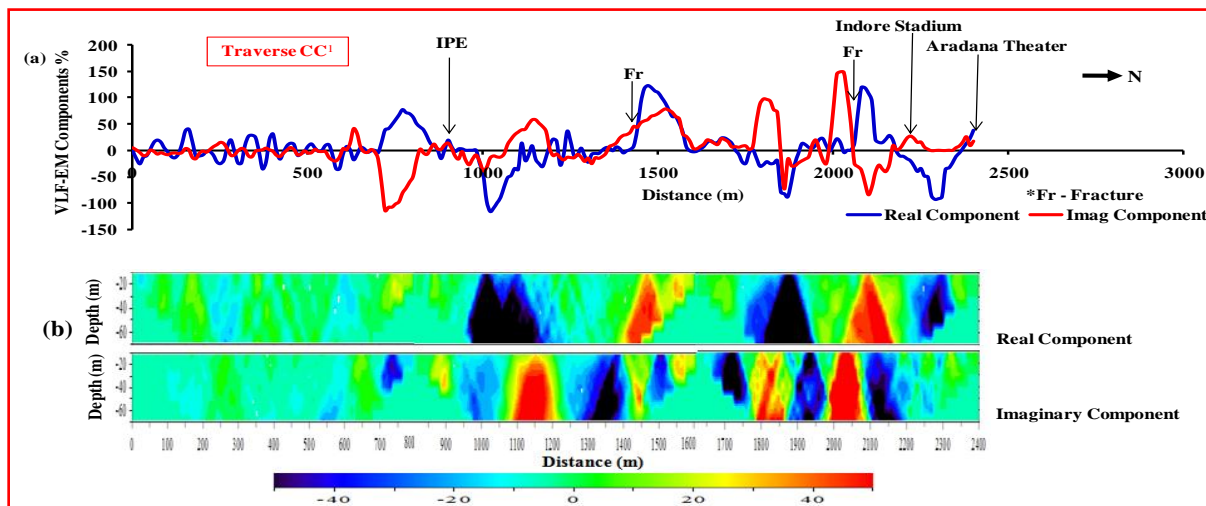


Figure: 7 (a), (b):- Fraser filtering graph and equivalent current density pseudo-section of Traverse CC<sup>1</sup>.

Traverse-DD<sup>1</sup> is running from a way out to Ramanthapur near IPE residences via a junction road near Spotvaluation, Residences, Burial Ground, Habsiguda Harithavanam, Tejasvi Vidyaranya School, Behind the Swagath Grand Hotel, Huda Complex, and 'A' Ground to Taranaka Junction with a total length of 2430m and is situated east of the study area.

Figure: 8(a) shows the values ranged from -100% to 175% is the real and imaginary component response of Fraser filtered data.

Figure: 8(b) shows different features of varying degree of conductivity, for instance, between stations 1920m and 2045m and between stations 2085m and 2190m, major conductive bodies at an approximate depth of 70m are indicated. The section shows several closures of conductive bodies at different depths. Figure: 8(a) reveals a number of anomalies, which reflects conductive subsurface structural trends of inferred fractures zones (at 1350, 1950 and 2200m) along the traverse.

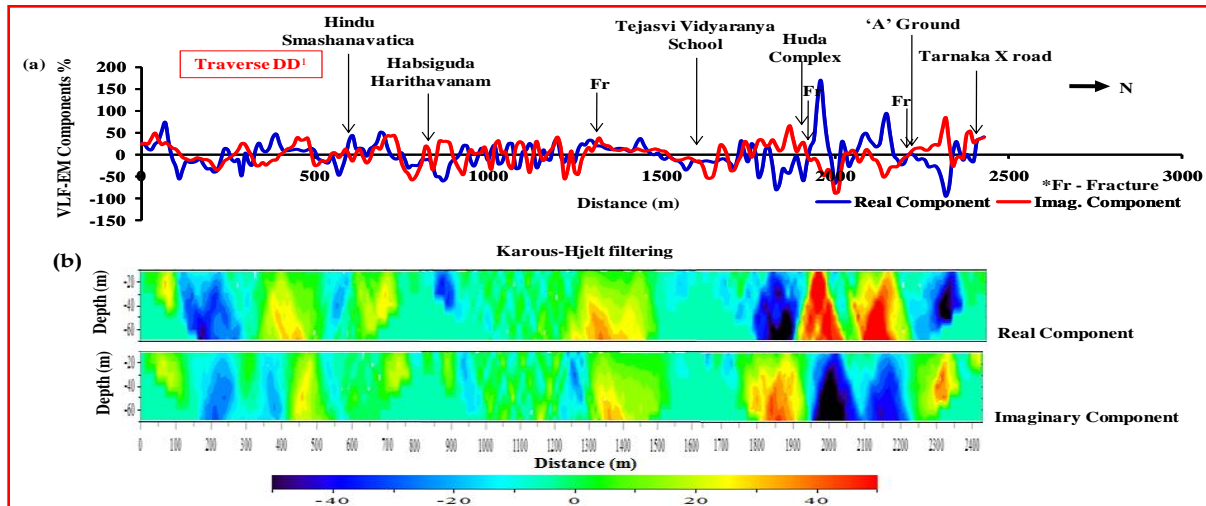


Figure: 8(a), (b):- Fraser filtering graph and equivalent current density pseudo-section of Traverse DD<sup>1</sup>.

Traverse-EE<sup>1</sup> indicates the path in N-S directions and it starts from Indoor Stadium Entrance - Professors Quarters - to its Junction road before Central Workshop, UCS with total length of 920m and lies towards north of the study area.

Figure: 9(a) shows the real and imaginary component response range from -160% to 195% of Fraser filtered data.

Figure: 9(b) shows a major conductive body at an approximate depth of 70m between stations 220m and 440m, forming an M-shaped conductive body. Also, a highly conductive body between stations 50m and 80m at an approximate depth of 30m, existing north side of the section. Figure: 9(a) reveals a number of anomalies, which reflects conductive subsurface structural trends of inferred fractures zones (at 70, 300 and 370m) along the traverse.

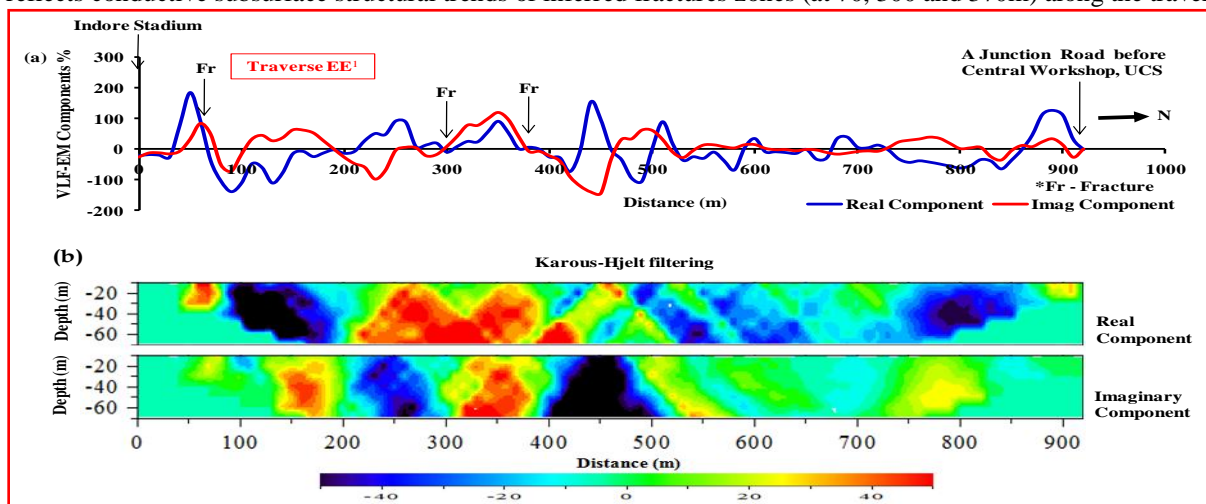


Figure: 9 (a), (b):- Fraser filtering graph and equivalent current density pseudo-section of Traverse EE<sup>1</sup>.

Traverse-FF<sup>1</sup> has the path in E-W directions and it starts from Ganga Hostel - Genetics and Microbiology Departments to Darga with total length of 720m and lies towards south of the study area.



Figure: 10(a) shows the response of real and imaginary Fraser filtered data ranged from -400% to 390%.

Figure: 10(b) shows different features of varying degree of conductivity trending in different directions, for instance, between stations 460m and 550m, major conductive body at an approximate depth of 70m trending in NW-SE. Highly conductive body between stations 360m and 415m is indicated. There are several pockets of highly conductive bodies cross-cut between stations 135m and 285m forming V-shaped conductive body. Generally, the section shows several closures of conductive bodies at different depths. Figure: 10(a) reveals a number of anomalies, which reflects conductive subsurface structural trends of inferred fractures zones (at 270, 390 and 500m) along the traverse.

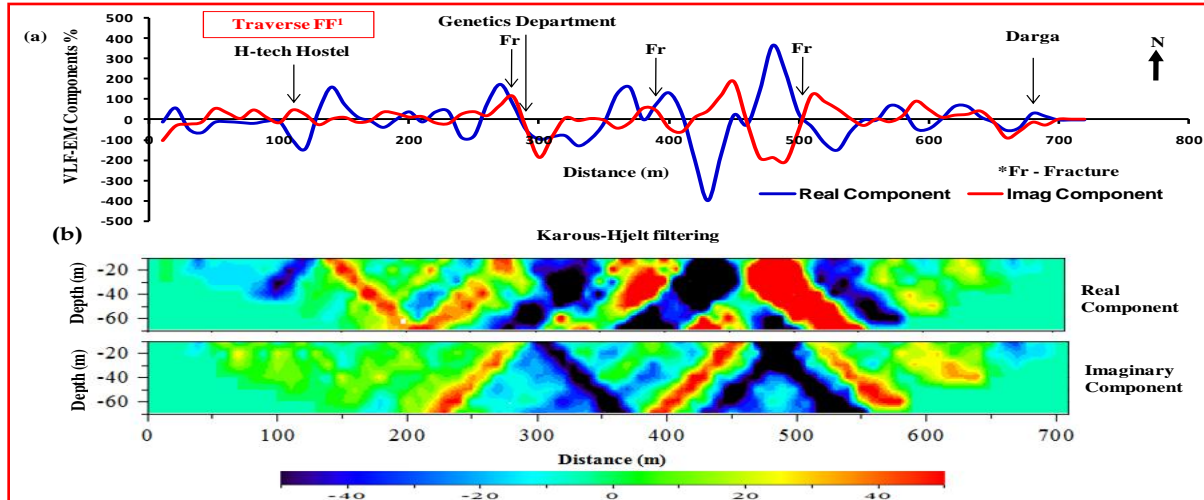


Figure: 10 (a), (b):- Fraser filtering graph and equivalent current density pseudo-section of Traverse FF<sup>1</sup>.

**Traverse-GG<sup>1</sup>** starts from Cafeteria - V.C Lodge-through Forest -to a road towards to IPE with the total length of 960m and lies towards south of the O.U Campus.

Figure: 11(a) reveals the anomaly response of real and imaginary Fraser filtered data ranged from -80% to 125%.

Figure: 11(b) is a section of the conductive body with linear major conductive bodies are very closely adjacent to each other as overlapping at an approximate depth of 70m between stations 34m and 500m. Towards the eastern part of the section, a highly conductive body is indicated between stations 795m and 860m at an approximate depth of 65m. Figure: 11(a) reveals a number of anomalies, which reflects conductive subsurface structural trends of inferred fractures zones (at 300, 440 and 720m) along the traverse.

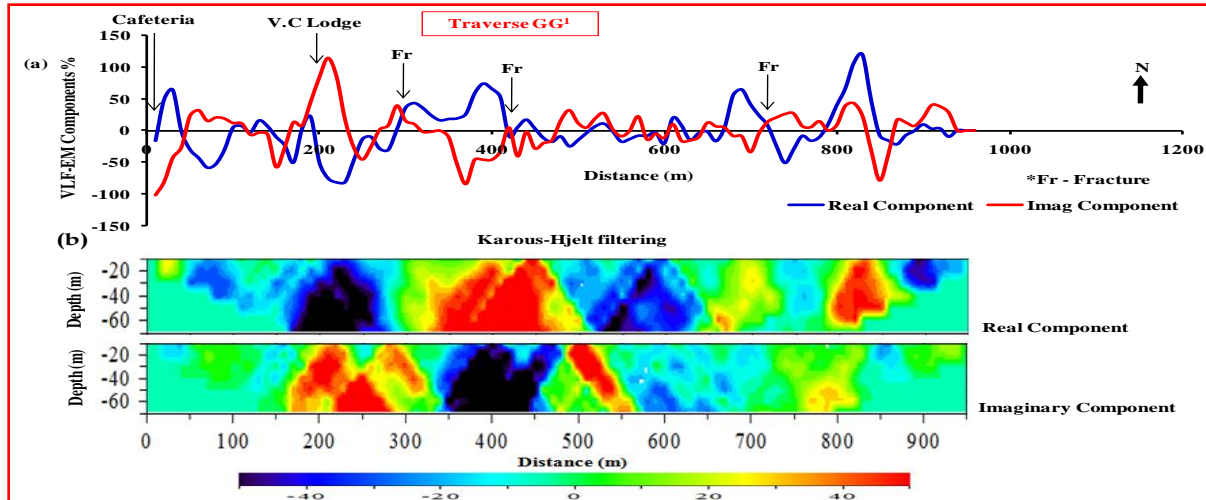


Figure: 11(a), (b):- Fraser filtering graph and equivalent current density pseudo-section of Traverse GG<sup>1</sup>.

**Traverse HH<sup>1</sup>** –is in N-S direction and lies middle of the study area with the total length of 490m, it starts from a road junction adjacent to Geography - Tagore Auditorium road - to Botanical Garden 2<sup>nd</sup> Gate, which is opposite to Botany and Zoology Department.

Figure: 12(a) shows the percentage of anomaly response of real and imaginary Fraser filtered data ranged from - 280% to 390%.

Figure: 12(b) is conductive body section with a linear major conductive body in the vertical direction between stations 215m and 340m at an approximate depth of 70m. Figure: 12 (a) reveals a number of anomalies, which reflects conductive subsurface structural trends of inferred fractures zones (at 260m) along the traverse.

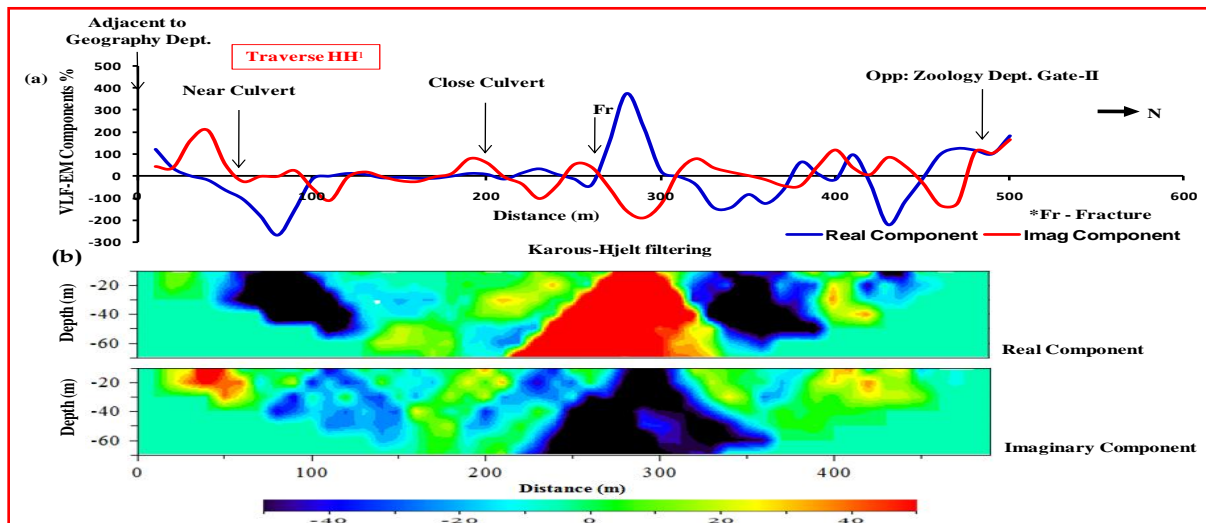


Figure: 12a), (b):- Fraser filtering graph and equivalent current density pseudo-section of Traverse HH<sup>1</sup>.

**Traverse-II<sup>1</sup>** runs from opposite to Law College (Adjacent to Landscape Garden)-‘D’ Hostel-Geophysics Department to a junction road towards O.U Press, in E-W trending with a total length of 560m and lies middle of the study area.

Figure: 13(a) shows the anomaly response of real and imaginary Fraser filtered data, the percentage ranged from - 190% to 250%.

In figure: 13(b) different features of varying degree of conductivity are delineated on the section, for instance, between stations 150m and 220m, and 410m and 490m major conductive bodies are shown. Similarly, between stations 220m and 245m, and 520m and 560m, highly conductive bodies at an approximate depth of 50m and 25m respectively present on the section. Figure: 13(a) reveals a number of anomalies, which reflects conductive subsurface structural trends of inferred fractures zones (at 170, 230, 410, 450 and 530m) along the traverse.

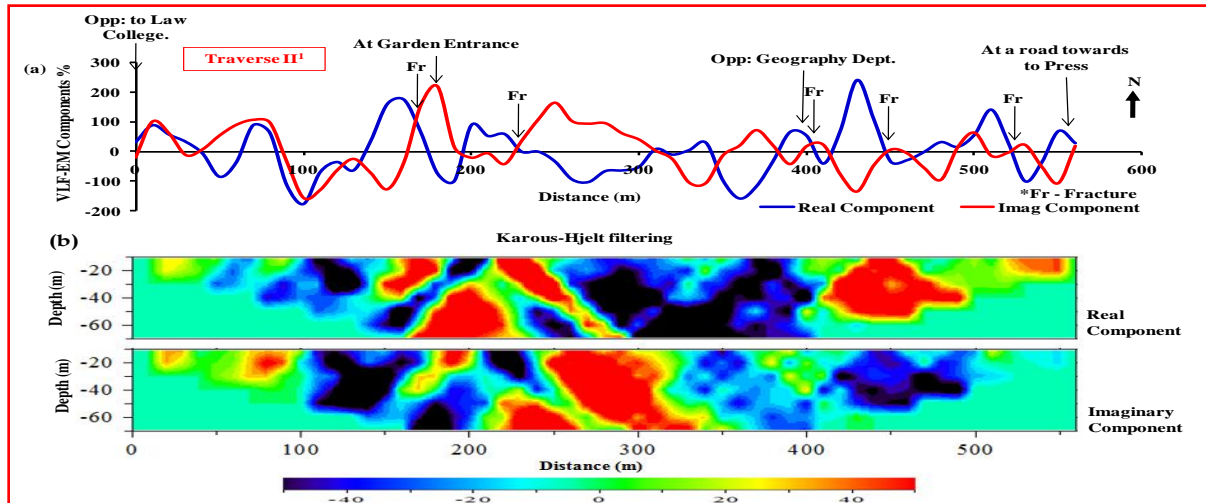


Figure: 13 (a), (b):- Fraser filtering graph and equivalent current density pseudo-section of Traverse II<sup>1</sup>.

Traverse-JJ<sup>1</sup> is 760m long in E-W trending lies south of the study area and it traverse from a road opposite to Telangana Mahila Sabha - Kinnera Hostel - to behind the Genetics Department - and close to Darga.

Figure: 14(a) shows real and imaginary Fraser filtered data response, the percentage ranged from -200% to 220%.

Figure: 14(b). The section is a conductive body with the highly conductive body between stations 50m and 80m at an approximate depth of 32m. Also, between stations 180m and 205m at an approximate depth of 70m in the vertical direction is shown. Several other closures of conductive bodies are present on the section with each conductive body coinciding with the points already identified on the profile as the fracture. Figure: 14 (a) reveals a number of anomalies, which reflects conductive subsurface structural trends of inferred fractures zones (at 60, 190, 350, and 440m) along the traverse.

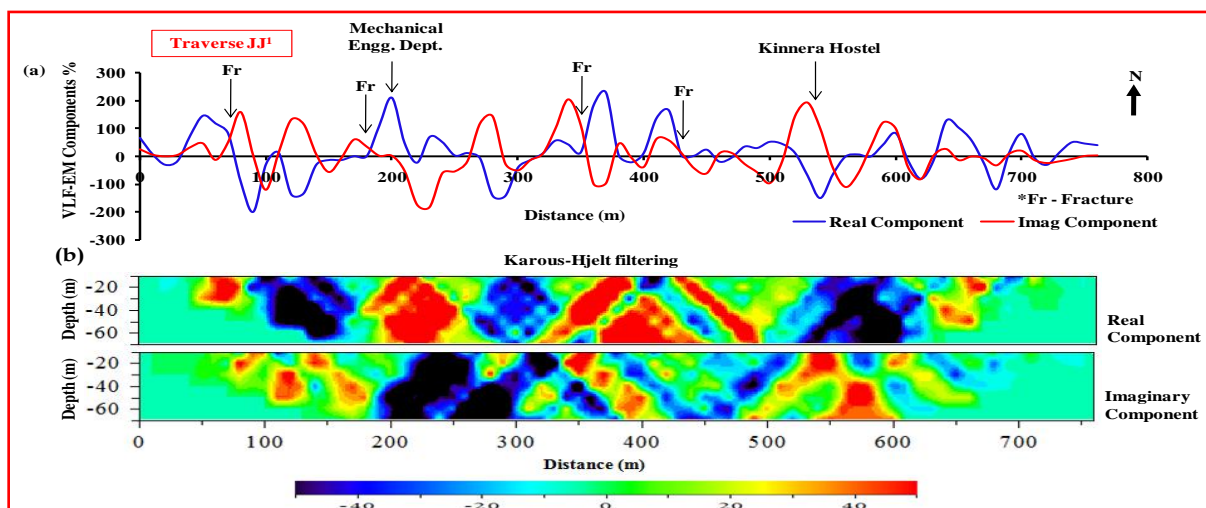
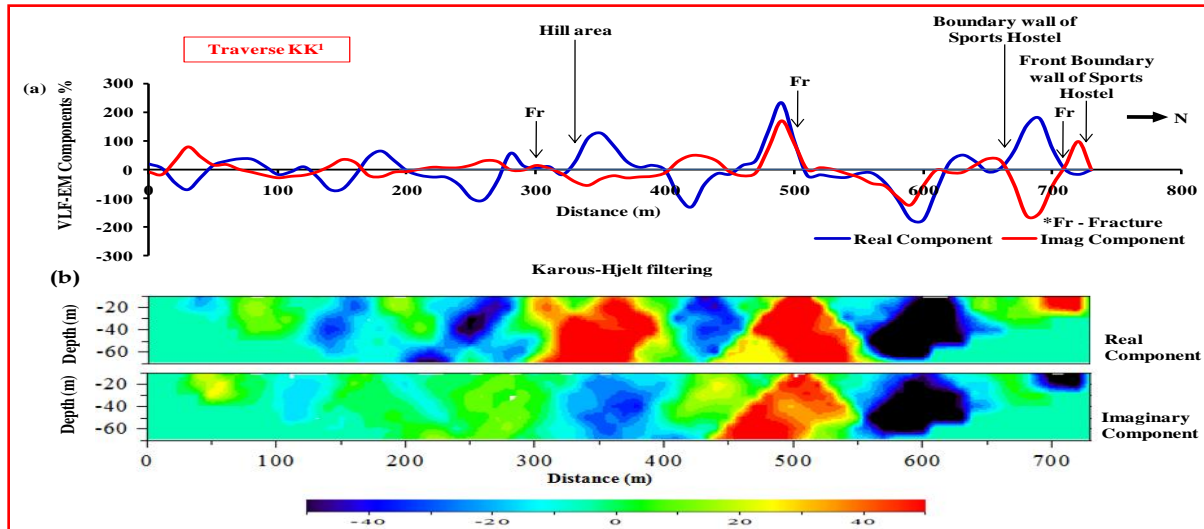


Figure: 14 (a), (b):- Fraser filtering graph and equivalent current density pseudo-section of Traverse JJ<sup>1</sup>.

**Traverse-KK<sup>1</sup>** is in E-W direction, passing from behind the Genetics Department, close to open Well - Hill Area - through Forest - to Sports Hostel front side Boundary wall with a total length of 730m and situated towards south of the study area.

Figure: 15(a) shows positive and negative peaks of the real and imaginary Fraser filter data, ranged from -190% to 240%.

Figure: 15(b) shows major conductive bodies between stations 300m and 400m, and 465m and 550m at an approximate depth of 70m. Eastern part of the section shows a highly conductive body between stations 690m and 740m at an approximate depth of 22m. Figure: 15(a) reveals a number of anomalies, which reflects conductive subsurface structural trends of inferred fractures zones (at 300, 500 and 710m) along the traverse.



**Figure: 15 (a), (b):-** Fraser filtering graph and equivalent current density pseudo-section of Traverse KK<sup>1</sup>.

**Traverse-LL<sup>1</sup>** indicates the path in E-W direction all along the 790m length to south of the study area and it starts from Darga (Behind the Genetics Department) - through Forest - to Towards IPE road.

Figure: 16 (a) shows Fraser filter data, the percentage of positive and negative peaks of the real and imaginary components, ranged from -200% to 120%.

Figure: 16 (b) shows several closures and pockets of features of conductive bodies at varying degree of conductivity. Between stations 340m and 550m, a major conductive body at an approximate depth of 70m is indicated. Figure: 16(a) reveals a number of anomalies, which reflects conductive subsurface structural trends of inferred fractures zones (at 410 and 490m) along the traverse.



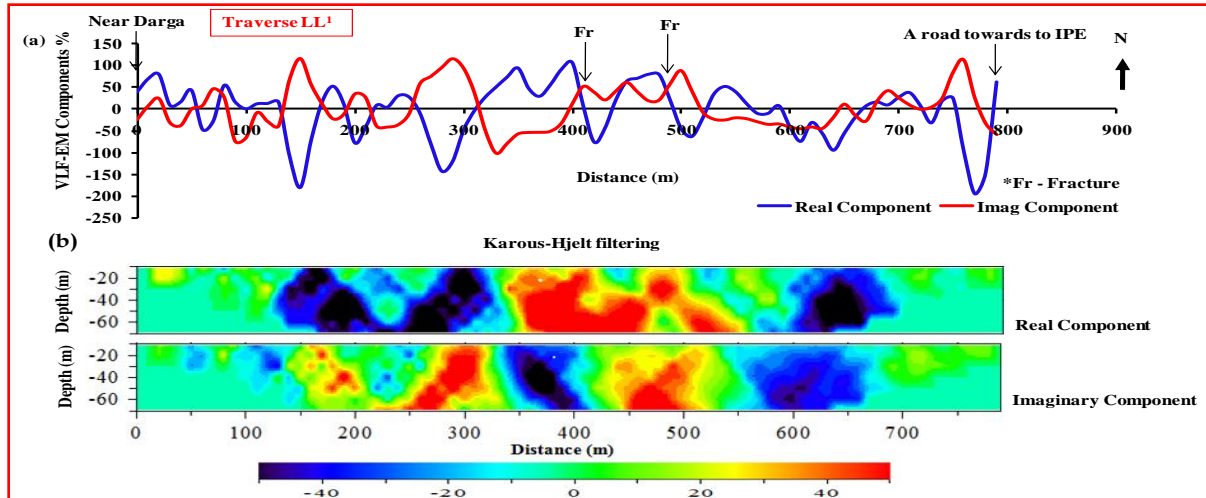


Figure: 16 (a), (b):- Fraser filtering graph and equivalent current density pseudo-section of Traverse LL<sup>1</sup>.

Traverse-MM<sup>1</sup> indicates its traverse in E-W direction all along the 560m length to south of the study area and it starts from ending station of FF<sup>1</sup> traverse near Darga (Behind the Genetics Department) inside the Forest - to a road up to a N-S direction.

Figure: 17 (a) shows the Fraser filtered data of in-phase and quadrature component, responses ranged in value from -100 % to 175% along the traverse.

Figure: 17(b) is a section of the highly conductive body between stations 220m and 240m at an approximate depth of 2m. Figure: 17 (a) reveals a number of anomalies, which reflects conductive subsurface structural trends of inferred fractures zones (at 240 and 250m) along the traverse.

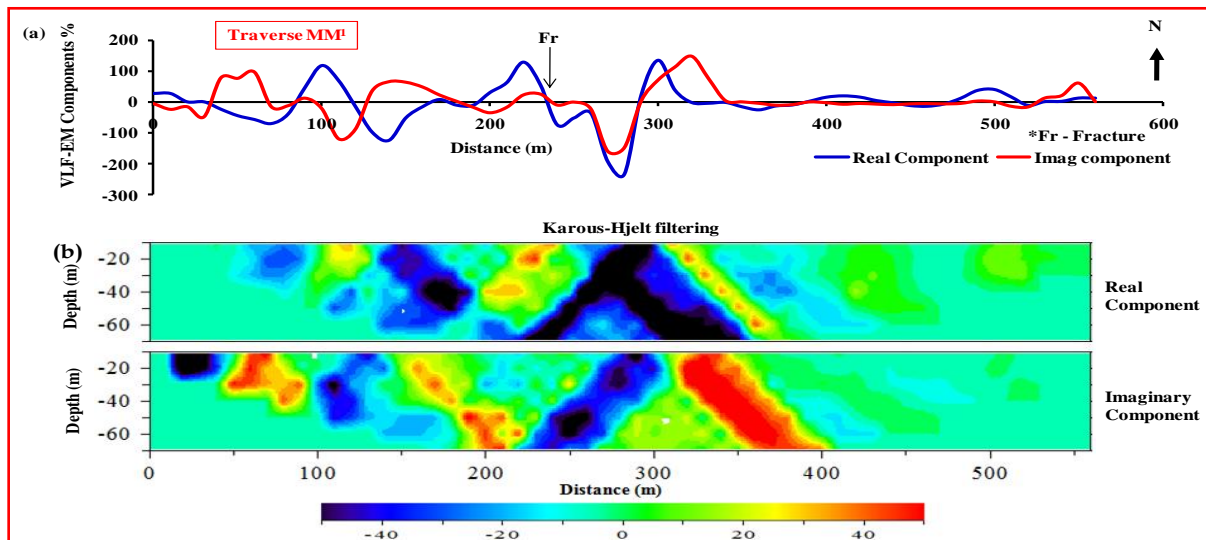


Figure: 17 (a), (b):- Fraser filtering graph and equivalent current density pseudo-section of Traverse MM<sup>1</sup>.

Traverse-NN<sup>1</sup> this 1560m and trending in an E-W direction lays towards below middle part of the study area and it traverse from Renuka Yellamma Temple - Administrative Building - College of Technology – IPE - to Dead End of the Residences Area.

Figure: 18 (a) shows the Fraser filtered data of in-phase and quadrature component, responses ranged in value from -140 % to 150% along the traverse.

Figure: 18 (b) revealed occurrence of major conductive bodies between stations 640m and 715m, and 900m and 990m at an approximate depth of 52m and 60m respectively. There are several pockets of highly conductive bodies are indicted along section at different depths. Figure: 18(a) reveals a number of anomalies, which reflects conductive subsurface structural trends of inferred fractures zones (at 700 and 1200m) along the traverse.

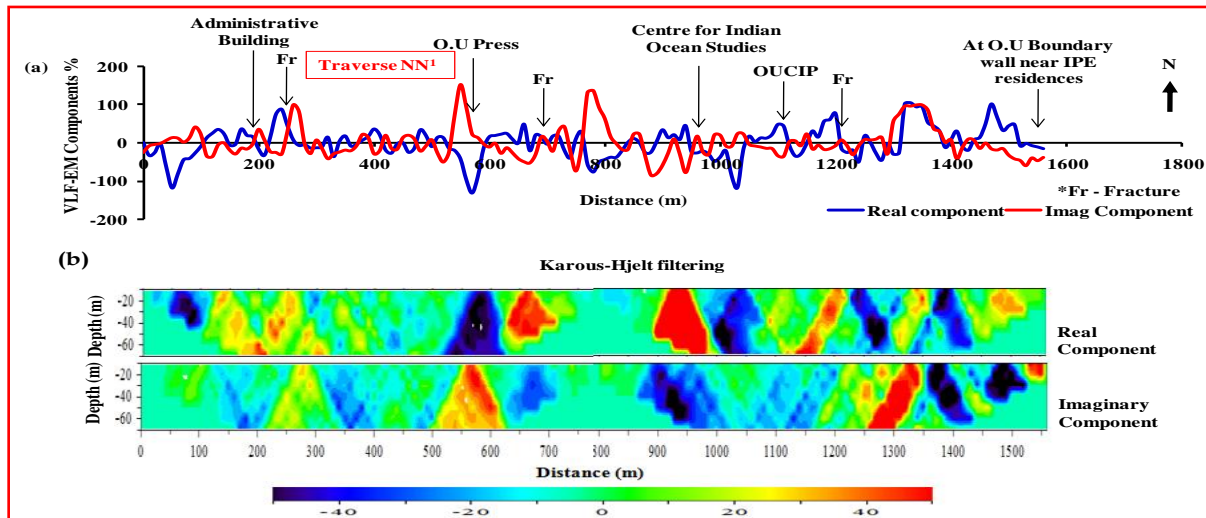


Figure: 18(a), (b):- Fraser filtering graph and equivalent current density pseudo-section of Traverse NN<sup>1</sup>.

Traverse-OO<sup>1</sup> starts from O.U Darga (Near Maneru Hostel) - to Spot Valuation Building running a total length of 440m to the east of study area.

Figure: 19(a) shows the in-phase and quadrature component percentage responses of Fraser filtered data, ranged in value from -140 % to 150% along the traverse.

Figure: 19 (b) shows a major conductive body at an approximate depth 45m between stations 340m and 405m. Similarly, between stations 220m and 305m, a linear highly conductive body is indicated. Figure: 19 (a) reveals a number of anomalies, which reflects conductive subsurface structural trends of inferred fractures zones (at 70 and 330m) along the traverse.

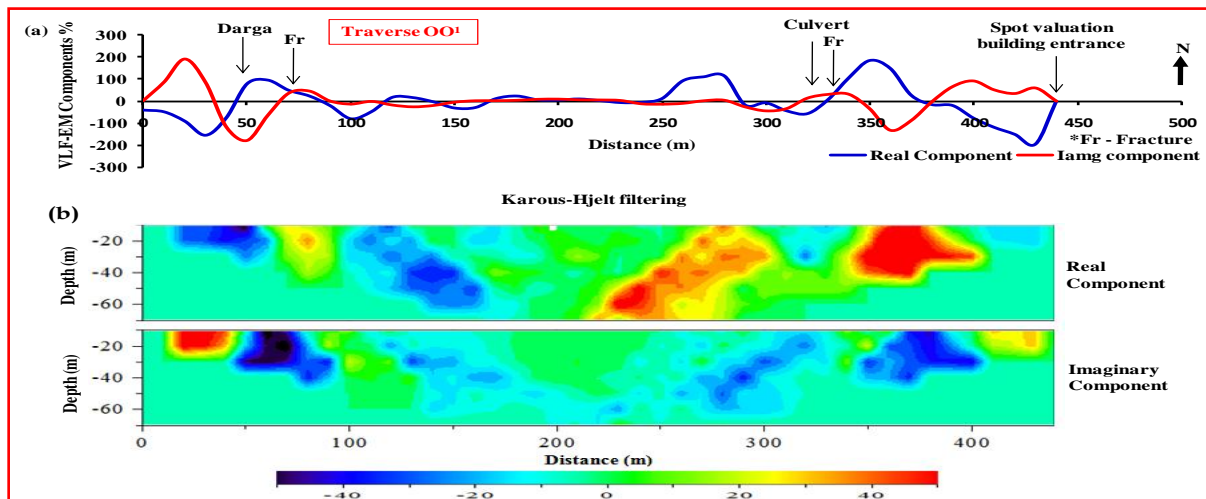
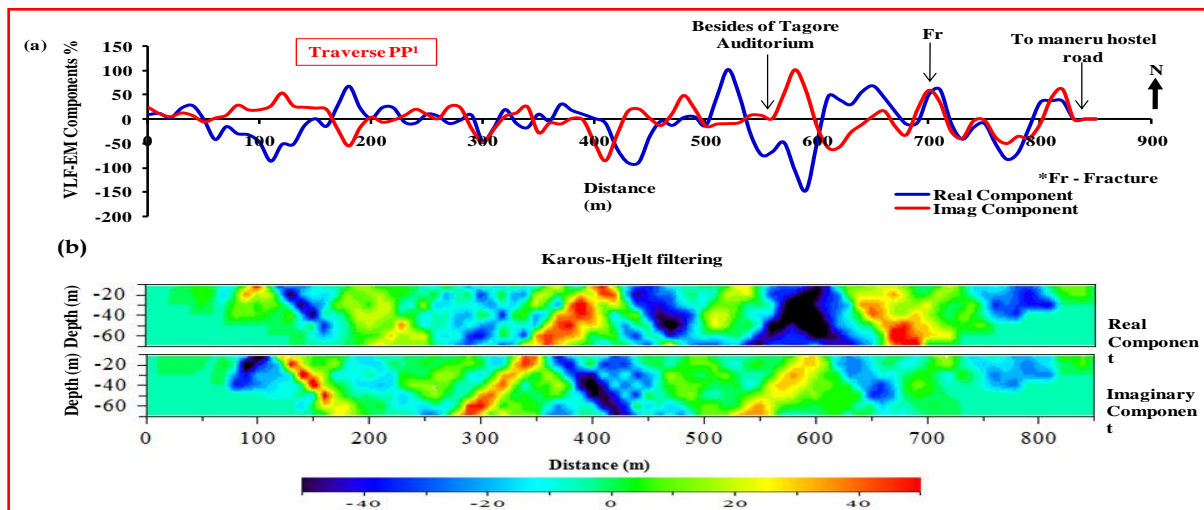


Figure: 19 (a), (b):- Fraser filtering graph and equivalent current density pseudo-section of Traverse OO<sup>1</sup>.

**Traverse-PP<sup>1</sup>** indicates its traverse in E-W direction nearly 850m in length approximately middle portion of the study area and it starts from one edge of the road of Landscape Garden, exactly opposite to O.U Library - inside the Landscape Garden - through Forest (adjacent to Tagore Auditorium) - to edge of the Maneru Hostel road.

Figure: 20(a) shows the anomaly response of real and imaginary Fraser filtered data, the percentage ranged from -150% to 100%.

Figure: 20 (b) shows several closures and pockets of features of conductive bodies at varying degree of conductivity between stations 640m and 710m, a highly conductive body at an approximate depth of 70m is indicated. Similarly, between stations 350m and 425m, a linear highly conductive body is indicated. Figure: 20(a) reveals a number of anomalies, which reflects conductive subsurface structural trends of inferred fractures zones (at 700m) along the traverse.



**Figure 20 (a), (b):-** Fraser filtering graph and equivalent current density pseudo-section of TraversePP<sup>1</sup>.

**Traverse-QQ<sup>1</sup>** indicates the path in E-W direction all along the 810m length to above middle of the study area and it starts from a junction road after Central Workshop, UCS - Botany and Zoology Departments - to towards to Arts College road.

Figure: 21 (a) shows the Fraser filtered data of in-phase and quadrature component, responses ranged in value from -110 % to 135% along the traverse.

Figure: 21(b) shows a major conductive body cross-cut between stations 320m and 460m forming V-shaped conductive body. Similarly, between stations 190m and 300m, a linear major conductive body is indicated. Generally, the section shows several closures of conductive bodies at different depths. Figure: 21(a) reveals a number of anomalies, which reflects conductive subsurface structural trends of inferred fractures zones (at 170, 250 and 460m) along the traverse.

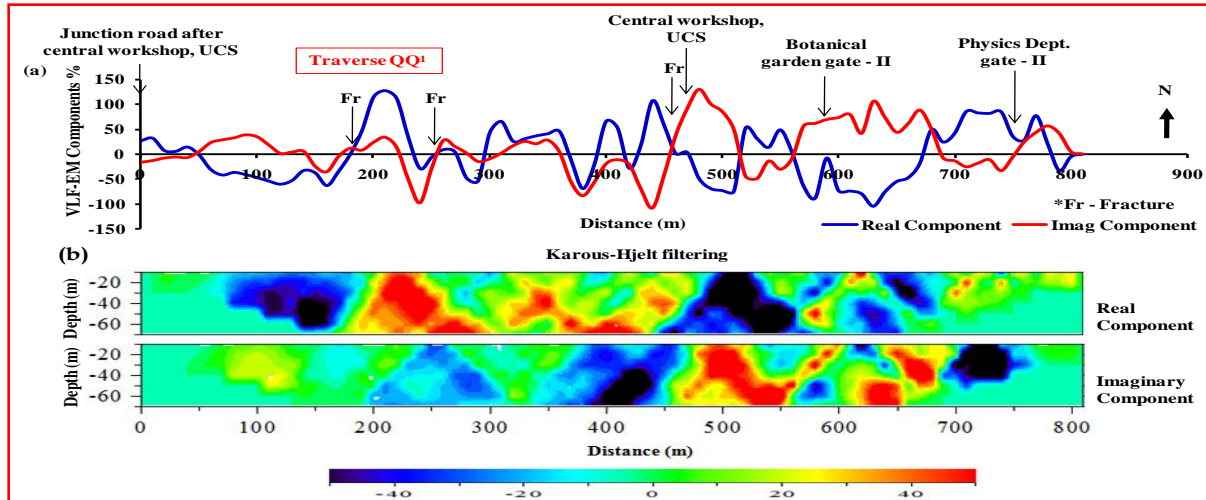


Figure 21 (a), (b):- Fraser filtering graph and equivalent current density pseudo-section of Traverse QQ<sup>1</sup>.

Traverse-RR<sup>1</sup> is E-W with a trending, 1400m long traverse lies to the north part of the study area and it starts from opposite to Directorate Admissions - Post Office - 'B' Hostel - Swimming Pool - to Professors Quarters.

Figure: 22 (a) shows the values ranged from -270% to 290% is the real and imaginary component response of Fraser filtered data.

In Figure: 22(b) different features of varying degree of conductivities are delineated on the section, for instance, between stations 40m and 85m, 895m and 960m, 1055m and 1135m at an approximate depth of 32m, 70m and 65m respectively. Similarly, between stations 250m and 320m, a conductive body at an approximate depth of 60m is indicated. Several other closures of conductive bodies are present on the section. Figure: 22(a) reveals a number of anomalies, which reflects conductive subsurface structural trends of inferred fractures zones (at 240, 300, 600, 950, 1060 and 1280 m) along the traverse.

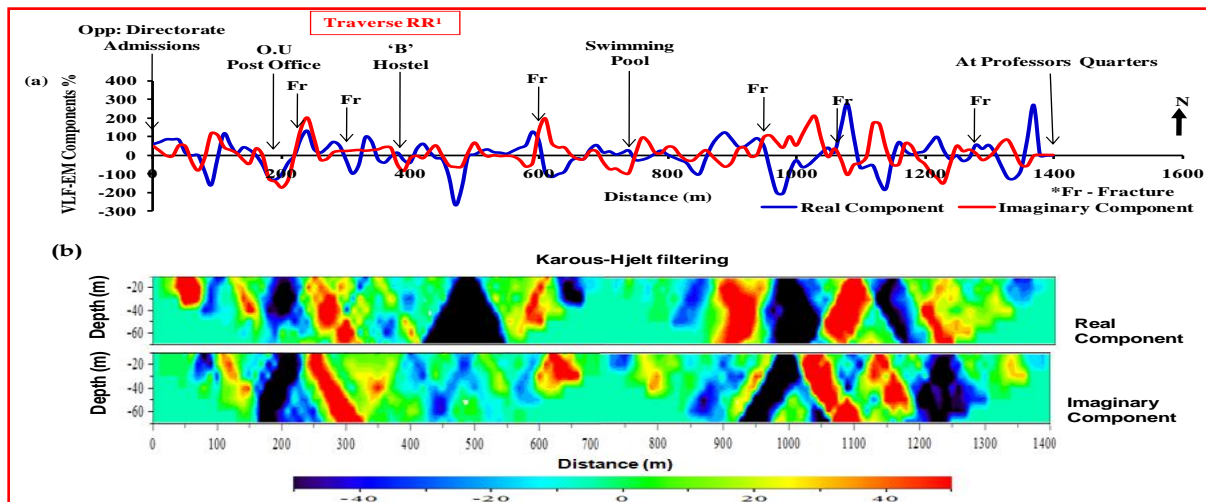


Figure 22 (a), (b):- Fraser filtering graph and equivalent current density pseudo-section of Traverse RR<sup>1</sup>.

Traverse-SS<sup>1</sup> is nearby Shivalayam adjacent to RTC Hospital - Manjeera Hostel - Bhagirathi Hostel - Basket Ball Court - to Indoor Stadium, running a total length of 590m to the North of study area.

Figure: 23 (a) reveals the percentage of anomaly response of real and imaginary Fraser filtered data ranged from -185% to 210%.



Figure: 23(b) shows a linear highly conductive body between stations 195m and 260m, at an approximate depth of 65m. Similarly a Major conductive body indicated on this section between stations 500m and 555m, at an approximate depth of 32m is indicated. Figure: 23(a) reveals a number of anomalies, which reflects conductive subsurface structural trends of inferred fractures zones (at 240 and 510m) along the traverse.

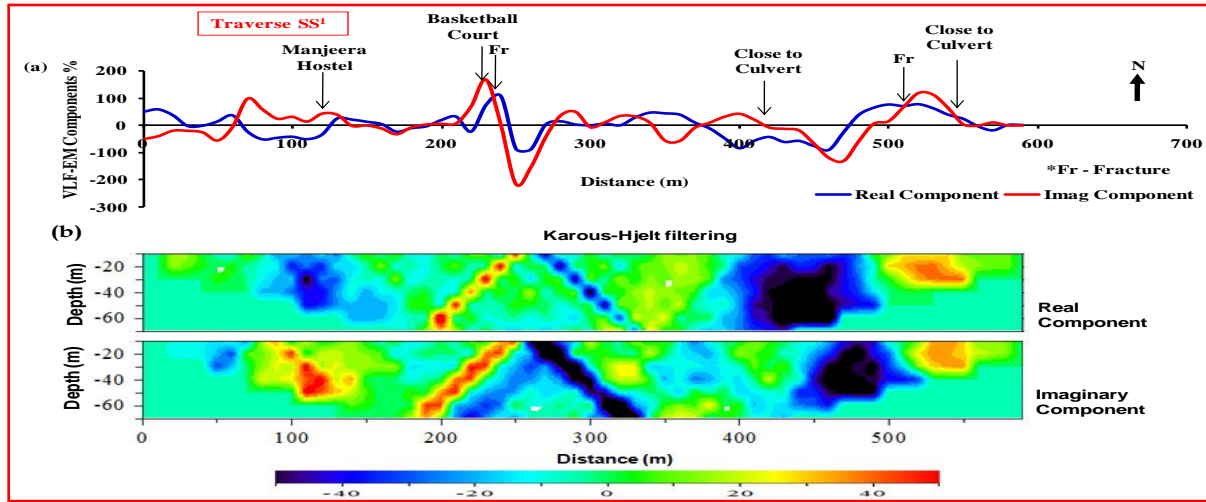


Figure: 22(a), (b) Fraser filtering graph and equivalent current density pseudo-section of Traverse SS<sup>1</sup>.

**Table: 1** Summary of the VLF-EM Method, subsurface fracture details in the study area.

S. No.	Traverse	Direction	Total Length (m)	Width of the Body along the traverse	Depth (m)	Conductive	Fractures along traverse	Remarks
1	AA'	N-S	2000	590m and 710m	70	650m conductive	500, 640 and 1450m	
2				1400m and 1490m	70	1445 m conductive		
3						1690 m dyke		
4	BB'	N-S	2200	515m and 620m	60	565 m low conductive	490 and 1850m	
5				1735m and 1890m	70	1810m conductive		
6	CC'	N-S	2400			1015m conductive	1470 and 2070m	
7				1400m and 1510m		1455m conductive		
8						1900m dyke		
9				2035m and 2170		2100 m conductive		
10	DD'	N-S	2430	1920m and 2045		1980m conductive	1350, 1950 and 2200m	
11				2085m 2190		2140 m conductive		
12						1820 m dyke		
13	EE'	N-S	920	220m and 330m	70	260m conductive	70, 300 and 370m	
14				280m and 440m	70	310m conductive		
15				490m		dyke		NE-SW Dipping
16	FF'	E-W	920			150m & 270m fault	270, 390 and 500m	
17						330m dyke		
18				360m and 410m	50	390m conductive		
19						440m dyke		
20						490m conductive		NW-SE Dipping
21	GG'	E-W	960			225m dyke	300, 440 and 720m	
22				340m and 490m	70	415m conductive		
23				795m and 850m	60	820m conductive		
24	HH'	N-S	490	215m and 350m	above 70	280m Fault	270m	
25	II'	E-W	560	150m and 220m	30	185m conductive	170, 230, 410, 450 and 530m	SE-NW Dipping
26				165m and 240m	above 70	205m conductive		
27				220m and 265m	45	240m conductive		NE-SW Dipping
28						365m Dyke		
29				415m and 500m	55m	460m conductive		
30				525m and 550m	20m	540m conductive		

31	JJ'	E-W	760	50m and 80m	20	65m conductive	60, 190, 350 and 440m	
32				185m and 260m	70	220m conductive		
33					60	380m conductive		NE-SW Dipping
34						440m and 510m Fault		
35	KK'	E-W	730	300m and 400m		350m Fault	300, 500 and 710m	
36				465m and 550m		510m conductive		
37				690m and 740m	30	715m conductive		
38	LL'	E-W	790	345m and 470m	70	410m conductive	410 and 490m	
39	MM'	E-W	560		20	230m low conductive	240 and 250m	
40	NN'	E-W	1560			595m Dyke	700 and 1200m	
41				640m and 720m	50	680m conductive		
42				900m and 1000m	70	950m conductive		
43	OO'	E-W	440	220m and 305m	70	270m low conductive	70 and 330m	NE-SW Dipping
44	PP'	E-W	850	350m and 400m		375m Fault	700m	
45	QQ'	E-W	810	190m and 300m		245m conductive	170, 250 and 460m	
46				310m and 390m		350m conductive		NW-SE Dipping
47				390m and 460m		425m conductive		NE-SW Dipping
48						740m Lineament		
49	RR'	E-W	1400	40m and 80m	35	60m conductive	240, 300, 600, 950,1060 and 1280m	
50						495m Dyke		
51				900m and 960m	70	930m conductive		
52						1000m Dyke		
53				1050m and 1135m	65	1095m conductive		
54	SS'	N-S	590			260m Lineament	240 and 510m	
55				500m and 560m		530m low conductive		

### Discussions:-

Very Low Frequency Electromagnetic (VLF-EM) survey has been conducted for the purpose of delineating subsurface features in the study area, Osmania University campus. A total of nineteen (19) VLF - EM profiles are acquired using ABEM WADI VLF instrument at every 10m interval.

The VLF-EM result mapped shallow linear conductors that are suspected fracture zones of varying length in the area.

The VLF electromagnetic traversing data are presented as plots of filtered real and filtered imaginary (in %) against station position. VLF –EM traverses from the study area are shown in Figure 4.5(a) to 4.23(a) and these shows the

linearly filtered real and imaginary components of the vertical magnetic field of the VLF data. Figures 4.5 (b) to 4.23 (b) shows a comparison of the Karous-Hjelt filtered real component (Karous and Hjelt, 1983<sup>[12]</sup>).

The real and imaginary components enable qualitative identification of the top of linear features i.e., points of coincident of crossovers and positive peaks of the real and filtered anomaly. From these plots (Figures 4.5 (a) - 4.23(a)), minor linear features suspected to be faults/fractured zones were identified. These suspected geological interfaces and 52 fractures are shown in the table: 4.1, delineated from the profiles, were shown occurring at varying distances on the traverses. These positive peaks mapped as basement fractures (52)/conductive bodies on the filtered real are zones of interest in groundwater exploration in hardrock terrain. The asymmetry of these conductive anomalies suggests that the conductive structures are dipping. Also, the anomaly patterns exhibit varying amplitudes, which are controlled by the depth of the body to the surface, its geometry, and attitude.

Figures (from 3(b) to 21(b)) show the corresponding KH filter pseudo sections of traverses AA<sup>1</sup>-SS<sup>1</sup>. These pseudo sections are the measure of the conductivity of the subsurface as the function of depth. The conductivity is shown as color codes. Different features of varying degree of conductivity trending in different directions were delineated on the sections.

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