VLF-EM and Total Magnetic Investigations for Identification of Permeable Groundwater Zones in a Hardrock Terrain, Osmania University Campus, Hyderabad, Telangana State, India.

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ABSTRACT

Very Low Frequency (EM) and Total Magnetic measurements were carried out in the Osmania University Campus, Hyderabad to delineate structural configuration and trace subsurface fracture zones at depth could represent groundwater potential zones. The present investigation consist of Nine (9) VLF-EM and Total Magnetic (AA[1], BB[1], CC[1], FF[1], II[1], NN[1], OO[1], QQ[1] and RR[1]) traverses with 10m interval in an area of approximately 6.58 sq kilometers (1627.32 acres) in a granitic terrain. 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. 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 fifty, subsurface fractures at different locations are highly permeable groundwater potential zones. Magnetic survey 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 on potential zones for groundwater.

Keywords: Very Low Frequency Electromagnetic Method (VLF-EM); Fracture zones; Structural configuration; Fraser filter; Groundwater.

INTRODUCTION

Very Low Frequency Electromagnetic (VLF-EM) method of geophysics utilizes very low frequency radio signals determine electrical properties of near surface and shallow bed rock 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[1]).

The magnetic method holds an important position among the various geophysical techniques used for groundwater exploration even though the method is suited more for iron ore minerals, areal mapping and profiling rather than studies of structure layer by layer. Furthermore, since, variations in susceptibility are more useful for obtaining information on the tectonic/structural features, intrusives and magnetic linear that contribute to the structural configuration of the study region. At the same time, this is a relatively fast and inexpensive method of survey requiring little by way of manpower or instrumentation. An additional advantage of magnetic methods is that they are equally well applicable for identifying subsurface structures.

GEOLOGY AND DRAINAGE

Here three types of granites exist – pink, grey and the leucogranites (Balakrishana and Rao, 1961[2]; Sitaramayya, 1971[3]) and some pegmatite patches traversed by narrow white apatite veins, which intersect each other randomly. The granitic host rocks are intruded at places with doleritic dykes. The general geological section consists of a surficial 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 15 m consists of hard impervious granite.

The drainage is mostly dendritic which is characteristic of the granitic country and becomes radial at some places. The general trend of the drainage is towards the south joining the musi river. There is nallah running parallel to the road leading to Eleguguttta hill, which takes many turns and finally attains north-south trend. There are three tanks in the area – Mohini Cheruvu, Landscape

Garden tank and Ramanthapur Cheruvu (Figure: 1). The last one falls outside the university area, which was once part of it.

The Landscape Garden tank was formed due to the construction of a small dam like bund which is in a valley across the nullah. The tanks total areal extent is about 1/2 sq.km. Under normal rainfall, the tank gets overflowed. However, due to the continuous drought for the last few years it does not contain much water. Of the three tanks, the major one is Mohini Cheruvu which gets filled with most of the University's run off water.

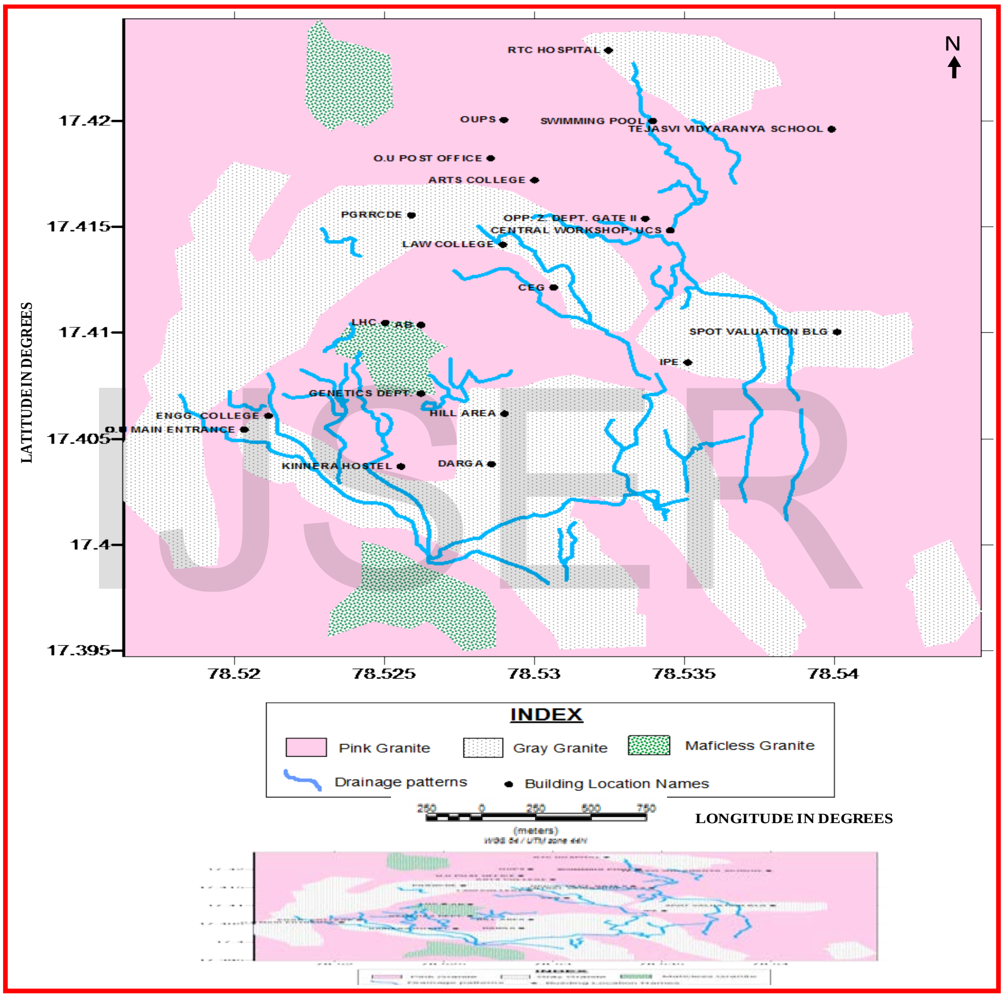

Figure: 1 Geology and Drainage Patterns of the Study area.

DATA BASE

VLF 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. VLF and Magnetic studies corresponding to a part of the map, were carried out roughly in comprising the Osmania University campus area (Figure:2), 78^0 31′ 00″ E longitude to 78^0 32′ 26″ E longitude and 17^0 23′ 45″ N latitude to 17^0 25′ 42″ N latitude total area of 6.58 square kilometers (1627.32 acres). The survey were directed towards tracing out and verifying the detailed geological setting and identifying conductive zones and different tectonic structures respectively in the area which could have a definite bearing on potential zones for groundwater.

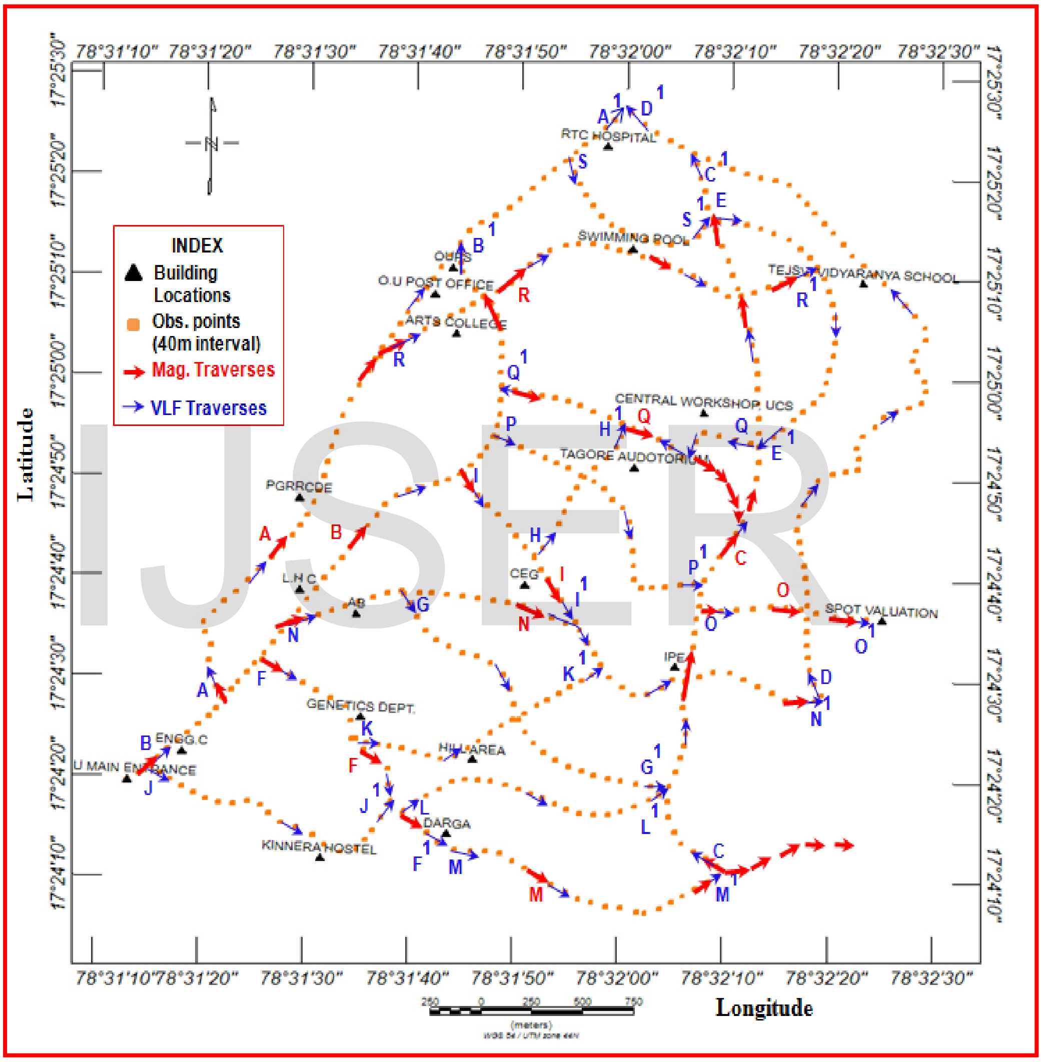

Figure:2 Location map of VLF-EM and Magnetic Surveys of Study Area.

ANALYSIS OF DATA

VLF-EM DATA

A qualitative interpretation of VLF-EM data is based on the 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 resistivities beneath the surface (Srigutomo et al., 2005[4]). This, therefore, ascertains a simple fact that the analytical signal of the real component takes off the Fraser filtered off the real component. The Fraser Filter (Q) (Fraser, 1969[5]) was computed using a filter operator as;

$$\mathbf{Q} = (Q_4 + Q_3) - (Q_2 + Q_1) \qquad \ldots (1)$$

Where **Q** is EM data and the subscript is station positions. This was applied to the real component VLF data to transform the data set to the filtered real VLF 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[6])

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, $2\Delta x$, $3\Delta x$), one can study the variation of current densities with depth. This filter is expressed as;

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

Where $\mathbf{\Delta z}$ is the assumed thickness of the current sheet, $\mathbf{\Delta x}$ 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[6]).

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[7]).

A simple filtering technique that transforms crossovers into peaks, removes regional gradients and also amplifies anomalies from near surface was suggested by Fraser, 1969[5]. 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.

An additional interpretation tool is pseudo-section obtained through filtering (Wright, 1988[8]). 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^1 to SS^1 with two filters by normalizing each time with its filter lengths of the filtered in-phase component.

TOTAL MAGNETIC DATA

Magnetic data collected in the study area are corrected for diurnal and normal correction. Recognition of characteristic patterns and shapes of anomalies in relation to particular rock units or geologic structures is one of the first steps in the qualitative interpretation of a magnetic map. With the advent of detailed surveys, many near-surface geologic features are so clearly expressed that their geologic origin is obvious in colour shaded-relief images. In the shaded-relief (Gunn, 1997[9], Davies et al., 2004[10], Gay, 2004[11]), folds look like folds, fault expressions can exhibit en echelon and an atomizing behavior (Grauch et al., 2001[12], Langenheim et al., 2004[13]) and individual dikes within swarms are clearly resolved (Hildenbrand and Raines, 1990[14], Modisi et al., 2000[15]). Magnetic anomalies produced by rocks with strong, reverse-polarity eminence display characteristic, high-amplitude negative anomalies (Books, 1962[16], Grauch et al., 1999[17]) that, without high-resolution data, might be confused with magnetic lows caused by a lack of magnetization, which are also negative but generally featureless (Airo, 2002[18]).

The present detailed magnetic investigations make a significant contribution for the fine elucidation of the subsurface magnetic structures in the hard rock terrain in Osmania University campus. The following section gives detail results of qualitative and quantitative analysis of the data.

VLF–EM AND MAGNETIC TRAVERSES

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Electromagnetic VLF magnetic traverses are carried all along parallel to the roads (15m away from the roads) in the N-S & E-W direction. Nine (AA^1, BB^1, CC^1, FF^1, II^1, NN^1, OO^1, QQ^1 and RR^1) traverses in all were taken up. Plots of the filtered real and imaginary parts were produced for every profile and they were interpreted in view of the existence of conductive zones that could be related to tectonic faults.

Figures: 3 to 11 are the diagrams of the magnetic, VLF and traverses along the AA^1, BB^1, CC^1, FF^1, II^1, NN^1, OO^1, QQ^1 and RR^1respectively. From an examination of these figures we can infer that, there is a direct correlation between magnetic (TMI) and magnetic coefficient of variation (C.V) are responding higher values over the conductive bodies lower values over the non-conductive bodies and they are correlated with VLF, Coefficient of variation are exactly correlated at disturbed and fractured zones.

At locations VLF with traverses oriented in the N-S direction a plot of filtered data shows real and imaginary components positive magnitude response intersection points resulting is probable fractured zones located at 490 and 1850m. Comparing with the electrical sections reveals that resistivity value of < 50Ωm are encouraging groundwater potentiality. Similarly sections FF^1 comparing magnetic and VLF data oriented in the N-S direction. A well prominent three fractured zones are delineated at 270, 390 and 500m, which exactly coincide magnetic and magnetic coefficient of variation. And also TMI showing the low values over the conductive bodies, high values over the non-conductive bodies.

Traverse AA^1 shown in Figur.3 is running in the N-S direction about 2000m long length extended up to west of the study area and it traverse from UFRO - under the Adikmet flyover – PGRRCDE – EFLU – B.Ed College to Tarnaka Junction,

Total magnetic response along the traverse AA1 (Fig.3a) at 620 nT , 500 nT, -800 nT, 600 nT and 400nT with corresponding distances 0-180m, 180-620m, 620-800m, 800-970m, and 1180-1300m respectively. Computed Coefficient of variation along the traverse is shown in (Fig.3b) mapped three tectonic disturbed zones marked as 1, 2 and 3.

Figure: 3(c) shows the Fraser filtered data (real or in-phase component and imaginary or quadrature component) show positive intensities suggesting the presence of shallow and deep conductors. This traverses is this s processed using the Karous–Hjelt filter (1983), current density plot for traverse as presented in Figure: 3(c) reveals a number of conductive and non conductive subsurface structural features and inferred fractures zones (at 500, 640 and 1450m)/faults along the traverse

In addition, to the above 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:3.d) reveals the presence of major anomalies at the southern side between 590m and 710m, and at the right 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.

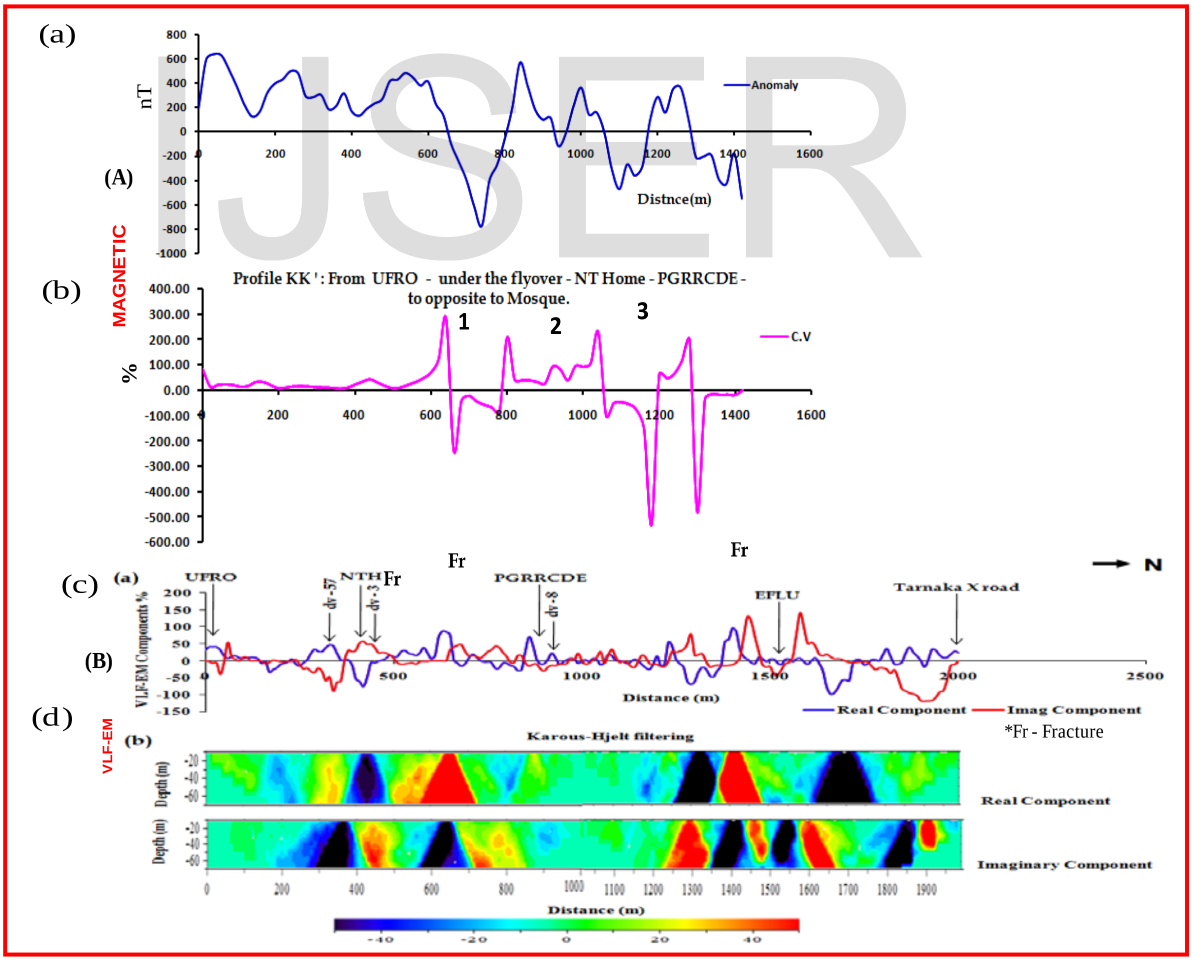

Figure: 3 Comparison of Geophysical Data with corresponding Sections for Traverses in the Study Area (Traverse: AA^1, from UFRO - under the Adikmet flyover – PGRRCDE -EFLU – B.Ed College to Tarnaka Junction).

(a) Total Magnetic Intensity, (b) Magnetic Coefficient of variation

(c) VLF Real and Imaginary coefficents and (d) Pseudo Section

Traverse BB^1 shown in Figure.4 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: 4(a), magnetic response along the traverse at 400-600m, 1000-1100m and 1200-1300m, magnetic response is 900, 250 and 100 nT respectively from opposite to UFRO to 'B' Hostel junction road, from the geology map the highs can be inferred to correspond to a basic intrusion.

The response of coefficient of variation (Fig.4(b) a series of highs and lows zones (1, 2 and 3) were identified , which are reflecting a low to moderate susceptibility can be attributed to the fracture granites.

Figure: 4(c) shows the Fraser filtered data of in-phase and quadrature component, responses ranged in value from –100 % to 175% along the traverse. Figure: 4(d) shows the corresponding K-H pseudo section of traverse BB^1. 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: 4(a) reveals a number of anomalies, which reflects conductive subsurface structural trends of inferred fractures zones (at 490 and 1850m) along the traverse.

Traverse CC^1 shown in Figure: 5. is situated east of the O.U Campus, about 2140m 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 to Professors Quarters.

The magnetic response Fig. 5(a) in traverse CC[1] is 800, 300 and 750nT and also 990, 500, 320 and 200nT. Correspond coefficient of variation fig. 5 (b) six zones (1, 2, 3, 4, 5 and 6) are traced, Figure: 5(c) 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: 5(d) 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 5(d), which reflects conductive subsurface structural trends of inferred fractures zones (at 1470 and 2070m) along the traverse.

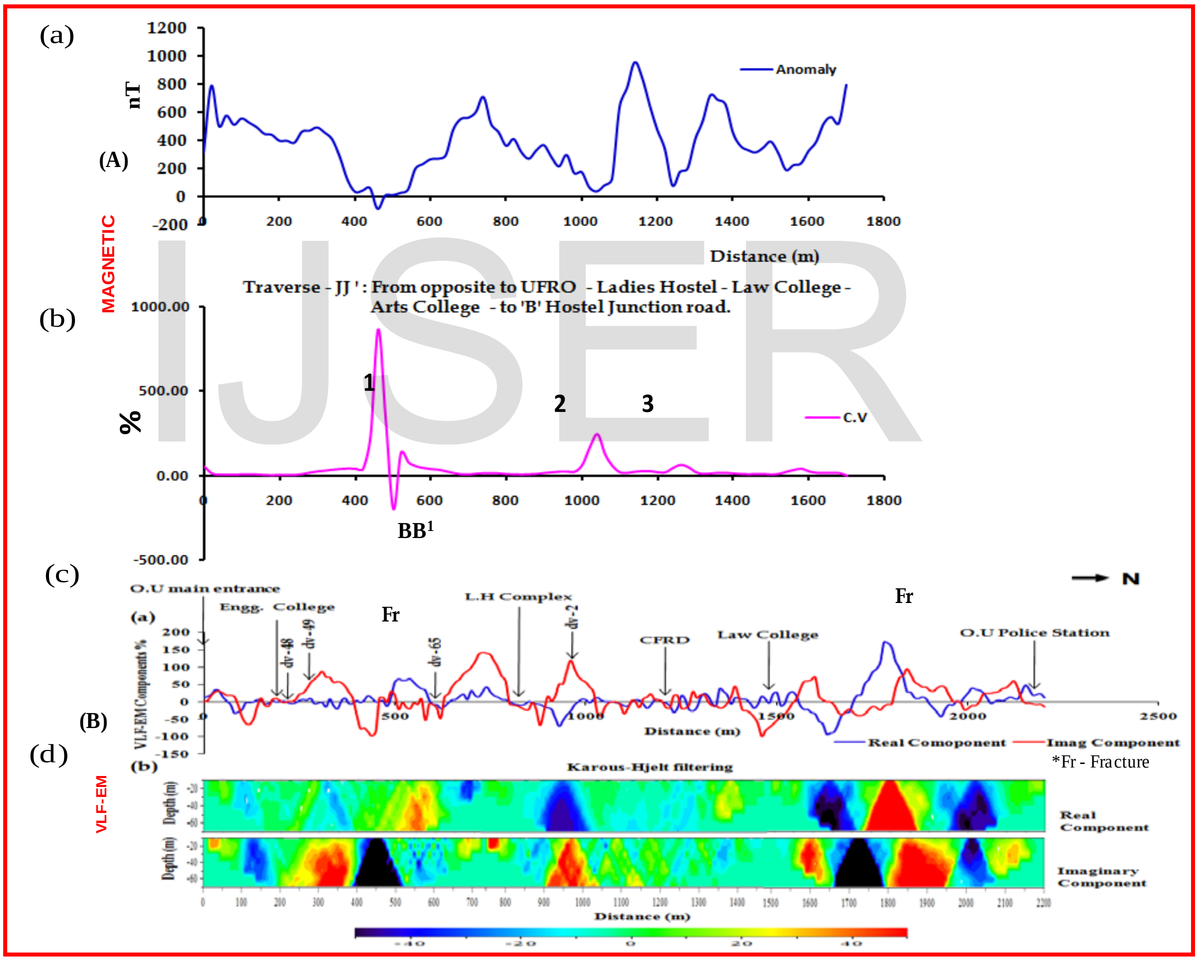

Figure: 4 Comparison of Geophysical Data with corresponding Sections for Traverses in the Study Area (Traverse: BB[1], from O.U Main Entrance – Engineering College – Ladies Hostel – Law College – Arts College to O.U Police Station). (a) Total Magnetic Intensity, (b) Magnetic Coefficient of variation (c) VLF Real and Imaginary coefficents and (d) Pseudo Section

Traverse FF[1] shown in Figure: 6, has the path in E-W directions and it starts from Ganga Hostel - Genetics and Microbiology Departments to Darga - inside the Forest to a road up to a N-S direction with total length of 1180m and lies towards south of the study area.

Here magnetic highs Fig.6 (a) at starting 0-250m and 1000m- at end of the traverse were 600nT to 700nT In between these two magnetic high minor responses are recorded. Figure: 6(b) coefficient of variation is significant variations at 800-1000m are marked, whereas two other 200-250m, 450-500m were noticed and three zones were identified. These two lows responses are not very clear as the geology indicated. The highly disturbed zone were traced 800-1000m varying to 200m width might be fault zones, and also an indication of groundwater potential zones.

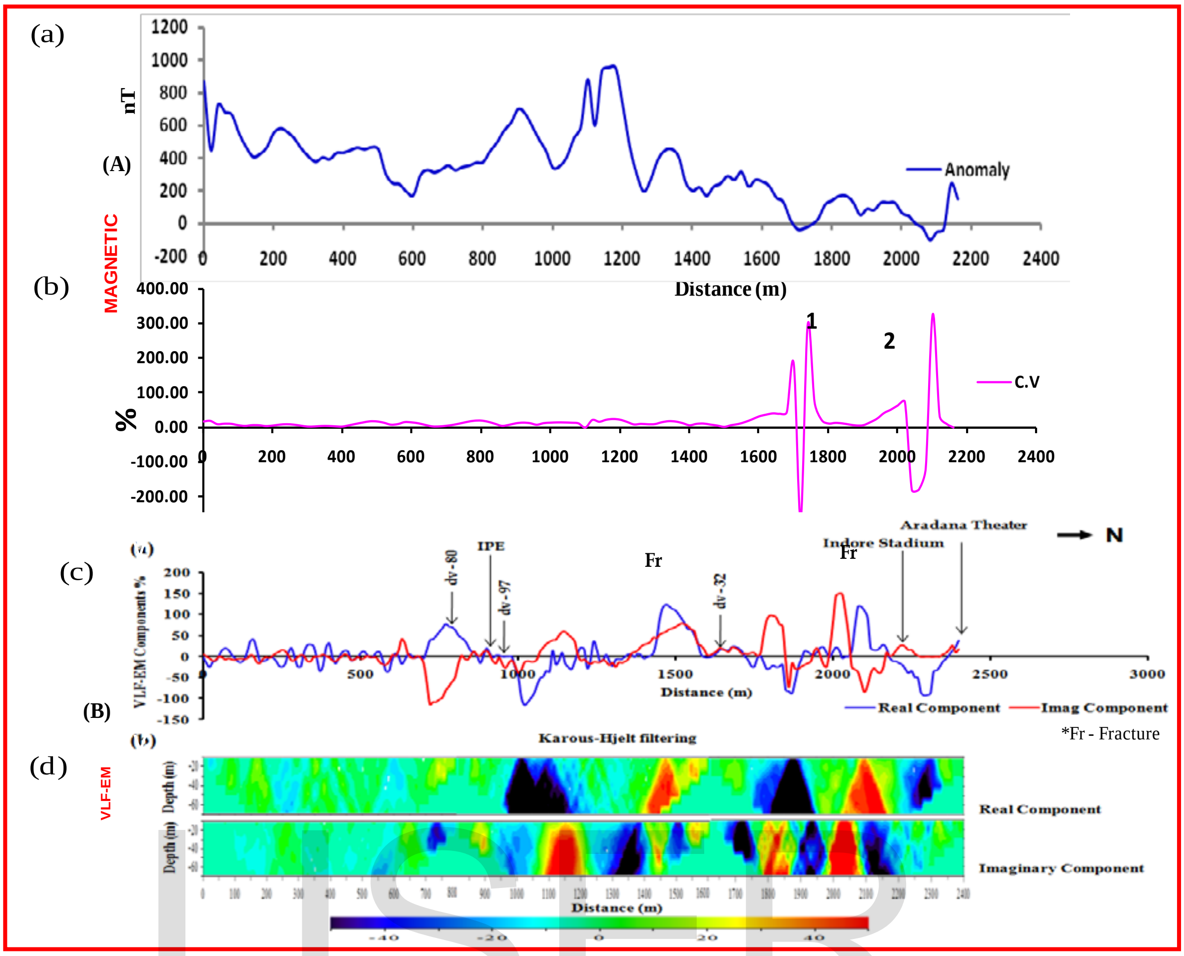

Figure: 5 Comparison of Geophysical Data with corresponding Sections for Traverses in the Study Area (Traverse: CC[1], from a point towards IPE, in N-S direction nearby Darga which is behind the Genetics Dept. – IPE – behind the residences of Maneru Hostel - Professors Quarters - Indore Stadium to Aradana Theater).

(a) Total Magnetic Intensity, (b) Magnetic Coefficient of variation

(c) VLF Real and Imaginary coefficents and (d) Pseudo Section

Figure: 6(c) shows VLF (real and imaginary components 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: 6(d) reveals a number of anomalies, which reflects conductive subsurface structural trends of inferred fractures zones (at 270, 390 and 500m) along the traverse.

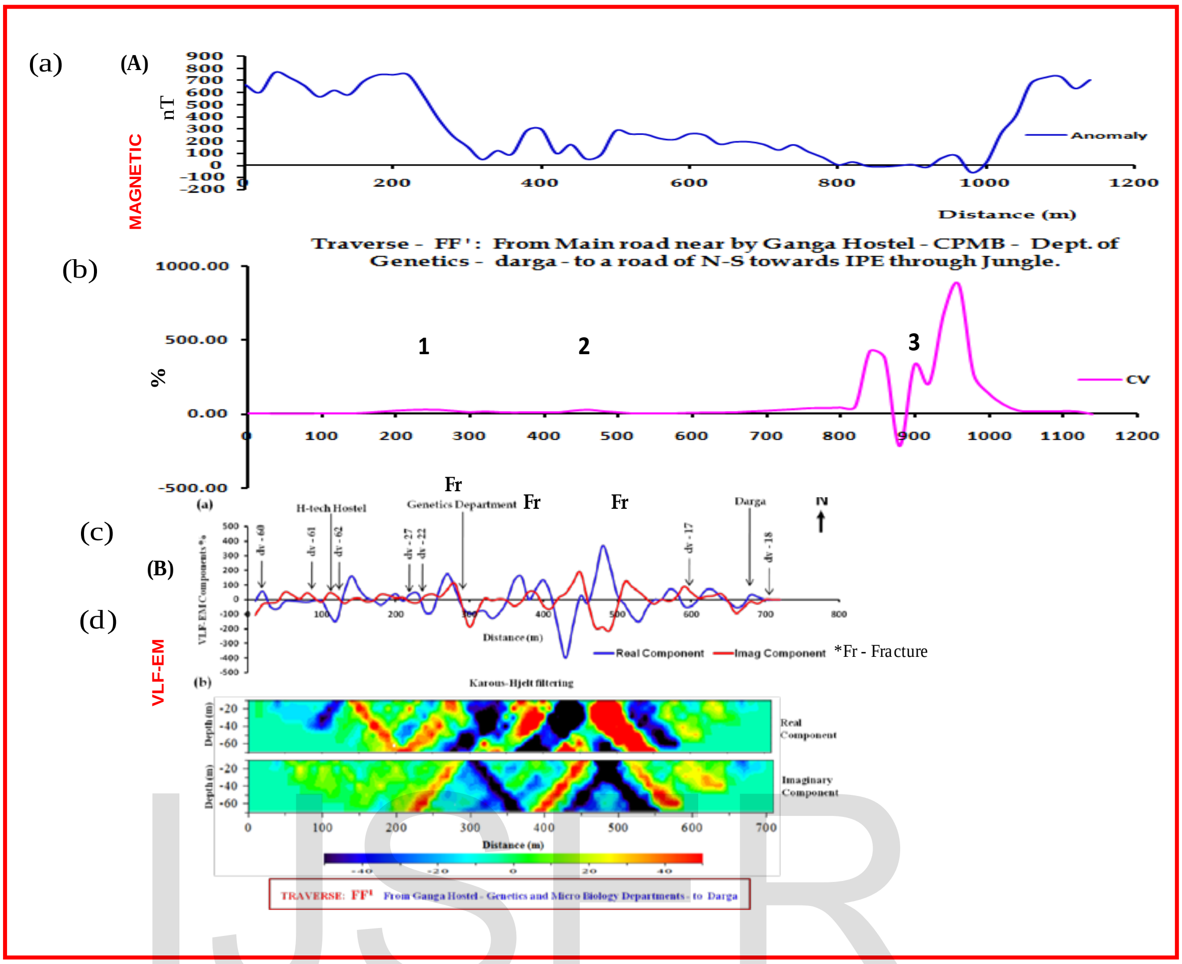

Figure: 6 Comparison of Geophysical Data with corresponding Sections for Traverses in the Study Area (Traverse: FF[1], from Ganga Hostel - Genetics and Microbiology Departments to Darga with total length of 720m and lies Towards South of the Study Area).

(a) Total Magnetic Intensity, (b) Magnetic Coefficient of variation

(c) VLF Real and Imaginary coefficents and (d) Pseudo Section

Traverse II[1] shown in Figure 7 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 620m and lies middle of the study area.

Figure: 7 (a) only one 500nT was observed at 480m varying with width is 200m variation. From the coefficient of variation map, only two disturbed magnetic zones were noticed at 0-85m and 170-300m. 0-85m width is the turning point of the road that is situated N-W part corner of the landscape garden, this may be attributed to the highly fractured zone whereas 200-330m very shallow conductive zone were observed. In the Coefficient of variation (Fig.7b)

Figure: 7(c) shows the anomaly response of real and imaginary Fraser filtered data, the percentage ranged from -190% to 250%.

In figure: 7(d) 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: 4.13(a) reveals a number of anomalies, which reflects conductive subsurface structural trends of inferred fractures zones (at170, 230, 410, 450 and 530m) along the traverse.

Traverse NN[1] shown in Figure: 8, 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.

The response of coefficient of variation a series of highs and lows six zones were identified (Fig.8b), which are low to moderate susceptibility can be attributed to the fractured granite are found in fair quantities, whereas 480 to 645m data in dyke.

Figure: 8(c) shows the Fraser filtered data of in-phase and quadrature component, responses ranged in value from –140 % to 150% along the traverse.

Figure: 8(d) 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: 8(a) reveals a number of anomalies, which reflects conductive subsurface structural trends of inferred fractures zones (at 700 and 1200m) along the traverse.

Traverse OO[1] shown in Figure: 9 start from O.U Darga (Near Maneru Hostel) to Spot Valuation Building running a total length of 440m to the east of study area.

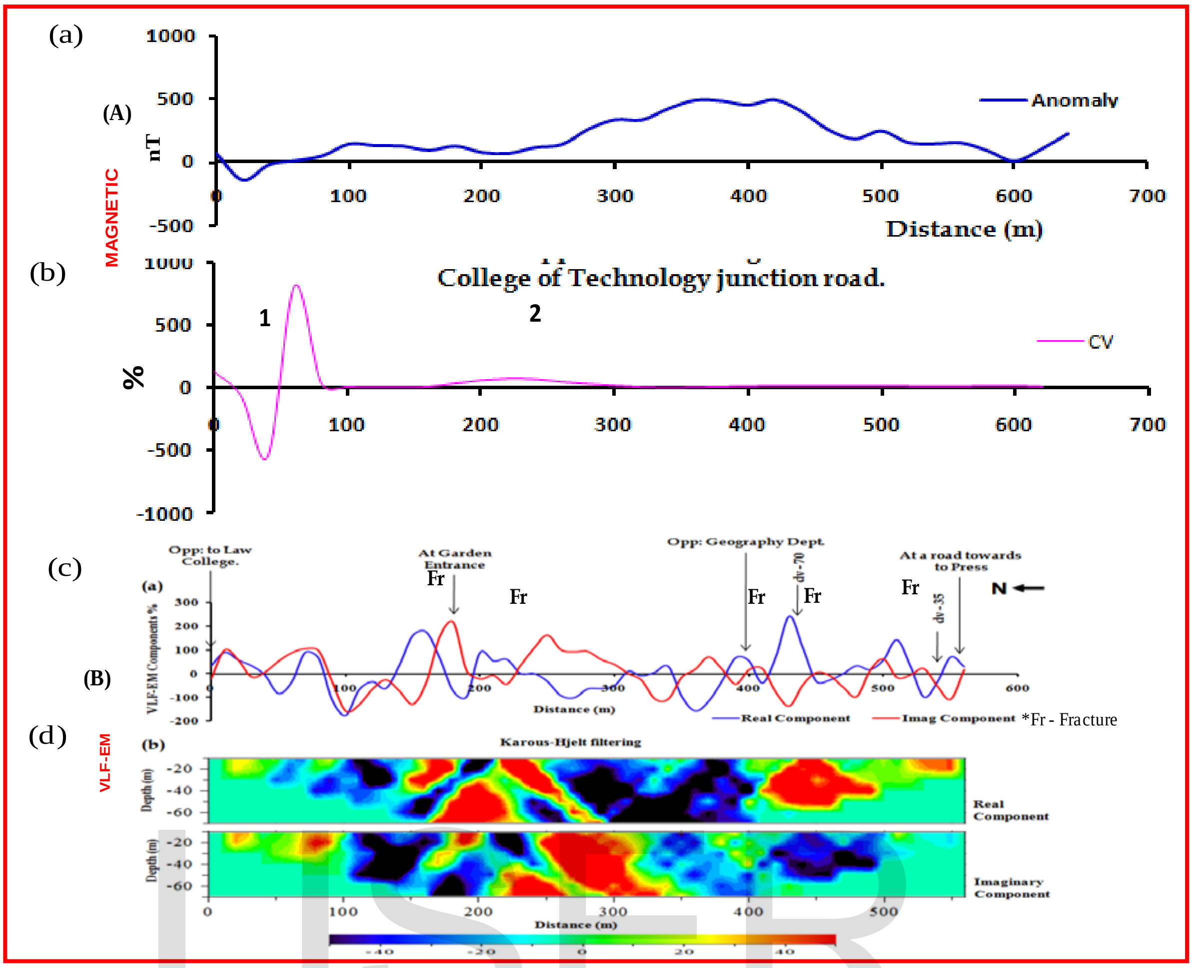

Figure: 7 Comparison of Geophysical Data with corresponding Sections for Traverses in the Study Area (Traverse: II[1], from opposite to Law College (Adjacent to Landscape Garden)-'D' Hostel - Geophysics Department to a junction road towards O.U Press, in E-W trending with a total length of 560m and lies middle of the study area).

(a) Total Magnetic Intensity, (b) Magnetic Coefficient of variation

(c) VLF Real and Imaginary coefficents and (d) Pseudo Section

Figure: 9(a) shows broad two high magnetic pairs observed in between 250 - 350m, the magnetic response 600 and 1100nT respectively. This might be interpreted as thick dyke; however the response on the coefficient of variation is not much. As per groundwater concerned the contact between either sides is a very good aquifer zone are traced.

Figure: 9(c) shows the in-phase and quadrature component percentage responses of Fraser filtered data, ranged in value from –140 % to 150% along the traverse.

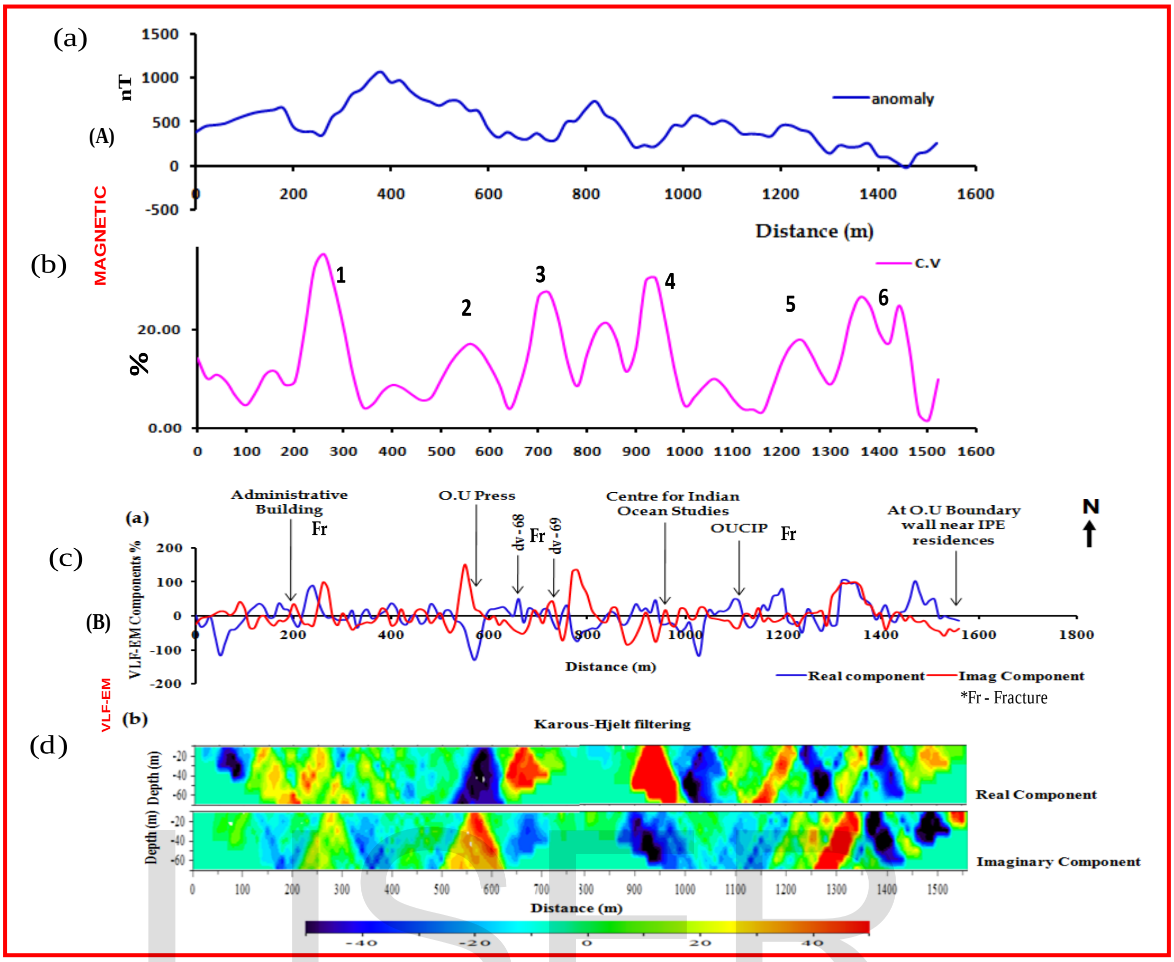

Figure: 8 Comparison of Geophysical Data with corresponding Sections for Traverses in the Study Area (Traverse: NN[1], from Renuka Yellamma Temple - Administrative Building - College of Technology – IPE to Dead End of the Residences Area).

(a) Total Magnetic Intensity, (b) Magnetic Coefficient of variation

(c) VLF Real and Imaginary coefficents and (d) Pseudo Section

Figure: 9(d) 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: 9(a) reveals a number of anomalies, which reflects conductive subsurface structural trends of inferred fractures zones (at 70 and 330m) along the traverse.

Traverse QQ[1] shown in Figure.10 indicates the path in E-W direction all along the 980m length to above middle of the study area and it starts from a junction road after Central Workshop, UCS - Botany and Zoology Departments towards to Arts College road.

There are four magnetic highs Fig.10a) at distances 0-180m, 180-400m, 400-580m and 800-980m, the magnetic response1400, 1000, 825, and 780nT respectively. Similarly the trends high and lows were also seen on the coefficient of variation. Along this traverse five broad zones were identified distances 0-120m, 120-250m, 335-475m, 675-820m and 820-930m correlating interestingly opposite to the Botany Department i.e., east side of the glass room, there was a big fracture has been traced at distance. Remaining zones were tallying the lineaments and tectonic disturbances mapped along the traverse (Fig.10b).

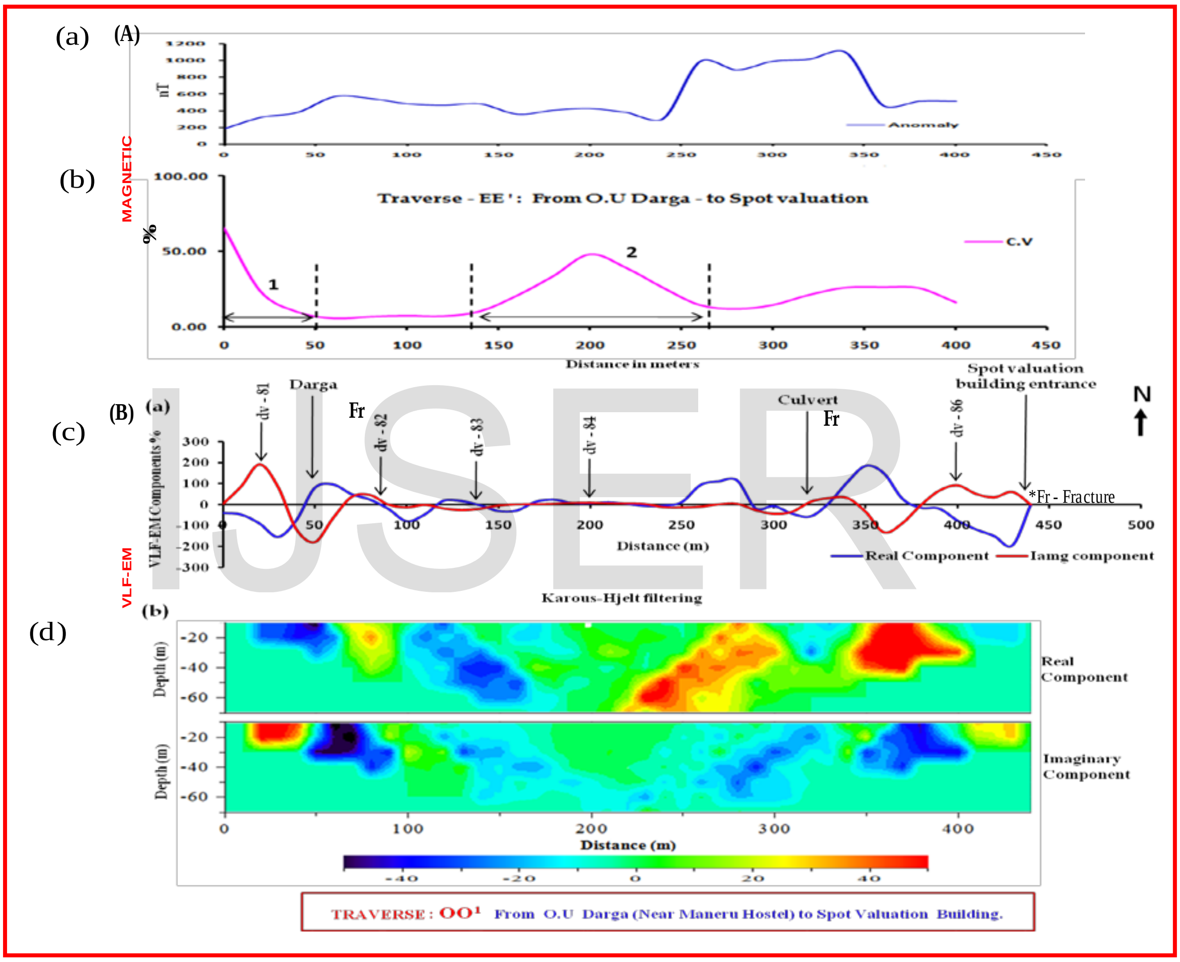

Figure: 9 Comparison of Geophysical Data with corresponding Sections for Traverses in the Study Area (Traverse: OO[1], from O.U Darga (Near Maneru Hostel) to Spot Valuation Building running a Total length of 440m to the East of Study Area).

(a) Total Magnetic Intensity, (b) Magnetic Coefficient of variation

(c) VLF Real and Imaginary coefficents and (d) Pseudo Section

Figure: 10(c) shows the Fraser filtered data of in-phase and quadrature component, responses ranged in value from –110 % to 135% along the traverse.

Figure: 10(d) 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: 10(a) reveals a number of anomalies, which reflects conductive subsurface structural trends of inferred fractures zones (at 170, 250 and 460m) along the traverse.

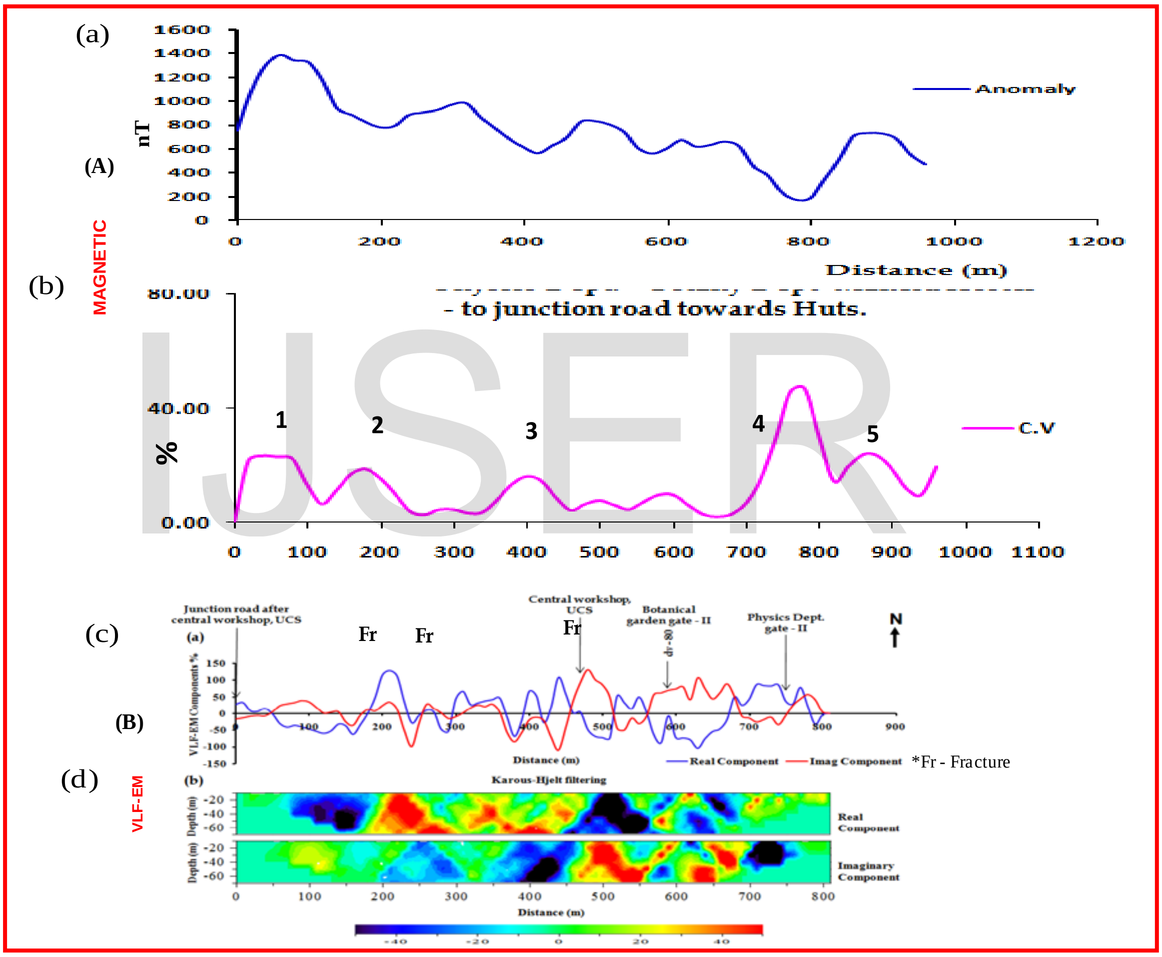

Figure: 10 Comparison of Geophysical Data with corresponding Sections for Traverses in the Study Area (Traverse: QQ[1], from A junction road after Central Workshop, UCS - Botany and Zoology Departments to towards to Arts College Road).

(a) Total Magnetic Intensity, (b) Magnetic Coefficient of variation

(c) VLF Real and Imaginary coefficents and (d) Pseudo Section

Traverse RR[1] shown in Figure.11 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.

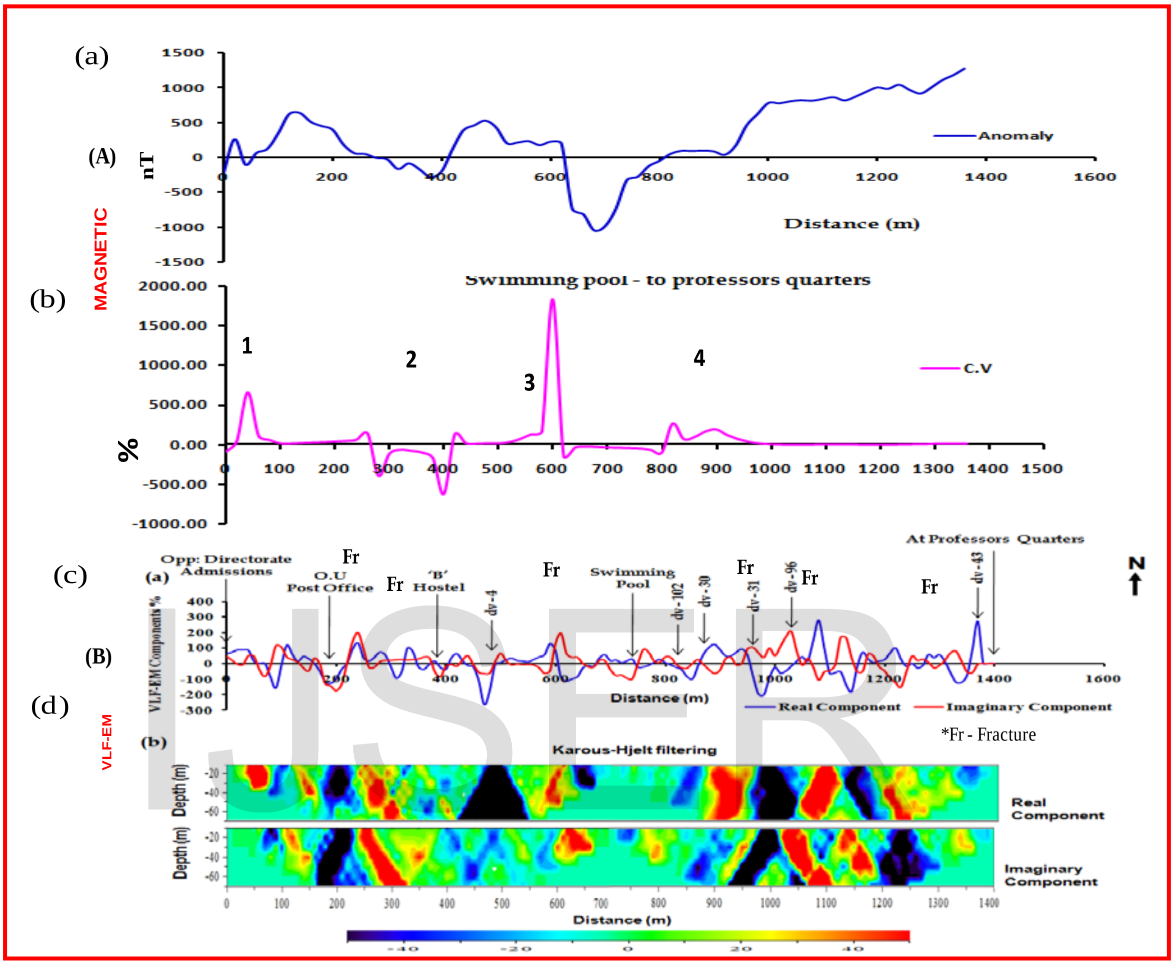

Figure: 11 Comparison of Geophysical Data with corresponding Sections for Traverses in the Study Area (Traverse: RR[1], from opposite to Directorate Admissions – Post Office - 'B' Hostel - Swimming Pool to Professors Quarters).

(a) Total Magnetic Intensity, (b) Magnetic Coefficient of variation

(c) VLF Real and Imaginary coefficents and (d) Pseudo Section

Figure.11(a) total magnetic intensity field is a sequence of alternating highs and lows the first arranging this is high at 150m, four tectonic zones were delineated, the zone (1) 25-70m, (2) 30-430m, (3) 520-630m and 780-950m, the magnetic response is 750, 525, 800nT respectively along conductive zones were traced. (1), (2), (3) and (4) coefficient variation (11b) zones also traced at the distances at the same distances coincide with the tectonically disturbed zones, whereas at 950m that is opposite to NRS hostel, a fault traced.

In Figure.11(c) 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 11(a) reveals a number of anomalies, which reflects conductive subsurface structural trends of inferred fractures zones (at 240, 300, 600,950, 1060 and 1280m) along the traverse.

The results of magnetic and VLF data Figure:3, 4, 5, 7, 8, 9, 10 and 11 are representation of along the traverses AA^1, BB^1, CC^1, FF^1, II^1, NN^1, OO^1, QQ^1 and RR^1 respectively are showing similar response of earlier traverses multi fractures are delineated, are summarized in table:1. From figures 3 - 11 the discussion above we can qualitatively and determine the relative contribution of magnetic and VLF methods. Two aspects emerge:

1) Magnetic and VLF methods are more sensitive to lateral and vertical litho variations and are useful for demarcating tectonically disturbed zones and conductive bodies which are correlative groundwater potential zones in O.U granitic terrain.

2) The VLF method is useful because the response has real and imaginary components from deeper horizons (Oluwafemi, O., Oladunjoye, M.A., 2013)

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Table: 1 A comparative study of information from VLF and magnetic surveys

S.No.	Traverse		Identified zones	Magnetic method Zone width (m)	VLF Point	Remarks/Groundwater significance &aquifer characteristic
	Magnetic	VLF-EM				
1	AA^1	AA^1	1	525 -820	650m	Conductive/Poor
2			2	900 – 960	---	Poor
3			3	1025 – 1330	---	Very good
4	BB^1	BB^1	1	405 – 610	---	Very good
5			2	990 – 1100	---	Good
6			3	1215 – 1300	---	Poor
7	CC^1	CC^1	1	0- 105 m	---	---
8			2	185 – 300	---	---
9			3	400 -545	---	Poor
10			4	545 – 680	---	Poor
11			5	680 -880	---	Poor
12			6	880 – 970	---	Poor
13			1	560 – 670	1455m	Low Conductive/Poor
14			2	800 – 1000	567m	Low Conductive/Poor
21	FF^1	FF^1	1	190 - 300	270m	Fault/Good
28	II^1	II^1	1	0 -85	---	Poor
29			2	170 -300	202m ,	Conductive/Very good
41	NN^1	NN^1	1	200 - 350	---	Good
42			2	480 – 645	595m	Dyke/Poor
43			3	645 -790	680m	Conductive/Very good
44			4	890 – 1000	950m	Conductive/Poor
45			5	1175 – 1300	1200m	Poor
46			6	1300 – 1500	---	Poor
47	OO^1	OO^1	1	0-50	50m	Good
48			2	135 – 270	265m	Conductive/Very good
50	QQ^1	QQ^1	1	0 – 120	---	Poor
51			2	120 – 250	245m	Conductive/Poor
52			3	335 – 475	350m,	Conductive/Poor
53			4	675 – 820	740m	Lineament/Poor
54			5	820 – 930	---	Poor
55	RR^1	RR^1	1	25 – 70	60m	Conductive/Very good
56			2	230 – 430	---	Very good/Poor
57			3	520 -630	595m	dyke
58			4	780 – 950	930m	Conductive/Very good

SUMMARY AND CONCLUSIONS

A qualitative analysis of vertical magnetic profiles has been performed to anticipate the subsurface structures and rock assemblages, where groundwater aquifer zones could be possible. From coefficient of variation profiles (Figure: 3(c) to 11 (c) , 1, 2, 3, 4 and 5 tectonic disturbed permeable zones were identified, which is showing as the groundwater occurence and aquifer characteristics are magnetic response. Are showin in Table-1.

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 1(c) to 11(c) and these shows the linearly filtered real and imaginary components of the vertical magnetic field of the VLF data. Figures 1 (d) to 11 (d) shows a comparison of the Karous-Hjelt filtered real component (Karous and Hjelt, 1983).

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 (Figures1 (c) - 11(c)), minor linear features suspected to be faults/fractured zones were identified. These suspected geological interfaces are shown in the table: 1, delineated from the profiles, was shown occurring at varying distances on the traverses. These positive peaks mapped as fractures/conductive bodies on the filtered real are zones of interest in groundwater exploration in hard-rock 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.

A figure (from 1 (d) to 11 (d)) shows the corresponding KH filter pseudo sections of traverses AA^1-SS^1. 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.

The VLF-EM results mapped shallow linear conductors thus are suspected fractures/conductive bodies of varying length in the area. Also, the electrical sounding results delineated 3-4 subsurface geological layers and mapped series of basement depressions. That coincide with the fracture zone which of significant hydro geological importance for groundwater exploration.

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