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Spatial Behaviour of the Dar-Zarrouk Parameters for Delineation of Groundwater Potential Zones in Sudda Vagu Basin of Nirmal District, Telangana, India

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Abstract
Electrical resistivity study is particularly important for aquifer mapping in hard rock areas, and it is also a common tool for defining the vertical and lateral distribution of subsurface resources. 120 Vertical electrical soundings (VES) with Wenner electrode configuration were carried out over Sudda vagu basin located in the northwestern part of Nirmal district in the granitic terrain and Deccan Volcanic Province (DVP) of Telangana to delineate the groundwater potential zones and the Dar-Zarrouk parameters were computed to generate the spatial variation maps of transverse resistance (T), longitudinal conductance (S), average transverse resistivity (ρt), and longitudinal resistivity (ρl), electrical anisotropy (λ) and formation resistivity (ρm) to decipher the resistivity properties of fractures for supportable groundwater development within the study area. The results demonstrate that the secondary geophysical indices provide a constructive solution in delineating the fresh water aquifers in the study basin. The longitudinal conductance (S) value varies from 0.1 to 0.9, suggesting that the entire study area reveals good to weak aquifer protective capacity rating and increase of 'S' values from one point to another infers increasing thickness of conductive layer in the present case. The variation in the coefficient of anisotropy from 1.1 to 2.9 at the 120 VES data sites, suggests the anisotropic disposition of the aquifers in the region. The low value of the protective capacity in the NW-SE trend of the basin is due to the absence of significant amount of clay as an overburden impermeable material, thereby enhancing the percolation of the aquifer. This practice of analysing VES data provided the direct solution to resolve problems in different hard rock terrains with a plain insufficiency of groundwater, which has a great social impact.

Keywords: *Vertical electrical sounding, Dar-Zarrouk parameters, Aquifer, Electrical resistivity, Sudda vagu basin*

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I. INTRODUCTION

The study of groundwater resources in granitic terrain has always remained a topic of discussion and crucial task for hydrogeologists as the potential groundwater zones/recharge in granitic terrain are limited to localized weathered, fractured and fissured circumstances. The groundwater potential in such an environment depends upon the thickness of the weathered/fractured layer overlying the compact basement rocks (Kumar et al., 2014). It is complex to identify and map such layers in the granitic terrain subsurface; equally incomprehensible is to perceive the infiltration, flow, accumulation and storage of groundwater. The availability of groundwater in such areas is largely due to the development of secondary porosity and permeability resulting from weathering and fracturing (Rai et al., 2015). To study the aquifer properties, such as its thickness and dimensions, the use of geological sequence, exploration, and subsequent drilling is used globally. Nonetheless, these procedures are both time consuming and very expensive. Therefore, geophysical techniques play a vital role in identifying and understanding the aquifers and advocating a superior correlation with geology and existing boreholes, if any (Maillet 2005).

Hydrogeological and geophysical studies carried out in the Deccan trap region (Rai et al., 2015) delineated aquifers and reported occurrence and movement of groundwater in intertrappeans/vesicular and fractured zones within the trap sequence and sedimentary formations below the traps, which are considered to be a potential source of groundwater. The geophysical techniques, the electrical resistivity profiling and vertical electrical sounding (VES) are most broadly deployed to delineate different layers such as top soil, weathered, fractured and bedrock zone for construction of suitable groundwater structures (Gupta et al., 2015). This paper enlightens the use of Dar-Zarrouk (D-Z) parameters (viz. total longitudinal unit conductance (S) and total transverse unit resistance (T)) along with other important indices (average longitudinal resistivity (ρl), average transverse resistivity (ρt), electrical anisotropy (λ), and formation resistivity (ρm) derived from D-Z parameters.

These parameters assume an important role in geoelectrical soundings, and are related to different combinations of thickness and resistivity for each medium and applied to define different groundwater characteristics and geological conditions (Batayneh, 2013). This type of studies has been carried out for the first time over Sudda vagu basin.

II. BRIEF GEOLOGY OF STUDY BASIN

The present study area Sudda vagu basin around Bhainsa region lie between 77° 47' 00" to 78° 02' 00" E Longitude and 18° 59' 00" N Latitude to 19° 17' 00" N Latitude in western part of Nirmal district Telangana state covers to area of 323.8 sq.km (Figure 1). The study area is a part of the Upper Cretaceous to Paleocene age of Sahyadri Group of Deccan trap represented by basalt covers major Central, NW and SW part and, Peninsular Gneissic Complex, comprising of Archaean to Paleoproterozoic granites and gneisses and covers southeast part of study area (Figure 2) The geological formations encountered in the study area are granites, granodiorites and banded gneisses. The Archaean rock consists of mainly of pink granite, grey biotite granite, and grey hornblende biotite granite. The pink granites and grey granites are closely associated with each other. The pink granite is generally porphyritic with large phenocrysts of pink orthoclase feldspar. Biotite, Chlorite, hornblende, epidote and tourmaline occur as accessories. The pink granites are more susceptible to weathering than the grey granites.

Deccan basalts comprise in the major part of the study area. Nearly horizontal lava flows are considered as a result of fissure type of lava eruption during late Cretaceous to early Eocene period. The Deccan trap basalts in Peninsular India are the result of fissure eruptions of molten lavas which flowed to long distances covering hundreds of kilometres of the country to form extensive flows. These rocks are generally horizontal and layered and each layer ranges from a few meters to 40.0 meters in thickness. The Basalts, though generally uniform in composition, show variation in colour, texture and mode of weathering and the deccan traps unconformable overlying the PGC-II rocks. In the study area of limestone Penganga group of Neo Proterozoic age continue isolated patches are presented in western part of Mahalingi to Meltaroda areas and south part of Umri area. The limestones are seen with typical elephant skin weathering. Special features of limestone like elephant skin weathering, bedding joints, caverns. Upper Cretaceous age Infratrappean bed N-S direction contact line of Takli to Taroda in continuous isolated patch exposed between the granite and overlying deccan trap basalt. The drainage network dendritic to sub- dendritic of study area.

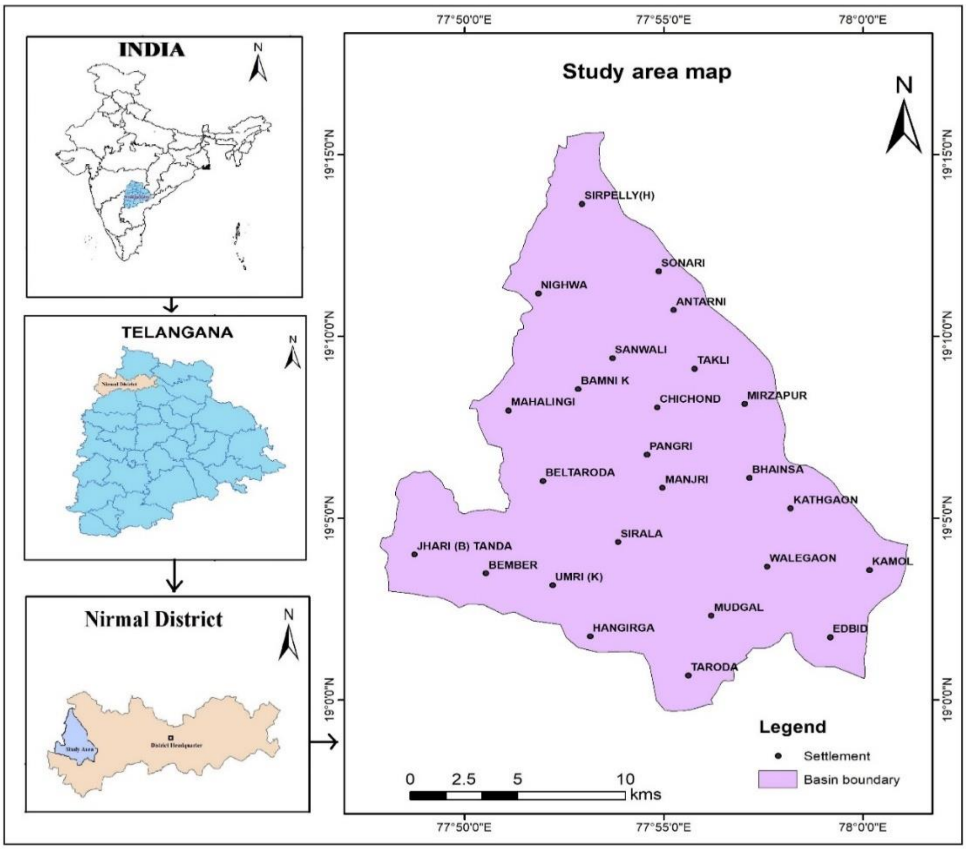

Figure1. Location map of the Sudda vagu basin area

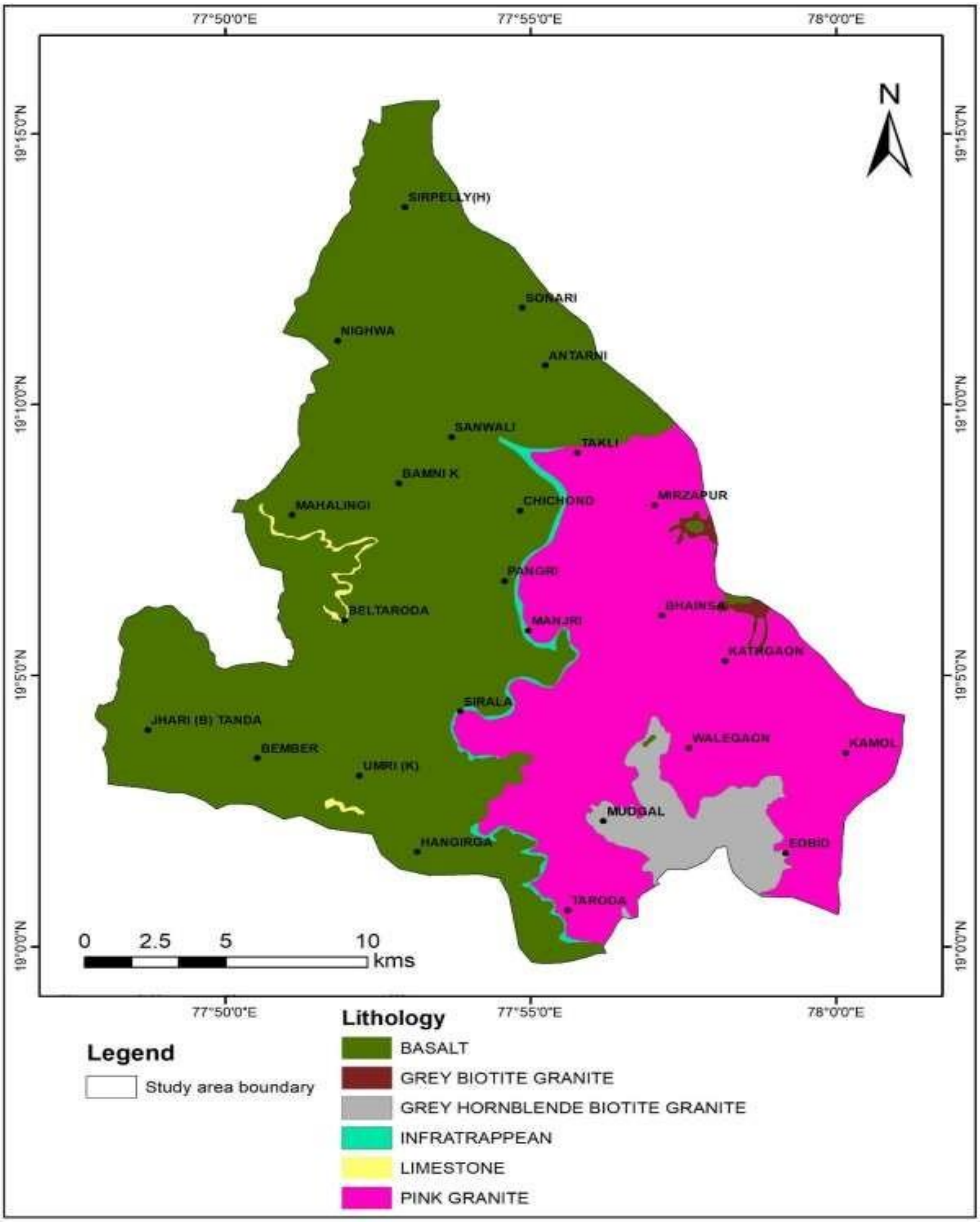

Figure 2. Geological map of the Sudda vagu basin area

III. MATERIALS AND METHODS

In the resistivity method two pairs of electrodes are used to measure the resistivity; one pair of current electrodes is used to transmit current into the ground and another pair measures the potential difference between two potential electrodes. In the present study, a total of 120 vertical electrical soundings (VES) were carried out using the Schlumberger configuration (Figure 3).

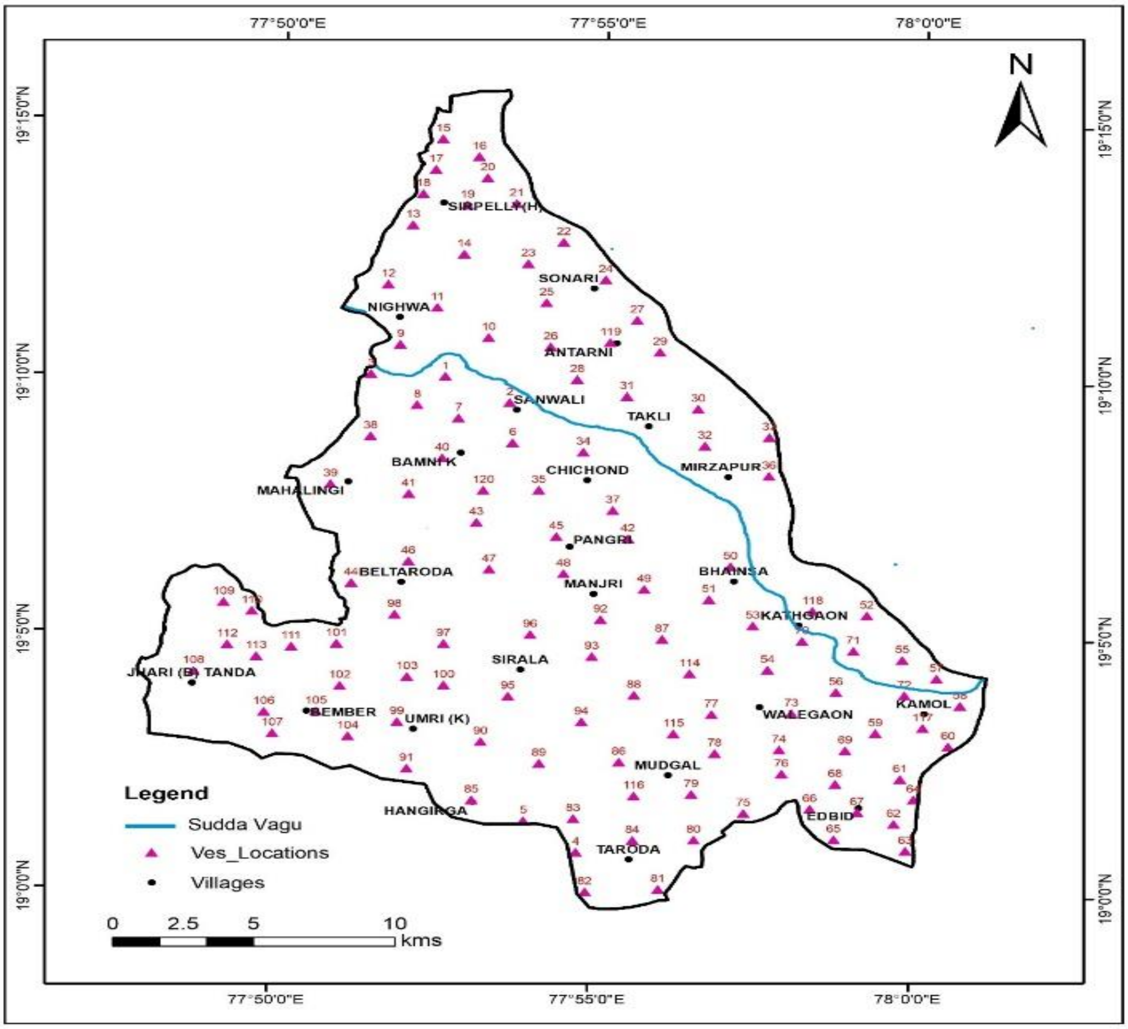

Figure 3. Locations of the vertical electrical soundings carried out in the study area

In Schlumberger configuration, the current electrode is symmetrically increased while the potential electrode is fixed at its initial distance until the resistance measured becomes too small. The apparent resistivity (ρa) is plotted against the corresponding half electrode spacing(AB/2) on a bi-logarithm graph to generate the sounding curves. The sounding curves were interpreted by computer assisted IPI2WIN software (Bobachev, 2003). VES field data is plotted on a double log graph sheet with apparent resistivity versus electrode spacing to obtaingeo-electrical parameters (layer resistivity and layer thickness) which suggested 2 to 4 layeredstructures in the study area. One-dimensional inversion results of some representative stationsare shown in Figure. 4. A flow chart showing the methodology of resistivity sounding is depicted (Figure 5).

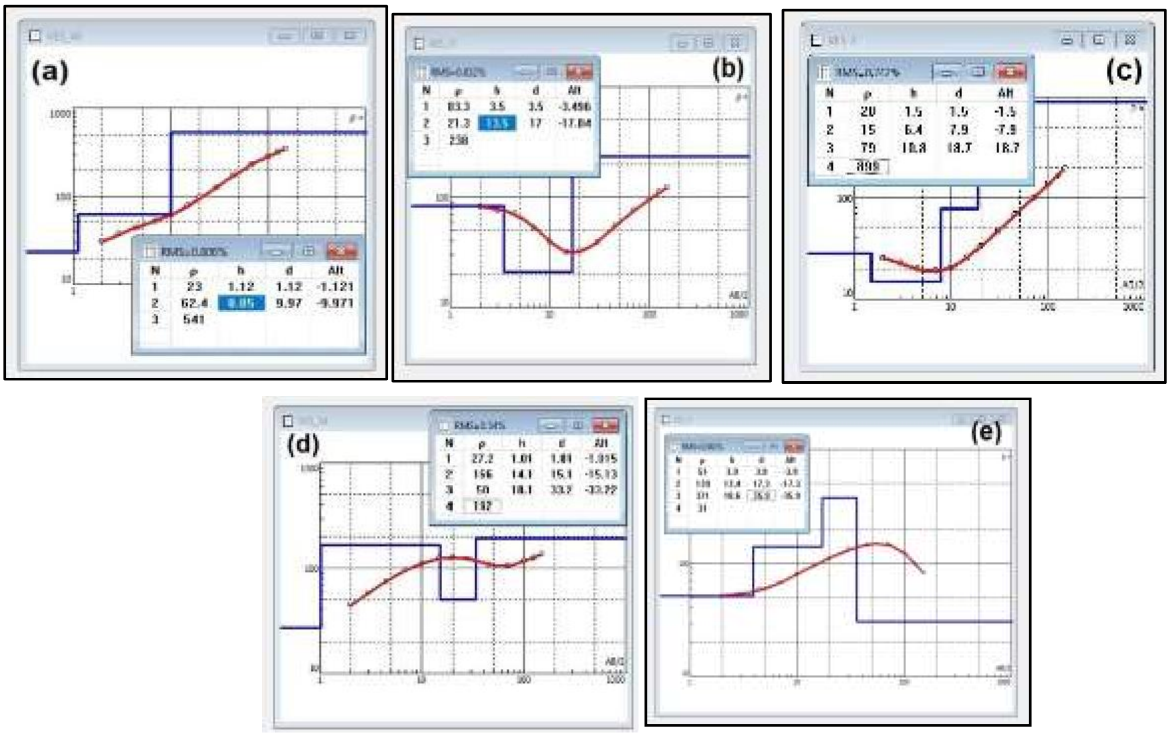

Figure 4. (a) Interpreted A-type VES curve; (b) Interpreted H-type VES curve; (c) Interpreted HA-type VES curve; (d) Interpreted KH-type VES curve; and (e) Interpreted AK-type VES curve

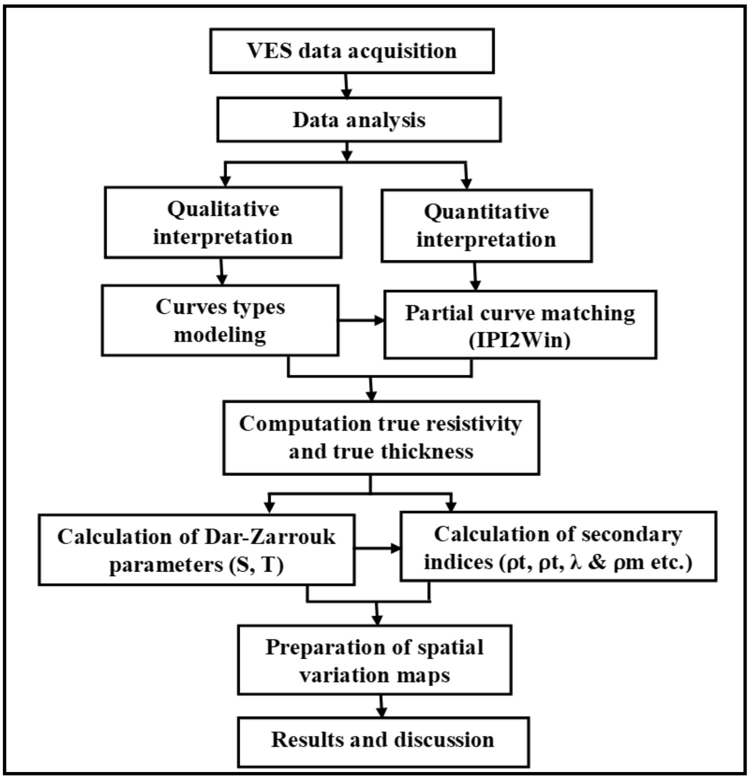

Figure 5. Flow chart of the methodology for electrical resistivity technique

The secondary geophysical indices (viz. Dar Zarrouk parameters) are thus very useful to comprehend the spatial distribution of groundwater in addition to the geometry of the sub- surface litho-units and provide a clue to aquifer prospective zones in the study area. The significance of D-Z parameters for obtaining hydrological properties of the aquifers has been studied by several workers (Niwas and Singhal 1981; Gupta et al. 2014; Shailaja et al., 2016; Suneetha et al., 2021). Maillet (1947) termed the Dar Zarrouk (D-Z) parameters: T, as the resistance normal to the face (transverse resistance) and S, as the conductance parallel to the face (longitudinal conductance) for a unit cross section area, which plays an important role in resistivity soundings.

A geo-electric layer is described by two basic parameters, resistivity (ρi) and thickness (hi), where the subscript i indicates the position of the layer in the section. Other geoelectric parameters like average transverse resistivity (ρt), average longitudinal resistivity (ρl), coefficient of anisotropy (λ) and formation resistivity (ρm). can be derived from its resistivity and thickness (Henriet, 1976). For i = 1, 2 ... n-layer, these parameters are:

Total longitudinal conductance (S) is defined as,

$S = \sum_{i}^{n} = 1 \frac{h_i}{\rho_i}$ ……………(1)

Similarly, the total transverse unit resistance (T) is defined as,

$T = \sum_{i}^{n} = 1\ h_i \rho_i$ ……………(2)

Using eq. (1), the longitudinal resistivity due to the current flowing parallel to the layers is given by,

$\rho l = \sum i = 1\ \frac{h_i}{s_i}$ ……………………(3)

H is the depth to the bottom most geoelectric layer. Similarly, the transverse resistivity due to the current flowing perpendicular to the layers is expressed using eq. (2) as,

$\rho t = \sum i = 1\ \frac{T_i}{h_i}$ …………………..(4)

Combining eq. (3) and (4), the coefficient of anisotropy (λ) is given by,

$\lambda = \sqrt{\rho t / \rho l}$ ……………………………(5)

Combining eq. (3) and (4), the formation resistivity (ρm) is given by,

$\rho m = \sqrt{\rho t\ \rho l}$ ………………..(6)

IV. RESULTS AND DISCUSSION

Henriet (1976) showed that the combination of layer resistivity and thickness in the D-Z parameters S (longitudinal conductance) and T (transverse resistance) may be of direct use in aquifer protection studies to signify the percolation of contaminants into the aquifer, and for the evaluation of hydrologic properties of aquifer. The protective capacity is considered to be proportional to the longitudinal unit conductance (S). Accordingly, the overburden protective capacity was evaluated using the total longitudinal unit conductance (S) values.

Longitudinal conductance (S)

Figure 6 shows the contour map of the longitudinal conductance computed using equation (1) the parameter magnitude ranges from 0.1 to 1.9 mhos, with a contour interval of 0.1 mhos. Increase of 'S' values from one point to another infers increasing thickness of conductive sedimentary layer in the present case. In the contour map, high values of longitudinal conductance are observed at northeastern margin of the Sonari to Talki, and Kathgaon, south part of Taroda, west part of Umri and Jhari Tanda areas, these high 'S' values indicate that the basement is at deeper depth. Low 'S' values indicate a shallow basement which can be seen on northern side in Nighwa, middle part in Mahalingi to Bhainsa, eastern side in Kamol area of the study and reveals low value of the protective capacities of the overburden rock materials which make the aquifer system in the area highly vulnerable to contamination. The longitudinal conductance (S) provides information on the variation of the resistive basement topography, as depth to the basement relates to S. The areas with moderate to good aquifer protective capacity correspond with zones of significant clayey overburden, which are adequate to protect the aquifer from contamination.

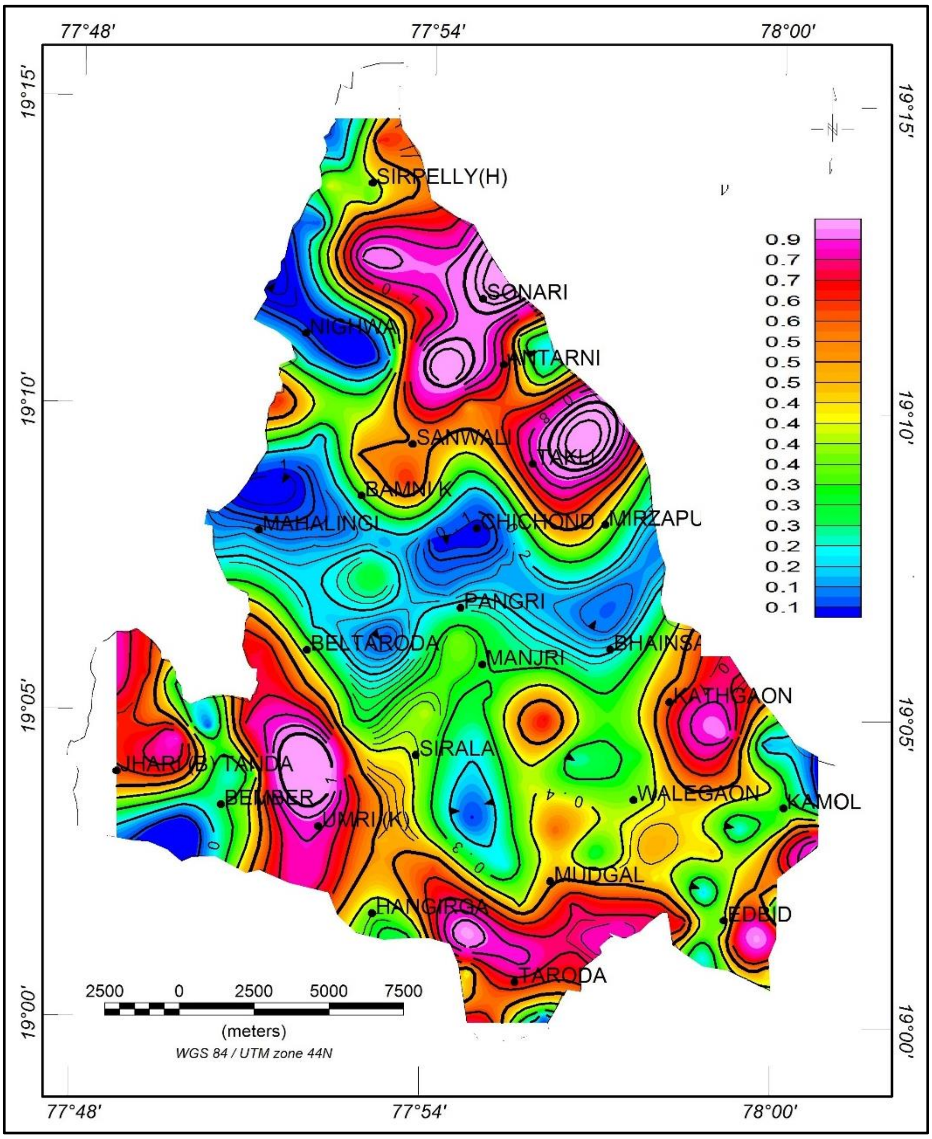

Figure 6. Contour map of the longitudinal conductance (S).

Transverse resistance (T)

Figure 7 shows the contour map of the transverse resistance 'T' computed using equation (2), the parameter magnitude ranges from 255.1 Ωm2 to 5101.9 Ωm2 with a contour interval of 1000 Ωm2. Increase of 'T' values from one station to another suggests an increase in resistivity and thickness of resistivity formations. In this contour map, 'T' values increase, which indicate thickening of high resistive bodies. Very high 'T' values (red to pink colour) are noticed from NW-SE trend, between Nighwa to west of Edbid and west part of Jhari tanda areas indicative very high transverse resistance readings correspond to highly resistive formations in the subsurface. While low T values (bluecolour) are related with low resistivity readings are noticed, formations (such as clayey /saline soil) and a comparatively shallow basement. In the study region low values are obvious at Sirpelly, Sonari, Talki, around Beltaroda, Taroda, and Kathgaon of the area (Figure 7).

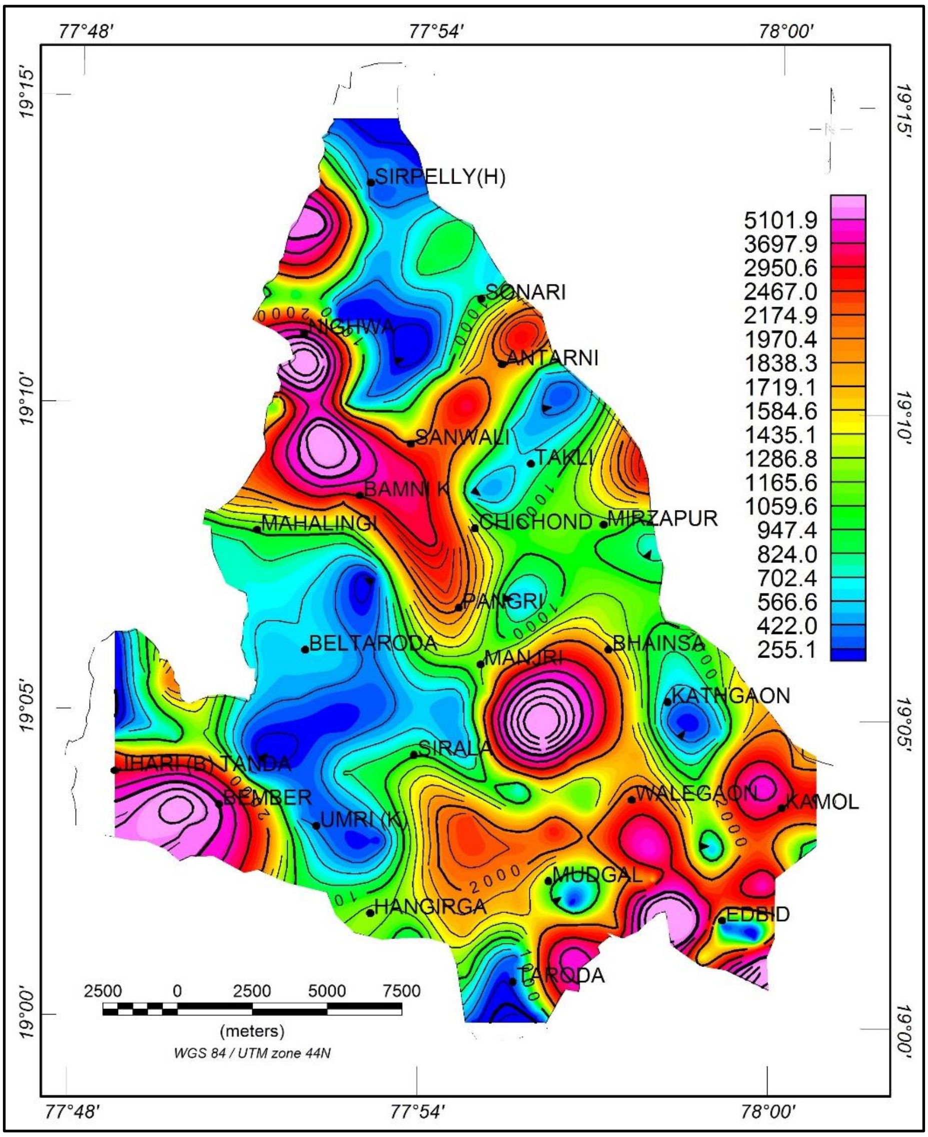

Figure 7. Contour map of the transverse resistance (T)

Longitudinal resistivity(ρl) and Transverse resistivity (ρt)

The contour image of the average longitudinal resistivity (Figure 8) computed using equation (3) shown with a contour interval of 20 Ωm and the values, as may be seen, range from 17.6 to150.5Ωm. Corresponding to the locations of high 'S' values observed in the Figure 6, a decrease of average longitudinal resistivity (ρl) is observed (Figure 8), thus sharing a goodconsistency. The low 'ρl' values are observed at Sirpelly,Sonari, Takli, aound Umri and high 'ρl'values are observed at northwest of the Nighwa, Mahalingi, Chichond, west of Bember, south of Sirala and Kamol areas. The transverse resistivity is usually more than the longitudinal resistivity in case the medium is heterogeneous (Flathe 1955), else the two parameters will beequal. This implies that the current flow and average hydraulic conduction along the longitudinal boundary are greater than those normal to the boundary plane (Ayolabi et al. 2010). Further, Keller (1982) was of the view that longitudinal resistivity is dominated by the more conductive layers (in the present case, clay and weathered/fractured basalts) whereas transverse resistivity increases quickly even if a small fraction of resistive layers. Similar trendsare also observed in the average transverse resistivity (ρt) calculated using equation (4) contourmap of the study area is shown in Figure 9 with a contour interval of 50 Ωm and the values range from 24.3 to 239.6 Ωm. It is observed in this image that average transverse resistivity values ρt show an increase towards southeast part. The high ρt observed near and around Bhainsa,Nighwa, Mahalingi, Chichond, west of Bember, south of Sirala and Kamol areas, and low ρt observed at around Umri and Soanri, Kathgaon, Taroda areas. Which is presumably due to thebasaltic and hard rock formation.

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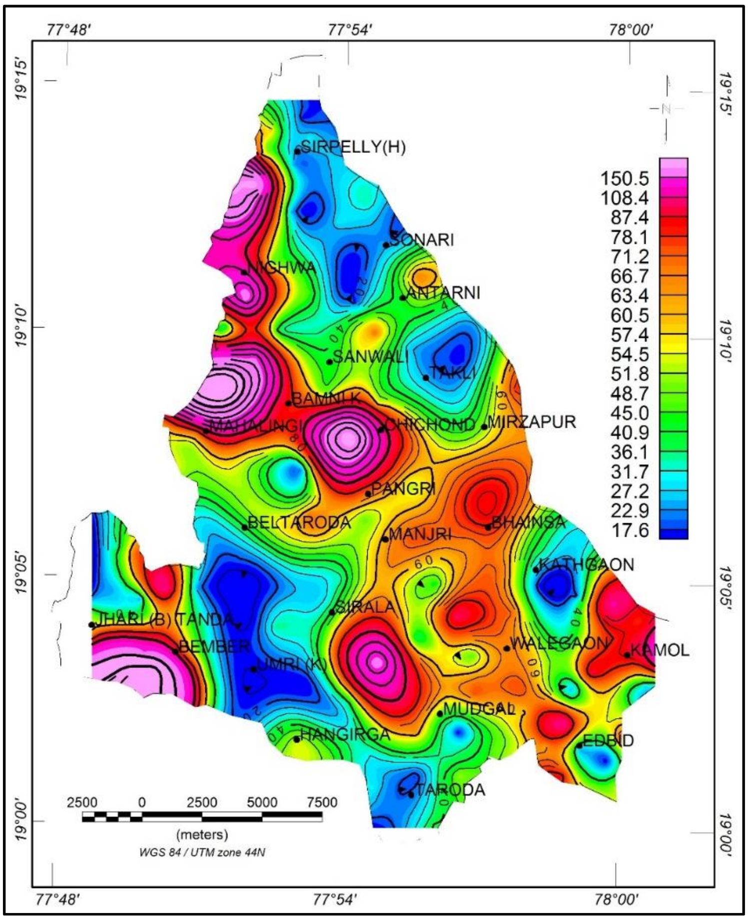

Figure 8. Contour map of the average longitudinal resistivity (ρl)

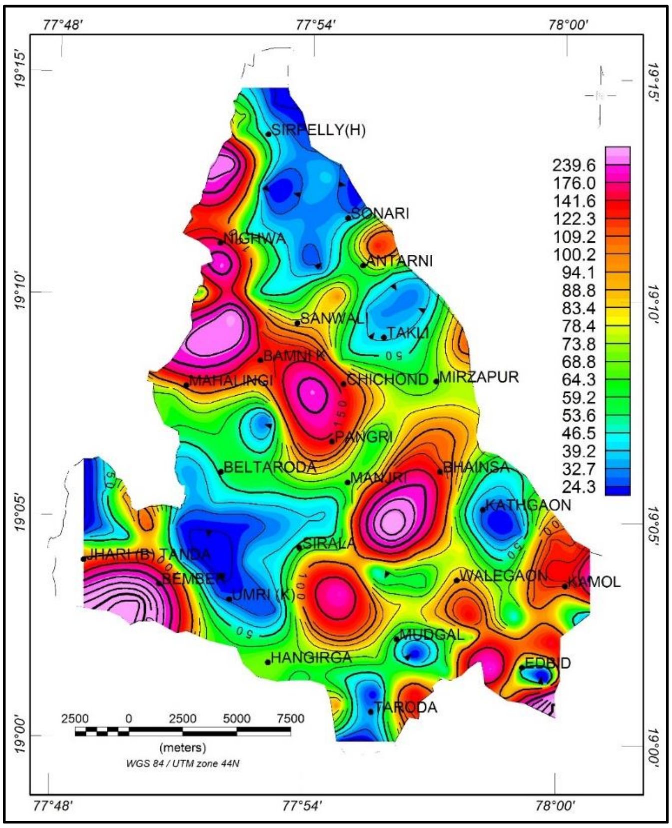

Figure 9. Contour map of the Average Transverse Resistivity (ρt)

Electrical anisotropy (λ)

Coefficient of anisotropy computed using equation (5), shows the coefficient of electrical anisotropy (λ) contour image of the study area and the values range from 1.1 to 2.9 (Figure 10). The increase of λ values in the central part point out to the increase of hardnessof rocks and these indications suggest the presence of hard lithological features (NaganjaneyluK and Harinaryana, 2004). The coefficient of anisotropy is another important parameter in theevaluation of groundwater prospects. In particular, this parameter helps in delineating fractured zones. In a homogenous rock matrix, there is no difference in resistivities measured along different azimuths. This is not the case when fractures/joints/faults are present. The coefficientof anisotropy is an electrical measure of the geological/structural in homogeneity present in anarea and is reflected in the increased ellipticity of its contours (Ramadass et al., 2002). The ratio of the major axis to the minor axis can be taken as the index of anisotropy. This index is greater than 1, but does not generally exceed 2.0 (Zodhy et.al., 1974). Broadly, areas with lowwater table fluctuations are associated with low anisotropy values, while areas with high watertable fluctuations are associated with relatively higher anisotropy values. Also, with increasinghardness and compaction of rocks there is an increase in the coefficient of anisotropy (Keller and Frischknect, 1966) and hence such areas are associated with low porosity and/or permeability. Low (blue colour) anisotropy zones at south downstream part of study area trending in mostly NW to SE direction, whereas at Mahalingi to Mudgal, north part of Nighwa,east of Bhainsa area, low values (< 1.1) are attributable may be due to fracture zones. High anisotropy (>1.4) zones categorized by elliptical shapes are observed in and around west of Bhainsa, Talki, Bamnik, south of Sonari, Sirpelly, and south part of areas Edbid, Umri, and Bember. It can thus be inferred that the areas having minimum water table fluctuation is relatedwith low λ values and higher water table fluctuation regions are associated with high λ values (Figure 10).

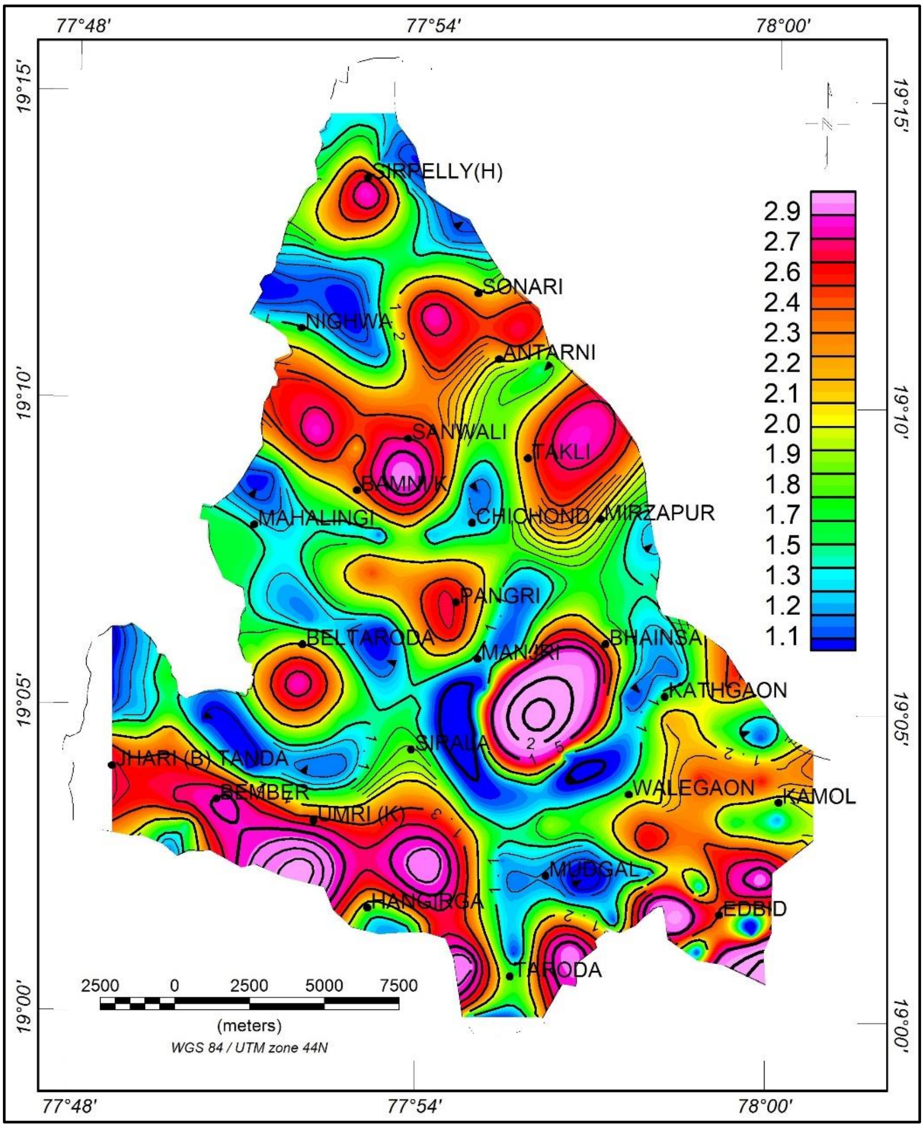

Figure 10. Contour map of the coefficient of electrical anisotropy (λ)

Formation Resistivity (ρm)

The contour image of the formation resistivity (Figure 11) and values are spread over a wide range from 21.7 Ωm to 174.6 Ωm, which were computed using equation 6. In this image, the high values are seen in the study area, which indicate presence of relatively high resistive bodies are noticed from NW-SE trend, between Nighwa to west of Edbid and west part of Jhari tanda areas. Low resistivities ranging 21 Ωm to 38.4 Ωm values are obvious at Sirpelly, Sonari, Talki, around Beltaroda, Taroda, Umri, Taroda and Kathgaon of the area, higher T values are typical of high resistivity formations and relatively deeper occurrences of basement, whereas low T values are linked with low resistivity formations (such as clayey soil) and a relatively shallow basement. The high transverse resistance (red to pink colour) results are indicative of extremely highly resistive subsurface formations. (Loke, M.H, 1999).

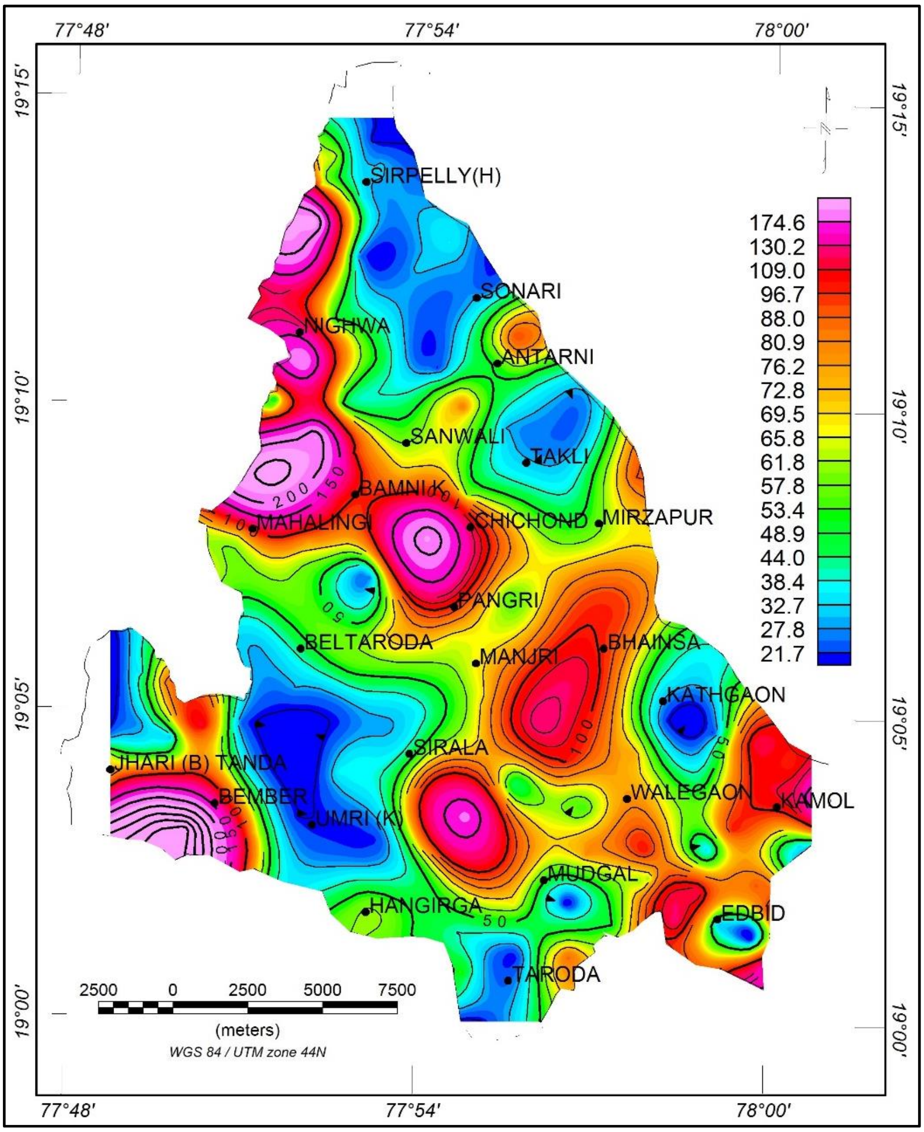

Figure 11. Contour map of the formation resistivity (ρm)

V. CONCLUSIONS

The Dar-Zarrouk parameters proved useful for delineating zones of groundwater potentials in a complex basement terrain. The longitudinal conductance (S) provides information on the variation of the resistive basement topography, as depth to the basement relates to S. The Sudda vagu basin area with moderate to good aquifer protective capacity correspond with zones of significant clayey overburden, which are adequate to protect the aquifer from contamination. The high T values are related to zones of high transmissivity aquifer materials and thus highly permeable, thereby enhancing the migration of contaminants within the groundwater system over large areas. These revelations are indications that the groundwater quality may have been impaired in the area. Electrical anisotropy (λ) is a crucial parameter in understanding the fracturing of a region. In the present study the λ values ranging between 1.1 to 2.9. the anisotropy zones at south downstream part of study area trending in mostly NW to SE direction, whereas at Mahalingi to Mudgal, north part of Nighwa, east of Bhainsa area, low values (< 1.1) are attributable due to fracture zones. High anisotropy (>1.4) zones categorized by elliptical shapes are observed in and around west of Bhainsa, Talki, Bamnik, south of Sonari, Sirpelly, and south part of areas Edbid, Umri, and Bember. It can thus be inferred that the areas having minimum water table fluctuation is related with low λ values and higher water table fluctuation regions are associated with high λ values. The present study assistances in illustrating the aquifers of the granitic terrain and basaltic flow of Sudda vagu basin and to evaluation the aquifer protective capacity as well as the fracture geometry using secondary geophysical indices.

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