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Aquifer characterization using geo-electric method in alluvial and hard rock area of Kota District, Rajasthan, India

Naziya Jamal and N. P. Singh
Department of Geophysics, Institute of Science, Banaras Hindu University
Varanasi-221005, India
Email: singhnpbhu@yahoo.co.in

Abstract

In present research, groundwater aquifer characterization study is performed for the Sangod block of Kota district, Rajasthan using the geo-electrical method of geophysics. A total of seventeen resistivity soundings are carried out at different locations in Sangod block of Kota district, Rajasthan. The interpretation of the sounding data revealed that the study area comprises of four to five geo-electric layers in the subsurface. The top layers consist of surface and sub-surface soil and the layers underneath the top layer are shale and resistive basement of semi compact to compact sandstone. In present study, Dar-Zarrouk (D-Z) parameters, viz., the total transverse resistance (T), total longitudinal conductance (S) and depth to the resistive substratum are computed to characterize the aquifer and to generate the resistivity regime of freshwater-bearing formations and its movement. The results of VES are also used to generate various hydro-resistivity maps such as 3D surface maps of total longitudinal conductance and total transverse resistance and resistant substratum contour map of the area. These maps reveal the litho-logical and geological changes in the subsurface of the area. The results also indicate the protective capacity of the underlying aquifers in the area, an indicator of probable contamination level of these aquifers.

Keywords: Groundwater exploration, Geophysical methods, Longitudinal conductance, Transverse resistance, Protective capacity of aquifers

1. Introduction

Groundwater is nature's hidden resource. Its exploitation has continued to remain an important issue due to its everlasting need for human civilization. Though there are other sources of water such as lakes, streams, rivers, ponds, etc., but none is as hygienic as groundwater because groundwater contains an excellent natural microbiological quality and generally adequate chemical quality for most uses (Okafor and Mamah 2012). Over exploitation of groundwater continued in past years have declined the water level in the area and therefore there is immense need of its monitoring and mapping of groundwater resources. As the study area lies under the semi-arid to arid regions of India with relatively lesser rainfall, the groundwater only remains the major source of irrigation activity and domestic supply in the area. Exploration of groundwater in hard rock terrain is a very challenging and difficult task when the promising groundwater zones are associated with fractured and fissured media. In this environment, the groundwater potentiality depends mainly on the thickness of the weathered/fractured layer overlying the basement (Mansour and Garni 2009). The most probable use of the electrical resistivity survey in hydrogeological investigation related to delineation of aquifer, lithologic boundaries and geological structures is to provide subsurface information (Bose et al., 1973) that can be used for mapping and management of groundwater resources as well as characterization of groundwater resources.

The vertical electric sounding (VES) is very popular and simple method for groundwater exploration, environmental, waste management, geochemical and other near surface engineering studies. In this study, the geo-electrical survey carried in the alluvial and hard rock areas of Sangod block of Kota district is used for groundwater exploration and hydro-geological investigation related to aquifer characterization. The results of VES at seventeen different locations are used to generate different contour maps such as total longitudinal conductance (S) and total transverse resistance (T) and resistant substratum contour map for inferring information about the litho-logical and geological changes for characterization of subsurface groundwater aquifer in the area.

2. Location and Geology of Study Area

The study area lies in between latitude 24° 50′ to 25° north and longitudes76° 15′ to 76° 28′ east. The study area lies in the parts of hard rock and alluvial regions of Sangod Block, Kota District, Rajasthan, India. The area is covered by a thin layer of alluvial soil of varying thicknesses. This soil cover is underlain by a thin layer of shale and further, underlain by semi fractured to highly fractured sandstone and semi compact to compact sandstone in the basement. The climate of the area can be categorized as semi-arid type with average annual rainfall of about 750 mm. The summers are very hot and winters are cold. The boundary of survey area and location of VES points are shown in Fig.1.

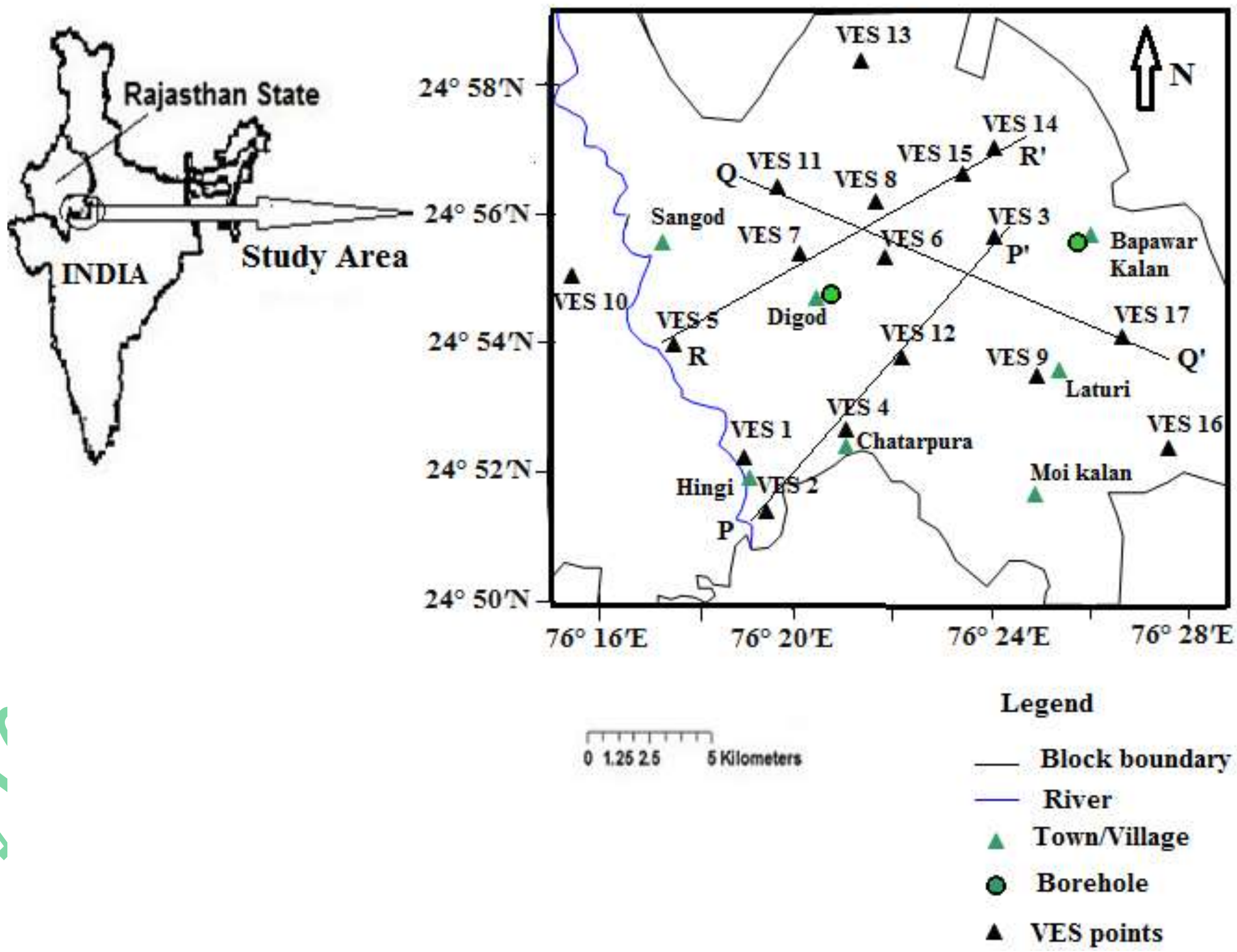

Fig.1. Map of the study area.

The rock formations exposed in Kota district are sedimentary in nature and belong to Vindhyan Super Group. These are overlain in most part of the district by the Quaternary alluvium. The Vindhyan Supergroup is composed mostly of low dipping formations of sandstone, shale, and carbonate, with a few conglomerate and volcaniclastic beds, separated by a major regional unconformity and several local unconformities (Bhattacharyya 1996). The regional unconformity occurs at the base of the Kaimur Group and divides the sequence into two units: the Lower Vindhyans (Semri Group) and the Upper Vindhyans (Kaimur, Rewa, and Bhander Groups). The outcrop pattern of the supergroup resembles a simple saucer-shaped syncline. It is generally believed that the Vindhyan basin was a vast intracratonic basin formed in response to intraplate stresses (Bose et al. 2001). The occurrence and movement of groundwater is mainly restricted within the weathered and fractured sandstone/shale (Amaresh and Prakash 2003). The principal recurrent river in the district is Chambal and its tributaries Kalisindh, Parvan and Parvati, all these are the main drainage system in the district. The main hydro-geological units of the study area are alluvium, shales, limestones and semi compact to compact sandstones.

3. Materials and Investigation Methods

In the DC resistivity method, current is introduced directly into the ground through a pair of current electrodes and the resulting voltage difference is measured between a pair of potential electrodes. This method provides the apparent resistivity distribution against depth. The depth of penetration of electrical signal is generally found to be approximately one-third of the distance between the electrode separations (Dahlin 2000; Maiti et al. 2011). The apparent resistivity values obtained from the field are plotted against the half electrode spacing on a log- log graph paper. In present study, a total of seventeen vertical electrical sounding data have been collected using Schlumberger configuration are initially interpreted using the curve matching techniques utilizing master curves (Koefoed 1979) and the corresponding auxiliary curves (Orellana and Mooney 1966). This initial interpretation provided geoelectrical layer parameters of the subsurface.

The Dar-Zarrouk (D-Z) parameters (T, transverse resistance and S, longitudinal conductance), (Maillet 1947) are computed for the further interpretation for characterization of aquifers in the area. T is the resistance normal to the face and S is the conductance parallel to the face for a unit cross-section area, which plays an important role in resistivity soundings. D-Z parameters are sufficient for computing the distribution of surface potential and hence electrical resistivity graphs (Henriet 1976). Later on, many other workers (Niwas and Singhal 1981, 1985; Shahid and Nath 2002; Singh et al. 2004; Khalil 2006; Mondal et al. 2013) have showed the significance of D-Z parameters for obtaining hydrological properties of the aquifers. As stated above, Henriet (1976) has 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 and for the evaluation of hydrologic properties of the aquifers. The protective capacity is considered to be proportional to the longitudinal unit conductance (S) (Oladapo et al. 2004; Ayolabi 2005; Atakpo and Ayolabi 2008; Atakpo 2013). Thus, the overburden protective capacity is evaluated using the total longitudinal unit conductance (S) values (Henriet 1976; Oladapo et al. 2004; Atakpo and Ayolabi 2008; Atakpo 2013). Therefore, with the view of evaluating/examining the hydrological properties of the aquifer used for supplying domestic and irrigation water in the area, attempts are made to compute transverse resistance (T) and longitudinal conductance (S) of the ground water in underlying aquifers of the area to characterize the aquifer.

4. Analysis of Vertical Electrical Sounding Data

4.1 Estimation of Dar-Zarrouk parameters

In present study a total of seventeen VES are carried out using Schlumberger configuration. The VES data are collected between 24° 47′ 30″ to 25° north and longitudes76° 15′ to 76° 30′ east in the Sangod block of Kota district, Rajasthan. In order to characterize the aquifers, to delineate the depth to the aquifer and its lateral extent and to estimate the aquifer protective capacity in the area contour maps for longitudinal conductance (S), transverse resistance (T), and resistant substratum are generated, which are used for understanding the spatial variation of these parameters to demarcate the fresh water bodies, to envisage effect of saline water ingress, if any, and to delineate the groundwater potential zones (Gupta et al. 2015). The layered model of transverse resistance (T) and longitudinal conductance (S) is shown in Fig. 2. The estimated D-Z parameters are shown in Table 1.

Table 1: Total longitudinal conductance, total transverse resistance and depth of resistant substratum

VES no.	Total longitudinal conductance (S) (mho)	Total transverse resistance (T) (ohm-m^2)	Depth of resistant substratum (m)
1	1.006402	3540.028	40.32
2	0.426045	10964.37	44.39
3	1.125236	14586.49	78.39
4	1.531699	60.7512	5.62
5	0.682454	3798.162	48.06
6	0.529202	702.494	14.017
7	1.927726	269.86	21
8	1.576678	8897.214	75.12
9	1.103595	106.7716	9.5
10	1.091905	6096.06	76.98
11	2.644144	188.841	22.3
12	0.363575	64505.57	41.02
13	0.913234	1012.102	28.69
14	2.044312	451.9116	28.62
15	0.851629	14111.9	93.54
16	0.616575	145.5964	8.362
17	1.579949	3301.05	62.93

4.1.1 Total longitudinal conductance

The total longitudinal conductance (S) is a parameter generally used to define target areas of groundwater potential. High S values usually indicate relatively thick succession and should be accorded the highest priority in terms of groundwater potential and vice versa (Worthington 1977). The total longitudinal conductance for each sounding is calculated using the following equation:

$$S = \frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} + ... + \frac{h_n}{\rho_n} \quad (1)$$

Or,

$$S = \sum_{i=1}^{i=n} \frac{h_i}{\rho_i} \quad (2)$$

Where, S is the total longitudinal conductance, $\sum$ is the summation sign, ρ_i and h_i are the resistivity and thickness of the i^{th} layer.

The total longitudinal conductance map of the study area (Fig. 3) and 3D surface map of total longitudinal conductance (Fig. 4) are constructed, based on computed values of total longitudinal conductance (Table 1). In present study, the longitudinal conductance (S) varies from 0.3 to 2.7 (in Siemens) with a contour interval of 0.1 (Fig. 3). The lowest and the highest S value are observed at location VES 12 and VES 11 respectively. The sounding locations with low to moderate S values represent fresh water region with minute or no contamination in the study area.

According to (Mogaji et al., 2007), the total longitudinal unit conductance values are utilized in evaluating the vulnerability or protective capacity of the aquifer because the earth medium acts as a natural filter to percolating fluid and that its ability to retard and filter percolating fluid is a measure of its protective capacity. The protective capacity of an overburden overlying an aquifer is proportional to its hydraulic conductivity (Henriet 1976). The longitudinal unit conductance values facilitate to classify the area into poor, weak, moderate, good, very good and excellent protective capacity zones (Oladapo and Akintorinwa 2007; Atakpo 2013). The region with longitudinal conductance (S) values greater than 10, are considered as zones of excellent protective capacity. The conductance values between 5 and 10 represents zones of very good protective capacity while S values ranging from 0.7 to 4.9 represents zones of good protective capacity. The area with S values in between 0.2 to 0.69 and 0.1 to 0.19 can be considered as zones of moderate and weak protective capacity respectively, whereas the conductance value less than 0.1 represents zones of poor protective capacity. On basis of this division, it is inferred that the study area represents a zones of moderate to good protective aquifer capacity and hence optimum for maintaining the freshwater aquifer in the area. Therefore, the subsurface aquifers in the area can be considered as freshwater aquifer.

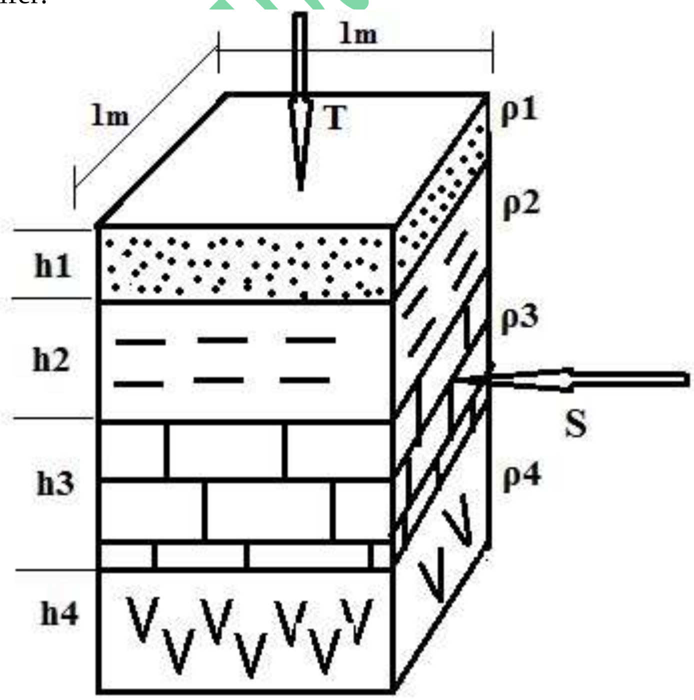

Fig.2. Layered model showing transverse resistance (T) and longitudinal conductance (S).

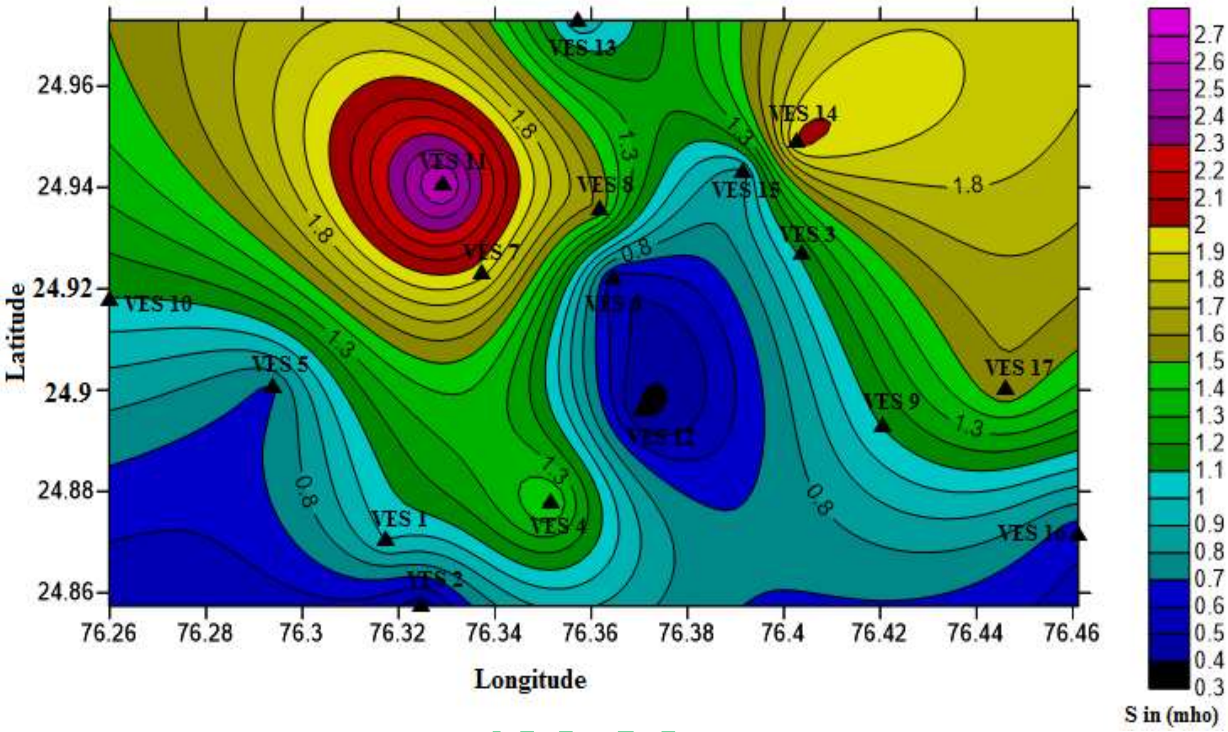

Fig.3. Total longitudinal conductance contour map of the area.

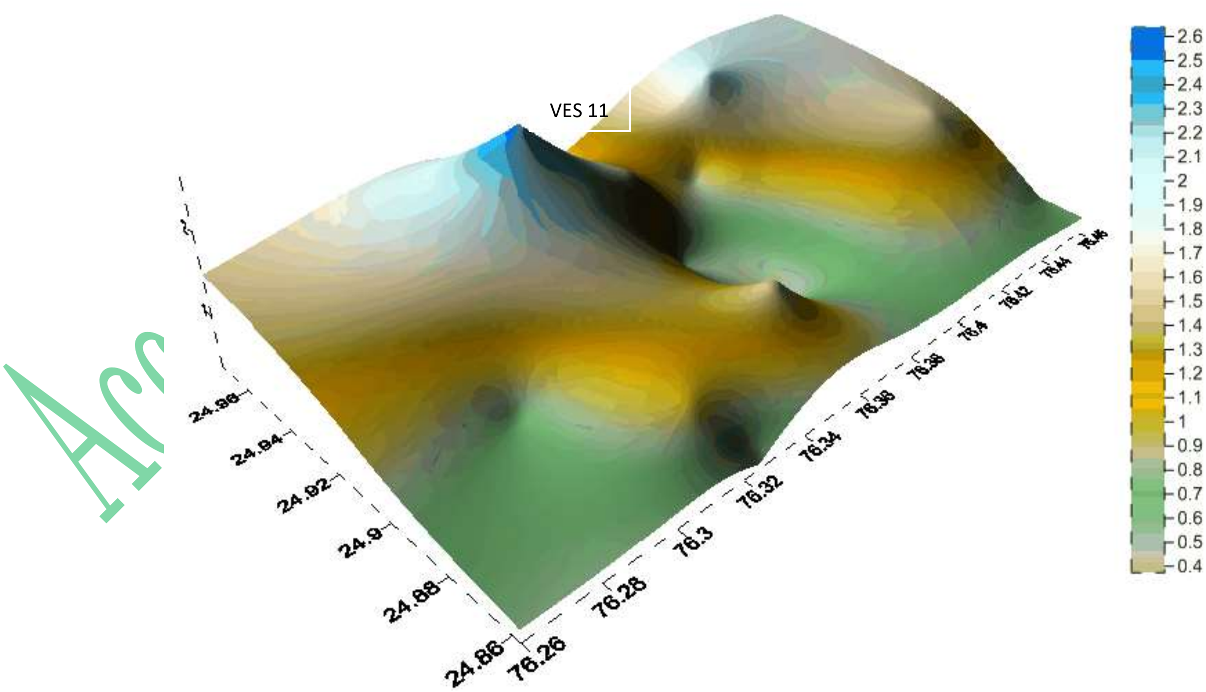

Fig.4. 3D surface map of longitudinal conductance of the area.

4.1.2 Total transverse resistance

The total transverse resistance (T) is one of the parameters used to define target areas of good groundwater potential. It has a direct relation with transmissivity, and the highest T values reflect most likely the highest transmissivity values of the aquifers or aquiferous zones and vice versa (Kumar et al. 2001). The total transverse resistance (T) for each sounding is calculated using the following equation:

$$T = \rho_1 h_1 + \rho_2 h_{2+} .....+ \rho_n h_n \quad (3)$$

Or,
$$T = \sum_{i=1}^{i=n} \rho_i h_i \quad (4)$$

Where, T is the total transverse resistance, $\sum$ is the summation sign, ρ_i and h_i are the resistivity and thickness of the i^{th} layer.

The total transverse resistance map of the study area (Fig. 5) and 3D surface map of total transverse resistance (Fig. 6) are prepared on the basis of computed values of total transverse resistance (Table 1). The sounding location VES 4 has lowest T values 60 ohm-m^2, while the sounding location VES 12 has highest T values representing the area with higher transmissivity values and thus suitable for aquiferous zones and giving the possibility of existence of aquifer around the VES 12.

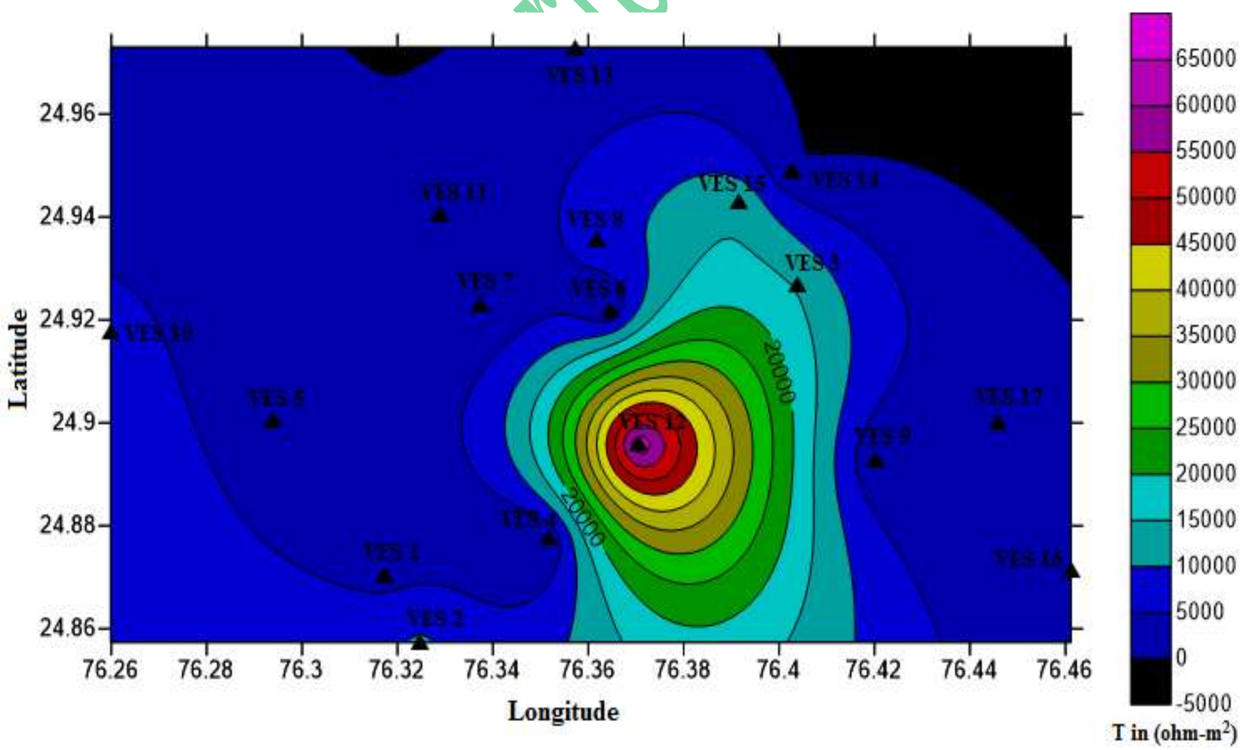

Fig.5. Total transverse resistance contour map of the area.

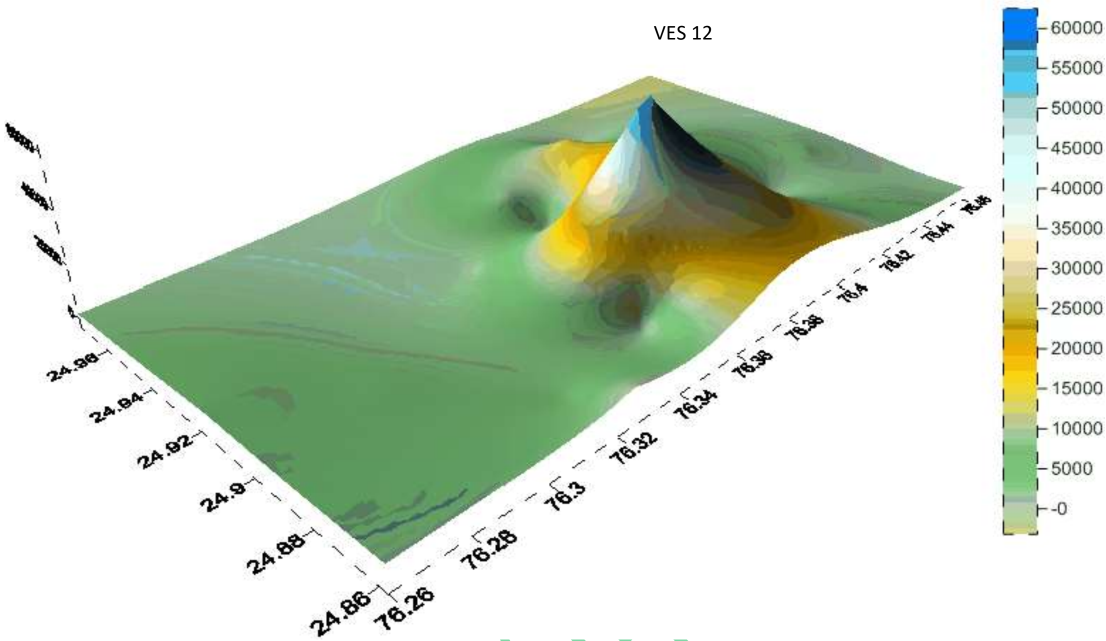

Fig.6. 3D surface map of total transverse resistance of the area.

4.1.3 Resistant substratum contour map

The resistant substratum contour map is a map of the elevation of fresh basement or bedrock beneath all the established VES and, thus, usually depicts the subsurface topography of the fresh

basement or bedrock across the area (Fig. 7). It is very important in hydro-geologic studies (Bala and Ike 2001; Dan-Hassan and Olorunfemi 1999; Olorunfemi and Okhue 1992; Olorunfemi et al. 1999). The VES results (shown in Table 1) are used to generate the resistant substratum contour map (Fig. 6). It represents the variation of depth of the resistive substratum. In present study thickness of alluvial cover varies due to variation in topography of basement rock.

At sounding location VES 4, the basement rock occurs at 6 m depth, whereas at sounding location VES 15 the basement rock (sandstone) occurs at a depth of 93 m, being the maximum in the study area.

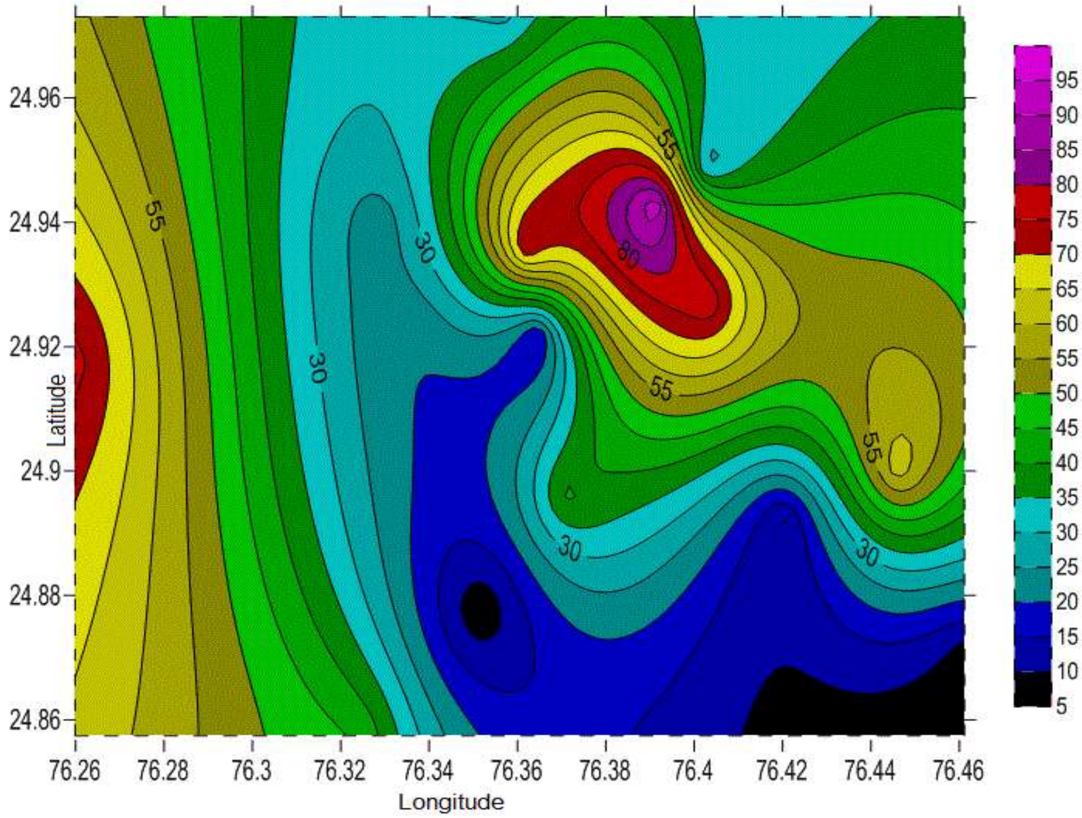

Fig.7. Depth substratum basement contour map.

4.2 Geo-electrical Cross-sections

4.2.1 Geo-electrical cross-section PP'

The geo-electrical cross section along the profile PP' encompassing the sounding locations VES 2,VES 4, VES 12 and VES 3 is based on the results of four vertical electrical sounding (Fig. 8). This profile lies close to the villages Hingi, Chatarpura and Gehunkheri. The top two layers consist of thin layers of surface and subsurface soils respectively, which are slightly thicker towards sounding location VES 2 and VES 12 and comparatively thinner towards VES 4 and VES 3. The average thickness of surface and sub surface (soil) layer is approximately 1.5 m and 5 m respectively. The resistivity of this layer is not uniform because of moisture content and soil type of this layer. Below, the subsurface soil, there is a layer of sand/gravel of varying thickness, thinner in between sounding locations VES 12 to VES 3, and the thickest portion beneath the sounding location VES 2. The fourth layer beneath the sounding location VES 3 consists of semi- fractured sandstone followed by basement rock of semi-compact to compact sandstone of very high resistivity with maximum thickness beneath sounding VES 4, while thickness of this layer decreases from sounding location VES 12 to VES 3 and VES 4 to VES 2. The presence of fractured sandstone of low resistivity below the sounding location VES 3 along the profile PP' could form the potential zone of fresh water aquifer in the area.

4.2.2 Geo-electrical cross-section QQ'

The geo-electrical cross section along profile QQ' consisting of sounding location VES 11, VES 6 and VES 17 is drawn based on evaluated geo-electrical parameters of three electrical soundings (Fig. 9). This profile lies along north-west and south-east of Sangod- Bapawar kalan road. The geo-electric cross section along this profile shows that the upper layer is a very thin layer of surface soil and subsurface soil. The resistivity of this layer varies because of moisture content and soil type of this layer. The third layer consists of sand of thickness 21 m and 12 m beneath sounding location VES 11 and VES 6 respectively. Below the subsurface soil layer, a very thick layer of shale is present at sounding location VES 17 with resistivity 56 ohm-m and thickness 57 m. The fourth and last layer is compact sandstone of very high resistivity. The depth to the compact sandstone is approximately 21 m, 12 m and 63 m beneath the sounding location VES 11, VES 6 and VES 17 respectively, with maximum thickness at sounding location VES 6.

4.2.3 Geo-electrical cross-section RR'

The geo-electrical cross section along the profile RR' consisting of sounding locations VES 5, VES 7, VES 8 and VES 15 and VES 14, is drawn based on the results of five vertical electrical soundings (Fig. 10). The cross section lies north to the villages Jogra, Digod and Kamolar. The first layer is very thin surface soil followed by the thin layer of varying thickness of subsurface soil having the thickest portion of about 7 m at VES 14. The resistivity of this layer varies due to moisture content and soil type of this layer. Below this subsurface soil layer, there are fractured and semi-fractured sandstones present beneath the sounding locations VES 5, VES 8 and VES 15 with maximum thickness at sounding location VES 15. This low resistivity zones of fractured/semi-fractured sandstone could be the possible freshwater aquifers in the area. There is presence of thin layer of sandy formation of thickness 11 m and 7.5 m, beneath the sounding location VES 7 and VES 8 respectively, and a thin layer of shale with resistivity approximately 19 ohm-m and thickness 18 m is present at sounding location VES 14. Thereafter, at depth of about 93 m basement rock (sandstone) of very high resistivity occurs at location VES 15 whose thickness increases towards VES 14 and VES 7, being maximum at VES 7. Therefore, there is possibility of freshwater aquifer below the sounding locations VES 5, VES 8 and VES 15 along the profile RR' with good protective capacity and little or no contamination.

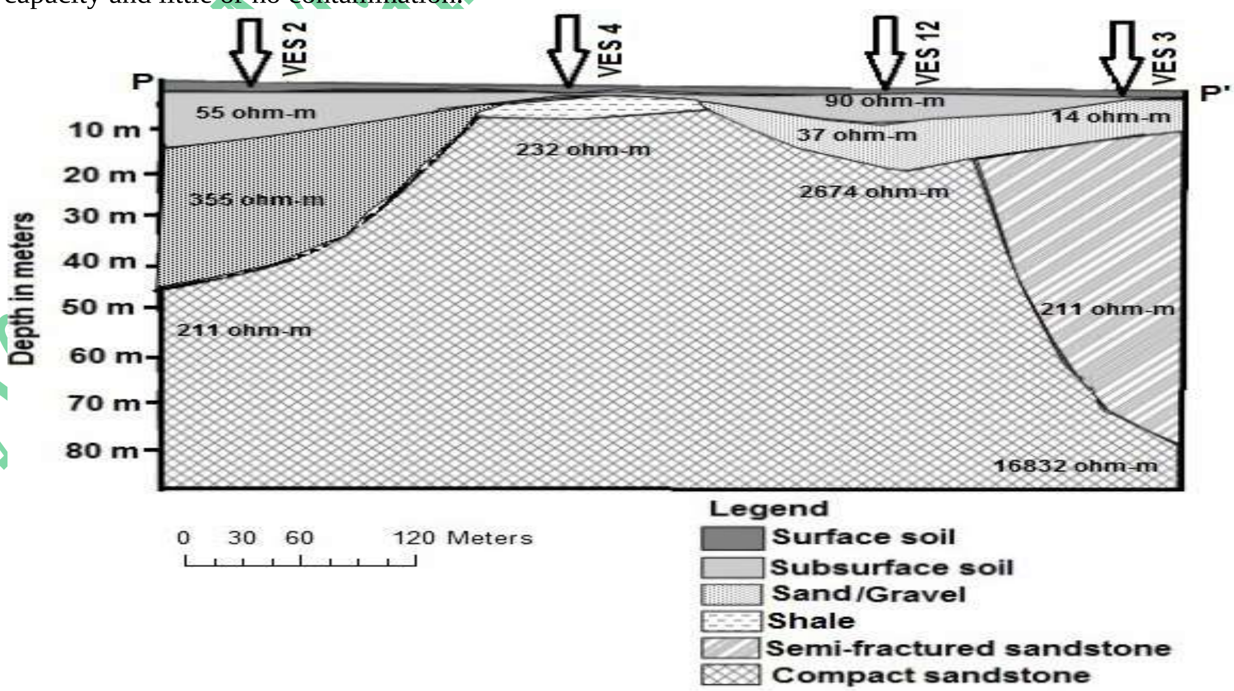

Fig.8. Geo-electrical cross-section along profile PP'.

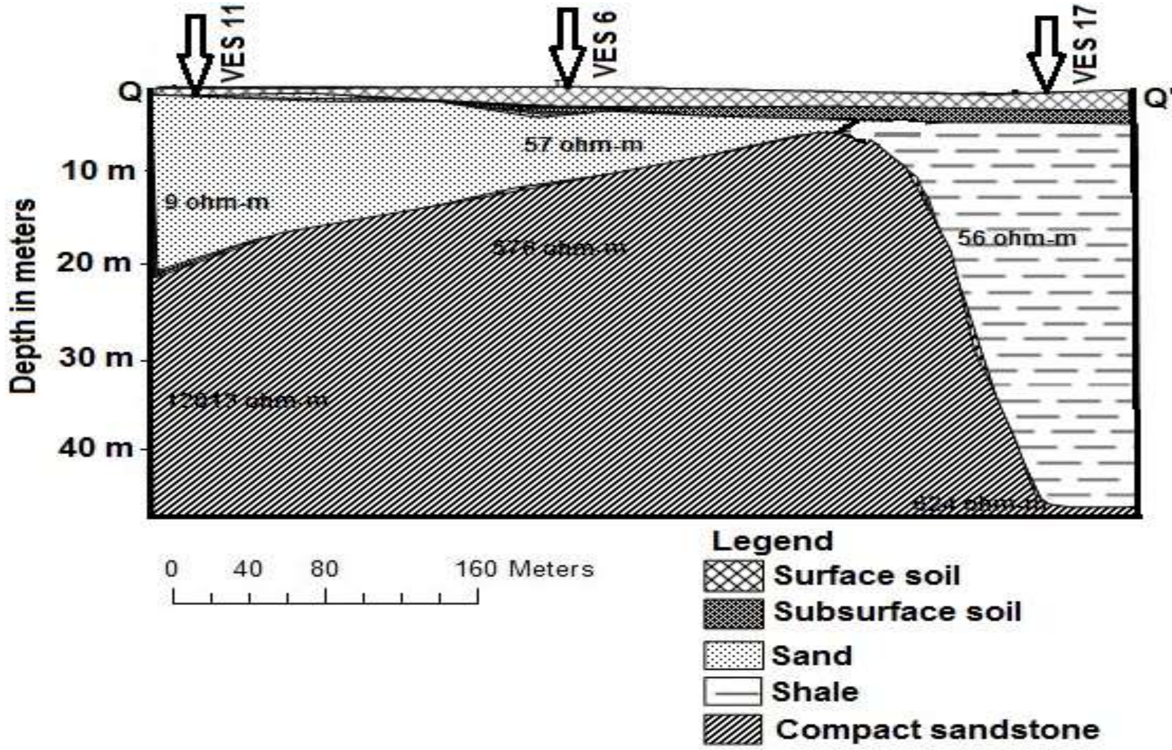

Fig.9. Geo-electrical cross- section along profile QQ'.

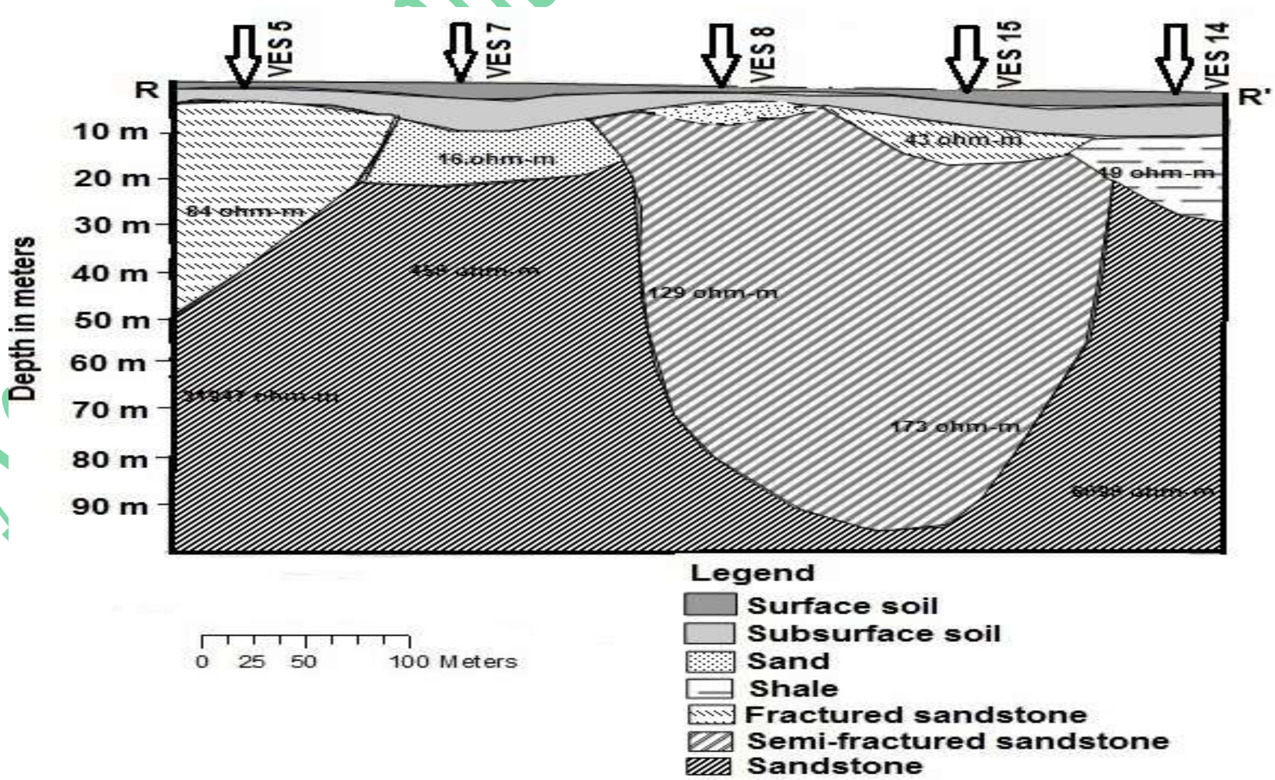

Fig.10. Geo-electrical cross-section along profile RR'.

5. Conclusion

The vertical electrical sounding (VES) is used for groundwater aquifer delineation and characterization in parts of hard rock and alluvial regions of Sangod block of Kota district, Rajasthan. The results of VES reveals that the study area consist of surface, sub-surface soil and a thin layer of shale followed by semi compact to compact sandstone at greater depth. However, result of some VES points reveals presence of loose sediment deposits and fractured to semi-fractured zones, which could be potential zones of fresh water aquifers in the area, which correspond to sounding locations VES 3 along the profile PP' and VES 5, VES 8 and VES 15 along the profiles RR'. The interpreted results of VES are used to generate geo-electric cross sections and different hydro-resistivity contour maps, i.e., total longitudinal conductance (S), total transverse resistance (T), which are found to be very supportive for discovering different hydro-geological and hydrological information of the area. The total longitudinal conductance map suggests moderate to good aquifer protective capacity of the study area, and thereby indicating possibility of freshwater aquifers. The prepared geo-electrical cross sections and resistant substratum contour map from the sounding results indicate different subsurface features and litho-logical changes occurring in the area, that could be used for groundwater management and contamination study of the subsurface aquifers.

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Corresponding Author
Nagendra Pratap Singh
Professor, Department of Geophysics, Institute of Science
Banaras Hindu University, Varanasi- 221005, India
Email: singhnpbhu@yahoo.co.in

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