Geoelectrical Characterisation and Behaviour of Laterites in the Konkan Coast, India

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INTRODUCTION

The electrical resistivity of rock is a property which depends on lithology, fluid content and fluid composition. Vertical Electrical Sounding (VES) furnishes detailed information on the variation of the electrical properties of different lithological layers and their individual thicknesses. This method is useful for a region where the conductivity varies merely with depth without any lateral variation. The technique is best adopted for determining depth and the resistivity of nearly horizontal rock strata. The VES has also been an important geophysical method for determining depth to the water table under such geological condition. The use of VES has some limitations due to which the interpretation of resistivity data could be ambiguous. The ambiguity may arise due to assumption of homogeneous, isotropic and horizontally continuous layer of resistivities, while in reality these conditions are rarely are fulfilled. The second major source of ambiguity stems from the assumption of lateral continuity and from the fact that since the distance MN is finite, the accuracy of measuring the electric field 'E' is about ±5%. Lateral in-homogeneities are reflected on the apparent resistivity curve by cusps and by jumps accompanying changes in the distance MN. The observed VES curve can thus be interpreted in different ways such that the resulting theoretical curve does not differ from the observed one by more than ±5%. This is known as **'the principle of equivalence'**. The **'principle of suppression'** is another important aspect which must be clearly understood for proper evaluation of the interpretations of resistivity sounding curves. According to this principle (Kunetz, 1966), a thin bed whose resistivity is intermediate between the overlying and underlying resistivities has no effect on the resistivity curve.

The basic aim of the study was to map, analyze and assess the characteristic features of the geoelectrical properties and parameters of laterites and their source rocks using geoelectrical mapping.

LOCATION OF THE STUDY AREA

In order to carry out the present study, two areas were selected with distinct geological settings. Tericol area which form the headland plateau along the Arabian Sea coast and the Satarda area in Maharashtra which is basically a low lying area located about 13km away from the sea. The details of the two areas under study area are given below:

The Tericol village study area is located in Pernem taluka in North Goa. It is a small coastal village located at the North western extremity of the state covering an area of about 1.43 km^2. It is the only village of Goa that is located across the river Tericol, at the scenic junction of the river with the Arabian Sea. It is located within the latitudes 15^{0}43'13"N and 15^{0}43'48.52"N and longitudes 73^{0}40'32.03"E and 73^{0}41'47.90"E (Fig.1). The region is shown on the Survey of India Toposheet No. 48 E 10/4 on 1:25000 scale. Goa Group of rocks consisting of Bicholim

Formation is exposed in the area. This formation is madeup of Quartz-Chlorite-Biotite Schist with layers of Chert and Iron oxides and is capped by thick but variable thickness lithomarge clay and a layer of laterite on the surface which are formed due to leaching of the basement rocks. There are few alluvial sand deposits along the southern side of the area.

The second study area is located in Satarda village about 13 km upstream of Tericol, in the Vengurla taluka of Sindhurg District, Maharashtra. It is bounded on the southern side by Tericol River and forms a part of its basin. The area is bounded between latitudes N15°44'21.42" and N15°45'18.91" (Fig.1) and longitudes E 73°47'26.48" and E 73°48'48.04" covering an area of 4.25 km^2. The area is covered by Dharwarian rocks represented locally by Banda group of rocks; dominantly made up of biotite garnet gneisses which are intruded by granitoid rocks. These are capped directly by laterites on the surface.

Fig.1 Location map of the two study areas

METHODOLOGY AND DATA COLLECTION

The Survey of India toposheets on 1:25000 were used as a primary reference to create base maps of both the study areas. Also Google satellite images were used to get the latest real-time information of the areas. All the necessary details such as drainage, roads, ground elevation contours, settlement areas were traced on the base map using AutoCAD. After a detailed study of the topography and land-use pattern, sites for carrying out the 'Vertical Electrical Soundings' (VES) were selected in random manner based on the space available for lateral extension. Reconnaissance survey of both the study areas were carried out with the help of the base-map and *Garmin Oregon 550* GPS (Global Positioning System) to identify the spots in the field. It was observed that some of the planned sites were unsuitable due to lack of a continuous strip of land of at least 200m length. Therefore, the spots were relocated in the best possible manner. Their coordinates were noted and positions were corrected on the base map.

A microprocessor based AC resistivity meter (SERM-1) was used with the Schlumberger configuration for the purpose of this study. A maximum AB/2 separation of up to 100m was adopted in Tericol area and the readings were taken at every 5m interval whereas at Satarda AB/2 separation varied from 70-200m. Total of 16 VES surveys at Tericol and 14 VES including

1 RVES surveys were carried out at Satarda area. The location of the VES sites in the respective study areas of Tericol and Satarda are shown in Figs. 2(a) and (b).

In the Radial Vertical Electrical Sounding (RVES) an interesting property is that the maximum apparent resistivity ρ_a is recorded along the direction in which the electrical conductivity is maximum. This is known as the ***paradox of anisotropy*** and it occurs since the current density in the major axis direction is higher with the result that the potential difference ΔV directly under the measuring electrodes is also highest in this direction. Consequently, ρ_a which is equal to $K.\Delta V/I$ is also largest in this direction where K is constant and I is current. The ellipse of apparent resistivities is an indicator of anisotropy. Under laboratory conditions of measurement, λ is the coefficient of anisotropy, whereas under field conditions, a somewhat similar parameter may be obtained by taking the ratio of the semi-major and minor axis (a/b). This is called as coefficient of apparent anisotropy, λ_a, or coefficient of fracturing when the anisotropy is caused because of the presence of conductive joints and fractures.

When a radial sounding is conducted, the apparent anisotropy corresponding to the given value of AB/2 spacing may be determined. Thus a graph showing the variation of λ_a with the electrode spacing AB/2 can be drawn at various AB/2 spacing. This will be helpful in delineating zones of fracturing, intensity of fracturing, etc. This technique is useful in hard rock areas, especially in fractured gneisses, dolomites, igneous rocks as well as lime stones.

The study of the geoelectrical parameters Longitudinal Unit Conductance S, Transverse Unit Resistance T, Longitudinal resistivity ρ_l, Transverse Resistivity ρ_t and Anisotropy λ is an integral part of the analysis of the electrical sounding data and also is the basis of important graphical procedures for the interpretation of the electrical sounding curves. The parameters T and S are known as the 'DAR ZARROUK' parameters.

INTERPRETATION OF VES DATA

The apparent resistivity curves can take any basic shapes known as Q or DH (Descending Hummel), A (Ascending), K (Displaced Anisotropic) and H (Hummel) type depending upon the relative magnitudes of ρ_1, ρ_2 and ρ_3. However, in the field one obtains curves which are combinations of two or more of the above types. Thus to get better results automated interpretation is required.

In the present study, the data has been interpreted using two different computer softwares ATO (Zohdy) and IGIS VES 2.0. ATO is developed by the United States Geological Survey. This automated interpretation overcomes the geophysical problem of non-uniqueness in the interpretation besides saving time. Multilayer data can thus be interpreted accurately using this software which otherwise is not possible by master curve method. The software **IGIS VES 2.0** is developed by Integrated Geo Instruments and Service Pvt Ltd. (IGIS), Hyderabad and uses the concept of inverse slope method to determine the true resistivity and layer thicknesses. This method has some advantages over the manual and other inversion techniques since it uses linear scale for plotting the data.

The plots of selected VES for the two study areas are given in Figs. 3(a) and (b) respectively for Tericol and Satarda areas

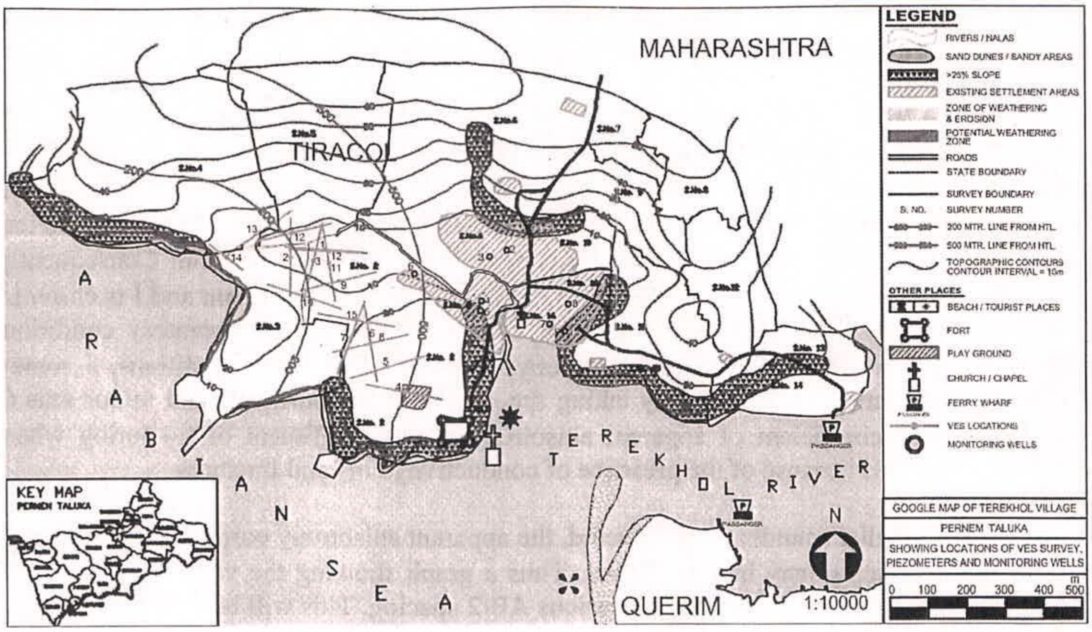

Fig. 2(a) Location of VES sites at Tericol study area

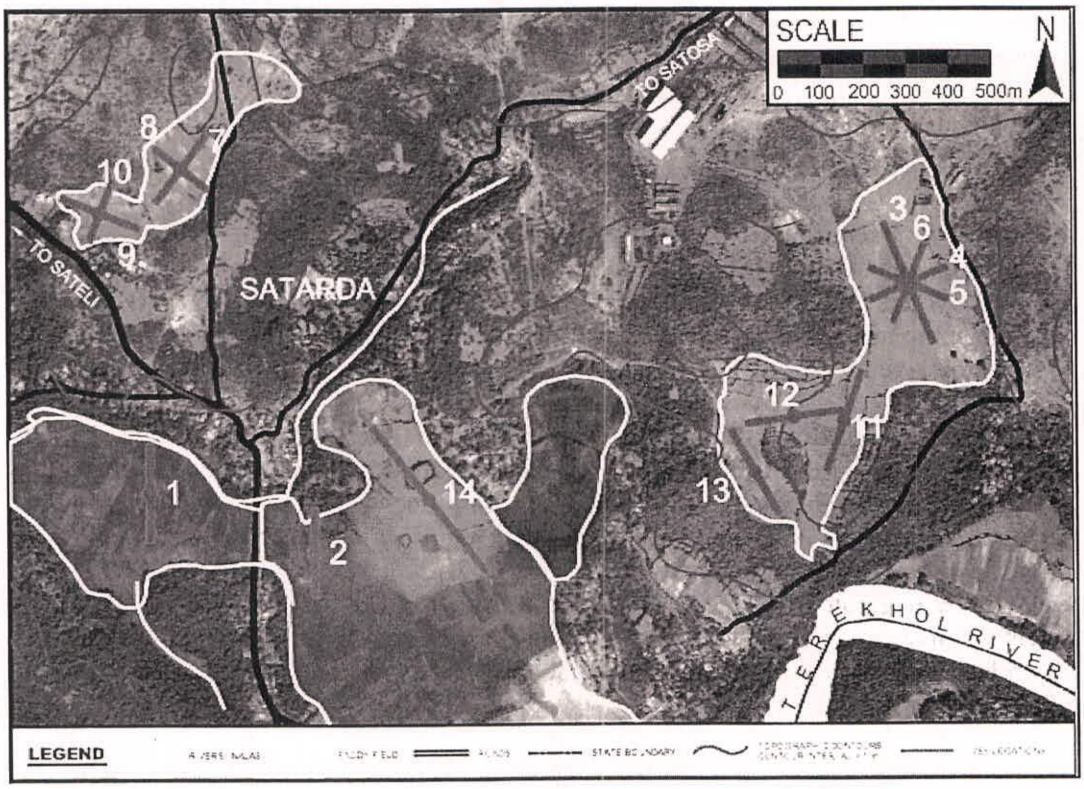

Fig. 2(b) Location of VES sites at Satarda study area

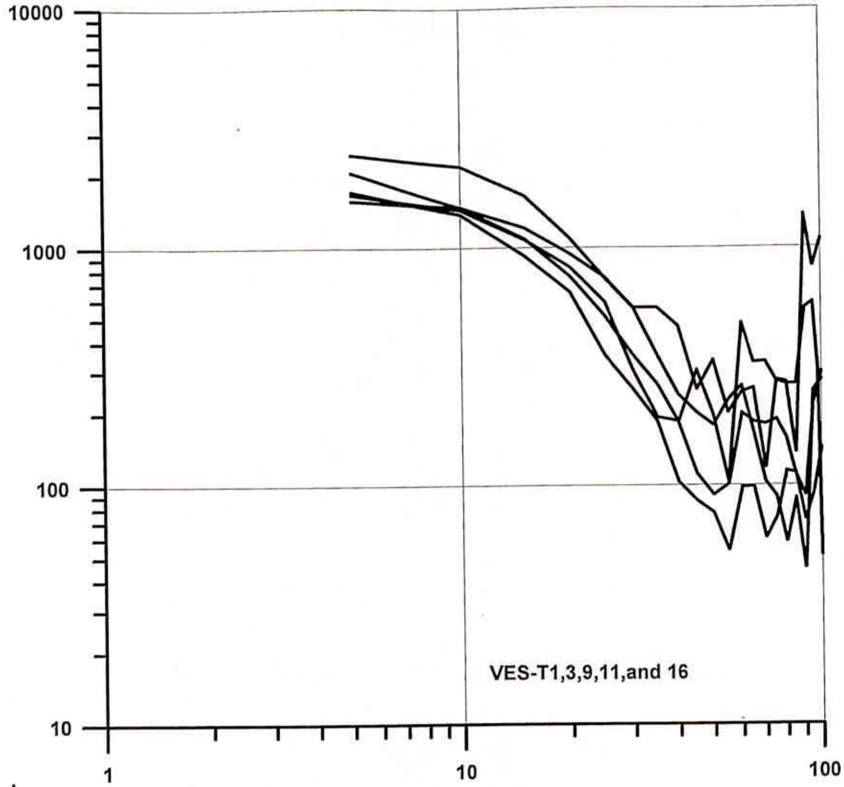

Fig. 3(a) The traces of the typical VES curves for Tericol Area

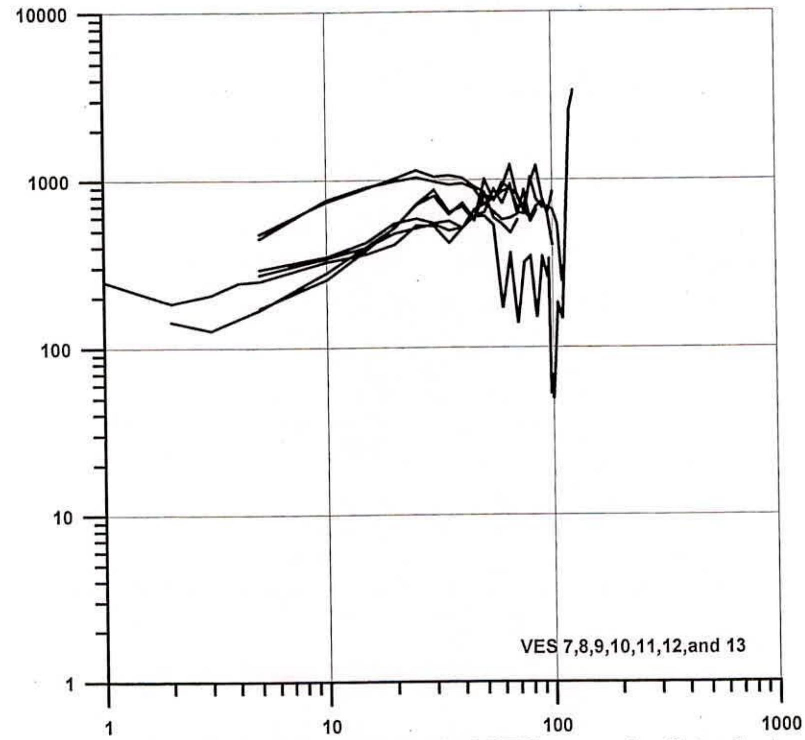

Fig. 3(b) The traces of the typical VES curves for Satarda Area

The example of interpreted VES curves using ATO (Zohdy) software for Tericol and Satarda are given in Figs. 4(a) and (b) respectively.

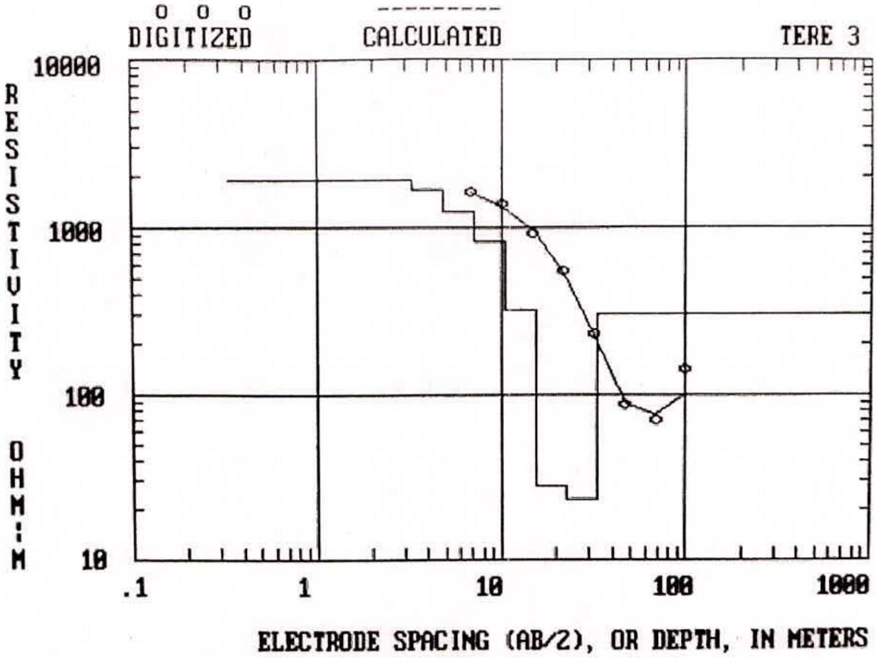

Fig. 4(a) Interpreted VES curve for Tericol

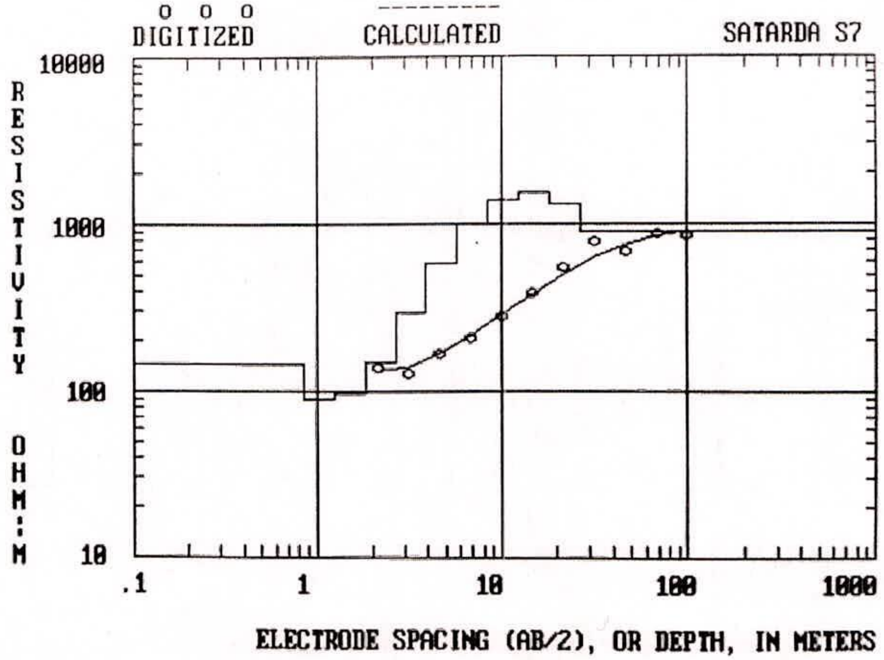

Fig. 4(b) Interpreted VES curve for Satarda

The interpretation of the VES data from both the study areas indicate that the lithology at Tericol is made up of hard laterite at the top which merges with soft laterite and then into lithomarge clay. The junction of the clay and basement rock is made up of a variable thickness fractured and saturated zone. Where as at Satarda area the laterite becomes hard and hard with depth as seen from continuous increase in apparent resistivity with AB/2 distance and there is no clay layer between the basement rock and the laterite. The aquifer at the junction of the basement rock and the laterite is almost absent in Satarda study area unlike at Tericol where a thin fractured aquifer exist at depth above the basement rock. The water saturated zone is encountered between 50m to 90m below ground at Tericol where as such water saturation zone is almost absent in Satarda area. Although the source rock of laterisation in the both the study areas are same the absence of intervening clay layer Satarda seems to open further study aspects.

Radial Vertical Electrical Sounding (RVES)

The inhomogeneity in the subsurface layers plays an important role in hydrogeological investigations. The inhomogeneity may be the result of fracturing, preferential weathering and variation in the depositional pattern, palaeo-channels, etc. For determination of the orientation of rock inhomogeneity and aquifer depth and thickness, Radial Vertical Electrical Sounding (RVES) needs to be conducted. In the present study, an AB/2 distance up to about 100m was adopted using the Schlumberger arrangement to collect the apparent resistivity data. The polar diagrams were prepared by plotting the apparent resistivity values along different azimuths for AB/2 separation of 5-25m, 30-40m and 45-100m for the Radial I (Figs. 5 a, b, and c). The coefficient of apparent anisotropy λ_a is then determined by taking the square root of the azimuthal ratios of maximum ($\rho_{a\ max}$) and minimum ($\rho_{a\ min}$) apparent resistivity values at a given AB/2. For an isotropic media, the $\lambda_a = 1$. Values of λ_a varies with the variation in the anisotropy. The anisotropy factor λ_a is calculated for different AB/2 as shown in Table 1.

Table 1 Coefficient of apparent anisotropy from RVES at Satarda

AB/2 (m)	N23^{0}W	N67^{0}E	N67^{0}W	N23^{0}E	$\lambda_a = \sqrt{\rho_{a\ max}} / \rho_{a\ min})$
	ρ_a (Ωm)	ρ_a (Ωm)	ρ_a (Ωm)	ρ_a (Ωm)	
5	24	5	11	30	2.5
10	574	8	18	43	2.7
15	26	14	31	27	1.5
20	26	46	41	51	1.4
25	25	28	38	35	1.2
30	43	59	49	52	1.2
35	46	96	67	61	1.4
40	29	141	109	80	2.2
45	342	52	157	201	2.6
50	223	183	82	178	1.7
55	38	202	233	327	2.9
60	899	50	195	154	4.3
65	1057	603	713	733	1.3
70	665	177	248	482	1.9
75	1070	660	805	923	1.3
80	1400	925	906	983	1.2
85	618	422	529	642	1.2
90	885	783	838	846	1.1
95	654	782	824	864	1.2
100	1472	982	1184	1246	1.2
				Average Anisotropy	1.8

From the plots of the RVES data it is found that the lithology in the area is anisotropic and the direction of anisotropy varies with depth. Between 5-25m depth the direction of major axis of the regular polygon obtained by joining resistivities of same AB/2 at different azimuths was at N23^{0}E (Fig. 5(a)). Between 30-40m depth, the direction changed to N67^{0}E as seen in Fig. 5(b). Whereas between 45-100m depth range, the direction of anisotropy changed to N23^{0}W (Fig. 5(c)).

Each change in direction of anosotrophy also is marked by a distinct change in the apparent resistivities. This change in the direction of anisotropy in the same alluvium probably is indication of the depositional environments of the alluvium.

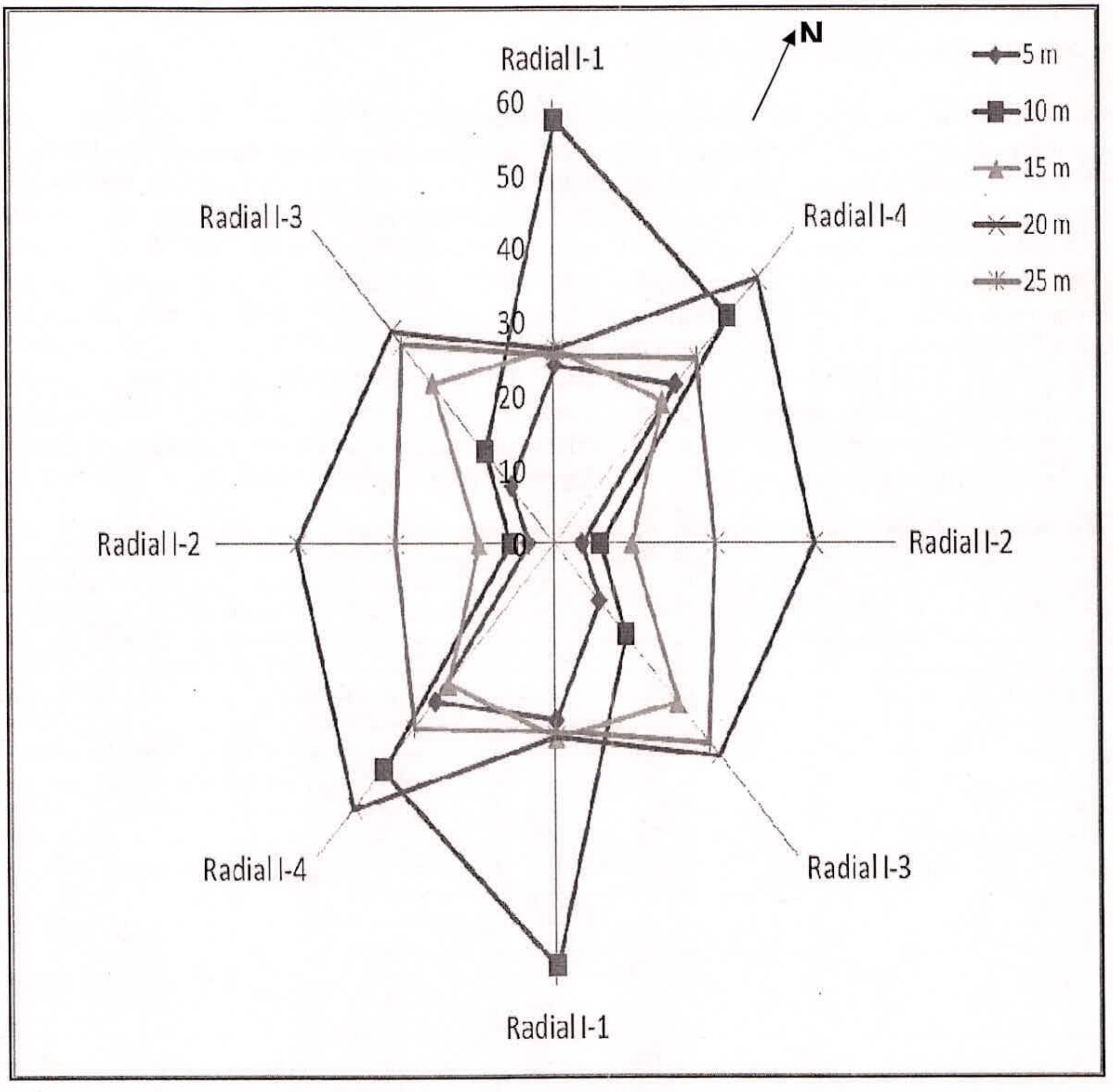

Fig. 5(a) Polar diagram of RVES-I for AB/2 between 5-25m

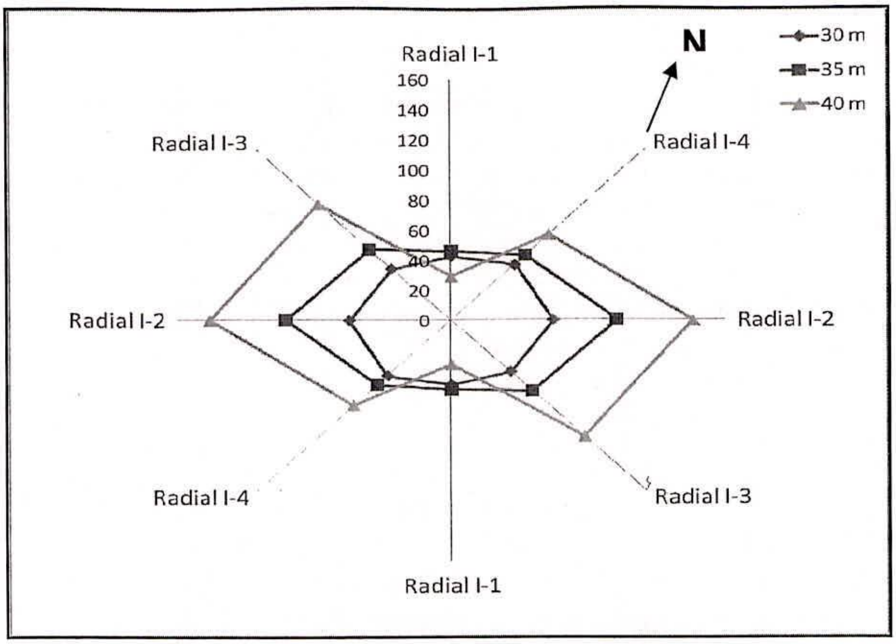

Fig. 5(b) Polar diagram of RVES-I for AB/2 between 30-40 m

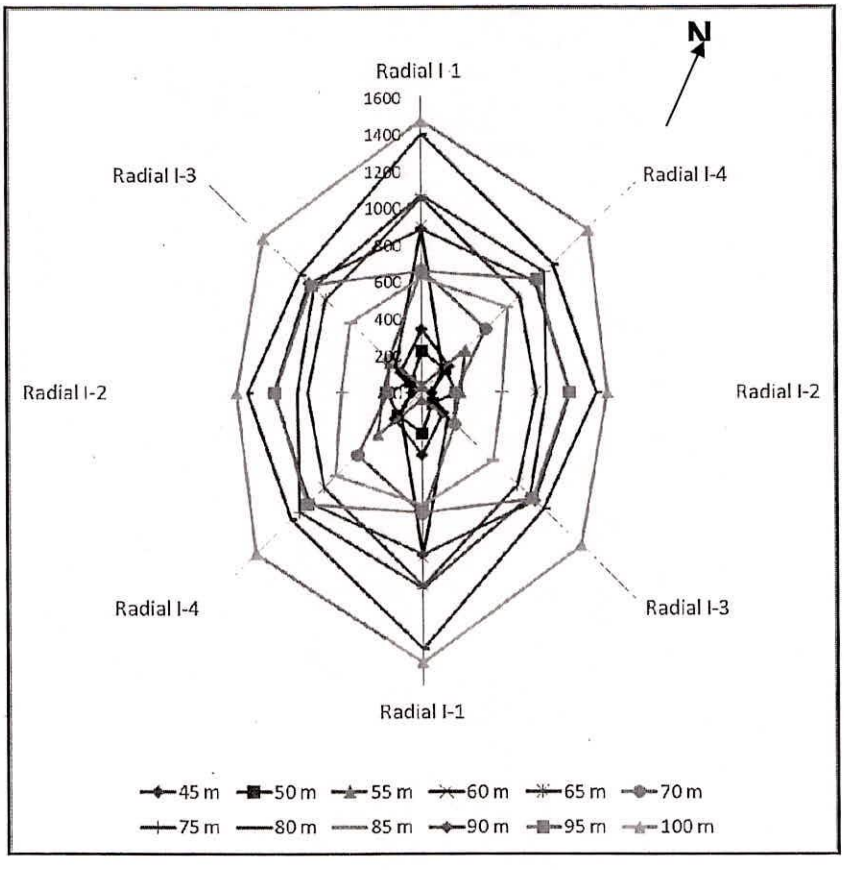

Fig. 5(c) Polar diagram of RVES-I for AB/2 between 45-100 m

CONCLUSION

The laterisation in the Konkan coast has been subject of debate even today. The laterites are highly variable in their thickness, composition and lithological disposition and hence their water bearing properties. Present study has clearly shown that some laterites are gradually becomes soft with depth and merge in a thick sequence of lateritic lays before they terminate on weathered and fractured basement rocks Whereas in other locations laterite become more compact and hard with depth and abruptly end on to the fresh and unweathered basement rocks. The groundwater is generally found at the contact of clay and weathered and fractured basement rocks. The laterites are anisotropic in nature and form shallow water table aquifers at low lying favorable topographic conditions.

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