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Geoelectrical Investigation of Subsurface Geology and Groundwater Occurrence in a Coastal Tableland

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Abstract: *Geo-electrical methods are often used to understand the subsurface geological formations and to locate groundwater potential zones. The main objective of the study was to understand the subsurface geology and groundwater occurrence in one of the coastal tablelands of Goa. Vertical Electrical Soundings (VES) were conducted at various sites in the study area using Schlumberger configuration. The data obtained was used to determine the resistivity and thickness of the subsurface geological formations, and to understand the occurrence of groundwater within the study area. The results reveal layered lithological formations and occurrence of a confined aquifer within the fractured basement and indicate presence of a perched aquifer in certain parts of the study area.*

Keywords: *Vertical electrical sounding (VES), Groundwater, Aquifer, Subsurface geology.*

1. Introduction

The State of Goa consists of coastal low lying plains along the west, the elongated ridges in the central region and high hills of the Western Ghats in the east. The coastal region consists of sandy beaches and alluvial mudflats separated by prominent tablelands. These tablelands are generally made up of flat-topped elevated landmass of about 40-80m height above mean sea level. They are covered with hard, massive laterite on the flat portion and detrital laterite on the slopes. These detrital laterite are the transported masses of massive laterite which are embedded in lateritic soils. The laterite varies in thickness from 5m to more than 30m and these are underlain by a thick sequence of lithomarge clay. The ground water in the fractured aquifer under the coastal plateau is often found below mean sea level.

The laterite located on the plateaus does not generally form aquifer because they cannot hold water due to their topographical settings. The lithomarge clay is dominantly impermeable although it can store and vertically transmit some quantity of water. Whenever rainwater percolates the porous and fractured laterite the water moves along the contact zone between the underlying low permeable lithomarge clay and the bottom of the overlying laterite to emerge as contact spring along the slope. Plateaus are separated from each other by coastal plains and tidal flat. In North Goa there are plateaus namely Keri-Pernem Plateau, Mapusa Plateau, Porvorim-Pilerne Plateau and Taleigao-Bambolim Plateau (Nadkarni *et al*, 2012). It is observed that in recent decades the industrial activities and human settlements have increased tremendously on these plateaus. Thus there is an increasing demand for water resource. This has lead to exploration of groundwater through different techniques on these plateaus.

In order to understand the subsurface geological setup and groundwater occurrence in Taleigao plateau near Panjim, a detailed geo-electrical investigation has been carried out. The data has been verified using available borehole data.

2. Location of the Study Area

The study area, Taleigao plateau, lies in the Tiswadi taluka of North Goa district. The study area is an east-west trending elongated plateau. The Arabian Sea lies to the west of the study area while to the South of the study area lies one of the main river of Goa i.e. Zuari river. The villages surrounding the study area are St.cruz, Taleigao in the North and Cacra, Navshi and Odxel in the south. The elevation of the area is 50-60m above mean sea level. The area is represented on Survey of India (SOI) toposheet number 48E/15/NW-A2 on 1:25000 scale. The study area lies between Latitudes 15° 25' 30"N and 15° 29' 30"and Longitudes 73° 47' 30" and 73° 52' 30". The Goa University campus located on this plateau has an area of 1.6302 km^2. The location of the study area is shown in **Figure 1.**

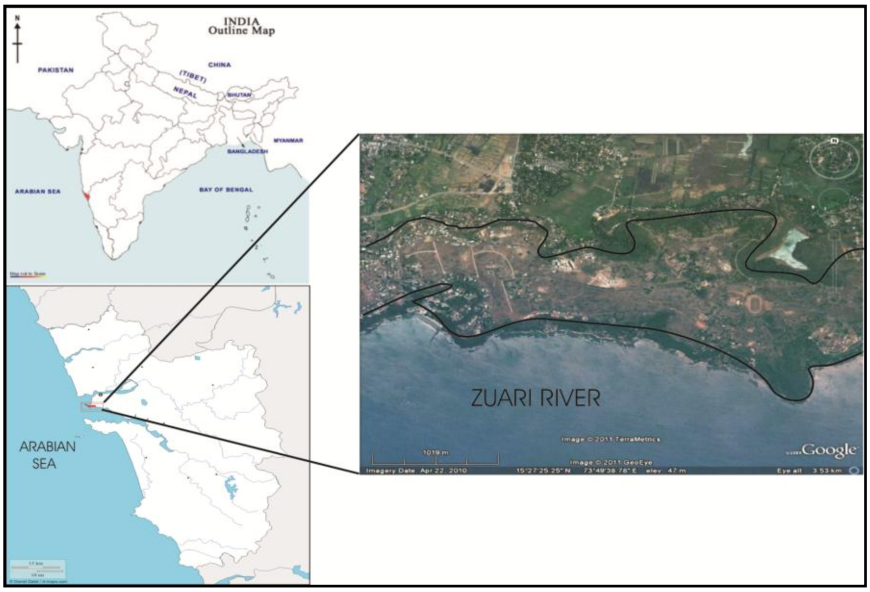

Figure1. *Location of the study area*

3. Hydrogeology of Goa

Goa in general is covered by Peninsular Gneissic Complex of Archean age and the Goa Group of meta-sedimentary and meta-volcanics rocks. These are intruded by mafic - ultramafic complexes and granites, and overlain by Deccan traps, laterites and beach sands. The laterites are the most important water bearing formations of Goa. They are developed either *in situ* in plateau area or are of detrital origin, which are generally occupying valley portions. Besides inherent porosity some of the laterites are highly jointed and fractured which influence their water bearing capacity. The topographic setting of laterites mainly controls its groundwater potential and occurrence.

The laterites in the plateau generally lack water table while those in the low lying area form potential water table aquifers. Irrigation dug wells tapping laterites generally range in depth from 3m to 10m and the depth of water level varies from 1m to 7m below ground level (bgl). Groundwater occurs under water table condition.

4. Local Geology

The study area comprises of rocks of Sanvordem Formation of Goa Group of rocks, which are equivalent to Chitradurga Group of Dharwar Supergroup (Gokul *et al*, 1985). Sanvordem Formation which forms the basement consists of argillites, quartzites and metagreywackes. The laterites are extensive and almost completely cover most of the study area. The basement rocks are exposed seldom, that too, only along the coastal boundary of the study area.

5. Methodology and Field Data Collection

Locations for Vertical Electrical Sounding (VES) were selected using toposheet. Microprocessor based (AC) Resistivity meter (SERM 1) was used to carry out the VES. This resistivity meter calculates and displays the resistance (R) and apparent resistivity (ρ_a). Didger software was used for preparation of base map and plotting the locations of VES. Five VES surveys were conducted in the pre-monsoon season and nineteen VES surveys were conducted in the post monsoon season. A total of 24 VES surveys were carried out. A total of 11 litholog data was collected from WRD, PWD, CGWB, PHE and Goa University; their locations are shown in **Figure 2**.

After the completion of all the surveys, the VES locations were transferred on the base map. The locations of the VES conducted are shown in **Figure 2**. This data was then plotted on a log-log graph paper of 62.5mm size with distance AB/2 along the X-axis and the apparent resistivity (ρ_a) along the Y-axis. Using a standard set of curves the interpretable data sets were manually interpreted. The results obtained were correlated with the different strata of corresponding resistivities and with the available litholog data. The different layer parameters were then utilized to calculate the geo-electrical parameters such as Longitudinal Unit Conductance, Transverse Unit Resistance, Longitudinal Resistivity, Transverse Resistance and Anisotropy.

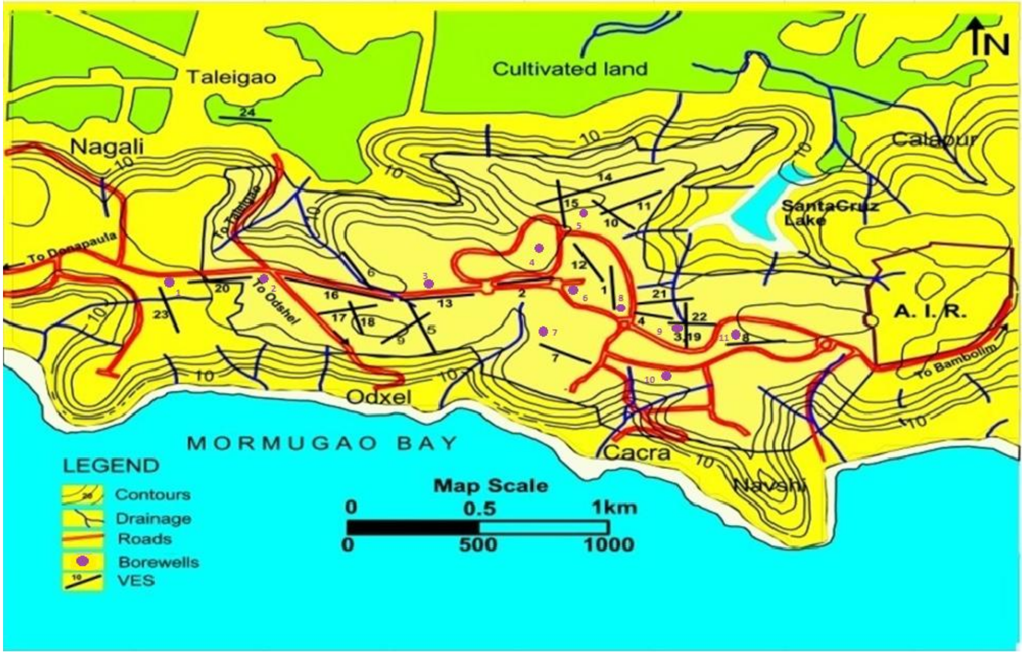

Figure2. *Base map with VES and Borehole locations*

6. Vertical Electrical Sounding

The geo-electrical survey requires the measurement of potential difference in the ground between suitably implanted electrodes. The important physical properties of the rocks for electrical surveying are the permeability and the resistivity (or conductivity) on which several techniques are based. The resistivity of rocks is strongly influenced by the presence of ground water and its quality which acts as an electrolyte besides rock matrix. For example, due to the good electrical conductivity of ground water the resistivity of a sedimentary rock is much lower when it is water saturated than in dry state. The minerals that form the matrix of a rock are generally poorer conductors than ground water; so the conductivity of sediments increases with the amount of ground water and dissolved salts it contains. The conductivity of a rock is proportional to the conductivity of the ground water, which itself is quite variable because it depends upon the concentration and the type of dissolved minerals and salts.

In the present study Vertical Electrical Sounding has been conducted using Schlumberger configuration, which has the capacity of deeper penetration. The AB/2 spacing of 5m was maintained throughout the survey and a maximum AB/2 of 200m was used for the survey. The MN/2 spacing was 1m to start, which was later increased to 2m at AB/2 of 25m, 3m at AB/2 distance of 50m and 4m at AB/2 distance of 75m.

7. Manual Interpretation Using Type Curves

Curve matching technique was used in the interpretation of VES. Out of the 24 VES conducted, graphs of 8 VES were matched with the two layer master curves and graphs of 3 VES were matched with three layer curve. The results of the same are shown in Table 1 and 2**.** VES curves that were interpreted using two layer master curves are shown in Figure 3.

Table1. *Interpreted layer parameters for two-layer VES curves*

VES No	ρ_1 (Ω m)	ρ_2 (Ω m)	h_1 (m)	h_2 (m)
VES 3	1100	157.3	15	∞
VES 4	490	205.8	11	∞
VES 6	950	190	14	∞
VES8	1100	220	14	∞
VES9	700	140	14	∞
VES19	1050	210	14	∞
VES22	1100	220	14	∞
VES 24	125	187	2.4	∞

Table2. *Interpreted layer parameters for three-layer VES curves.*

VES No	ρ_1 (Ω m)	ρ_2 (Ω m)	ρ_3 (Ω m)	h_1 (m)	h_2 (m)	h_3 (m)
VES 5	1400	140	∞	11	55	∞
VES 14	2800	280	∞	9	27	∞
VES 16	40	200	∞	14	42	∞

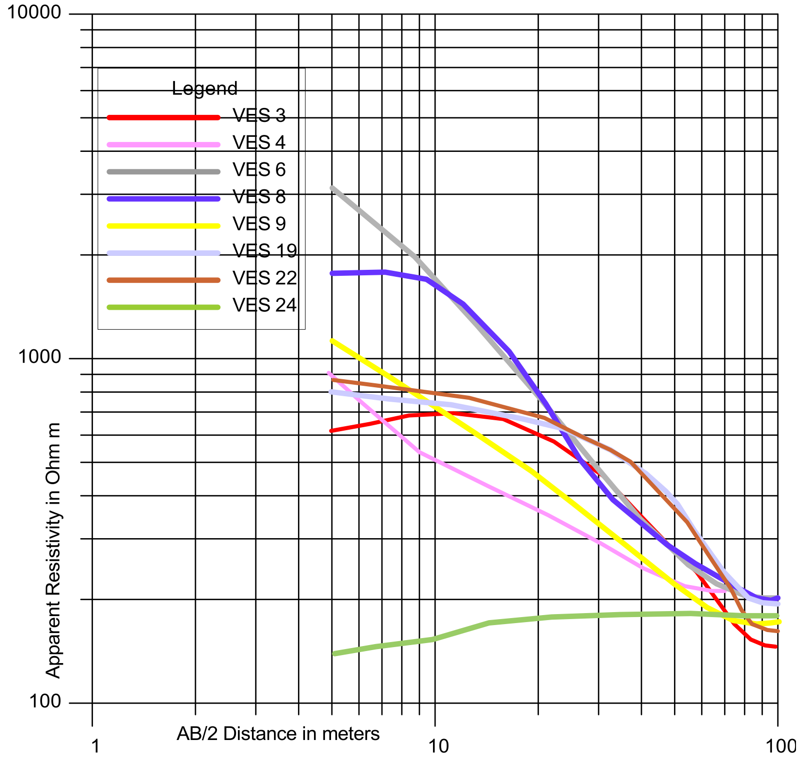

Figure3. *VES curves that were interpreted using 2-layer master curves*

8. GEO-ELECTRICAL PARAMETER ESTIMATION

The data from Table 2 was used to compute five different geo-electrical parameters. These include longitudinal unit conductance (S), transverse unit conductance (T), longitudinal resistivity (ρ_L), transverse resistance (ρ_t) and anisotropy (λ). These five parameters were determined for only those VES points which were interpreted manually.

1) Longitudinal Unit Conductance, $S_1 = h_1/\rho_1$ mho
2) Transverse Unit resistance, $T_1 = h_1 \times \rho_1$ Ω m^2
3) Longitudinal Resistivity, $\rho_L = h_1 / S_1$ Ω m
4) Transverse Resistivity $\rho_t = T_1 / h_1$ Ω m
5) Anisotropy, $\lambda = \sqrt{\rho_t/\rho_L}$ Dimensionless

The average longitudinal conductance (S) was calculated by using the following formula,

$S_1=h_1/\rho_1$, $S_2 = h_2/\rho_2$, $S_3 =h_3/\rho_3 \ldots Sn = h_n/\rho_n$

Similarly the average transverse unit resistance (T) was calculated by using the formula,

$T1 = h_1\times\rho_1$, $T_2 = h_2\times\rho_2$, $T_3 = h_3\times\rho_3 \ldots T_n = h_n \times \rho_n$,

The average longitudinal conductance (S) and the average transverse unit resistance (T) were used for calculation of average longitudinal resistivity (ρ_L) and the average transverse resistivity (ρ_t) using the formula, ρ_L= H/S and ρ_t = T/H, where 'H' represents the total thickness of the geo-electrical column.

The anisotropy (λ) was then calculated from the ρ_1 and ρ_t using the formula

$\lambda = \sqrt{(TS)}/H$. The computed values are shown in Table 3.

Table3. *Calculated Geo-electrical Parameters of VES stations*

VES No	Total Longitudinal Conductance (S) mho	Total Transverse Resistance (T) Ohm-m^2	Average Longitudinal Resistivity (ρ_L) Ohm-m	Average Transverse Resistivity (ρ_t) Ohm-m	Anisotropy (λ)
VES 05	0.4006	23100	164.75	350	1.45
VES 14	0.0996	33600	361.44	933	1.60
VES 16	0.56	8960	100	160	1.26

Note: *It is seen from the above table that the geological formation is moderately anisotropic*

9. Results and Discussion

The Vertical Electrical Sounding data gathered were analyzed by curve matching technique. The results of the interpreted Vertical Electrical Soundings indicate presence of a confined aquifer in the study area. The confined aquifer is present in the fractured basement rocks which belong to the Sanvordem formation. The general trend seen in all the readings was that there was general decrease in the apparent resistivity readings and a sudden drop of resistivity seen whenever aquifer was encountered. Total 11 VES readings were used to interpret using type curves. It was observed that VES readings give fairly realistic modal of the subsurface.

Based on the geo-electrical survey, the area has been divided into two blocks, the western block and the eastern block. It was observed that in the eastern block the curve shows a drop in the resistivity reading at a depth range of 80-90m. VES 7, VES 8 and VES 22 show a drop in the resistivity reading at depths of 80-90m. This indicates the presence of confined aquifer at the depths of 80-90m. Similar trend was seen in most of the readings taken in the eastern block.

In the western block, a different scenario was seen in the trends of the VES curves. Along with the drop in the resistivity readings seen at depth ranges of 80-90m there was another drop seen which was at a depths of 55-65m. Three VES curves plotted i.e. VES 5, VES 6 and VES 9 show two drop in the resistivity readings one in the range of 55-65m and second drop in the range of 80-90m. Most of the readings plotted from the western block showed similar trend with two drops. During the investigation two boreholes were drilled in the study area which confirms the presence of a perched aquifer in the eastern block at a depth of 55-65m. This perched aquifer might be present in the form of a lens as it is encountered only in certain areas.

In addition to this, a geo-electrical section was prepared and were compared with the nearest available litholog data**.** A fair degree of accuracy was obtained in the correlation of the geo-electrical section and the litholog data shown in Figure 4. The geo-electrical sections and borehole data indicates varying thickness of laterite and undulating nature of the basement. VES which were conducted with AB/2 distance of 200m shows general trend of decrease in the apparent resistivity up to a depth of approximately 90m, then there is increase in the readings which corresponds to compact basement rock below the confined aquifer. With the help of the data from Table 2, a geo-electrical cross section has been prepared and is shown in Figure 5**.**

Figure4. *Correlation of the geo-electrical section with litholog data.*

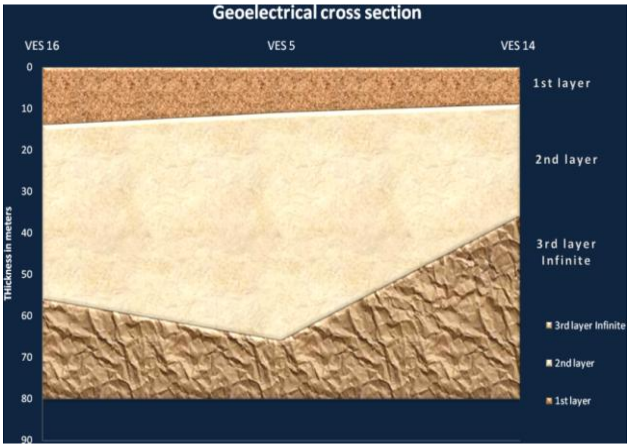

Figure5. *Geoelectrical cross section*

10. CONCLUSIONS

The outcrops of the laterite exposed in the study area are generally hard and compact in nature and are very difficult formations to conduct electrical surveys. The VES data collected from the study area has indicated some important aspects; the general subsurface lithology in the tableland is made up of top lateritic layer of variable thickness. This lateritic layer is underlain by a thick layer of clays of various compositions as indicated by varying colors in the borehole logs. The basement topography is non horizontal that is the surface of the basement rock is very much undulating in nature. The contact zone of basement rock and the clay horizon is made of weathered and sometimes fractured basement rock which forms the major confined aquifer in the area. This can be seen in the form of sudden fall in the resistivity values at these depths. The thickness of this weathered and fractured layer is variable and is generally less than 2m in thickness.

In the western part of the tableland the presence of gravelly bed is detected at depths varying from 40m to 70m below ground. This gravelly bed is discontinuous and is composed of quartz pebbles and sand. Sometimes perched water is present in this layer. This phenomenon is not witnessed in the eastern parts of the study area.

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