Groundwater potential estimation using Vertical Electrical Sounding measurements inMogral river basin, Kasaragod district, Kerala.

Gopinathan Nair A., Manoharan A.N., Suraj P.R.
Department of Geology, Government College Kasaragod
Mohammed Aslam M. A. (Corresponding Author)
Department of Geology, Central University of Karnataka, Kalaburagi.

Abstract:-Vertical Electrical sounding was conducted in Mogral river basin for the detection of water bearing rock layer under the surface.The VES analysis provided a general sequence of high resistivity in the first layer consisting of hard laterite/dry lateritic soil followed by low resistivity layer (porous laterite) and bottom layer of moderate to high resistivity (weathered/fractured crystalline rock to massive crystalline rock). Most of the sounding curves obtained in the basin were of Q type. The resistivity value of the first layer (ρ1) of the river basin varied from 275 ohm-m at Mogral Kadavu to a highvalue of 9494 ohm-m at Kollya. The resistivity value of the second layer (ρ2) varied from 6.31 ohm-m at Mogral Kadavu to 3802 ohm-m at Chathapady. The resistivity value of the third layer (ρ3) showed a range from 2.2 ohm-m at Mogral Kadavu to 6968 ohm-m at Bovikkanam. This indicated the variation of third layer from weathered and fractured crystalline rocks to massive crystalline rocks. Comparatively higher resistivity value of third layer at places like pady 2 and Bovikkanam indicated massive hard rocks. The thickness of the third layer could not be determined, as it represented the basement rock. In the midlands and the lowlands of the basin the dominant phreatic aquifer is laterite. The clayey sand which forms the second layer is the dominant aquifer in the coastal area.

Key words: -Mogral river basin,Ohm's law,Vertical Electrical Sounding,Schlumberger array

1 Introduction

The study of quality and availability of groundwater has become a major concern and primary need for our society. A number of methods, ranging from water witching to the hydrogeological and geophysical methods, are practiced for the investigation of subsurface water. The geophysical techniques are widely applied, because of its reliability and advances in computer software, all over the world for groundwater exploration. The geophysical investigation combined with surface hydrogeological observations provides excellent information on groundwater occurrence in an area.

The physical properties of different objects of the earth, with respect to electrical, gravitational and magnetic characters, are not uniform at many places. The geophysical differences or anomalies are taken as the criteria for the detailed study. These anomalies can be measured or quantified by various geophysical techniques. Geophysical methods are very useful in assessing the groundwater potentiality of geological formations, estimating thickness of weathered zone, depth to bedrock, fractures in hard rock terrain and delineating resistive granular zones in sedimentary formation and paleochannels (Uwamungu and Senthil, 2015). There are marked contrast in formations and physical properties of earth horizontally and vertically. This variability of physical properties are due to the variations in occurrence of groundwater is helpful in identifying and delineating the groundwater potential formations. The groundwater occurs within the fracture, joint and weathered zones of a formation. The size of such structures and their interconnectivity determine the groundwater yield (Chandra et al., 2004).

2 Methodology

Apparent resistivities from 38 locations of the study area were determined by electrical resistivity method using Schlumberger array. In this survey, electric current was passed through a pair of steel current electrodes to the terrain and the drop in potential was measured across a couple of potential electrodes. The depth of penetration of electric current is related to the spacing of the electrodes. At each arrangement, an apparent resistivity was determined on the basis of the measured potential drop, the supplied current and the gap between electrodes. Sequences of measurements were done for depth profiling or vertical electrical sounding (VES). The apparent resistivity values were plotted against half current electrode spacing AB/2 and deduced sub surface layers using computer software. The resistivity curves of each location were drawn with the aid of software IPI2 WIN and from

which resistivity and thickness of deduced layers were prepared.

3 Electrical resistivity methods

The electrical resistivity method is used to detect subsurface anomalies by the flow of electric current through the ground. This technique analyzes resistivity parameters of earth objects by measuring the resistance offered by various formations in the ground. This method has got potential applications in groundwater exploration, mineral exploration, geothermal exploration, permafrost mapping, engineering studies and geological mapping (Abdullahi et al., 2014). Electrical resistivity methods are largely conducted for both regional and detailed surveys for the exploration of groundwater on behalf of their better resolving powers, low cost and vast range of applications in the field (Balakrishna et al., 1978; Chandrasekhran, 1988; Asfahani, 2013; Raju, 2014). Electrical resistivity surveys of underground terrain have been applicable to infer the thickness and resistivity of formation for evaluating groundwater potential and for pointing boreholes in fractured confined aquifers (Muchingami et al., 2012).

Many of the rocks resist the flow of current in them. The resistivity of an aquifer is controlled by the quality of water in them, porosity and permeability of the aquifer and the temperature of the sub surface environment. Ideally, as porosity, hydraulic conductivity, water content and water salinity of a formation increases the resistivity decreases. Resistivity of clay and shale are relatively lower compared to saturated sand and gravel. The electrical resistivity of weathered rocks commonly varies with depth(Mallick and Roy, 1968; Koefoed, 1979). The rock formations saturated with water having high ionic strength are characterized by very low resistivity value (Gilkeson and Wright, 1983).The resistivity values of different materials including rocks, alluvium, sand, clay and water has shown in Table 1.

Table 1 Resistivity values of different materials

Material)	Resistivity (Ω m)
Alluvium	10 to 800
Sand	60 to 1000
Clay	1 to 100
Groundwater (fresh)	10 to 100
Sandstone	$8 - 4 \times 10^3$

Shale	20 -2 x10^3
Limestone	50 – 4 x 10^3
Granite	5000 to 1,000,000

(Keller and Frischknecht, 1996)

3.1 Basic principles

The electrical resistivity method is based on Ohm's law. The law states that the current (I) passing through a conductor is directly proportional to the voltage (V) applied across it and inversely proportional to the resistance (R) of the conductor (Equation 1).

$$I = \frac{V}{R} \qquad (1)$$

Where, R is measured in ohms, I in amperes and V in volts. The resistance R depends on the length and thickness of a conductor. Resistance decreases with area of cross section (A) and increases with the length (L) of the material (Equation 2).

$$R = \rho \frac{L}{A} \qquad (2).$$

Where, ρ is the electrical specific resistance (ohm-m), a characteristic of the material through which current flows.

The earth's materials are not homogeneous and it varies along depth as well as laterally in a terrain. Hence the resistivity values obtained by passing current through the ground are not the true resistivity. That is, the resistivity value measured at the surface of the earth is the apparent resistivity and its measurement along depth by electrical resistivity survey is known as vertical electrical sounding (VES). In VES direct current is introduced into the ground by means of two current electrodes (AB). The current induces a potential difference due to the resistance offered by the formation of earth. This induced potential between any two points is measured by another set of electrodes (MN) (Figure 1). If a potential difference ΔV is measured for a known current (I), the apparent resistivity ρ_a of the earth section can be computed by the following relation (Equation 3)

$$\rho_a = K \frac{\Delta V}{I} \qquad (3)$$

Where, K is the geometric (spacing) factor which depends upon the electrode configuration.

3.2 Schlumberger array

The current effectively penetrates to a depth that is generally 20–40 % to that of the spacing of outer current electrode (AB) and dependent on the earth resistivity in VES method by the Schlumberger array (Edwards, 1977). The electric current is made to flow deeper and deeper sections of the formation by fixing current electrodes wider from the center of the array, after each measurement. At the same time, the position of the potential electrodes has to be increased along with the increase in gap between the current electrodes. This is needed to keep the detection of voltage above the noise level. VES is useful in ascertaining the thickness of overburden as well as thickness and resistivity of subsurface formations (Telford et al., 1990).
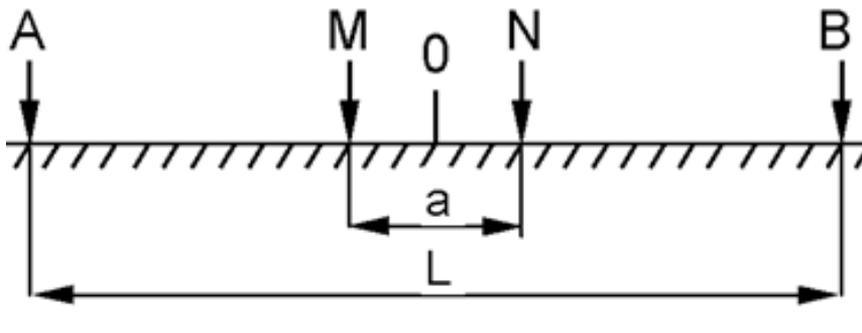
Figure 1 Electrode configurations for Schlumberger array.

4 VES in Mogral river basin

A total of 38 VES were conducted in Mogral river basin using the Schlumberger array with maximum current electrode spacing of AB/2 = 100 m to obtain values of resistivity and thickness of different sub surface formations (Figure 2). The apparent resistivity data derived from VES survey was plotted against half of the current electrode spacing (AB/2) using IPI2WIN software. It was used to interpret curves of resistivity sounding by curve matching technique.

This involves the analysis of field curve and the matching theoretical curve. The thickness and resistivity of the geophysical layers were computed. The nature of VES curve of each location varies with apparent resistivity (ρ_a) and thickness of the geoelectric layers and total depth of passage of current (Maitra and Ghose, 2008). The geoelectrical layers may be corresponding to the geological set up of the region.The sounding curves terminate on higher resistivity layer indicate the basement rock (Mohammed-Aslam et al., 2010). A three layered model consisting of compact laterite at the top, porous laterite at the middle and fractured to massive basement rock formation at the bottom was inferred from the field data.
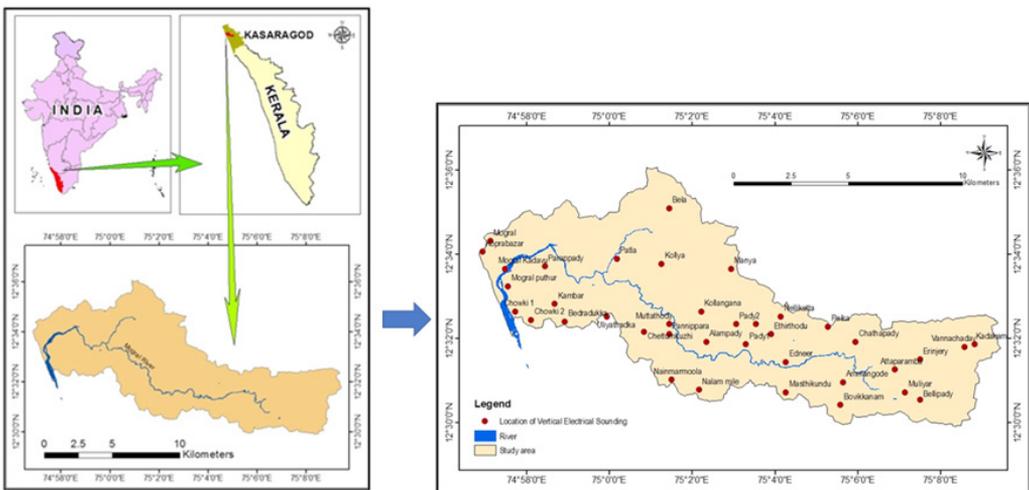
Figure 2 Locations of VES conducted in Mogral river basin.

In a resistivity method, a typical two layer section may represent the area having a finite first layer and an infinite second layer. In two layer section either the resistivity of first layer is greater than the second layer ($\rho1 > \rho2$) with an ascending type curve or vice-versa with dissenting type curve. In a three layer section, of different combinations of resistivity distributions (Table 2), four type curves are possible (Zohdy et.al.,1974).

Table 2 Types of resistivity curves

Resistivity distribution	Types of curves
$\rho1<\rho2<\rho3$	A type
$\rho1>\rho2>\rho3$	Q type
$\rho1>\rho2<\rho3$	H type
$\rho1<\rho2>\rho3$	K type

A- Type curve is acquired in hard rock terrain with a thin layer of conductive top soil. Here the resistivity of layers continuously increases with depth. A type curves were not observed in the study area.

In areas where the resistivity of layers continuously falls with depth, Q types of curve were observed. Koprabazar, Mogral, Mogral Kadavu, Mogralputhur, Chowki 1, Chowki 2, Parappady, Bedradukka, Kambar, Muttathody, Kollya, Kollangana, Chettumkuzhi, Pannipara, Pady1, Nellikatta, Paika, Athrukuzhi, Edneer, Ammangode, Erinjery, Vannachadav and Bellipady regions of the study area exhibits profiles of this nature.

H type curves were obtained in terrains with a low resistivity layer of weathered or water saturated formations sandwiched between layer of high resistivity in the upper part and a hard rock with high resistivity at bottom part of a terrain. Patla, Bela, Naimarmoola, Alampay, Nalam mile, Pady 2, Masthikundu, Bovikanam and Kadakam have shown this type of curve.

The K type sounding curves show a high peak flanked by low resistivity values on either side. Such types of curves were seen in areas where massive layer of high resistivity between layers relatively low resistivity at top and bottom. Such types of curves are generally encountered in coastal areas where fresh water aquifer lying in between clay layer at the top and a zone of saline water in the bottom. In Mogral river basin the K type curve is due to the presence of hard laterite, which has comparatively high resistivity, between layer of top laterite soil and weathered crystalline rocks . K type curves were found at Uliyathadka, Manya, Ethirthodu, Chathapady, Muliyar and Attaparamba.

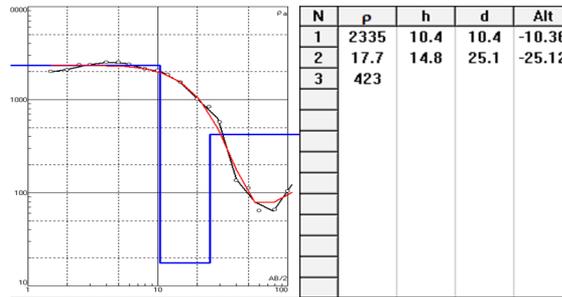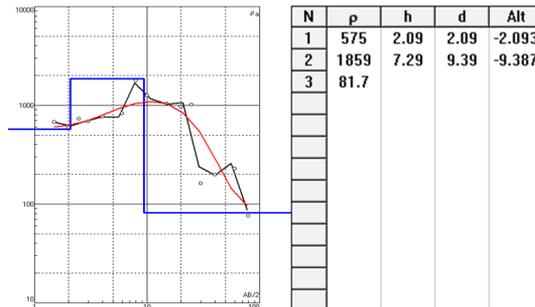In a four layer conditions, eight types of complex combinations are possible

as AH, AK, HA, KH, KQ, QQ, QH and HK. The four layer condition was not encountered in the present study.

5 Results and Discussion

The VES curves were drawn and interpreted by computer software IPI2 WIN. Based on these interpretations, the parameters *p* and h of each location were estimated. Curves of all the 38 locations indicated a three layered successions in the river basin. Among the plotted field curves, 9 curves are H type, 6 curves are K type and 23 curves are Q type. H type curve were obtained in hard rock terrains which consists of dry soil of high resistivity at the top as the first layer, a water bearing laterite layer of low resistivity as the second layer and crystalline rock of high resistivity as the lower layer. This type of resistivity curve was obtained in Mogral river basin in locations of Koprabazar, Mogral, Mogral Kadavu, Mogralputhur, Chowki 1, Chowki 2, Parappady, Bedradukka, Kambar, Muttathody, Kollya, Kollangana, Chettumkuzhi, Pannippara, Pady2 and Edneer. The K type curves can be obtained in terraines in which the resistance of middle layer is higher than top and bottom layers. The K types of curves were found at Uliyathadka, Manya, Ethirthodu, Chathapady, Muliyar and Attaparambu. The Q type curve seen in coastal areas, were indicative of locations of probable salt water intrusions in underground fractures and pore spaces. The sounding curves of Mogralriver basin is shown in Figure 3 to 5. The Table paired with each Figure represents layer number (N), resistivity (ρ) and depth to the bottom (h) of each layer.

N	ρ	h	d	Alt
1	9494	3.14	3.14	-3.136
2	1417	11.5	14.6	-14.59
3	149			

Figure 3Q- type curve at Kollya

N	ρ	h	d	Alt
1	2335	10.4	10.4	-10.36
2	17.7	14.8	25.1	-25.12
3	423			

Figure 4 H- type curve at Kadakam.

N	ρ	h	d	Alt
1	575	2.09	2.09	-2.093
2	1859	7.29	9.39	-9.387
3	81.7			

Figure 5 K-type curve at Uliyathadka

The thickness and resistivity layers obtained from the resistivity curves of each location were compiled in the Table 3.

Table 3 Resistivity and thickness of various layers and type of curve

VES No.	Location	Latitude (dd)	Longitude (dd)	Thickness (m)		Resistivity (Ω m)			Type of curve
				h1	h2	ρ1	ρ2	ρ3	
1	Koprabazar	12.573	74.947	1.21	16	2721	242	52.3	Q
2	Mogral	12.572	74.952	0.928	8.48	3360	591	19.8	Q
3	Mogral Kadavu	12.561	74.958	0.398	7.59	275	6.31	2.2	Q
4	Mogralputhur	12.554	74.959	0.392	6.71	2858	623	27.5	Q
5	Chowki 1	12.544	74.962	0.546	4.78	2788	1061	196	Q
6	Chowki 2	12.536	74.965	0.589	5.11	2764	685	213	Q
7	Parappady	12.562	74.974	0.992	3.62	5791	1342	256	Q
8	Bedradukka	12.54	74.982	3.97	21.3	3709	1020	128	Q
9	Kambar	12.547	74.978	1.11	3.83	9272	1152	291	Q
10	Uliyathadka	12.542	74.999	4.27	30.4	575	1859	81.7	K
11	Muttathody	12.539	75.024	1.46	15.6	1213	262	144	Q
12	Patla	12.565	75.003	8.57	6.59	1941	22	463	H
13	Kollya	12.563	75.021	3.14	11.5	9494	1417	149	Q
14	Bela	12.585	75.024	19.1	15.5	1173	121	777	H
15	Manya	12.561	75.049	2.87	1.69	599	1601	171	K
16	Kollangana	12.544	75.037	0.867	15.4	2353	79.7	8.46	Q
17	Chettumkuzhi	12.536	75.014	0.694	4.42	1818	599	81.1	Q
18	Pannippara	12.535	75.024	1.26	5.70	1454	534	130	Q
19	Nainmarmoola	12.517	75.025	2.08	83.2	1255	344	599	H
20	Alampady	12.532	75.039	5.79	3.93	5149	108	322	H
21	Nalam mile	12.513	75.036	0.739	12.82	2718	222.2	335.39	H
22	Pady 1	12.531	75.055	1.59	11	8965	1270	242	Q
23	Pady 2	12.539	75.051	9.38	47.7	1460	146	3243	H
24	Nellikatta	12.542	75.069	0.446	7.52	7026	1898	236	Q
25	Paika	12.538	75.088	2.99	10.2	5882	1460	200	Q
26	Athrukuzhi	12.539	75.059	0.691	7.55	6091	1992	276.4	Q
27	Masthikundu	12.512	75.071	0.755	0.637	3061	80.3	889	H
28	Ethirthodu	12.535	75.065	3.93	2.0	1975	3679	263	K
29	Edneer	12.524	75.071	0.421	47.6	8757	345	65.9	Q
30	Bovikkanam	12.507	75.093	6.73	48.4	3772	222	6968	H
31	Ammangode	12.516	75.094	2.44	8.02	1605	276	141	Q

32	Chathapady	12.532	75.099	0.263	8.17	731	3802	314	K
33	Muliyar	12.512	75.119	2.81	27.9	288	2591	5.61	K
34	Attaparamba	12.521	75.115	1.25	2.69	825	2812	397	K
35	Erinjery	12.525	75.125	1.08	45.9	5020	1223	2.37	Q
36	Vannachadav	12.53	75.143	0.831	8.34	2883	1497	619	Q
37	Kadakam	12.531	75.147	10.4	12.5	2335	17.7	423	H
38	Bellipady	12.509	75.125	0.99	8.84	7032	2450	265	Q

The resistivity value of the first layer ($\rho 1$) of this basin was in the range from 275 ohm-m at Mogral Kadavu to a highvalue of 9494 ohm-m at Kollya and the thickness varies from 0.263 m (Chathapady) to 10.4m (Kadakam). The resistivity value of the second layer ($\rho 2$) varied from 6.31 ohm-m at Mogral Kadavu to 3802 ohm-m at Chathapady. The thickness of second layer varied from 0.637 m (Masthikundu) to 83.2 m (Nainmarmoola). The existence of hard laterite at Uliyathadka, Manya, Nellikkatta, Athrukuzhi, Ethirthodu, Chathapady, Muliyar, Attaparamba and Bellippady have resulted comparatively higher resistivity (>1500 ohm-m) values of the second layer. The lithomargic clay layer and weathered crystalline rock exists below the laterite layer in the study area. Along the coastal region, the probable second layers of clayey sand have shown very low value of resistivity. The resistivity value of the third layer ($\rho 3$) was varying from 2.2 ohm-m at Mogral Kadavu to 6968 ohm-m at Bovikkanam. This variability could be due to lithomargic clay and fractured crystalline rocks to massive crystalline rocks. Comparatively higher resistivity value of third layer at places like pady 2 and Bovikkanam indicated the occurrence of massive crystalline rocks.The thickness of the third layer could not be determined. The spatial variations in resistivity of inferredsecond and third layers are shown in figures 6and 7. In the midlands and the lowlands of the basin, laterite acts as the dominant phreatic aquifer. The weathered and fractured crystalline rocks were also good aquifers. The dominant aquifer in the coastal area is clayey sand which was identified as the second layer in this study. Contouring the apparent resistivity is an important method, through which one can easily identify the groundwater potential areas (Sarma and Sarma, 1982).
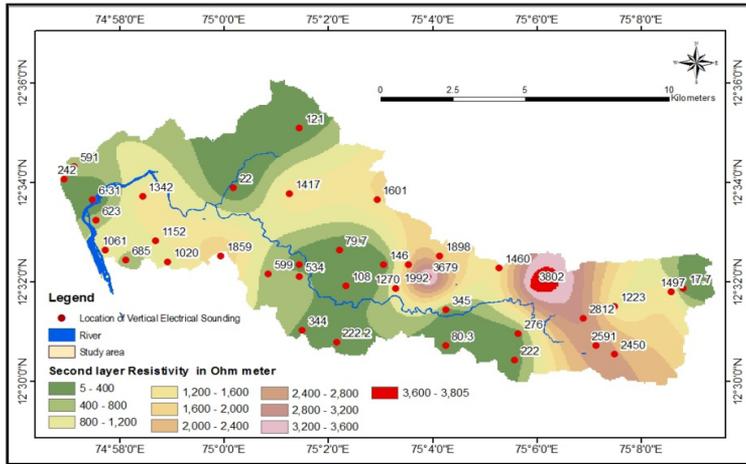
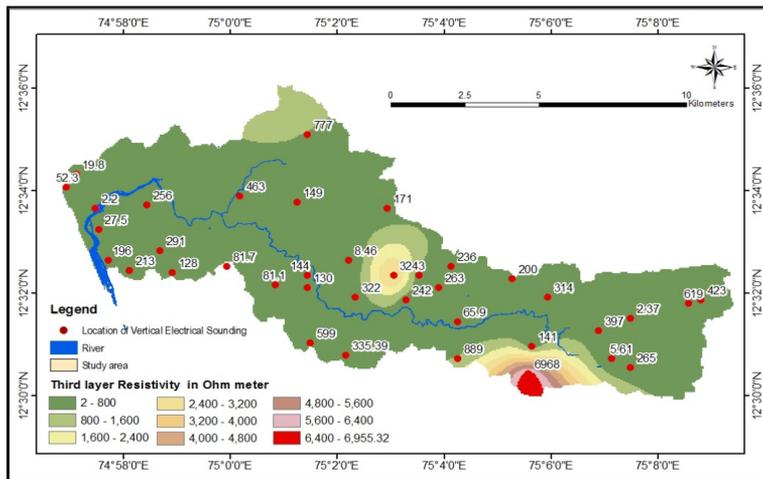Figure 6. Resistivity variations of second layer of Mogral river basin.

Figure 7. Resistivity variations of third layer of Mogral river basin.

The transit of groundwater in the area is largely controlled by joints and other structurally weaker planes, openings in rock formations, interconnection of weaker

planes and their spatial extent. The analysis and interpretation of the VES data showed that the distributions of various underground layers are not consistent within the Mogral river basin. While sandy soil intercalated with clay is the dominant phreatic aquifer of the coastal plains, layers of laterite and lithomargic clay formations are the dominant phreatic aquifers of lowlands and the midlands. The areas where the top soil, laterite and weathered rock is very narrow or absent, are not suitable for development of groundwater through open dug wells. This type of terrain is not identified in the study area. The potential aquifers deduced from this study are given as Table 4.

Table 4 Potential aquifer types of Mogral river basin

Geomorphic unit	Geophysical layer	Aquifer type
Coastal plain	Second layer	Clayey sand
Lowland region	Second layer	Laterite
Midland region	Second layer	Laterite
	Third layer	Weathered/Fractured Crystalline rock.

The yield from a hard rock is determined by the size, location and interconnection of the fractures, and also the quantity of accumulated material that may be blocking the fractures and recharging sources. Compared to the shallow aquifer, the volume of water occupied in fractured hard rocks is less and this amount further decrease as fractures become narrower at deeper levels. The cumulative amount of water occupied in the fractures of the hard rock terrain is meager. The location of potential fracture zones in hard rock area is extremely important to yield large amounts of groundwater. The resistivity data provided decisive information about the presence of the conducting underground fracture and groundwater occurrence of this area. Analysis of the data revealed that shallow aquifers are the probable potential sources in the lowland and midland region.

6 Conclusion

Electrical resistivity survey was found useful and reasonably accurate for delineating the subsurface water bearing formations. The layer of low resistivity

value indicates an aquifer of higher groundwater potential and layer of high resistivity indicate an aquifer of lower groundwater potential. In the present study the second layer (porous laterite) and the third layer (weathered / fractured crystalline rock) were found to be the potential aquifers of Mogral river basin.

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Corresponding Author: maslam.in@gmail.com