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ORIGINAL ARTICLE

INVESTIGATION OF SUBSURFACE AND GROUNDWATER STATE AT GADILAM RIVER SUB –BASIN, TAMIL NADU, INDIA.

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ABSTRACT

The electrical resistivity method is extremely useful to investigate the nature of subsurface formations by studying the variations in their electrical properties. This method assumed considerable importance in subsurface exploration because of very good resistivity contrasts among the lithological units, controlled depth of investigation, ease of field operations and low cost of instrumentation and operation. The Vertical Electrical Sounding (VES) method by Schlumberger electrode array applied in 20 Locationsat Gadilam River Sub Basin in Tamil Nadu, India. The Signal stacking Resistivity Meter Model SSR-MP-ATS was used to collect the VES data by employed a Schlumberger electrode configuration, with one side current electrode spacing (AB/2) ranging from 1 to 100 m and the potential electrode (MN) from 0.5 to 10 m. The concept of the VES data interpreting is the foundation of IPI2Win. It means for a VES data are treated as a unity representing the geological structure of the Gadilam River watershed. The output Geo-electrical layers with iso- resistivities and thickness in spatial maps by using ARCGIS software were created. Accordingly, the following zones with different resistivity values were detected, corresponding to different formations: (1) identification of lithologyGadilam River Sub Basin, (2) strata's saturated with fresh groundwater, (3) determine saltwater horizon.

Keywords VES, Signal stacking Resistivity Meter, SSR-MP-ATS, Schlumberger electrode, Geo-electrical layers, ARCGIS.

1.INTRODUCTION

Geophysical surveys employ advanced parameters of scientific measurement to study the physical properties of the earth in order to find out the differing patterns relating to geological formation, rock type, weathering thickness, porosity and fractured zones (Plummer et al., 1999, (Singh et al., 2006).This type of scientific investigation has acquired greater importance in recent times in studying environmental problems and for assessing sub-surface water potentials (Sarma. S.V.S. et al (2004), Arulprakasam. V et. al.,(2009). The information acquired, when interpreted together with specific field observations lead to a better understanding of geophysical characteristics and considerably reduce ambiguities and uncertainty and help in narrowing down the range of possible solutions in a given specificity.

Hydrogeophysical methods within the general ambit of geophysical surveys have become crucial in recent times. Estimation of ground water potential through geophysical prospecting has become universal owing to the fact that water has become one of the most precious resources of nature in many parts of the world(Olorunfemi and Fasoyi, 1993; Olasehinde, 1999; Alile et al., 2008). The ever increasing demand for water, the geophysical constraints which limit the supplies, over exploitation, unscientific management, pollution, changing world climatic pattern and such other contributory factors have made water a premium product. A combination of these factors has also led to massive shrinkage in ground water levels. Hence, the adoption of advanced methods for proper targeting, assessment and management of ground water resources have become important.

In earlier phases, ground water investigation was limited to unconsolidated alluvial and semi consolidated sedimentary tracts. In recent years, greater importance is attached to exploration of ground water in hard rock areas. have done pioneering work in hard rock terrain to estimate ground water

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resources of the Deccan area using the electrical resistivity methods.

Among the many options available in geophysical methods, electrical resistivity methods have been the widely used ones by field geologist in ground water exploration. Even though other methods like seismic, gravitational and magnetic methods are used, electrical resistivity is most widely used method in regional and local surveys because its great resolving power, inexpensiveness, its extensive and wide range of field applicability.

Anomalous conditions or in homogeneities within the ground, such as electrically better or poorer conducting layers, are inferred from the fact that they deflect current and distort the normal potential. This, in brief, it is the principle of measuring sub-surface variation in electrical resistivity. The underlying fact is that a good electrical resistivity contrast exists between the water bearing formations and the sub-surface rocks (Zohdy et al., 1974). The initial fluids in rocks conduct current electrolytically and resistivity is controlled by porosity, water content as well as the quantity of dissolved salts (Baines et al. 2002). The clay minerals however are capable of storing electrical charges and current conduction and hence, clay minerals are electrolytic (Zohdy et al, 1974)

Geoelectrical processing or geoelectric exploration uses exceedingly diverse principles and techniques and utilizes both stationary and variable currents produced either artificially or by natural processes. In resistivity method, a current (a direct or very low frequency alternating current) is introduced into the ground by two or more current electrodes, and the potential difference is measured between two points (probes) suitably placed with respect to the current electrode. The potential difference for unit current sent through the ground is a measure of the electrical resistance of the ground between the probes. The measured resistance is a function of the geometrical configuration of the electrodes and the electrical parameters of the ground. There are basically two types of resistivity measurements. The first is known as geoelectric profiling or mapping. In this method, the electrodes and probes are shifted without their relative positions being changed. The second method is the geoelectric sounding which takes recourse to changing the position of the electrodes with reference to a fixed point. Wenner and Schlumberger methods of configuration electrode are the two frequently used methods in resistivity sounding. Wenner configuration is mostly used in shallow exploration works, while the Schlumberger configuration is used for both shallow and deeper investigations.

2.MATERIALS AND METHODS

Study Area:

The sub basin lies between 79º 0’ E to 79º 47’ E longitudes and 11º 30’ N to 11º 55’ N latitudes. The total are-al extent of the Gadilam sub basin spreads to an area of 900.08 Sq.km. The study area is covered by Survey of India topographic sheets 58M/1, 58M 2, 58M /5, 58M/6, 58M /9, 58M /13 57M/10 and 57M /14 (Fig. 1). The sub basin includes major part of Villupuram district which originates from Kallakkurichchitaluk and passes through Thirukkovilur and CuddaloreTaluksof Villupuram districts in Tamilnadu

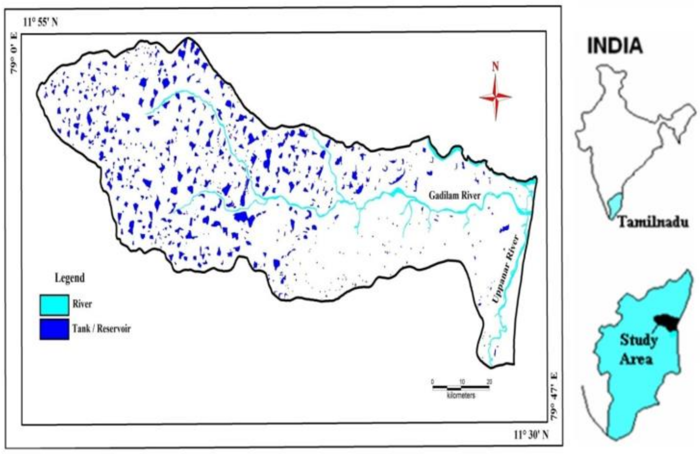

Fig1.Location Map of Study area.

Geology and Climate:

The Gadilam river basin is characterized by different geological formations, reflecting the various geological eras. Achaean rocks outcrop near AriyurPillaiyarkuppam and Kunnathur. These outcrops show well developed folding evidencing the faulting and migmatisation. According to Subramaniyam (1969), the rocks, considered to be of Archaean, had actually formed in the Post-Archaean period, as evidenced by the presence of well formedchloritic, hornblendic gneisses, granites and charnockites due to different types of metamorphism. The beginning of Mesozoic has been marked by the most interesting and widely distributed fossiliferrous sedimentary facies. The deposition of Cretaceous formations has commenced with the transgression of sea during middle to upper Albian times and continued to stay upto the close of Danian. The depositional basin is found to have been marked with minor epiorogenic oscillations. The presence of Eocene foraminiferal assemblages in the Ariyalur series of the Tertiary era, it is understood that marine condition has been stayed even in the Tertiary Era which has witnessed numerous marine transgressions and regressions. The presence of unfossiliferrous and cuddalore sandstone has strongly testified as the marine regression in the Miocene (Blanford, 1865; Furon and Lemoin, 1939; Rama Rao, 1964). After the phase of marine regression, the sedimentary basin has undergone deep weathering and subsequently yielded to accommodate the deposition of Sub-recent to Recent Alluvium.

The Gadilam basin gently dips towards east. The long profile of the river is as illustrated that the slope of the river profile (1:9.6) is gentle from the catchments area. This continues up to the distance of 50 km from the estuary, beyond which it is almost flat (1:24). The flat profile of the river is noticed only in the sedimentary terrain like Cretaceous and its later formations. The meandering courses of the river follows the SW – NE fault plane and in some cases maintain parallelism with E-W fault plane (Muthukrishnan, 1993). Small dunes occur near the mouth of river Gadilam. The study area show the beach features like berm, ridges and sand dunes. Before reaching the sea, the Gadilam River distributes its supply into three branches of streams. Northern most distrubutary confluences with sea after encircling Devanampattinam. The southern mostdistrubutary merges with Uppanarriver at Cuddalore old town. The central one joins with the sea through Devanampattinam. The beaches in the river mouths around Cuddalore are having only gentle slope without any cliffs, wave cut terraces, stacks etc., and also devoid of any river made features.

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The hydrogeology studyof an area will help in understand the characteristic of the aquifer system, fluctuation in groundwater level, flow and recharge mechanisms. Importance of hydrogeology was well documented by Vendie Chow (1964). Detailed work on hydrology and water resources engineering were initiated by several authors (Theis, 1935; Hvorslev, 1951; Hantush, 1960; Walton, 1970 andNutbrown, 1976. The average annual water level in Cuddalore district is 14.8 m BGL and that of Villupuram district is around 5.6 m BGL. The shallow water level was observed in the upstream side of the basin and that of deeper water level is in the downstream side. The water table fluctuation ranges between 0.22 m BGL and 2.3 m BGL.Three different levels of optimum yield have been found in the hard rock region, low optimum yield in areas of less the 25 m^3/day. Moderate optimum yield in areas from 25 to 50 m^3/day and higher optimum yield in area of more than 50 m^3/day. It has been found that higher optimum yield is suggestive of higher permeability. The region of high optimum yield was suggested for well development, low yield were found to be scattered throughout the region (Aravindhan et al. 2004b). The dug well gives the yield of 62.9 m^3/day and 42.3 m^3/day respectively.

Apart from the coastal region, the entire Tamil Nadu receives only the occasional showers, for nearly 55 days in a year. The coastal region is often flooded by rainfall during the NE monsoon season (October - November). Devanampattinam is prone to flooding especially during cyclone due to its low relief, which is almost equal to high tide level. Humidity of the lower reaches of Cuddalore varies from 63% to 87% while the upper reaches show a relative humidity of 55% to 67% (Muthukrishnan, 1993).

Southwest monsoon, bringing sporadic rainfall, blows in the months from June to September. The Northeast monsoon during October to December months brings appreciable rain and wind with the velocities of 5 to 15 km/hr. The months of March to May remain very hot while January to February stand to be the winter. As per the records of the Indian meteorological Department, (IMD), temperature ranges from 25ºC to 31ºC in the study area.

Generally distribution of rainfall in Tamilnadu is scanty with respect to other states. As far as Gadilam basin is considered, almost 60% of the year, it remains dry, but the coastal region gets considerable rainfall. Total precipitation during March to May has always been found to be subordinate to the other two periods. The origin of this precipitation appears to be of a conventional type as it occurs during the hottest part of the year. The rainfall received during the northeast monsoon is more effective and contributing 61% of annual precipitation, it ranges between 632.4 and 1403mm. The average annual rainfall of the Cuddalore district is 1876 mm and that of Villupuram district is around 1245 mm.

Data and Method:

Field Survey:

Schlumberger electrode configuration has been carried out in 77 locations of the present study area. VES have been conducted to describe the sub-surface water potential as well as its quality, resistivity of a variety of sub-surface formations, existence of deeper fresh water aquifer and depth to basement configuration of the study area. The maximum distance of spread of electrodes is 100 meters. The resistivity value (ρ) for fixed distance between the electrodes has been noted by passing current between them. The value 'ρ' corresponds to the true resistivity, if the ground is homogeneous and isotropic. The obtained 'ρa' is from the measurement over a layered heterogeneous.

Interpretation:

The main aim of the resistivity technique is to understand the nature of the subsurface formations through the measurements made over the surface of the earth. This is achieved in two steps: (a) determining parameters like resistivities and depths of various geoelectric layers from the field data and (b) translating this derived information into meaningful site-specific subsurface information. The first stage, i.e., the process of getting resistivities and thicknesses of the subsurface formations from the observed resistivity data is being termed as 'interpretation' in geophysical literature. But in real sense this process should be termed as 'analysis' and inferring the nature of subsurface formations from the results of analysis should be termed as 'interpretation'. The resistivities of formations by themselves do not carry any meaning unless they are translated in terms of lithological and geological formations. For this purpose, the background knowledge regarding the interrelation between the lithological units and their resistivities is necessary. This information can only be obtained through detailed correlative studies. The success of resistivity data interpretation depends on this background knowledge.

Inverse Slope Method:

The facilities in fast computation of apparent resistivity curves for multilayered media has brought the concept of using iterative process of analyzing the resistivity sounding data. In this process an initial guess is made of the model parameters for resistivities and thicknesses of the layers. Based on these values apparent resistivity curve is generated using either recurrence formula or filter coefficients. This curve is compared with the field curve and the differences between the points of the observed and model curves are obtained and the model is automatically revised to minimize the differences. This process known as iteration is continued till the differences between the observed and theoretical curves are reduced to the minimum. The final model having least error represents the layer parameters of the sounding (Fig. 2).

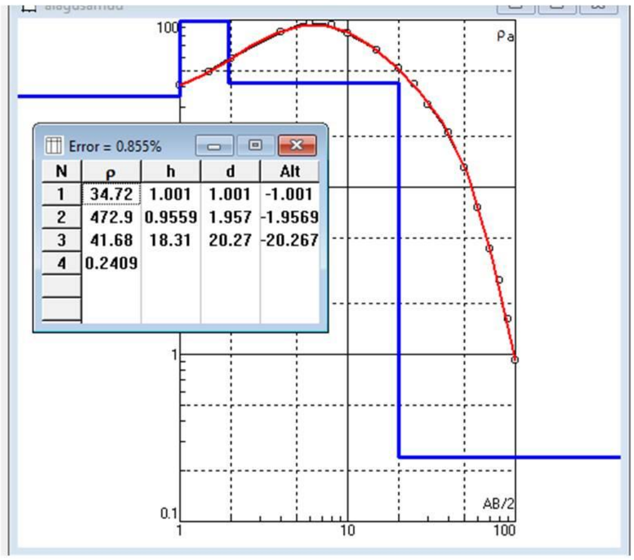

Fig. 2. IPi2WIN computer inversion program output in Arasur Village

Zohdy (1989) suggested a method in which no initial guess is required. Zohdy starts assuming that the number of layers in the initial model as well as in the updated onesequals the number of digitized points (equally spaced on logarithmic scale) on theobserved apparent resistivity curve. The resistivity of the first layer is taken to be thevalue of the first point; the second layer resistivity takes the second point value and so onalong the curve. The depth of each layer is taken as the electrode spacing at which theresistivity was measured multiplied a constant which is determined by calculating theroot mean square (RMS) % deviation between the observed and calculated apparentresistivity values at the data points. The adjustment of depths by this procedure continuesuntil the RMS% deviation is a minimum. The adjustment of the amplitude of apparentresistivity is done iteratively by varying the resistivities of the model layers whilekeeping the boundaries fixed. Each layer resistivity is adjusted by a factor equal to theratio of the observed and calculated apparent resistivities.

The final interpretation has been made using the computer inversion program IPi2WIN (Gopinath et al 2015). The computed value has been compared with relevant field values (manual interpretation value). It is noted the error sandwiched between computed and manual is very meager.

The obtained resistivity and thickness of various layers, iso apparent resistivity for different depths and type of curves for the study are furnished in results.

3.RESULTS

The shapes of the field curves for different combinations of resistivity layers. For this purpose the apparent resistivity values obtained in electrical sounding are plotted on log-log scale against half current electrodeseparation *AB/2*in case of Schlumberger and electrode separation *a*in case of Wennerconfiguration. Then the shape of the curve is critically observed to get an ideaqualitatively about the number of layers and the order of resistivities.

If the subsurface is a single homogeneous layer of infinite thickness (thickness very large compared to electrical sounding spread) the apparent resistivity curve will be a straight line parallel to *AB/2* or *a* axis and its ordinate value gives the resistivity of the formation. (Example: Thick uniform clay deposit, uniform sandy layer saturated up to the surface etc).

If the subsurface formation is composed of two layers, a surface homogeneous layer of resistivity $\rho1$ overlying an infinitely thick homogeneous layer of resistivity $\rho2$ depending on the values of $\rho1$ and $\rho2$ two situations may arise. One of the situations is - resistivity of the second layer $\rho2$ is greater than the resistivity of the first (top) layer. In this case for very small current electrode separations compared to the thickness of the first layer (h), the apparent resistivity values will be equal to $\rho1$ and for very large electrode current separations compared to *h*the value will be nearly equal to $\rho2$ (asymptotically approaches the value$\rho2$ with increase of electrode separation). At intermediate values of AB/2 or “a” the curve raises from $\rho1$ to $\rho2$ smoothly. In case the second layer resistivity is infinite (very high), the curve rises continuously at an angle 45^{o} (example: Uniform saturated sandy formation overlying bedrock. If the bedrock has finite resistivity $\rho2$ the curve approaches the value of $\rho2$ for large values of AB/2. These curves are called ascending type curves. In the second situation when $\rho2 < \rho1$, the apparent resistivity curve starts with a value of $\rho1$ for small separations, (compared to the thickness of the first layer) and decreases with increasing separations finally reaching the value of $\rho2$ asymptotically for very large electrode separations. If the second layer has very low resistivity (near to zero) the curve goes on decreasing continuously, sandy formation overlying clay or sands saturated with saline water like seawater. If the bottom layer is clay the resistivity of the curve reaches the value of clay at large electrode spacing and if it is with saline water (like seawater) the curve shows a continuous decrease. These curves are called descending type of curves.

If the subsurface formations are composed of three layers with resistivities$\rho1$, $\rho2$ and $\rho3$ four types of curves are possible. They are

1. $\rho1 > \rho2 < \rho3$ – H - Type
2. $\rho1 > \rho2 > \rho3$ – Q – Type
3. $\rho1 < \rho2 < \rho3$ – A – Type
4. $\rho1 < \rho2 > \rho3$ – K – Type

Table. 1. Typical Three layer possible hydrogeological sections

H-Type	Q-Type	A-Type	K-Type
Sandy Soil	Sandy Soil	Clay	Clay
Clay	Silty Sand	Silty Sand	Fresh water sand
Hard bed rock	Clay	Hard bed rock	Clay

The four layer cases represent the situation with resistivities $\rho 1$, $\rho 2$, $\rho 3$ and $\rho 4$. Eight types of curves (Orellana and Mooney, 1966) are possible with various combinations and permutations of resistivities as listed below

1. $\rho 1 < \rho 2 < \rho 3 < \rho 4$ – AA – Type
2. $\rho 1 > \rho 2 < \rho 3 < \rho 4$ – HA – Type
3. $\rho 1 > \rho 2 < \rho 3 > \rho 4$ – HK – Type
4. $\rho 1 < \rho 2 < \rho 3 > \rho 4$ – AK – Type
5. $\rho 1 < \rho 2 > \rho 3 < \rho 4$ – KH – Type
6. $\rho 1 < \rho 2 > \rho 3 > \rho 4$ – KQ – Type
7. $\rho 1 > \rho 2 > \rho 3 < \rho 4$ – QH – Type
8. $\rho 1 > \rho 2 > \rho 3 > \rho 4$ – QQ – Type

Table. 2. Typical four layer possible hydrogeological sections

AA-Type	Clay Silty Sand Sand with fresh water Bedrock	**HA-Type**	Silty Sand Clay Sand with fresh water Bedrock
HK-Type	Silty sand Clay Sand with fresh water Clay / Sand with saline water	**AK-Type**	Clay Silty sand Sand with fresh water Clay / Sand with saline water
KH-Type	Clay Sand with fresh water Clay Bedrock	**QH-Type**	Sandy layer Silty sand Clay Bedrock
KQ-Type	Clay Sand with fresh water Silty sand Clay / Sand with saline water	**QQ-Type**	Sand Silty sand Clay Sand with saline water

From the IPi2WIN output, it is inferred that 14 samples comprised of three layer curves and the remaining 6 are four layered curves. By studying these curves a typical geoelectrical section has been formulated for the study area and tabulated below.

Table .3. Typical Hydrogeological Curve of the Study area based on IPi2WIN Output

Type of hydrogeological sections	Number of Samples	Percentage of Samples
A - Type	7	35
K - Type	3	15
Q - Type	1	5
H - Type	3	15
HK – Type	3	15
QQ - Type	1	5
QH - TYPE	2	10

Isoresistivity

On the basis of interpreted VES results, iso-resistivity contour maps are prepared for the four geoelectrical layers. It is possible to demarcate the area with different ground water quality from the geophysical data (Pal and Majumdar,2001). The first layer (Fig.3) resistivity ranges from 0.03 ohm. m to 7061ohm.m. The low resistivity (less than 3 ohm.m) exists in major part of the study area. It may be due to sand with saline water.

The high resistivity (more than 200 ohm.m) in eastern part of the area may be due to Coastal Alluvium formation. The resistivity range of 12 - 50 ohm.m which exists in most of the area, may be due to sand formation. The second layer (Fig. 4) resistivity ranges from 0.17 to 1963ohm.m. The low resistivity (less than 30ohm.m) are indicate in thick clay formation in the study area. The high resistivity (more than 1000 ohm.m) which exists in Eastern side may be due to Coastal alluvium Formation. The third layer (Fig. 5) resistivity ranges from 0.105 to 4999ohm.m. The low resistivity layer (less than 3 ohm.m) existing around central part of the the study area is attributed to Shelly sand formation. The layer with resistivity ranging from 500 to 1000 ohm.m existing at the western side may be due to semi fractured rock. The resistivity more than 150 ohm.m which exist towards western side for compact hard rock with minor fractures while less than 150 ohm.m towards eastern side of the area which are occupied by sedimentary rock. The resistivity contour 150 ohm.m is the boundary between hard and sedimentary rocks of the region.

The fourth layer (Fig. 6) resistivity ranges from 0.42 to5.22ohm.m. The low resistivity (less than 3 ohm.m) in eastern part of the study area may be due to sand with saline water and middle part of the study was indicate the sedimentary formation.

The thickness of first layer (Fig. 7) ranges from 0.55 to 7.15 m at Naduveerapattu (Loc. No. 8) are identified in higher thickness alluvium formation. The second layer thickness (Fig. 8) ranges from 0.95 m at Arasur (Loc. No. 5) and Ulundurpettai (Loc. No. 19) to 45.72 m. The third layer (Fig. 9) which most significant for the groundwater occurrence in hard rock area has its minimum thickness of 9.83 m at Veeraperumanallur (loc. No. 64) and maximum extend is not predictable

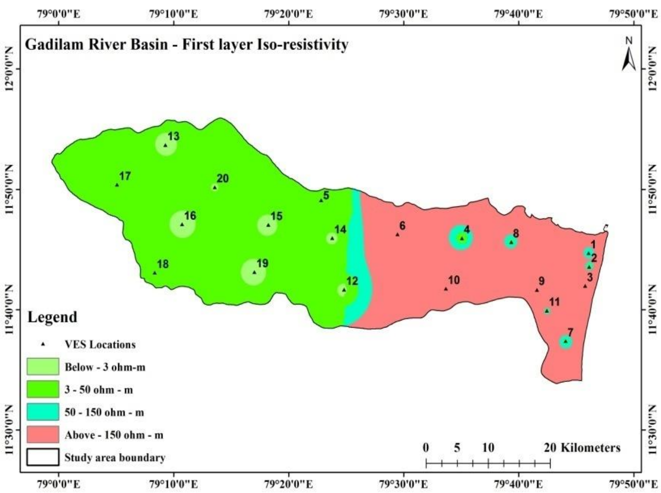

Fig. 3 First Layer Isoresistivity Map

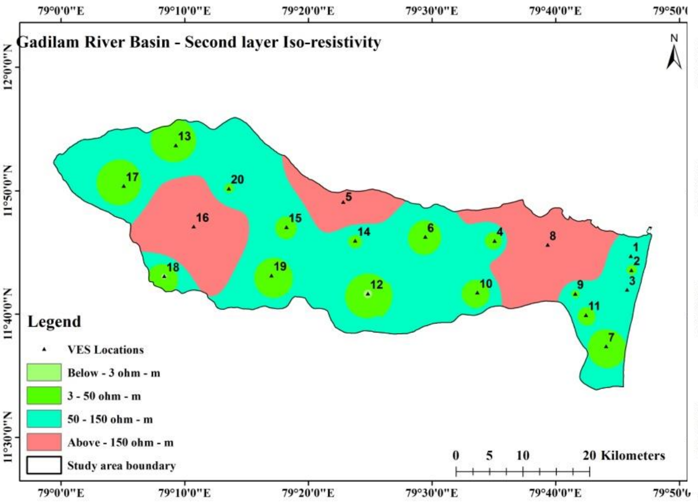

Fig.4. Second Layer Isoresistivity Map

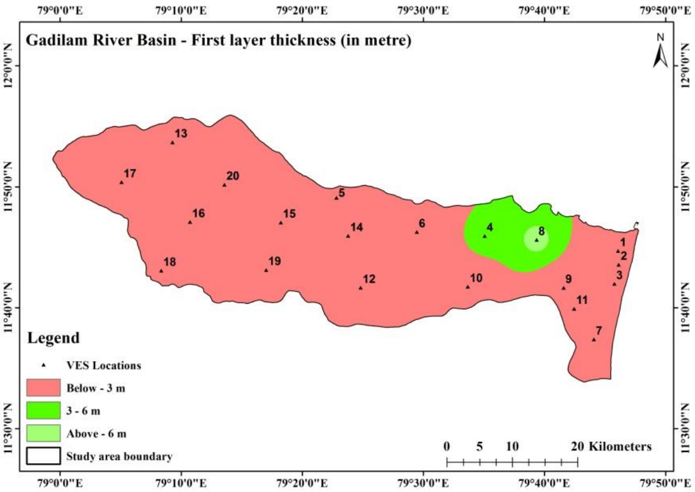

Fig. 7. First Layer Thickness (m)

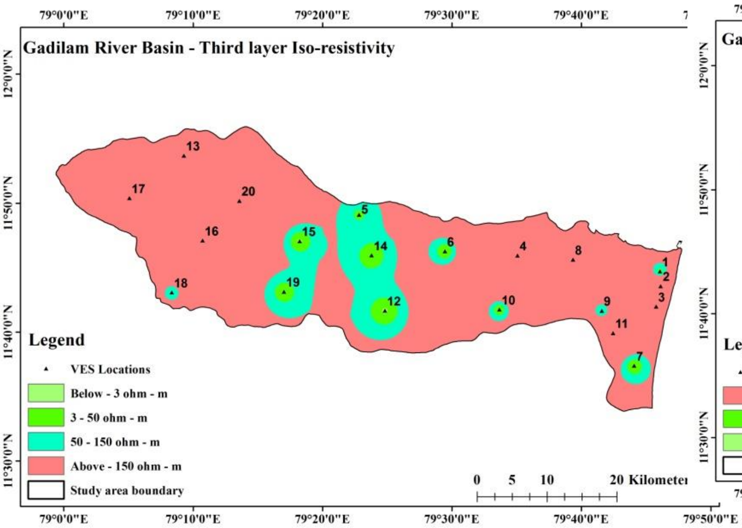

Fig. 5. Third Layer Isoresistivity Map

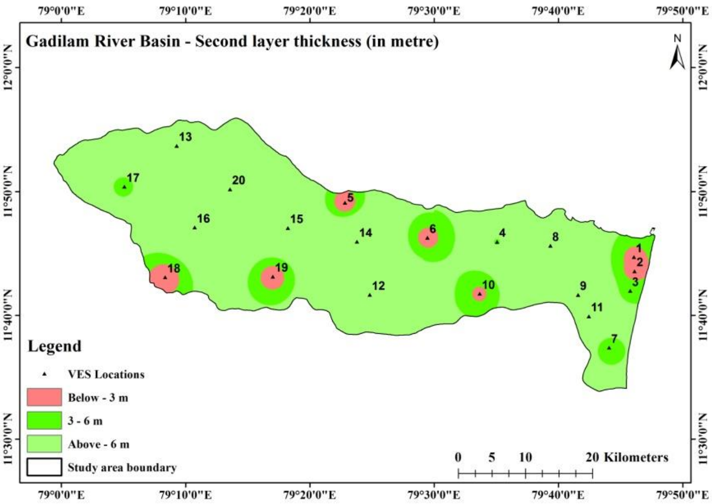

Fig. 8. Second Layer Thickness (m)

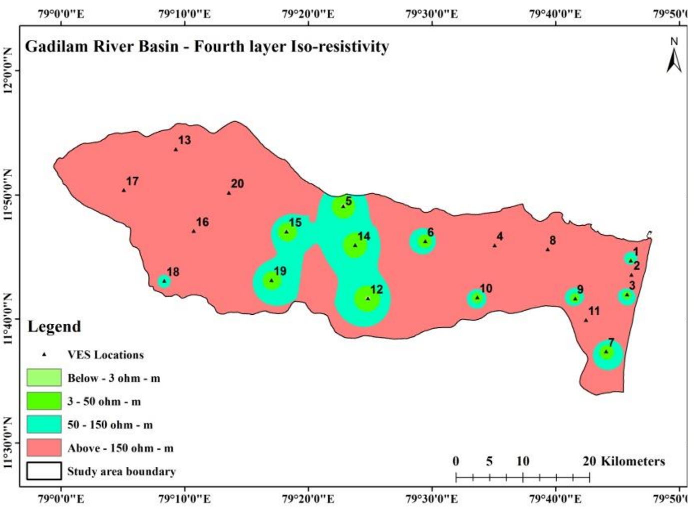

Fig.6. Fourth Layer Isoresistivity Map

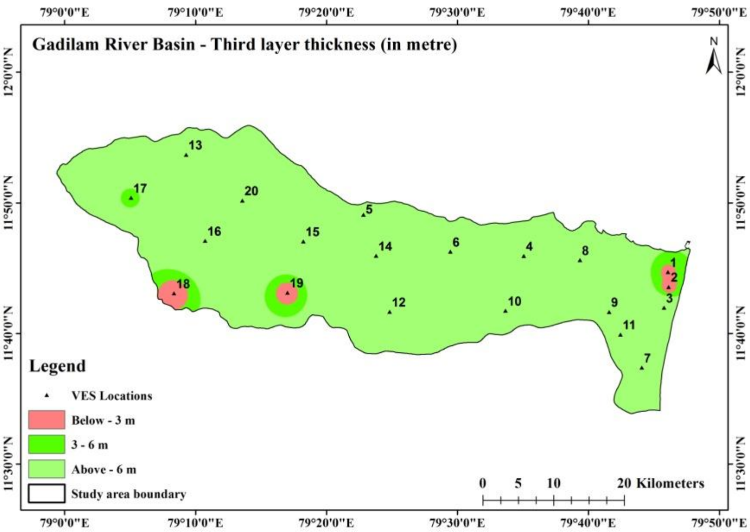

Fig. 9: Third Layer Thickness (m)

4.CONCLUSION

The present study of investigation of subsurface and groundwater state at gadilam river sub –basin using electrical resistivity technique has helped to understand the sub surface lithological condition and layer thickness variations. The three layers comprised of top soil, weathered zone and massive formation whereas four layers characterized by top soil, weathered part, fractured zones and massive rocks. Compact formation show high resistivity value and low resistivity value indicate presence of the fractured formation in hard rock terrain and sea water intrusion along the coastal area.

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