DELINEATE SUBSURFACE LITHOLOGY AND GROUNDWATER INVESTIGATION OF ONGUR SUB BASIN, SOUTH 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 77 Locations at Ongur 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 Ongur 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 lithologyOngur 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.

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 al., 2009, Senthilkumar et al 2017). 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.

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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 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.

Study Area:

The sub basin lies between 79°30’ and 80°00’ east longitudes & 12°15’ and 12°30’ north latitudes. The total are-al extent of the Ongur sub basin spreads to an area of 1480.08 Sq.km. The study area is covered by Survey of India topographic sheets 57P/11, 52P/15, 57P/16 and 57P/12 (Fig. 1). The sub basin includes major part of Kancheepuram district and remaining part from Tiruvannamalai and Villupuram districts of Tamilnadu.

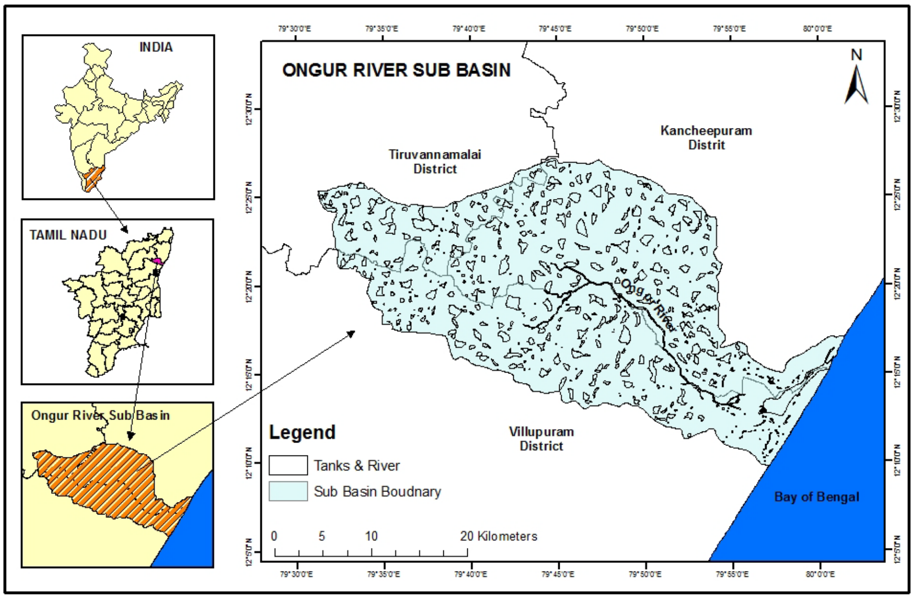

Fig1.Location Map of Study area.

Geology and Climate:

A clear separation of crystalline hard rock terrain in the west and coastal sedimentary rock units in the eastern part was observed based on the lithological units. The oldest crystalline rocks of Archaean age, covering an area of major part, comprise granites, gneisses, charnockites and associated basic and ultrabasic intrusive. The granitic rocks are medium to coarse grained and less massive than the charnockites. Charnockites are well foliated and generally strike in NNE-SSW direction covered by thick weathered mantle supporting good vegetation and land use practice of the study area. Geomorphologically following features have been deduced, Buried Pediment is covered in major part (63.34 %) of the study area. Low lying lands are seen along the central part of the study area. Structural hills exist east of Acharapakkam town. Coastal areas are occupied by beach ridges, lagoon, marshy land, coastal high lands and coastal plains. Flood plain is seen along the river course of Ongur River. Lateritic upland was seen in the eastern part cover an area of 127.06 sq. km (8.59%) and areal extent of coastal dune was 123.65 sq. km (8.35%). A lagoon was another interesting landform unit observed near the confluence of River Ongur, covering an area of 80.6 sq. km and influence Kalveli Tank, during high tide periods of both diurnal and seasonal.

Ground water level keeps variable within the aquifer. This is due to the natural twelve-monthly Hydrological cycle where ground water yielding aquifer is principally recharged through rain water. This recharging depends on a variety of factors like climate, geomorphology, topography, and soil and importantly sub surface geology (Senthilkumar et al., 2014). Due to the retreating monsoon, south India receives the rain fall of more than 50% during the month of October, November and December. One or more cyclones cross the study area during this period with heavy rain. Southern State of India also receives the rain fall through south west monsoon and non monsoon period to certain extent. For a better understanding of the hydrometeorological data becomes important while dealing with ground water studies and it is imperative to know the behaviour of different meteorological parameters of an area.

The study area covers the entire Parts of study area of Ongur sub river Basin. The tropical climate condition prevails in the study area and located in the tropographical climate zone. Ongur river sub basin experiences the tropical climate. It conveniently divided into four seasons, the post monsoon period from January to February, the summer from March to May, the south-west monsoon seasons from June to September and North-east monsoon from October to December. The Ongur sub basin experiences a hot climate with an average annual temperature of 32°C. The maximum temperature recorded in the summer season, rarely the temperature exceeds this maximum in the study area. The study area, maximum humidity reaches in the month of November and December and minimum humidity is 65 % and 80 % from the month of March and August. The northeast monsoon contributes a larger share of the total rainfall of the region (October to December) compared to the southwest monsoon (July to September). The average rainfall observed from the records is around 720 mm, nearly 60% of which is recorded during the northeast monsoon.

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.

Computer Inversion 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).

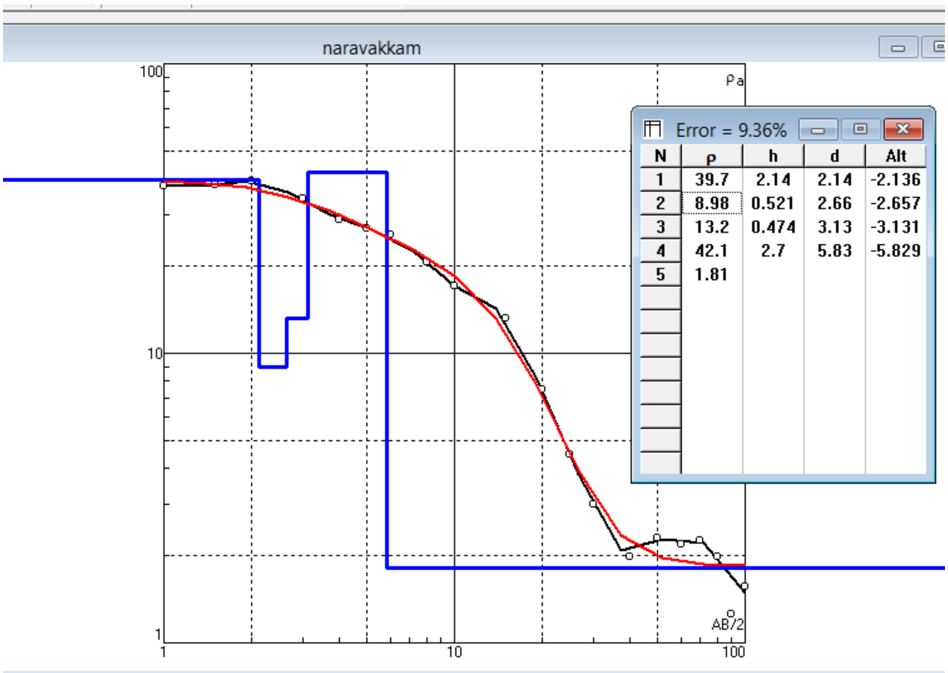

Fig. 2. IPi2WIN computer inversion program output in Naravakkam Village

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.

Results and Discussion

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 ρ1 overlying an infinitely thick homogeneous layer of resistivity ρ2 depending on the values of ρ1 and ρ2 two situations may arise. One of the situations is - resistivity of the second layer ρ2 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 ρ1 and for very large electrode current separations compared to *h*the value will be nearly equal to ρ2 (asymptotically approaches the valueρ2 with increase of electrode separation). At intermediate values of AB/2 or "a" the curve raises from ρ1 to ρ2 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 r2 the curve approaches the value of ρ2 for large values of AB/2. These curves are called ascending type curves. In the second situation when ρ2 <ρ1, the apparent resistivity curve starts with a value of ρ1 for small separations, (compared to the thickness of the first layer) and decreases with increasing separations finally reaching the value of ρ2 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 spacings 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 resistivitiesρ1, ρ2 and ρ3 four types of curves are possible. They are

1. ρ1 >ρ2 <ρ3 – H - Type
2. ρ1 >ρ2>ρ3 – Q – Type
3. ρ1 <ρ2<ρ3 – A – Type
4. ρ1 <ρ2>ρ3 – 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 ρ1, ρ2, ρ3 and ρ4. Eight types of curves (Orellana and Mooney, 1966) are possible with various combinations and permutations of resistivities as listed below

1. $\rho1 < \rho2 < \rho3 < \rho4$ – AA – Type
2. $\rho1 > \rho2 < \rho3 < \rho4$ – HA – Type
3. $\rho1 > \rho2 < \rho3 > \rho4$ – HK – Type
4. $\rho1 < \rho2 < \rho3 > \rho4$ – AK – Type
5. $\rho1 < \rho2 > \rho3 < \rho4$ – KH – Type
6. $\rho1 < \rho2 > \rho3 > \rho4$ – KQ – Type
7. $\rho1 > \rho2 > \rho3 < \rho4$ – QH – Type
8. $\rho1 > \rho2 > \rho3 > \rho4$ – QQ – Type

Table. 2. Typical four layer possible hydrogeological sections

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

From the IPi2WIN output, it is inferred that 74 samples comprised of three layer curves and the remaining 3 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	54	70
K - Type	9	12
Q - Type	1	1
H - Type	10	13
HA – Type	2	3
AK - Type	1	1

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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 1.1 ohm. m to 221 ohm.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 south eastern side 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 2.4 to 2747 ohm.m. The low resistivity (less than 3 ohm.m) exists in Grandipuram (Loc.No. 58) and Marakkanam (Loc.No.77) may be due to sand with saline water. 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 0.5to 47040 ohm.m. The low resistivity layer (less than 3 ohm.m) existing around Eyipakkam 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 1.00 to 1999 ohm.m. The low resistivity (less than 3 ohm.m) which exists in south of Kaluveli lake may be due to sand with saline water. The resistivity (more than 1000 ohm.m) which exists towards western and northern sides attributed to the presence of massive rock. Here, the boundary of the hard rock is shifted towards the eastern side of the area.

The thickness of first layer (Fig. 7) ranges from 0.1 m at Kattugudalur (Loc. No. 3) to 5.7 m at Kolathur (Loc. No. 30). The second layer thickness (Fig. 8) ranges from 0.4 m at Manimangalam (Loc. No. 1) and Karuvampakkam (Loc. No. 57) to 22.5 m at Chunambedu (Loc. No. 66). The third layer (Fig. 9) which most significant for the groundwater occurrence in this zone has its minimum thickness of 0.2 m at Nagar (loc. No. 64) and maximum extend is not predictable.

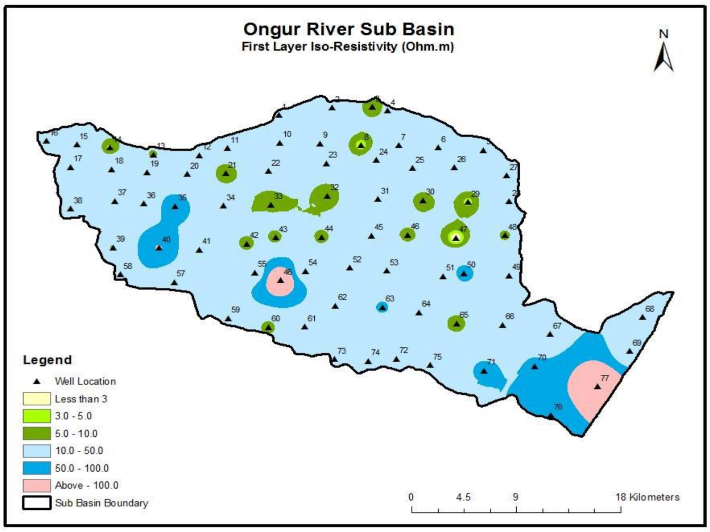

Fig. 3 First Layer Isoresistivity Map

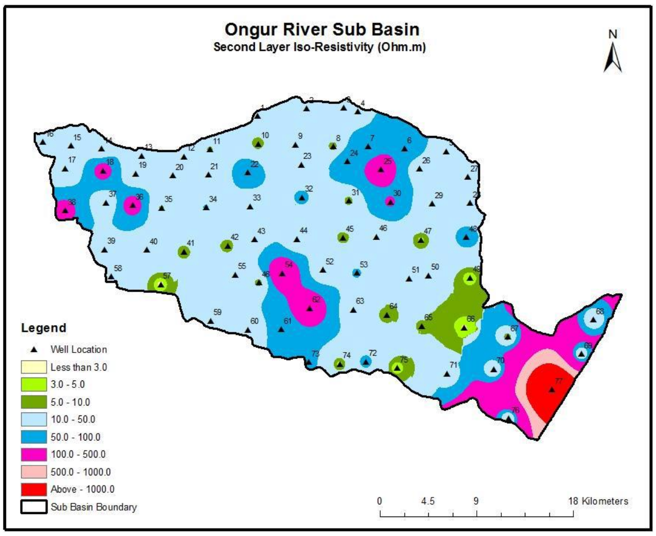

Fig.4. Second Layer Isoresistivity Map

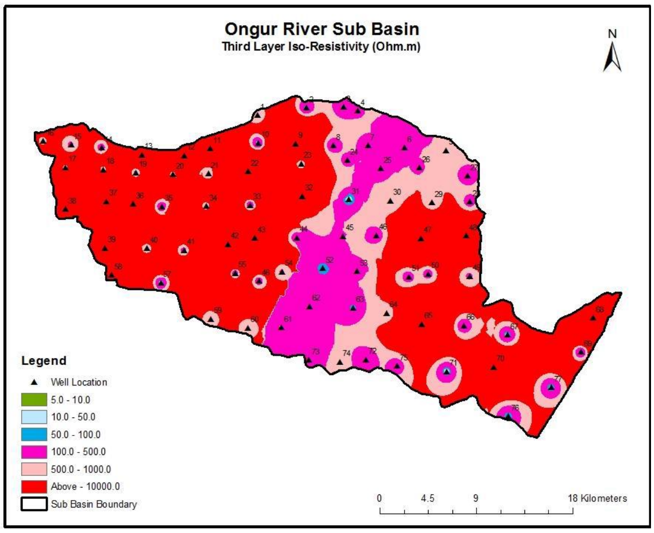

Fig. 5. Third Layer Isoresistivity Map

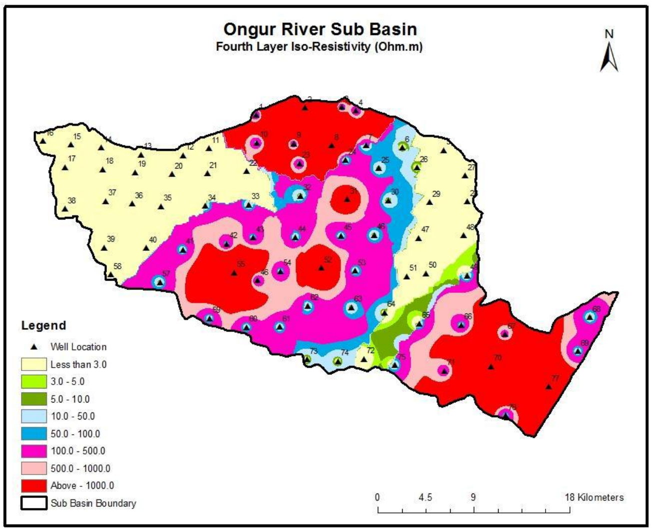

Fig.6. Fourth Layer Isoresistivity Map

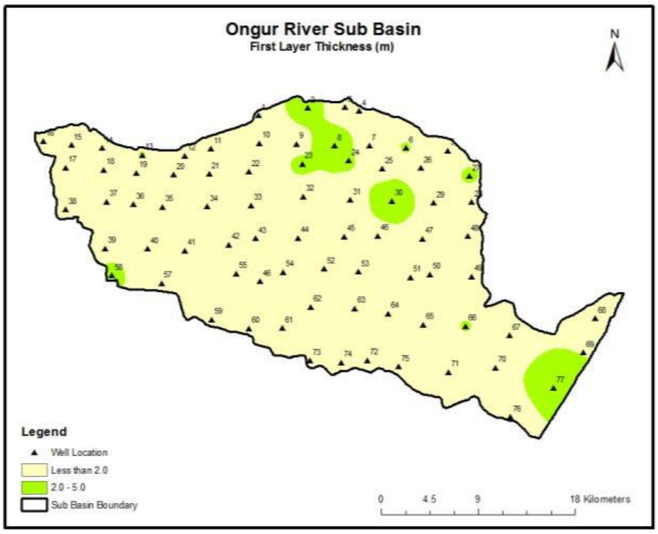

Fig. 7. First Layer Thickness (m)

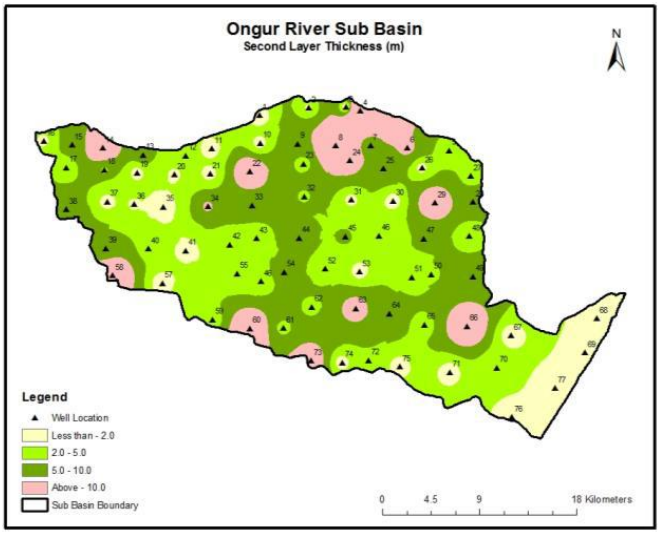

Fig. 8. Second Layer Thickness (m)

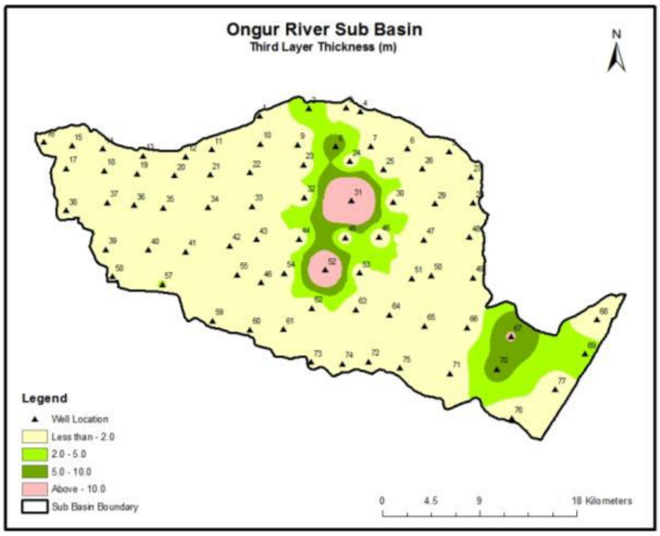

Fig. 9: Third Layer Thickness (m)

Iso-apparent Resistivity:

The Isoapparent Resistivity maps at the depth of -10 m, -20 m, -30 m, -40 m and -50 m from the surface have been prepared and to identify high and low resistivity zones (Pal et al,2001) in the study area. These iso-apparent resistivity contours are very much helpful in delineating the lateral variation of the subsurface geology. Generally, high resistivities formations show poor conductivity values and a low resistivity value indicates good conductors, have suggested iso-apparent resistivities are useful in delineation of low apparent resistivity zone equals with that of thicker weathered formation. Iso-apparent resistivity at -10 m ranges from 3.76 Ω m - 214.68 Ω m. The low resistivity has been observed at Timmapuram (Loc.No.8) and the highest resistivity of 521 Ω m has been identified in Sengenikuppam (Loc.No.36) (Fig. 10).

The high resistivity (above 50 ohm.m) at -10 m below ground surface indicat, the presence of compact formation at shallow depth. These high resistivity zones are seen as pockets in the study area.

The Iso-apparent resistivity at -20 m details the distribution of resistance at the depth of 20 m from the surface. The low and high resistivity values range from 4.98 Ω m to 342.17 Ω m respectively (Fig 11). The minimum resistivity is observed in Timmapuram (Loc.No.8) and at the 4.98 Ω m and maximum resistivity value of 342.17 Ω m is observed at Sengenikuppam (Loc.No.36).

Low resistivity values (below 50 ohm.m) in this depth indicate presence of good weathered formation. Major part from central region to eastern coastal comprises above-mentioned low resistivity values which are suitable groundwater exploration. Iso-apparent resistivity at the depth of -30 m show the resistivity ranges from 2.75 Ω m-428.84 Ω m (Fig. 12). The low resistivity is observed at Timmapuram (Loc.No.8) and maximum resistivity is at Sengenikuppam (Loc.No.36). Generally, in hard rock terrain, -30 m depth are occupied by the massive rock formation. In the -30 m depth, low resistivity indicates the presence of weathered / fractured zones. In the study area low resistivity (30 m depth) are found in Nemam (Loc. No. 4), Chithamur (Loc. No. 5), Timmapuram (Loc. No. 8), Nallur (Loc. No. 13), Tholupedu (Loc. No. 31), Olakkur (Loc. No. 43), Avanippur (Loc. No. 50), Pannaiyur (Loc. No. 52), Grandipuram (Loc. No. 56), Nolambur (Loc. No. 60), Kolathur (Loc. No. 65), and Chunambedu (Loc. No. 66).

These low resistivity zones are good potential groundwater zones. The low resistivity found in the some places near coastal tract are may be due to saline intrusion.

The resistivity values ranges from 1.98 Ω m- 504.72 Ω m at -40 m depth (Fig.13). The low resistivity are observed in Naravakkam (Loc.No.69) and highest resistivity in Sengenikuppam (Loc.No.36). Presence of low resistivity at -40 m depth indicates existence of fracture zones. Sea water intrusion is indicated by low resistivity at few coastal regions at this depth. Isoapparent resistivity at -50 m depth range from 2.33 Ω m to 5989.78 Ω m (Fig. 14). The low resistivity has been observed at Naravakkam (Loc.No.69) and the highest resistivity of 521 Ω m has been identified in Sengenikuppam (Loc.No.36).

The weathering and fractured zone are prominent at the south part, few pockets at central regions. Sea water intrusion is confirmed by the presence of low resistivity along the coastal locations at various depths.

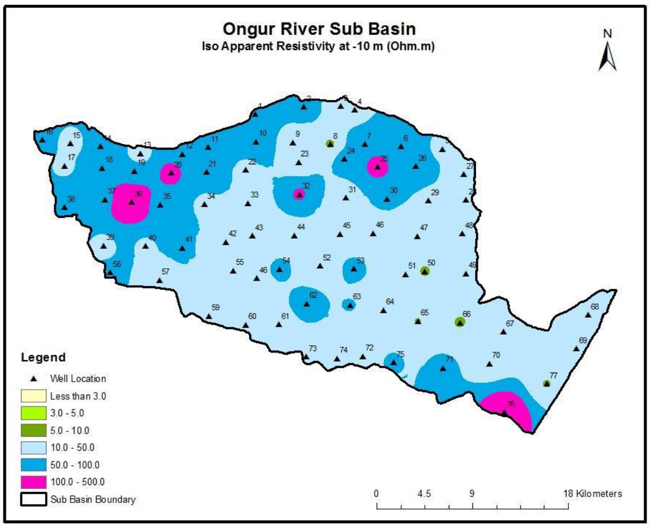

Fig. 10. Isoapparent resistivity at -10 m depth from surface

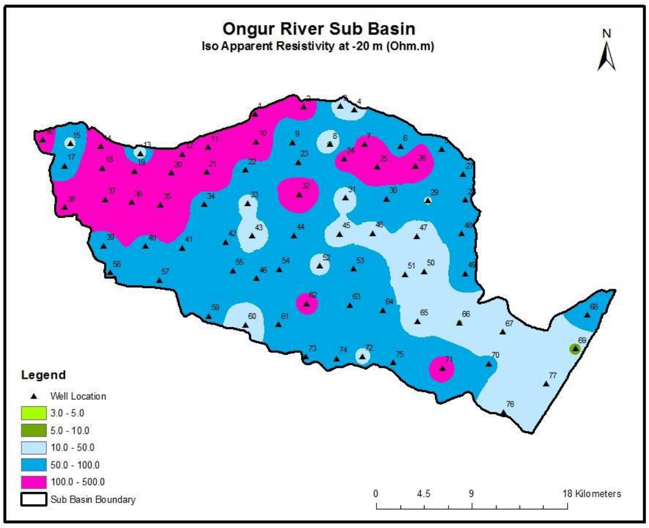

Fig. 11. Isoapparent resistivity at -20 m depth from surface

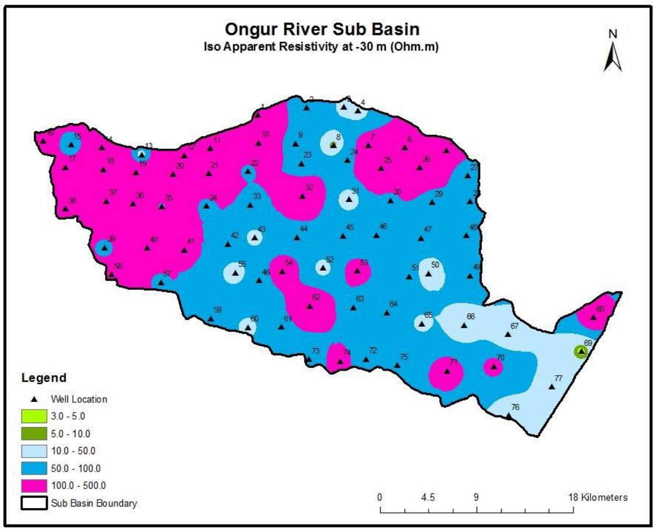

Fig. 12. Isoapparent resistivity at -30 m depth from surface

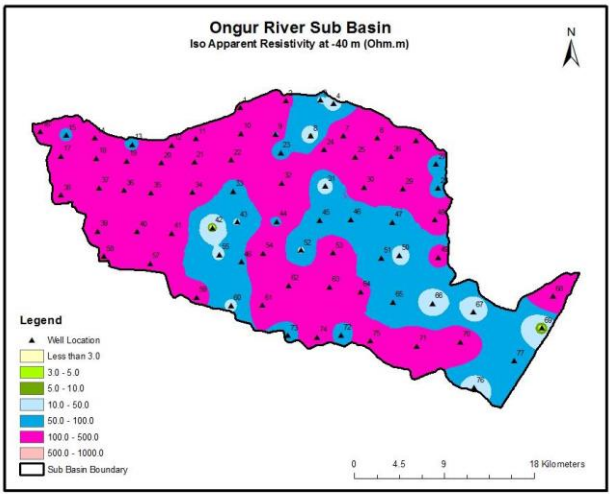

Fig. 13. Isoapparent resistivity at -40 m depth from surface

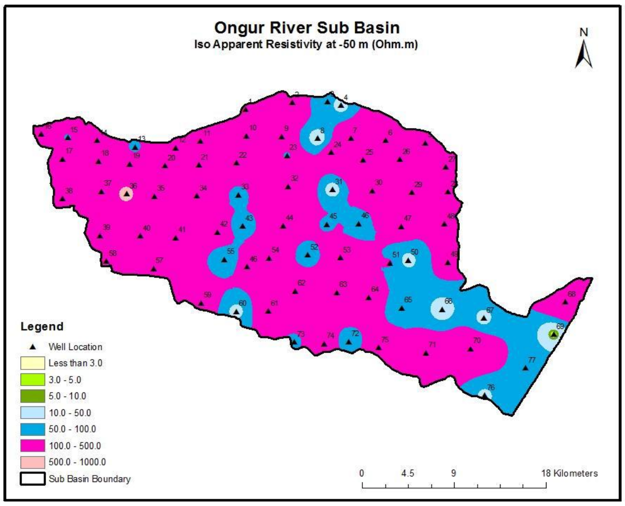

Fig. 14. Iso - apparent resistivity at -50 m depth from surface

Conclusions

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. Iso-apparent resistivity at various depths such as -10, -20, -30, -40, and -50 m from the surface show that depth to the basement increases towards the coast from western part of the study area to eastern region.

Reference

- Alile, M.O., S.I. Jegede and O.M. Ehigiator, (2008): Underground water exploration using electrical resistivity method in Edo State, Nigeria. Asian J. Earth Sci., 1: 38-42.
- Arulprakasam. V. 2009, Report on Spot Electrical Sounding Survey in parts of Vanur block of Villupuram District, Tamilnadu. CGWB, SECR, Unpublished Report.
- Gopinath. V.S.T, Vinodh. K, Gowtham. B and Arulprakasam. V (2015) Geoelectrical Characterization Of Substrata By Using Geoelectrical Imaging Technique In Ongur River Sub Basin, Tamilnadu, India, International Journal of Scientific Engineering and Applied Science (IJSEAS) - Volume-1, Issue-6, pp 451 – 457.
- Olasehinde, P.I., (1999): An integrated geological and geophysical exploration for groundwater in the basement complex of west central Nigeria. Water Resourses, 10: 46- 49.
- Olorunfemi, M.O and S.A. Fasoyi, (1993): Aquifer types and the geoelectric/hydro geologic Characteristic of part the central basement terrain, Niger State. J. Afr. Earth Sci., 16: 309-317.
- Orellana.E& Mooney H.M, 1966, Master curves of Schlumberger Arrangement. (Pub-lished).

- Pal, S.K. and Majumdar,R.K.(2001) Determination for groundwater potential zones using iso-resistivity map in the alluvial areas of Munger district, Bihar, Jour. Earth Sciences, nos. 1-4,pp.16-26.
- Plummer, C.C., D. Mc Geory and D.H. Carlson, (1999): Physical Geology. 8th Edition, McGraw Hill Co. Inc., New York, pp: 48-56.
- Sarma. S.V.S., Harinarayana. T, Virupakshi. G, Someswara Rao. M. Madhusudana Rao, Nandini Nagarajan, Sastry. T.S. and Sprabhakar E. Rao, (2004) Magneto Telliricinves-tigations in the Deccan Trap covered areas of Nagpur-Wardha Region India, Jour. Of geophysics, October 2004, Vol XXV, No.4, pp 87-91.
- Senthilkumar, S., Gowtham, B., Vinodh, K., Arulprakasam, V., and Sundararajan, M. (2017). Delineation Of Geoelectric Layers Using Imaging Techniques In Coastal Blocks Of Thiruvallur District, Tamil Nadu, Indian journal of Geo-marine Sciences, Vol. 46(05), May 2017., pp.986-994.
- Senthilkumar, S., Balasubramanian, N., Gowtham, B., Lawrence, J. F. (2014). Geochemical signatures of groundwater in the coastal aquifers of Thiruvallur district, south India, Appl Water Sci, DOI 10.1007/s13201-014-0242-2.
- Singh, K.K.K., A.K.S. Singh, K.B. Singh and A. Singh (2006): 2D resistivity imaging survey for siting water-supply tube well in metamorphic terrains: A case study of CMRI campus, Dhanbad, India. The Leading Edge, 25: 1458- 1460.
- Zohdy, A.A.R, (1974) Application of surface geophysics to groundwater investigators, USGS, Washington D.C.
- Zohdy, A.A.R, (1989) A new method for the automatic interpretation of Schlumberger and Wenner sounding curves, Geophysics, v. 54, n 2, pp 245 – 253.