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Audio magneto telluric and geoelectric signatures of un-consolidated coastal sedimentary formations-an integrated geophysical approach for targeting freshwater phreatic aquifers

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Key words: Audiometer telluric, Phreatic aquifer, Ground water

Abstract

For exploring groundwater resources in any terrain, employing vertical electrical sounding [VES] technique is the common practice. This study pertains to comparing and correlating Audio magneto telluric [AMT] profiling with 1D vertical electrical sounding to prospect the groundwater potential pocket for an irrigation project in an unconsolidated coastal sedimentary terrain for targeting freshwater phreatic aquifers in saline environment. The area falls in Chinnamanulur village of Kilvelur block in Nagappattinam district, Tamil Nadu, South India. A borewell drilled to a depth of 150 feet was not successful as good sand aquifers could not be met. The area of investigation is with an extent of about twenty acres of agricultural land. There are two shallow tubewells of about 16 feet depth and with these two sources only water need is managed. The TDS [Total dissolved solids] of this well is 385 PPM [parts per million]. An attempt has been made to prospect the freshwater aquifers by an integrated geological, hydrogeological and geophysical approach with combined geoelectric and AMT sounding/scanning. Three two-dimensional audio magneto telluric imaging followed by three 1 dimensional vertical electrical soundings [1D VES] were conducted. A shallow sand aquifer zone could be explored and one pilot borehole was drilled engaging calyx drill to a depth of 30 meters. A good medium to coarse grained sand with a thickness of 10 meters was encountered from 18 to 28 meters below ground level. As the soil samples and water were tasted frequently for every two meters, found to be good without any brackish/salinity taste and no marine gastropod shells were encountered in soil samples, a tubewell of 178 mm diameter was bravely constructed to a depth of 29m without conducting electrical well logging. The well was developed and completed after 4 days. As the attempt, findings and results were encouraging and positive; the tubewell was constructed successfully and fruitfully. The discharge of well is reported to be 63 liters per minute [LPM] and the quality of water is also good and fresh. It is recommended to test the water sample physiochemically tested for suitability for agriculture.

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Introduction

The Nagappattinam district and terrain is generally predominant with marine origin sediments with lot of in situ groundwater quality problems. Due to quality issues agriculturists did not take much risk in deep drilling to tap groundwater. The very shallow- shallow aquifers are generally good and fresh in nature. The deep and very deep aquifers are brackish to saline in general. It is reported that the tubewell constructed up to a depth of 37 meters for village water supply is with a TDS of 1480 PPM in the nearby vicinity. A comprehensive protected drinking water supply schemes [CWSS] have been implemented almost for all the rural villages of Nagappattinam district from Kollidam river mainly due to many quality issues and one among is, the excess iron and TDS contents of groundwater.

Geological and hydrogeological background

The entire Nagappattinam district is plain terrain with a gentle slope towards east. The district falls in both Cauvery and Vennar sub basins. The terrain of the district is sedimentary underlain by various geological formations ranging in age from Pliocene to the recent alluviums and dominated by semi consolidated sedimentary Quaternary formations consisting of fluvial, fluvio-marine and marine facies. The Litho units are soils, fine to coarse grained sands, silts, clay, laterites, gravels etc. The geomorphic units being alluvial plains, deltaic plan and flood plains. Flood plain deposits are found near the river courses.

The major geological formations are alluviums, fluvio marine shale, silt, marine sands sandy clay. The geomorphic setup is the result of action of the major rivers, fluctuation in the sea level, tidal effects of Bay of Bengal and forces of wind. Depositional regime comprises of a coastal plain under marine influence, a flood plain of fluvial regime with an intermixing section of both fluvial and marine influences. Sand dunes and beach ridges are very common along the sea coast. Major part of the district is covered by black clayey soils. The district forms part of the Cauvery River basin and is drained by a network of rivers like Cauvery, Kollidam, Arasalar, Vettar and Pamniyar. South- and south-central parts are drained by the distributaries of Vennar viz, Vettar, Pamniyar etc. The drainage pattern is sub dendritic.

Ground water occurs in all the geological formations ranging in age from lower Miocene to Recent, under unconfined, semi confined and confined conditions. The occurrence and movement of ground water are controlled by climate, topography, geomorphology, geology and structures etc. Groundwater is developed by shallow filter points for domestic, shallow tubewells of 2 to 3 numbers are coupled for agricultural purposes which are the common practice. The district receives maximum rainfall during Northeast monsoon period i.e. October to December. The average district rainfall is 1405.8 mm. In the post-monsoon period, the average water level ranges between 1.1 to 3.3 m and in the pre-monsoon period it varies from 2.1 to 5.5 m. iron and TDS are the two major parameters that renders most of the sources as non-potable. As per the central water commission [CWC] categorization of blocks, six blocks come under poor and saline category and of which Kilvelur, Keezhaiyur, Nagappattinam blocks are in this category.

Geophysical exploration

Geophysical methods can be used to measure the spatial distribution of the physical properties of the subsurface specifically related to the depth of aquifer and its quality, and the subsurface lithology, structure. Geophysical methods, however, do not directly determine water quality or the geologic units. These must be interpreted from the distribution and magnitude of the physical properties interpreted from geophysical surveys. The application of Geophysical techniques to explore ground water is referred as Ground water geophysics or Hydro geophysics. Essentially the geophysical methods comprise of measurement and interpretation of signals from or induced physical phenomena generated as a result of the spatial changes in or more physical properties of sub terrain formation. The electrical resistivity is an intrinsic function of groundwater chemistry, and the degree of saline intrusion can be readily interpreted. Electrical methods also have the advantages of being non-intrusive, economical, and are relatively fast. DC resistivity methods can be used to measure the bulk resistivity of the subsurface. Bulk resistivity represents the resistivity of the entire subsurface, including both the solid and liquid phases. Electrical resistivity is the property which controls the amount of current that passes through a rock when a potential difference is applied, given by Ohms law, V=IR, (V) voltage, (I) current, (R) resistance. The resistivity of pore fluid depends upon the concentration of ions in the fluid. Saline water has high concentrations of total dissolved solids, mostly sodium and chloride ions, which are highly conductive. Therefore, water with high salinity has very low resistivity. DC resistivity introduces electrical currents into the ground through current electrodes in contact with the soil. The resulting electrical potential (voltage) is measured between two potential electrodes.

The resistivity is defined as the resistance offered by a unit length of a substance of a unit area to the flow of electric current when the voltage is applied at the opposite faces (Fig. 1&2).

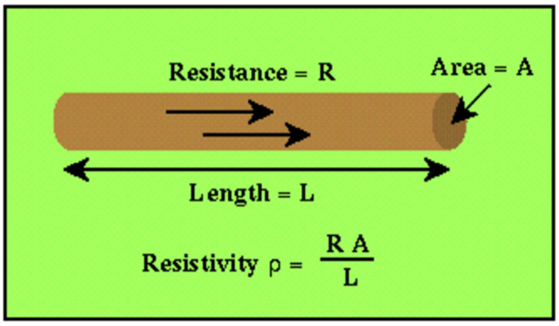


Fig. 1. Resistivity

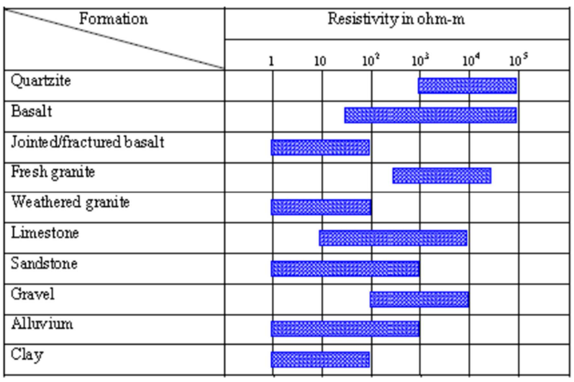


Fig. 2. Resistivity survey field layout

The inverse of resistivity is termed as conductivity and the inverse of resistance is called conductance. Resistivity of a geological formation may be considered as a function of moisture content (porosity and water saturation) and salinity of the saturating water. The rocks containing high concentration of metallic minerals and saline water may show resistivities less than 1 ohm-m to a few ohm-m. The resistivity of a formation can be used to know the nature of the formation and distinguish the saline and fresh water zones (Fig. 3).

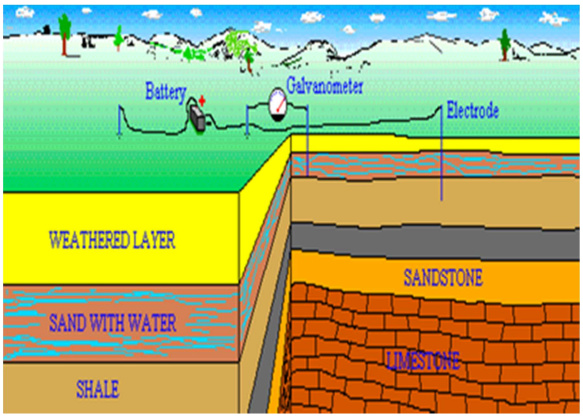


Fig. 3. Audidiomagneto telluric imaging

Audidiomagneto telluric imaging

Audidiomagneto telluric imaging is a geophysical technique coming under Electromagnetic method, based on theories of magneto telluric sounding method, MT method, AMT method, frequency sounding method, Natural Electrical Prospecting method and so on. It monitors abnormal variation of electrical resistivity, which is generated by different geological bodies.

Materials and methods

Working principle

The AMT technique water detector is based on magneto telluric (MT) method, which is an important geophysical method to study the Earth's electrical structure using the natural EM field as its source. The ADMT water detector used in this study works on the Electromagnetic Wave Propagation principles based on Maxwell's equation. The electromagnetic wave frequency of (0.1Hz~5 KHz) is applied by this detector. The depth of electromagnetic wave is related to frequency and resistivity. When frequency fixed, the higher the resistivity, lower the frequency deeper depth of penetration is achieved. ADMT-300S electric water detector is specially designed for detecting underground water resource, which is convenient, efficient and accurate. At present, it is one of the most economic and effective rapid detecting method employed for groundwater and geothermal prospection. The wiring diagram during fieldwork is as shown in the diagram.

Two-poles profile measuring method

This method is mainly used for confirming the position, width and general depth of geological anomalous body (Fig. 4 &5).

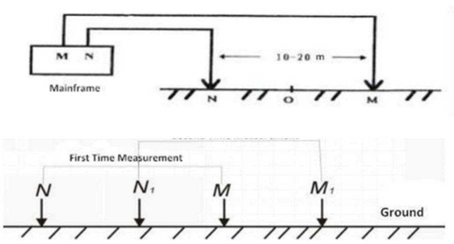


Fig. 4. Field layout of MN electrodes

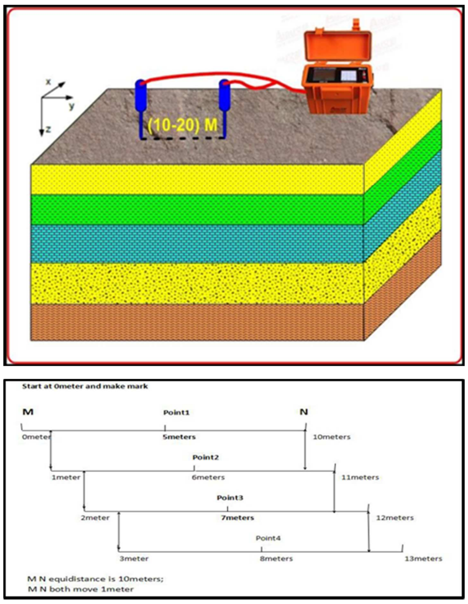


Fig. 5. MN electrodes shifting in field

Geophysical explorations carried out in the area of investigation

Audio magneto telluric imaging

Initially two-dimensional Audio magneto telluric [2D AMT] imaging was done using ADMT-300S water detector (Fig. 6&7). Totally four profiles were run to prospect the feasible potential pockets. One profile was run near the failed borehole of 150 feet deep to study the subsurface. All the four profiles were run keeping the MN electrode spacing constant to 10 meters and dot point spacing i.e. interspacing of observation points to 01 meters constant. The detector is capable of scanning up to a depth of 300 mbgl. The mid-point between MN electrodes is the observation point. The profile traverse is north to south. All the profiles and data have been stored in CSV format as excel files in the Mobile installed with ADMT app. Each profile is exhibited in 2D view. The X-axis abscissa represents the observation points along the profile line and the Y-axis ordinate denotes the depth in meters below ground level. The color scale indicates the milli-volt values and the dark blue color indicating the least and red color denoting the maximum mv values. The low anomaly zones with dark blue contours and the high anomaly zones with red color contours.

Fig. 6. D AMT scanning in the field with ADMT-300S model

Fig. 7. ADMT-300S scanner

Geoelectric exploration- 1D vertical electrical sounding [1D VES]

One dimensional vertical electrical sounding [1D VES] have been carried out in the low millivolt anomalous prospective zones of 2D AMT profiles, using IGIS Hyderabad make, model SSR-MP-AT-S microprocessor-based resistivity system, employing Schlumberger configuration with minimum AB/2 separation as 100 m and maximum AB/2 electrode separation as 350 meters traversing in east-west direction (Fig. 8). The instrument displays, SP, I, R, pa and strip [true resistivity] resistivity and all these geoelectric parameters have been manually noted and saved in the system in notepad format. In total three VES have been conducted- VES 7, VES 10 and VES 11.

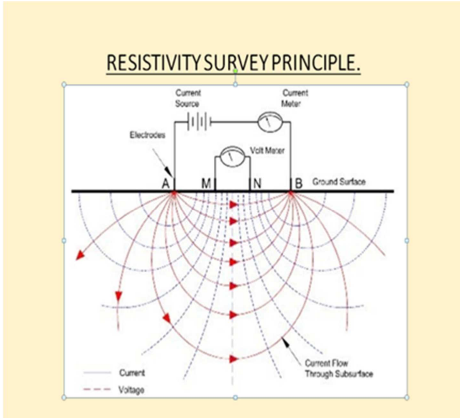
Fig. 8. IGIS-SSR-Mp-AT-S resistivity meter

All the AMT profiles, data saved in the mobile and 1D VES data saved in the machine have been transferred to the laptop for further processing, interpretations and analysis. The VES curves have been qualitatively and quantitatively interpreted using IPI2 Win and Rinvert software packages to get the geoelectric parameters and ultimately geoelectric sections have been generated. Based on the geological, hydrogeological conditions integrating the 2D AMT profiles, contours with the geoelectric sections the subsurface lihology have been delineated and deciphered. Finally, the groundwater potentials and prospective fresh water sand aquifers have been targeted.

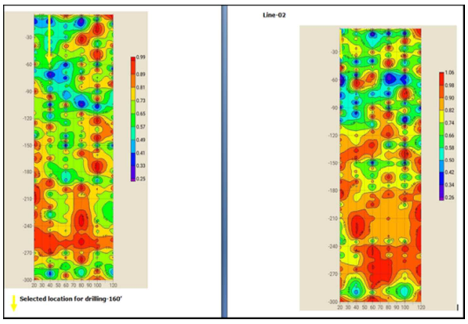
Results and discussion

2D AMT profiles

Totally four 2D AMT profiles were run, they are Line-01,02,03 & 04. In Line-01 profile the minimum and maximum millivolt [MV] values are 0.25 & 0.99 (Fig. 9).

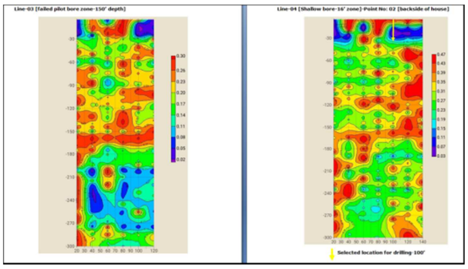


Analysis of 2D AMT profiles, contours and VES curves, geoelectric parameters and sections



Line-01 Line-02

2D AMT profiles



Line-03 [Failed pilot bore zone-150'] Line-04 [Shallow bores-16' zone]

Failed borehole drilled location Failed borehole drilled location

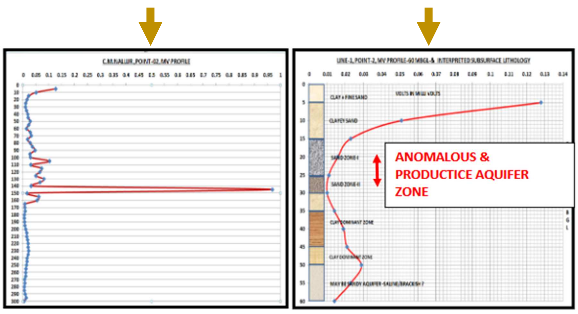


Fig. 9. Point-2, MV profile 300m depth & 60m depth

The light blue and dark blue low contour anomalies indicate the sandy aquifer zones. In this profile dominant low anomalies can be seen from 0 to 100 mbgl. In deeper depths anomalies are scattered & not dominant. In the MV profile of point 02-Line-01, generated to a depth of 60m crystal clearly shows very low MV anomaly between depth range of 15-30 m with mv values of 0.01 to 0.022 mv, where in good sand aquifers of fresh water nature was struck confirming the significance of such low anomalies. This anomaly being the prominent, encouraging where sand aquifers may be got at shallow depths, was recommended in correlation with VES findings, to drill pilot bore. As interpreted and anticipated a good medium to coarse grained sand pocket was encountered below 18 m depth with a thickness of 09m.

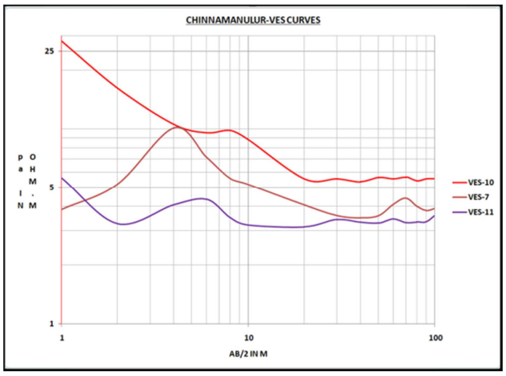


Fig. 10. VES curves-10,7 & 11 (Analysis of 1D VES curves, geoelectric sections)

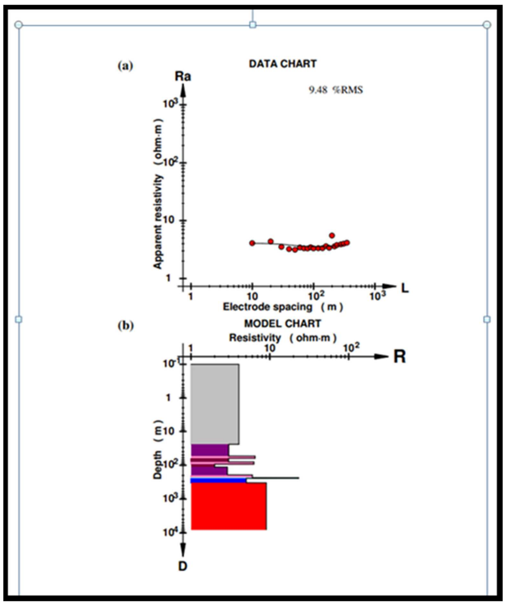


Fig. 11. ves-11, inverse modeling-Interpreted by Rinvert software

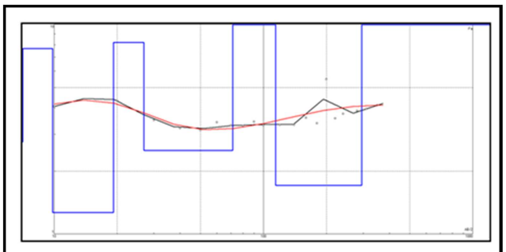


Fig: C.M.Nallur, VES-11-VES curve [Fitting error-5.24%]

N	ρ	h	d	Alt
1	2.76	3.31	3.31	-3.30
2	7.67	6.53	9.84	-9.84
3	1.26	9.34	19.2	-19.1
4	8.2	7.66	26.8	-26.8
5	2.51	44.6	71.4	-71.4
6	19.9	9.76	81.2	-81.1
7	10.7	33.2	114	-114.
8	1.7	181	295	-295.
9	66.5			

Table: , Geoelectric parameters

Fig. 12. VES-11 interpreted by IPI2 Win

In line-02 profile too same anomaly pattern is exhibited, where at point 2 low MV anomaly is prominent. The low and high values are 0.26 & 1.06 MV respectively. In Line-03 the least and maximum MV values are 0.02 & 0.3 respectively. The failed borehole was drilled to a depth of 150 feet @ point no 8, where high MV anomalies can be observed and no good sand aquifers was not encountered. Two low anomalies are observed at shallow depths @ points 2-3 & 9-12. Of course, some good low anomalous zones could be seen in deeper depths but due to quality issues and geoelectric investigation results are not positive, deep bore was not suggested. In line-04 the low and high MV values are 0.03 & 0.7 respectively. Good low anomalies can be seen between points 1-4 and 9-12 that too in shallow depths only. Another bore point @ point 10 of this profile, was recommended as second preference to be drilled up to 30m. At deeper depths too only some blue color anomalies which are not prominent are exhibited sporadically.

Geoelectric profiles and sections

In total three 1D VES 7, 10 & 11 were conducted (Fig. 10, 11&12) and the minimum and maximum recorded apparent resistivity values are 3.12 & 28.29 Ωm. All the three VES curves are combination of mostly QQ type curves and multilayered geoelectric earth. The pa values of the very deepest sounding data VES-11 are in the low range 2.1 to a maximum of 5.468 Ωm indicative of brackish/saline quality of water. The low true resistivity values of 2.7 & 1.7 Ωm of VES-11 registered in the depth range of 71 and 295 mbgl may be indicative of brackish/saline nature of the deep aquifers too.

Correlation of AMT and VES profiles

The integrated and correlative studies of both AMT and geoelectric profiles throws light on the subsurface geology. In both profiles no good prominent anomalous zones can be observed below 120 mbgl clearly revealing the poor possibility of occurring prospective potential pockets (Fig. 13, 14&15).

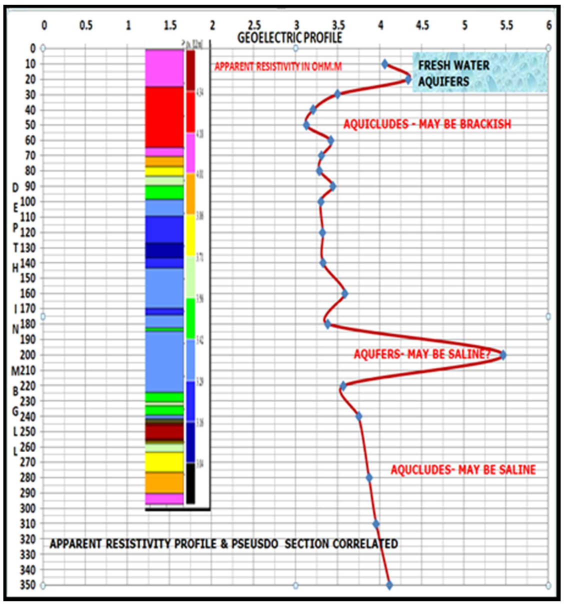


Fig. 13. Apparent resistivty profile & pseudo section correlation

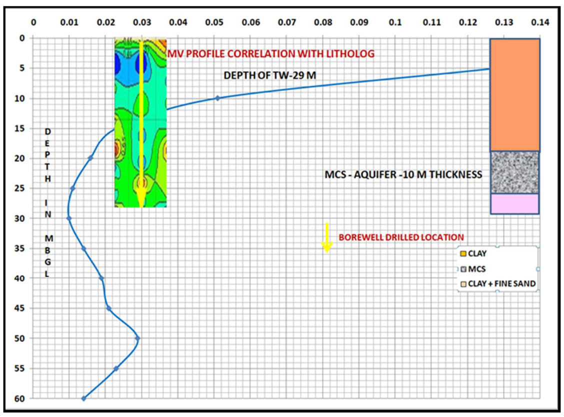


Fig. 14. Correlation of 2D AMT profile & litholog

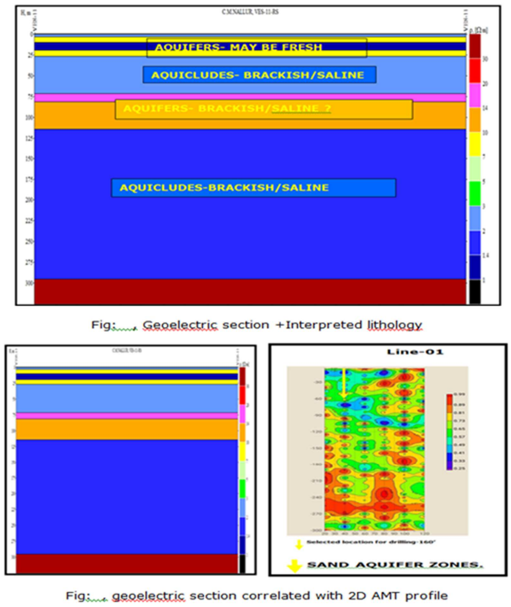


Fig. 15. GES + interpreted lihology & GES correlation with2D AMT Profile

Findings and outcome of the integrated research study

Fig. 16 and 17 depicted the Findings and outcome of the integrated research study.

Fig. 16. Bore soil samples- yellowish white clay-0 to 19m & MCS-19-28m

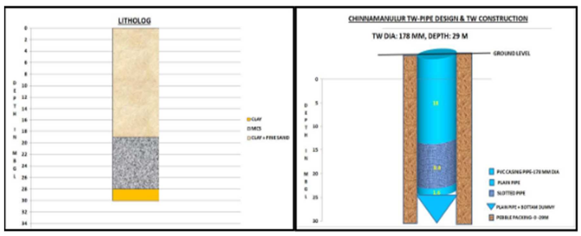


Fig. 17. Litholog and tubewell design & construction

Based on the integrated geophysical investigations coupled with detailed geological, hydrogeological studies, the area of investigation namely

Chinnamanulur in Kilvelur block of Nagai district is a coastal sedimentary terrain with many groundwater quality problems. From the early previous studies of this area by various researchers, organizations and departments also reveal the same report. Though any hydrogeochemical investigations have been done by us, based on the findings of geoeletric and AMT surveys a shallow fresh water aquifer could be successfully and fruitfully targeted and exploited for irrigational need with minimum investment by this integrated approach. The outcome and successful result of this investigation hold good for the benefits of farmers facing many constraints in groundwater exploitation.

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