

Evaluation of shallow aquifers contamination along Cauvery River Basin using Electrical resistivity and hydro chemical investigations

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ABSTRACT

The reasons for deterioration of quality of water in coastal aquifers are many. To investigate some of them, electrical resistivity surveys were carried out in the study area namely Cauvery sedimentary basin. A total of about 300 vertical electrical soundings (VES) using Schlumberger array was used for the study. Groundwater samples were also collected from shallow dug wells, hand pumps and ponds at sounding locations for chemical examination of TDS and chloride to correlate with the resistivity data for confirmation of quality of the groundwater. The sources of freshwater in the study area include the shallow unconfined aquifer below the dry unconsolidated layer as well as a series of confined aquifers below it.

The resistivity data was analyzed for true values by inverting the sounding data using partial curve matching as well as software methods. The interpretation of VES data reveal that the low resistivity regions corroborate with higher TDS and Chloride values mostly falling over areas occupied by rivers, canals and inlets which are connected to the sea. The seawater might be flowing into the mainland through these inter connected canals, rivers and inlets due to the action of waves and shore currents resulting in the infiltration of sea water into the shallow aquifers. The permeable zones occurring in proximity to backwater canals are most vulnerable for saline water intrusion and may further damage the deeper aquifers through seepage. The present surveys have clearly established regions of saltwater contamination and causes for deterioration of shallow aquifers. The present surveys helped in the classification of low resistivity regions, corroborating well with the high cut off values of TDS and chloride. This demarcates clearly saltwater contaminated areas. These results may possibly help in taking preventive measures to obstruct backwater flow through rivers and inlets due to tidal action by constructing barriers to safeguard the environmental disorders.

Key words: Coastal aquifers, Saltwater intrusion, Vertical electrical sounding, Water analysis and Cauvery basin.

INTRODUCTION

Water requirements have increased manifold with the growing population and rising industrial and irrigation growth in India. With the growing living standards and health awareness of mankind, the demand for good quality of water is increasing day by day. Many coastal aquifers in the world, especially shallow aquifers experience an intensive saltwater intrusion caused by both natural and human induced processes. The study area is situated between Puducherry in the north and Chidambaram in the south (Figure 1), close to the Bay of Bengal coast in the East. Groundwater levels were deteriorating due to low rainfall and trapping of ground water through pumps for irrigation, industrial and drinking purposes. Consequently, the river system connected with the sea is experiencing reverse flow of sea water due to action of waves and shore currents. The flow of backwaters in Gingee, Mallattar, Gadilam, Uppenar and Vellar streams flowing in the study area are likely to aid recharge through infiltration and seepage of shallow layers where the permeable beds are exposed in the river bottom.

Excessive pumping of freshwater from an aquifer reduces the water pressure and intensifies the effect of drawing nearby sea water into permeable zones. Indiscriminate drilling of bore wells and hand pumps for discharge of groundwater at various depths may also causes the invasion of saltwater into freshwater aquifers by inward flow. This may causes the pollution of the underground water in the coastal area and hence, reduces the potability of such water for human use. In order to distinguish such polluted zones and causes for pollution of underground water along the coast, Geophysical investigations comprising of Vertical Electrical Resistivity soundings have been used.

Geology and Hydrogeology

The area is occupied by Tertiary sediments, ranging in age from Eocene to Mio-Pliocene (Figure 2) with most part covered by Quaternary sediments. The Quaternary (Recent) formations in the region are represented by laterites and alluvium. Laterite occurs as thin cap over the Cuddalore formations. The alluvium in the area is composed of

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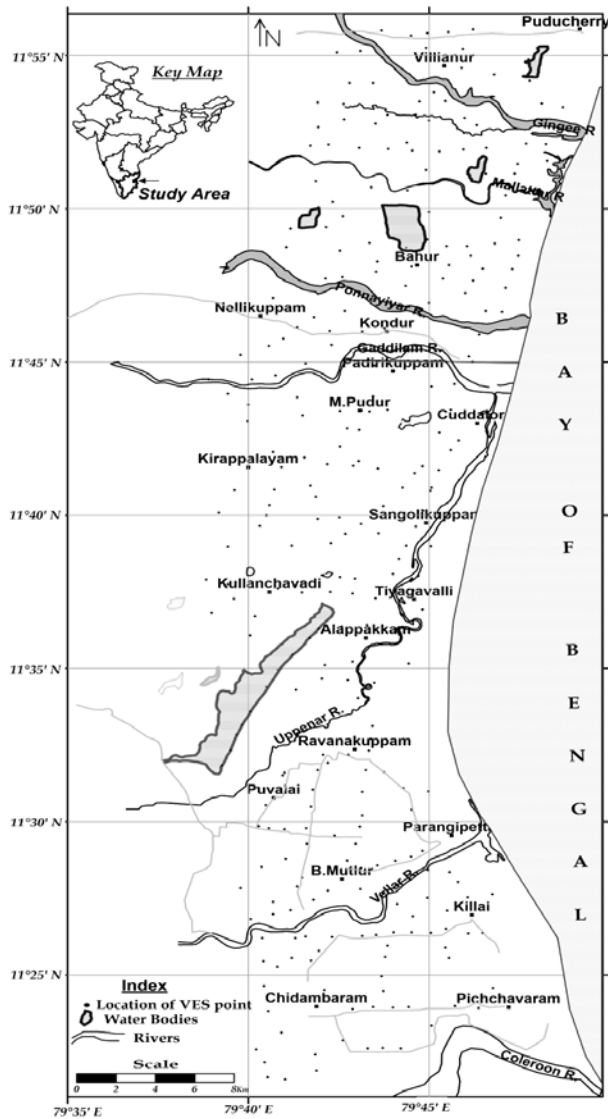


Figure 1. Location Map.

sands, clays, silts, gravels and kankar. Thick alluvial deposits are formed along the course of Rivers Ponnaiyar, Gadilam, Malattar and Gingee. The Tertiary formations are represented by the Kadapperikuppam, Manaveli and Cuddalore formations. The study area is covered by Cuddalore formation composed of thick succession of pebbly and gravelly, coarse-grained sandstones with minor clays, rarely with thin seams of lignite (Subramanyam, 1969). In the North western margin, the Cuddalore formation overlies the Ramanathapuram formation by completely concealing them and overlapping the Vanur sandstones. In the North eastern portion they overlie the Manaveli formation. The thickness of these formations varies from 30 m to 130 m at outcrop area and maximum thickness of 450 m is along the coast in the South eastern side (Subramanyam and Selvan, 2001).

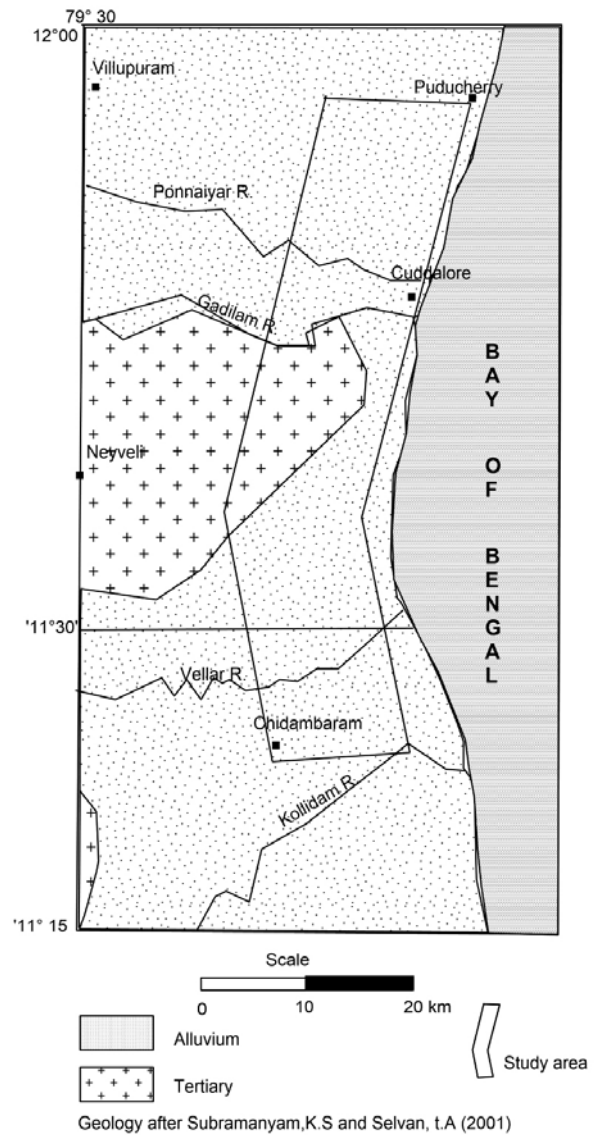


Figure 2. Regional Geology Map.

Groundwater occurs in Tertiary formations under un-confined to semi-confined condition. The depth of the tube wells tapping this aquifer ranges between 25 m and 50 m bgl.

The stratigraphy of the area has been established by the Oil and Natural Gas Commission (Varadarajan, 1969) by carrying out detailed geological, geophysical surveys and drilling 9 shallow boreholes. The area under study can broadly be classified into western high ground and eastern Gadilam-Ponnaiyar and Vellar alluvial plains. The drainage of the area is controlled by the Gingee, Malattar, Ponnaiyar, Gadilam, Uppenar and Vellar rivers and their tributaries. These rivers, though perennial, have only insignificant flows. The Bahur tank in the northern part and Perumal Eri in the south-central part of the area stores ample rain water and serves the needs of irrigation domain and may

Table1. Derived Resistivity ranges for different formations.

S.No.	Resistivity (Ω -m)	Lithology
1	100-500	Laterite, Lateritic soil
2	250-800	Dry Beach sand
3	1-10	Clay/sand/gravel/sandstone with saline water
4	10-30	Clay/sand/sandstone with brackish water
5	30-200	Sand/gravel/sandstone with freshwater

also recharge the shallow aquifers through seepage and infiltration. The observed water levels in the recent alluvial aquifers ranges between 2.18 to 20 m below ground level (Central Groundwater Board, 2012). Decline in water levels recorded on an average by 1 to 1.5 m annually due to excessive usage of groundwater for all purposes.

Methodology and Instruments

The electrical resistivity method is more commonly used for ground water exploration to demarcate an aquifer with freshwater and saltwater due to substantial resistivity contrast between them. Electrical resistivity soundings, using Schlumberger electrode configuration were carried out with half current electrode separations (AB/2) from 1 to 100m. A total of 300 electrical resistivity soundings were conducted, covering a total area of 770 km² (Figure 1) deploying high precision equipment consisting of Scintrex make square-wave TSQ-3 transmitter and RDC-10 receiver. Briggs and Stratton four stroke, 8 H.P generators was used for producing 230 V alternating current.

Groundwater samples collected from dug wells and tube wells at nearby sounding locations all over the study area were analysed for cations and anions respectively by Flame photometer and Spectrophotometry at NLC Chemical laboratory, Neyveli by adopting standard procedures (APHA, 1998).

Analysis of Data

The resistivity sounding data has brought out AH, HA, KH and HK type of field curves and majority of the soundings represented four layer model. The observed field curves are interpreted qualitatively with partial curve matching technique by using two layer master curves and auxiliary curves (Bhattacharya and Patra, 1968) initially and estimated the number of layers and their parameters. By taking these layer parameters, an initial model is generated using computer software (IX-1D, 2002) which is then iterated until a good match between the observed and the theoretical curve is found. Finally, an appropriate hydrogeological model was generated by overcoming the fundamental limits of the resistivity method.

Chemicals, which are strong electrolytes, such as potassium chloride and sodium chloride, can greatly reduce the resistivity of ground water to less than 1 ohm-m even at fairly low concentrations (Daniels and Alberty, 1966). In general, the ambiguity exists in discriminating clay or saline water zone by observing the range of resistivity values. The order of TDS and Chloride values in individual water sample will help to distinguish the clay or saltwater polluted zone. The higher order TDS and Chloride values in correlation with low resistivity values indicate the zone of contamination with saltwater (salinization).

Discussion of Results

Resistivity of an individual aquifer may vary depending on the quality of the water which in turn is controlled by the amount of dissolved solids in it. The resistivity method is an effective tool to detect any changes in quality of groundwater causing freshwater and saltwater imbalances in coastal aquifers (Urish, D.W. and Frohlich, R.K., 1990). Layer resistivities obtained by the inversion process are controlled by the quality of the water and host rock formation (Burger, 1992). This will help in easy conversion of various resistivity layers into subsurface geological formations with different hydrological conditions. The relationship between the fresh, brackish and saline water with their host media is derived from the analysis of resistivity data for the study area. The following table is prepared based on the resistivity variations for different subsurface formations in correlation with available borehole litholog data.

The water analysis results show that higher TDS and Chloride represent the contamination of saltwater with groundwater. However, the cut off values vary with the area. The cut off values for the contamination of salt water was determined as 1000 ppm for TDS and 250 ppm for Chloride (Balía Roberto et al., 2003). The Environmental Protection Agency (EPA) recommends against the consumption of water having TDS more than 500 ppm. Variations of TDS and Chloride components will readily recognize the areas of different water quality and higher than cut off values will help differentiating saltwater invaded areas very clearly. The drinking water

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Table 2. Drinking water quality standards.

S.No.	Parameter	BIS	ICMR	WHO
1	TDS	500 mg/l	500 mg/l	500 mg/l
2	Chloride	250 mg/l	200 mg/l	200 mg/l
3	Sulphate	200 mg/l	200 mg/l	200 mg/l

- BIS: Bureau of Indian Standards
- ICMR: Indian Council for Medical research
- WHO: World Health Organization

quality standards were tabulated below as per the different organizations.

Two different regions i.e VES stations falling within the 500 m radius from river (close to river path) and VES stations falling outside the 500 m radius (away from river path) were analyzed critically for the quality of the shallow aquifers and causes for change of water quality. The resistivity sounding curves located close to river path are characterized by descending curve showing steep fall and indicating unsaturated soil on top to saltwater saturated sediment below it. Figure 3 shows four typical sounding curves selected in the region of rivers characterized by steep fall of resistivity. The VES curve RS54 observed along Gingee River has four layers. The two consecutive layers below top layer have shown the resistivities of 10.3 and 3.6 Ohm-m respectively below a depth of 2 m. These are possibly corresponding to sand and sandy clay layers contaminated with saltwater. The VES curve RS67 has shown a very distinct low resistivity zone of 2.7 Ohm-m below a depth of 0.55m. This layer possibly represents saline sand or saline clay. The VES curves RS32 and RS34 observed near Malattar has also shown low resistivities for unconfined sand layer below top unsaturated soil. The low resistivity's for shallow layers indicate the infiltration of saltwater. The VES curves located close to the rivers Ponnaiyar, Gaddilam, Uppenar and Vellar has also shown low resistivities for shallow unconfined aquifer.

The sounding curves located away from the river path (backwater channels) have indicated a different subsurface resistivity picture as far as shallow layers are concerned. Figure 4 represent the typical sounding curves namely, RS106, RS121, RS206 and RS59 picked from the study area but away from the vicinity of backwater channels. The shallow layers below the top unsaturated soil cover have resistivities of more than 30 Ohm-m. The layers having higher order resistivities correspond to sand layer saturated with fresh water. From the above analysis, it can be inferred that the region occupied close to backwater channels is influenced by the saltwater infiltration in to the shallow layers

The resistivity contour maps prepared for two different depth segments i.e 5 m and 10 m reflecting the variations in resistivity's based on inverted values. The resistivity contour map (Figure 5) shows resistivity variations for depth segment of 5 m.

The resistivity contour map has indicated low contour values (light grey shades) along the river courses of Gingee, Malattar, Ponnaiyar, Gadilam, Uppenar and Vellar. The contact between low and higher resistivity contours is clearly seen at the passage of Gadilam River. The northern and southern parts, being low lying areas, is characterized with lower order resistivities indicating infiltration of saltwater whereas the central part dominated by high resistivity values is not affected much except the track of rivers. The area between Padirikuppam and B.Mutlur is not affected by seawater leaving a segment passing through Uppenar along northeast-southwest direction in the middle of the study area. The area in the west of Uppenar along Sangolikuppam and Ravanakuppam in the direction of river is characterized with lower order resistivity values suggesting saltwater infiltration. However, the areas close to bay in the east of Uppenar has indicated high resistivities, which may correspond to sand dunes. The area bounded by Vellar is also characterized with lower order resistivity values suggesting deterioration in the quality of water.

The resistivity contour map (Figure 6) for the depth segment of 10m depicts the resistivity variations indicating low resistivity values along the path of rivers. However, the higher range of resistivity values from more than 10 Ohm-m to less than 30 Ohm-m indicates the variation in water quality from saline to brackish in the shallow layers. The resistivity contour map (Figure 6) for 10m depth indicated improved resistivity values varying from 10 to 30 ohm-m compared to 5 m depth segment suggest the improvement in quality of water from saline to brackish. This will further suggests the contamination prevails at shallow levels only due to backwater infiltration. The lower order contour trends noticeably followed the direction of river, clearly indicating the infiltration of saltwater into the shallow aquifers through backwater channels.

The Total Dissolved Solids (TDS) contour map (Figure 7) for shallow levels ranging the depths from 4.5 to 10 m shows higher values along the river courses confirming the lower order resistivities.

The higher order TDS values having more than 1000 ppm were observed south of Devalakuppam between Gingee and Malattar rivers; near Bahur, Kondur along Ponnaiyar and Gadilam rivers; Burgespettai, Cuddalore and Kudikadu areas along Uppenar river and Tiyagavalli, B.Mutlur and Chidambaram areas along Vellar river. The contour map

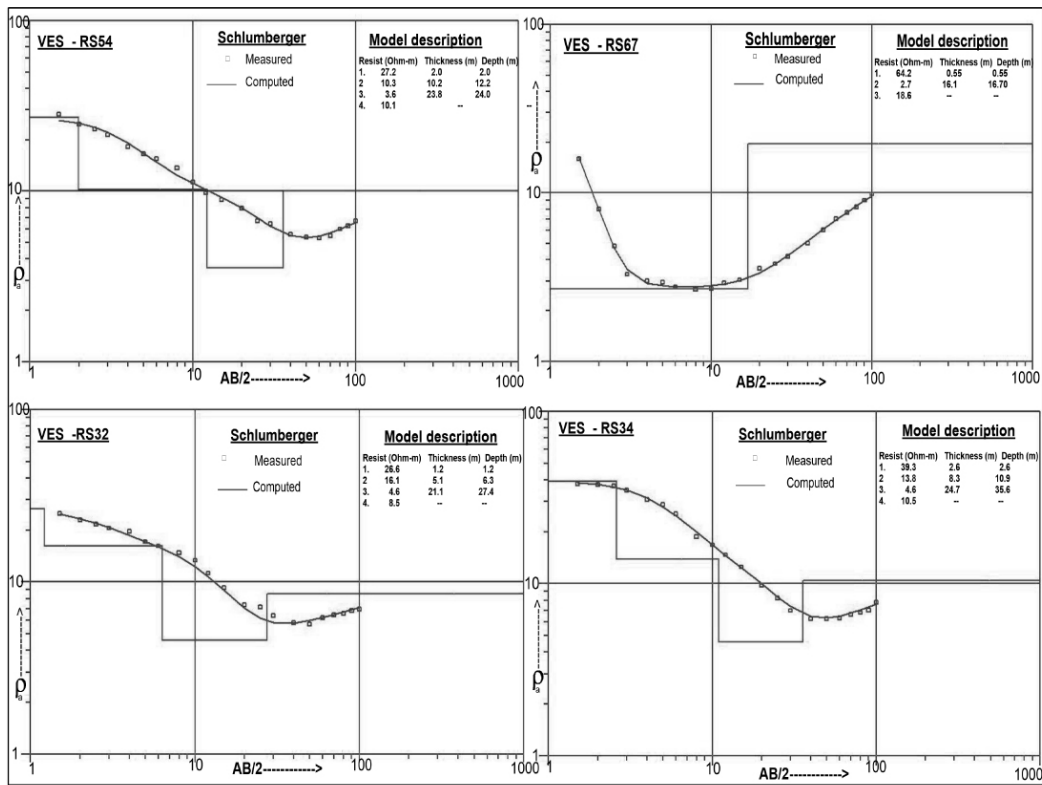


Figure 3. Interpretation of Typical VES Curves close to River path.

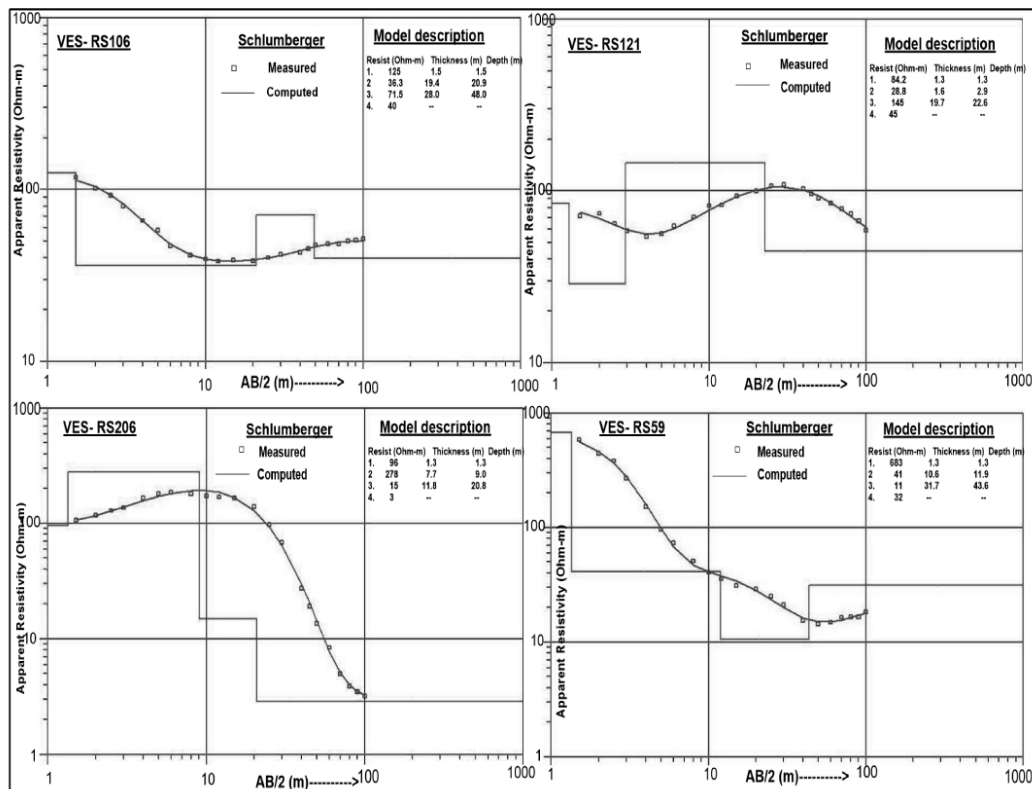


Figure 4. Interpretation of Typical VES Curves away from River path.

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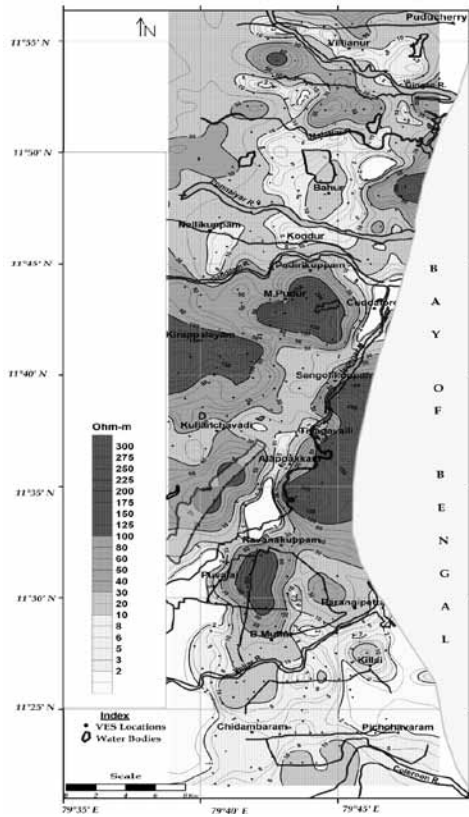


Figure 5. Resistivity contour map for 5m depth.

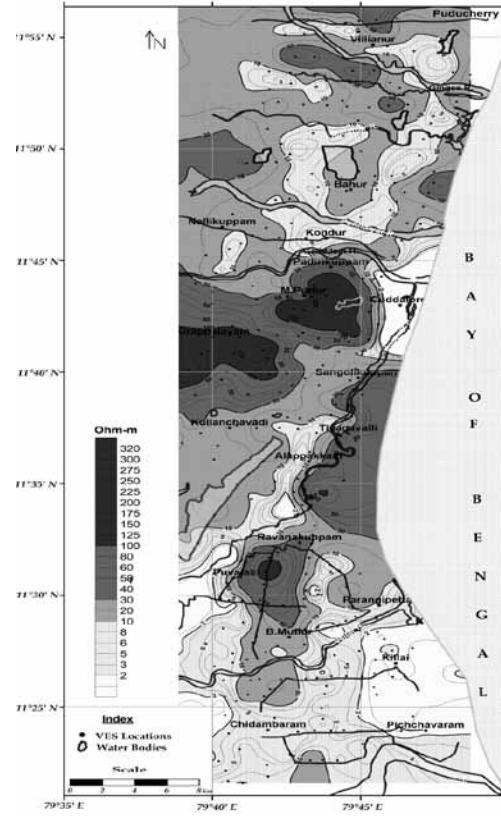


Figure 6. Resistivity contour map for 10m depth.

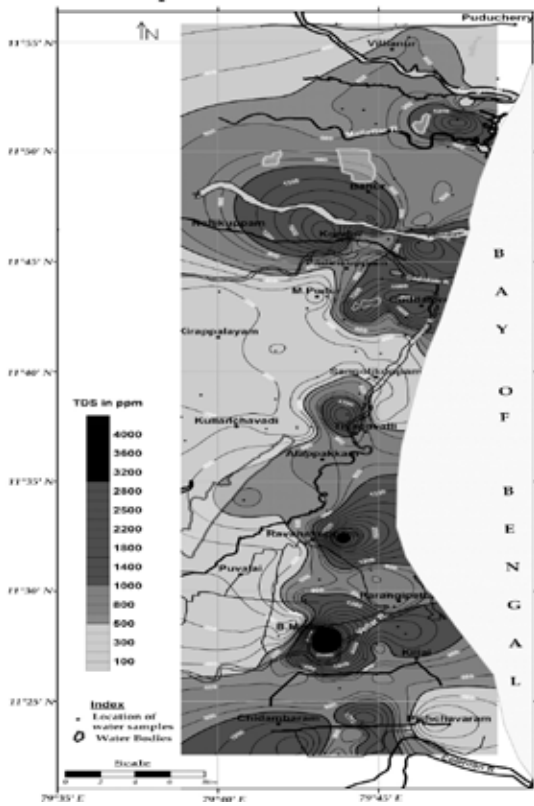


Figure 7. Total Dissolved Solids (TDS) Distribution Map.

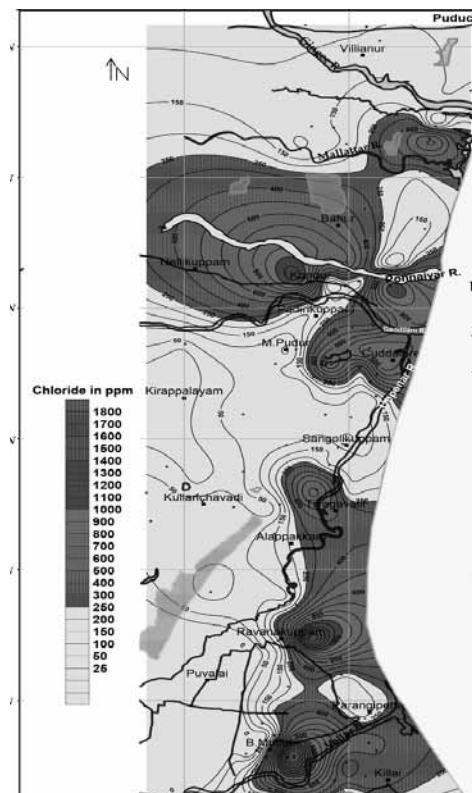


Figure 8. Chloride Distribution Map.

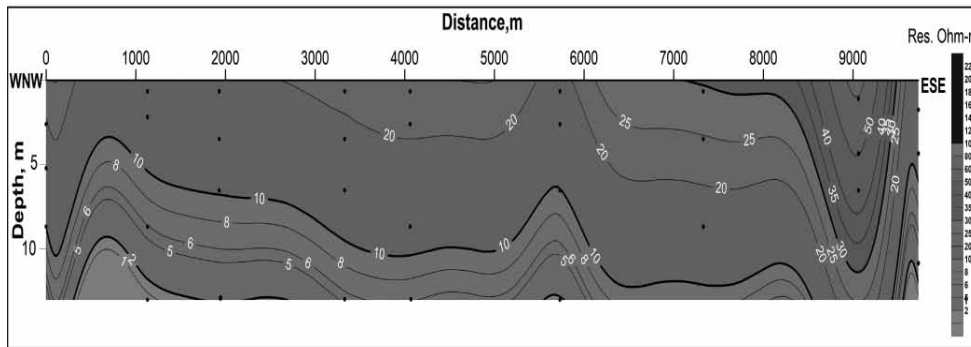


Figure 9. Resistivity Pseudosection along Gingee River.

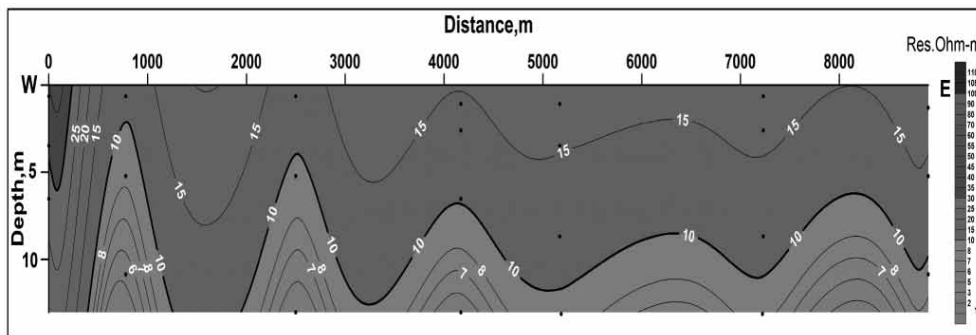


Figure 10. Resistivity Pseudosection along Malattar River.

(Figure 8) for Chloride has also reflected with higher order values having more than 250 ppm at all these locations corroborating with high TDS and low resistivity values. Therefore, it is evident from the above discussion that the water analysis results correlate well with resistivity results indicating contamination of saltwater along the area traversed by rivers, which carry the backwaters from the sea on tidal action.

Two resistivity pseudo sections were prepared using inverted data along the direction of Gingee and Malattar rivers from west to east to verify the subsurface resistivity distribution for classification of water quality. A total of nine VES stations were used for preparing Gingee section with light grey and black representing minimum and maximum values respectively. The Gingee section (Figure 9) shows low resistivity variations (1 to 10 Ohm-m) for the depths 4 to 12 m and 10 to 30 Ohm-m above this zone. These low resistivity values suggest the deterioration of quality of water. The high resistivity zone (> 30 Ohm-m) below station 8 corresponds to the sand dune with freshwater.

The resistivity pseudo section (Figure 10) along Malattar river covers seven resistivity sounding curves in east-west direction shows low resistivity variations (<10 Ohm-m) below depth from 3 to 12 m and 10 to 20 Ohm-m above it. The lower order of resistivity distribution along the section indicates the contamination of freshwater aquifers with saline water.

CONCLUSIONS

The resistivity investigation has clearly classified the variations in resistivities for different depths. The lower order resistivity values ranging from 1 to 10 ohm-m were demarcated mostly along the course of rivers and its peripheries. These low order resistivity values in correlation with water samples analysis data lead to the confirmation of subsurface formation without ambiguity. Water samples with TDS (more than 1000 ppm) and Chloride (more than 250 ppm) in low resistivity regions suggests the deterioration in quality of groundwater. The saltwater infiltration become maximum when highly permeable sediment formations make in contact with backwater carrier river path. The pseudo sections have also shown the low resistivity distribution at shallow depths suggesting the contamination of aquifers with saline water. It is observed from our present study that Contamination in unconfined shallow aquifers of the coastal regions is less in the regions where habitation is less. The analysis of resistivity and water analysis data was useful in precise determination of nature of shallow subsurface layers in the study area. The present study is also helpful to demarcate vulnerable areas of backwater flow in to the mainland for taking necessary measures to obstruct backwater flow by constructing barriers to safeguard the environmental degradation.

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ACKNOWLEDGEMENTS

The authors thank Addl. Director General, Geological Survey of India, S.R., Hyderabad and General Manager, Neyveli Lignite Corporation Ltd. Neyveli for their kind approval to publish the data, (the data collected has been collected under sponsored category in 2009-2012, with terms and conditions). The authors are also grateful to geological team of NLC Ltd for useful discussions on hydrogeology of the area. Authors are thankful to Dr.M.R.K.Prabhakar Rao and Prof.B.Venkateswara Rao for constructive suggestions. We also thank Dr.M.R.K.Prabhakar Rao for editing the manuscript. We are grateful to Chief Editor for his support.

Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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