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Tsunamigenic Impact in Coastal Shoreline Area Study using 2D ERI in between Thoothukudi to Manapad, Tamilnadu, India

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Keywords: Freshwater, saline water, resistivity, 2D ERI and Gulf of Mannar.

Abstract

The aim of the study is about beaches in the study area acts like a sponge but the groundwater along the beach is very dynamic. The flow direction of the beach groundwater is mainly governed by the physical and geological characteristics of the beaches as well as the waves and tide conditions in the sea due to tsunamigenic events from Indian Ocean Tsunami 2004. In the northern sector of the study area there are numbers of open wells close to the sea being used to draw water for portable purposes by the villagers settled along the beaches. Such field observation suggests that the seawater intrusion is limited in some areas of the study area. Through the 2D Electrical Resistivity Imaging (ERI) technique, an attempt is made to understand the interface zone of the seawater intrusion and the land groundwater along the beach groundwater table due to Tsunagenic impact. This technique involves transition of electrical currents into the ground between two electrodes and measuring of voltage between the other two electrodes in transect, the profile with predetermined interval of distances either parallel or perpendicular to the coastal zone is decided. CRM-500 resistivity measuring instrument, multicore cable, stainless steel electrodes are the hardware and "RES2DINV" is the software that were used for conducting the 2D Electrical Resistivity Imaging study.

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Introduction

Coastal aquifer is an integral part of water resources for coastal folks. The coastal aquifers provide an interface produced between the fresh and saline water. This interface is the product of physical and chemical properties of these two water bodies and as well as external process [7], [1],[23]. The seaward flow of freshwater is gained by the recharge in the hinterland area through rain fall and river and also the product of pressure gradients existing within the coastal medium. The influence of oceanic oscillations (tides and waves) on the exchanges processes occurring at the ocean beach interfaces. The saltwater intrusion in the coastal aquifers has thoroughly been studied using observation wells and water sample analysis. The shortcoming of water wells to map the saltwater intrusion is that lateral resolution is limited by well spacing which in turn is controlled by the access and economic issues [12], [14].

With the change of pressure gradient in the beach zone due to oceanic oscillation (tide and waves) and chemical weathering are the major causes for the degradation of coastal aquifers [2]. The utilization of freshwater resources by sinking of wells into freshwater aquifer and abstraction via pumping altered the subsurface pressure gradient on head. The intrusion not only renders the resource within the aquifer useless but also alters the chemical composition of the groundwater in the coastal aquifer [24],[8],[6]. The tsunamis spawned by the magnitude of 9.0 earthquake on December 26, 2004 were the result of motion of sea floor above the earthquake fault. The tsunami wave originated from the 1200km fault line and devastated the Indian Ocean Nations in the east and west directions than north and south directions. The coastal zones in the east and west coasts of India were affected. Data collected from various ports from east and west coasts of India have recorded the time of imparts of wave heights. Rapid assessment of coral reef in the Gulf of Mannar in and around of 21 coral islands have revealed no significant damage to the status of reef system. Vertical electrical sounding and 2-D imaging studies in the coastal zones of Ramanathapuram, Tuticorin and Kanniyakumari districts have delineated the zones of raditional stress of tsunami waves by resistivity contrasts are discussed in detail. The earthquake, which measured M 9.0 on 26th December, 2004 took place at the epicenter was at N 03 o34' and E 96o13' on the seafloor, between Indian plate and Burma plate has released the total energy of 32,000 Megatons of TNT or 1.33 x 10 20 Joules. The tsunami caused extensive damage in southern regions of India and Andaman Islands. In Tamilnadu, Colachal, Cape Comorin, Velankanni, Nagapattinam, and Cuddalore were severely affected. Aquaculture farms in the areas of Kovalam, Marakkanam , Cuddalore, Sirkali, Vellar estuaries, Nagapattinam and Velankanni, where the pumps and other properties were lost. The salt and freshwater interfaces in the coastal zones can be delineated with these two contrasting water bodies of volume and densities described [11]. These differences are produced by the dissolved solids within each other. The solid mass dissolved in the saline water is greater than the freshwater. With these contrast chemical properties of components of the fresh and saline water interface can be

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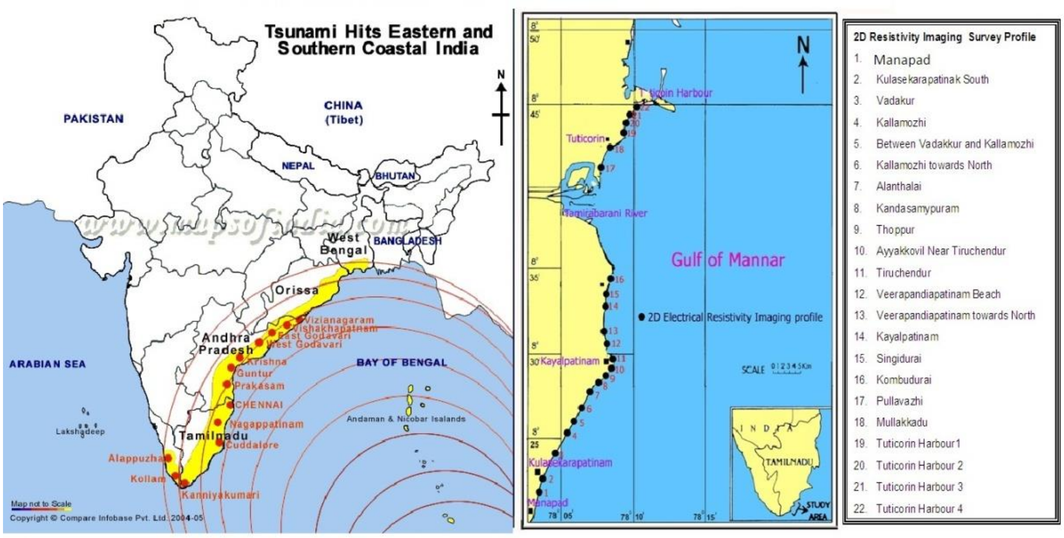
identified by the application of resistivity technique. If the freshwater pressure exceeds that of the denser saline water the flow would be towards the sea from the land. This flow can be determined by the levels and gradients of the ground water tables. Tuticorin: (Lat. N 8o45' – Long. E 78o12') Tsunami smashed at Tuticorin port at 09:51 hours when tide was 0.39 m. At this movement tidal water was on the upward trend and goes to a maximum of 1.62m at 10:02 hours lowest tide recorded at 11:08 hours as below as -0.27m due to this effect.The coastal community in the coastal districts of Kanniyakumari, Tirunelveli, Tuticorin, Nagapattinam and Cuddalore districts are tapping the groundwater resources from the coastal aquifers. Recent uprush of tsunami wave over these coastal belts has caused groundwater salinization of soils which has become unfit to any kind of vegetation and also for drinking or domestic utility. Most of the paddy field and coconut groves in the worst affected districts of Kanniyakumari and Nagapattinam are covered with stagnant of sea water. Assessment and comparison of pre and post tsunami data of groundwater quality in the coastal aquifers in Colachal area delineated sea water intrusion.

Aim of the study

The present study is to map the tsunamigenic impact of hydrogeological geometry of the saline and freshwater bodies in the coastal aquifer and to identify the subsurface structural features in the coastal sectors through the application of 2D electrical resistivity imaging studies from Thoothukudi to Manapad, Tamilnadu.To confirm this urge we have conducted 2D electrical imaging studies in these areas. The study is to visualize the three dimensional depth wise variations of salinities from the surface to the depth. The length of the wedge of the saline water body in the fresh water zone depends upon permeability, hydraulic boundary and relative densities of fresh and saltwater.To delineate subsurface salinization of the freshwater zones in between Manapad and Thoothukudi region, electrical imaging technique was adopted.

Description of the study

The study area is a coastal sector of 65 km length from Thoothukudi to Manapad trending towards N20ºE to S20ºW in the southern part of Gulf of Mannar, India. The coastal sector between Tiruchendur and Thoothukudi is extensively sandy beach with sporadically rocky outcrops in the locations of Kayalpattanam and Pullavazhi. The Cliffed and rocky platform shores with sandy beaches are prevalent in the coastal sector between Tiruchendur and Manapad (Figure 1). The rocky platform and cliffed shoreline are constituted with calcareous sandstone. The cliff sections at Manapad and Tiruchendur are acting as headlands and diffract the incident waves. In these cliffed sections the stages of wave cutting cave formation are located at 1.5m and 3m above Mean Sea Level (MSL). A well developed zeta bay between the Manapad and Tiruchendur headlands where beach rock act as anchorage for bay development. Similar zeta form coastal compartments are evident from Tiruchendur to Thoothukudi from the field survey.



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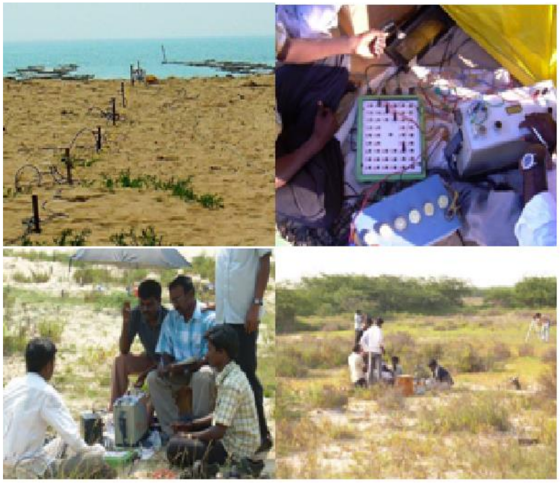

Figure.1 Location map and field work data collection for 2D electrical resistivity imaging surveys between Thoothukudi and Manapad.

Instrumentation and method

To study the interface of salt and freshwater in the coastal zone, 2D electrical resistivity imaging techniques adopting the Wenner configuration by using the Aquameter CRM 500, multi-core cables, stainless steel electrodes and RES2DINV software are used. 40 beach profiles were surveyed for topographical variations using Auto-level from high water line to a distance of 150m towards the land. The 22 profiles were selected for electrical resistivity imaging study. The electrical resistivity imaging profile survey starts from high water line to a length of 99m with electrode intervals of 3, 6, 9, 12, 15, 18, 21 and 24m respectively for all profiles perpendicular to the shoreline in the landward side. Here 40 stainless electrodes were pierced 15 to 20cm into the sandy layer with an interval of 3m connected with multi-core cables and in turn, these cables are connected to Aquameter CRM 500 passing through manually operating switching panel [3],[4] and [5]. The current and potential electrodes can be conveniently moved with the increasing of electrode spacing within the panel.

Morphodynamic characteristics features of the beach

The classifications of the morphodynomic state of beaches were carried in other parts of the study area by Ramanujam et. al., 1996. The topographical variation using auto level in that area was measured for beach face slope, back shore width and average dune height. The average backshore elevation of the study area was measured as 2.2m from Mean Sea Level (MSL). The maximum back shore elevation of 6.69m was recorded at Ayyakovil in the coastal section between Tiruchendur and Manapad, and minimum backshore elevation of 0.73m was measured at Pullavazhi in the coastal section from Tiruchendur and Thoothukudi. The Beach gradient measured in the study areas was classified as low (0.0507 to 0.2828m). The coast is categorized as semidiurnal meso tidal (Less than 2m) zone. The waves from deep ocean approach the shoreline from WNW direction during January to September and NEN direction during November to February with average wave height of about 0.70m and the wave period that ranges from 6 to15 seconds [18].

Result and Discussion

Electrical resistivity imaging study with aid of topographical variation helps in identifying the subsurface geological structural features and freshwater and saltwater distribution within 99m towards land in the coastal zone. The resistivity of the rocks varies with many factors such as mineral composition, porosity, and fracture, fracture filling fluids and fluid saturation [22]. This factor also was related by Archie's empirical equation Archie ; . = a.wnmsl (. = bulk resistivity of rock formation, n = porosity, s = degree of saturation, l = 2, m = 1.3-2.5 and a = 0.5-2.5). The common rock forming minerals are insulator, in general the rocks and minerals conduct electricity by electrolytic conduction within the water continued in their pore fissures

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on joints, the conductivity of the submerged ridge in the coastal section dependent upon fresh/saline water in filtered through the rocks. Thus crystalline or compact rocks exhibit a low porosity, have a high resistivity, compared with more porous sedimentary rocks such as sand stone. Contrary to the relationship between electrical resistivity and hydraulic conductivity is direct, so the porous, permeable dry sands exhibit the highest electrical resistivity values.

Clay soil or clay bearing rocks and soils tend to have lower resistivity than non-clay bearing sedimentary rocks or soils [2]. The acquired result clearly shows that inversion resistivity that ranging from 0.1 to 22,110 Ohm.m in the study area indicate the subsurface heterogeneity. It is obvious that the beach ridges with centrally synclinal form aligned parallel to the shoreline in the landward side are delineated at the depth of 1.5 to 3m in the areas of Kulasekarapattanam, Vadakkur, Kallamozhi, Alanthalai, Kandasamypuram and Thoppur with the progression of resistivity that ranges from 250 to 22119 Ohm.m. Single ridges were identified in the locations of Kallamozhi and Ayyakoil display array of resistivity that ranges from 250 to 2432 Ohm.m at depth of 6m to 8m (Figure 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 2.10, 2.11,2.12, 2.13, 2.14,2.15,2.16, 2.17, 2.18, 2.19, 2.20,2.21 and 2.22).

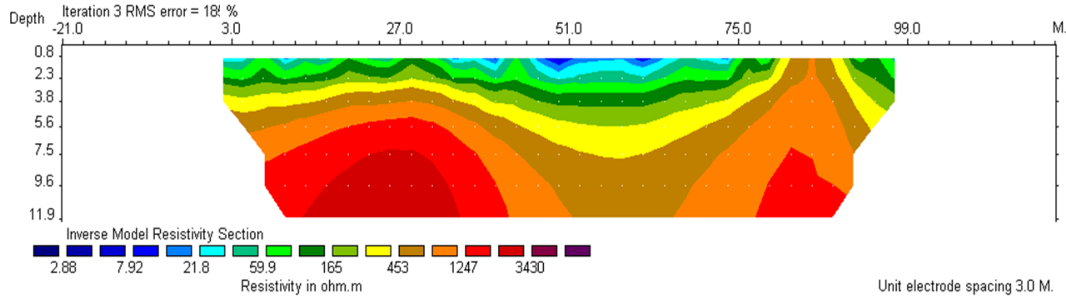

Figure 2.1 2D electrical resistivity imaging pseudosection depicts the distribution of beach ridges, saltwater and freshwater aquifer in the coastal areas of Manapad

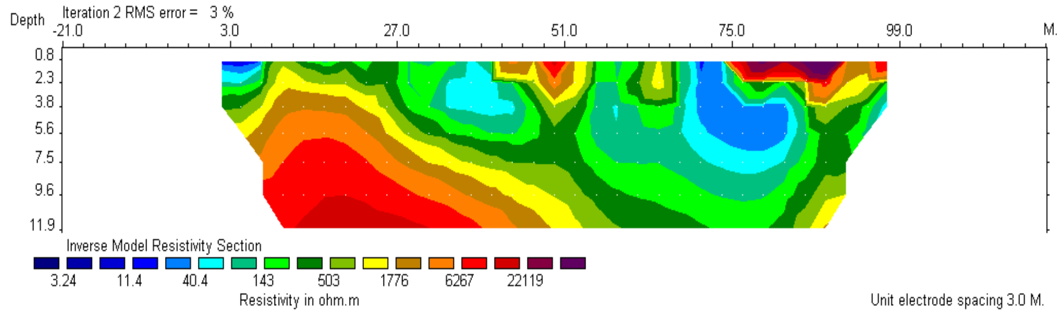

Figure 2.2 2D electrical resistivity imaging pseudosection depicts the distribution of beach ridges, saltwater and freshwater aquifer in the coastal areas of Kusekarapattinam-North (K-N).

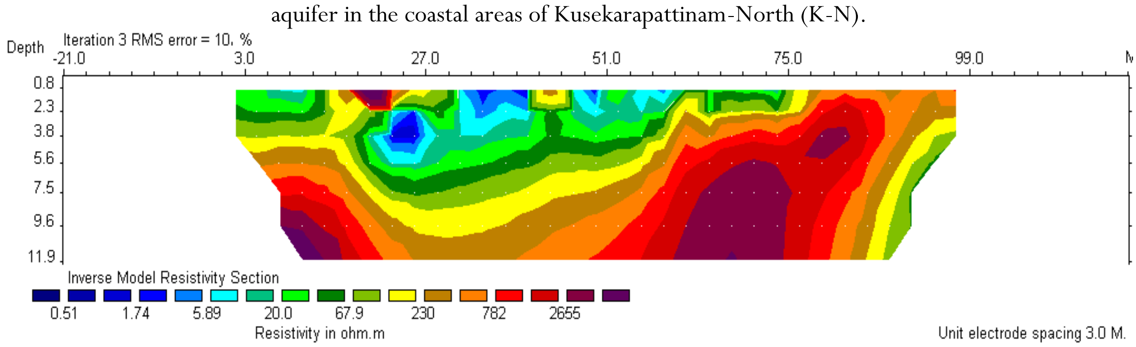

Figure 2.3 2D electrical resistivity imaging pseudosection depicts the distribution of beach ridges, saltwater and freshwater aquifer in the coastal areas of Vadakur (V).

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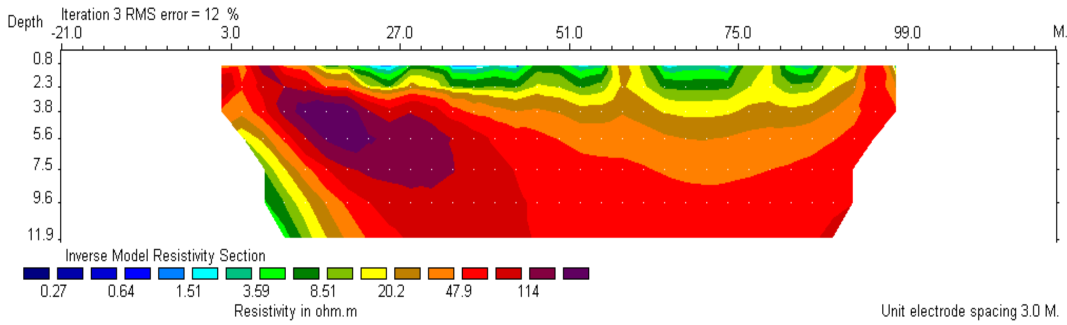

Figure 2.4 2D electrical resistivity imaging pseudosection depicts the distribution of beach ridges, saltwater and freshwater aquifer in the coastal areas of Kalamozhi North (K1-N).

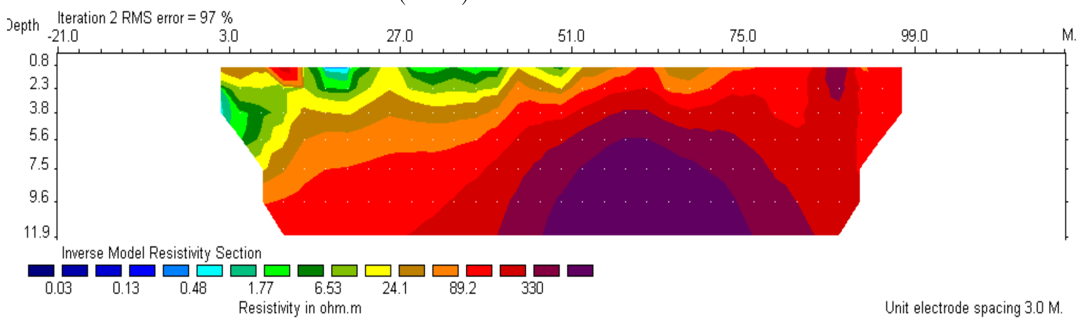

Figure 2.5 2D electrical resistivity imaging pseudosection depicts the distribution of beach ridges, saltwater and freshwater aquifer in the coastal areas of Kalamozhi South (K1-S).

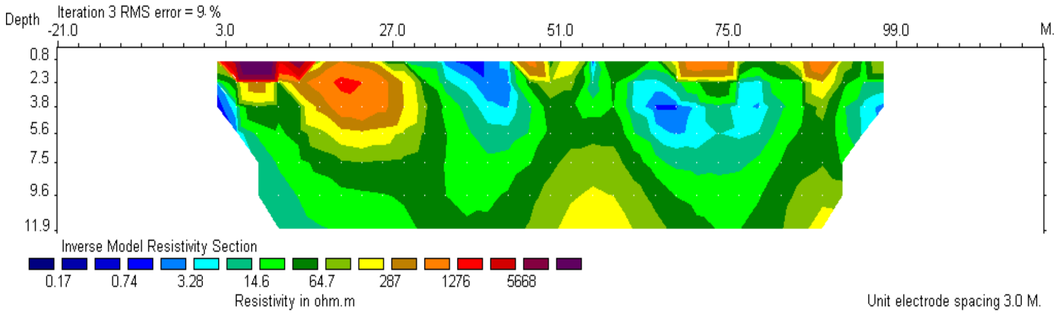

Figure 2.6 2D electrical resistivity imaging pseudosection depicts the distribution of beach ridges, saltwater and freshwater aquifer in the coastal areas of Near Alanthalai (A-N).

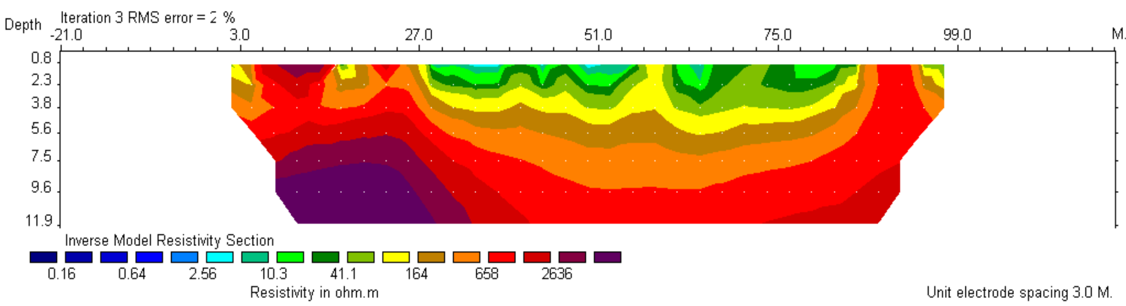

Figure 2.7 2D electrical resistivity imaging pseudosection depicts the distribution of beach ridges, saltwater and freshwater aquifer in the coastal areas of Alanthalai (A).

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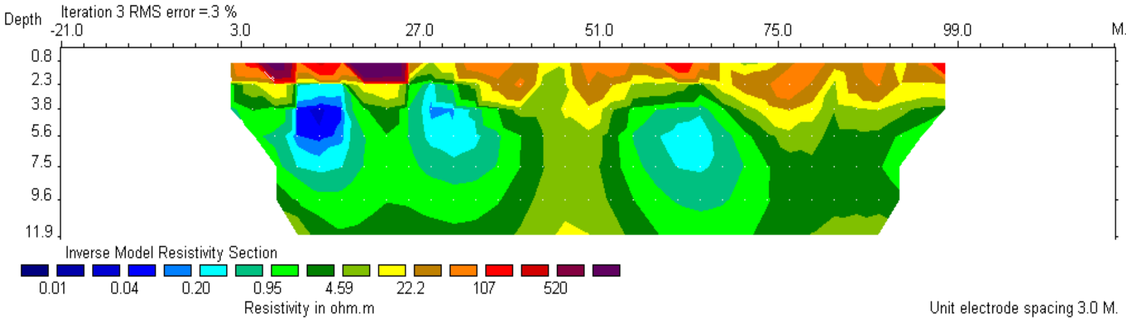

Figure 2.8 2D electrical resistivity imaging pseudosection depicts the distribution of beach ridges, saltwater and freshwater aquifer in the coastal areas of Kandasamy Puram (K2).

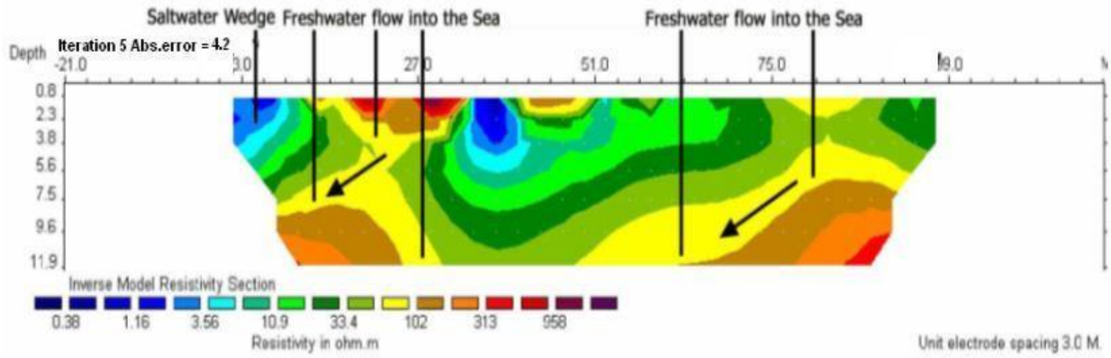

Figure 2.9 2D electrical resistivity imaging pseudosection depicts the distribution of beach ridges, saltwater and freshwater aquifer in the coastal areas of Thopur (T).

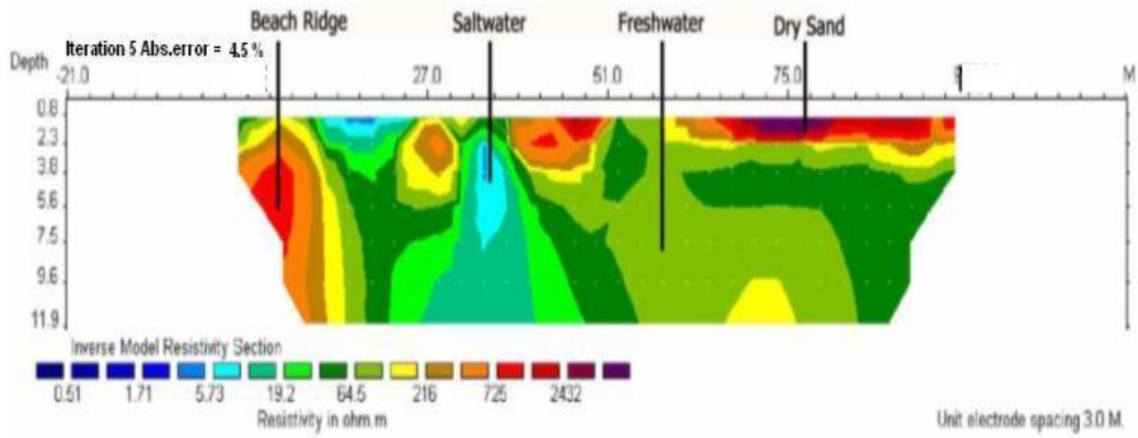

Figure 2.10 2D electrical resistivity imaging pseudosection depicts the distribution of beach ridges, saltwater and freshwater aquifer in the coastal areas of Ayyakkovil (A2).

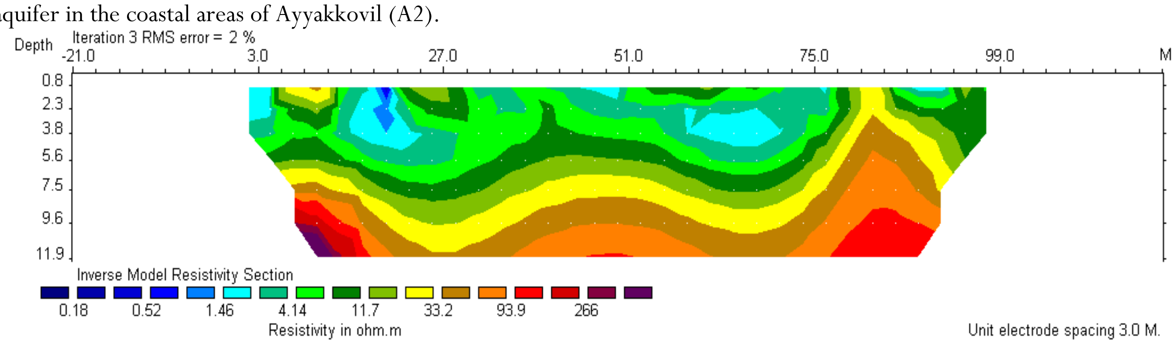

Figure 2.11 2D electrical resistivity imaging pseudosection depicts the distribution of beach ridges, saltwater and freshwater aquifer in the coastal areas of Tiruchendur North (T2-N).

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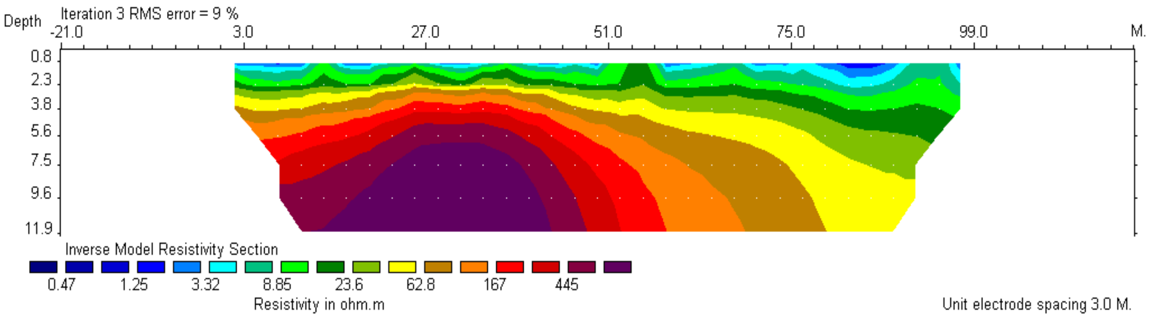

Figure 2.12 2D electrical resistivity imaging pseudosection depicts the distribution of beach ridges, saltwater and freshwater aquifer in the coastal areas of Veerapandiapattinam (V2).

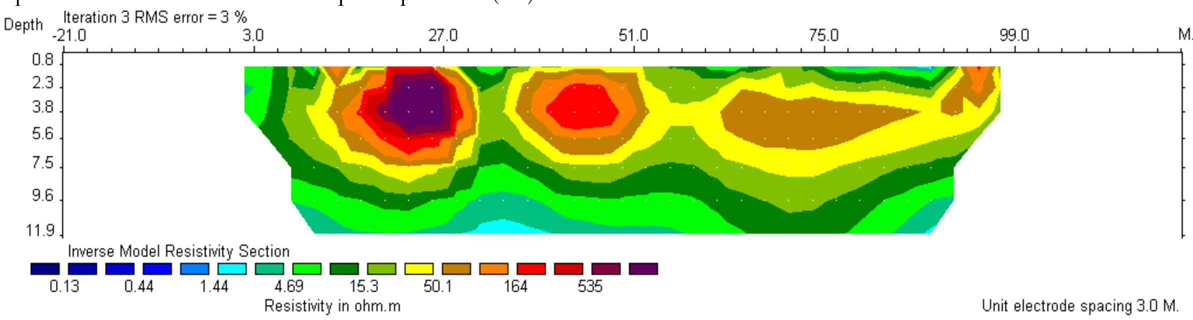

Figure 2.13 2D electrical resistivity imaging pseudosection depicts the distribution of beach ridges, saltwater and freshwater aquifer in the coastal areas of Veerapandiapattinam North (V2-N).

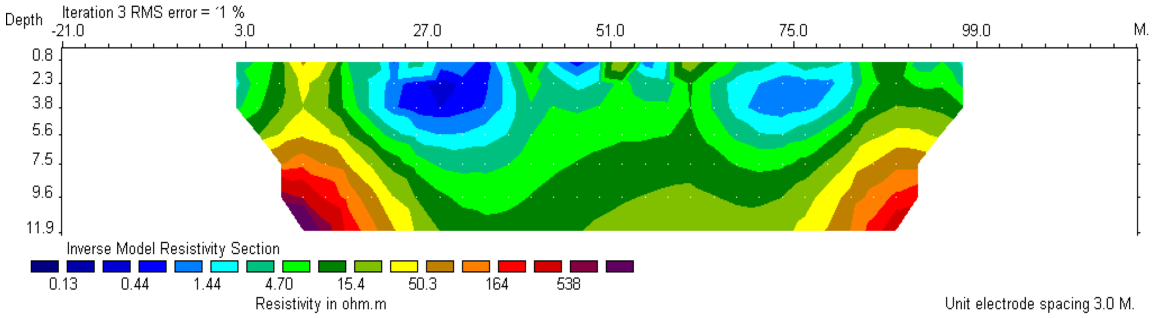

Figure 2.14 2D electrical resistivity imaging pseudosection depicts the distribution of beach ridges, saltwater and freshwater aquifer in the coastal areas of Kayalpattinam (K3).

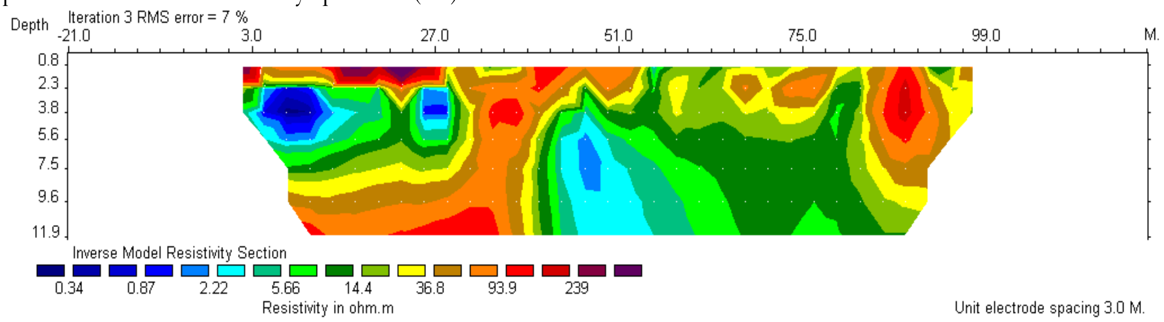

Figure 2.15 2D electrical resistivity imaging pseudosection depicts the distribution of beach ridges, saltwater and freshwater aquifer in the coastal areas of Singithurai (S).

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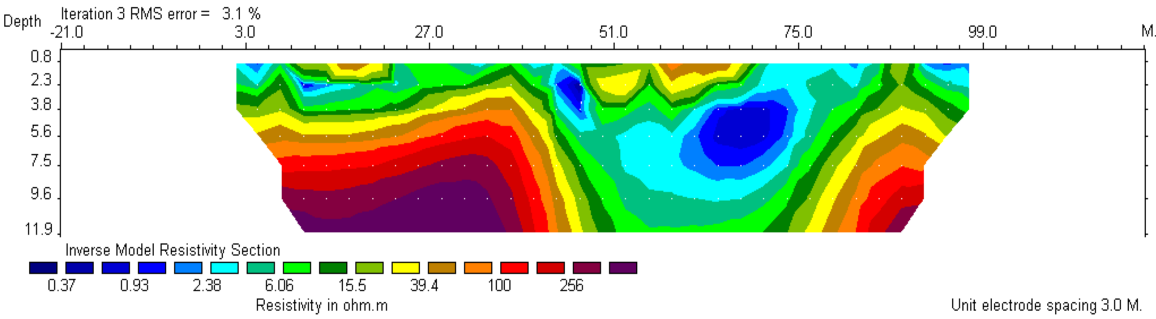

Figure 2.16 2D electrical resistivity imaging pseudosection depicts the distribution of beach ridges, saltwater and freshwater aquifer in the coastal areas of Kombudurai (K4).

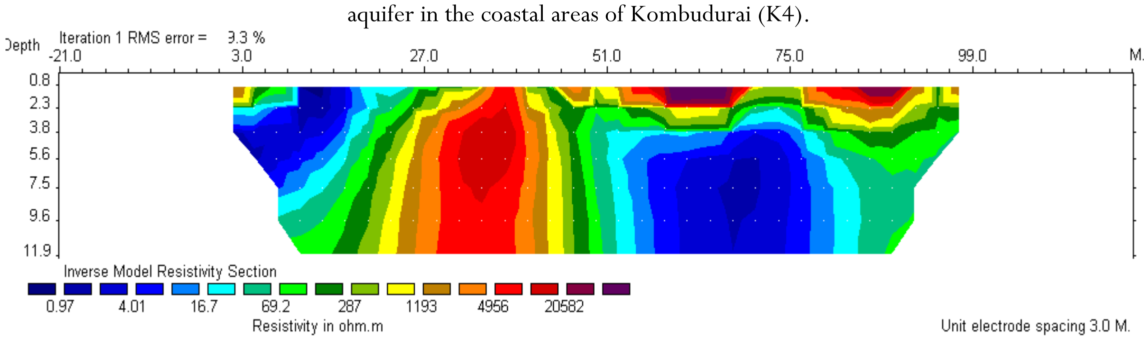

Figure 2.17 2D electrical resistivity imaging pseudosection depicts the distribution of beach ridges, saltwater and freshwater aquifer in the coastal areas of Pullavali (P).

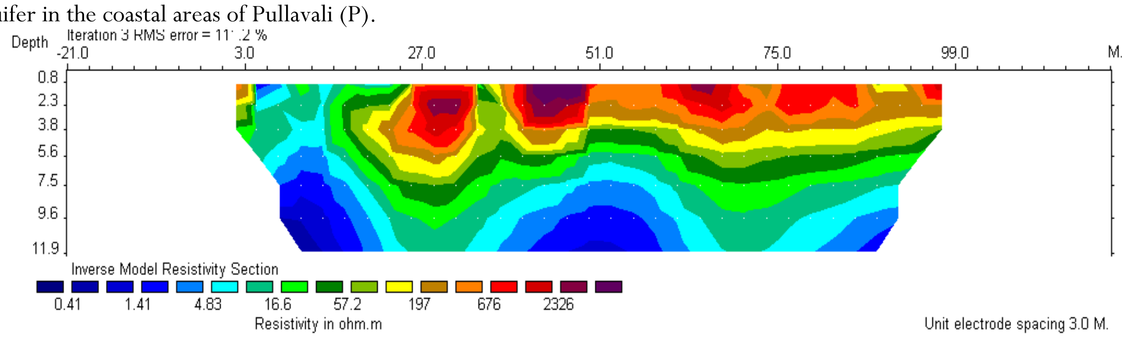

Figure 2.18 2D electrical resistivity imaging pseudosection depicts the distribution of beach ridges, saltwater and freshwater aquifer in the coastal areas of Mullakkadu (M).

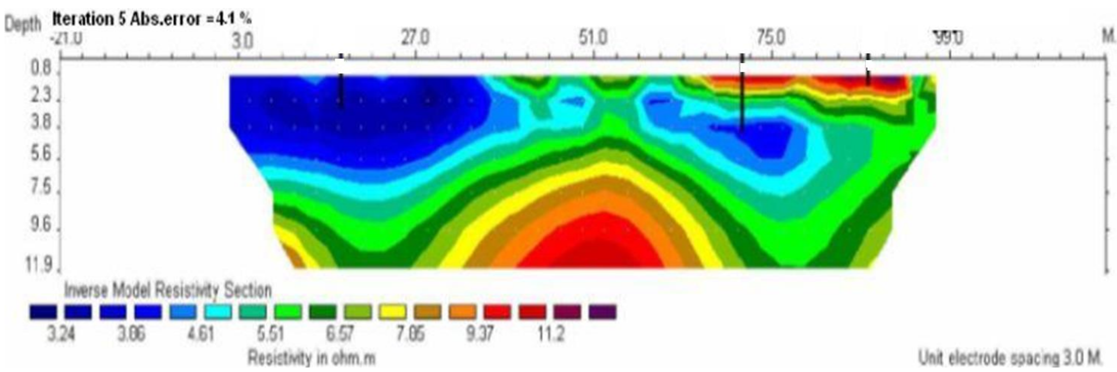

Figure 2.19 2D electrical resistivity imaging pseudosection depicts the distribution of beach ridges, saltwater and freshwater aquifer in the coastal areas of Thoothukudi Harbour (TH).

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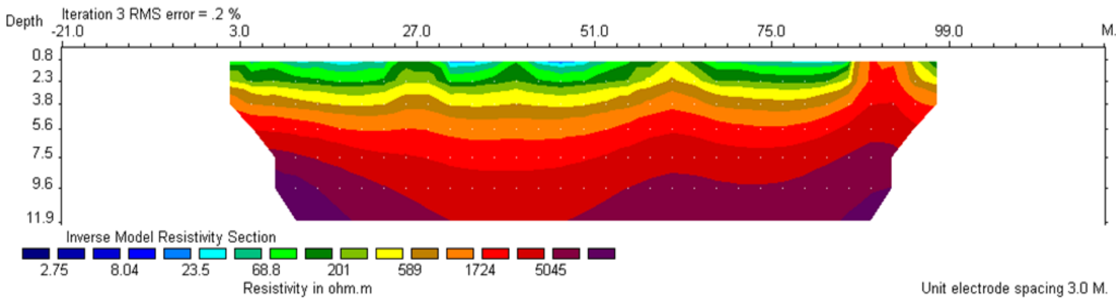

Figure 2.20 2D electrical resistivity imaging pseudosection depicts the distribution of beach ridges, saltwater and freshwater aquifer in the coastal areas of Thoothukudi Harbour Center point (THCP).

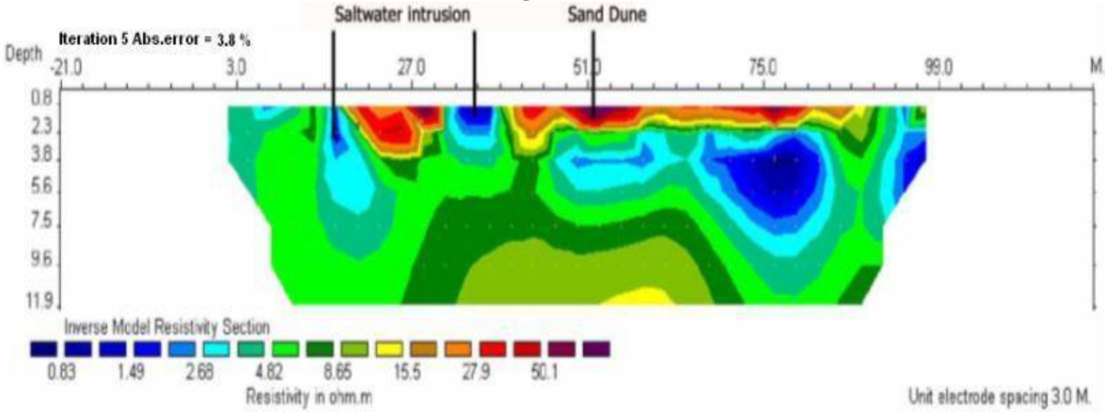

Figure 2.21 2D electrical resistivity imaging pseudosection depicts the distribution of beach ridges, saltwater and freshwater aquifer in the coastal areas of Thoothukudi Harbour Near South (TH-S).

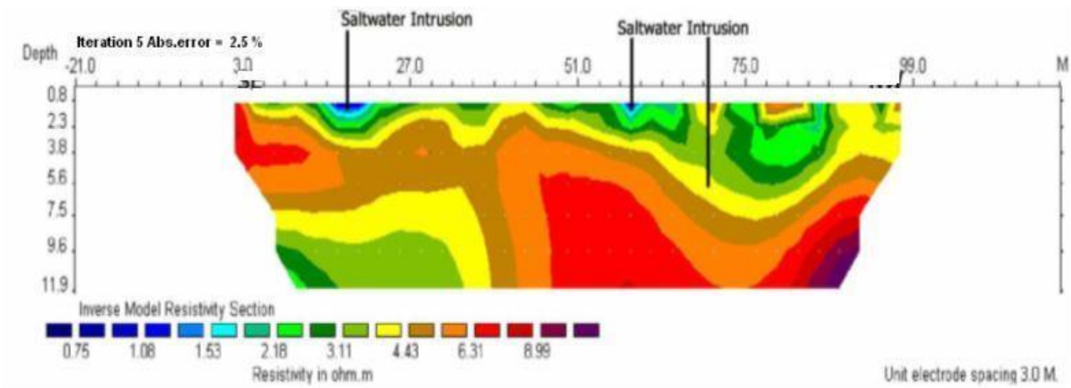

Figure 2.22 2D electrical resistivity imaging pseudosection depicts the distribution of beach ridges, saltwater and freshwater aquifer in the coastal areas of Thoothukudi Port Trust Harbour South (TPTH-S)..

Conclusion

In the coastal section from Tiruchendur to Thoothukudi, the beach ridges in the subsurface are typically single head with range of resistivity values from 250 to 20582 Ohm.m. It is a common practice to ensure the relationship between the resistivity and pore water and total dissolved solids in the groundwater allowing the distinction between the fresh, brackish and saline water within the coastal aquifer [9],[10],[11],[16]. The study area is neither completely silicic nor carbonate rocks, the beach rocks are mainly constituted with calcareous sandstone or Calcarenite and beach sediments [15],[17],[19]. The ranges of resistivity values were identified in the field condition as beach rock or rocky ridge greater than 250 Ohm.m; freshwater zone from 25 to 200 Ohm.m and brackish water 7-25 Ohm.m and saline water from 1 to 7 Ohm.m. The delineation of saltwater intrusion, freshwater zone, and brackish water zone and beach ridges based on the contour pattern of apparent resistivity was retrieved from the 2D electrical resistivity images. The distribution pattern of freshwater zone in the areas from Manapad to Tiruchendur oscillates from 60 to 70% and the saltwater zones (including saltwater + brackish and clay rich zone) and fluctuates from 13 to 33% and remaining rocky ridges show the variation from 7 to 20%. In the area

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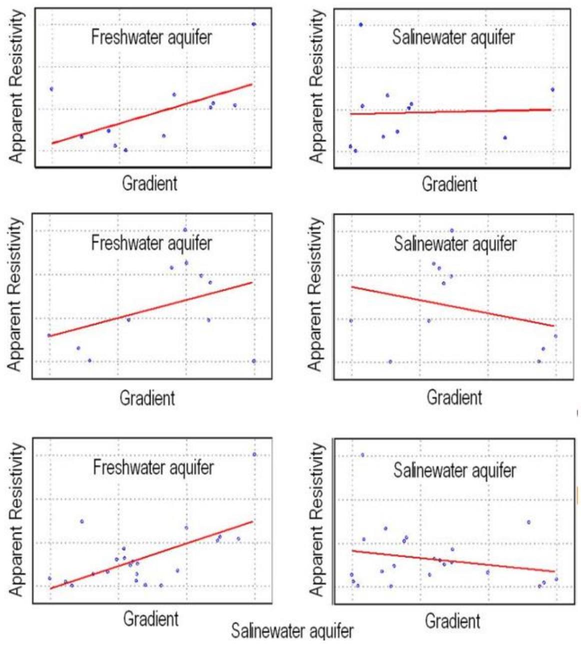
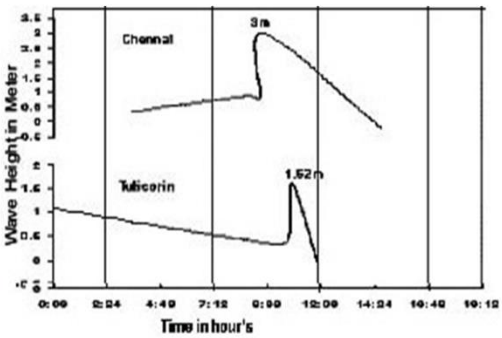
of Veerapandiapattanam, Kayalpattanam, Singidurai, Kombudurai, Kallamozhi, and Mullakadu, the saltwater zone (saline + brackishwater) are vary from 50.84 to 68% and freshwater zone divulges from 23% to 38% only. The rocky coast including the submerged beach ridges and beach rocks confirm the percentages of variation from 5 to 26% in the coastal zone between Thoothukudi and Tiruchendur. Rocky coasts with subsurface beach ridges disclose the average percentage of 29 in the coastal sector from Manapad to Tiruchendur. The saltwater infiltration in this sector is constrained to 10%. The freshwater in this zone is reasonably high with the percentage of 45. The compactness of submerged beach ridges from Manapad to Tiruchendur consistently show the higher resistivity values than the submerged beach ridges recorded in the areas of Tiruchendur and Thoothukudi. Comparatively the low resistivity distributions observed for the beach ridges in between Tiruchendur to Thoothukudi the areas can be accounted to the intrusion of saltwater in the beach rocks. The incursion of saltwater through the pores, fissures or poorly cemented beach rocks in between Tiruchendur and Thoothukudi have masked true resistivity values of the beach rocks. The increase of pore water salinity decreases the measured resistivity. The average percentage of beach rock recorded in this sector is 20%.The freshwater aquifer zone recorded as 26.5% in the area is comparatively less than that of the Manapad to Tiruchendur sector, but the saltwater occurrence is very high and enhanced to 17%. The high resistivity values of 1276 to 5600 Ohm.m recorded for sand dunes at surface level signify that the hydraulic conductivity and resistivity is directly proportional to 11 any dry earth materials. The average percentages of dune deposits are recorded as 2.96% and 3.80% for the coastal zones of Manapad to Tiruchendur and Tiruchendur to Thoothukudi respectively. The presence of clay complicates interpretation of inversion resistivity values. The recognition of lower apparent resistivity bounded by high resistivity zones clearly shows the presence of dispersed or interbedded clay encircled by the sandstone aquifer. The electrical resistivity imaging studies have delineated the higher percentages of 16.86 dispersed or interbedded clay bed in the coastal sectors between Tiruchendur to Thoothukudi and coastal sector from Manapad to Tiruchendur display very low percentage of 3.35 of clay bed. Elevation of the recharge zones in the sand dunes and sandy ridges areas of Kallamozhi, Alanthalai, Thoppur and Ayyakovil are prime reasons for discharge of the freshwater to the discharge zone in the vicinity of high waterline in the coastal sectors in these area. The low hydraulic gradients in the areas, Veerapandiapattanam, Kayalpattanam Singidurai, Kombudurai, Pullavazhi and Mullakadu favour incursion of seawater at the junction of land-sea boundary due to forcing mechanism of waves and tides. Dispersive circulation [22],[21] and different densities of saline and freshwater interaction in the interface is responsible for seawater intrusion.Topographic gradient versus apparent resistivity values reveal the relationship that the increase of the gradient increases the water quality in the coastal aquifer (Fig. 3).





Tsunami Wave affected in Thoothukudi and Chennai

Fig. 3 Shows the correlation matrix of topographic gradient versus apparent resistivity values in the coastal areas between Manapad-Tiruchendur, Thoothukudi-Tiruchendur and Manapad-Thoothukudi.

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Fig.4. The study area Trichendur temple in present stage,2012

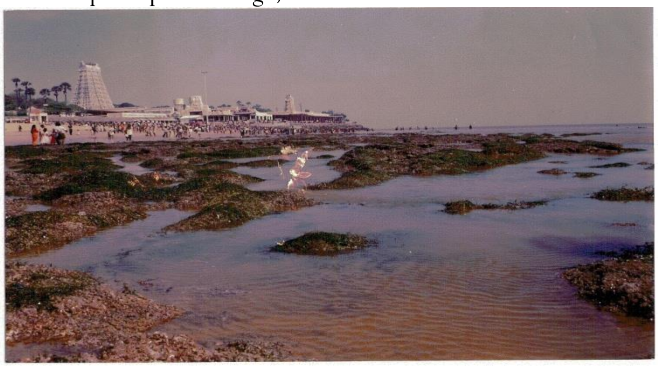

Fig.5. Trichendur temple rocks exposed before tsunami

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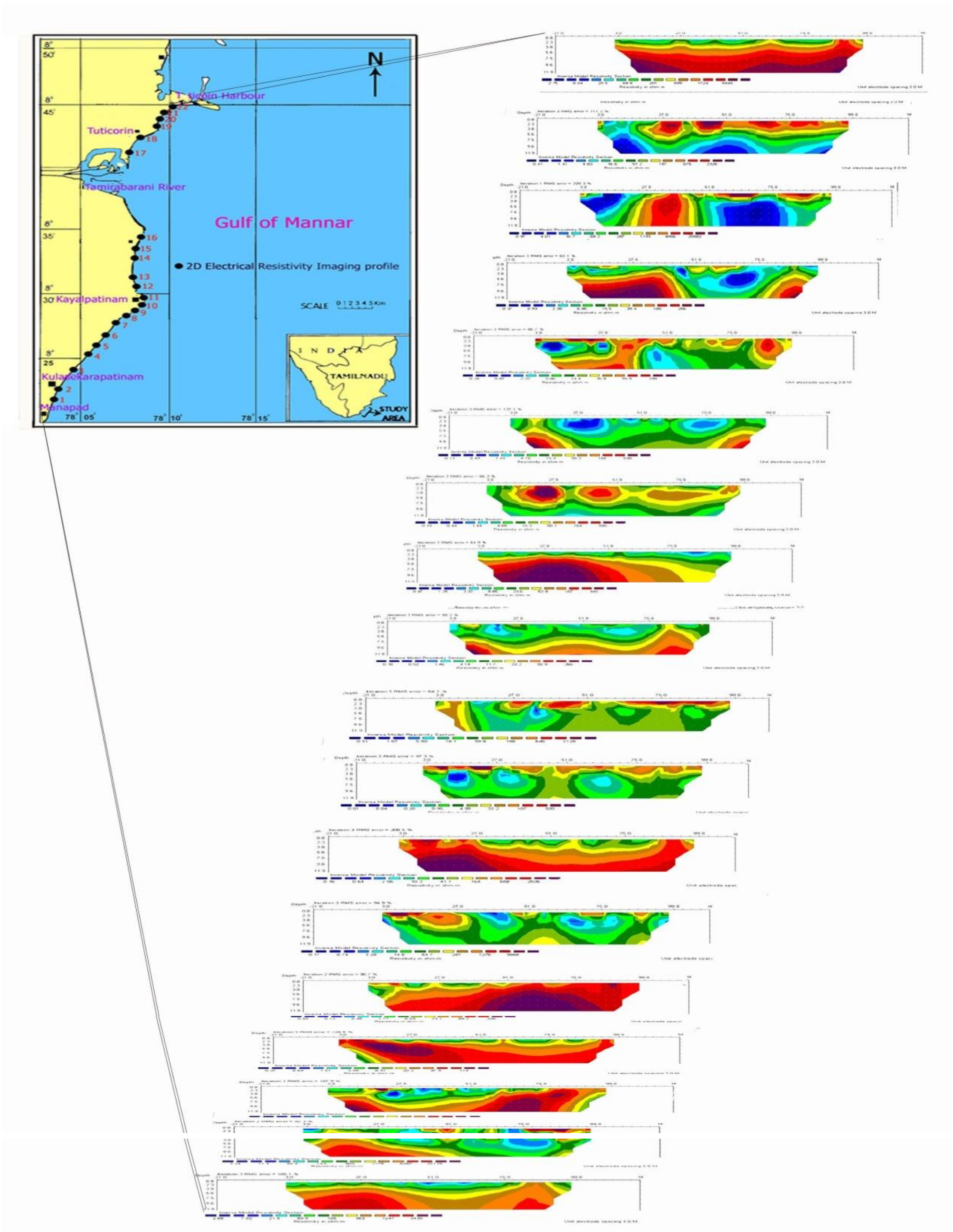

Figure 4. Sequential display of the distribution pattern of beach ridges, freshwater and saltwater aquifers dispositioned in the coastal sections from Kulasekarapattanam South to Thoothukudi Harbour (Profiles 1- 18) through 2D electrical resistivity imaging pseudosections.

The correlation of apparent resistivity values of freshwater zones with topographic elevations for the areas from Manapad to Tiruchendur show higher correlation coefficient of 0.54 and for the 12 areas from Tiruchendur to Thoothukudi is correlated as

0.39. Similar correlation coefficients recorded for the saltwater zones in these area with the gradients reveal that the saltwater intrusion is more pronounced (the correlation coefficient -0.28) in the coastal zone between Tiruchendur (Fig.4 & 5) to Thoothukudi and than coastal sector from Manapad to Tiruchendur where the saltwater intrusion is comparatively low (the correlation coefficient recorded as 0.04). The negative correlation recorded in Tiruchendur – Thoothukudi sector obviously gives explanation that the decrease of topographic elevation favored the increase the saltwater intrusion, whereas the low correlation coefficient as 0.04 recorded in the coastal sector between Manapad to Tiruchendur implies the prevalent of higher topographic gradient that avert the infiltration of saltwater into the coastal aquifer. In the low gradient regions the quality of water bodies deteriorated because of the interaction of sea water with the beach ground water. The subsurface disposition of the sandstone ridges in the areas of Kulasekarapattanam South to Thoothukudi Harbour Profiles 1-18 (Fig..6) acts as a barrier for the storage of the freshwater from the recharge zone of higher elevation and also prevents the infiltration of sea water in the coastal aquifer for further infiltration of sea water into the coastal aquifer due to the tsunamigenic event. The maximum tsunami wave height at Tuticorin was 1.62 m at 10:02 hours. Though Tuticorin and Chennai aligned in the east coast the tsunami wave directly attacked Chennai at 08:50 hours and it took more 01:10 hour to hit Tuticorin. This is because, the diffracted tsunami wave around Sri Lanka attacked Tuticorin. The difference due to tsunami wave was only 0.69 m. Further stress factor due to diffracted waves were less when compared to the direct hit of the tsunami waves. In this conjunction the coral has enough strength to bear the tsunami attack As a result of that tsunami has no significant impact on corals and associated habitat in the Gulf of Mannar. The exertion of radiational stress in the coastal zone is clearly expressed by 2D Electrical Resistivity Imaging technique. These geophysical techniques are very sensitive with respect to the change a hydraulic conductivity due to Tsunami instrusion in the study area.

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