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Dr.K.Srinivasamoorthy (PI)

Dr.D.Senthilnathan (Co.PI)

Equipment used for the field Survey

Recording Readings during the Field Survey

1 D sounding using Schlumberger Configuration

Multi Electrode spreading for 2 D Sounding using Wenner- α configuration

Field survey for 2 D investigations

Field crew for 1D and 2 D investigations

1 BACKGROUND

Many areas of the world use groundwater as their main source of freshwater supply. With the world's population increasing at an alarming rate, the freshwater supply is being continually depleted, increasing the importance of groundwater monitoring and management. One of the major concerns most commonly encountered in coastal aquifers is the induced flow of saltwater into freshwater aquifers caused by groundwater over pumping known as saline water intrusion. In places where groundwater is being pumped from aquifers that are hydraulically connected to the sea, the induced gradients may cause the migration of saltwater from the sea toward wells on land. The key to control this problem is by maintaining proper balance between the amount of water pumped from aquifer and amount of water being recharged. Delineation of the saltwater/freshwater interface and close monitoring of the position variation of the interface is aided by geophysical field surveys, which are the fundamental components of efficient counter measures for the saline water intrusion. The main purpose of groundwater resource management and legislation in coastal areas should be the safeguarding of a sustainable social and economic development.

India with a long coastline of 7500 km, with 25% of the population living in the coastal areas. Most of the urban centers are located along the coastal zone due to ease in availability of groundwater. Availability of groundwater along the alluvial tracts of rivers and coastal areas confining semi and unconsolidated sediments helped mankind to go in for deeper groundwater exploration, resulting in problems like salinity hazard, salt water intrusion and land subsidence. Saline intrusion in coastal aquifers is of major concern (Batayneh, 2006) because it constitutes the commonest of all the pollutants in freshwater aquifers. Excessive withdrawal of groundwater coupled by significant decrease in recharge contributes to the problem. The extent of saline water intrusion is influenced by nature of geological settings, hydraulic gradient, rate of groundwater withdrawal and its recharge (Choudhury et al. 2001).

1.1 GROUNDWATER AND SEAWATER INTRUSION

When an aquifer is in hydraulic connection with saline water, a portion of the aquifer would contain saltwater while other portions contain fresh water. Freshwater is slightly less dense (lighter) than saltwater, and as a result tends to float on top of the saltwater when both fluids are present in an aquifer. There is a relationship based on the density difference between saltwater and freshwater that can be used to estimate the depth to saltwater based on the thickness of the freshwater zone above sea level. The relationship is known as the Ghyben-Herzberg relation (Fig.1.1). The boundary between the freshwater and the saltwater zones is not sharp but instead is a gradual change over a finite distance, and is known as the zone of diffusion or the zone of mixing.

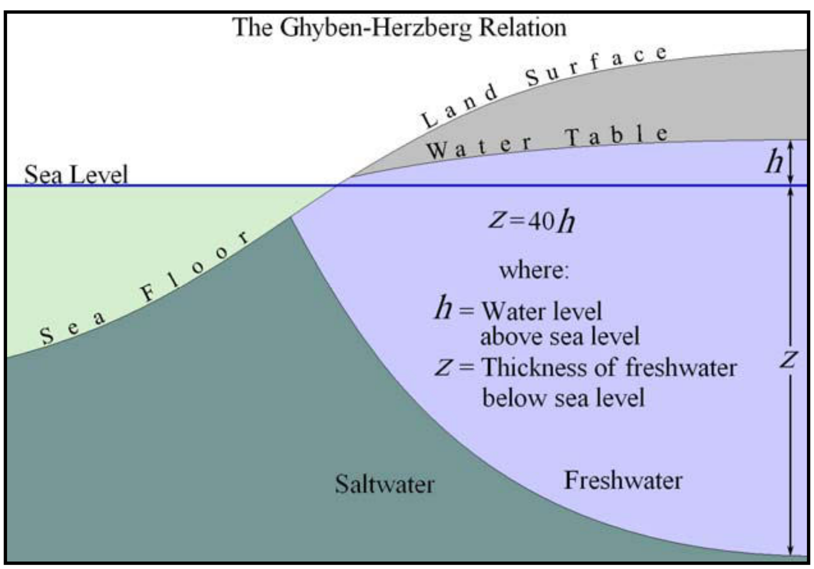


Figure 1.1 Ghyben-Herzberg Relation for saline water intrusion

Two mixing processes (diffusion and dispersion) continuously move saltwater into the freshwater zone. Flow in the freshwater zone sweeps this mixed brackish water toward the shoreline where it discharges at submarine seeps. The processes of recharge, flow, mixing, and discharge all work in unison to hold the interface position in a roughly stationary position. A change to one or more of these processes can result in change in the position of the interface; an inland movement of the interface boundary known as lateral intrusion. When a well is pumped, water levels in the vicinity of the well are lowered, creating a drawdown cone (Fig. 1.2). If a saltwater zone exists in the aquifer beneath the well, the saltwater will rise up toward the well screen. This rising up of saltwater is known as up coning and is the second type of seawater intrusion. Seawater intrusion into coastal aquifers leads to impairment of the quality of the freshwater aquifers.

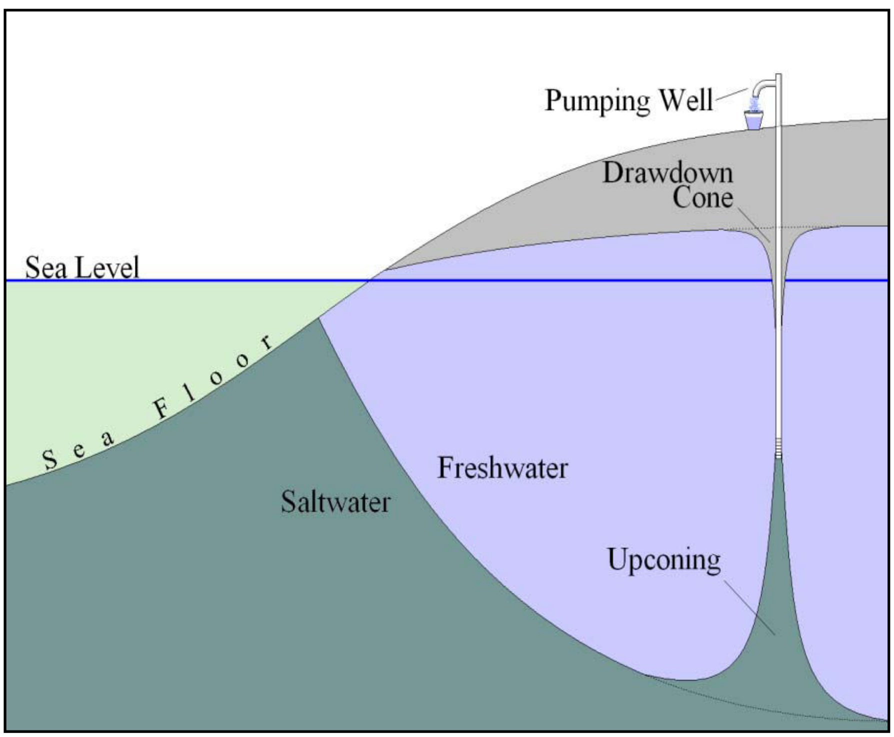


Figure1.2 Up coning of saline water due to excessive pumping

1.2 BACKGROUND OF SALINE WATER INTRUSION

1.2.1 Factors Affecting the Coastal Aquifers

Coastal sedimentary aquifers are among the most productive aquifers and due to this the stress on them are also more. Caution needs to be exercised while developing these aquifers, as over development can result in various adverse environmental impacts including seawater intrusion and land subsidence.

1.2.2 Land Subsidence

Large scale of withdrawal of ground water, especially from the artesian aquifers can sometimes result in land subsidence due to compression of the aquifers. Land subsidence poses serious problems to buildings and other structures. Sometimes this causes inundation of low lying areas, resulting in sea water ingress. The subsidence depends on the nature of sub surface formations, their extent, magnitude and duration of the artesian pressure decline.

1.2.3 Sea Water Intrusion

When groundwater is pumped from aquifers that are in hydraulic connection with the sea, the gradients that are set up may induce a flow of salt water from the sea toward the well. The migration of salt water into freshwater aquifers under the influence of groundwater development is known as seawater intrusion. There is a tendency to indicate occurrence of any saline or brackish water along the coastal formations to sea water intrusion. The salinity can be due to several reasons and mostly it can be due to the leaching out of the salts from the aquifer material. In order to avoid mistaken diagnoses of seawater intrusion as evidenced by temporary increases of total dissolved salts, Revelle recommended Chloride-Bicarbonate ratio as a criterion to evaluate intrusion. In India, sea water intrusion is observed along the coastal areas of Gujarat and Tamil Nadu.

1.2.4 Up coning of Saline Water

When an aquifer has an underlying layer of saline water and is pumped by a well penetrating only the upper freshwater portion of the aquifer, a local rise of the interface below the well occurs. This phenomenon is known as upconing. The interface is generally near horizontal at the start of pumping. With continued pumping, the interface rises to progressively higher levels until eventually it reaches the well. This generally necessitates the well having to be shut down because of the degrading influence of the saline water. When pumping is stopped, the denser saline water tends to settle downward and to return to its former position.

Upconing of sea water is reported from the Lakshadweep and other small islands. In these islands, the fresh water floats over saline water as a thin lens and for every drop one unit of the fresh water the saline water rises by forty units. Due to this, the islands do have very fragile ground water system and no pumping can be recommended here. The fresh water has to be skimmed to avoid upcoming.

1.2.5 Geogenic Salinity

This is the most common quality problem observed in the coastal aquifers. Here the salinity is due to the leaching of the salts in the aquifer material. In some cases, the formation water gets freshened year after year due to the leaching effect.

1.2.6 Pollution

Rivers are the major contributors of pollution of the coast and coastal aquifers. Almost all the rivers in our country are polluted mostly due to sewerages and industrial effluents.

1.2.7 Sea Level Rise

The anticipated sea level rise due to global warming poses a serious threat to the coastal aquifers, especially the small island aquifers. The rise in the sea level will push the fresh water seawater interface more inland along coastal aquifers and will submerge low lying areas with sea water, thereby making the shallow aquifers saline. The small Lakshadweep islands will be the worst affected by sea level rise.

Hence, understanding of saline intrusion is essential for the management of coastal water resources (Ginzburg and Levanon, 1976).The intrusion of seawater has been identified by many approaches such as isotope studies, geochemical and geophysical studies. In studying the thickness and geometry of depositional systems, a common procedure is to make use of information from geological research, drilling, and exploitation boreholes. However, these methods are expensive and time consuming, preventing their use on a large scale. In contrast, geophysical measurements can provide a less expensive way to improve the knowledge of a set of boreholes (Maillet et al. 2005). The resistivity technique has its origin in 1920 (Koefoed, 1979). Geophysical studies gains advantage due to non-invasive technique and no requirement of water sampling, relatively inexpensive, can be used for rapid and economical monitoring of large areas, assist in the optimization of the required number of monitoring wells and electrical conductivity / resistivity are intrinsic properties of groundwater chemistry that are readily interpreted in terms of the degree of groundwater contamination (Ebraheem et al., 1990; 1997). The presence of seawater causes groundwater to be considerably saline, hence the aquifer resistivity is reduced considerably, and the resistivity method can delineate the boundaries of the body of saline water. The fact that a resistivity contrast exists at the interface between fresh and saline water is sharp, the resistivity method has proved useful. For this reason, in many cases, geophysical prospecting techniques can provide complementary data that enable geological correlation, even in sectors where there are no data from boreholes. Indirect geophysical methods (like VES surveys) generate continuous data throughout a given profile. It is helps in understanding spatial relations between fresh, brackish, and saline water, which commonly coexist in coastal aquifers.

Water is important natural resources of Pondicherry which must be judiciously used to promote developmental activities. The groundwater quality in the study area is a principal source for different purposes and meets 99% of freshwater demand, and acts an essential role in the socioeconomic development. The total annual availability of water for all uses (domestic, irrigation and industrial purposes) in the study area is 200 MCM per year. As per the groundwater resource estimation (GEC, 1997) committee for development of groundwater in Pondicherry regions is very high 179% indicating major portions of the study area to be considered vulnerable to water level depletion. The shallow aquifers along the coast show signs of salinity. In this regard, limitations have to be heeded for the future growth and management of water resources. Hence mapping of saline water ingress into the landward region using geophysical methods is of primal importance. Demarcation of zones of saline water intrusion will be helpful to adopt proper regulatory measures to restrict further intrusion of saline water into the costal aquifers. Hence the key goal of this venture is to demarcate the groundwater - saline water interface using electrical resistivity methods.

1.3 SCOPE OF WORK

The main objective of the current study is the following:

- To investigate the location and extend of the fresh-salt water interface in the aquifers of the study area using Electrical Resistivity Tomography (ERT) techniques combined with available hydrogeological data.
- To determine the aquifer geometry of the coastal tracts of the Pondicherry region.
- Demarcation of the aquifer zones.

1.4 METHODOLOGY

The methodology adopted for the present study is as follows:

- Literatures regarding water quantity and quality pertaining to the study area will be collected to get an enhanced initiative to the present study.
- Collection of meteorological data like rainfall, water table fluctuations and litho logs for correlation.
- Geophysical resistivity surveys in definite pattern along the coastal tracts to demarcate the direction and distance of saline water ingress.
- Integration of results with GIS to demarcate the directions/distance of saline water intrusion.

2. INTRODUCTION

Water is one of the most important natural resources to a life support system. In the land hydraulic system, when the fresh groundwater is withdrawn by pumping wells at a faster rate than it can be replenished, a drawdown of the water table occurs with a resulting decrease in the overall hydrostatic pressure. When this happens near an ocean coastal area, saltwater from the ocean intrudes into the freshwater aquifer. The result is that freshwater supplies become contaminated with saltwater, as is happening to some coastal communities such as those along coasts in India. The most common definition of saline water intrusion as defined by Freeze and Cherry (1979) as "the migration of saltwater into freshwater aquifers under the influence of groundwater development". Saline water intrusion includes the salt water wedge in the surface water area in coastal river systems. The saline water encroachment into freshwater supplies has become cause for concern within the last couple of centuries as populations in coastal areas have risen sharply and placed greater demands on fresh groundwater reserves. Saltwater intrusion causes many ecological, environmental, social and economic problems in coastal areas like Pondicherry region. Although the impact of saline water intrusion has only been recognized for a relatively short period, the outcome of this problem could be very severe in the future.

Managing aquifers affected by saline water intrusion is crucial. The hydrogeological conditions are mostly complex and dynamic due to the activities like aquifer tectonics, human influences and other geological conditions. Larger data sets are essential with reference to the hydrological properties of the aquifers which are being got from observation and pump wells located in the area of study. Due to non availability of continuous observation wells it is not feasible to get a better picture with reference to the saline water intrusion into the aquifers. Geophysical resistivity prospecting is a supplementary cost-effective and non-invasive method that will provide continuous subsurface structural information to help in mapping the saline water – freshwater interface. Geophysical resistivity techniques offer a suitable method for determining the saline water intrusion due reduced costs, simplicity of technique, easier data interpretation and rugged instrumentation. This in turn also reduce the necessity of pumping tests which are time consuming and expensive. The main purposes for conducting the geoelectrical resistivity imaging surveys is to create preliminary hydrogeological/geophysical expectation model confining to the study area, easier to correlate with geological, lithological and tectonic information for generating circumstances that could provide answers to the key hydrogeological questions for the area and purpose of investigations, to generate 2D geophysical models to categorize saline water intruded target area to suggest remedial measures.

2.1 GEOGRAPHY

The proposed study area forms the coastal regions of the Puducherry region situated between $11^{o}50'$ and $12^{o}03'$ N latitudes and $79^{o}45'$ and $79^{o}55'$ E longitudes with a total area of 68 sq. km (Fig.2.1). It is bounded on the east by Bay of Bengal, on the north and west by Villupuram and south by Cuddalore districts of Tamil Nadu state. It is not a contiguous area and is interspersed with enclaves of territory of Tamil Nadu. The region is divided into seven communes namely Puducherry, Ozhukarai (Oulgaret), Bahour, Ariyankuppam, Villianur, Nettapakkam and Mannadipet. Besides Puducherry municipal town, there are two more towns in the region namely Kurumbapet and Ozhukarai. Pondicherry's average elevation is at sea level, and a number of sea inlets, referred to as "backwaters" can be found. There are two important rivers one being the River Gingee which traverses the region diagonally from North- West to South-East and the other, Pennaiyar, which forms the Southern border of the study area. The river Gingee bifurcates into two as Ariankuppam and Sunnambar rivers. The tributaries of the river Gingee are Vikravandi, Pambaiyar and Kuduvaiyar. Malattar is the tributary of river Pennaiyar. The topographic maps namely 58M/9, 58M/13, 57P/12, 57P/16 on a scale of 1:50,000 from Survey of India published in the year 1972 were used for the preparation of base maps and thematic maps.

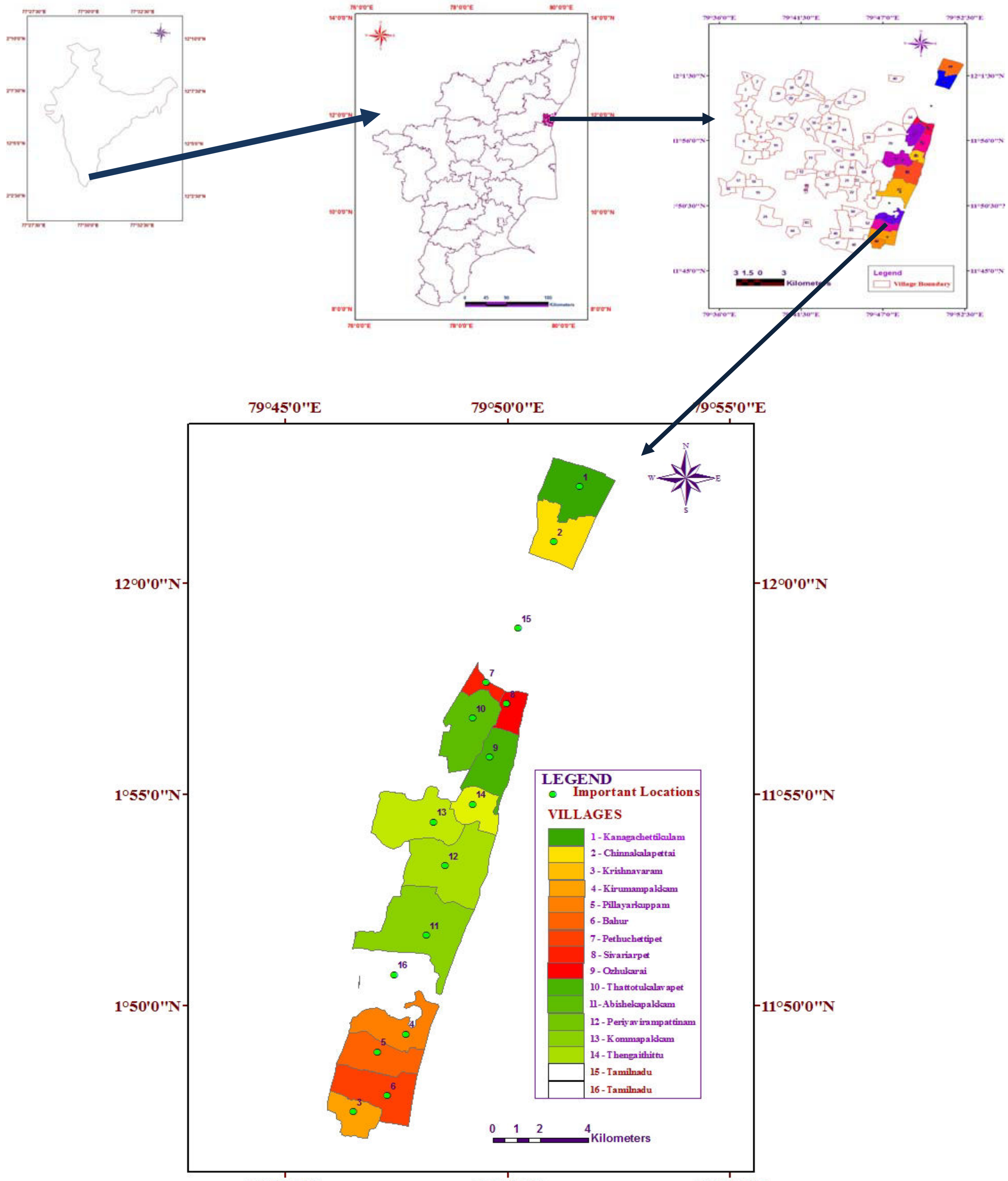


Figure 2.1 Location and Block map of the study area

2.2 POPULATION

As per the population census, 2011 the study area had a total population of about 946,600 of which male and female were 466,143 and 480,457 respectively. There was change of 28.73 percent in the population compared to population as per 2001 (Fig. 2.2).

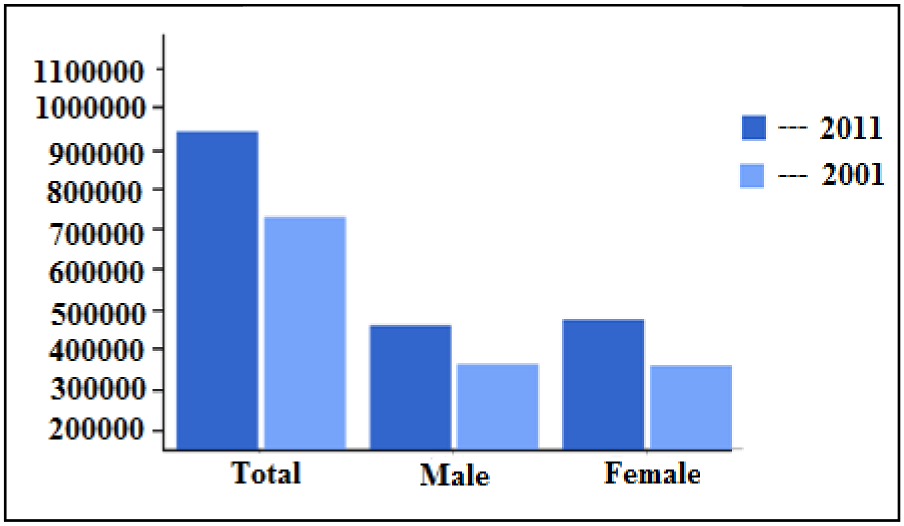


Fig. 2.2 Population of Pondicherry regions

In previous census of India 2001, Puducherry recorded an increase of 20.88% when compared to the population on 1991. The initial provisional data suggest population density of 3,231 in 2011 compared to 2,510 during 2001. Total area falling under Puducherry is 293 sq.km. Average literacy rate of Puducherry in 2011 were 86.13 compared to 80.66 of 2001. The gender wise, male and female literacy were 92.07 and 80.40 respectively. The sex ratio in Puducherry stood as 1031 per 1000 male (Table 2.1). Settlements are sparsely distributed throughout the study area where a bulk is identified at the center portion of the study area (Fig.2.3).

Table 2.1. Population of Pondicherry region (source: Census of India)

Description	2001	2011
Actual Population	735,332	946,600
Male	369,428	466,143
Female	365,904	480,457
Population Growth	20.88%	28.7%
Area Sq. Km	293	293
Density/km^2	2,510	3,231
Pondicherry Population	75.47%	76.06%
Sex Ratio (Per 1000)	990	1031
Child Sex Ratio (0-6 Age)	967	969
Average Literacy	80.66	86.13
Male Literacy	88.44	92.07
Female Literacy	72.84	80.4
Total Child Population (0-6 Age)	87,232	95,432
Male Population (0-6 Age)	44,352	48,459
Female Population (0-6 Age)	42,880	46,973
Literates	522,782	733,075

2.3 ROAD

The study area is situated at a distance of 162 kilometres to the south of Chennai. It is well served by roads, railways and airways. The state highway SH 49 passes through Pondicherry (Fig.2.4). It is also well connected by electric broad gauge railway line. Pondicherry has an airport with facilities for the landing of small aircraft. A network of all weather metalled roads connecting every village exists in the territory. Pondicherry has a road length of 2552 km (road length per 4.87 km^2), the highest in the country (Table 2.2).

Table: 2.2. Roads and their classification

Sl.No.	Type of Road	Length in (KM)
1	National Highways	64.65
2	State Highways	49.304
3	District and other Roads	173.384
4	Rural Roads	164.964
	Total	452.302

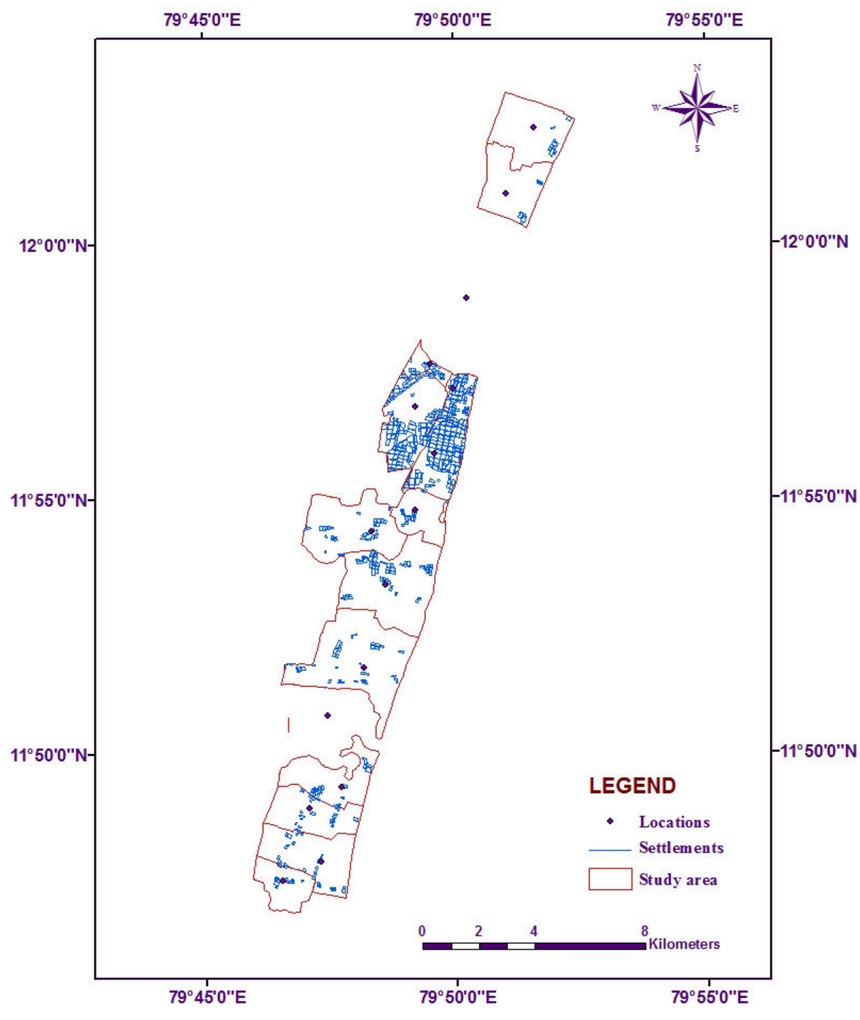


Figure 2.3 Settlements at the study area

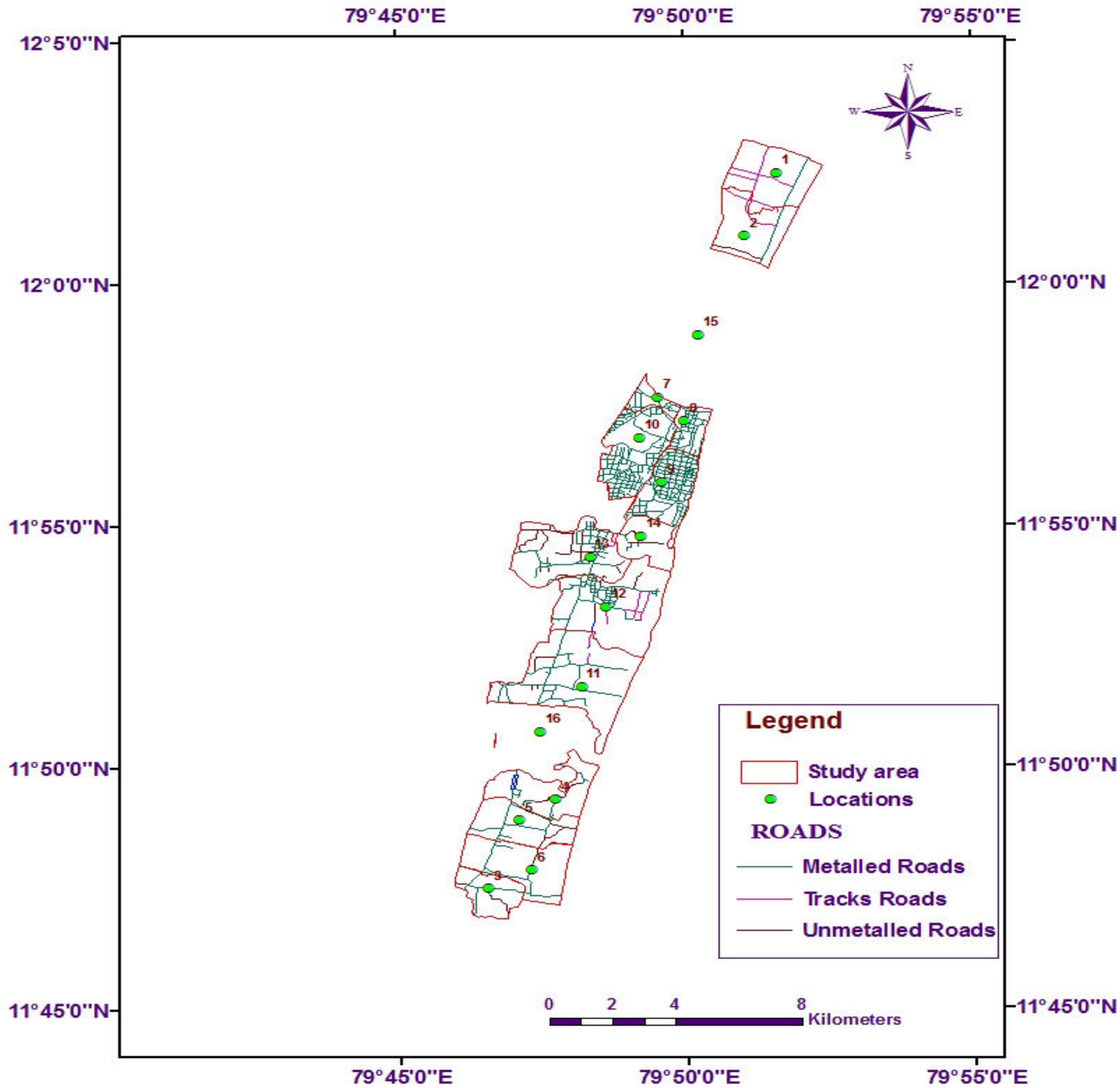


Figure 2.4 Road map of the study area

2.4 ADMINISTRATIVE DETAILS

For the purpose of administration the study area is divided into four taluks viz. Puducherry, Ozhukarai, Villianur and Bahour. The taluks are further divided into commune panchayats. The Puducherry taluk comprises of Ariyankuppam commune, Villianur taluk with two communes, viz. Villianur and Mannadipet, and Bahour taluk with two communes, viz. Bahour and Nettapakkam.

District	Taluks	Municipalities	Communes
Puducherry (Pondicherry)	Bahour	None	Bahour and Nettapakkam
	Ozhukarai	Ozhukarai	-
	Puducherry	Puducherry	Ariyankuppam
	Villianur	-	Mannadipet and Villanur

Source: *Wikipedia - Pondicherry*

2.5 GEOLOGY

The U.T. of Puducherry is underlain by the semi-consolidated and unconsolidated sedimentary formations ranging in age from lower Cretaceous to Recent, lying on Archaean basement. The generalised stratigraphic succession of the formations encountered in the four regions and their ground water potentials in brief are as follows. The region has a seaward dipping with increased thickness of strata consisting of unconsolidated and semi-consolidated formations lying on Archaean basement (Table 2.3). The sediments are mainly clay, claystone, silt, siltstone, marl, limestone, sand, sandstone and gravel. All these sediments occur as alternating strata. These sedimentary formations range in age from Cretaceous to Recent. The stratigraphic successsion of the geological formations is presented in the following table (After CGWB Chennai). The geology of the area under investigation comprises of recent alluvium and Mio-Pliocene Cuddalore formations of Quaternary formations the geology of entire Pondicherry region is discussed for the ease of interpretation (Fig.2.5).

Table 2.3 Stratigraphic succession of the geological formations in Pondicherry area (*geology of the present area of investigation).

	Period	Formations	Lithology
Quaternary*	Recent	Alluvium, Laterite	Sands, Clays, silts, kankar and gravels, laterite.
	Mio-Pliocone	Cuddalore Formations	Pebbly and gravelly coarse grained sandstones with minor clays and siltstones with thin seams of lignite
		--Unconformity----	
Tertiary		Manaveli formation	Yellow and yellowish brown, grey calcareous siltstone and claystone and shale with thin bands of limestone.
	Paleocene	Kadapperikuppam formation	Yellowish white to dirty white sandy, hard fossiliferous limestone calcareous sandstone and clays.
		----Unconformity---	
		Turuvai limestone	Highly fossiliferous limestone, conglomerate at places, calcareous sandstone and clays.
	Upper Cretaceous	Ottai clay stone	Greyish to greyish green claystones, silts with thin bands of sandy limestone and fine grained calcareous sandstone.
		Vanur sandstones	Quartzite sandstones, hard, coarse grained, occasionally feldspathic or calcareous with minor clays.
Mesozoic	Lower Cretaceous	Ramanathapuram formation (unexposed)	Black carbonaceous silty clays and fine to medium grained sands with bands of lignite and medium to coarse grained sandstones.
		----Unconformity----	
Archaean		Eastern Ghat Complex	Charnockite and Biotite Hornblende Gneiss.

The Achaean is represented by the rocks of Eastern Ghat complex comprising Charnockites and Gneisses. Coarse grained acid Charnockite is noticed in the low mounds along the bed of Varahanadhi, west of Tiruvakkarai. The Biotite-Hornblende Gneiss is exposed north-west of Puducherry region associated with the Charnockites. The Eastern Ghat complex forms the basement for Cretaceous-Tertiary sediments in the region. The yield of wells drilled in these formations in general is meagre.

2.5.1 Cretaceous (Mesozoic) Sediments

The oldest sedimentary formations are the Cretaceous sediments of Mesozoic era and are exposed in the north-western part of the Region and north of Varahanadhi River. The trend of these formations is NE-SW. Four stratigraphic units were identified by the ONGC namely the Ramanathapuram, Vanur, Ottai and Turuvai formations.

2.5.2 Ramanathapuram Formations

The Ramanathapuram formations representing the Lower Cretaceous age are not exposed anywhere. They were encountered only in boreholes drilled north of Varahanadhi river and also between Ponnaiyar and Varahanadhi on the western part of the region. At Ramanathapuram, they are unconformably overlain by younger Cuddalore formations, whereas in the rest of the area drilled, they are overlain by Vanur sandstones. They comprise alternate layers of sands, sandstone and Carbonaceous-Claystone with thin seams of lignite. The thickness of this formation ranges between 55 and 250m.

2.5.3 Vanur Sandstone

The Vanur sandstones represent the oldest unit of the upper Cretaceous formations. These formations comprise coarse-grained friable, greyish white, pebbly sandstones, Felspathic at places with veins of aragonite and with thin intercalations of dark grey to greenish grey shales.

These sandstones are also encountered in the boreholes drilled north of Varahanadhi and in the eastern part of the region between Ponnaiyar and Varahanadhi. The thickness of this formation is 152m at Vanur whereas it is only 52 m at Katterikuppam.

2.5.4 Ottai Clay stones

The Ottai formations consist of black to greenish grey claystone with bands of limestone and calcareous and micaceous silts and siltstones. These are exposed in comparatively larger area covering part of Valudhavur, Ottai and Pulichappallam villages (north of Gingee River). These formations are encountered in the boreholes drilled to the north of Varahanadhi river and in the deeper boreholes drilled south of Varahanadhi river in the western half of the region. The outcrops of this formation are commonly yellowish grey in colour. The thickness of this formation is about 139 m at Karasar, over 231 m at Lake Estate and about 88 m at Kalapettai.

2.5.5 Turuvai Limestones

The uppermost of the upper Cretaceous formation know at Turuvai limestones are exposed as a narrow strip in NE-SW direction, extending from Mettuveli in the south to Abirampattu of Tamil Nadu in the north. The Turuvais comprise fossiliferous, cement grey limestone with a few bands of sandstones. These are highly conglomeratic with pebbles of quartz at places as seen in the dug well section at Royapudupakkam. But, this formation is limited in thickness.

2.5.6 Paleocene (Tertiary) Formations

The Paleocene formations of lower Tertiary are represented by the Kadapperikuppam and Manaveli formations in the region.

2.5.7 Kadapperikuppam Formations

The Kadapperikuppam formations are exposed near Pillaiyarkuppam, Sedarapattu, Kadapperikuppam and Alankuppam. These formations are essentially calcareous sandstones, yellowish grey to dirty white in colour with thin lenses of clay and shale and bands of shell limestone.

2.5.8 Manaveli Formations

The Manaveli formations belong to upper Paleocene age and formations comprise yellowish brown calcareous sandy clay and shales with pieces of thin shell and limestone bands. The upper contact with Cuddalore sandstone is unconformable and is marked by laterite. These formations occur in a small stretch covering the villages Manaveli, Thiruchitrambalam, Kottakkarai and east of Alankuppam. These are encountered in the boreholes drilled in the area north and south of Varahanadhi river towards east.

2.5.9 Cuddalore Formations

The upper Tertiary sediments in the area are represented by Cuddalore formations are Mio-Pliocene age. The Cuddalores are composed of thick succession of pebbly and gravelly, coarse-grained sandstones with minor clays rarely with seams of lignite. Silicified wood has been noticed at places in the outcrops and well sections. They occur as two widely separated outcrops of ferruginous laterite high ground, one on the north-western margin known as Tiruvakkarai ridge, the other in the north-eastern portion along the coast. All other older formations are cropped out in between these two patches. In the north-western margin, the Cuddalore overlie Vanur sandstones, which is underlain by the Ramanathapuram formations. In the north-eastern portion they overlie the Manaveli formations. The thickness of these formations varies from 30 to 130 m at outcrop area and maximum thickness of 450 m is observed at Mnapattu along the coast in the south-eastern side.

2.5.10 Recent (Quaternary) Formations

The Recent (Quaternary) formations in the Region are represented by laterites and alluvium. Laterite occurs as thin cap over the Cuddalore formations. Thick alluvial deposits are built-up along the course of Ponnaiyar and Gingee rivers covering three fourths of Puducherry region. It occurs in the interstream area and also north of Gingee river in the area extending from Puducherry town on the east to Usteri tank on the west. The alluvium in the area is composed of sands, clays, silts, gravels and kankar. The thickness of alluvium varies from 10 to 55 m at different places with a maximum of 55 m at Satyamangalam.

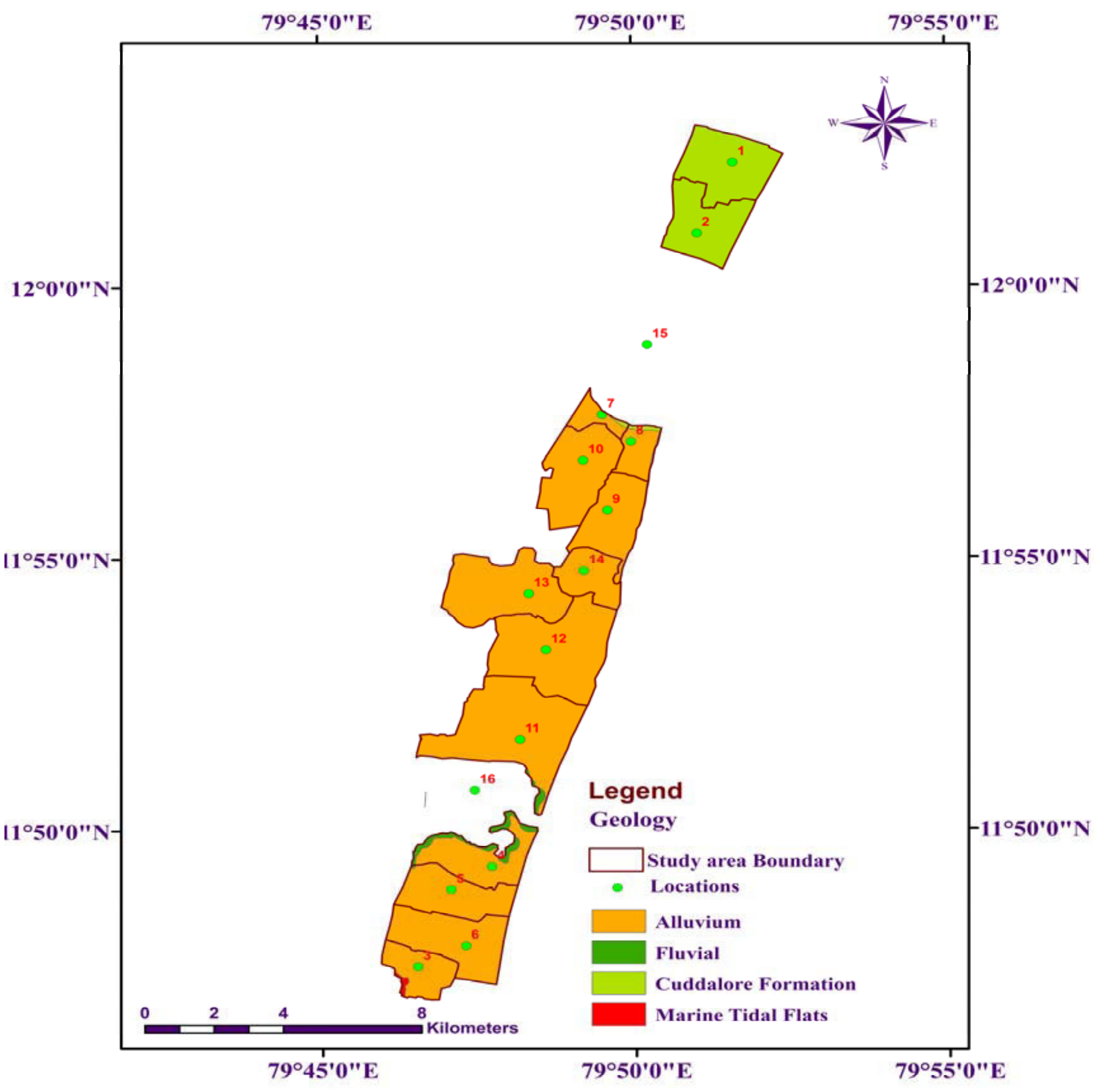


Figure 2.5. Geology of the study area

2.6 Application of Remote Sensing and GIS

Applications of Remote Sensing (RS) and Geographical Information System (GIS) in the field of hydrology, water resource development and management are rapidly increasing. In developing accurate hydrogeomorphological analysis, monitoring, ability to generate information in spatial and temporal domain and delineation of land features are crucial for successful analysis and prediction of groundwater resources. However, the use of RS and GIS in handling large amount of spatial data provides to gain accurate information for delineating the geological and geomorphological characteristics and allied significance, which are considered as a controlling factor for the occurrence and movement of groundwater used along with topographic maps.

In recent years, increasing recourse is made to the integration of remote sensing and GIS in the area of environmental applications. The integration of remote sensing and GIS has proven to be an efficient tool in groundwater studies (Krishnamurthy et al. 1996; Krishnamurthy and Srinivas 1996; Sander 1996; Saraf and Choudhury 1998), where remote sensing serves as the preliminary inventory method to understand the groundwater prospects and conditions and GIS enables integration and management of multi-thematic data. The resultant vector data can be used in image classification and raster image statistics within vectors query and analysis.. In addition, the advantage of using remote sensing techniques together with GPS in a single platform and integration of GIS techniques facilitated better data analysis and their interpretations.

IRS P6 LISS III data on 1: 50000 scales (Fig.2.6) have been used for the generation of thematic maps by integration with ARCGIS v 9.2 for the present study.

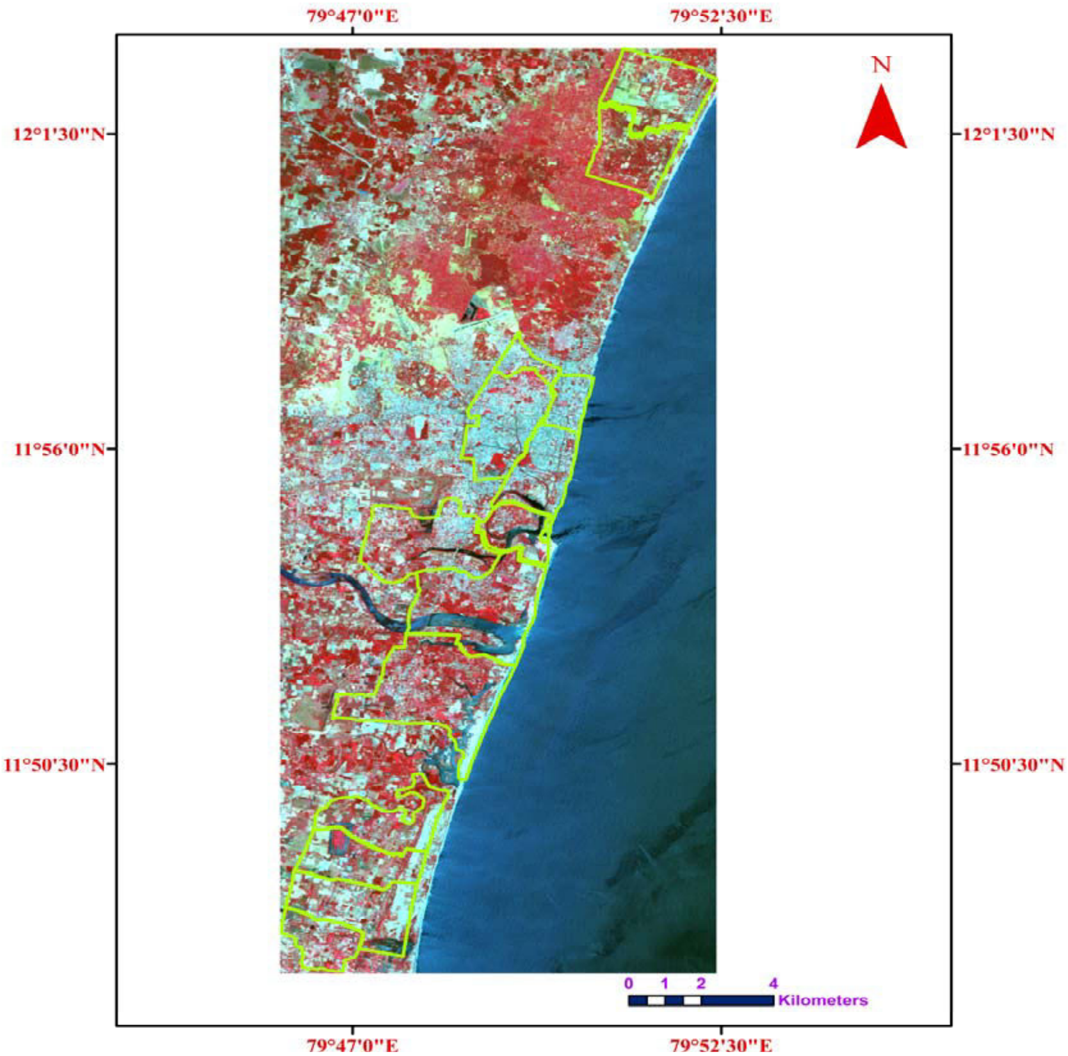


Figure 2.6. Remote sensing imagery of the study area

2.7 STRUCTURAL TRENDS

The general strike of Cretaceous and Palaeocene trends northeast-south west with gentle dips ranging from 2° to 5° towards southeast. The cuddalore formations also strikes same as the Cretaceous and Palaeocene but with a higher degree of dip upto 10°. The cretaceous and Palaeocene formations form an inlier might have been exposed due to the denudation of the

LITERATURE SURVEY

Electrical resistivity tomography (ERT) is a non-destructive geo-electrical prospecting method that analyses subsurface materials in terms of their electrical behavior, distinguishing between them according to their electrical resistivity, the property that indicates the degree to which a material resists an electrical current passing through it. The concentration of ions in a rock, therefore, is conditioned by the amount of fluid present in its pores or fractures, an amount that depends on the texture of the rock, which is to say, its degree of weathering and porosity. Greater ion mobility leads, as a consequence, to lower resistivity or, which is much the same, to greater conductivity (Orellana, 1982). These theoretical aspects describe the behavior pattern of the different materials (Aracil, 2002; Aracil, et al., 2002 and 2003). Consequently, once the geo-electrical prospecting campaign using tomography is underway, different resistivity values will be determined and attributed to materials that will permit the identification of lithological units of differing natures, lithologies with different textures or degrees of deterioration, structural (fractures) and geomorphological aspects (caves and infills), etc. (Flint et al., 1999; Porres, 2003).

This method is based on the positioning of an array of electrodes along a transversal section, each separated at a particular distance according to the required degree of resolution (less spacing between electrodes, greater resolution) and depth of the investigation (greater spacing between electrodes, greater depth). With all the electrodes connected to the measuring equipment, and using a specific sequential programme created for each objective, the programme 'decides' which groups of electrodes should be in operation at any given time and in what layout (Loke, 2000). Each one of these four electrode arrays or quadripoles takes a measurement of the resistivity that is attributed to a particular geometric point in the subsurface, whose position and depth in the image depends on the position of the quadripole and on the spacing between the electrodes that constitute it. The electrical images are, in fact, cross-sections of land that reflect the distribution of resistivity values at different depths corresponding to the different layers of investigation. Therefore, the depth of investigation will depend on the spacing between electrodes. The selected layout may easily run deeper than 100 m, even though shallower test boreholes into the subsurface have the definite advantage of greater resolution, as there is generally less separation between electrodes. As a rule, for images with the same number of electrodes, the resolution of the investigation decreases logarithmically in relation to the depth (Dahlin and Loke, 1998). When studying complex structures the density of measurements is fundamental, especially where geological 'noise' is present (a distortion provoked by some small-scale geological heterogeneities when measuring an image). Thus a network of very disperse measurements could really overlook important features of the sub-soil or could generate false structures (Dahlin and Loke, 1998).

Geophysical resistivity surveys are regularly used for studies related to ground water investigations. Resistivity profiling delineates the lateral changes in resistivity that can be correlated with steeply dipping interfaces between two geological formations in the subsurface. Resistivity sounding determines the thickness and resistivity of different horizontal or low dipping subsurface layers, including the aquifer zone (Kalpan Choudhury and Saha, 2004). However there are some serious limitations in such investigations as they fail to distinguish between formations of similar resistivities such as saline clay and saline sand, which causes low resistivity due to water quality. Ambiguity regarding low resistivity also arises from the enhanced mobility of ions in areas of high geothermal activity. An integration of geophysical method combined with chemical data largely resolves the uncertainty.

The electrical resistivity method is widely used in groundwater exploration studies (Todd, 1959) because it's least expensive of all geophysical methods requiring no specially trained technicians to operate the instrument. Water barren formations can be identified based on the contrast in electrical resistivity (Zohdy et al. 1974). Master curves and tables for VES enhanced the development in resistivity surveys (Orellana and Mooney, 1966).Well documented studies on electrical resistivity were also carried out by Kelter and Frischknecht (1966), Zohdy et al. (1974), Ramachandra Rao (1975), Harinarayana (1977), Patangay (1977), Todd (1980), Ramteke (2002) and Venkateswara Rao et al. (2004). Balasubramanian (1980) has tabulated the ranges of resistivity values for common hard rock and their water bearing decomposed products of the peninsular India. The resistivity of highly weathered saturated gneisses of Archaean age ranges from 27 to 120 Ωm. Electrical resistivity method is proved to be more appropriate for groundwater studies in hard rock terrains (Bhimasankaran and Gaur, 1977 and Balakrishnan et al. 1984). Roy and Elliot (1981) made a significant observation regarding depth and exploration using DC electrical methods within a specified domain of the resistivity, layer thickness and electrode spacing. Electrical resistivity surveys were also conducted in shales for the estimation of resistivity and the depth to basement by Balakrishnan et al. (1979) and found fruitful results. Balasubramanian et al. (1985) worked on the resistivity method by the combination of iso-resistivity and isopach map to classify the freshwater and saltwater horizons. Arumugam (1989) attempted for the identification of groundwater potential zones by geophysical and pump test analysis. Later the involvement of computer in the analysis of the resistivity data for direct interpretation was carried out to attain significant results (Basokus, 1990). The earth resistivity surveys were used to define groundwater contamination (Lawrence and Balasubramanian, 1994). In the hard rock terrain with insitu weathering and fresh water beneath, this method is used to find the thickness of the weathered layer (Chidambaram, 2000). Characterization of groundwater flow regime by fracture network was carried out with the help of geophysical methods by Deevashish Kumar (2002). Integrated geophysical and seismic refraction prospecting was carried out in Coastal belt of Bengal by Sahu et al. (2002). Balaram Das et al. (2007) has highlighted the utility of the electrical resistivity and induced polarization methods along with chemical data for successful delineation of contaminated/polluted groundwater zones in part of Birbhum district, West Bengal. Similar work was done by Saha et al. (2007) to identify the hidden oldham fault in the Shillong plateau and Assam valley of North East India using geophysical and seismological investigations. PWD and TWAD has conducted geophysical resistivity survey in many parts of the study area and identified groundwater potential zones for public utility.

Geo-electrical survey is considered as the most successful geophysical method for detection of groundwater/aquifers. There is substantial change in groundwater resistivity with chemical contamination of water. Several workers were successful in locating chemically contaminated groundwater (Cartwright and McComas, 1968; Stollar and Roux, 1975; Kelly 1976). The Resistivity/conductivity contrast between fresh water and contaminants contain an ionic concentration of radicals, which is considerably higher than that found in fresh ground water. In general, increased ionic concentration or total dissolved solids (TDS) results in higher electrical conductivity (low resistivity). Thus, an aquifer zone containing contaminants can be delineated by resistivity method. But when the contrast in resistivity between fresh groundwater and contaminated groundwater is very low, it is difficult to distinguish an aquifer zone containing contaminant (target) from the zone with natural groundwater. However, correlation of resistivity and chargeability data is very useful for solving these ground water problems. The application of IP sounding in ground water problems have been described by different workers like Vacquier et al. (1957), Sumi (1965) and Badmer et al. (1968). Ogilvy and Kuzmina (1972) have established the usefulness of IP survey for specifying the position of the interface between fresh and saline water. As such, the combined resistivity and IP sounding was carried out for delineating the aquifer zones contaminated by high fluoride (Balaram Das et al. (2007).

Jhonson et al., 2008 used high resolution electrical resistivity soundings to demarcate the density differences of the saline water, the gradients and hydraulic properties of the multi-layered sandy aquifers, and the shape of the fresh water/salt water interface in the coastal aquifers of Los Angeles, California. Groen etal., 2008 used resistivity combined with cone penetration tests to map groundwater salinity and lithology to locate fresh and saline water interface and identified freshwater lens recharged by rainwater infiltrating the dune area. Post etal., 2007 used TDEM measurements to identify the fresh groundwater extension along the offshore region of Lisbon. Geological and Geophysical investigations were carried out by Ardau et al., 2002 in the coastal plain of Italy and demarcated saline water intrusion in the Pleistocene-Holocene sedimentary cover aquifers. Origin of brackish to saline groundwater in the coastal area of Netherlands based on geological, geochemical, isotopic and geophysical data was attempted by Post etal., 2003 and demarcated salinity source from paleogeographic development during Holocene. Rosquist and others (2003) identified Leachate plume migration in two landfill sites in South Africa along the downstream direction by using electrical imaging techniques and it was further conformed by geochemical investigations. Identification of groundwater redox conditions and conductivity was combined to identify movement of contaminant plume was attempted by Naudet and others (2004) by using electrical imaging techniques in parts of South east France and observed good linear correlation between conductivity and electrical tomography methods. Contaminated site mapping was attempted by using GPR method and electrical tomography methods in Brazilian site and identified low resistivity values are confined to oil spilling sites. Imaging techniques was attempted by Abdel Latif Mukthar and others (2000) in a landfill site at Malaysia to study the contaminant flow along groundwater flow direction. Electrical imaging was attempted by Kariem et al., 2012 in the oasis shallow aquifers of the Nefzaoua region of Tunisa and demarcated storage basins of irrigation excess water contribute to the increase in salinity. Adeoti et al., (2010) attempted for saline water intrusion using electrical resistivity tomography in Lagos state, Nigeria and identified intrusion at depths 13m and 64 m confining to the fresh water aquifers. Geophysical prospecting studies in coastal zones of the Iberian Peninsula have been attempted by Avila et al., 2004 and identified saline water intrusion. Satrani et al., 2011 used Electrical Resistivity Tomography for the demarcation of saline water intrusion in Basilicata region, southern Italy and concluded, top soil layer with high resistivity values not affected by the saline water intrusion but occurrence of intrusion was noted at greater depths. Nur islami (2011) identified the brackish water zone at depths of 20 -30 m using resistivity inverse model in North Kelantan – Malaysia region and concluded salinization of groundwater. Hamdan et al., 2010 attempted for demarcation of saline water intrusion in Chania area, Greece and concluded that a major normal NE-SW fault zone is responsible for the groundwater salinization. Vertical electrical sounding (VES') surveys and chemical analyses of groundwater have been executed in the coastal plain of Acquedolci, Northern Sicily by Cimini et al., 2008 with the aim to circumscribe seawater intrusion phenomena and identified values <10 Ωm along the western part of the study area as affected by saline water intrusion with higher chlorine content. Integrated hydrogeochemical and geophysical methods were used to study the salinity of groundwater aquifers along the coastal area of north Kelantan has been attempted by Samsudin et al., 2008 and demarcated freshwater/salt water interface at a distance of 6 KM from the beach and suggested the second aquifer as intruded by saline water. VES soundings to map saline water intrusion in fresh water aquifer in Israel was attempted by Ginzburg A and Levanon A, 1976 demarcated low resistivity layers associated with saline water. Time lapse resistivity investigations was attempted by Virginie Leroux, Torleif Dahlin (2006) in Sweden glaciofluvial deposits and identified salt spreading during winter causes an increase in salinity. ERT was conducted in the coastal alluvium of Gokceada-Turkey by Ekinci et al., 2007 and demarcated seawater-freshwater interface at a depth of 7-8 m. Investigation of Saline water intrusion in the coastal alluvial aquifers of Carey Island, Malaysia was attempted by Samira Igroufa (2010) and detected saline water intrusion at shallow depth around 10 m and extending down to a depth more than 40 m.

Ron Barker and Thangarajan, (2001) attempted to delineate contaminant zone in a Tannery belt of Dindugal town by using electrical imaging techniques and identified resistivity values lesser than 1.0 Ωm as contamination zones. Electrical imaging represents a re-emergence of an old technology. The technology has been hampered by high cost compared to other methods. However, through advances in field equipment design capability, and the development of computer algorithms necessary to effectively and accurately reduce and present the geophysical data, electrical imaging is now cost competitive with more commonly used geophysical techniques. Hence lesser studies pertaining to this method are available from the Indian point of view. The new and future applications of this technique for the efficient development of groundwater resources will change the way groundwater aquifers are exploited and managed. Survey was also conducted in Shales by Balakrishnan et al., 1979 to determine the permeability and porosity in sand stone. Balasubramanian et al., (1985) worked on the resistivity method by the combination of isoresistivity and isopach map and classified the fresh water and salt water horizons. The earth resistivity surveys were used to define ground water contamination (Lawrence and Balasubramanian, 1994). Harikrishna Prasad et al., 2011 used multi proxy methods like remote sensing, GIS, Hydrogeology, Hydrochmistry and geophysical investigations to reveal the saline water intrusion in Koleru lake, India and identified salt-water intrusion up to 40 km along the northern part of the lake. Satish et al., 2011 attempted to demarcate the zone of mixing between seawater and groundwater in the coastal aquifer of south Chennai, Tamil Nadu using Electrical Resistivity Tomography and identified the influence of saline water comparatively higher in northern part of the study area than the southern part. Vertical Electrical Soundings (VES) employing Schlumberger configuration have been deployed in the eastern and south eastern Kolkata metropolis by Saha and Choudhary, 2005 for delineating the subsurface saline water zone and the interpretation of VES data indicate the disposition of saline / brackish zones at a depth of 50 m. An attempt on sea water intrusion in the Kovaya Limestone Mine, Saurashtra coast of India has been attempted by Paras R. Pujari and Abhay K. Soni, 2008 and identified high dissolved solids (>1,000 mg/l) and high chloride (3,899 mg/l) from the groundwater samples and ERT suggests possible saline water intrusion with low resistivity zones (0 - 3 Ω m) along area where intensive mining is going on.

4. METHODOLOGY

Electrical Resistivity Tomography imaging (ERT imaging) is one of the electrical geophysical techniques that are used in the assessment of saline water intrusion mainly to study the freshwater/seawater interface and soil salinization (Bear et al., 1999; De Franco et al., 2009; Yaouti et al., 2009).

In the present work BTSK WDDS-2/2B Digital Resistivity Meter was used to perform a total of 20 profiles located respectively at 5 m to 600 m from the shoreline. The profiles were oriented perpendicular to the shoreline. The electrodes were stainless steel electrodes pierced 30 to 40 cm. The Wenner - α protocol was applied with a number of electrodes varying from 20 to 34 spaced of 5 m and/or 10m leading to an investigation depth ranging from 30 – 55.7 m. The electrodes are connected through multicore cables to a switching panel which is placed in the middle of the profile. The current and potential terminals from the switch panel are connected to the respective terminals of the BTSK WDDS-2/2B Digital Resistivity Meter. The switching panel consist series of sockets connected to the electrodes through the multicore cable system. The current terminal pin and the potential terminal pin which are connected with the current source and the resistivity measuring instrument can be inserted in the appropriate sockets for measuring the resistivity between any two electrodes without actually changing the electrodes along the profile. The multiple sounding along the selected profile registered the horizontal and vertical resistivity changes. These resistivity values are used to create a 2D Electrical Resistivity Images of the cross section of the profile. The pseudo section contouring method is used to plot the data collected through the field experiments (Antony Ravindran 2010, Voeikov 1988, Post 2005). The pseudo-section reflects the true resistivity distribution along the profile and therefore can be used as a base for qualitative interpretation. To minimize the differences between the measured and the calculated apparent resistivity values, the inversion method are applied (Antony Ravindran et al. 2012). The inversion method projects a 2D model of a subsurface by using the measured data and by using RES2DINV software program (Geotomo Software, 2010).

4.1 VERTICAL ELECTRICAL SOUNDING

Vertical (1D) Electrical Sounding (VES) are for determining the layered aquifers of different litho units. In majority of the cases, VES demarcates the number of layers, thickness and resistivity. The basic idea of resolving the vertical resistivity layering is to stepwise increase the current-injecting electrodes AB spacing, which leads to an increasing penetration of the current lines and in this way to an increasing influence of the deep-seated layers on the apparent resistivity ρA. In general, linear electrode configurations are used for resistivity measurements. The most popular configurations are Wenner and Schlumberger, which varies basically on electrodes spacing. Wenner system is used for quantitative interpretation and this method is well suited for geoelectrical profiling. Reversing/inversion are applied to reduce the number of layers, their resistivities and thickness from a measured value. The step-wise measured apparent resistivities are plotted against the current electrode spacing in a log/log scale and interpolated to a continuous curve. This plot is called sounding curve, that is the base of all data inversion to obtain the resistivity/depth structure of the ground. Now, varieties of software programs are available, that allow rapid inversion of resistivity layers. On the basis of resistivity values the software iterates the measured resistivity data to the theoretical data. On obtaining a "best fit" the iteration process is stopped until the root mean square (RMS) error is within the prescribed limit.

4.2 ANALYSIS WITH THE IPI2WIN SOFTWARE

The vertical electrical surroundings were analyzed with the help of IPI2WIN software (Version 3.01, 2003) developed by Moscow state University for interpretation of geoelectrical investigations by curve matching method.

4.3 TYPE OF VES CURVES

The apparent resistivity ratio of $\rho a/\rho 1$ for a two layer case when plotted on a double logarithmic plot as a function of L/h (L=AB/2, h=thickness of the layer), the values of $\rho 2/\rho 1$ vary from 0 (perfectly conducting substratum) to α (perfectly insulating substratum). It will be seen that ρa approaches $\rho 1$ when current electrode separation is small compared with thickness of top layer and $\rho 2$ when it's large. The transition from $\rho 1$ to $\rho 2$ is however; smooth and no simple general rule based on specific properties of curve can be devised to find thickness h1. The addition of third layer sandwiches the top layer and substratum, the problem becomes complicated, apparent resistivity curve can then take four basic shapes known as Q (or DH, descending Hummel), A (Ascending), K (or DA displaced Anisotropic) and H (Hummel type with minimum) depending upon the relative magnitudes of $\rho 1$, $\rho 2$ and $\rho 3$.

The locations of the profiles are given in Fig. 4.1 and the names and are listed in Table.4.1 Secondary data's like rainfall and litho logs were collected from the respective organizations and used for the interpretation of the resistivity data. The methodology adopted for the present study is given below as a flow chart Fig.4.2.

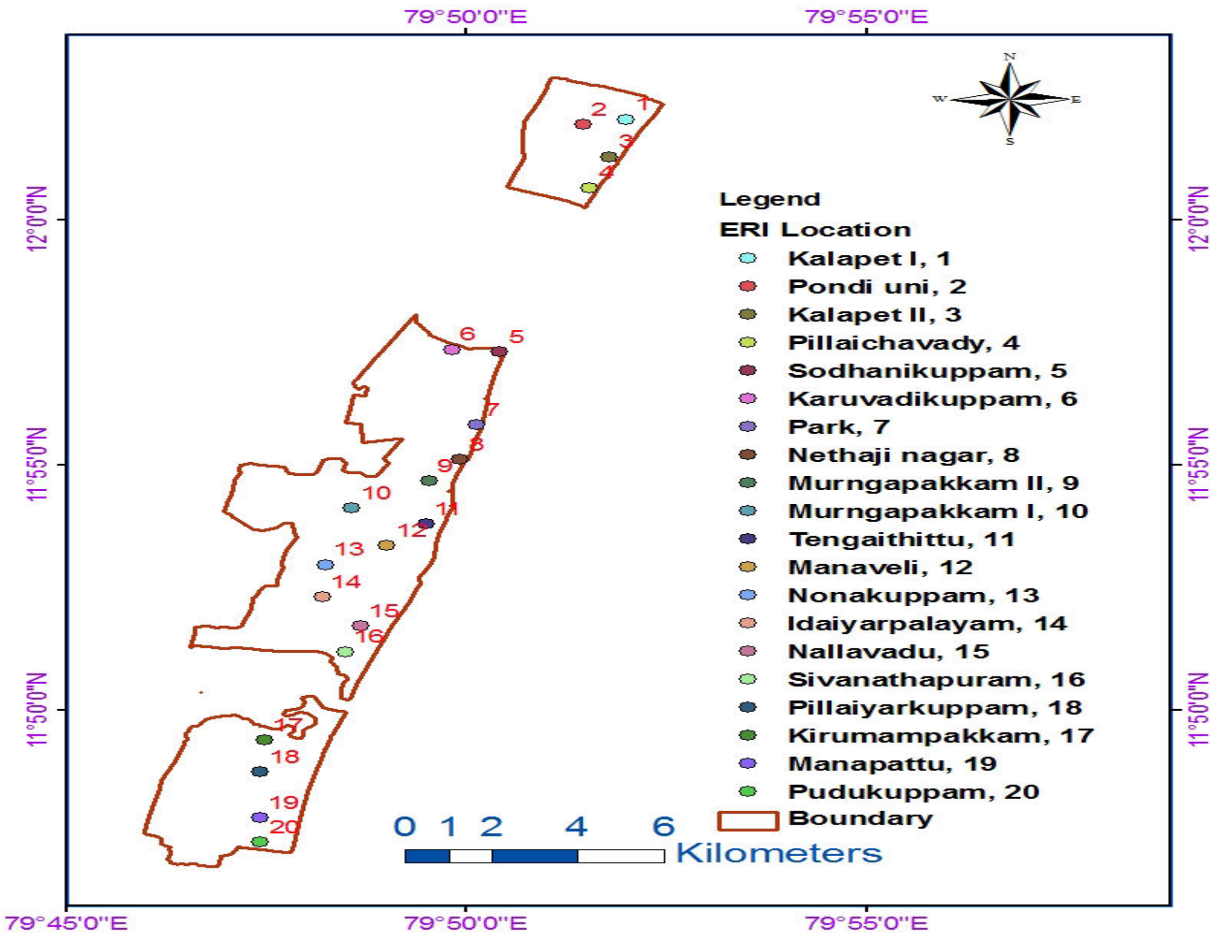


Fig.4.1 Locations of the ERI soundings

Table 4.1 Names of the locations with Latitudes and Longitudes

S.No	Location	Latitude	Longitude
1.	**Kalapet 1**	E 12°2’4”	N 79°51’6”
2.	**Pondicherry University**	E 12°1’56”	N 79°51’ 27”
3.	**Kalapet II**	E 12°1’17”	N 79°51’48”

4.	**Pillaichavadi**	E 12^{o}0’39”	N 79^{o}5’33”
5.	**Sodanaikuppam:**	E 11^{o}57’18’	N 79^{o}50’25”
6.	**Karuvadikuppam**	E 11^{0}57’28”	N 79^{o}49’49”
7.	**Park**	E 11^{o}55’49”	N 79^{o}50’8”
8.	**Nethaji Nagar**	E 11^{o}55’7”	N 79^{o}49’55”
9.	**Murugambakkam 1**	E 11^{o}48’33”	N 79^{o}48’33”
10.	**Murugambakkam- II**	E 11^{o} 54’40”	N 79^{o} 49’32”
11.	**Tengaitittu**	E 11^{o}53’48”	N 79^{o}49’30”
12.	**Manaveli**	E 11°53'51”	N 79^{o}49’11”
13.	**Nallavadu**	E 11^{o}51’44”	N 79^{o}48’14”
14.	**Idayarpalayam**	E 11^{o}52’20”	N 79^{o}48’11”
15.	**Nonankuppam**	E 11^{o}53’12”	N 79^{o}48’13”
16.	**Sivananthapuram**	E 11^{o}51’12”	N 79^{o}48’30”
17.	**Kirumambakkam**	E 11^{o}49’25”	N 79^{o}47’30”
18.	**Pillayarkuppam**	E 11°48”00’’	N 79^{o}47’26”
19.	**Manapattu**	E 11^{o}47’50”	N 79^{o}47’24”
20.	**Pudukuppam**	E 11^{o}47’50”	N 79^{o}47’28”

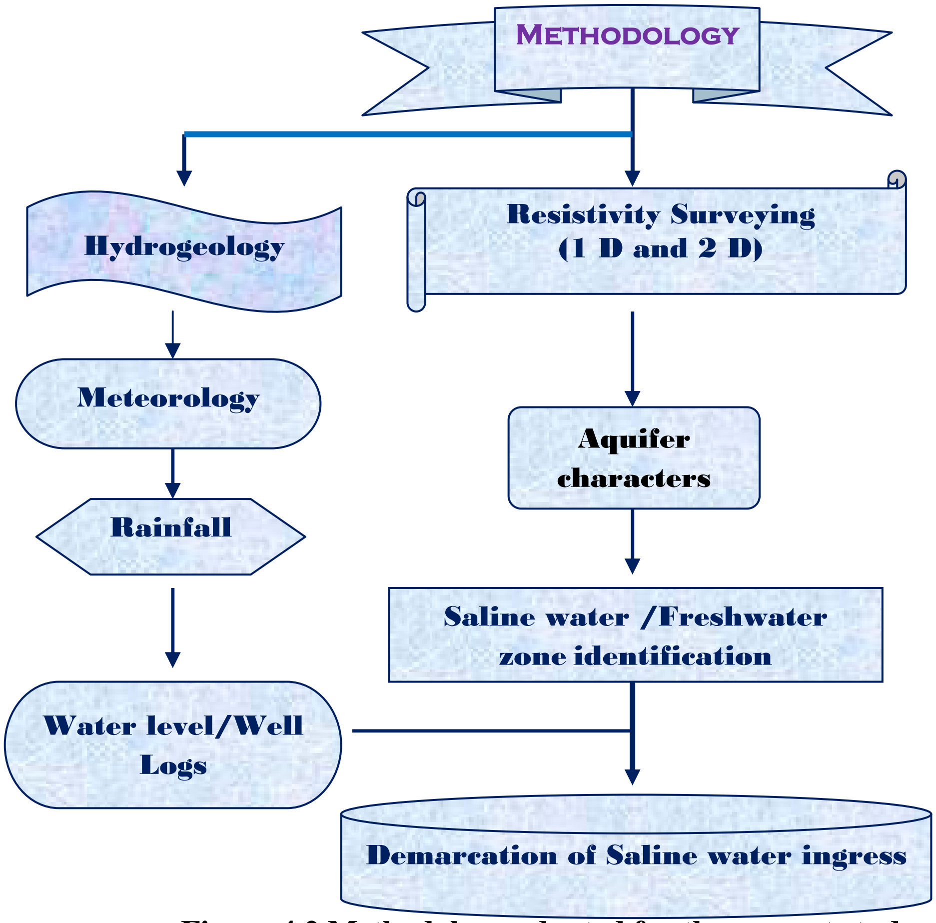


Figure 4.2 Methodology adopted for the present study

4.4 INTRODUCTION TO RESISTIVITY SURVEYS

The purpose of electrical surveys is to determine the subsurface resistivity distribution by making measurements on the ground surface. From these measurements, the true resistivity of the subsurface can be estimated. The ground resistivity is related to various geological parameters such as the mineral and fluid content, porosity and degree of water saturation in the rock. Electrical resistivity surveys have been used for many decades in hydrogeological, mining and geotechnical investigations. More recently, it has been used for environmental surveys. The resistivity measurements are normally made by injecting current into the ground through two current electrodes (C1 and C2), and measuring the resulting voltage difference at two potential electrodes (P1 and P2) Fig 4.3. From the current (I) and voltage (V) values, an apparent resistivity (*pa*) value is calculated. *pa* = kV / I where k is the geometric factor which depends on the arrangement of the four electrodes. Figure 2 shows the common arrays used in resistivity surveys together with their geometric factors. Resistivity meters normally give a resistance value, R=V/I, so in practice the apparent resistivity value is calculated by *pa*=kR. The calculated resistivity value is not the true resistivity of the subsurface, but an "apparent" value which is the resistivity of a homogeneous ground which will give the same resistance value for the same electrode arrangement. The relationship between the "apparent" resistivity and the "true" resistivity is a complex relationship. To determine the true subsurface resistivity, an inversion of the measured apparent resistivity values using a computer program must be carried out.

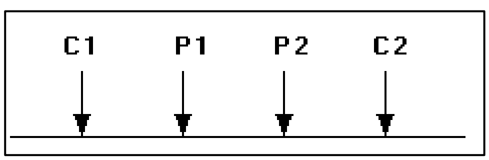


Figure 4.3 Four electrode array for measuring ground resistivity

4.5 TRADITIONAL RESISTIVITY SURVEYS

The resistivity method has its origin in the 1920's due to the work of the Schlumberger brothers. For approximately the next 60 years, for quantitative interpretation, conventional sounding surveys (Koefoed, 1979) were normally used. In this method, the centre point of the electrode array remains fixed, but the spacing between the electrodes is increased to obtain more information about the deeper sections of the subsurface. The spacing for some important resistivity survey are given in Fig. 4.4 and the models are given in Fig. 4.5.

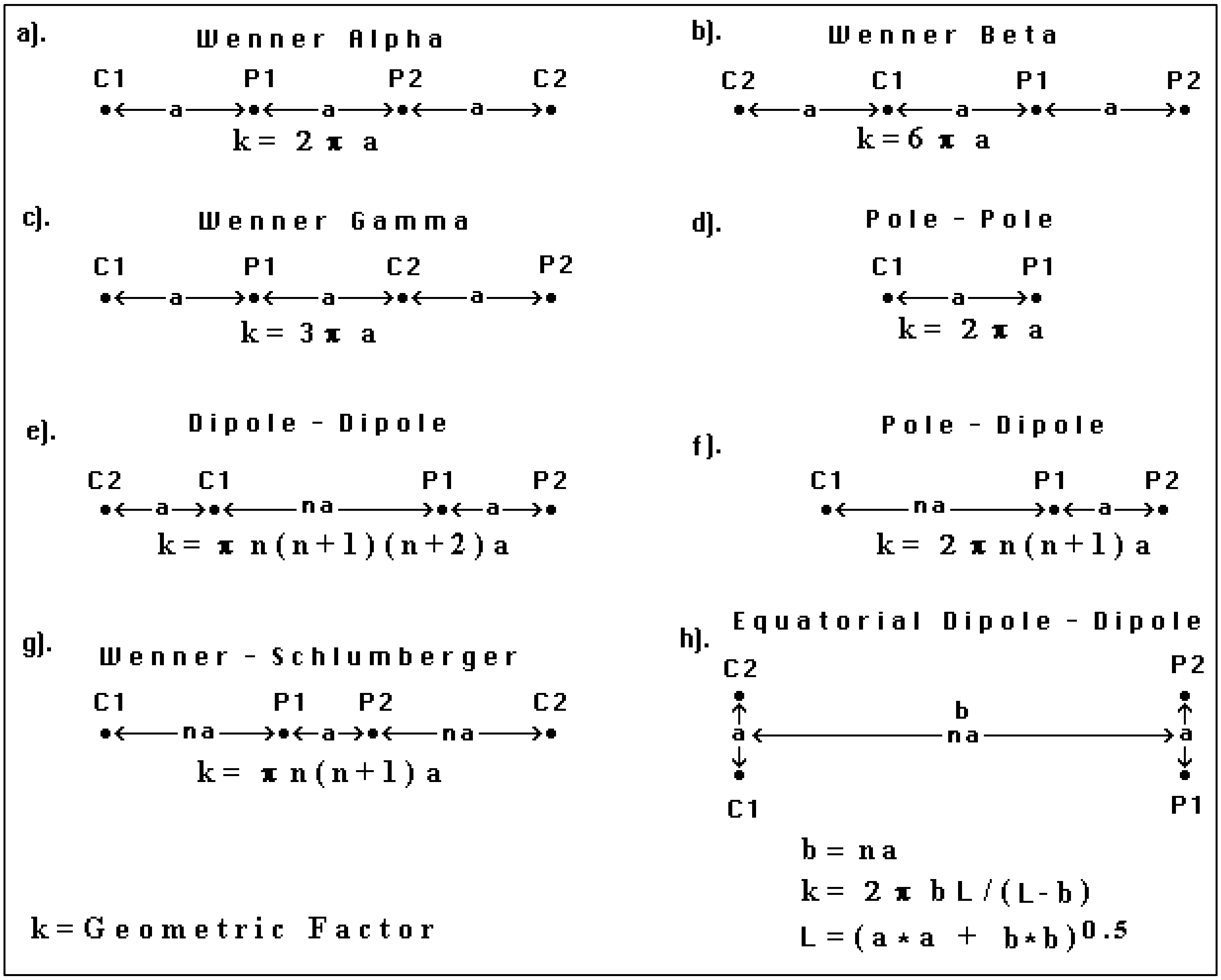


Figure 4.4 Common arrays used in resistivity surveys and their geometric factors (Loke,2001)

The measured apparent resistivity values are normally plotted on a log-log graph paper. To interpret the data from such a survey, it is normally assumed that the subsurface consists of horizontal layers. In this case, the subsurface resistivity changes only with depth, but does not change in the horizontal direction.

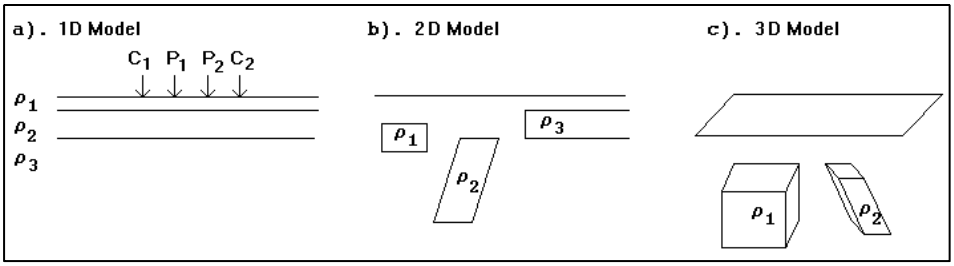


Figure 4.5 Three different models used in Resistivity measurements

4.5 THE RELATIONSHIP BETWEEN GEOLOGY AND RESISTIVITY

The resistivity values for some common rocks, soils and other materials are given in table 4.2 (Keller and Daniels and Alberty 1966).

Table 4.2 Resistivity values of rocks, soil and chemical materials (Loke, 2004)

Material	Resistivity (Ω•m)	Conductivity (Siemen/m)
Igneous and Metamorphic Rocks		
Granite	5×10^{3} - 10^{6}	10^{-6} - 2×10^{-4}
Basalt	10^{3} - 10^{6}	10^{-6} - 10^{-3}
Slate	6×10^{2} - 4×10^{7}	2.5×10^{-8} - 1.7×10^{-3}
Marble	10^{2} - 2.5×10^{8}	4×10^{-9} - 10^{-2}
Quartzite	10^{2} - 2×10^{8}	5×10^{-9} - 10^{-2}
Sedimentary Rocks		
Sandstone	8 - 4×10^{3}	2.5×10^{-4} - 0.125
Shale	20 - 2×10^{3}	5×10^{-4} - 0.05
Limestone	50 - 4×10^{2}	2.5×10^{-3} - 0.02
Soils and waters		
Clay	1 - 100	0.01 - 1
Alluvium	10 - 800	1.25×10^{-3} - 0.1
Groundwater (fresh)	10 - 100	0.01 - 0.1
Sea water	0.2	5
Chemicals		
Iron	9.074×10^{-8}	1.102×10^{7}
0.01 M Potassium chloride	0.708	1.413
0.01 M Sodium chloride	0.843	1.185
0.01 M acetic acid	6.13	0.163
Xylene	6.998×10^{16}	1.429×10^{-17}

Igneous and metamorphic rocks typically have high resistivity values. The resistivity of rocks depends on the degree of fracturing and fractures filled with groundwater. Sedimentary rocks, which are more porous, contain high water content record with lower resistivity values. Wet soils and fresh ground water have even lower resistivity values. Clayey soil normally has a lower resistivity value than sandy soil. The resistivity of ground water varies from 10 to 100 Ω m, depending on the concentration of dissolved salts. The low resistivity (about 0.2 Ω m) of sea water due to the relatively high salt content. This makes the resistivity method an ideal technique for mapping the saline and fresh water interface in coastal areas. The resistivity values of metals like iron have extremely low resistivity values. Chemicals that are strong electrolytes like potassium chloride and sodium chloride reduce the resistivity of groundwater to less than 1 Ω m. Weak electrolytes like acetic acid, is comparatively smaller. Hydrocarbons, such as xylene, typically have very high resistivity values. This makes the resistivity and other electrical or electromagnetic based methods very versatile geophysical techniques.

4.6 2-D ELECTRICAL IMAGING SURVEYS

A more accurate model of the subsurface is a two-dimensional (2-D) model where the resistivity changes in the vertical direction, as well as in the horizontal direction along the survey line. In this case, it is assumed that resistivity does not change in the direction that is perpendicular to the survey line. In many situations, particularly for surveys over elongated geological bodies, this is a reasonable assumption. For 1-D resistivity surveys 10 to 20 readings are recorded, while in 2-D imaging surveys involve about 100 to 1000 measurements. The cost involved for a typical 2-D survey is higher than the cost of a 1-D sounding survey.

4.7 2-D RESISTIVITY SURVEY METHOD

One of the new technologies is the use of 2-D electrical imaging/tomography surveys in mapping areas with moderately complex geology (Griffiths and Barker 1993). Such surveys are usually carried out using a large number of electrodes, 25 or more, connected to a multi-core cable. A laptop microcomputer together with an electronic switching unit is used to automatically select the relevant four electrodes for each measurement (Figure 4.6). The figure shows the setup for a 2-D survey with electrodes along a straight line attached to a multi-core cable. The multi-core cable is attached to an electronic switching unit which is connected to a laptop computer. In a typical survey, most of the fieldwork is in laying out the cable and electrodes. After that, the measurements are taken automatically and stored in the computer. Most of the survey time is spent waiting for the resistivity meter to complete the set of measurements. The Figure 5 shows an example for Wenner electrode array for a system with 20 electrodes.

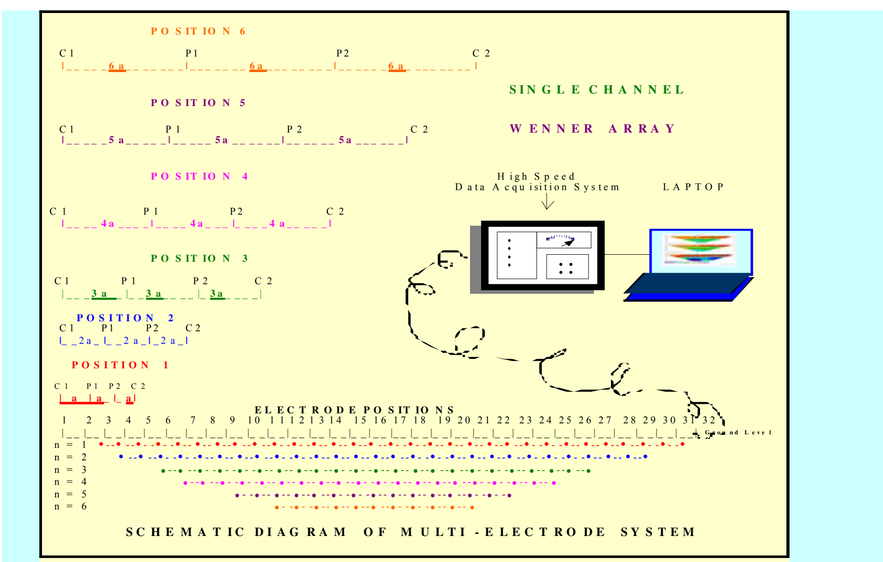


Figure 4.6 Electrode arrangement for 2D survey

In this example, the spacing between adjacent electrodes is "**a**". The first step is to make all the possible measurements with the Wenner array with electrode spacing of "1a". For the first measurement, electrodes number 1, 2, 3 and 4 are used. Electrode 1 is used as the first current electrode C1, electrode 2 as the first potential electrode P1, electrode 3 as the second potential electrode P2 and electrode 4 as the second current electrode C2. For the second measurement, electrodes number 2, 3, 4 and 5 are used for C1, P1, P2 and C2 respectively. This is repeated down the line of electrodes until electrodes 17, 18, 19 and 20 are used for the last measurement with "1a" spacing. For a system with 20 electrodes, note that there are 17 (20 - 3) possible measurements with "1a" spacing for the Wenner array. After completing the sequence of measurements with "1a" spacing, the next sequence of measurements with "2a" electrode spacing is made. First electrodes 1, 3, 5 and 7 are used for the first measurement. The electrodes are chosen so that the spacing between adjacent electrodes is "2a". For the second measurement, electrodes 2, 4, 6 and 8 are used. This process is repeated down the line until electrodes 14, 16, 18 and 20 are used for the last measurement with spacing "2a". For a system with 20 electrodes, note that there are 14 (20 - 2x3) possible measurements with "2a**"** spacing.

The same process is repeated for measurements with "3a", "4a", "5a" and "6a" spacing to get the best results, the measurements in a field survey should be carried out in a systematic manner so that, as far as possible, all the possible measurements are made. This will affect the quality of the interpretation model obtained from the inversion of the apparent resistivity measurements (Dahlin and Loke 1998). When the electrode spacing increases, the number of measurements decreases. The number of measurements that can be obtained for each electrode spacing, for a given number of electrodes along the survey line, depends on the type of array used. The Wenner array gives the smallest number of possible measurements compared to the other common arrays that are used in 2-D surveys. The survey procedure with the pole-pole array is similar to that used for the Wenner array. For a system with 20 electrodes, firstly 19 of measurements with a spacing of “1a” is made, followed by 18 measurements with “2a” spacing, followed by 17 measurements with “3a” spacing, and so on. For the dipole-dipole, Wenner-Schlumberger and pole-dipole arrays, the survey procedure is slightly different. As an example, for the dipole-dipole array, the measurement usually starts with a spacing of “1a” between the C1-C2 (and also the P1-P2) electrodes. The first sequence of measurements is made with a value of 1 for the “n” factor (which is the ratio of the distance between the C1-P1 electrodes to the C1-C2 dipole spacing), followed by “n” equals to 2 while keeping the C1-C2 dipole pair spacing fixed at “1a”. When “n” is equals to 2, the distance of the C1 electrode from the P1 electrode is twice the C1-C2 dipole pair spacing. For subsequent measurements, the “n” spacing factor is usually increased to a maximum value of about 6, after which accurate measurements of the potential are difficult due to very low potential values. To increase the depth of investigation, the spacing between the C1-C2 dipole pair is increased to “2a”, and another series of measurements with different values of “n” is made. If necessary, this can be repeated with larger values of the spacing of the C1-C2 (and P1-P2) dipole pairs. A similar survey technique can be used for the Wenner-Schlumberger and pole-dipole arrays where different combinations of the “a” spacing and “n” factor can be used. One technique used to extend horizontally the area covered by the survey, particularly for a system with a limited number of electrodes, is the roll-along method. After completing the sequence of measurements, the cable is moved past one end of the line by several unit electrode spacing. All the measurements which involve the electrodes on part of the cable which do not overlap the original end of the survey line are repeated (Fig. 4.7).

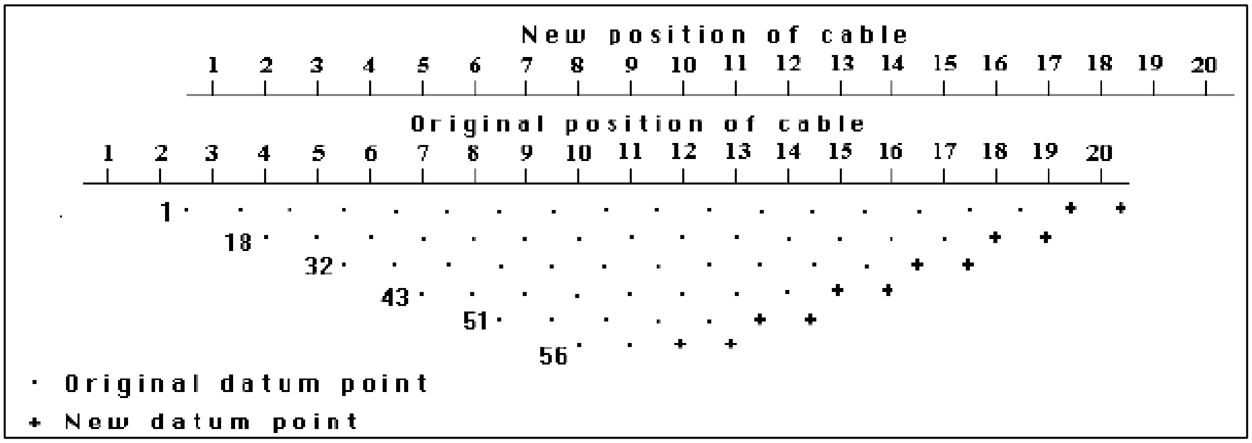


Figure 4.7 Pseudo section data plotting method

Plot the data from a 2-D imaging survey, the pseudo section contouring method is normally used. In this case, the horizontal location of the point is placed at the mid-point of the set of electrodes used to make that measurement. The vertical location of the plotting point is placed at a distance which is proportional to the separation between the electrodes.

4.7.1 Wenner array

This is a robust array which was popularized by the pioneering work carried by The University of Birmingham research group (Griffiths and Turnbull 1985; Griffiths, Turnbull and Olayinka 1990). Many of the early 2-D surveys were carried out with this array. In Figure 4.8, the sensitivity plot for the Wenner array has almost horizontal contours beneath the centre of the array. Because of this property, the Wenner array is relatively sensitive to vertical changes in the subsurface resistivity below the centre of the array. However, it is less sensitive to horizontal changes in the subsurface resistivity. In general, the Wenner is good in resolving vertical changes (i.e. horizontal structures), but relatively poor in detecting horizontal changes (i.e. narrow vertical structures).

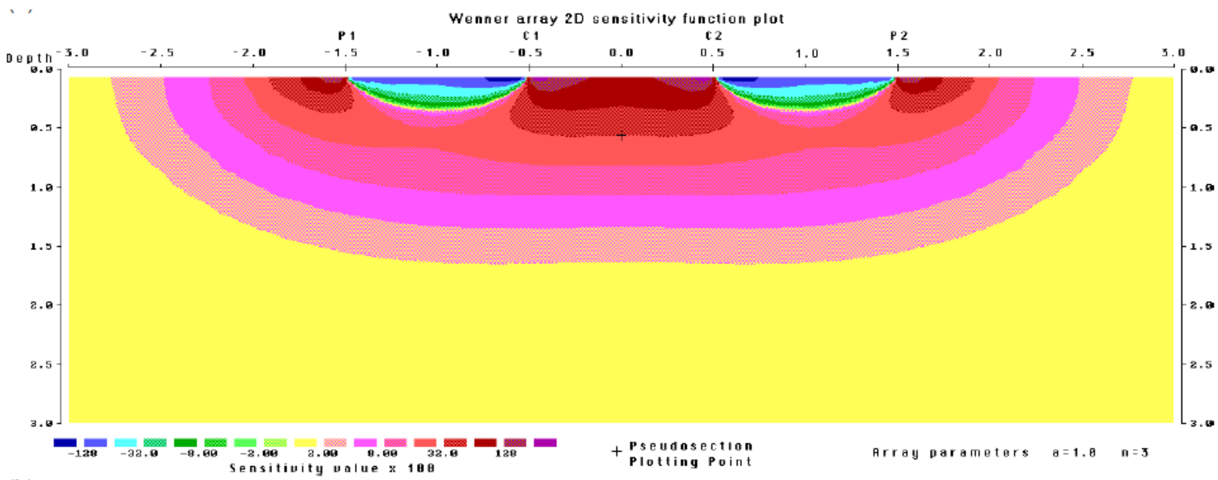


Figure 4.8 Pattern for Wenner configuration

4.8 FORWARD MODELING PROGRAM

The free program, RES2DMOD.EXE, is a 2-D forward modeling program which calculates the apparent resistivity pseudo section for a user defined 2-D subsurface model. The program helps to choose the finite-difference (Dey and Morrison 1979a) or Finite-element (Silvester and Ferrari 1990) method to calculate the apparent resistivity values. In the program, the subsurface is divided into a large number of small rectangular cells. The program also assists in choosing the appropriate array for different geological situations or surveys. The arrays supported by this program are the Wenner (Alpha, Beta and Gamma configurations, Wenner-Schlumberger, pole-pole, inline dipole-dipole, pole-dipole and equatorial dipole-dipole (Edwards 1977). Each type of array has its advantages and disadvantages. The Alpha configuration is normally used for field surveys and usually just referred to as the "Wenner" array). This program will help in choosing the "best" array for a particular survey area after carefully balancing factors such as the cost, depth of investigation, resolution and practicality. The RES2DMOD.EXE program shows the shape of the contours in the pseudo section produced by the different arrays over the same structure can be very different. The choice of the “best” array for a field survey depends on the type of structure to be mapped, the sensitivity of the resistivity meter and the background noise level. In practice, the arrays that are most commonly used for 2-D imaging surveys are the (a) Wenner, (b) dipole-dipole (c) Wenner-Schlumberger (d) pole-pole and (d) pole-dipole. Among the characteristics of an array that should be considered are (i) the sensitivity of the array to vertical and horizontal changes in the subsurface resistivity, (ii) the depth of investigation, (iii) the horizontal data coverage and (iv) the signal strength. The median depth of investigation gives an idea of the depth to which can map with a particular array. The median depth values are determined by integrating the sensitivity function with depth. In layman's terms, the upper section of the earth above the "median depth of investigation" has the same influence on the measured potential as the lower section. This tells roughly how deep we can see with an array. This depth does not depend on the measured apparent resistivity or the resistivity of the homogeneous earth model. After the field survey, the resistance measurements are usually reduced to apparent resistivity values. Practically all commercial multi-electrode systems come with the computer software to carry out this conversion. In this section, we will look at the steps involved in converting the apparent resistivity values into a resistivity model section that can be used for geological interpretation. It is assumed that the data is corrected for RES2DINV format. The conversion program is provided together with many commercial systems.

5.1 INTRODUCTION

Vertical Electrical Sounding (VES) technique in Resistivity methods cannot measure the signatures from sub-surface in lateral directions. Further, the depth-wise resistivity changes are not possible being measured with the Resistivity Profiling/mapping technique. Both these conventional techniques commonly employ a four-electrode set-up where the signatures from a singular depth level of the subsurface can be measured on the surface. Resistivity variations, both in lateral and vertical directions, can be measured concurrently by using Multi-electrode systems (Griffiths and Turnbull, 1985; Griffiths et al.1990; Barkar, 1992) connected to multi- core cable (Griffiths and Barker 1993). The number of electrodes with the multi-electrode systems can be, for example, 48, 72 or 96 etc with specified inter-electrode spacing. The inter-electrode spacing can be varied from the specifications as per the available area and topography. In any case, a traverse of length from half a kilometer to one kilometer horizontal distance can be covered in a single- run depending upon the size of the array. Conventional Electrode Configurations namely, Dipole-dipole, Three-electrode, Two-electrode, Wenner, Schlumberger etc. can be applied for sub-surface data acquisition. To cover horizontal traverses in a phased manner, 'role-along' and / or 'move-on' techniques as per the situation are applied in which case the set of electrodes are moved forward in a systematic 'pre-set' manner. The depth down below the traverse can be increased by increasing the array size sequentially depending upon the 'depth of investigation 'of the corresponding array. Each array has got its own investigation depth, depending upon the theories like 'maximum contribution concept' (Roy and Apparao, 1971) or 'median depth concept' (Edwards, 1977). Some are following the data presentation method as proposed by Hallof (1957).

High-resolution electrical surveys play an important role in data acquisition especially in noisy areas. This is achieved by over lapping data levels with different combinations of Dipole lengths and Dipole's separations, as a whole, when Dipole-dipole array is applied. Similar combinations are possible with Wenner-Schlumberger and Three-electrode arrays also. The number of data points produced by such High-resolution survey is more than twice that obtained with a conventional array in routine application and hence a better area coverage and resolution can be achieved. After analysis and processing of the measured data in the field, pseudo-depth sections are constructed (Hallof, 1957, Edwards, 1977, Apparao and Sarma, 1981, 1983 and 1993) with over lapping data levels. By having such redundant measurements using the overlapping data levels, the effect of more noisy data-points will be reduced. Finally, High-resolution resistivity (HERT) surveys play a significant role especially for scanning the subsurface in noisy areas for better data coverage so that the sub-surface architecture can be studied with reasonable precision and faster survey.

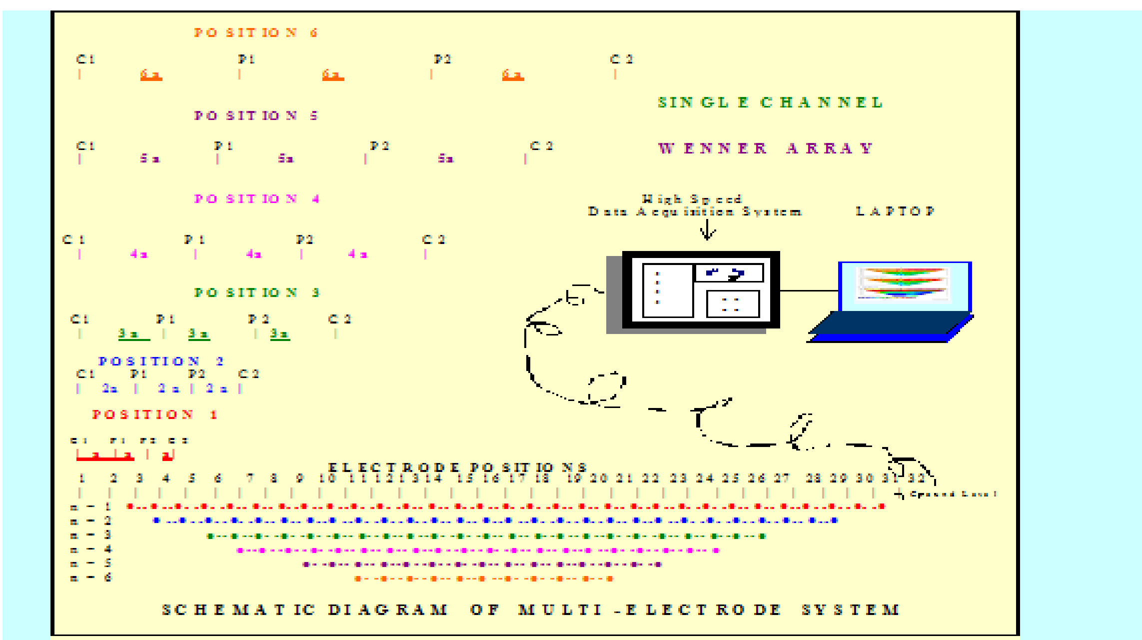


Figure 5.1 Schematic diagram of multielectrode system for Wenner array

Seawater intrusion occurs when heavy pumping withdraws fresh water at a faster rate than it can be renewed. The seawater/freshwater interface are thus displaced inducing the fresh groundwater contamination with salt water. Seawater intrusion is considered among the most hazardous and widespread coastal aquifer contamination mechanisms (Bear et al., 1999; Custodio and Bruggeman, 1987; Steyl and Dennis, 2009). Electrical Resistivity imaging (ERI) is one of the electrical geophysical techniques that are used in the assessment of sweater intrusion mainly to study the freshwater/seawater interface and soil salinization (Bear et al., 1999; De Franco et al., 2009; Yaouti et al., 2009). Hence an attempt has been made in the present study area by adopting Electrical resistivity imaging to demarcate the extent of saline water intrusion into the coastal aquifers.

5.2 PRESENT SURVEY

In the present work BTSK WDDS-2/2B Digital Resistivity Meter was used to perform a total of 20 profiles located respectively at 5 m to 1.5 m from the shoreline. The profiles were oriented perpendicular to the shoreline. The Wenner - α protocol was applied with a number of electrodes varying from 31 to 32 spaced of 5 m and/or 10m leading to an investigation depth ranging from 27.7 – 55.4 m. The electrodes were stainless steel electrodes pierced up to a depth of 30 to 40 cm. The pseudo section has been attempted using RES2DINV software. Salt water has been poured at the electrode points to ensure good contact with the earth. Reasonably flat surface were chosen for the surveys. Figure 5.2 shows the ERI locations.

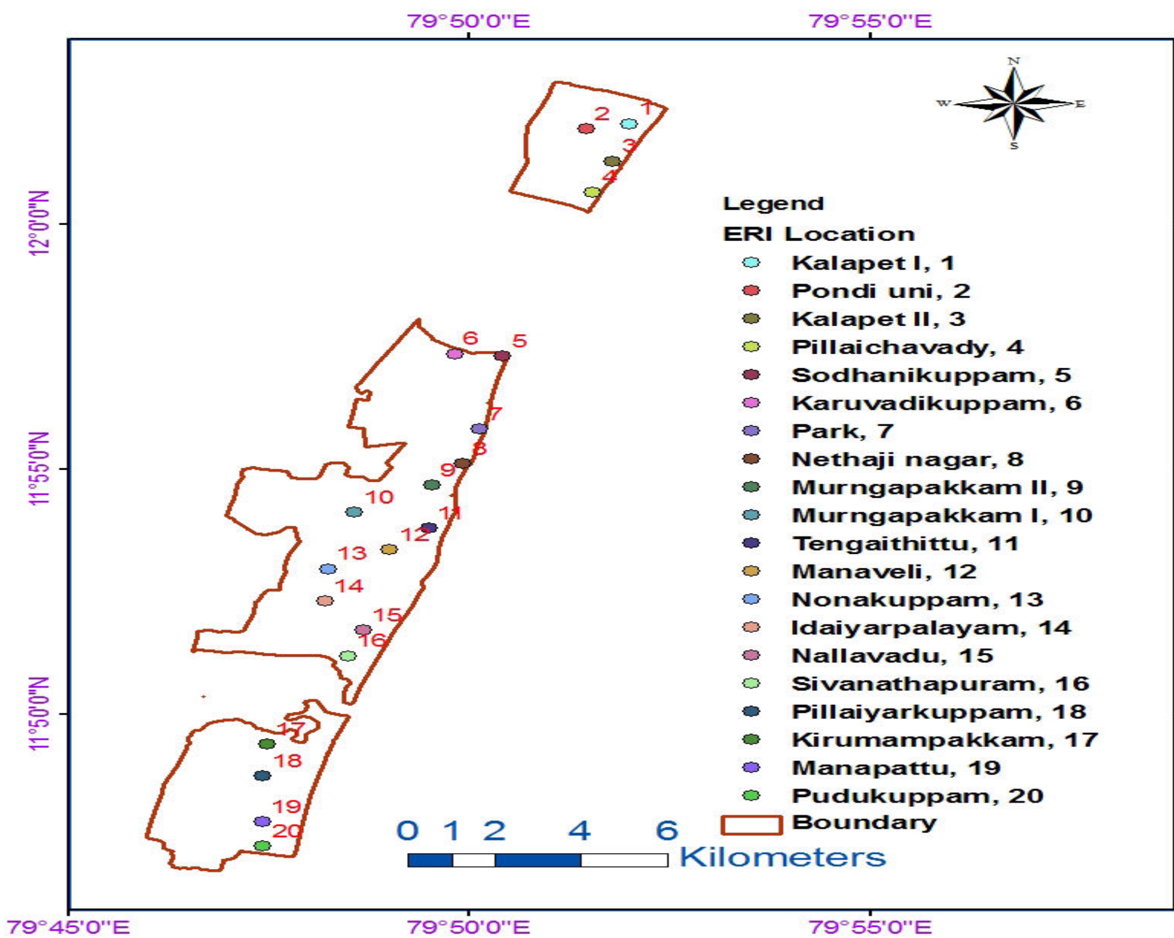


Figure 5.2 ERI location map

5.2.1. Kalapet 1

The first ERT, Profile (Fig. 5.3B) performed near Kalapet-1 bearing the Latitude E12^{o}2’4” and Longitude 79^{o}51’6” about 376.08 m orthogonal to the coast. The subsurface layer resistivity obtained by the inversion process is controlled by the resistivity of the pore water and the resistivity of the host rock (Burger, 1992). The geoelectrical image shows a variation in resistivity distribution, with electrical resistivity values from about 3.41-1484.0 Ωm. Lower electrical resistivity values, with a resistivity range of less 3.41 Ωm, were observed at a depth of 19.0 to 21.0 m irrespective of its orientation towards sea and the reduced values may be due to

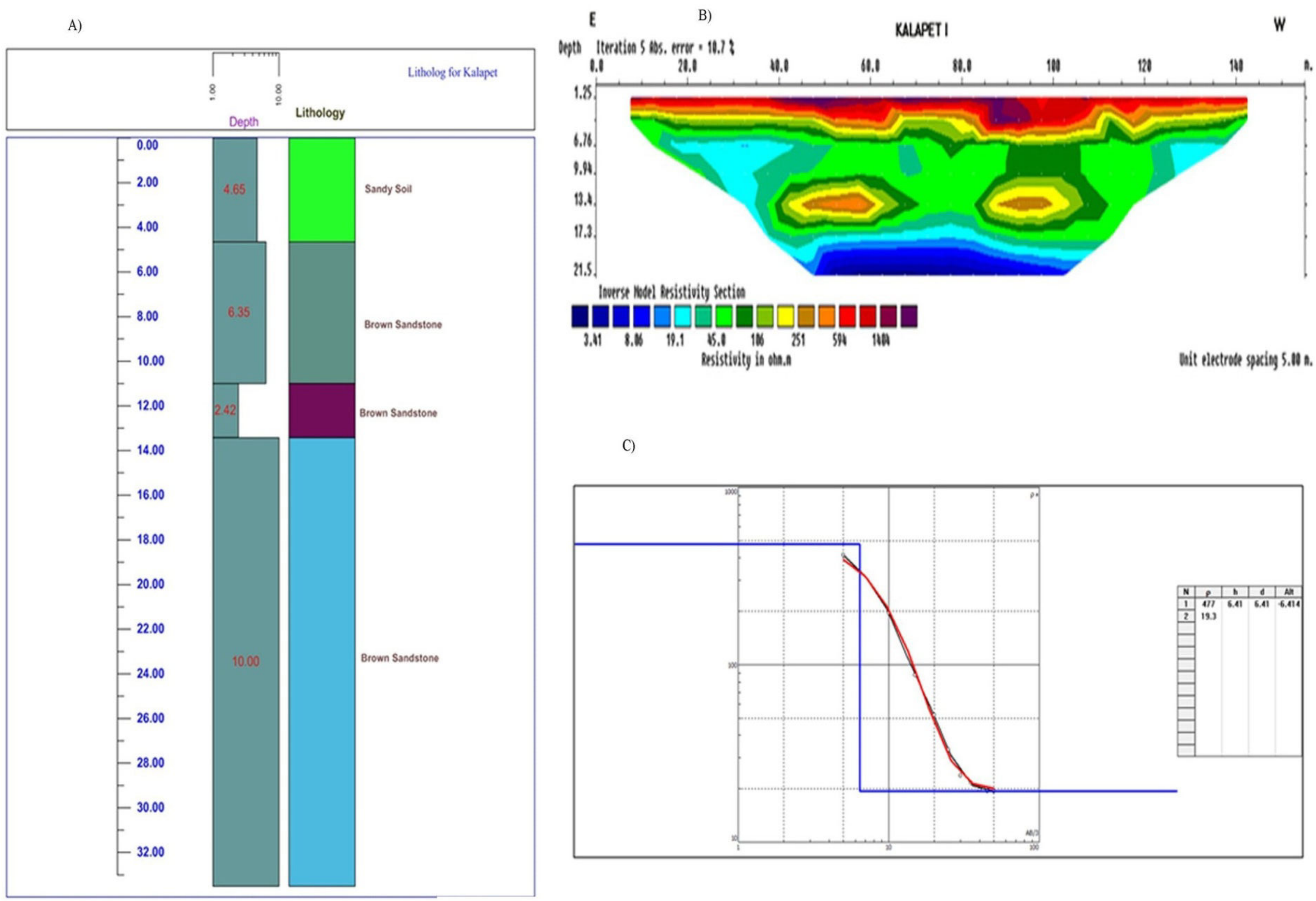


Figure No. 5.3 A) Litholog, B)ERI profile and C) 1d image of Kalapet I saturated strata for a subsurface seawater flow zone. Saline water has a resistivity below 1.0 Ω m, in particular seawater has an average resistivity of 0.2 Ω m (Parasnis, 1977; Nowroozi et. al., 1999), while a layer saturated by saline water and dissolved solids has resistivity in the range of 8 to 50 Ω m (Zohdy, 1999; Nowroozi et al., 1999). Therefore, based on these values of resistivity of layers saturated by saline water and dissolved solids, resistivity data obtained in this work highlight the presence of strata saturated with brackish to saline water. A gradual decrease in the resistivity value with depth indicates the wet nature of the subsurface formation. The dry formation with higher resistivity is confined to shallow depth and as depth increases the wetness of the formation increases with decrease in resistivity. The presence or absence of clay formations interbedding the sandstone formations influences the resistivity values where sediments without clay may vary from 1 to 100 Ωm while the resistivity of wet clays alone may vary from 1 to 250 Ωm. The presence of two patches indicates the incidence of wet clay formations at a depth of 13 to 17 m. Thus, a wide range of resistivity is often reported for a particular water saturated material. In order to get a brief idea and to infer the litho units involved the litho log (Fig. 5.3 A) were also taken for interpretation in which the 2D and 1D (Fig. 5.3C) were in good correlation. The zone influenced by saline water was the sandstone formation and the traces of saline water were noted below a depth of 19.0 m indicating the up coning of saline water into the sandstone formation. Starting from a distance of 19.0 m up to a distance of 21.5 m traces of saline water intrusion was observed and further migration towards inland was also noted indicating the contaminated nature of the sand stone formation. This fact was well in conformity with the higher EC (> 6000 μS/Cm) and Cl values observed from the nearby bore location.

5.2.2 Pondicherry University

The second profile (Fig. 5.4 B) was performed inside the Pondicherry University campus bearing the Latitude E12^{o}1'56" and Longitude 79^{o}51' 27" about 1.3 KM orthogonal to the coast with an electrode spacing of 5m between the depths of 150 m with a total vertical depth of 27.7 m. The First layer between depths of 0-3.0 m has resistivity values ranging from 103 to 237 Ωm. The second layer is between depths 3.0 m and 11.0 m with resistivity ranging from 360 to 546 Ωm. From the first layer resistivity it is inferred that the formation might be of lateritic top soil due to its higher resistivity values, which has been confirmed during field survey. The second layer with higher resistivity values is inferred as sandstone formation. The exposure of the sandstone formation is noted along the western corner of the profile direction, which was confirmed during field check. The higher resistivity values (546 Ωm) noted in the middle of the profile at a depth of 10 m is mainly due to the presence of medium and fine grained sandstone without any influences of saline water. Lower resistivity values (29.5 Ωm) are observed at a depth of 23.5 m is inferred as brackish water zone. Since a resistivity value of 45 ohm m (Wilson, 2006) is used to delineate brackish groundwater with 1% mixing of saline water within the aquifer; the groundwater is interpreted to be brackish in nature. Electrical resistivity sounding using 1D interpretation (Fig.5.4C) was attempted in the same location, demarcates a two layer cases with a resistivity range of 301 Ωm up to a depth of 24 m, is in well conformity with the 2D image indicating the presence of top soil followed by fine grained and medium grained sandstone formations. At a depth of 24 m the resistivity of the formation has decreased up to 2.89 Ωm indicating the presence of brackish water. The present 2D profile and 1 D interpretation was correlated with the lithology (Fig.5.4A) from the nearby bore confirms the interpretation made. Groundwater samples collected from the observation bore

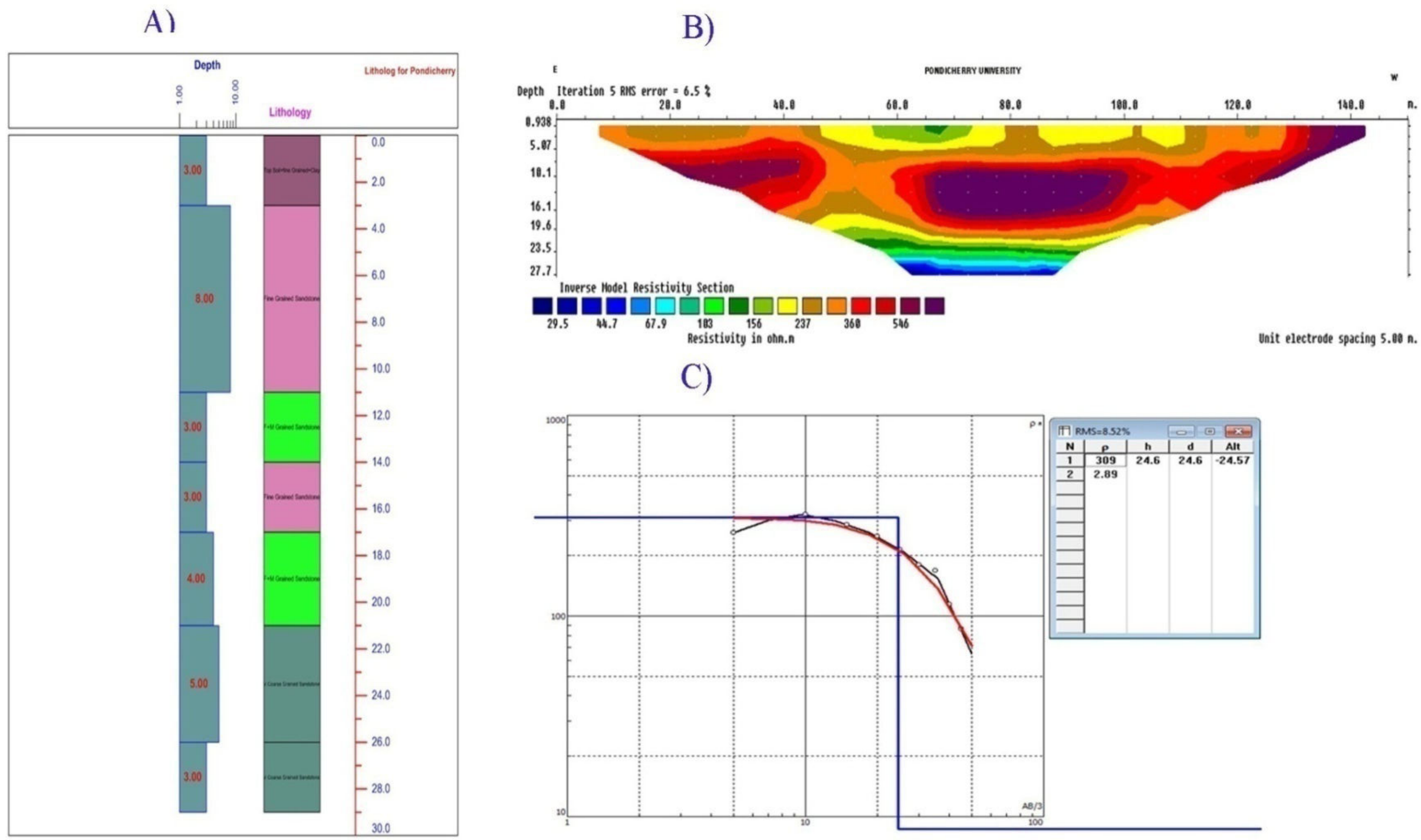


Figure No. 5.4 A) Litholog, B)ERI profile and C) 1d image of Pondicherry university used for the interpretation of litho log confirms the brackish nature of saline water with higher EC (>3000 μS/Cm) and Cl (350 mg/L) ratios. From the resistivity investigations it is confirmed that saline water intrusion is not the phenomenon but the saline water contamination due to the trapped saline water within the aquifer. This salt water might have been trapped during the transgressive movement of the ancient sea during the Mio-Pliocene age (GSI,2006). Thus it is inferred that saline water found at the shallow depth (30 m) was probably trapped during the marine transgression and/or it migrated from depth by differential pressure gradient.

5.2.3 Kalapet II

The third ERT, Profile (Fig. 5.5b) performed near Kalapet-1I bearing the Latitude E12^{o}1'17" and Longitude N79^{o}51'48" about 300 m orthogonal to the coast. The geoelectrical image shows a variation in resistivity distribution, with resistivity values ranging between 2.73 - 1183 Ωm. Lower electrical resistivity values (2.73 Ωm) were observed at a depth of 21.5 to 26.2 m irrespective of its orientation towards sea and the reduced values may be due to subsurface seawater flow zone. Gradual decrease in resistivity value with depth indicates the wetted nature of the subsurface formation. The top layer with resistivity range of 1183 Ωm indicates dry sand formation without water content along eastern and western parts of the profile. Lower resistivity values (209 Ωm) are also noted in the central part of the profile indicating the soil formation admixed with water particles. An intermediate layer with lower resistivity values (15.5 Ωm to 209 Ωm) indicates the gradual wetting index increasing with depth also decreases the resistivity values. Thus, a wide range of resistivity is noted in the profile with reference to the presence or absence of water saturated material. For the better interpretation 1D profile (5.5 C) of the sub surface were also interpretated using IPI2WIN software to infer the total layers involved. From the plot two layers were demarcated the top soil zone with high resistivity (345 Ωm) with a

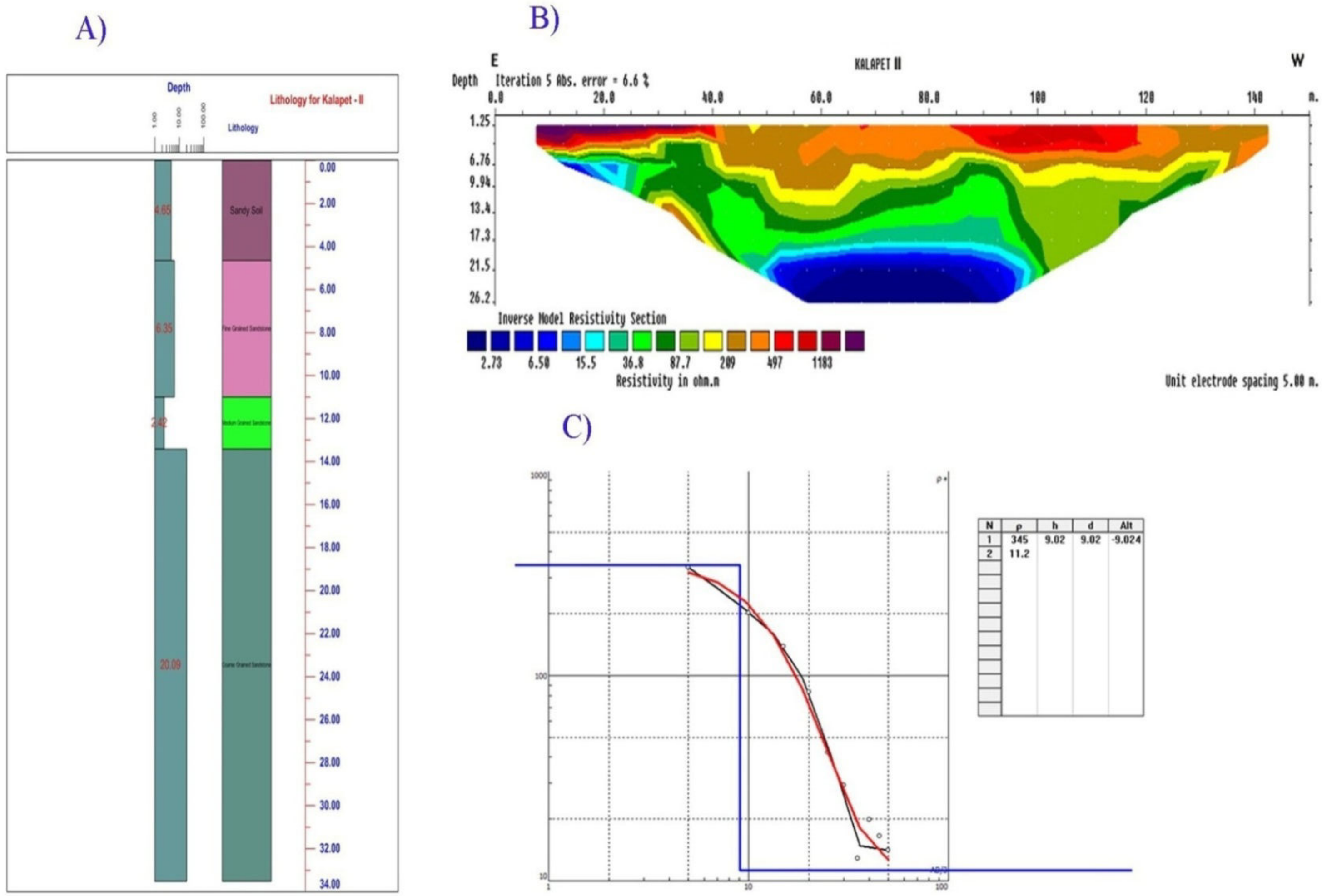


Figure No. 5.5 A) Litholog, B)ERI profile and C) 1d image of Kalapet II depth of 9.2 m and the second zone is interpreted as of sandstone with a low resistivity (11.2 Ωm) indicating the saline water intruded zone. Further the resistivity profile was correlated with the available litho log from the nearby bore hole location, from the log it is inferred that lower resistivity zones are the sandstone formations with varying grain size and the bottom most formations was interpreted as coarse grained sandstone which shows traces of saline water intrusion. From this survey it is confirmed that the saline migration into the coastal aquifers at shallow depth (<30m) from an orthogonal distance of 117.9 m to 257.9 m from the coast.

5.2.4 Pillaichavadi

The fourth ERT, Profile (Fig. 5.6 A) performed near Pillaichavadi bearing the Latitude E12^{o}0'39" and Long N79^{o}5'33" about 20 m orthogonal to the coast. The geoelectrical image shows a variation in resistivity distribution, with electrical resistivity values ranging between 3.83 – 93.6 Ωm. Lower resistivity values (3.83 Ωm) was observed at shallower depth along the eastern part of the profile towards the Bay of Bengal. This low resistivity is inferred as saline water intrusion due to the proximity of sea. The boundary of saline water intrusion is clearly observable in the resistivity images, where more conductive saline water wedge progressively loses its thickness as it moves away from the water side and approaches the sandy formations. From the image it is identical that seawater intrusion is less extensive, in fact resistivity values are significantly higher away from the coast and towards the coast they are lower. Higher resistivity values (93.6 Ωm) have been noted along the western part of the profile indicating the presence of groundwater potential zone at a depth of 13.0 to 26.2 m. The low resistivity of the profile might be due to the very wet marine

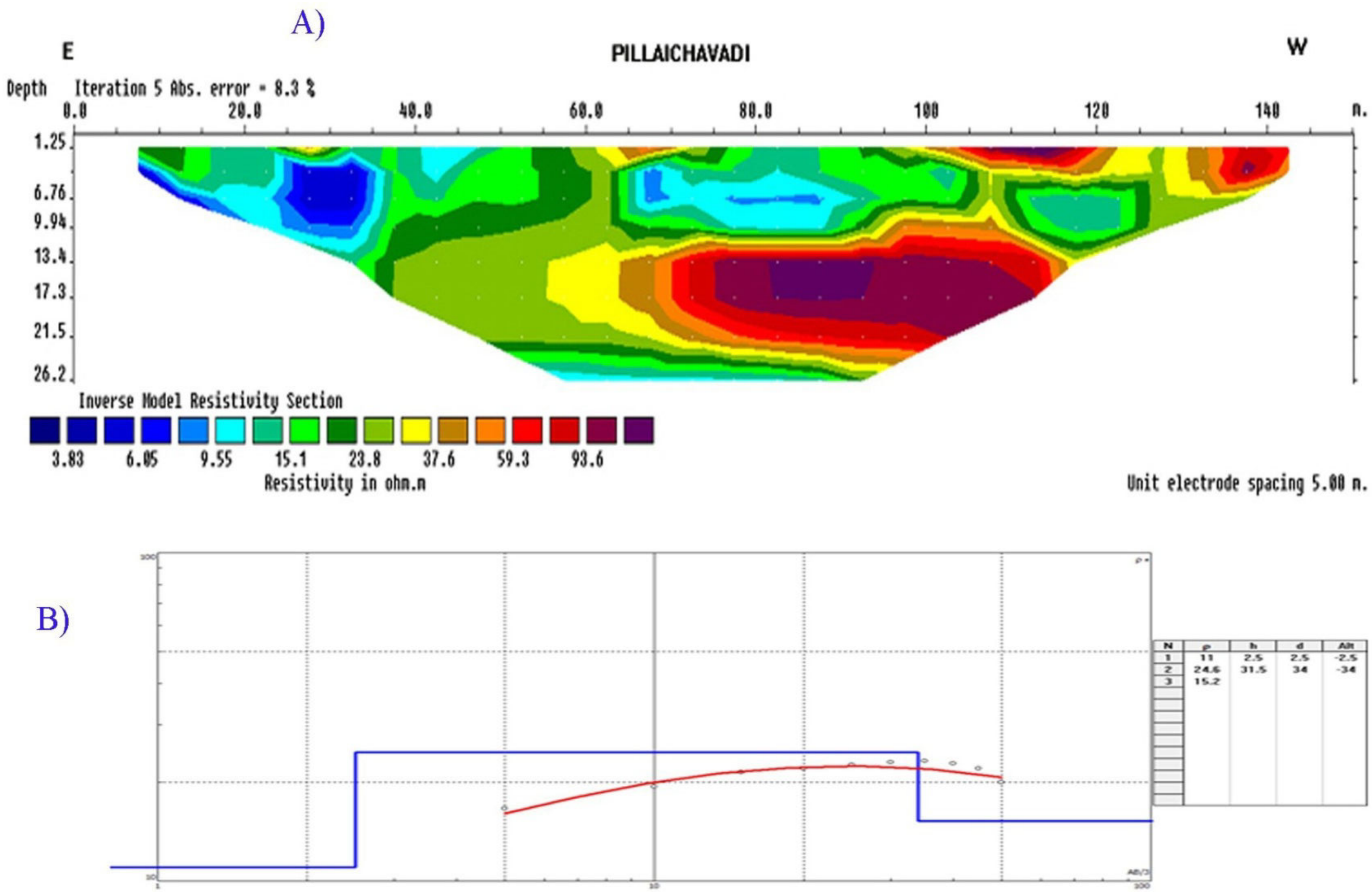


Figure No. 5.6 A) ERI Profile and B) 1d image of Pillaichavady deposits overlying the sedimentary formations which have decreased the resistivity contrast, since half the total voltage signal received at the surface is contributed by the layer above the depth of investigations. Tidal influences/shore line changes might be the major factors influencing saline water intrusion at shallow depth (Edwards, 1977). To gain a better insight of the subsurface strata 1D resistivity sounding (5.6 B) was also attempted with a total spread of 50m in the same location where imaging has been performed. A total of three layers were demarcated from the data point, in which the first layer resistivity was 11 Ωm with a total thickness of 2.5 m and the second layer with a resistivity range of 24.6 Ωm with a total thickness of 31.5 m and the third layer with a resistivity range of 15.2 m was also identified. The lower resistivity values at the surface might be due to the top soil zone often intruded by saline water due to its proximity to the coast and or might be due to the tidal/shore line changes influences (Edwards, 1977). This view is identical with the higher resistivity values observed along the western part of the profile direction with higher resistivity values indicates the non influence of the saline water. The second layer might be the coarse sandstone formation recorded with higher resistivity values sand witched between two low resistivity zones. The bottom lower resistivity zone might be the fine or medium sandstone formations. Since no lithology was available for the present study area no correlation has been made.

5.2.5 Sodanaikuppam:

The fifth profile (Fig. 5.7 B) was performed at Sodanaikuppam bearing the Latitude 11^{o}57'18' and Longitude N79^{o}50'25" about 20m orthogonal to the coast with an electrode spacing of 5m between the length of 150 m with a total vertical depth of 26.2 m. The First layer identified with a depth of 0-4.0 m has resistivity values ranging from 203 to 477 Ωm. The second layer is

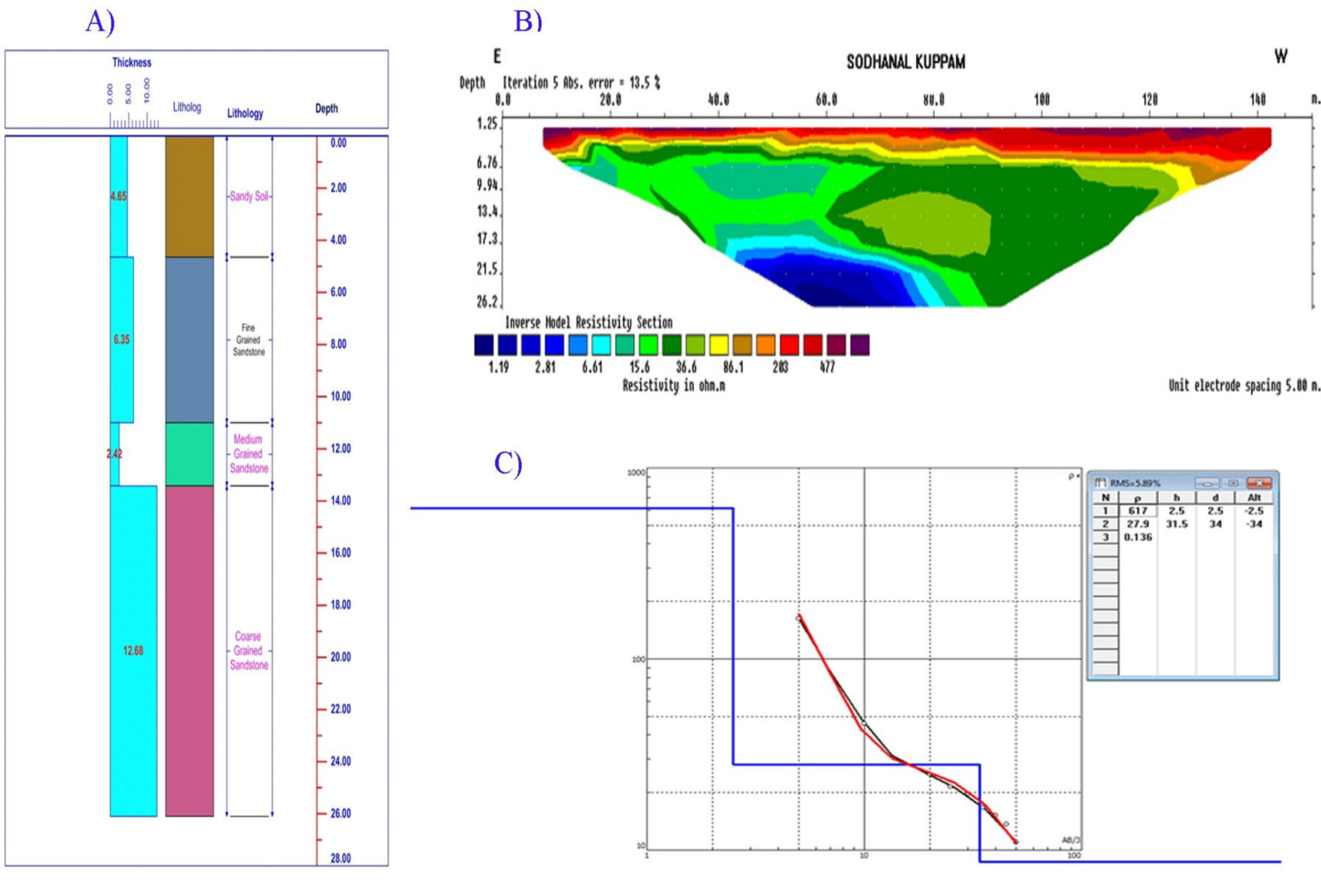
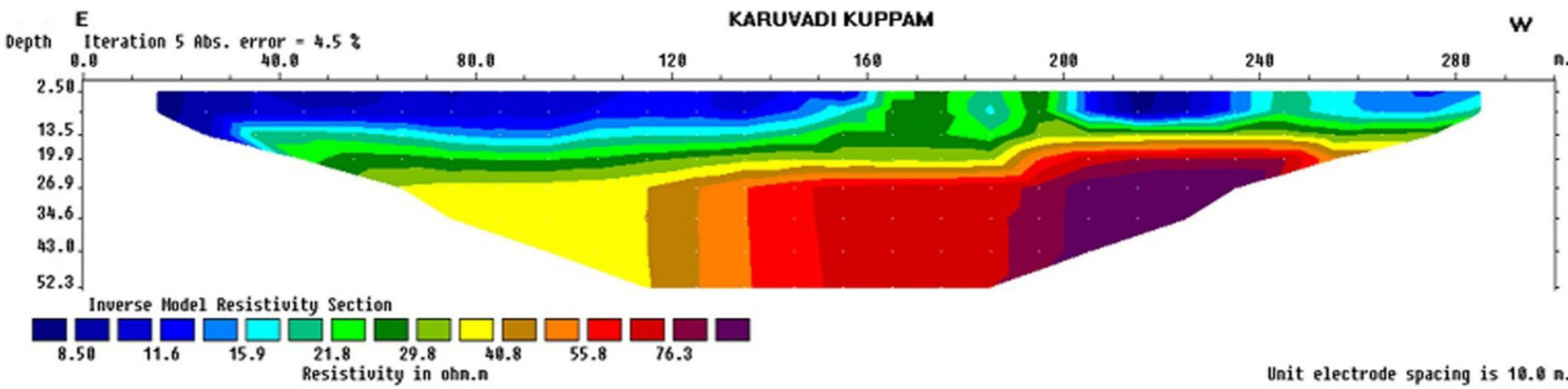


Figure No. 5.7 A) Litholog, B)ERI profile and C) 1d image of Sodhaikuppam between depths 6.76 m and 26.20 m with resistivity values ranging from 6.61 to 86.1 Ωm. From the first layer resistivity value it is inferred that the formation might be the top soil due to its higher resistivity values. The second layer with medium resistivity values is inferred as sandstone formation. The steep decline in the resistivity value with depth indicates the influence of saline water at depth ranging between 21.5 to 26.2 m, which is in conformity with the resistivity profiles conducted at Kalapet I and Kalapet II regions with saline water intrusion at the identical depth. Electrical resistivity sounding (5.7 C) attempted in the study area demarcates three different layers, the first layer with a resistivity of 617 Ωm interpreted as top soil with a total thickness of 2.5 m followed by the second layer with resistivity range of 27.9 Ωm with a thickness of 31.5 m deduced as sandstone with fine to medium grained and the third layer with a very low resistivity of 0.136 Ωm demarcated as coarse sandstone intruded by saline water. The litho log confirms the above statement with a top soil of 4.5 m thickness followed by fine grained and medium grained sandstone formation up to a depth of 14.00 m and the coarse grained sandstone with a thickness of 12.68 m up to a depth of 26 m. The groundwater sample collected from the observation bore hole used for the interpretation of the litho log confirms the saline nature of groundwater with higher EC (>4000 µS/Cm) and Cl (475 mg/L) ratios.

5.2.6 Karuvadikuppam

The sixth profile (Fig.5.8A) was performed at Karuvadikuppam bearing the Latitude E11^{0}57'28" and Longitude N79^{o}49'49" about 1.5 KM orthogonal to the coast with an electrode spacing of 10 m between the length of 300 m with a total modeled depth of about 52.3 m. Inverse model resistivity 2D section shows low resistivity up to a depth of about 19.9 m followed by high resistivity layers showing lateral inhomogeneities. The second layer is between depths 19.9 to 26.9 m with resistivity values from

A)



B)

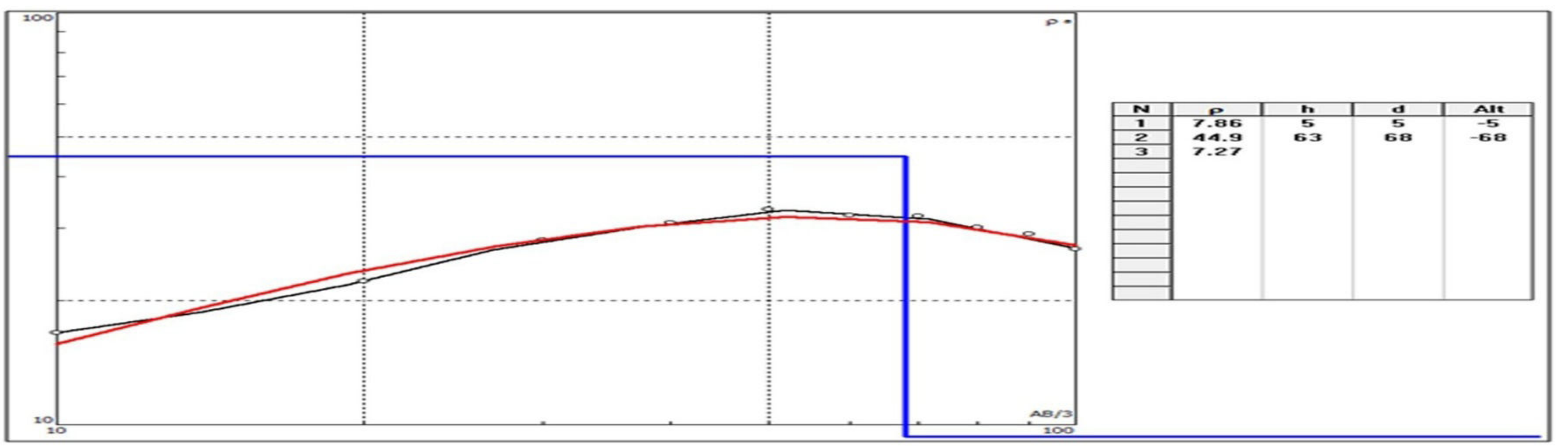


Figure No. 5.8. A) ERI profile and B) 1d image of Karuvadykuppam

21.8 to 29.8 Ωm. From the first layer resistivity value it is inferred that the formation might be made up of clayey sand due to its lower resistivity values. The second layer with medium resistivity values is inferred as sandstone with clay admixture inferred from the exposed formation at the spacing of electrodes between 160 to 200m. A higher resistivity value (76.3 Ωm) at the right side of the profile is demarcated as the sandstone formation. A clear divide between the sandy clay formation and the sandstone formations is observed at a depth of 34.6 m to 52.3 m along the right side of the profile. Increase in resistivity values along the right side of the profile indicates the massiveness of the sandstone formation. To further gain insight regarding the layers involved, resistivity sounding (Fig. 5.8 B) was attempted which demarcated three layers with varying resistivity values. The first layer with lower resistivity values (7.86 Ωm) demarcates the layer as clayey sand and the second layer with resistivity values of 44.9 Ωm may be interpreted as sand stone formations with varying grain sizes. There were a slight difference between the inference made between the 2D and 1 D investigations where the second layer interpreted by 2D demarcates the second layer with low resistivity values and the third layer as the layer with higher resistivity values but in the 1 D investigations the top soil zone and the sandy clay formations were united together to generate a composite image of the two. The sand stone formations were interpreted as the zone with higher resistivity values. This is mainly during the inversion process which varies according the software used for the resistivity interpretation. Since no litho logs were identified for the present study area no attempt has been made for the correlation with the litho logs.

5.2.7 Park

The sixth profile (Fig.5.9 A) was performed at Park bearing the Latitude E11^{o}55’49” and Longitude N79^{o}50’8” about 50 m orthogonal to the coast with an electrode spacing of 5m

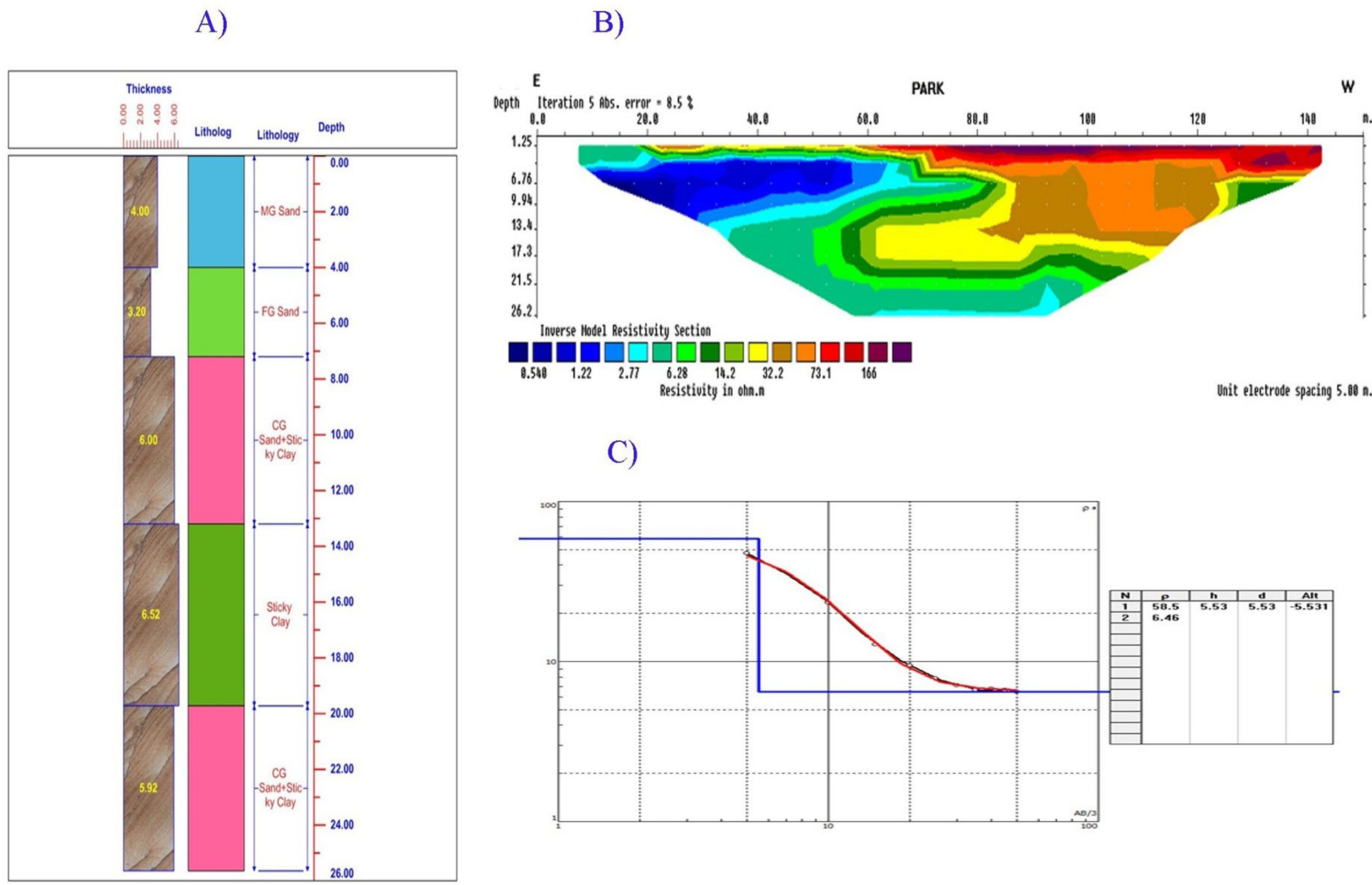


Figure No. 5.9 A) Litholog, B)ERI profile and C) 1d image of Park between the depths of 150m with a total modeled depth of about 26.2 m. The geoelectrical image shows variation in resistivity distribution, with resistivity ranging between 0.540 -166 Ωm. The lower resistivity values were noted along the eastern part of the profile at a depth ranging from 6.76 to 17.3 m indicating the formation intruded by saline water. The extension of this zone is noted from 0 m to 60 m towards land. Along the western part of the profile after the distance of 60 m there was a gradual increase in resistivity values confining a geological divide at this particular depth. The first layer resistivity was ranging from 6.28 to 166 Ωm where lower resistivity values are noted along the eastern part of the profile whereas along the western portion of the profile the thickness of the first layer showed an increasing trend and also an increase in the resistivity value which might be interpreted as top soil. A gradual decrease in the resistivity value at a spread of 60 m is noted along the eastern part of the profile whereas along the western part of the profile there was a gradual decrease in resistivity with an increase in depth. From this profile it is evident that the lower resistivity value noted along the eastern portion of the profile might be interpreted as saline water intrusion up to an extent of 60 m towards inland. In order to gain a better knowledge about the subsurface formations, 1D profile (Fig.5.9 C) of the sub surface were also attempted using IPI2WIN software. From the survey it is identical that a total of two layers are involved with variation in resistivity values. The first layer with a resistivity range of 58.5 Ωm up to a depth of 5.53 m followed by a second layer with resistivity of 6.46 Ωm. Higher resistivity values for the first layer might be due to the presence of top soil. A marked decrease in resistivity value along the eastern part of the profile from ERT is not been observed in the 1 D image, might be the spacing of electrode which masks the resistivity values (Apparao and Sarma, 1981). The geological divide noted at a distance of 60 m during 2D imaging has not been identified in the 1 D survey, might be due to the variation in the spacing of electrodes. For the better interpretation the lithology from a nearby bore hole which at present used for domestic purposes has been taken for the interpretation and identification of the sub surface litho units. The litho log (Fig. 5.9 A) demarcated medium grained sandstone formation up to a depth of 4 m which is evident in both (1D and 2D) resistivity surveying methods. The second layer identified at a depth between 4m to 7m with a decrease in resistivity is mainly due to the presence of fine grained sandstone formation which is frequently wetted by the precipitation due to the higher porosity and permeability. The lower resistivity zone (0.548 Ωm) along the eastern part of the profile direction confirms the role of saline water intrusion into coarse grained sand admixed with sticky clay. The presence or absence of clay might reduce the resistivity values but the presence of coarse grained sandstone formation with greater porosity and permeability should show an increased resistivity value even though found admixed with clay formation. As noted the geological divide observed at a spread distance of 60 m might be due to the variation in the thickness of the top soil, as noted along the eastern part of the profile the thickness of the top soil zone is very meager when compared with the thickness observed along the western portion of the profile. Frequent flushing of rain water due to the higher thickness of top soil has resulted in higher resistivity values, but along the eastern part the meager thickness of top soil and already saline water intruded sandstone formation has resulted in lower resistivity. From this survey it is confirmed that the saline migration into the coastal aquifers at shallow depth (<30m) from an orthogonal distance of 800 m to 860 m from the coast.

5.2.8 Nethaji Nagar

The profile was performed at Nethaji Nagar bearing the Latitude E 11^{o}55'7" and Longitude N79^{o}49'55" about 10 m orthogonal to the coast. The geoelectrical image shows a variation in

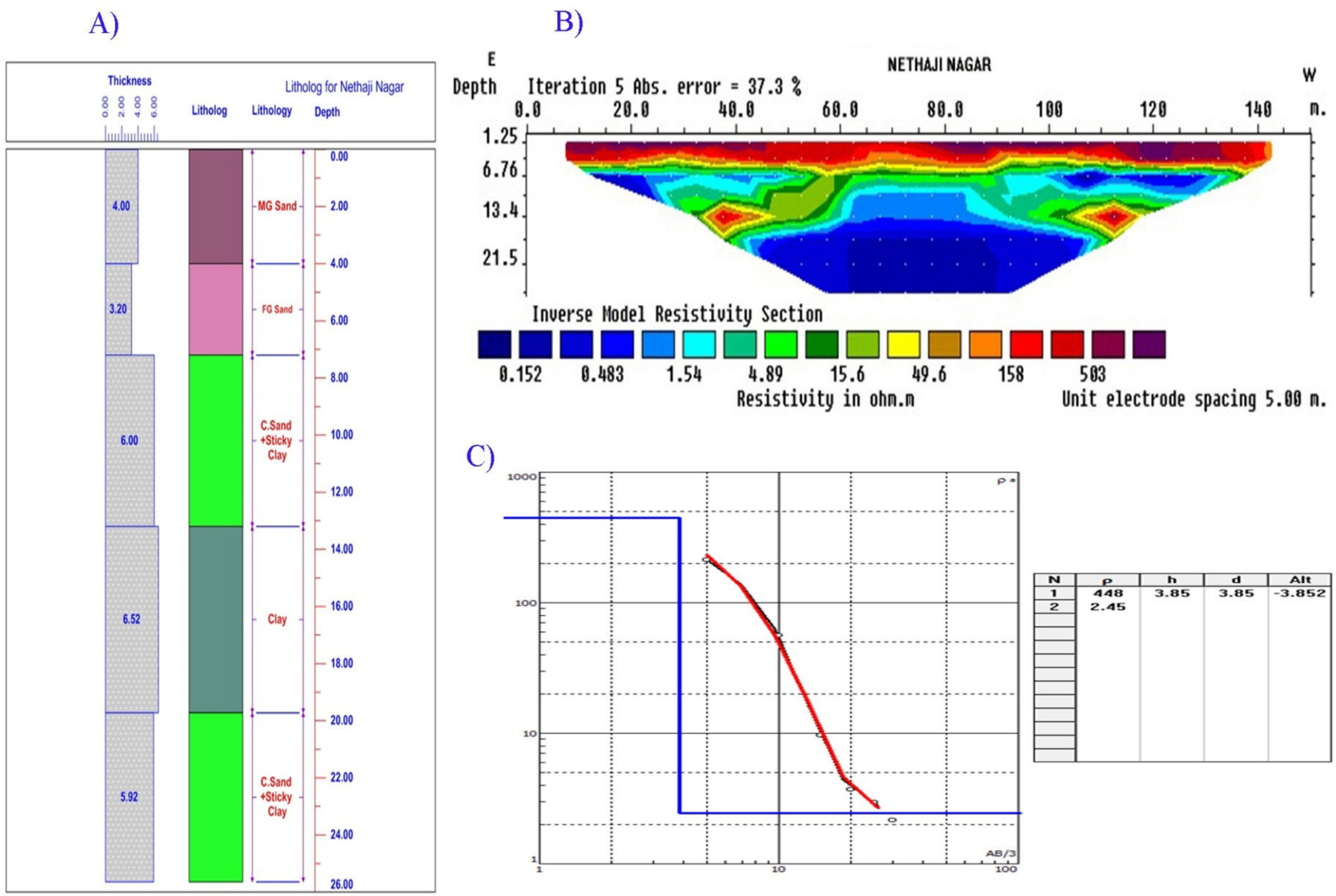
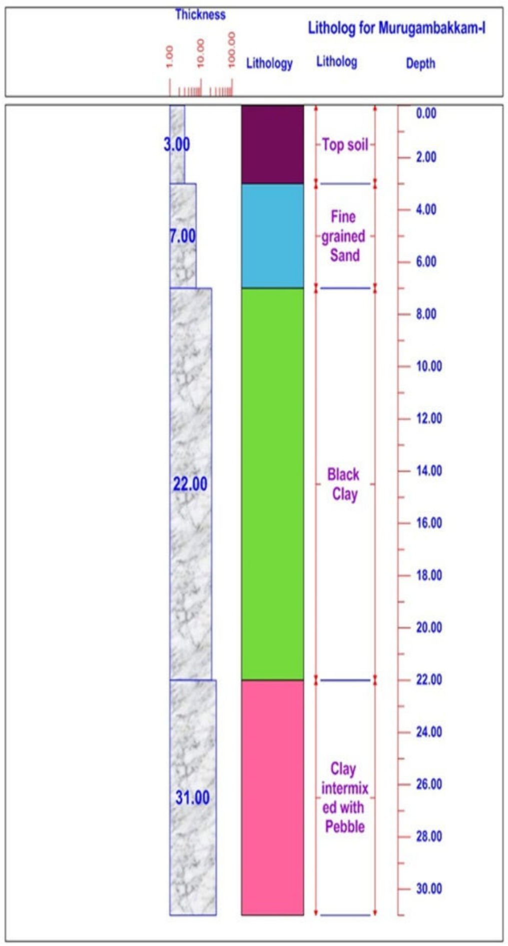


Figure No. 5.10 A) Litholog, B)ERI profile and C) 1d image of Nethaji nagar resistivity distribution, with electrical resistivity values from 0.152 - 503 Ωm (Fig. 5.10 B). Lower resistivity value (0.152 Ωm) observed at a depth of 13.4 to 21.5 m irrespective of its orientation confirms the impact due to saline water intrusion. The top layer with resistivity range of 503 Ωm indicates sand formations evenly distributed along the direction of the profile line. Pockets of intermixed high and low resistivity values are noted along the directions of the profile in depth between 6.76m and 13.4m might be due to the interbedded clay formation which is in conformity with the litho logs. The alternate wet and dry intermixing has given rise to the alternative high and low resistivity zones. Thus, a wide range of resistivity is noted in the profile with reference to the presence or absence of water saturated material. In order for better interpretation, 1D profile of the sub surface (Fig. 5.10 C) were interrelated using IPI2WIN software to infer the total layers involved. From the plot two layers were demarcated, the first layer as top soil zone with high resistivity (448 Ωm) with a total depth of 3.8 m and the second zone interpreted as a low resistivity zone (2.45 Ωm) could be the saline water intruded zone in view of the 2D profile. Hence, from the survey the demarcation between the top soil and the adjoining saline water intruded zone is clearly identified at shallow depth. Further the resistivity profile was correlated with the available litho log (Fig. 5.10 A) from the nearby bore hole location. From the log it is inferred that the top soil zones are the medium grained sand formations which recorded higher resistivity values up to a depth of 4 m and the intermediate traverses of low and high resistivity zones are mainly due to the fine grained sand, coarse grained sandstone, intermixed with clay formations. The zone intruded with saline water is demarcated as clay formation interbedded with coarse grained sandstone formation. Since, the fraction of clay mixing is lower, the presence or absence of clay formation did not influence the resistivity values; hence the lower resistivity zone is mainly due to the saline water intrusion into the aquifer formation. From this survey it is confirmed that the saline migration into the coastal aquifers at shallow depth (<30m) from a orthogonal distance of 60.0 m to 150 m and still the intrusion is found to be extending deeper inland should be confirmed with more parallel resistivity surveys.

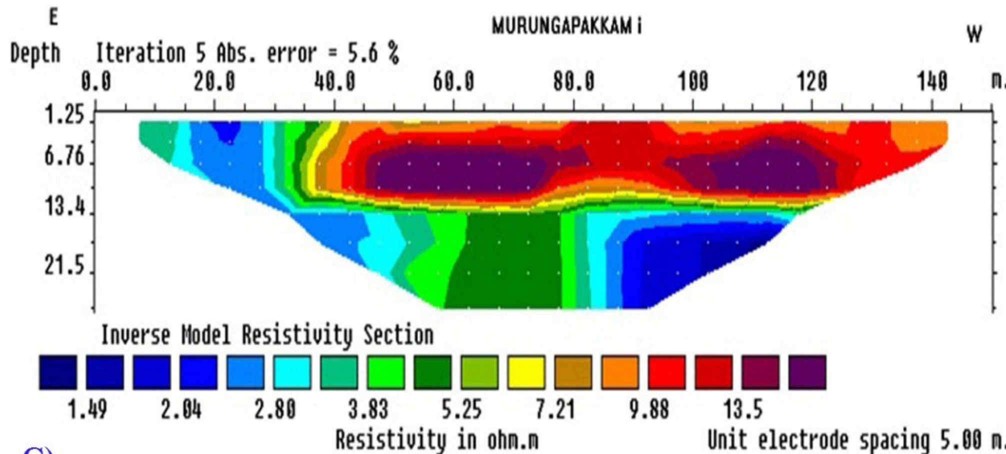
5.2.9 Murugambakkam 1

The profile (Fig. 5.11 B) was performed at Murugambakkam bearing the Latitude E11°48'33" and Longitude N 79°48'33" about 1.5 km orthogonal to the coast with an electrode spacing of 5m between the depths of 150m with a total modeled depth of about 21.5 m. The geoelectrical image shows a lateral decrease in resistivity with increasing depth indicating the inhomogeneities in lithology (Adeoti et al., 2010). A higher resistivity zone was noted along the western part of the profile direction at shallow depth (1.25 to 13.5 m) indicating the presence of higher resistivity top soil but when compared with other resistivity of the top soil zones from all the profiles attempted in the study area, this is the one that recorded with lower resistivity value. A lower resistivity zone was noted at shallower depth along the eastern part of the profile line and found to be extending deeper up to a depth of 21.5 m indicating the extension of the single layer and by field observation this layer was interpreted as sandstone formation. This lowering of resistivity might be mainly due to the influence of the Thengaithittu estuary due to its proximity (36 m) near the survey line. From the resistivity value observed no traces of saline water intrusion were observed but the lower resistivity zone along the western part of the profile line at a depth of 13.4 to 21.5 m might be due to the estuarine environment. From the profile it is interpreted that lowering in resistivity values is mainly due to the litho units prevailing in the study area with no traces of saline water. For further confirmation the 1 D profile (Fig.5.11 C) at the same location were taken for interpretation. From the

A)



B)



C)

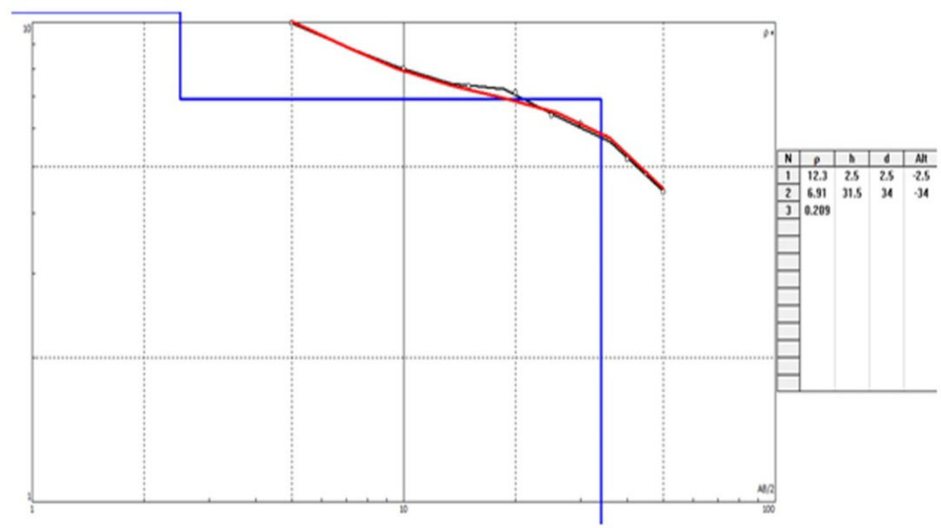
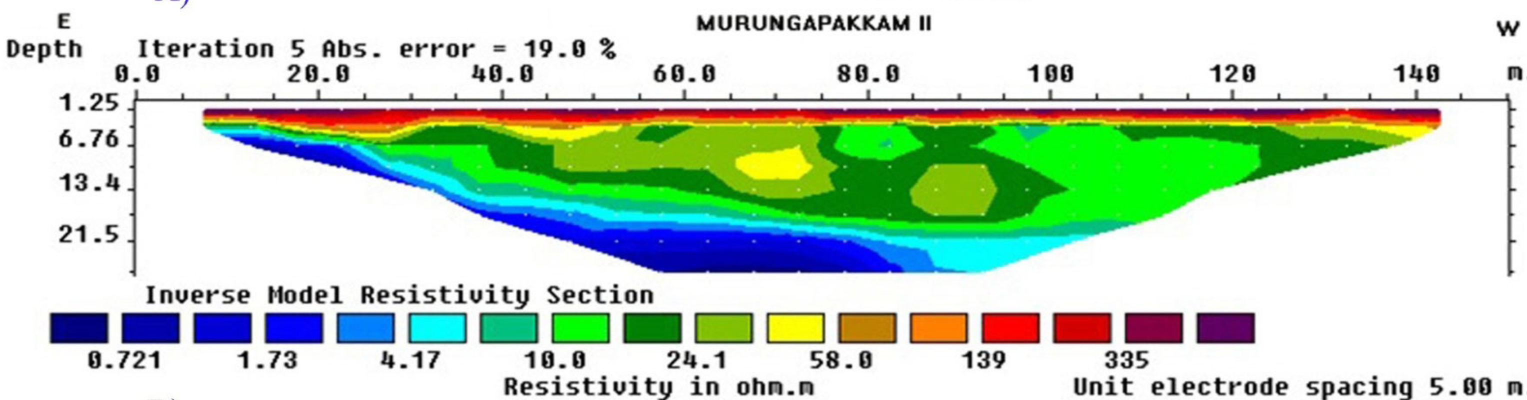


Figure No. 5.11 A) Litholog, B)ERI profile and C) 1d image of Murungapakkam I investigation a total of three layers were demarcated. The first layer with a resistivity range of 12.3 Ωm up to a depth of 2.5 m is in good correlation with the top soil resistivity values noted from the 2 D profile. The second layer with a resistivity range of 6.91 Ωm up to a depth of 31.5 m is interpreted as the zone influenced by the estuarine environment. A third layer at a depth of 31.5 m recorded a lower resistivity value (0.209 Ωm), might be due to the influence of saline water intrusion at deeper depth which could not be identified from this profile. For further information a litho log (Fig. 5.11 A) from the nearby location is used for the interpretation. From the litho log the top soil up to a depth of 3 m is confirmed. The second layer up to a depth of 7 m is the fine grained sand formation which is in conformity with the field data. Hence the influence of Tengaitittu estary which is contaminated due to the release of effluents and it is already a closed one has influenced the resistivity value of the second layer with gradual decrease in the resistivity value. The third formation with still lower resistivity value is mainly due to the presence of clay formation. Hence from the plot it is inferred that the lowering in the resistivity value is mainly due to the influence of Tengaitittu estuary and no traces of saline water is found.

5.2.10 Murugambakkam- II

The profile (Fig5.12 A) was performed at Murugambakkam- II bearing the Latitude E11^{o} 54’40” and Longitude N79^{o} 49’32” about 800 m orthogonal to the coast with an electrode spacing of 5m between the depths of 150m with a total modeled depth of about 21.5 m. The geoelectrical image shows a lateral decrease in resistivity with increasing in depth indicating the inhomogeneities in lithology. The higher resistivity layer identified up to a depth of 3m may be the top soil zone with a resistivity range of 335 Ωm. Followed by the top soil a gradual decrease in the resistivity value with depth

A)



B)

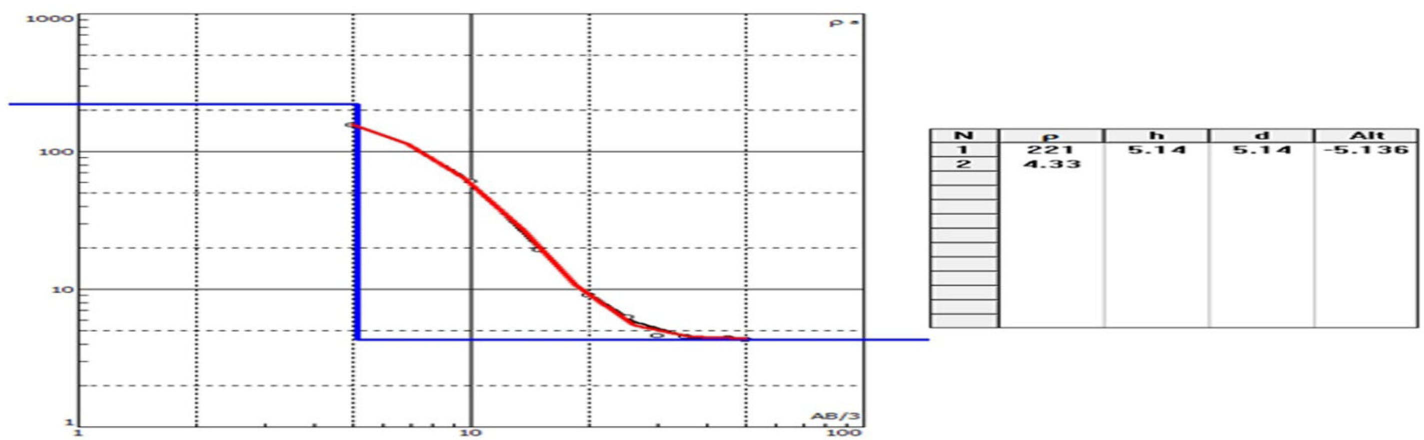
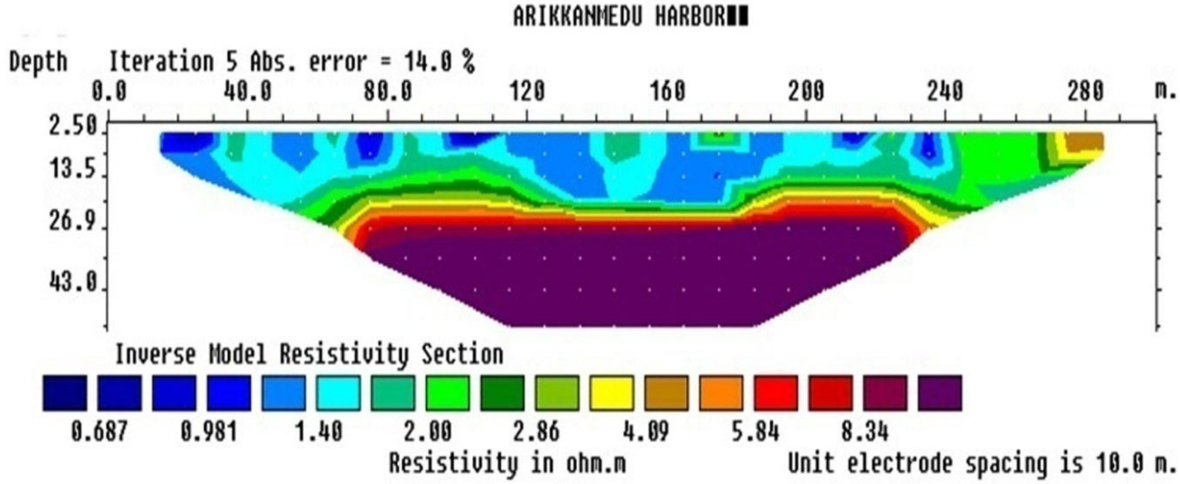
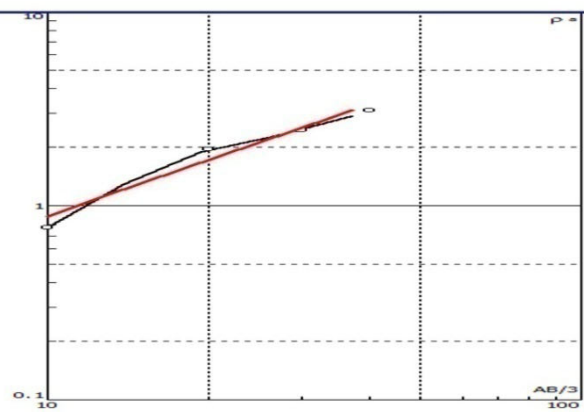


Figure No. 5.12A) ERI profile and B) 1d image of Murungapakkam II indicating the presence of lower resistivity zones with depth. A lower resistivity zone identified along the eastern part of the profile at a depth of 6.76 m and found to extend up to a depth of 21.5, seems to spread laterally indicating the influence of saline water intrusion. Since, this location was in close proximity with the Thengaitittu estuary (100m) the lower resistivity might also be due to the influence of this estuary. Along the western part of the profile there was a gradual decrease in resistivity values indicating the layered subsurface formations. From the resistivity values observed a clear demarcation between the saline water intruded zone and the zones influenced by the estuary which is contaminated with sewages could not be made. For further confirmation, 1 D resistivity data (5.12 B) was taken for the interpretation purposes. From the profile a total of two layers were demarcated. The first layer has been interpreted as top soil with resistivity range of 221 Ωm up to a depth of 5.14 m. The second layer with a resistivity range of 4.0 Ωm is interpreted as the lower resistivity zone might be the sand formation intruded by saline water. The 1 D interpretation was in close conformity with the 2 D profile. Since no litho log was available the first layer with higher resistivity value is interpreted to be as the top soil zone. The second layer with a low resistivity zone is interpreted as the saline water intrusion into the aquifer and the extension of saline water intrusion is identified up to a depth of 21.5 m indicates the up coning of saline water due to the over extraction of groundwater. The geological barrier with a low resistivity zone is interpreted as clay formation. The influence of Tengaitittu estuary has also been taken into consideration, if the influence of estuary in the aquifer is identified, then the resistivity value should fluctuate within 1. 0 Ωm , since the resistivity range fluctuated between 0.72 to 1.0 Ωm the influence of both the sea water and estuary can be recorded for lower resistivity values (Aracil et al., 2000). Hence from the profile, the lowering in the resistivity value is mainly due to the influence of saline water along with the estuarine environment. For further confirmation the 1 D profile (Fig. 5.12 c) at the same location were taken for interpretation. From the investigation a total of three layers were demarcated. The first layer with a resistivity range of 12.3 Ωm up to a depth of 2.5 m is in good correlation with the top soil resistivity values and the second layer with a resistivity range of 6.91 Ωm up to a depth of 31.5 m is interpreted as the zone influenced by the estuarine/saline water environment. A third layer after a depth of 31.5 m recorded with a lower resistivity values of 0.209 Ωm is recorded might be due to the influence of saline water intrusion at deeper depth which could not be identified from this profile.

5.2.11Tengaitittu

The profile (Fig. 5.13 A) was performed at Tengaitittu bearing the Latitude E11^{o}53'48" and Longitude N79^{o}49'30" about 600 m orthogonal to the coast with an electrode spacing of 10 m between the depths of 280 m with a total vertical depth of 43.0 m. First layer Inverse model resistivity 2D section shows lower resistivity up to a depth of about 26.9 m followed by a high resistivity layers showing lateral inhomogeneities. The second layer is between depths 26.9 to 43.0 m with resistivity values from 4.09 to 8.34 Ωm. From the first layer resistivity value it is





N	ρ	h	d	Alt
1	0.325	5	5	-5
2	36.7			

Figure No. 5.13 A) ERI profile and b) 1d image of Thengaithittu be inferred that the formation might be made up of top soil with sand formation due to its lower resistivity values. The resistivity value was in conformity with the sea water resistivity which indicates the saline water intrusion into the top soil zone. The second layer with medium resistivity values is inferred as clay formation admixed with sand. To further gain insight regarding the layers involved, resistivity sounding (Fig. 5.13B) has been attempted which demarcated two layers with varying resistivity values. The first layer with a low resistivity values (0.325 Ωm) demarcates the layer as top soil contaminated with saline water and the second layer with resistivity values of 36.7 Ωm interpreted as clay mixed sand formations with varying grain sizes. Traces of saline water up to a depth of 26.9 m are identified in the present area. Since no litho logs were identified for the present study no attempt has been made for cross correlation with the logs.

5.2.12 Manaveli

The profile (Fig.5.14 B) was performed at Manaveli bearing the Latitude E 11°53'51" and Longitude N79^{o}49'11" about 1.3 km orthogonal to the coast with an electrode spacing of 10 m between the depths of 280 m with a total depth of about 43.0 m. The First layer identified depths of 0-13.5 m has resistivity values ranging from 42.4 to 55.1 Ωm. The second layer is between depths 13.5 m and 36.2 m has resistivity values ranging from 8.92 to 11.6 Ωm. From the first layer resistivity value it is inferred that the formation might be made up of top soil due to its higher resistivity values. A gradual decline in resistivity was noted indicating the presence of stratified litho units, but a gradual higher resistivity was noted at a depth of 43.0 m indicating the presence of another formation with higher resistivity. The second layer has been interpreted as clay formation which was confirmed during the field. Electrical resistivity sounding (Fig. 5.14 C) attempted in the study area demarcates two different layers, with a first layer resistivity of

21.0 Ωm interpreted as top soil with a total thickness of 14.8 m followed by the second layer with resistivity range of 14.7 Ωm, might be the clay formation with low resistivity values. For better information about the litho units the litho log profile (Fig. 5.14 A) conducted nearby bore hole location has been taken for interpretation. The first layer has been identified as the top soil followed by clay mixed medium and fine grained sandstone formation together up to a depth of 13 m indicates the stratified nature of the litho units. The second layer has been interpreted as the medium grained sand and clay formation which was in conformity with the resistivity values recorded. From the profile it is inferred that no traces of saline water intrusion has been recorded but the low resistivity recorded is mainly due to the presence of clay formations.

5.2.13 Nallavadu

This profile (Fig. 5.15 B) was performed at Nallavady bearing the Latitude E11^{o}51'44" and Longitude N79^{o}48'14" about 1 KM orthogonal to the coast. The data acquired were inverted using RES2DINV to obtain depth ranging from 0 to 52.3 m using 10 m electrode spacing. The first layer, between the depths of 0 and 13.5 m has resistivity values ranging from 13.8 Ωm . The second layer is between depth 13.5 m and 43.0 m and has resistivity values of 0.78 Ωm and 3.29 Ωm. The third layer has resistivity of 13.8 Ωm between depth 43.0 and 52.3 m. The second and third layers have varying resistivity distributions. These layers appear to consist of top soil, clay, shale and sandstone. A prompt saline intruded zone is noted at a depth of 19.0 m to 34 m indicating the litho units saturated with saline water. At a depth of 43 to 52 m there appears to be a high resistivity zone with resistivity range of (22 Ωm) evenly distributed throughout the profile. For the better interpretation of the data resistivity soundings (Fig. 5.15 C) were

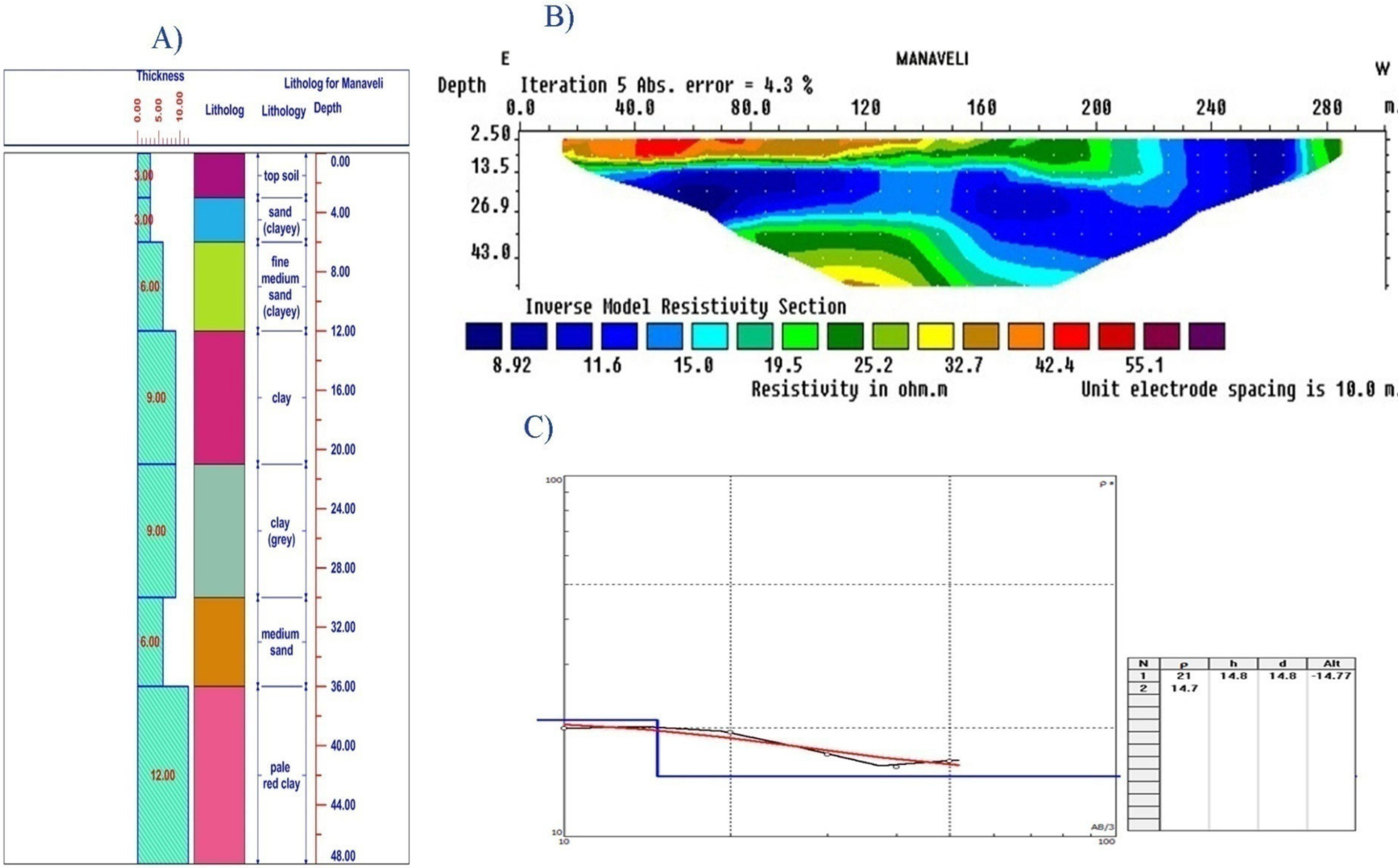
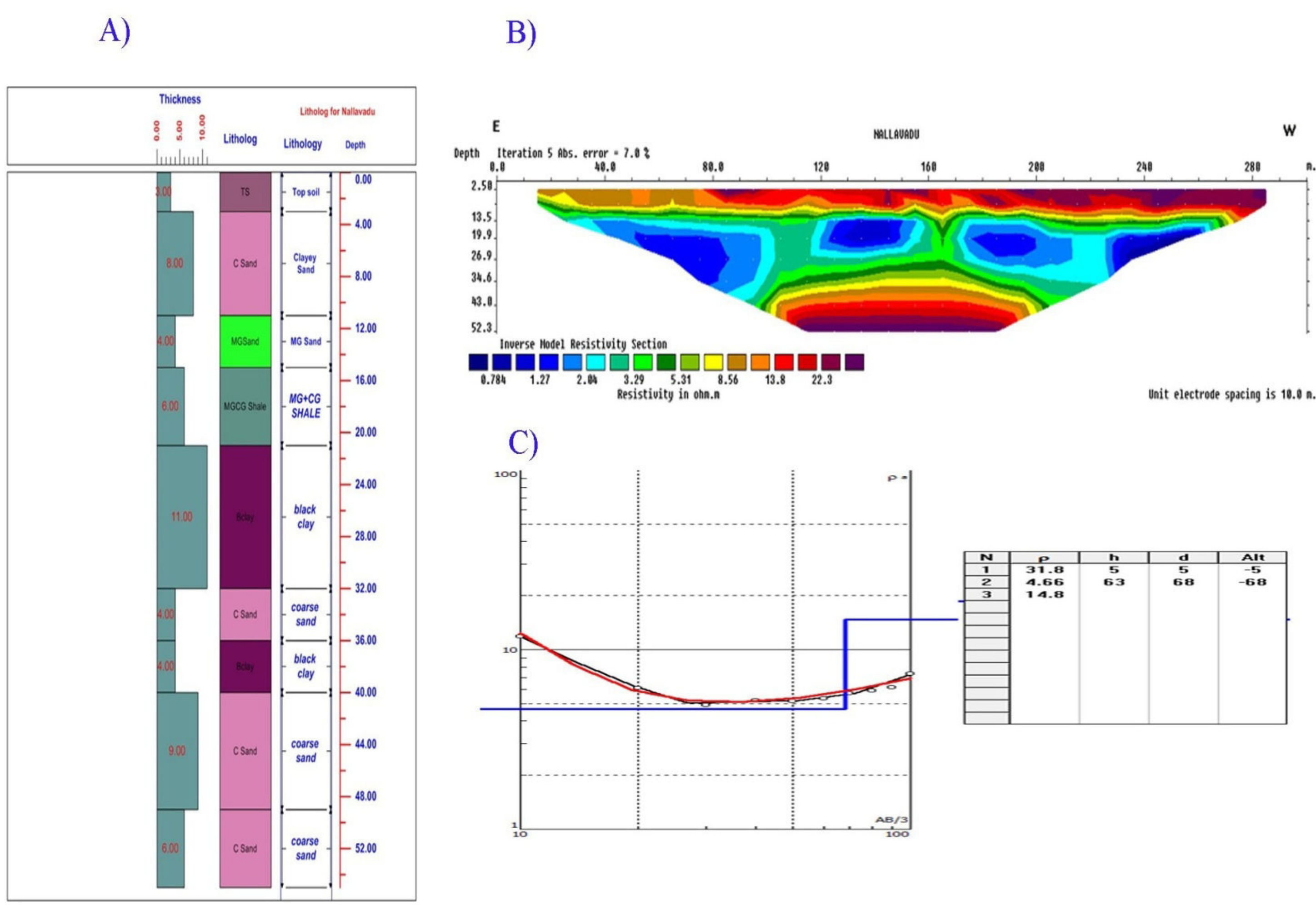


Figure No. 5.14 A) Litholog, B)ERI profile and C) 1d image of Manaveli



N	ρ	h	d	Alt
1	31.8	5	5	-5
2	4.66	63	68	-68
3	14.8			

Figure No. 5.15 A) Litholog, B)ERI profile and C) 1d image of Nallavadu attempted by DC resistivity survey utilizing the Wenner array. The measurements were performed along the same Profiles achieved in the 2 D measurements. It is a well known fact that increase of potential electrode spacing is marked by discontinuity in the field curve. From the interpretation the area of study is demarcated into three geoelectrical layers. The first layer is represented by alluvial deposits with higher resistivity values. The second layer with a low resistivity might be due to the presence of shale, clay and sand stone formation saturated with sea water. The third layer with higher resistivity value might be due to the presence of sandstone. The litho log collected (Fig. 5.15 A) from a pumping well near by the survey location confirms the above statement with a top soil of 3.0 m thickness followed by medium grained, coarse grained sand along with clayey silt and clay formation starting from a depth of 3.0 m up to a depth of 43.0m indicating the saline intruded zone. It was doubted that the presence of clay formations might be the reason for lower resistivity values misinterpreted for saline water intruded zone. But when comparing with the sea water average resistivity value of 0.2 Ω m and the resistivity of clay formations both wetted and dry as 1 Ω m to 250 Ω m (Bauer et al.,) the resistivity value observed in this particular zone (0.784 Ω m) is in good conformity with the sea water resistivity values. Hence it is confirmed that, lower resistivity values are not mainly due to the presence of clay formations but due to the saline water intrusion into the aquifers. The groundwater sample collected from the observation bore hole used for the interpretation of the litho log confirms the saline nature of groundwater with higher EC (>4000 μS/Cm) and Cl (475 mg/L) ratios. From the profile it is confirmed that saline water intrusion is confined up to a distance of 1.280 KM inland.

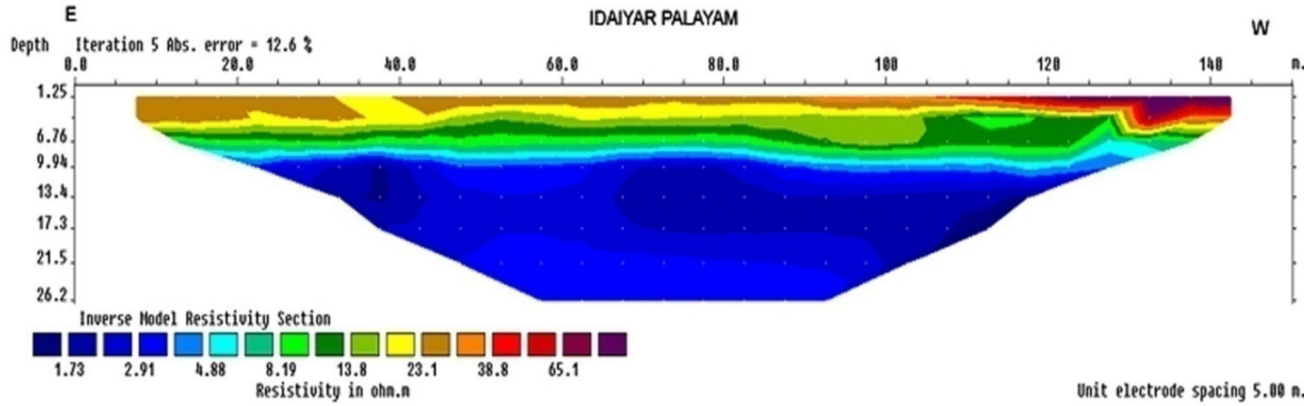
5.2.14 Idayarpalayam

The profile (Fig. 5.16 B) was performed at Idayarpalayam bearing the Latitude E11°52'20" and Longitude N79°48'11" about 2.1 KM orthogonal to the coast with an electrode spacing of 5m between the depths of 140 m with a total vertical depth of 26.2 m. First layer Inverse model resistivity 2D section shows higher resistivity up to a depth of about 13.4 m followed by a low resistivity layer showing lateral inhomogeneities. The second layer is between depths 13.4 to 26.2 m with resistivity values from 1.73 to 2.91 Ωm. From the first layer resistivity value it is inferred that the formation might be made up of top soil with sand formation due to its higher resistivity values. The second layer with medium resistivity values is inferred as clay formation admixed with sand. A clear divide between the top soil and the clay formation is observed at a depth of 13.4 m. To further gain insight regarding the layers involved, resistivity sounding (Fig. 5.16 C) has been attempted which demarcated two layers with varying resistivity values. The first layer with a high resistivity values (20.0 Ωm) demarcates the layer as top soil sand and the second layer with resistivity values of 3.08 Ωm may be interpreted as clay mixed sand formations with varying grain sizes. No traces of saline water intrusions were identified, since the low resistivity is mainly due to the presence of clay formations.

5.2.15 Nonankuppam

The profile (Fig. 5.17 A) was performed at Nonankuppam bearing the Latitude E11°53'12" and Longitude 79°48'13" about 2.5 KM orthogonal to the coast with an electrode spacing of 5m between the depths of 140 m with a vertical depth of 26.2 m. First layer 2D section shows higher resistivity up to a depth of about 19.94 m followed by a low resistivity layers showing lateral inhomogeneities. The second layer is between depths 19.9 to

A)



B)

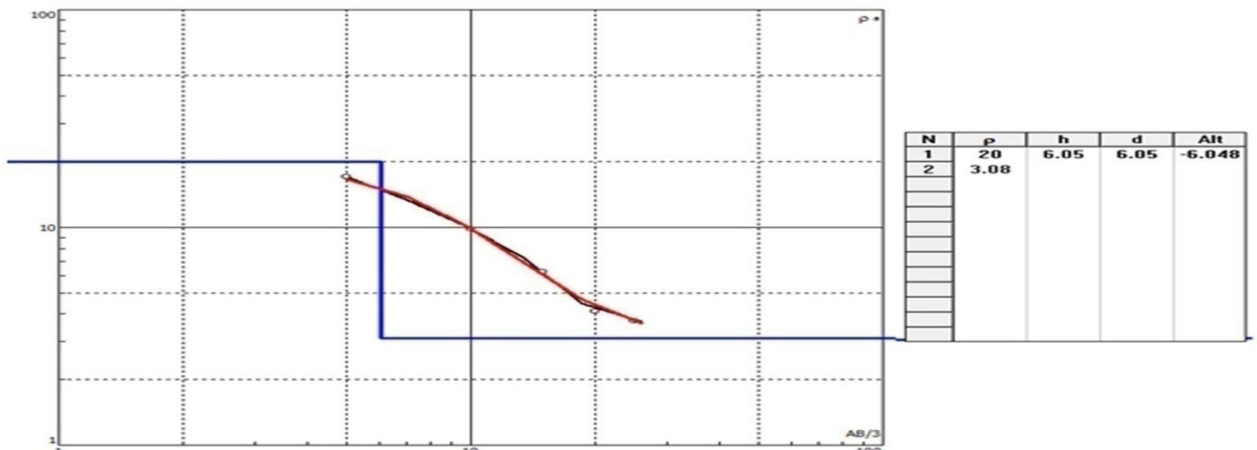
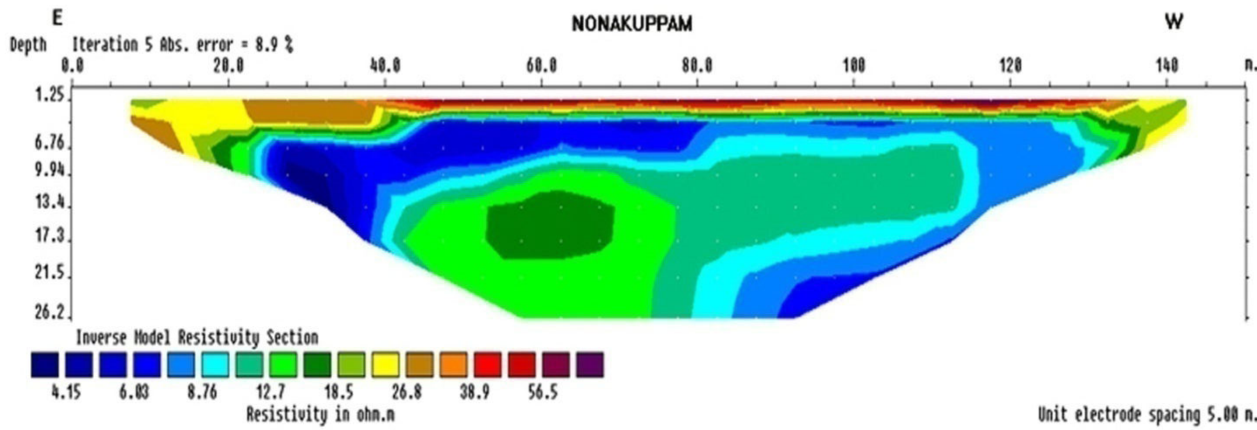


Figure No. 5.16 A)ERI profile and B) 1d image of Idayarpalayam

A)



B)

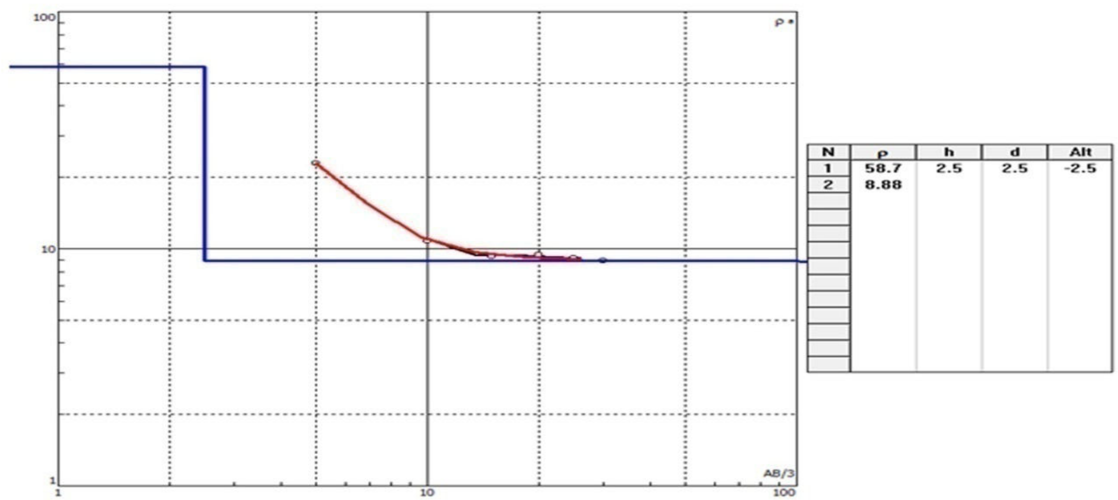


Figure No. 5.17 A) ERI profile and B) 1d image of Nonakuppam

21.5 m with resistivity values from 4.15 to 21.5 Ωm. From the first layer resistivity value it is inferred that the formation might be made up of top soil with sand formation due to its higher resistivity values. The second layer with medium resistivity values is inferred as sandstone admixed with clay formation inferred from the resistivity values. A clear divide between the clayey sand formation and the sandy clay formations is observed at a depth of 21.5 m to 26.2 m along the eastern part of the profile. Increase in resistivity values along the left side of the profile indicates the massiveness of the sandy clay formation. To further gain insight regarding the layers involved, resistivity sounding (Fig.5.17 B) was attempted which demarcated two layers with varying resistivity values. The first layer with a high resistivity values (58.7 Ωm) demarcates the layer as top soil sand and the second layer with resistivity values of 8.8 Ωm may be interpreted as clay mixed sand formations with varying grain sizes. There were a slight difference between the inference made between the 2D and 1 D investigations where the second layer interpreted by 2D demarcates the second layer with low resistivity values and the third layer as the layer with higher resistivity values but in the 1 D investigations the top soil zone has been demarcated where the other formations have been linked together in the inversion process so that a complete 2 layer case has been reported. Since no litho logs were identified for the present study area no attempt has been made for the correlation with the litho logs.

5.2.16 Sivananthapuram

The profile (Fig. 5.18 B) was performed at Sivananthapuram bearing the Latitude E11^{o}51’12”and Longitude N79^{o}48’30” about 322.8 m orthogonal to the coast with an electrode spacing of 5m between the depths of 140 m with a total vertical depth of 26.2 m. The First layer identified depths of 0-13.4 m with resistivity values ranging from 14.0 to 20.9 Ωm. The second layer is between depths 20.9 m and 26.2 m has resistivity values ranging from 1.20 to 6.23

Ωm.From the first layer resistivity value it is inferred that the formation might be made up of top

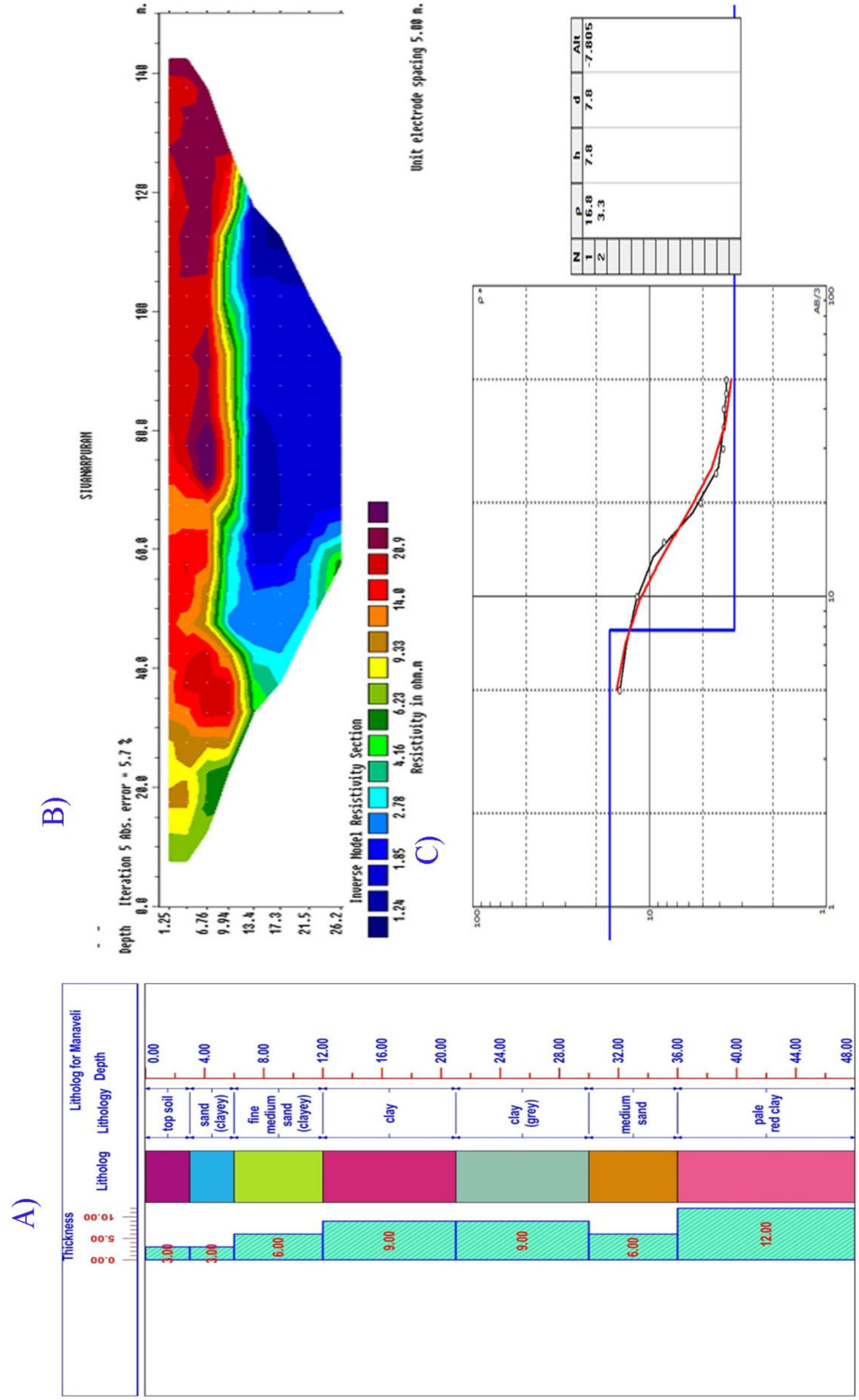


Figure No. 5.18 A)Litholog, B)ERI profile and c) 1d image of Sivanathapuram soil due to its higher resistivity values. At the eastern part of the profile a low resistivity zone is identified as fine grain sandstone which has been confirmed with field check. A gradual decline in resistivity was noted indicating the presence of stratified litho units. Electrical resistivity sounding (Fig. 5.18 C) attempted in the study area demarcates two different layers, the first layer with a resistivity of 16.8 Ωm interpreted as top soil with a total thickness of 7.8 m followed by the second layer with resistivity range of 3.3 Ωm, might be the presence of medium to fine grained sandstone, but a gradual decrease in the resistivity value indicate the presence of still lower resistivity values, might be interpreted as the clay formation with low resistivity values of 1.20 Ωm. For better information about the litho units the litho log (Fig. 5.18 A) profile conducted nearby bore hole location has been taken for interpretation and from that the first layer has been identified as the top soil followed by fine grained sandstone, medium grained sandstone and clay formations together up to a depth of 13 m indicates the stratified nature of the litho units. The second layer has been interpreted as the clay formation which was in conformity with the resistivity values recorded. From the profile it is inferred that no traces of saline water intrusion has been recorded but the low resistivity recorded is mainly due to the clay formations.

5.2.17 Kirumambakkam

The profile (Fig. 5.19 B) was performed at Kirumambakkam bearing the Latitude E11^{o}49’25” and Longitude N79^{o}47’30” about 1.3 KM orthogonal to the coast with an electrode spacing of 5 m between the depths of 140 m with a total vertical depth of 26.2 m. The first layer resistivity was ranging from 13.3 to 35.5 Ωm from depth ranging from 0.0 to 17.3 m. The second layer is between depths 17.3 m to 26.2 m with resistivity range from 6.37 to 10.4 Ωm. From the first layer resistivity it is inferred that the formation might be made up of top soil due to its

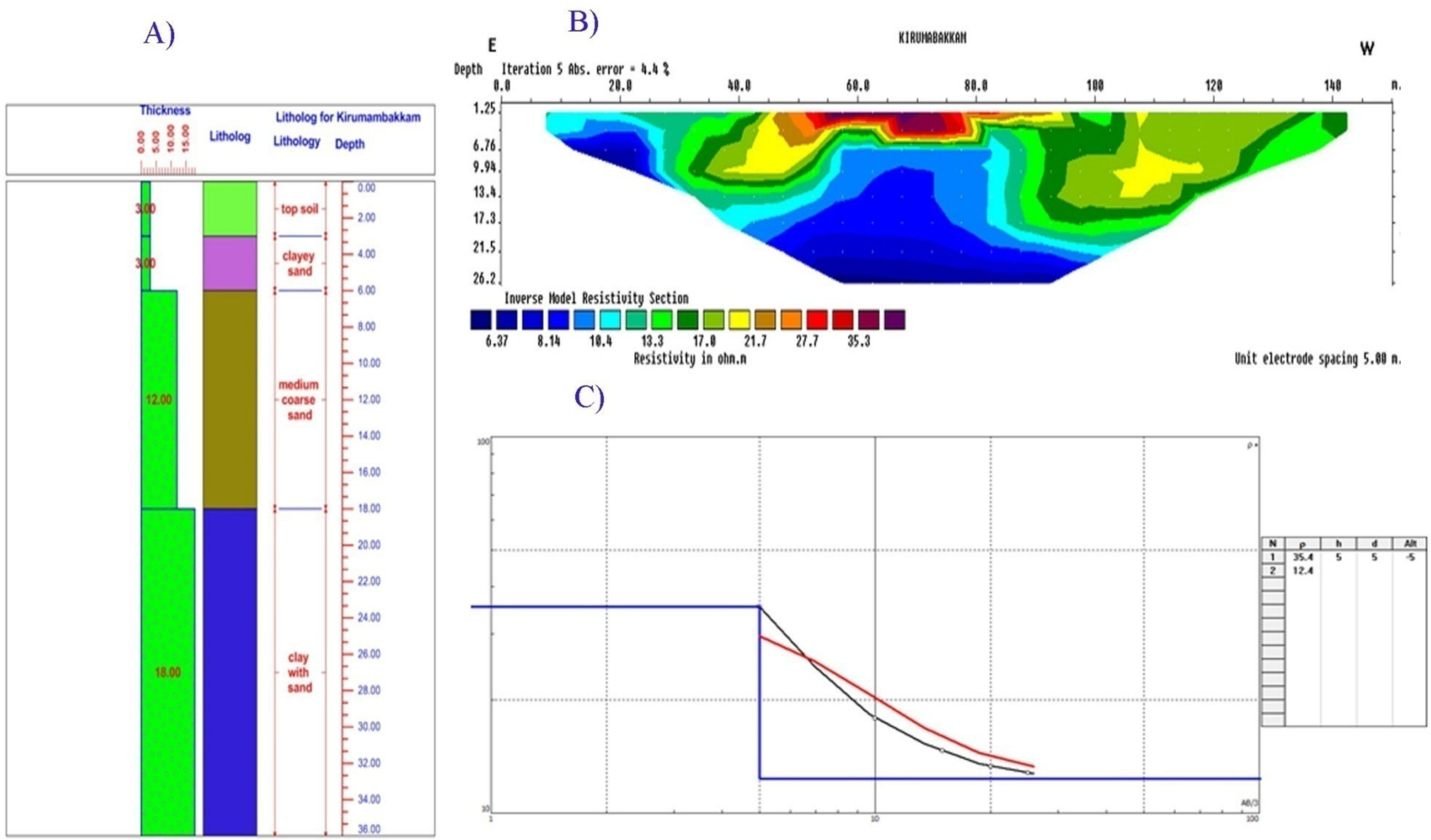


Figure No. 5.19 A) Litholog, B)ERI profile and C) 1d image of Kirumampakkam higher resistivity values. At the eastern part of the profile a low resistivity zone (6.37 Ωm) might be the continuation of the second layer which is exposed at the eastern part of the profile direction. The first layer was found to be extending to greater depth along the eastern and western parts of the study area as patches of medium resistivity zones. Electrical resistivity sounding has also been attempted in the study area to infer the differences between the 2 D and 1 D soundings. The sounding (Fig. 5.19 C) demarcate two different layers, the first layer with a resistivity of 35.4 Ωm interpreted as top soil with a total thickness of 5 m followed by the second layer with resistivity range of 12.4 Ωm, might be due to the presence of intermixing of medium to fine grained sand mixed with clay formations. For better information about the litho units the litho log (Fig, 5.19 A) profile conducted nearby bore hole location has been taken for interpretation and from that the first layer has been identified as the top soil followed by clayey sand and medium grained to coarse grained sandstone formations up to a depth of 18m this is in good conformity with the 2 D resistivity soundings. The second layer is the clay with sand formation which has been recorded with lower resistivity values. The patch of second layer extension has been identified along the eastern part of the profile which is well visible from the resistivity values. From the profile it is inferred that no traces of saline water intrusion has been recorded but the low resistivity recorded is mainly due to the presence of clay sand formations.

5.2.18 Pillayarkuppam

The profile (Fig. 5.20 B) was performed at Pillayarkuppam bearing the Latitude E11^{0}48"and Longitude N79^{o}47'26" about 1.3 KM orthogonal to the coast with an electrode spacing of 5 m between the depths of 144 m with a total vertical depth of 26.2 m. The first layer resistivity was ranging from 35.5 to 35.5 Ωm from depth ranging from 0.0 to 17.3 m. The second layer is identified between depths 17.3 m to 26.2 m with resistivity range from 6.37

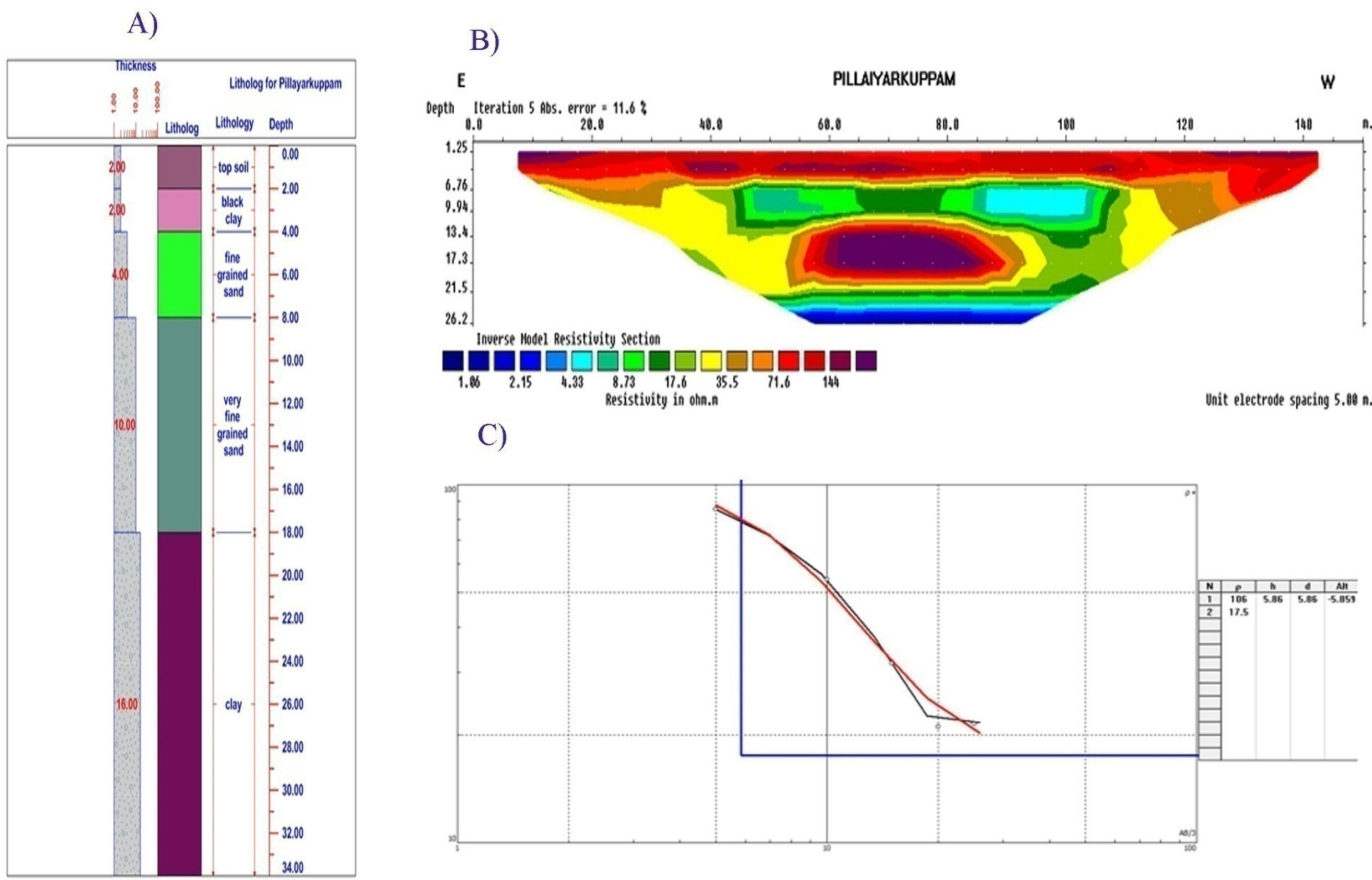
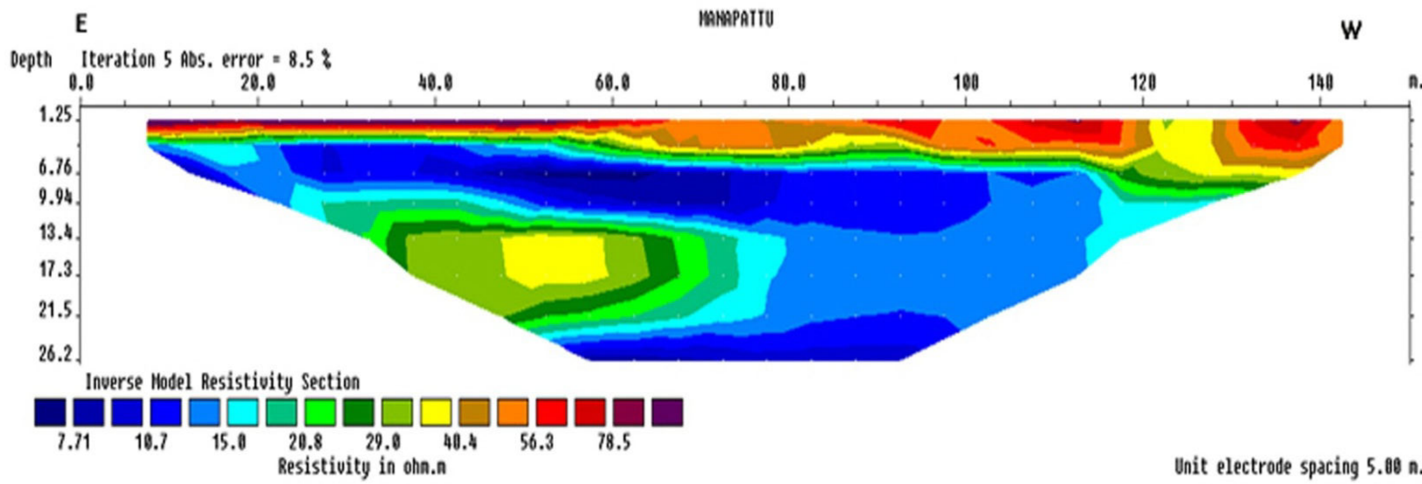


Figure No. 5.20 A) Litholog, B)ERI profile and C) 1d image of Pillaiyarkuppam to 10.4 Ωm. From the higher resistivity values the first layer might be interpreted as top soil formation. The second layer with lowering resistivity might be due to the intermixing of clay layers with sand formations. A low resistivity zone at a depth of 26.2 m might be the presence of clay formations without any interbedding formation. A higher resistivity zone present at a depth of 13.4 m to 21.5 m equal to the resistivity of the top soil. This higher resistivity might be due to the absence of water with increasing depth. Electrical resistivity sounding has also been attempted in the study area to infer the differences between the 2 D and 1 D soundings. The sounding demarcate two different layers, with a first layer resistivity of 106 Ωm interpreted as top soil with a total thickness of 5.8 m followed by the second layer with resistivity range of 17.5 Ωm, might be due to the presence of intermixing of medium to fine grained sand mixed with clay formations. For better information about the litho units the litho log profile conducted nearby bore hole location has been taken for interpretation and from that the first layer has been identified as the top soil followed by black clay formations. The second layer is identified as clay, fine grained sand and very fine grained sand up to a depth of 10m. The presence of a high resistivity zone might be in the location where very fine sand might have been exposed. The sand formation with or without water exhibits a higher resistivity zones except if the formation is with saline water. The third layer inferred with low resistivity values (1.06 Ωm) at a depth of 26.2 m is correlated to the clay formation. Hence from the profile it is inferred that there is no traces of saline water and the lower resistivity is mainly due to the presence of clay formations.

5.2.19Manapattu

The profile (Fig. 5.21 A) was performed at Manapattu bearing the Latitude E11^{o}47’50” and Longitude N79^{o}47’24” about 800 m orthogonal to the coast with an electrode spacing of 5 m between the depths of 140 m with a total vertical depth of 26.2 m. First layer resistivity for 2D

A)



B)

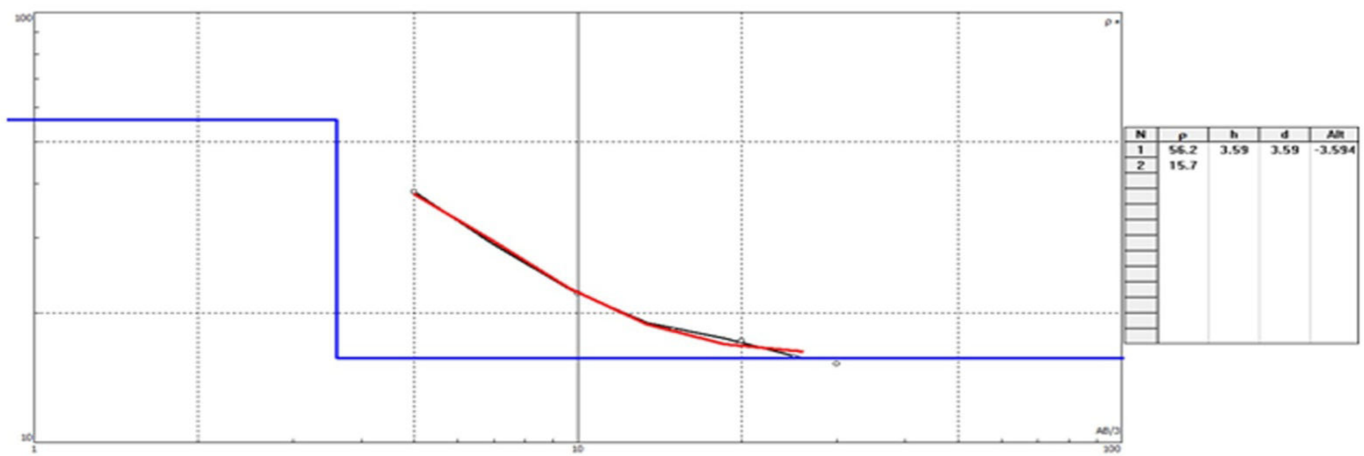
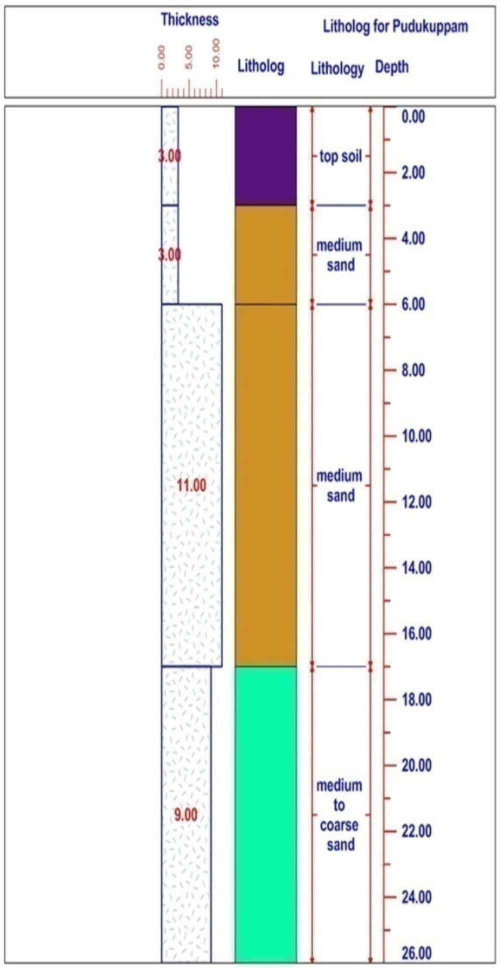


Figure No. 5.21 A)ERI profile and B) 1d image of Manapattu section shows higher resistivity up to a depth of 3.0m along the eastern part of the profile while along the western part there is an increase in the layer up to a depth of 6.76 m followed by a low resistivity zone extending towards the entire depth of the profile. The second layer is between depths 6.76 to 26.2 m with resistivity values from 7.71 to 40.4 Ωm. A patch of higher resistivity zone is noted along the eastern part of the profile at a depth of 17.3 to 26.2 m indicating the existence of a high resistive zone or might be interpreted as a dry formation. From the first layer resistivity value it is inferred that the formation might be made up of top soil due to its higher resistivity values. The second layer with low resistivity values is inferred as clay formation admixed with sand. A higher resistivity zone is found in between two low resistivity zones. This zone is identified as sandstone formation but due to the lower resistivity observed it is inferred as sandstone formation intermixed with clay formation. The bottom most layer is identified as a pure clay formation due to its lower resistivity. To further gain insight regarding the layers involved, 1 D resistivity sounding (Fig. 5.21 B) was attempted which demarcated two layers with varying resistivity values. The first layer with a high resistivity values (56.2 Ωm) demarcates the layer as top soil up to a depth of 3.59 m, and the second layer with resistivity values of 15.7 Ωm may be interpreted as clay mixed sand formations with varying grain sizes. No traces of saline water is observed with reference to the profile generated the lower resistivity value is mainly due to the inter mixing of sand with clay formation. Since no litho logs were identified for the present study no attempt has been made for cross correlation with the logs.

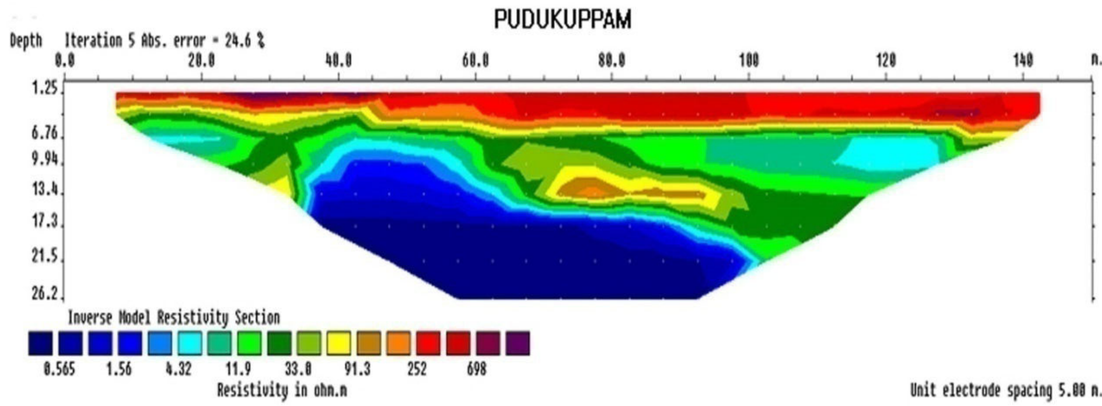
5.2.20 Pudukuppam

The profile (Fig.5.22 B) was performed at Pudukuppam bearing the Latitude E11^{o}47'50" and Longitude N79^{o}47'28" about 622 m orthogonal to the coast with an electrode spacing of 5m between the depths of 140m, with a total depth

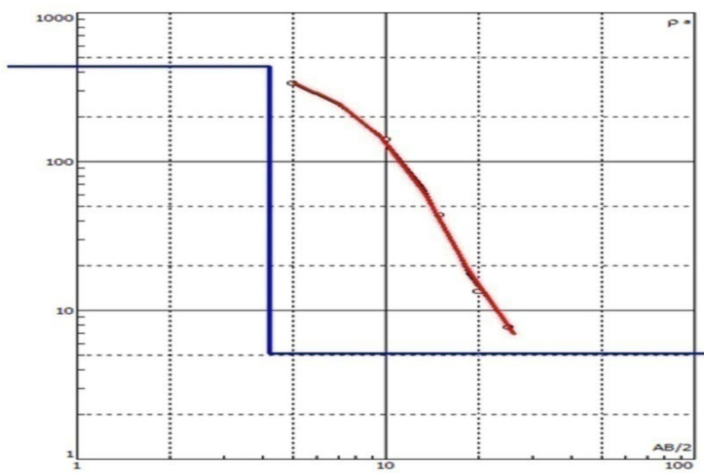
A)



B)



C)



N	ρ	h	d	Alt
1	438	4.18	4.18	-4.177
2	5.12			

Figure No. 5.22 A) Litholog, B)ERI profile and C) 1d image of Pudukuppam of penetration of 21.5 m. The higher resistivity layer identified up to a depth of 3m may be the top soil zone with a resistivity range of 698 Ωm. The second layer with a resistivity range of 11.9 Ωm 91.3 Ωm from a depth of 3.00 m to 17.3 m. The third layer with a resistivity range of 0.565 to 4.32 Ωm from depth of 17.63 to 26.2. A steeper lowering of resistivity is noted from the top most layer to the bottom layer indicating the inhomogeneities in the subsurface formation. For further confirmation the 1 D resistivity data (Fig. 5.22 C) was taken for the interpretation purposes. From the profile a total of two layers were demarcated. The first layer has been interpreted as top soil with a resistivity range of 438 Ωm up to a depth of 4.18 m. The second layer with a resistivity range of 5.12 Ωm is interpreted as the lower resistivity zone might be the sand formation interbedded with variation in grain size fractions. The 1 D interpretation was in close conformity with the 2 D profile. For further information a litho log from the nearby location is taken for the interpretation of the layers involved. From the litho log data (Fig. 5.22 A) the top soil up to a depth of 3 m is confirmed. The second layer with a low resistivity zone is interpreted as the medium grained sand formation. The third layer with a very low resistivity of (0.565 Ωm) is the medium to coarse grained formation with traces of saline water intrusion. Hence from the plot it is inferred that saline water intrusion is high up due to the over extraction of groundwater.

5.3 TRACES OF SALINE WATER INTRUSION

The traces of saline water intrusion along the northern parts of the study area in location Kalapet I and II traces of saline water intrusion have extended up to a distance of 1.5 KM inland (Fig. 5.23).

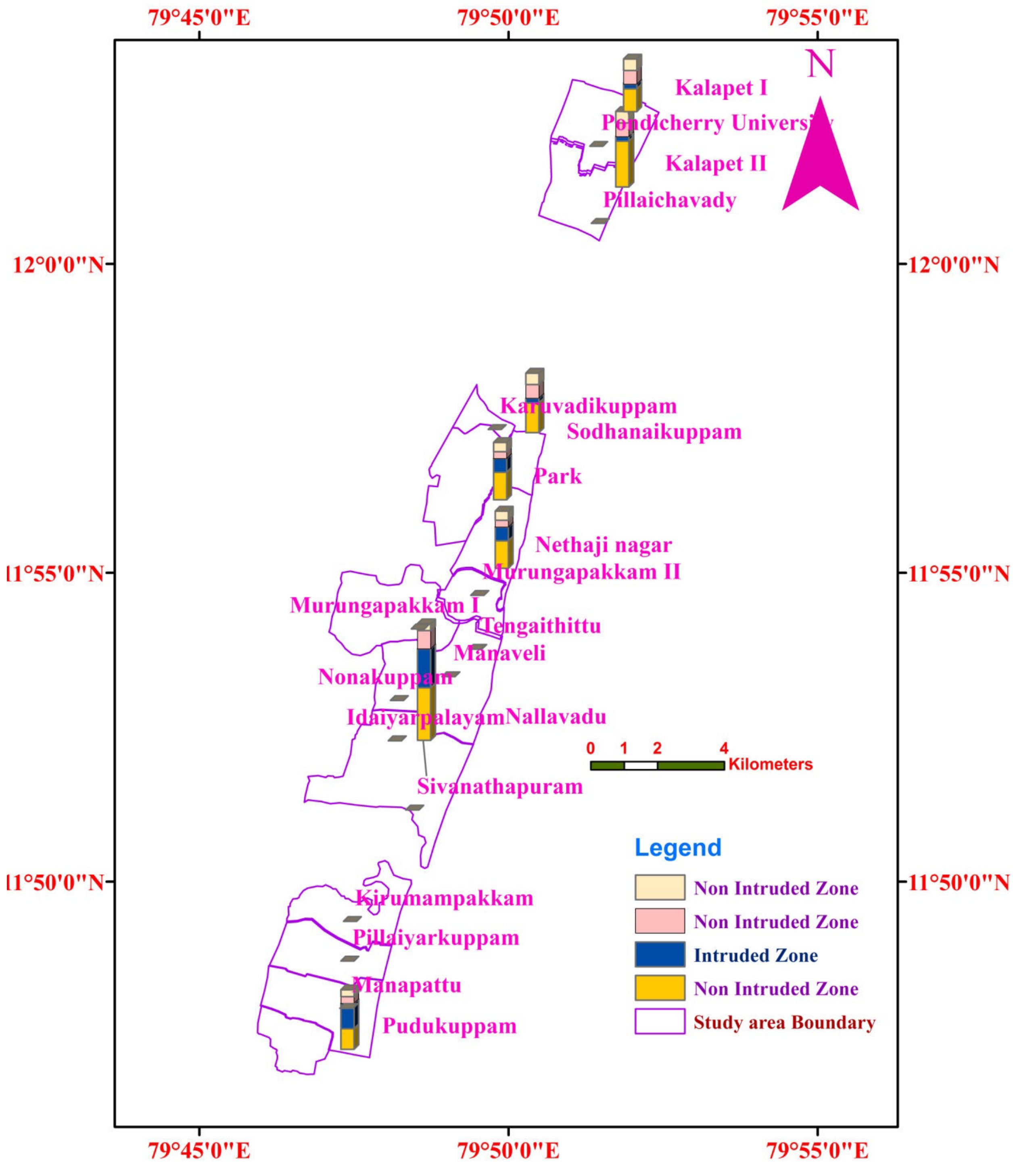


Figure No.5.23 Saline influence zone

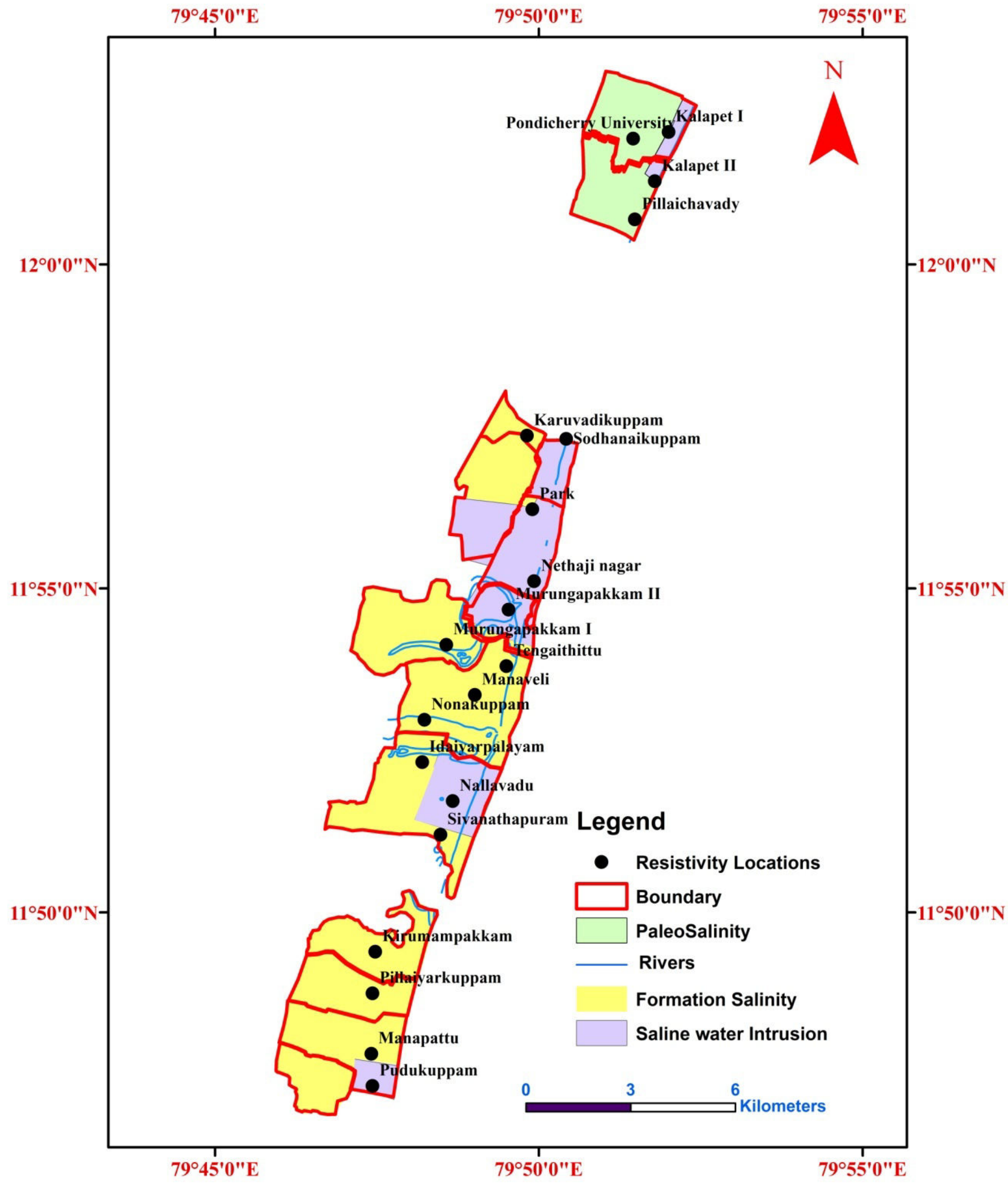


Figure No. 5.24 Classification of saline influences

Along the central parts of the study area in locations like Murugambakkam, Idayarpalayam and Nonankuppam the effect of saline water intrusion have been identified up to a distance of 5 KM inland and found to extend further inland should be confirmed by additional geophysical surveying along the western parts of the study area. Along the Southern parts of the study area in locations like Pudukuppam, Kirumambakkam and Manapattu saline water intrusion is found to extend up to a distance of 1 KM inland. Hence to conclude three different traces of saline water into the coastal aquifers are noted (Fig.5.24). The first is mainly due to the hydrodynamic connection between the coastal aquifers and the saline water, this type of intrusion is prominent along the northern part of the study area in locations like Kalapet. In the central portion of the study area the influences of the litho salinity has a greater impact to determine the salinity in the coastal aquifers. The formations interbedded with clay admixtures recorded lower resistivity might not be taken as saline water intruded zone but due to the presence of clay mineral assemblages the quality of groundwater in those aquifers are poor for domestic and drinking consumption. In the middle portions of the study area the presence of estuaries has a greater impact on the salinity in the groundwater. Hence the salinity into these aquifers are not due to direct saline water intrusion but due to the impact of estuaries with saline water. The southern portion of the study area is dominated by the lithological salinity where the quality is not suitable for domestic consumption.

6. SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 SUMMARY

A detailed Electrical Resistivity Imaging was carried in the Puducherry region situated between 11°50' and 12°03' N latitudes and 79°45' and 79°55' E longitudes with a total area of 68 sq. km by acquiring 20 ERI and VES soundings to gain insight regarding the impact of saline water intrusion into the coastal aquifers. The geology of the study area is underlain by the semi-consolidated and unconsolidated sedimentary formations ranging in age from lower Cretaceous to Recent, lying on Archaean basement. The general strike of Cretaceous and Palaeocene trends northeast-south west with gentle dips ranging from 2° to 5° towards southeast. The major physiographic units are generally observed namely (i) Coastal plain, (ii) Alluvial plain and (iii) Uplands. Geomorphology of the area encompasses alluvium plain, flood plain, moderate buried pediments, shallow buried pediments and coastal plain or upland. The soil type of the study area is dominated by clay and sand stone with little clay and black clay distributed along the borders of the study area. The temperature of the area ranges between 41°C to 25°C. Higher humidity above 70% is noted during August to April. The normal annual rainfall is 1205mm. Winds are generally light to moderate in velocity during the summer and early southwest monsoon season. The irrigation facility of the Union Territory is very developed as 90 % of the cultivated area is irrigated. Pondicherry is mainly irrigated through tanks and tube wells. There are 84 tanks in the region which helps to irrigate 6,765 hectares of land with a capacity of holding 46.4 mcm of water. The study area encompasses of three major aquifer systems, namely, (a) unconsolidated quaternary alluvial deposits of recent period, (b) Unconsolidated to semi-consolidated Tertiary Cuddalore sandstone formation of Mio-Pliocene period and (c) semi consolidated Mesozoic Vanur and Ramanathapuram sandstone formation of the Upper to Lower cretaceous period. Among the various water bearing formation of Cretaceous age, the Ramanathapuram and Vanur formation form potential aquifers. They occur in the north-western part of Pondicherry. The most potential Cuddalore sandstone of Mio-Pliocene age comprises of sandstone, sands and gravels. The alluvial aquifer comprises of sands and grovels and this formation occupies nearly three forth of the region. The annual rainfall of the region replenishes both the surface and ground water. There are 59 system tanks and 25 non-system (rainfed) tanks, which irrigate about 6600 Ha of land. The utilizable groundwater resources (at 85% of the gross recharge potential) was assessed at 151 MCM. Since alluvial aquifers cover about 90% of the Puducherry region, water level in the wells is fairly shallow ranging between 12 to 14 m below ground level.

Electrical Resistivity Imaging has been attempted by BTSK WDDS-2/2B Digital Resistivity Meter with a total of 20 profiles located respectively at 5 m to 1.5 m from the shoreline. Wenner – α method was adopted and the profiles were oriented perpendicular to the shoreline. The total number of electrodes used varies from 31 to 32 spaced of 5 m and/or 10m leading to an investigation depth ranging from 27.7 – 55.4 m. The pseudo section attempted using RES2DINV software. The first ERT, Profile performed near Kalapet-1 showed electrical resistivity varying from 3.41-1484.0 Ωm with a total depth coverage of 3.41 Ωm. Saline water intrusion was observed at a depth of 19.0 m indicating the up coning of saline water into the sandstone formation. This has also been confirmed with 1 D investigation and by correlation with litho log and groundwater samples collected near the profile line recorded higher EC (> 6000 µS/Cm). The second profile was performed at Pondicherry University with a distance of 1.3 KM away from the coast. The First layer between depths of 0-3.0 m has resistivity values ranging from 103 to 237 Ωm. The second layer between depths 3.0 m and 11.0 m with resistivity ranging from 360 to 546 Ωm. The first layer inferred as laterite and second layer as sandstone formation. No traces of saline water intrusion have been identified and the reason for low resistivity is mainly due to paleo saline water. The third profile at Kalapet-1I, 300 m orthogonal to the coast recorded resistivity values ranging between 2.73 -1183 Ωm. The second layer with low resistivity indicated the saline water intruded zone. The next profile was performed at Pillaichavadi about 20 m away from the coast. The geoelectrical image shows a variation in resistivity ranging between 3.83 – 93.6 Ωm. Lower resistivity values (3.83 Ωm) is inferred as saline water intruded zone. The fifth profile at Sodanaikuppam about 20 m away from the coast recorded resistivity values from 203 to 477 Ωm. Saline water intrusion was noted at depth between 21.5 to 26.2 m confirmed with litho logs and higher EC values from the nearby bore well. The sixth profile at Karuvadikuppam about 1.5 KM towards land demarcated low resistivity up to a depth of about 19.9 m separate the second layer with medium resistivity values. No traces of saline water intrusion were recorded and the variation in resistivity values is mainly due to the significance in litho units. The next profile performed at Park about 50 m away from the coast recorded lower resistivity values 6.28 to 166 Ωm at depth ranging from 6.76 to 17.3 m indicating the formation intruded by saline water. The next profile performed at Nethaji nagar about 10 m away from the coast recorded resistivity distribution between 0.152 - 503 Ωm confirming the saline migration into the coastal aquifers at shallow depth (<30m) at a distance of 18 to 150 m away from the coast and still found to be extending deeper inland. The next profile at Murugambakkam about 1.5 km away from coast line shows lateral decrease in resistivity with increasing depth indicating the inhomogeneities in lithology. Influence of Tengaithittu estuary which is highly contaminated by effluents have reduced the resistivity value at shallower depth along the western part of the profile line was noted. No traces of saline water intrusion have been identified and has been confirmed by 1 D profile. The next profile performed at

Murugambakkam- II about 800 m away from the coast line. The higher resistivity layer (335 Ωm) demarcated as top soil followed by the zone influenced by saline water intrusion at a depth of 21.5 m with a resistivity range of 4.0 Ωm. The next profile performed at Tengaitittu about 600m away from the coast. The first layer with lower resistivity (0.325 Ωm) demarcates the layer as top soil contaminated with saline water extending up to a depth of 26.9 m. The second layer with resistivity values of 36.7 Ωm interpreted as clay mixed sand formations with varying grain sizes. The next profile performed at Manaveli about 1.3 km from the coast. A total of three layers were demarcated with varying resistivity. No traces of saline water intrusion have been identified in the present study area and the variation in resistivity is mainly due to the variation in litho units and grain size. The next profile performed at Nallavadu about 1 KM away from the coast. The resistivity ranges between 8.92 to 55.2 Ωm. Traces of saline water intrusion at a depth of 19.0 to 34.0 m with resistivity values of 0.78 Ωm and 3.29 Ωm. The next profile was performed at Idayarpalayam about 2.1 KM away from the coast. The resistivity ranges between 1.73 to 65.1 Ωm. The first layer with resistivity values (20.0 Ωm) demarcates the layer as top soil sand and the second layer with resistivity values of 3.08 Ωm as clay mixed sand formations. No traces of saline water intrusions were identified, since the low resistivity is due to the clay formations, confirmed with litho log from the nearby bore hole. The other profile performed at Nonankuppam with a distance 2.5 KM away from the coast recorded resistivity values between 4.16 to 56.5 Ωm. The 1 D sounding demarcates a total of three layers with high resistivity zone (58.7 Ωm) as the top soil followed by drop in resistivity at second layer (8.8 Ωm) interpreted as clay mixed sand formations. The next profile performed at Sivananthapuram about 322.8 m orthogonal to the coast. The resistivity values ranges between 1.20 to 20.9 Ωm. The first layer in conformity with litholog was demarcated as top soil and a low resistivity at the eastern part of the profile as fine grained sandstone. No traces of saline water intrusion have been identified from the profile and the variation in litho units are the reason for the variation in the resistivity values. The next profile performed at Kirumambakkam about 1.3 KM away from the coast line. The total depth of penetration was 26.2 m with resistivity variation between 6.37 to 35.5 Ωm. Litho log confirmed a total of two layers, the first with as top soil with higher resistivity 35.5 Ωm. The second layer with a resistivity range of 12.4 Ωm is the sand mixed clay formations. No traces of saline intrusion have been identified and the low resistivity is mainly due to the presence of clay sandy formations. The other profile was performed at Pillayarkuppam about 1.3 KM inland with a total vertical depth of 26.2 m. The first layer with resistivity range of 35.5 to 35.5 Ωm inferred as top soil and the second layer with resistivity range between 6.37 to 10.4 Ωm inferred as clay mixed sand formations. Litho log confirms the above fact and no traces of saline water and the lower resistivity is mainly due to the presence of clay formations. The other profile performed at Manapattu about 800m towards inland from the coast with a total vertical depth of 26.2 m. The resistivity values ranges between 7.71 to 78.5 Ωm. A total of three layers were demarcated with the first layer inferred as the top soil followed by the second layer with lower resistivity values due to the presence of clay formations. A high resistivity zone found in between these two zones inferred as the sand stone formation intermixed with clay. No traces of saline water are observed and the salinity is mainly due to the variation in litho units and the presence of clay formations. The final profile was performed at Pudukuppam about 622 m towards inland from the coast with a total depth of 21.5 m with resistivity variations between 0.5 to 698 Ωm. A total of three layers were demarcated, the first layer being the top soil with higher resistivity values. A steep lowering of resistivity with increasing in depth suggests the inhomogeneities in the subsurface formation. The plot inferred the presence of saline water intrusion due to the over extraction of groundwater. In general from the plots, along the northern parts of the study area saline water has been intruded up to a distance of 1.5 KM. In the central parts of the study area saline intrusion is identified up to a distance of 5 KM inland and found to be further extending. Along the Southern parts of the study area saline intrusion extending up to a distance of 1 KM inland is noted.

6.2 CONCLUSION

Geophysical resistivity investigations infer saline water prominent in locations like Kalapet 1, Kalapet 2 up to an extent of 1 km away from the coast. This saline intrusion has been mainly due to the over pumping of the coastal shallow aquifers which has created a hydrodynamic connectivity between the fresh water in the aquifers and saline water in the coast. In Pondicherry University campus elevation played a dominant role in controlling the saline water intrusion. But lower resistivity values noted inside the campus has been identified as the Paleosaline water that might have been occurred during the formation of the sedimentation. In Kalapet II saline water intrusion has been identified at a depth of <30 m indicating the over abstraction of fresh water has paved a way for the intrusion of saline water. In Pillaichavadi region, the top soil/ sand deposits have been identified to be intruded by the saline water. This intrusion has been correlated due to the proximity to the coast or the tidal/shore line changes have a greater influence on the intrusion of saline water. In sodanaikuppam the shallow aquifers at the depth of 27 m have been identified to contain the traces of saline water intrusion which has been confirmed by the chemistry of groundwater sample collected near by the survey point. In Karuvadikuppam survey line no traces of saline water intrusion has been identified due to the change in the litho units from Cuddalore sandstone to the alluvial aquifers. The litho units of the alluvial aquifers are mainly composed of clay, clay mixed with sand, and sand stone formation ranging in grain size from fine grained to coarse grained in nature. In botanical garden the top soil has been identified as the sand formation and prominent saline water intrusion has been identified in this formation. In Nallavadu region salinity traces were observed in the shallower depth confining to the litho units which are medium grained to coarse grained in nature. In Nethaji Nagar a prominent saline water intrusion has been identified at shallower depth due to the presence of litho units like sandstone formation coarse grained in nature. And the saline water intrusion is found to be extending deeper inland. In Murugambakkam I and II the influence of Tengatittu estuary was prominent where the top soil was recorded with lower resistivity. Tengaitittu estuary act as a dump of sewages/wastes generated in Pondicherry regions. Hence the impact of estuarine water quality has a greater impact to determine the quality of water in the aquifers. In Manaveli site no traces of saline water intrusion has been identified and the lower resistivity values are mainly due to the stratified litho units identified in that locations. In Sivananthapuram the same trend followed where the lower resistivity values are confined to the litho units identified there as clay formations interbedded with sand formations. In Nonankuppam the same trend follow as that of the Manaveli formation where the traces of saline water has not been identified and the salinity of the water there is mainly due to the influences of litho units identified. In Idayarpalaym the traces of saline water intrusion into the aquifers were not recorded and the salinity in the aquifers has been correlated mainly due to the varying litho units. In Tengaitittu region the influence of estuary was well noticed with a lower resistivity value in the top soil indicating the contaminated nature of the estuary has a greater impact on the top soil resistivity. In Kirumambakkam region, no traces of saline water intrusion have been recorded but the low resistivity recorded is mainly due to the presence of clay sand formations. In pillayarkuppam region the same trend has been noted where the litho salinity has a greater impact on the resistivity values obtained from that particular region. In Manapattu region the lithology was dominated by clay mixed sand formation with varying grain sizes. Hence saline water intrusion traces have not been identified. But the salinity of water is mainly due to the lithological salinity. In Pudukuppam region the coarse grained sandstone formation have identified with traces of saline water intrusion, hence traces of saline water intrusion is identical in this region at shallow depth. The second layer with a low resistivity zone is interpreted as the medium grained sand formation. The third layer with a very low resistivity of (0.565 Ωm) is the medium to coarse grained formation with traces of saline water intrusion. Hence from the plot it is inferred that saline water intrusion is high up due to the over extraction of groundwater. Hence to conclude three different traces of saline water into the coastal aquifers are noted. The first is mainly due to the hydrodynamic connection between the coastal aquifers and the saline water, this type of intrusion is prominent along the northern part of the study area in locations like Kalapet. In the central portion of the study area the influences of the litho salinity has a greater impact to determine the salinity in the coastal aquifers. The formations interbedded with clay admixtures recorded lower resistivity might not be taken as saline water intruded zone but due to the presence of clay mineral assemblages the quality of groundwater in those aquifers are poor for domestic and drinking consumption. In the middle portions of the study area the presence of estuaries has a greater impact on the salinity in the groundwater. Hence the salinity into these aquifers are not due to direct saline water intrusion but due to the impact of estuaries with saline water. The southern portion of the study area is dominated by the lithological salinity where the quality is not suitable for domestic consumption.

6.3 RECOMMENDATIONS

The planning to prevent saline water intrusion into the coastal fresh groundwater should form the part of integrated water management strategies including, comprising surface water and groundwater; both in terms of water quantity and water quality. This requires cooperation, information, study, planning and legislation. The following measures (van Dam, 1999) can be proposed for the alleviation of saline water intrusion:

- Adopting techniques like recycle and reusing of domestic and industrial waste water. Planting crops that require little water and espousing water saving techniques like drip irrigation and canal lining. Pumping of recycled water into subsoil and creating barrier against saline water intrusion.

- Planning of abstraction wells in inland area due to the increase in freshwater lens and reduction in saline water up coning due to variation in elevation.

- Increasing natural recharge by suggesting proper land use, check dams construction, surface runoff prevention.

- Suggestion of appropriate recharge structures by means of recharge wells with well screens in aquifers at any desired depth. Suggesting induced recharge nearby river and groundwater extraction locations. De-siltation of ponds and tanks so as to increase the induced recharge.

- The saline/brackish groundwater that is below fresh groundwater can be abstracted and used for cooling or for desalting, which results in the increase in the volume of freshwater and decline in saline groundwater.

- By a series of monitoring wells along the identified saline-freshwater boundary and regular supervising the water level and water chemistry. The observations of groundwater levels should be carried out with intervals of a few weeks, for instance twice a month.

- Data regarding the present and estimated future water requirements must be known by the water scientists in order to plan the future water requirements.

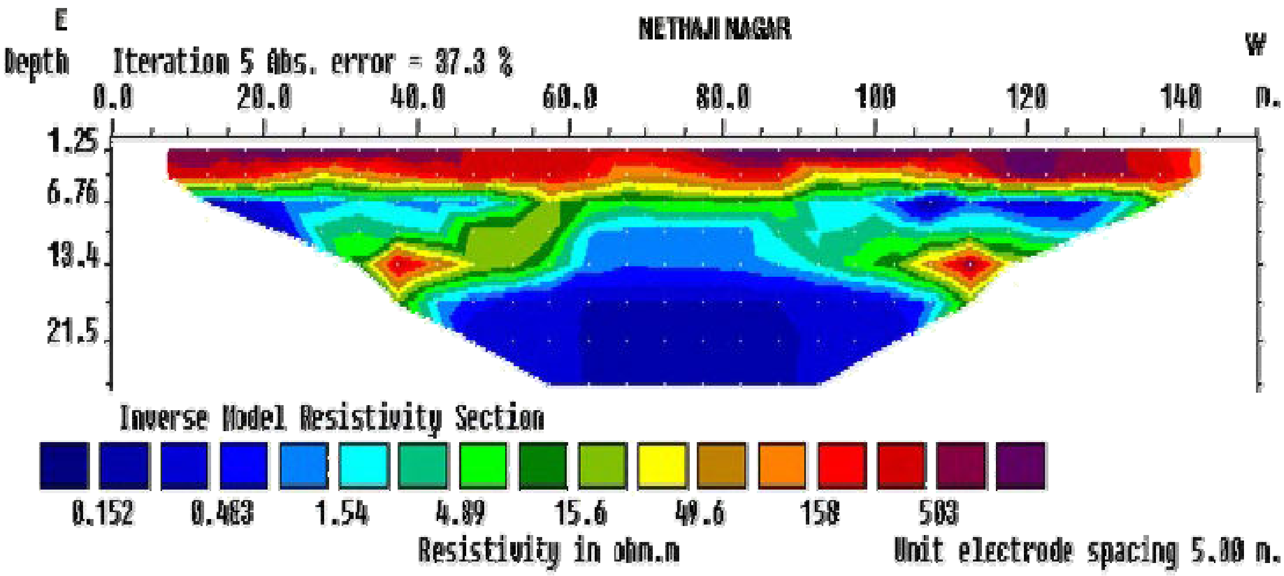
- Three dimensional transient and steady state modeling of groundwater with variable densities linked with GIS to recognize the present and past groundwater requirements and budgeting.

- Scientific evaluation to characterize the hydrogeological and biogeochemical controls affecting the efficiency of aquifer storage and recovery systems.

Project Completion Report

MAPPING OF SALINE WATER INTRUSION ALONG THE COASTAL TRACTS OF PONDICHERRY REGION USING ELECTRICAL RESISTIVITY METHODS

DSTE Sanction No.10/DSTE/GIA/RP/JSA-I/2013/208 dated 05.04.2013



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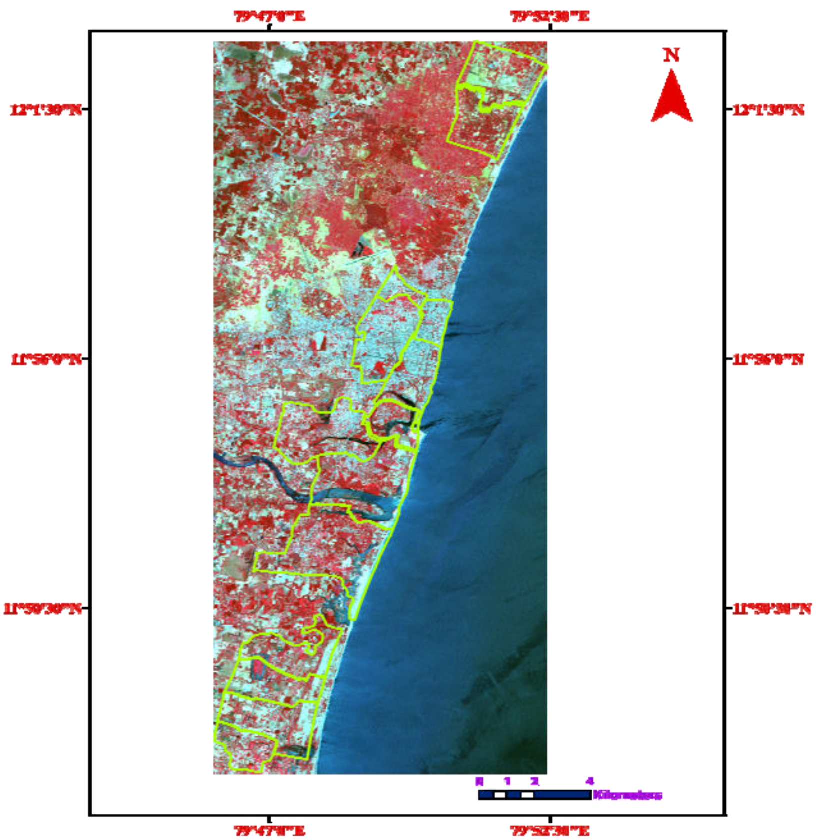

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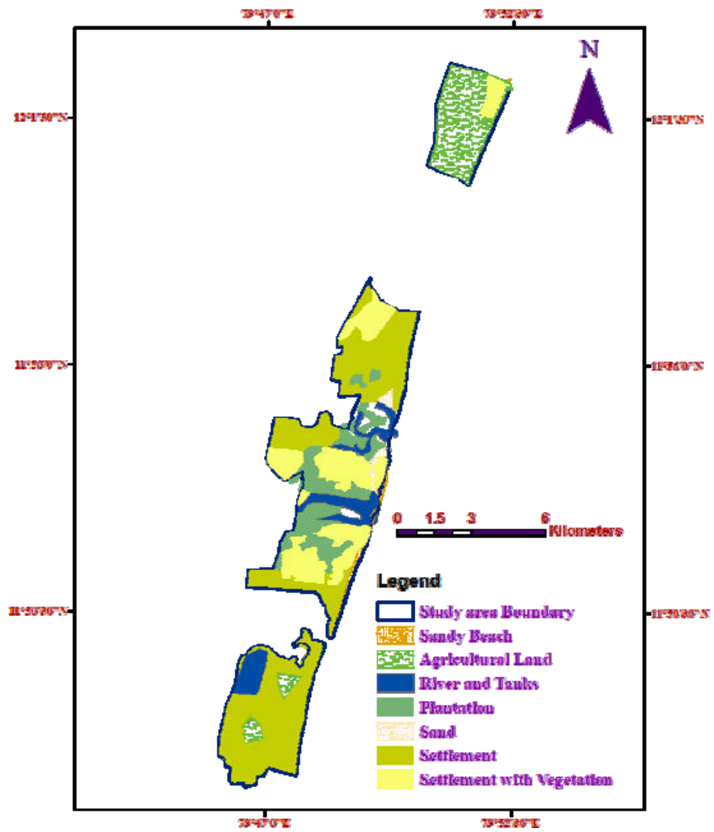

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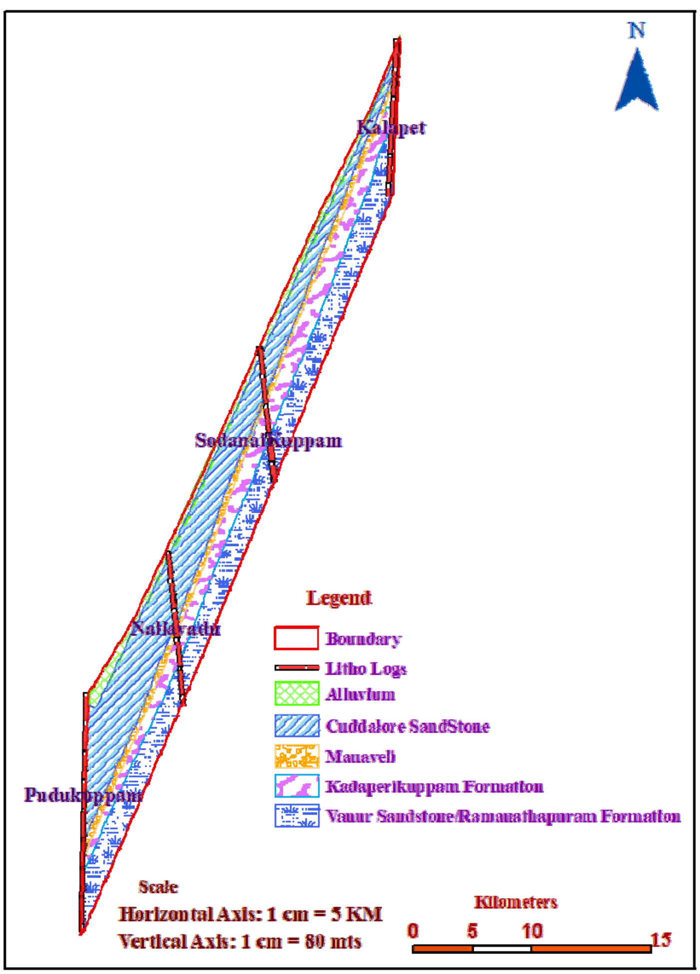
1.5
3
6
Kilometers
Legend
Study area Boundary
Sandy Beach
Agricultural Land
River and Tanks
Plantation
Sand
Settlement
Settlement with Vegetation

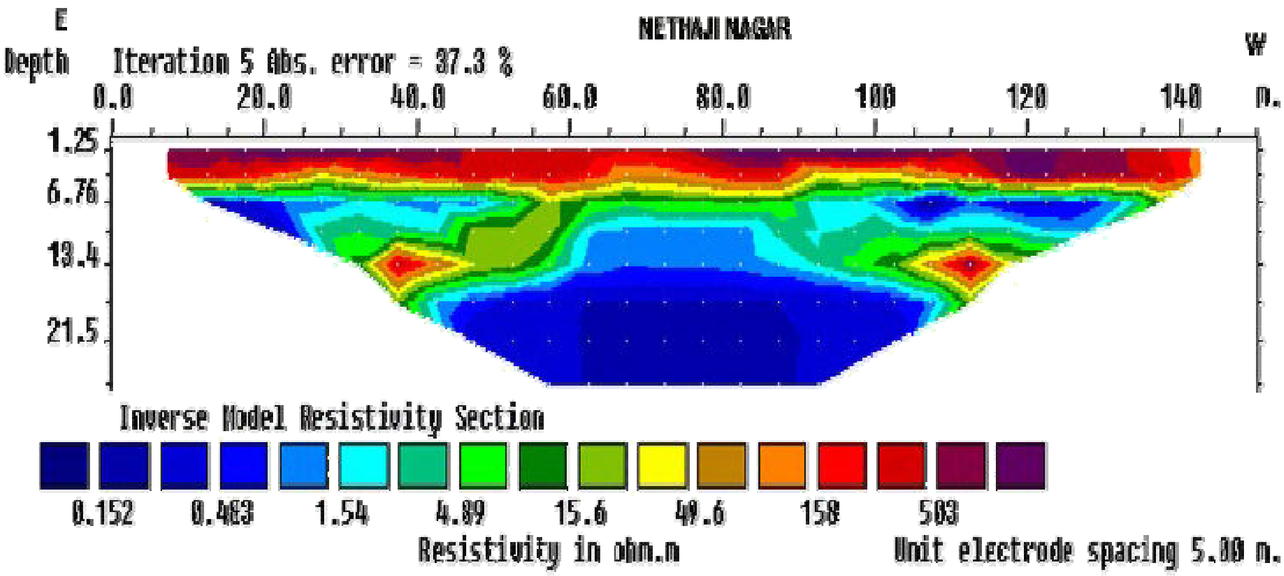


N
Kalapet
Sodanaikuppam
Nallavadu
Pudukuppam
Legend
Boundary
Litho Logs
Alluvium
Cuddalore SandStone
Manaveli
Kadaperikuppam Formation
Vanur Sandstone/Ramanathapuram Formation
Scale
Horizontal Axis: 1 cm = 5 KM
Vertical Axis: 1 cm = 80 mts
Kilometers
0
5
10
15

Project Completion Report

MAPPING OF SALINE WATER INTRUSION ALONG THE COASTAL TRACTS OF PONDICHERRY REGION USING ELECTRICAL RESISTIVITY METHODS

DSTE Sanction No.10/DSTE/GIA/RP/JSA-I/2013/208 dated 05.04.2013



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