

# **An Integrated Study on Seawater Intrusion Using Geoelectrical Resistivity and GIS Techniques in Part of Pondicherry, South-East Coast of India**

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**ABSTRACT:** The survey was conducted along in the district of Pondicherry, on the southeast coast for delineating the regions contaminated by saline water as well as to demarcate areas affected by anthropogenic activities. The geological structure and vertical changes in the subsurface environments was studied by preparing thematic maps using the spatial variation of iso-resistivity and thickness maps. The Schlumberger electrode configuration has been used for acquisition of data from the field and seven VES have been done across the study area. The interpreted values are matched with the master curves and are mostly belong to multi-layered curves, namely KH, HA, followed by H, QH and Q type. The distance between the coast and the sounding locations varies from 0.023 km to 6.85km respectively. It is observed that 3 layer curves are dominated in the study area. The resistivity of the study area varies from 0.046 to 148  $\Omega$ m and thickness ranges from 0.031m to 39.6m respectively. Spatial distribution maps of first layer resistivity shows that 3.26 km<sup>2</sup> areas having noticed as intruded the sea water. The second layer resistivity ranges from 0.046 to 148  $\Omega$ m and spatial distribution map shows that majority of the area is safer for sea water intrusion and their areal extent is 35.59 km<sup>2</sup>. Less significant areas (1.47 km<sup>2</sup>) are noticed as salinization. Spatial distribution of third layer resistivity values varies from 0.082 to 44.4  $\Omega$ m. In this layer, sea water is intruded in less significant areas of 1.92 km<sup>2</sup>. Thickness of the third layer ranges from 2.54m to 46.5m. The fourth layer resistivity inferred that majority of the area is safer for sea water intrusion.

**KEYWORDS:** Saltwater intrusion, aquifer, electrical resistivity, spatial distribution, Schlumberger configuration.

## **I. INTRODUCTION**

Worldwide, freshwater with acceptable quality is a problematic trends for human living. Due to the great demand of water for drinking and for industrial purposes, water resources are more affected by anthropogenic contaminants. Coastal aquifers are being deteriorated due to hydraulic contact with the sea which leads to marine intrusion [1]. Saltwater intrusion is defined as the replacement of fresh water in coastal aquifers by saltwater due to the motion of a saltwater body into the freshwater aquifer. Seawater intrusion is a natural process that occurs in all coastal aquifers and limited to coastal areas only. Due to natural process seawater displaces and mixes with the fresh groundwater in coastal aquifers due to the density difference existing between waters of different salinities. Geological formation determines the saline water intrusion and the degree of intrusion may vary from few meters to kilometres [2]. The hydraulic conductivity, aquifer type and thickness, climate condition and groundwater level with respect to mean sea elevation and distance from the coastline of pumping wells also determine the saline water intrusion [3]. The transition zone between salt and fresh water is the hydrodynamic dispersion of dissolved salt [4]. Many research works had been

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widely done to locate saltwater and its movement. The hydrological, geochemical and exploration geophysics studies have been done but geophysical methods have been found as a best tool to give best results in the study of saltwater intrusion [5], [6],[7], due to the influence of the pore water content over resistivity. The vertical electrical sounding technique is one of the most practical and easiest methods to acquire resistivity data in the field [8].

As the resistivity is decreased with saltwater, seawater intrusion can be delineated using electrical resistivity methods [9].The present study aims at using electrical resistivity sounding and geographical information system to study seawater intrusion and extent of pollution in the parts of Pondicherry area.

## II. STUDY AREA

The study area is located in the district of Pondicherry on the East coast of India (location map shown in fig. 1). It lies between  $79^{\circ} 45' 21'' - 79^{\circ} 52' 4''$  E longitudes and  $11^{\circ} 51' 38'' - 12^{\circ} 03' 26''$  N latitudes. It is limited on the east by the Bay of Bengal and on the other three sides by the Villupuram and Cuddalore districts of Tamil Nadu State. The area is subjected to a tropical and humid climate and the annual rainfall is around 1272.7 mm. The temperature ranges from a minimum of  $17^{\circ}\text{C}$  to a maximum of  $42^{\circ}\text{C}$ . Geologically, the study area has three types of formations namely Charnockite, Cuddalore sandstone and alluvium. The Study area is well connected by road transport network namely East Coast Road and Chennai – Vedaranyam National highways and by rail to Villupuram – Chennai.

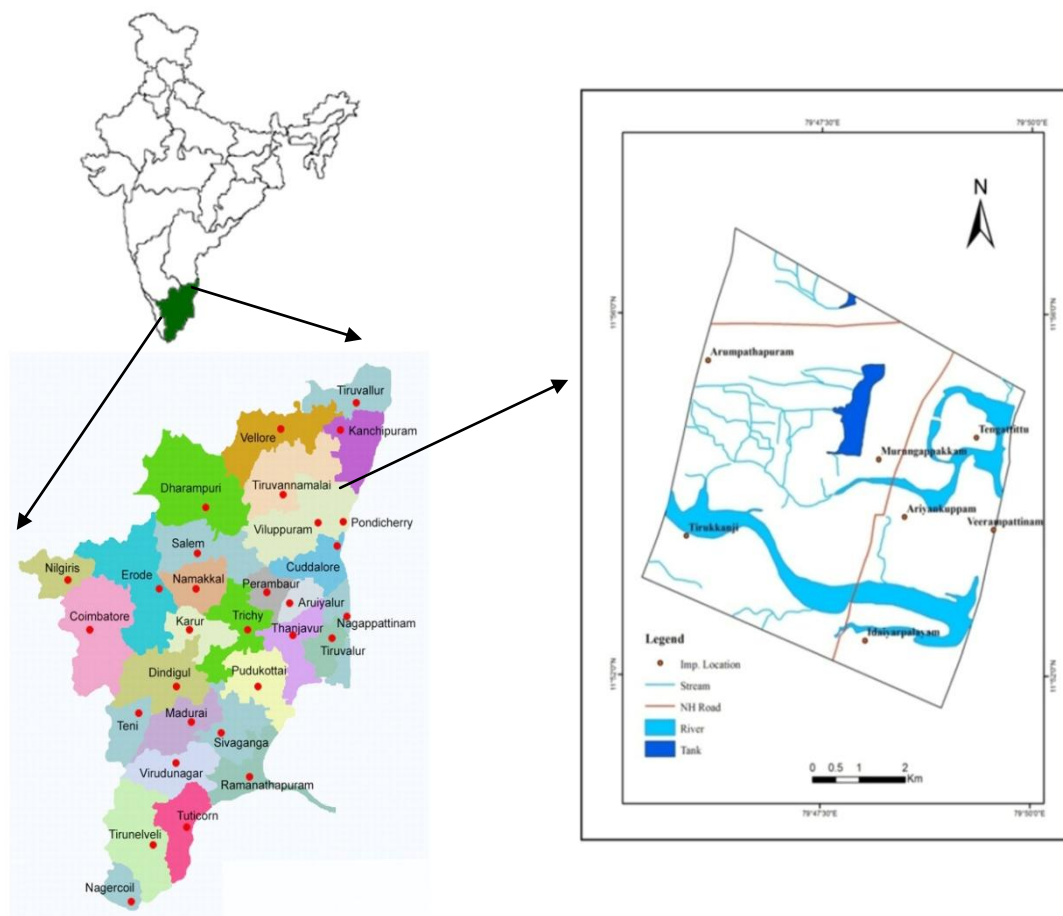


Fig. 1 Location Map of the Study Area

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## III. METHODOLOGY

In the present study, geoelectrical resistivity survey was carried out at 7 selected locations within the study area by adopting Schlumberger configuration with maximum electrode spacing of 100m of current electrode, (AB/2), with spread up to 100m was undertaken to signify complete lithology of the study area. The resistivity measurements were recorded using resistivity meter of SSR-MP-AT-ME model. This type electrical resistivity method has been successfully used for prospecting groundwater in different sedimentary and hard rock terrains. The curve matching technique has been used to interpret the results using IPI2win computer software to generate the curve. The GIS software has been also used to find out the extent of seawater intrusion.

## IV. RESULTS AND DISCUSSION

### VERTICAL ELECTRICAL SOUNDING CURVES

The measured field VES data were interpreted using the curve matching technique with the help of master curve types (A, Q, H, K) using IPI2Win (version 2.0) software. The analytical results revealed that different types of curves were identified on the basis of subsurface resistivity data. The nature of VES curve depends on the geological formation and hydrogeological conditions of the study area. The curve types H and Q followed by KH, HA, and QH type have been identified and they have been used for understanding the sub surface lithological variation, resistivity and thickness of aquifer and ground water quality.

Table 1: Resistivity and layer thickness of the study area

Sl. No.	VES Location	I <sup>st</sup> Layer		II <sup>nd</sup> Layer		III <sup>rd</sup> Layer		IV <sup>th</sup> Layer		Curve Type
		Resistivity (Ωm)	Thickness (m)	Resistivity (Ωm)	Thickness (m)	Resistivity (Ωm)	Thickness (m)	Resistivity (Ωm)	Thickness (m)	
1.	Idaiyarpalayam	1.86	1	18.1	0.671	1.22	3.94	2099	-	KH
2.	Murungapakkam	68.8	1	0.046	0.031	8.97	46.5	754	-	HA
3.	Arumparthapuram	112	1.2	8.75	1.33	29.8	8.72	8.6	39.6	H
4.	Manaveli	35.8	1	0.068	0.031	6.73	16.8	80.3	-	HA
5.	Veerampattinam	4.32	1	139	0.361	0.498	2.54	37.6	-	QH
6.	Sandikuppam	3.8	1	33.5	0.863	0.082	3.73	4.45	-	KH
7.	Natesan Nagar	226	1	148	2.92	44.4	16.4	4.93	-	Q

Sounding curves were interpreted quantitatively and qualitatively. The qualitative interpretation involved in evaluation of curves for estimation of volume of sand deposit in the studied area. The geophysical survey was conducted and the curves were checked with IPI2Win software and the average RMS error was 6.84%. The minimum and maximum RMS error was 2.54% and 10% respectively. The inverse slope, curve matching technology and the curve matching was found to give useful results in the estimation of weathered zone thickness and depth of bedrock [11]. Curve matching is adopted here with the objectives to delineate the thickness of the aquifer zones. The data analysed by curve matching techniques and IPI2Win for 7 locations have been compared. The layer parameters like apparent resistivity (pa) and thickness (h) of different layers were arrived. Minor deviations due to subsurface discrepancies and the error in the field data is corrected by smoothing the field curve to have easy interpretation. More importance was given for thickness and resistivities of various layers in hydrogeochemical studies. A maximum of 4 layers was identified in few regions, but major part of the study area is dominated mainly by 3 layers as shown in Table 1

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## GEO-ELECTRICAL SECTION

Understanding of resistivity sounding data is wholly a scientific application of approximating the subsurface by horizontal layers, and identifies the thickness and true resistivity. Interpretation of resistivity data is carried out as a two branched strategy; one is qualitative and the other quantitative. In qualitative interpretation, the nature and characteristics such as gradient, sharpness and width of each sounding curve are studied. In quantitative interpretation, the subsurface is approximated to a series of layers and the true parameters of resistivity and thickness are estimated by adopting various forms of optimization techniques.

The number of layers to be incorporated in modelling and inversion can be identified from the characteristics of the respective sounding curves. The effect of lateral in homogeneities is removed in each sounding curve [12] so as to attribute the observed signal entirely too vertical distribution of resistivity. Although, data interpretation by curve-matching [13], [14] is in unclear, computer algorithms based on optimization techniques, which has become much popular owing to their efficiency and speed in computation. The survey was conducted along the coast for delineating the regions contaminated by saline water as well as to demarcate areas affected by anthropogenic activities. The distance between the coast and the sounding locations varies from 0.023 km to 6.85km respectively. The sounding locations distance between the coasts is Idaiyarpalayam (2.186 km) Murungapakkam (2.83 km) Arumparthapuram (6.85 km) Manaveli (5.74 km) Veerampattinam (0.023 km) Sandikuppam (6.1 km) and Natesan Nagar (3.11 km).The maximum depth of investigation was up to 100 m BGL.

## SPATIAL DISTRIBUTION OF RESISTIVITY AND THICKNESS LAYERS

The Top layer resistivity and thickness spatial distribution maps (Fig.3 & 4) shows that the area is categorized into four classes namely, <20, 20 - 60, 60 - 100 and >100  $\Omega m$  respectively. The resistivity value of <20  $\Omega m$  indicates the area is under salinization or sea water intrusion in east, west and southern part of the study area. The locations are Idaiyarpalayam, Sandikuppam and Veerampattinam and their areal extent is 3.26  $km^2$ . The resistivity of 20 - 60  $\Omega m$  and 60 - 100  $\Omega m$  indicates the area is medium contaminated water/sea water intrusion and spatially covered 14.29 and 13.81 square kilometre respectively. The less sea water intrusion resistivities are noticed in the northern part of the study area and their areal extent is 17.69 $km^2$ . The first layer thickness of the top layer is less than 2m in the entire study area.

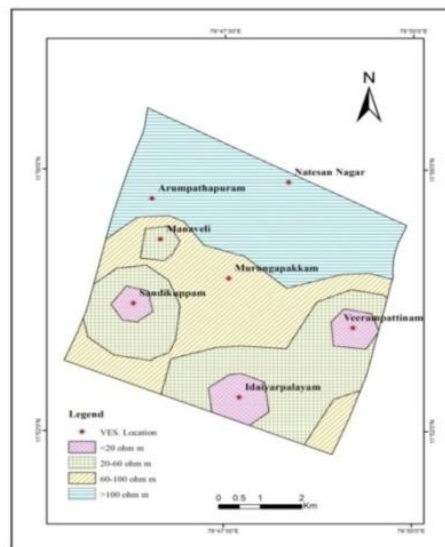


Fig. 3 First layer resistivity spatial distribution

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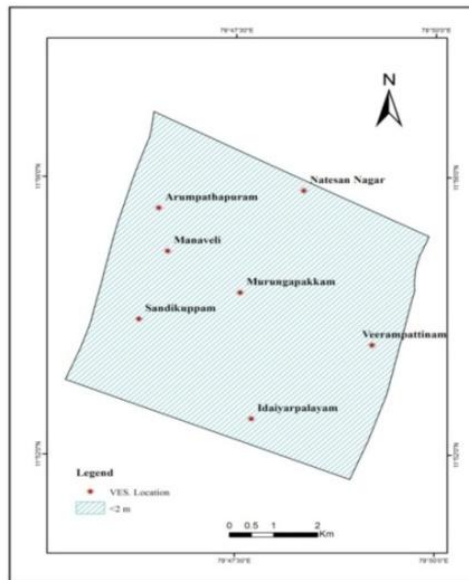


Fig. 4 First layer thickness spatial distribution

The second layer resistivity indicates (Fig.5) less than 20  $\Omega\text{m}$  covered the west and southern part of the study area and their areal coverage is 1.47  $\text{km}^2$  and indicates the area is under sea water intrusion. The majority of the area is covered under  $>100 \Omega\text{m}$  and it indicates that this area is no such sea water intrusion activities are occurred. The second layer thickness (Fig.6) is classified as  $<4$ , 4 - 8 and 8 - 16m. Majority of the second layer is covered less than 4m thickness and their areal extent is 46.09  $\text{km}^2$ . The 4 - 8 m and 8 - 16m thickness is covered less than 3 square kilometres and occupied in the northern part of the study area.

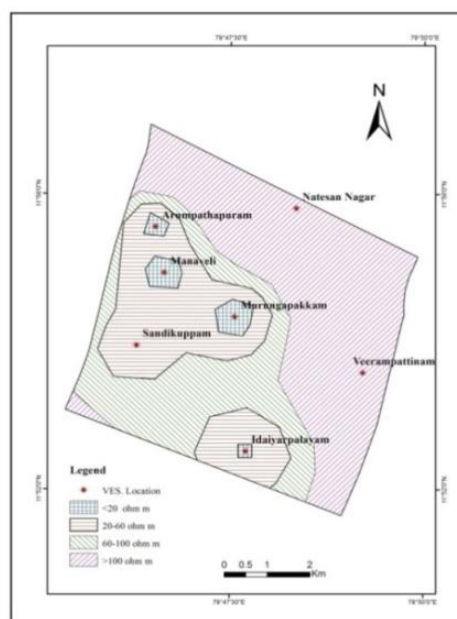


Fig.5 Second layer resistivity spatial distribution

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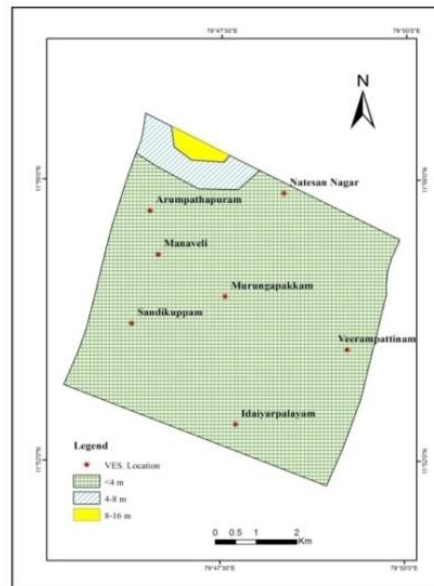


Fig. 6 Second layer thickness spatial distribution

The third layer resistivity and thickness spatial distribution map (Fig.7 & 8) shows that the majority of the area is not under sea water intrusion or salinization. The resistivity value is more than  $100\ \Omega\text{m}$  and their areal extent is  $30.83\ \text{km}^2$  and covers throughout the study area except the selected parcel of the area. In this layer, sea water intrusion is noticed in smaller area of  $1.92\ \text{km}^2$  and their resistivity value is less than  $20\ \Omega\text{m}$ . In the third layer, less than 4m thickness is noticed in the eastern side as a small patch. Majority of the study area is having 60 - 100m and  $>100\text{m}$  thickness and their areal extent is 26.40 and 13.65 square kilometres respectively.

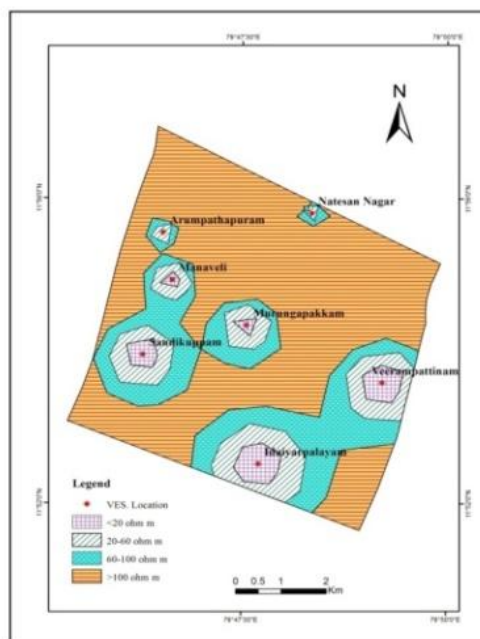


Fig. 7 Third layer resistivity spatial distribution

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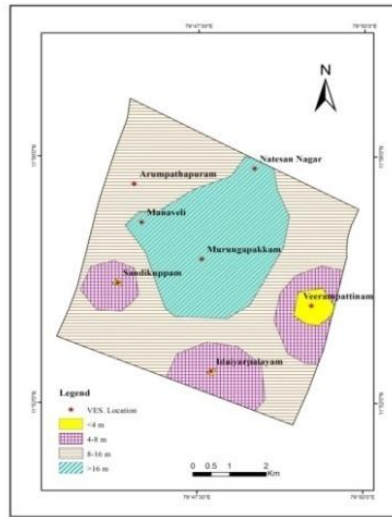


Fig. 8 Third layer thickness spatial distribution

The fourth layer resistivity indicates (Fig.9) that less than  $20\ \Omega\text{m}$  covered the west and northern part of the study area and their areal coverage is  $0.57\ \text{km}^2$  and indicates the area is under sea water intrusion. The majority of the area is covered under  $>100\ \Omega\text{m}$  and it indicates that this area is no such sea water intrusion activities are occurred and their areal extent is  $42.57\ \text{km}^2$ .

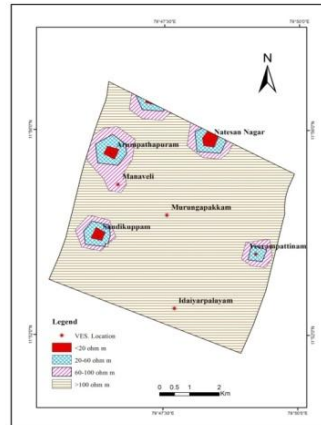


Fig. 9 Fourth layer resistivity spatial distribution

## V. CONCLUSION

The electrical resistivity studies indicate that three major zones were delineated as weathered, fractured, top soil, sandy layer and clayey layer in coastal sediment region. The survey was conducted along the coast for delineating the regions contaminated by saline water as well as to demarcate areas affected by anthropogenic activities. The distance between the coast and the sounding locations varies from 0.023 km to 6.85km respectively. The Spatial distribution maps of first layer resistivity shows that  $3.26\ \text{km}^2$  areas having noticed as intruded the sea water. Thickness spatial distribution map show that the entire area having the less than 2m thickness. It is also inferred that the contaminated water found at the shallow level is not able to percolate below due to the presence of intervening clay formation. The second layer resistivity ranges from 0.046 to  $148\ \Omega\text{m}$  and spatial distribution map shows that majority of the area is safer for sea

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water intrusion and their areal extent is 35.59 km<sup>2</sup>. Less significant areas (1.47 km<sup>2</sup>) are noticed as salinization. Thickness map indicates that 46.09 km<sup>2</sup> areas are having 8 - 16m thickness and less than 4m is covered tiny areas. Spatial distribution of third layer resistivity values varies from 0.082 to 44.4  $\Omega$ m in the study area. In this layer, sea water is intruded in less significant areas of 1.92 km<sup>2</sup>. Thickness of the third layer ranges from 2.54m to 46.5m and 60-100m thickness is predominantly occupied in the study area. The fourth layer resistivity inferred that majority of the area is safer for sea water intrusion.

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