Geophysical Techniques to Delineate Saline and Fresh water aquifers in the Coastal stretch of Kanyakumari, Tamil Nadu, India

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Abstract: The geophysical survey was carried out on the west coast of Kanyakumari district to identify probable aquifer zones with the help of Schlumberger electrical sounding and Dar Zarrouk parameters. Vertical Electrical Sounding (VES) was carried out in 9 locations in the study area. Resistivity meter model SSR-MP-ATS was used for the survey and interpretations were made using IPI2WIN software. Spatial maps for resistivity and thickness at various depths were created. The VES locations are dominated by curve types QHA, HKA, KHA, H, KH, HAK, and QH. The spatial behavior of the D–Z parameters confirmed the presence of salty and freshwater aquifer structures in coastal aquifers. The Longitudinal unit conductance (S) values ranged between 0.5 and 10.7. The transverse unit resistance (T) of the study area varied from 131.7 to 18216 Ωm^2. The anisotropy (λ) values ranged from 1.4 to 2.5. High longitudinal conductance is an indication of saline water intrusion. From the spatial map, it is observed that high S values are towards the northern portion of the study area, which indicates saltwater aquifers. Similarly, aquifer anisotropy, <1.45 λ indicates freshwater aquifer, 1.45-2.5 λ indicates moderately freshwater aquifer, and >2.5 λ indicates saline water aquifer. Hence, this study of electrical resistivity using Dar Zarrouk parameters, proved to be an effective method for identifying and differentiating the fresh groundwater from salt water of the study area.
Keywords: Aquifer, Vertical Electrical Sounding, Dar Zarrouk parameters, Kanyakumari.

Introduction

The majority of the world's population resides in the coastal zones. Because of the continuous interaction between the oceans and the land, coastal zones are always changing. Aquifers along the coast are under stress due to the large population and the increased water needs of contemporary living (Dhiman and Thambi, 2009). Groundwater, the primary source of freshwater in coastal areas, is used indiscriminately to meet the growing demands for water for domestic, agricultural, and industrial uses (Hamed et al., 2018; Behera et al., 2019; Prusty and Farooq, 2020). Excessive withdrawal of groundwater causes seawater intrusion which is a major problem faced by the coastal community. Seawater intrusion is caused by geogenic or anthropogenic such as aquifer overexploitation due to over-pumping, coastal tides, aquaculture practices, low groundwater levels, or the high seawater level, and the reverse phenomenon gives rise to submarine groundwater discharge (George et al., 2023). All aquifers that come in contact with the sea have a dynamic freshwater-seawater interface. Understanding the spatial and temporal variation of this interface is important for groundwater development and the prevention of seawater intrusion (Zhou, 2011).

There are several techniques used in identifying the subsurface geological layers and the underlying aquifers. Among several methods or techniques, near-surface geophysical methods are irreplaceable tools to explore the subsurface at the economical expense of energy, money, and manpower. Through geophysical surveys, it is possible to detect differences in physical properties within the Earth's crust. Among all the geophysical methods, the electrical resistivity method is widely used for groundwater exploration studies (Pradhan et al., 2022). It helps to identify seawater intrusion based on resistivity values (Vengadesan and Lakshmanan, 2019). The resistivity measured in the ground is predominantly controlled by the amount of moisture and water within the soil and rock (a function of the porosity and permeability), and the concentration of dissolved solids (salts) in that water (Meindinyo et al., 2017). VES is an electrical resistivity method that involves the rapid measurement of variations of the ground resistance with unit depth. VES is done for 1-d information of depth-wise resistivity variation (Sundararajan et al., 2012). In this method, an artificially generated current is injected into the ground as a result of which the current distributes itself depending upon the conductivity of the subsurface. As the earth is not homogeneous so there will be a difference in conductivities at different parts. When the current comes in touch with a conductive body, then it easily passes through it showing low resistivity. But rocks also conduct electricity due to the fluid or water (electrolyte) content in the pores or voids within them. Thus, if the porosity is high, then the resistivity will be low.

The electrical resistivity method has gained considerable importance in the field of groundwater exploration because of its low cost, easy operation, and efficiency to detect water-bearing formations (Karthik et al., 2022). The methods of the geo-electrical survey are helpful for understanding the variations in litho-units and are important to determine the occurrences of groundwater (Pradhan et al., 2019; Sekar et al., 2021; Pradhan et al., 2022). In the Kanyakumari district, the availability of groundwater is gradually decreasing as a result of excessive groundwater extraction, surface water irrigation, mining, expanding urban complexes, and industrial facilities. The objective of this study is to use geophysical techniques for delineating the saline and freshwater aquifers in the coastal stretch of Kanyakumari. Delineation of the saline and freshwater aquifers can resolve groundwater scarcity and saline water intrusion problems in the district.

Study area

Kanyakumari is the southernmost district of Tamil Nadu. The coastal zone extends between latitude N 08° 02' and 08° 22' and longitude E 77° 04' and 77° 35'. The study area is bounded by the Gulf of Manner in the East, Kerala in the West and North West, the Indian Ocean, and the Arabian Sea in the South and South West directions (Fig. 1). The coastal region is a narrow strip of plain region along the coast with a width of 1 to 2.5 km (Thamarai, 2008). The geomorphic characteristics present in the district include beach terraces, low cliffs, sandy beaches, dunes, rocky coasts, estuaries, and wetlands. The main deposits in the area are gypsum, ilmenite, garnet, and monazite. The district is drained by two principal rivers, Kodayar and Paralayar, and their tributaries (Balachandran, 2008). The area receives rainfall during both the southwest and northeast monsoon seasons. The study area passes through different coastal blocks of the district, Agastheeswaram, Rajakkamangalam, Kuruthencode, Killiyoor, and Munchirai. A five km buffer zone is created around the western coastline for the detailed investigation of fresh and saline aquifers of the study area.

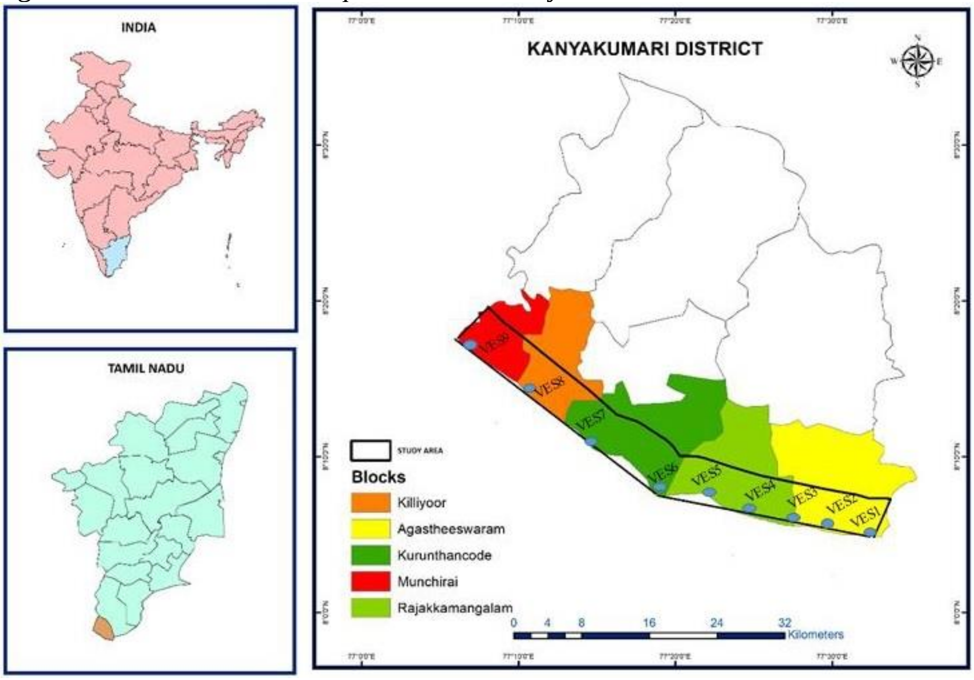


Fig. 1. Location map of the study area.

Geology and Hydrogeology

The coastal zone of the Kanyakumari district comprises unconsolidated sandy formations of different deposition environments belonging to quaternary age (Perumal et al., 2010). Charnockite, granite gneiss, leptinite, leptinite gneiss, peninsular gneiss, laterite, Warkalai sandstone, variegated clay, and river alluvium contribute towards the basement of the study area (Thamarai, 2008). The basement rocks are overlain by red soil, lateritic soil, clayey soil, river alluvium and coastal alluvium, black, red, and red sandy soils of thickness ranging from 1 m to 1.5 m in most places. In certain regions, laterite capping may be seen next to the coast (Fig. 2). In the study area the groundwater is stored in both porous and fissured formations. The major aquifer formations include unconsolidated and semi-consolidated formations and (ii) weathered, fissured, and fractured crystalline rocks (Balachandran, 2008). Groundwater occurs under phreatic conditions in the weathered mantle and semi-confined to confined conditions in the fracture and fissured zones of these rocks. In alluvial formation, the groundwater occurs under water table conditions (Srinivas et al., 2014).

Materials and methods

In the present study, nine (09) VES surveys using Schlumberger configuration were carried out at different locations of the study area. Resistivity meter SSR-MP-ATS was used for the survey (Fig. 3). Four electrodes are arranged in a line around a common midpoint in the Schlumberger array. The two outer electrodes, A and

B, are current electrodes, and the two inner electrodes, M and N, are potential electrodes placed close together. The AB/2 separations have been up to 200 m. The electric current of known intensity is inserted into the surface using electrode AB and the associated potential difference is measured using electrode MN. Changing the position of the electrodes will help to demarcate several subsurface layers. The obtained apparent resistivity signal values have been interpreted through the curve-matching technique using IPI2WIN software (Table 1). These values are then used to create a pseudo section of the study area. The resistivities of the rock types at different depth levels are used to determine the depth, thickness, and boundary of an aquifer, the interface of saline water and freshwater zone, the porosity and water content in the aquifer, hydraulic conductivity of aquifer and transmissivity of the aquifer (Karthik et al., 2020; Pradhan et al., 2022).

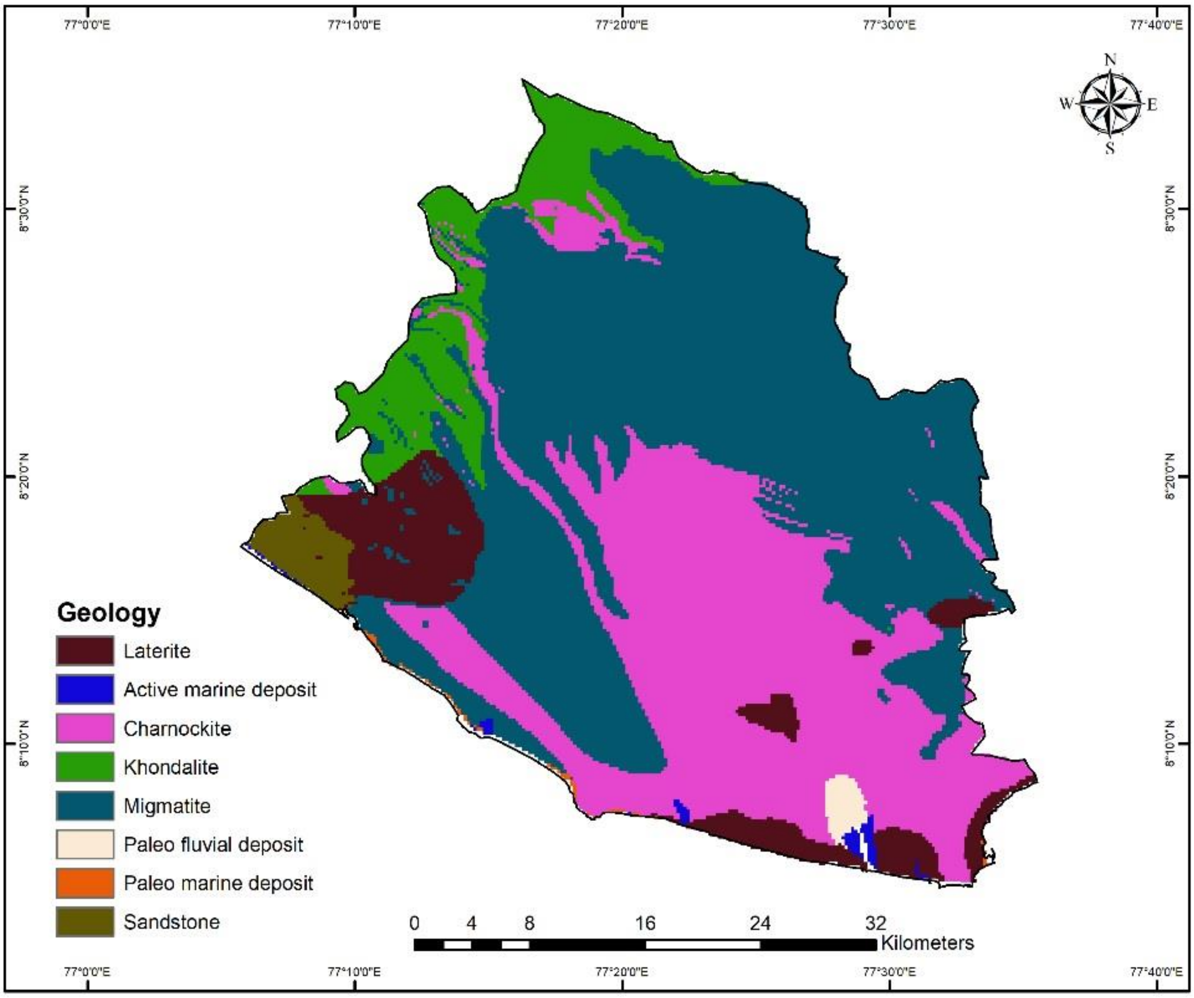


Fig. 2. Geology map of Kanyakumari district.

Fig. 3. Photograph shows VES Survey using SSR MP ATS Resistivity meter.

Dar-Zarrouk Parameters

The Dar-Zarrouk parameters were computed to generate the spatial variation maps of transverse resistance (T), longitudinal conductance (S), transverse resistivity (ρt), and longitudinal resistivity (ρL), to decipher the resistivity contrast of fresh water and saltwater-bearing formations (Naidu et al., 2021). The geoelectric parameters such as aquifer resistivity "ρ" and aquifer thickness "h" are used to determine the Dar-Zarrouk parameters namely Transverse resistance (T), Longitudinal conductance (S), and Aquifer anisotropy (λ).

If there are n geoelectric layers of thickness $h1, h2, \ldots$, hn and resistivity $\rho 1, \rho 2, \rho 3, \ldots, \rho n$ for a unit block of H $= \sum_{i=1}^{n} hi$ square area and thickness (Patil et al., 2018; Vijayaprabhu et al., 2022). The *S* and *T* are equivalent to an anisotropic block with a square unit such that the unit resistance.

Transverse resistance (T) is,

$$T = h1\,\rho 1 + h2\,\rho 2 \ldots\ldots\ldots hn\,\rho n = \sum_{i=1}^{n} hi\,\rho i$$

Longitudinal conductance (S) is,

$$S = h1/\rho 1 + h2/\rho 2 \ldots\ldots\ldots hn/\rho n = \sum_{i=1}^{n} hi/\rho i$$

Aquifer anisotropy (λ)

This equation describes the layers' transverse resistivity (ρt) when a current flow through them at right angles to the layers.

$\rho t = (T/H)$

The longitudinal resistivity Rho L (ρl) to the current flowing parallel to the layers is defined as,

$\rho l = (H/S)$

Electrical anisotropy (λ) is given by

$\lambda = \sqrt{\rho t/\rho l}$

Table 1. VES data of the study area.

VES no	Location	ρ1	ρ2	ρ3	ρ4	ρ5	ρ6	H1	H2	H3	H4	H5	Tr	S	λ	Curve Type
		Resistivity (ohm-m)						Thickness (m)					DZ parameters			
1	Kanyakumari beach	1654	434	69.5	473	30.7	19742	0.663	2.71	4.08	9.93	20.8	7891.752	0.763868	2.033414	QHQ
2	Dharakapathi Beach	1658	20.2	177	17.5	453		1.62	3.02	3.88	120		5533.724	7.029546	1.534623	HKA
3	Manakudy Beach	102	362	16.7	3.4	14.7		1.3	1.19	22.8			944.14	1.381302	1.427952	KHA
4	Anna Nagar Beach	584	14.7	1755				3.36	94.1				3345.51	6.407114	1.502228	H
5	Blue Beach	176	621	23.4	59867			2.99	2.67	11.4			2451.07	0.508468	2.069334	KH
6	Muttam Beach	41.5	18.5	62.3	1010	83	28637	1.44	1.1	7.94	13.5	48.3	18218.67	0.8169	1.687814	HAK
7	Colachel Beach	214	10.9	92.4	4.88	4804		2.62	2.74	5.95	19.2		1234.022	4.262439	2.377105	HKA
8	Thengapattanam Beach	160	34.9	1.95	2367			1.36	7.41	20.5			516.184	10.73364	2.543039	QH
9	Neerody Beach	24.1	12.3	1.87	25.4			1.97	5.19	10.9			131.697	6.332571	1.599043	QH

Results and Discussions

The VES data has been analyzed using the curve-matching method used in the IPI2Win software. The analyses of sounding curves obtained from geophysical survey data over the areas have brought out five to six subsurface geo-electric patterns. VES locations dominated by curve types QHA (ρ1>ρ2 >ρ3<ρ4>ρ5), HKA (ρ >ρ2 <ρ3>ρ4>ρ5), KHA (ρ1<ρ2 >ρ3>ρ4<ρ5), H (ρ1 >ρ2<ρ3), KH (ρ1 <ρ2>ρ3<ρ4), HAK (ρ1>ρ2<ρ3<ρ4>ρ5) and QH (ρ1>ρ2>ρ3<ρ4) (Fig. 4). VES data of the study area is shown in Table 1. The H and KH type curves (VES 4 and 5) reflect the unconfined weathered, confined weathered, and fractured aquifers, respectively, in a given region (Omosuyi et al., 2021; Vijayaprabhu et al., 2022). As a result, all curve types include H or K types, suggesting that groundwater accumulation and storage are adequate. VES 8 and 9 show QH-type of curves, indicating complex lithology overlain by softer strata, which can be an excellent local for the groundwater potential zones. An attempt was also made to prepare a vertical pseudo section of resistivity and generate possible resistivity models of the study area. The pseudo-sections will facilitate an understanding of the variations of subsurface lithology and be helpful to delineate potential freshwater aquifer zones (Fig. 5) (Table 2). Profile “a” shows pseudo-section for VES locations 1-6 and Profile “b” shows VES locations 6-9.

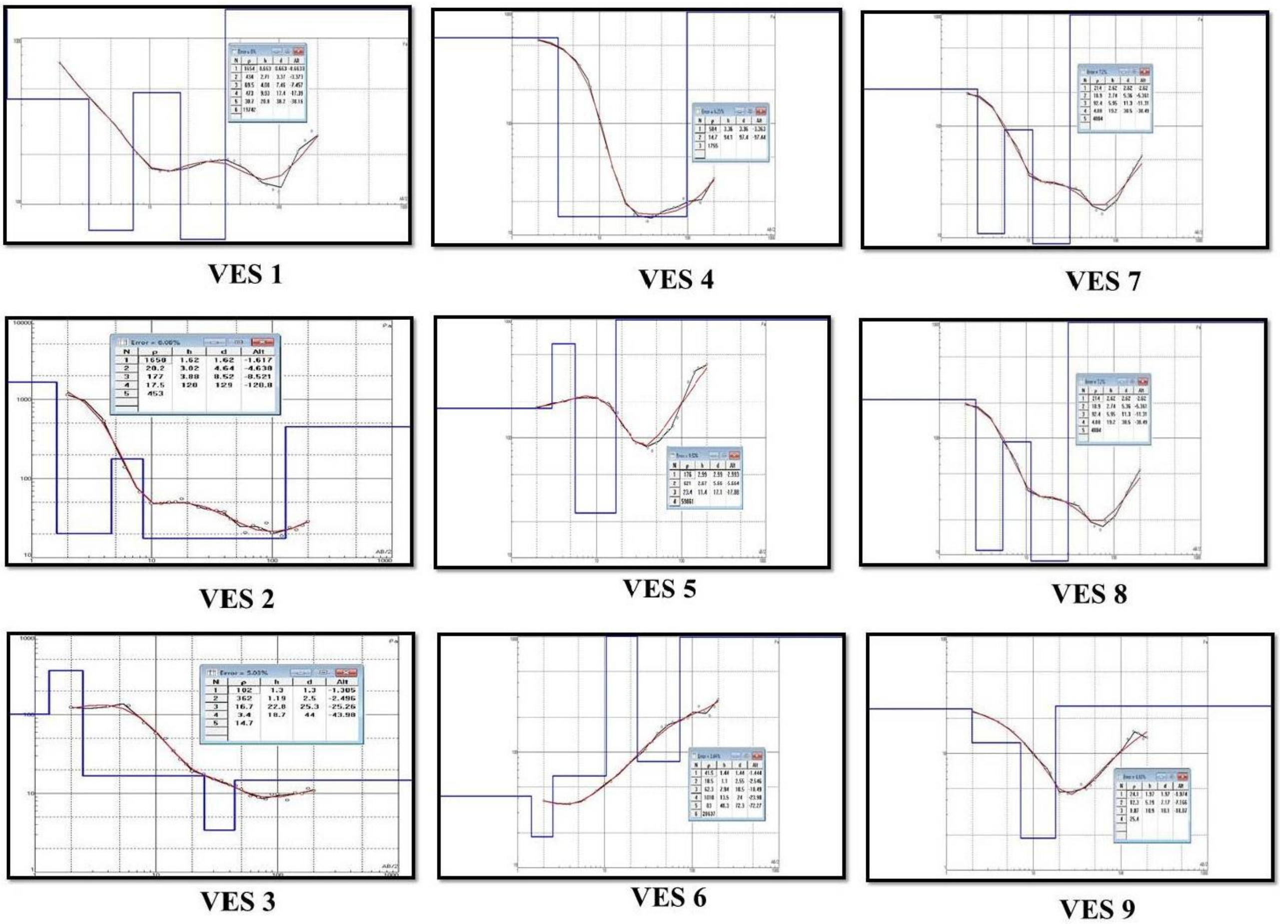
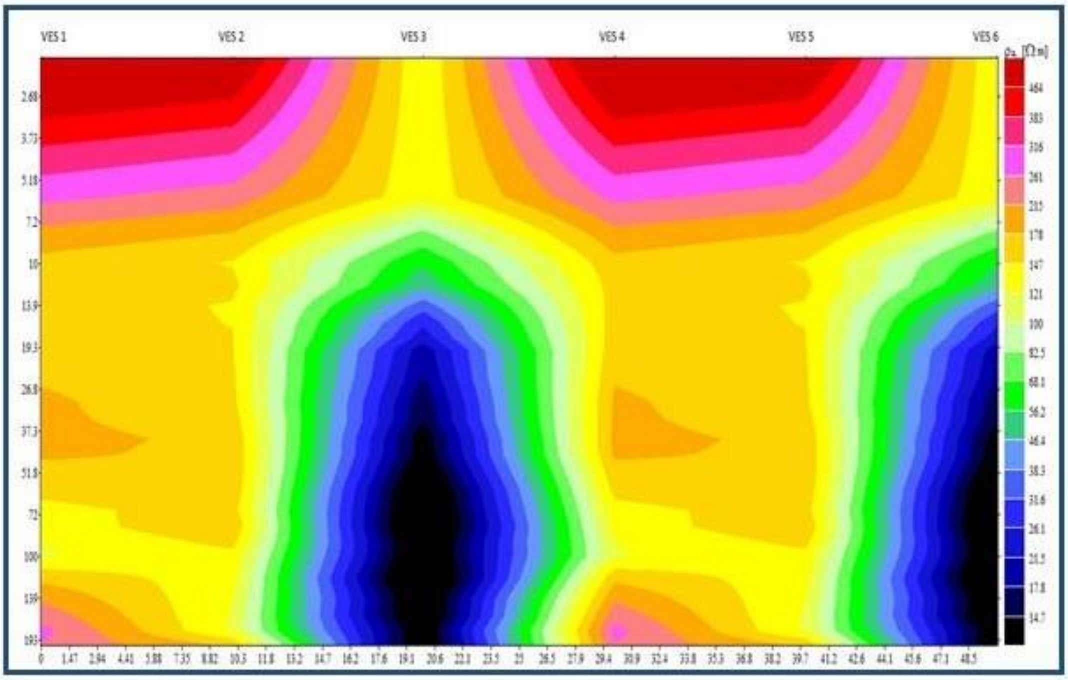


Fig. 4. VES curves of the study area.

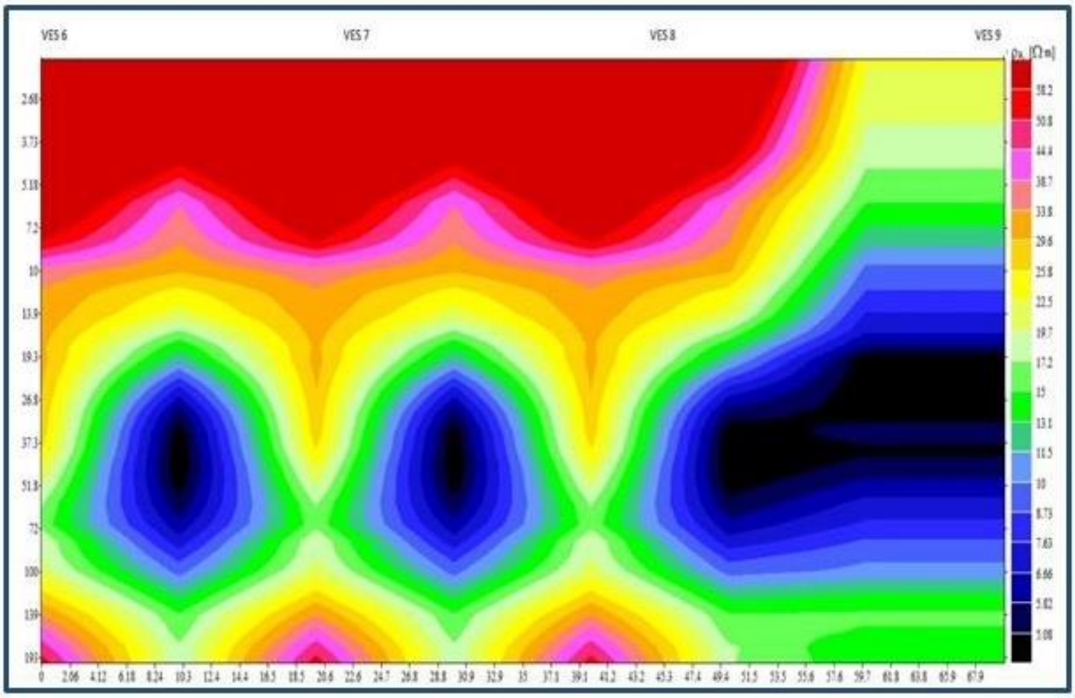
The first layer resistivity (ρ1) varied from 24.1 to 1658 Ωm where low resistivity was found in VES location 9 and high resistivity in VES location 2. The layer thickness of the first layer found in 0.663 to 3.36. A low thickness value was found in VES 1 and a high thickness was noticed in VES 4. The second layer resistivity (ρ2) varied from 10.9 to 621 Ωm where low resistivity was found in VES 7 and high resistivity in VES 5. The layer thickness of the first layer was found at 1.1m to 94.1m, a low thickness value was found in VES 6, and a high thickness was noticed in VES 4. A very low resistivity value of less than 1.87 Ωm of the third layer (ρ3) was observed in VES 9 and high resistivity value of 1755 Ωm was noted in VES 4. In the third layer, a low thickness 3.88m is noticed in the central part and the thickness increases to 5m on either side. The high layer thickness of 22.8m is observed in VES 3. The fourth layer resistivity (ρ4) varied from 3.4 to 59867 Ωm where low resistivity was found in VES location 3 and high resistivity in VES location 5. The layer thickness of the first layer was found lower thickness 9.93 m in VES 1 and a high thickness of 120 m was noticed in VES 2. The fifth layer resistivity (ρ5) varied from 14.7 to 4804 Ωm where low resistivity was found in VES 3 and high resistivity in VES 7. The layer thickness of the fifth layer found low thickness 20.8 is noticed in VES 1 and a high thickness of 48.3 m was noticed in VES 6 (Fig. 6).

The Longitudinal unit conductance (S) values ranged between 0.5 and 10.7. The transverse unit resistance (T) of the study area varied from 131.7 to 18216 Ωm^2. The anisotropy (λ) values ranged from 1.4 to 2.5 (Fig. 7). The spatial behavior of the D–Z parameters confirmed the presence of salty and freshwater aquifer structures in coastal aquifers. High longitudinal conductance is an indication of saline water intrusion.

Transverse resistance values are often connected with zones of high transmissivity and, consequently, highly permeable zones to fluid flow. Transverse resistance <100 Ωm^2 indicates fresh aquifers, 100-500 Ωm^2 indicates moderate fresh aquifers and >500 Ωm^2 indicates saline water aquifers. Lower Aquifer anisotropy λ values link to high aquifer potential areas (Singh and Singh, 2003). The southern portion (Dhwarakapathi, Manakudy and Anna Nagar beach) is predominantly with low λ values, hence they are very good groundwater potential areas.



a) Pseudo section for VES 1-6



b) Pseudo section for VES 6-9

Fig. 5. Pseudo section for Kanyakumari coastal zone based on VES locations.

Table 2. Resistivity range of subsurface layers (Venkateswara et al., 2019).

Sl. No	Resistivity in Ωm	Formation
1	< 10	Clayey sands/Highly weathered formation
2	10 – 60	Weathered formations
3	61 – 150	Lateritic gravel/Semi weathered/Fractured formation
4	>150	Hard rock

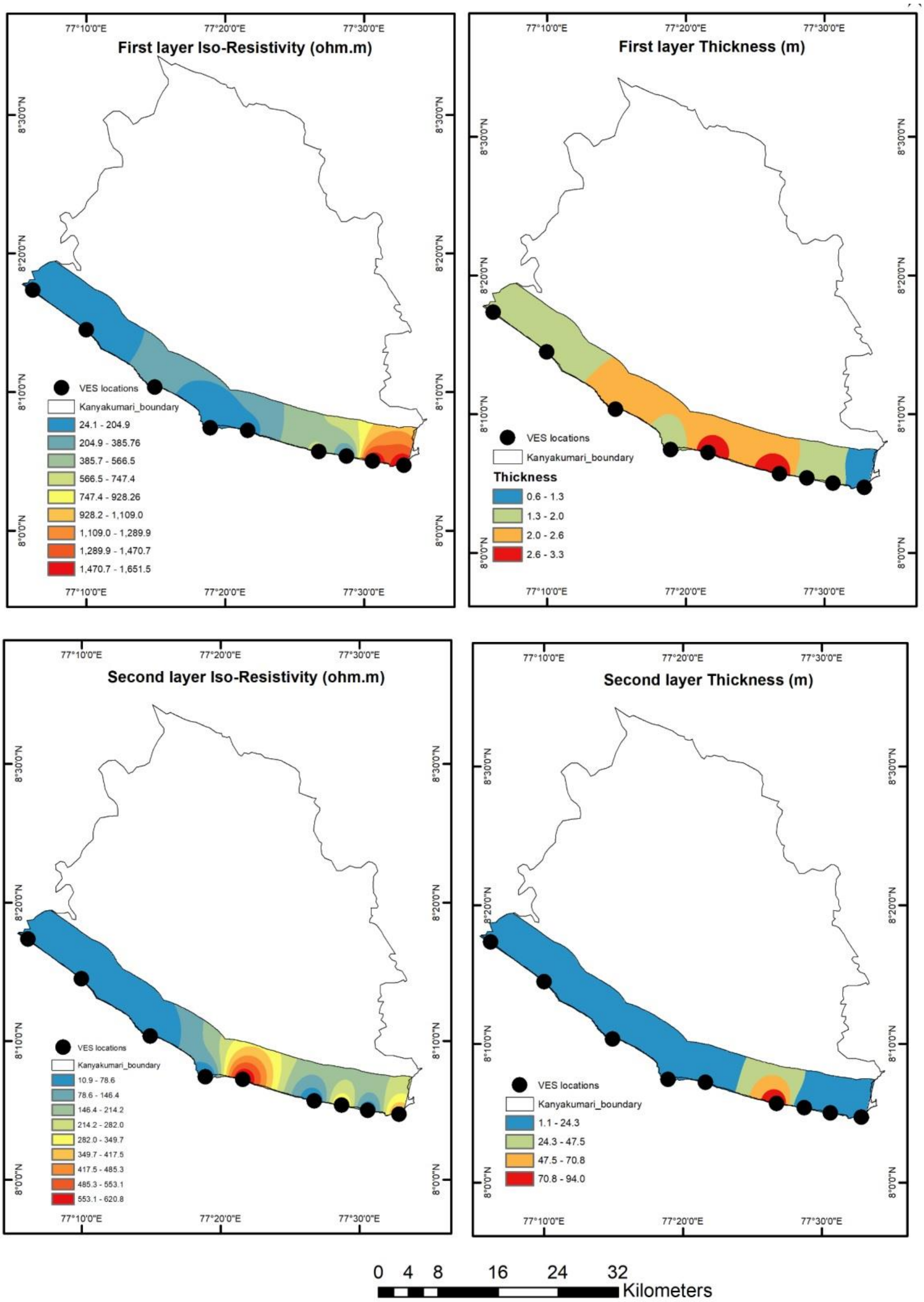


Fig. 6. Spatial distribution map for iso-resistivity and thickness of various geoelectric layers.

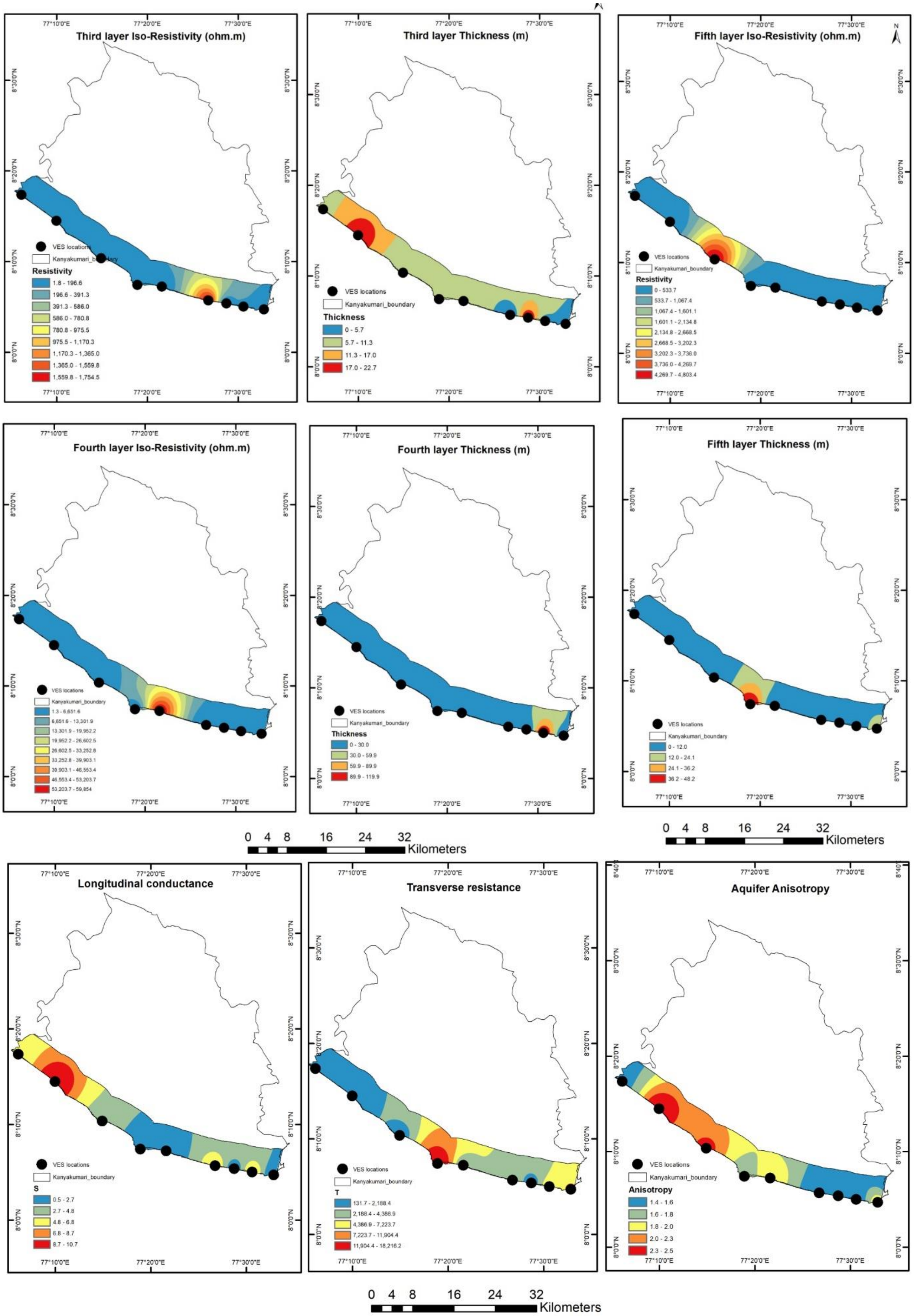


Fig. 7. Spatial distribution map of Longitudinal conductance, Transverse resistance, and Aquifer anisotropy.

Conclusion

In the present study, Vertical Electrical Sounding (VES) was used to delineate the subsurface resistivity as well as the thickness and depth of the Kanyakumari coastal zone. The VES locations are dominated by curve types QHA, HKA, KHA, H, KH, HAK, and QH. All curve types include H or K types, suggesting that groundwater accumulation and storage are adequate. The pseudo section prepared helps to locate the aquifer zones. The spatial behavior of the Dar Zarrouk parameters confirmed the presence of salty and freshwater aquifer structures in coastal aquifers. From the longitudinal conductance values the saltwater aquifers could be identified and is towards the northern portion of the study area. The southern portion is predominantly with low λ values; hence they are very good groundwater potential areas. Hence, this study of electrical resistivity using Dar Zarrouk parameters, proved to be an effective method for identifying and differentiating the fresh groundwater from salt water of the study area.

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Conflict of Interest

The authors have no conflict of interest regarding this work.

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