Computation of aquifer parameters using geo-electrical techniques for the North Chennai coastal aquifer

T. Siva Subramanian & Marykutty Abraham*
Centre for Remote Sensing and Geo informatics, Sathyabama Institute of Science and Technology, Chennai, Tamil Nadu, India
*[E-mail: marykuttyabraham06@gmail.com]

Computation of aquifer characteristics, such as hydraulic conductivity, transmissivity, formation factor, and porosity utilizing the geophysical method is less complex compared to that using arduous pumping test. Vertical electrical soundings directed in 33 areas in the north Chennai coastal aquifer in the Araniyar–Kosasthalaiyar basin demonstrates that the geo-electrical technique is a valuable tool to assess subsurface development and aquifer parameters. High values of hydraulic conductivity and transmissivity were recorded in the western part of the investigated region. Spatial conveyance of Dar Zarrouk parameters and aquifer parameters are helpful in evaluating the examined territory and for finding the favorable area for extraction. This study demonstrates that aquifer properties of coastal area are found to improve while moving away from the drift. Aquifer parameters were calculated using a pumping test and a geophysical technique in the examined zone and they were found to match. The investigation demonstrates that the geo-electrical study is a good alternative for the estimation of aquifer parameters instead of the laborious pumping tests.

[Keywords: Aquifer parameters; Coastal aquifer; Geophysical technique; Vertical electrical soundings; Pumping test]

Introduction
Coastal aquifers are commonly affected by saltwater intrusion due to over-extraction of groundwater. Aquifer parameters have an important role to play in better groundwater management and this study focused on their determination in the area of investigation. A geophysical survey was used for aquifer characterization and saltwater intrusion study during the last four decades. Although the usual methods for aquifer characterization are the pumping test, slug test, geophysical well logging and laboratory analysis of core samples, and vertical electrical soundings (VES), the VES method was the preferred option because of its control over the depth of investigation, simple and elegant interpretation techniques, and invasive nature. Aquifer characteristics such as hydraulic conductivity \((k)\) and transmissivity \((T)\) were usually found by \textit{in situ} pumping test. A geophysical electrical survey provided useful information on aquifer parameters such as hydraulic conductivity and transmissivity in situations where pumping test data were not available\(^1\). Estimation of aquifer parameters by geophysical survey has been discussed by many researchers\(^2,9\). In several studies, aquifer transmissivity for porous media was estimated from transverse resistance and longitudinal conductance\(^10,11\). The most important hydraulic parameters for groundwater flow modeling are hydraulic conductivity and transmissivity\(^12,13\). Relationships between hydraulic conductivity and formation factor; hydraulic conductivity and aquifer resistivity; and transmissivity and transverse resistance were established\(^14\). The Dar Zarrouk parameters (transverse resistance and longitudinal conductance) were calculated to determine the aquifer parameters\(^15,18\). Porosity was computed from formation factor for consolidated clay, sand, and gravel formations\(^19\). High clay content reduces resistivity and hydraulic conductivity\(^15\). The investigation gauged hydraulic conductivity and transmissivity from resistivity and layer thickness, utilizing a geophysical method and compared it with the pumping test results. The investigation was carried out in the coastal aquifer in the vicinity of the Araniyar-Kosasthalaiyar river basin and the purpose of the geophysical method was to reduce use of time-consuming pump tests for estimation of aquifer parameters.

Study area
The study area lies between 79°55' and 80°25'E longitudes and 13°00' and 13°35'N latitudes and it comes under the Survey of India topographical maps 57C6, 57C7, 57C8, 57C4, and 57C3. The study area
belongs to coastal aquifer of north-east Chennai bound by the Bay of Bengal in the east, Araniyar river in the north, and Kosasthalaiyar river in the south; and the western boundary is taken as 20 km from the Bay of Bengal (Fig. 1). This coastal aquifer is well known for its arenaceous formation called the Coromandel formation belonging to the Holocene age. The study area has elevations varying from 1 to 20 m above mean sea level. The area, composed of formations of quaternary, tertiary, and Upper Gondwana, is underlain by crystalline rocks. The geological formation of the Upper Gondwana consists of gravel, fine-to-coarse sand, clayey silt, and clayey sand. The eastern part is covered with coastal alluvium. The western side is covered with sand, silt, and alluvium soil deposits underlain by a fissured formation. The average annual rainfall of the region is 1150 mm from both the south-west north-east monsoons.

**Materials and Methods**

*Pumping test*

A pump test was conducted to evaluate the performance of the wells and the aquifer characteristics of the study area. The data from the test were analyzed using the Ramsahoye–Lang method\(^{20}\). Transmissivity of an aquifer is computed using the *in situ* pumping test on an exploratory well in the area\(^{21}\).

\[
T = \frac{2.3Q}{4\pi\Delta S}
\]

where \(Q\) = Discharge in \(m^3/\text{day}\) and \(\Delta S\) = Drawdown in m

*Geo-electrical method*

VES were used to determine the aquifer parameters of the formation and the resistivity meter DDR 3 was used for the field work. Thirty-three soundings were carried out at various locations within the study area in the Araniyar–Kosasthalaiyar river basin in the North Chennai coastal aquifer. The Schlumberger configuration, one of the geophysical methods, was applied in the field. The method is easier and faster compared to other geophysical methods and the results were interpreted using RES2DINV software\(^{22}\).

The flow of current, or resistivity, differs for various strata depending on the geological formation, chemical composition, density, porosity, and the

![Fig. 1 — Study area map showing the locations of Vertical Electrical Soundings](image-url)
extent of saline water intrusion. On the basis of the resistivity of the subsurface strata, the depth at which groundwater is available as well as aquifer characteristics could be determined. Application of current into the ground through two current electrodes and the measurement of resultant potential difference between two potential electrodes carried out are shown in Figure 2.

where
I: current unit;
V: potential unit;
O: VES measuring point;
AB: distance between current electrodes;
MN: distance between potential electrodes.

The apparent resistivity for this configuration was calculated using the formula:

\[
(p_a) = \frac{\pi \times (AB / 2)^2 - (MN / 2)^2 \times R}{MN}
\]

where \(\pi\) is 22/7 and \(R\) is the resistance.

Dar Zarrouk parameters

Longitudinal conductance (SL): In longitudinal conductance, the current flow is parallel to the layers:

\[
SL = \sum h_i / \rho_i
\]

where SL is longitudinal conductance in mhos, \(h_i\) is layer thickness, and \(\rho_i\) is layer resistivity.

Transverse resistance (RT): The transverse resistance of the layers is calculated from the true resistivity values:

\[
RT = \sum h_i \times \rho_i
\]

where RT is the transverse resistance in \(\Omega m^2\).

Aquifer parameters

Hydraulic conductivity \((k)\): In a porous aquifer, hydraulic conductivity can be computed from layer resistance:

\[
k (m/day) = 10^{-5} \times 9.75 \times \rho^{1.195} \times 60 \times 60 \times 24
\]

Transmissivity \((T)\): Transmissivity is an important parameter which helps to evaluate the aquifer parameters. Aquifer transmissivity is calculated as the product of the hydraulic conductivity and layer thickness:

\[
T = k \times h
\]

where \(k\) is the hydraulic conductivity in m/day, and \(h\) is the layer thickness in m.

Formation factor \((FF)\): The formation factor is obtained from hydraulic conductivity:

\[
FF = [k/a] / m
\]

where FF is the formation factor, \(k\) is the hydraulic conductivity (m/day), \(a\) is tortuosity factor for unconsolidated sands (0.62), and \(m\) is cementation exponent, 2.15.

Porosity \((\phi)\) %: The porosity of an aquifer is obtained from the following relation determined from Archie’s experiments:

\[
FF = a/\phi m
\]

Thus, \(\phi = (a/FF)/m\)

where \(\phi\) is porosity in per cent, FF is the formation factor, \(a\) is the tortuosity factor (for unconsolidated sands, \(a = 0.62\)), and \(m\) is cementation exponent (2.15).

Results and Discussions

Geophysical survey

The values obtained for the resistivity and thickness of the layers was interpreted utilizing the RES2DINV programming for the 33 locations of VES in the examined territory. The interpretation indicates that the topmost layer is covered by clay and silty clay, while the second layer is composed of fine-to-medium sand, which forms the aquifer, and the third layer consists of coarse sand, gravel, and pebbles.

Aquifer resistivity \((\rho, \Omega m)\)

The minimum value of aquifer resistivity (0.71 ohm-m) was recorded in Thangalperumbalam in the eastern part and the maximum value (5128.66 ohm-m) was observed in Thachoorkoot Street in the western part (Fig. 3). The center segment indicates medium values for aquifer resistivity.
Aquifer resistivity increases toward the western side. Lower values of aquifer resistivity seen in the eastern side are because of saline water intrusion in the zone.

**Aquifer thickness (h, m)**

Aquifer thickness was found to be minimum (3.82 m) at Ponneri and maximum (29.21 m) at Janappanchathiram Koot Street. Lower estimates were found in the eastern side of the region and in a few places close to the Araniyar and Kosasthalaiyar rivers. Aquifer thickness increases toward the western boundary as shown in Figure 3.

**Dar Zarrouk parameters**

The Dar Zarrouk parameters and aquifer parameters were computed following the procedures described above and the values obtained for the various parameters for the 33 locations studied are presented in Table 1.

**Longitudinal conductance (SL)**

Longitudinal conductance was low in Neidavoyal (0.003 mhos) and was most astounding in Sirupazhaverkadu (1.796 mhos). High longitudinal conductance in the eastern side (Table 1) is because of saltiness. High longitudinal conductance was recorded close to Pulicat Lake because of high salt content. Longitudinal conductance diminishes toward the western side. A few towns close to the western and central regions indicated low longitudinal conductance due to changes in topographical development.

**Transverse resistance (RT)**

Transverse resistance was minimum (83.545 Ωm²) in Siruphaverkadu and maximum (1,98,512.923 Ωm²) in Manali New Town (Table 1). The value was low on the eastern side because of seawater interruption and a low value was recorded close to Pulicat Lake because of high saltiness. The central part demonstrates medium transverse resistance. Transverse resistance increases toward the western limit because of accessibility of fresh water in the western side. Towns close to the western region and the central zone demonstrated high values of transverse resistance, which is due to the influence of the Araniyar and Kosasthalaiyar rivers and changes in land arrangement.

**Aquifer parameters**

Aquifer parameters such as hydraulic conductivity and transmissivity were computed for all the 33 locations.

---

![Spatial distribution maps of Aquifer Resistivity and Aquifer Thickness](image)
Hydraulic conductivity \((k)\): Hydraulic conductivity was extremely minimal in Thangal Perumbalam \((0.006 \text{ m/day})\) in the eastern part and maximum \((240.416 \text{ m/day})\) in Thachoorkoot Street in the west (Fig. 4). This could be due to alluvial and fluvial development in the eastern part of the examined zone. The effect of Araniyar and Kosasthalaiyar rivers and changes in geographical arrangement are the reasons for these variations.

Transmissivity \((T)\): Transmissivity was minimal in Sirupazhaverkadu \((0.085 \text{ m}^2/\text{day})\) in the eastern side and was astounding in Janppanchathiram Koot Road \((6986.869 \text{ m}^2/\text{day})\) in the west. Transmissivity values were discovered to be increasing toward the west. This might be because of the alluvial and fluvial arrangement of the eastern part of the investigation region. High values of transmissivity were recorded in the western side of the examination region, which is because of the effect of the Araniyar and Kosasthalaiyar streams and changes in topographical array. The spatial dispersion of transmissivity is given in Figure 4.

Formation Factor \((FF)\): The formation factor was the least \((0.205)\) in Kathivakkam in the east and was maximum \((16.003)\) in Thachoorkoot Road in the west. Low values of the formation factor in the east show seawater interruption and changes in the geographical arrangement; furthermore, the values increase because of water quality change toward the western side. A few towns close to the eastern side

<table>
<thead>
<tr>
<th>Point</th>
<th>Location</th>
<th>Longitude conductance ((\text{SL, mhos}))</th>
<th>Transverse resistance ((\text{RT, } \Omega\text{m}^2))</th>
<th>Hydraulic conductivity ((k, \text{ m/day}))</th>
<th>Transmissivity ((T, \text{ m}^2/\text{day}))</th>
<th>Formation factor ((FF))</th>
<th>Porosity ((\phi)) %</th>
</tr>
</thead>
<tbody>
<tr>
<td>VES1 Kathivakkam</td>
<td>0.217</td>
<td>345.794</td>
<td>0.021</td>
<td>0.149</td>
<td>0.205</td>
<td>1.674</td>
<td></td>
</tr>
<tr>
<td>VES2 Tulsikuppam</td>
<td>0.16</td>
<td>586.027</td>
<td>0.047</td>
<td>0.381</td>
<td>0.301</td>
<td>1.399</td>
<td></td>
</tr>
<tr>
<td>VES3 Mugathuvaram</td>
<td>0.442</td>
<td>296.814</td>
<td>0.066</td>
<td>0.636</td>
<td>0.354</td>
<td>1.299</td>
<td></td>
</tr>
<tr>
<td>VES4 Puzhuthivakkam</td>
<td>0.353</td>
<td>531.012</td>
<td>0.097</td>
<td>1.11</td>
<td>0.422</td>
<td>1.196</td>
<td></td>
</tr>
<tr>
<td>VES5 Kattupalli</td>
<td>0.562</td>
<td>300.069</td>
<td>0.043</td>
<td>0.463</td>
<td>0.288</td>
<td>1.429</td>
<td></td>
</tr>
<tr>
<td>VES6 Karungali</td>
<td>0.728</td>
<td>154.336</td>
<td>0.015</td>
<td>0.135</td>
<td>0.178</td>
<td>1.786</td>
<td></td>
</tr>
<tr>
<td>VES7 Thangal Perumbalam</td>
<td>0.361</td>
<td>415.888</td>
<td>0.006</td>
<td>0.06</td>
<td>0.115</td>
<td>2.193</td>
<td></td>
</tr>
<tr>
<td>VES8 Nehru Nagar</td>
<td>0.415</td>
<td>496.425</td>
<td>0.107</td>
<td>1.039</td>
<td>0.442</td>
<td>1.17</td>
<td></td>
</tr>
<tr>
<td>VES9 NTECL ash dyke</td>
<td>0.26</td>
<td>721.874</td>
<td>0.139</td>
<td>1.279</td>
<td>0.498</td>
<td>1.107</td>
<td></td>
</tr>
<tr>
<td>VES10 Athipattupudhu Nagar</td>
<td>0.022</td>
<td>51697.55</td>
<td>0.233</td>
<td>2.476</td>
<td>0.634</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td>VES11 Athipattu</td>
<td>0.161</td>
<td>817.213</td>
<td>0.217</td>
<td>2.083</td>
<td>0.614</td>
<td>1.005</td>
<td></td>
</tr>
<tr>
<td>VES12 Ooranambedu</td>
<td>0.208</td>
<td>539.222</td>
<td>0.118</td>
<td>1.046</td>
<td>0.462</td>
<td>1.147</td>
<td></td>
</tr>
<tr>
<td>VES13 Kadapakkam</td>
<td>0.257</td>
<td>583.345</td>
<td>0.022</td>
<td>0.223</td>
<td>0.21</td>
<td>1.653</td>
<td></td>
</tr>
<tr>
<td>VES14 Sirupazhaverkadu</td>
<td>1.796</td>
<td>83.545</td>
<td>0.008</td>
<td>0.085</td>
<td>0.135</td>
<td>2.034</td>
<td></td>
</tr>
<tr>
<td>VES15 Manali New Town</td>
<td>0.205</td>
<td>5491.169</td>
<td>3.733</td>
<td>81.836</td>
<td>2.305</td>
<td>0.543</td>
<td></td>
</tr>
<tr>
<td>VES16 Vallur</td>
<td>0.271</td>
<td>4150.91</td>
<td>1.631</td>
<td>35.748</td>
<td>1.568</td>
<td>0.649</td>
<td></td>
</tr>
<tr>
<td>VES17 Vallur Camp</td>
<td>0.174</td>
<td>6986.538</td>
<td>1.26</td>
<td>11.866</td>
<td>1.391</td>
<td>0.687</td>
<td></td>
</tr>
<tr>
<td>VES18 Nandiyambakam</td>
<td>0.005</td>
<td>91711.567</td>
<td>0.898</td>
<td>10.532</td>
<td>1.188</td>
<td>0.739</td>
<td></td>
</tr>
<tr>
<td>VES19 Neidavoyal</td>
<td>0.003</td>
<td>198512.923</td>
<td>1.18</td>
<td>12.156</td>
<td>1.349</td>
<td>0.697</td>
<td></td>
</tr>
<tr>
<td>VES20 Kattur</td>
<td>0.116</td>
<td>807.215</td>
<td>0.358</td>
<td>2.896</td>
<td>0.774</td>
<td>0.902</td>
<td></td>
</tr>
<tr>
<td>VES21 Thattaianmani</td>
<td>0.148</td>
<td>1143.38</td>
<td>0.356</td>
<td>3.215</td>
<td>0.773</td>
<td>0.903</td>
<td></td>
</tr>
<tr>
<td>VES22 Minjur</td>
<td>0.135</td>
<td>9049.37</td>
<td>5.91</td>
<td>153.057</td>
<td>2.854</td>
<td>0.492</td>
<td></td>
</tr>
<tr>
<td>VES23 Maratoor/ Kalpakkam</td>
<td>0.128</td>
<td>6597.836</td>
<td>4.915</td>
<td>90.639</td>
<td>2.62</td>
<td>0.512</td>
<td></td>
</tr>
<tr>
<td>VES24 Somanjeri</td>
<td>0.142</td>
<td>8557.488</td>
<td>5.91</td>
<td>143.306</td>
<td>2.854</td>
<td>0.492</td>
<td></td>
</tr>
<tr>
<td>VES25 Vannipakkam</td>
<td>0.02</td>
<td>37754.83</td>
<td>15.546</td>
<td>184.84</td>
<td>4.476</td>
<td>0.399</td>
<td></td>
</tr>
<tr>
<td>VES26 Anuppampattu</td>
<td>0.099</td>
<td>9498.63</td>
<td>7.192</td>
<td>139.809</td>
<td>3.127</td>
<td>0.471</td>
<td></td>
</tr>
<tr>
<td>VES27 Lingapayampettai</td>
<td>0.005</td>
<td>163052.281</td>
<td>14.238</td>
<td>169.286</td>
<td>4.297</td>
<td>0.406</td>
<td></td>
</tr>
<tr>
<td>VES28 Jaganathapuram</td>
<td>0.025</td>
<td>40972.681</td>
<td>20.431</td>
<td>120.34</td>
<td>5.083</td>
<td>0.376</td>
<td></td>
</tr>
<tr>
<td>VES29 Amoor</td>
<td>0.04</td>
<td>28041.117</td>
<td>25.55</td>
<td>635.688</td>
<td>5.64</td>
<td>0.358</td>
<td></td>
</tr>
<tr>
<td>VES30 Ponneri</td>
<td>0.016</td>
<td>84275.69</td>
<td>22.459</td>
<td>85.795</td>
<td>5.312</td>
<td>0.368</td>
<td></td>
</tr>
<tr>
<td>VES31 Janappanchathiram Koot Road</td>
<td>0.006</td>
<td>196737.749</td>
<td>239.194</td>
<td>6986.869</td>
<td>15.965</td>
<td>0.221</td>
<td></td>
</tr>
<tr>
<td>VES32 Thatchoor koot Road</td>
<td>0.007</td>
<td>180128.269</td>
<td>240.416</td>
<td>6226.781</td>
<td>16.003</td>
<td>0.22</td>
<td></td>
</tr>
<tr>
<td>VES33 Pudhuvoval</td>
<td>0.01</td>
<td>103201.861</td>
<td>123.836</td>
<td>3327.464</td>
<td>11.754</td>
<td>0.254</td>
<td></td>
</tr>
</tbody>
</table>
are affected by Pulicat Lake, Buckingham Canal, and industrial effluents. The central portion demonstrates medium values of the formation factor. Spatial dispersion of the formation factor is given in Figure 5.

Porosity (φ) %: Porosity was minimal in Thatchoor koot Road (0.220) and maximum (2.193) in Thangalperumbalam. High values of porosity are recorded in the north-eastern part of the investigated territory and a high value is recorded close to Pulicat Lake (Fig. 5). This might be due to alluvial and fluvial deposits close to the ocean and the lake. Porosity diminishes toward the western limit owing to variation in land development. Porosity is low in the western side of the investigated region because of arenaceous development and changes in topographical arrangement.

Comparison of transmissivity

Transmissivity by the geo-electrical method and pump test were compared. Two pump tests were conducted to compute the transmissivity of the study area. Transmissivity of the aquifer was computed from an in situ pumping test of the exploratory well in the study area.

Near the location VES 22 (Minjur), Transmissivity, 
$T = \frac{2.3Q}{4\pi \Delta S}$ (223.51 m$^2$/day),

where $Q =$ Discharge in m$^3$/day (348.19 m$^3$/day) and $\Delta S =$ Drawdown in m (0.285 m).

Near the location VES 30 (Ponneri), Transmissivity, 
$T = \frac{2.3Q}{4\pi \Delta S}$ (87.84 m$^2$/day),

where $Q =$ Discharge in m$^3$/day (129.6 m$^3$/day) and $\Delta S =$ Drawdown in m (0.27 m)

Transmissivity values of location VES 22 and VES 30 using the geo-electrical method were computed as 216.96 m$^2$/day and 85.795 m$^2$/day, respectively.

The transmissivity value obtained from the pumping test directed in Minjur village was 223.51 m$^2$/day, which is close to the transmissivity value computed by translation of geo-electrical parameters (216.96 m$^2$/day). The transmissivity value obtained from the pumping test directed in Ponneri village was 87.84 m$^2$/day, which is very close to that obtained by translation of geo-electrical parameters (85.795 m$^2$/day). The observed transmissivity values

![Spatial Distribution of Hydraulic Conductivity and Transmissivity](image-url)

Fig. 4 — Spatial distribution maps of Hydraulic Conductivity and Transmissivity
using the two strategies fall within the permissible range and this demonstrates the appropriateness of geo-electrical techniques for the calculation of aquifer parameters.

Classification of transmissivity of the study area based on the Gheorghe classification (1978) is given in Table 2. The study reveals that 12% of the study area falls in the high transmissivity class (above 500 m²/day) and 21% of the area falls in the negligible transmissivity class (0.5 m²/day).

**Graphical relationship established**

Hydraulic conductivity has an association with layer resistivity. Along these lines, the locale with low resistivity value in the examined zone, which is thought to be the interface of salt water and fresh water, will naturally have low pressure-driven conductivity. Pressure-driven conductivity corresponds to penetrability. Therefore, the aquifer parcel having high pressure-driven conductivity will be extremely porous to groundwater flow. Graphical relationships are established between (i) \( k \) and FF and (ii) \( RT \) and \( T \).

Figure 6 shows the relationship between hydraulic conductivity and formation factor with \( R^2 = 1 \). This empirical relation is constrained to unconsolidated sediments where the aquifer is anisotropic in nature.

**Hydraulic conductivity** = \( 0.62 \times \text{Formation factor}^{2.15} \)

Figure 7 shows the relationship between transverse resistance and transmissivity with \( R^2 = 0.776 \). A good power relationship exists between transmissivity and transverse resistance.

The geo-electrical parameters are helpful to calculate aquifer parameters where pumping test information is not available. This coastal aquifer is prone to seawater intrusion as it can transmit water at
high rate because of high porosity, high transmissivity, and high pressure-driven conductivity. The present investigation has outlined that geoelectrical study can be utilized to include the Dar Zarrouk parameters and aquifer parameters and their relationship.

Conclusion

Hydraulic conductivity, transmissivity, formation factor, and porosity of the coastal aquifer were computed from geo-electrical parameters, a process that is less tedious and less expensive compared to the laborious pumping tests. Relationships were established between (i) $k$ and FF and (ii) RT and $T$. The investigation concludes that aquifer parameters of seaside aquifers improve as the separation from drift increases and moves toward the western side. Spatial appropriation of aquifer parameters is useful in identifying potential regions for groundwater exploration. Comparison between pumping test results and those from the geo-electrical study reveals that aquifer parameters can be obtained from geo-electrical techniques instead of going for pumping tests.

Acknowledgment

The authors thank Mr. Pushparaj, Sathyabama Institute of Science and Technology for his support in interpolating the spatial distribution maps. The authors also thank the anonymous reviewers for their useful comments on the manuscript.

References


