Detection of submarine groundwater discharge to coastal zone study using 2d electrical resistivity imaging study at Manapad, Tuticorin, India

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Submarine Groundwater Discharge (SGD), is identified at Manapad headland using 2D Electrical Resistivity Imaging study. The study area is covered with the calcareous marine sediments and shells materials formed by the tectonic upliftment. Measured apparent resistivity values are inverted into inversion resistivity pseudosection by using RES2DINV 3.56 software and iterated to calculate resistivity model. Resistivity zones with a range of values from 31 to 174 Ohm.m act as permeable pathway for freshwater discharge to the down stream side towards sea.

[Keywords: Submarine Ground water Discharge, Resistivity imaging, Aquifer, Manapad]

Introduction

Groundwater flows directly into the ocean wherever a coastal aquifer is connected to the sea\(^1\). Sea water intrusion is another important process that leads to the coastal groundwater salinization. About 70\% of the world population residing along the coastal zones faces this crucial problem\(^2,3,4\). Hydrogeologist and Oceanographer are literally looking up the same problem from different angles. Submarine groundwater discharge occurs, where an aquifer is connected hydraulically with the sea bottom and the groundwater pressure head is above sea level\(^5,6\). Slow seepage of the groundwater that flows out along most of the shorelines of the world may be more important volumetrically than discrete springs\(^7\).

Analytical and numerical technique mainly depends on the evaluations of the thickness of the aquifers, and representation of hydraulic conductivities, which are usually difficult to obtain well-constrained values except in very well studied areas. Submarine groundwater measured using manual seepage meter. Many seepage meters are needed, because of the natural spatial and temporal variability of seepage flow rates. Most serious disadvantages of coastal studies are that manual observation of seepage meters are very labor intensive. Other technique is also used to detect submarine groundwater. In addition to geochemical tracers, geophysical tracers such as groundwater temperature can be used to estimate groundwater discharge rates\(^8\).

The study area is located at headland of Manapad (Fig.1) in the Gulf of Mannar coast. Length, width and elevation of this headland are 2500 m, 400 m, and 25 m respectively. This headland is constituted

![Fig. 1—Shows the Manapad headland and Aerial View. The 2D electrical resistivity imaging profiles 1 and 2 were carried out in land and profile 3 was carried out in the sea bottom at a depth of 1.5 m.](image-url)
with calcareous marine sediments with broken shells and the upper part is covered with the recent eolian sediments. Due to the dissolution of shell fragments by rainwater the top layer of the head land is karstified as thin lamina, and at some places, the percolation of rainwater made typical structure “Vertical Piping”. Trend of headland brings into line NE-SW direction. Tectonic deformation in this area was responsible for the uplift of the marine sediments in to head land. Except western part, the other sides are engulfed by sea water. Wave set up and tidally driven oscillations are found more in the southern and eastern sides of the headland, where cliff sections exposed, due to wave erosion. In the northern part only diffracted waves arrive. High porous and permeable nature of calcareous sandstones of the head land permeates all the rainfall and transforms as groundwater. The elevation of the emerged headland is 25 m above MSL that develops good hydraulic gradients that drive the stored up groundwater as source for submarine groundwater discharge. Groundwater flows directly discharged through connected coastal aquifer into ocean. Submarine groundwater discharge from the headland is widespread across the rocky shores in the southern, eastern and western parts of the headland. High wave activity and deeper bathymetric conditions prevailing in the southern and eastern parts are imperiling to field study. Coastal setting with low wave activity and shallow water condition exist in the northern side favours to conduct 2D electrical resistivity imaging study in the land as well in the offshore region.

**Materials and Methods**

Geophysical resistivity imaging studies were carried out in the study area, to characterize the subsurface lithological and hydrological condition of the Manapad headland. The groundwater discharges into coastal bays of the Delmarva Peninsula were studied through electrical resistivity and streaming resistivity survey. After the World War II electrical resistivity techniques were successfully used to delineate freshwater and saltwater boundaries in the coastal areas. Russian geophysical surveys mapped freshwater discharge into the Caspian sea. By employing multi channel resistivity technique the groundwater discharge in the coastal region was surveyed in different parts of the world.

Two types of electrodes were used for this study. In the land area stainless steel electrodes were utilized to carryout the 2D electrical resistivity imaging study. To carryout the 2D electrical resistivity imaging at sea bottom and along the high waterline specially equipped electrodes of 2 m length of bamboo tipped with 15 cm length stainless steel and insulated with cable were used. While doing the survey in the offshore and along the high waterline, these bamboo electrodes were driven 20 to 30 cm below the interface of soil-water in the sea bottom, so that the current induced through the current electrodes is passed into the deeper part of the subsurface. The deeper penetration of the bamboo electrodes would pass the current below the sediment- water interface otherwise dissipation of current along the sediment water interface or into seawater would be resulted into improper contact. With this 2D electrical resistivity imaging study, the research was able to infer the geological structure of an aquifer, the degree of water saturation and quality of the groundwater. 2D electrical resistivity imaging study involves measuring of a series of constant traverses with the increase of electrode spacings in each successive traverse, increases the depth of penetration. So that apparent resistivity measured at various depths is used to construct a vertical contoured section, displaying the variations of resistivities both lateral and vertical direction the section. For the present study, multicore cables with 48 terminals for the electrode connection, Aquameter CRM 500, and specially designed switch panel with 48 sockets for electrode connections, 48 stainless steel electrodes and 12 volt battery are utilized in the land survey.

To detect the pathway of submarine groundwater discharge from the headland, three 2D electrical resistivity imaging profiles to a length of 200 m each with 5 m spacing were carried at the altitudes of 6 m above MSL for the first profile. Second profile at 3 m above MSL and third profile at -1.5 m below sea level in the northern flank of the headland.

From the electrical resistivity imaging studies carried out in the three profile lengths of 200 m each, the penetration depth of 19.8 m were obtained for each section after the inversion of resistivity by using RES2DINV Ver.3.56 software. Major conclusions drawn from the analyses of the three 2D electrical resistivity imaging in the northern flank of the...
Results and Discussion

The electrical resistivity imaging surveys carried out along profile 1 exhibit high resistivity layers with resistivity values 412 to 2307 Ohm.m and 200 to 733 Ohm.m reveal the layer thickness of 9 m and 6 m from the surface. A vertical structural pattern with of 25 m width from delineates from surface to a depth of 19.8 m was identified with the range of resistivity values from 31 to 690 Ohm.m in the first 2D electrical resistivity imaging section. It shows a sharp vertical boundaries with the increasing of resistivities of 31, 74, 174, 412 and 690 Ohm.m towards the centre. By centering the high resistivity zone, the reversal of same pattern of resistivities towards the other end was observed. The resistivity zones with a range of values from 31 to 174 Ohm.m act as permeable pathway for freshwater discharge to the down stream side towards sea. On the flanks of the vertical structure, horizontally distorted layers of beds presumably saturated with freshwater exhibit the resistivity values from 31 to 200 Ohm.m.

The extension of the same structural pattern with similar dimension with the resistivity values of 15 to 35 Ohm.m is also elucidated in the profile 2 also. These distorted layers impregnated with freshwater are delineated from 4 m to 18 m depths. Low resistivity that ranging from 5 to 13 Ohm.m at the depth of the 19 m on either sides of vertical structure in the profile 1 imply the brackish water zones. Similarly, the low resistivity zones in the second profile with the resistivity values that ranges from 0.08 to 9 Ohm.m with similar pattern and depth are observed as in the first pseudosection. These low resistivity layers are engulfed by the freshwater zone with a range of resistivity values of 35 to 122 Ohm.m below 6 m from the surface.

Third resistivity imaging profile was carried out 25 m offshore at the depth of -1.5 m below sea level exhibits an increase of resistivity values with the increase of depth. Upper layer of the sea bottom upto depth 9 m thickness strata below the sediment water interface shows, low resistivity that ranges from 0.06 to 8 Ohm.m. Below 9 m depth, the increase of resistivity values from 19 to 40 Ohm.m is recorded for the sediment layers of 7.0 m thickness in the sea bottom. This zone clearly demarcates the diffusion zone of submarine freshwater discharge.

Analyses of three electrical resistivity imaging sections clearly reveal that the continuum of aquifers from the profile 1 to profile 3. Further it is clearly seen from the imaging sections that the diffusion zone in the aquifer is narrow at headward side and broader in seaward side. Generally the aquifer in the offshore region should be brackish, but the proportional increase of fresh water discharge decreases entrapment of saltwater in the diffusion zone. The decrease of entrainment of saltwater in the diffusion zone could be possible only by the flow of the fresh
water from the higher hydraulic gradient. For this study the maximum and minimum fresh water levels of the freshwater aquifer thickness and the distance between profiles were measured from pseudosections. From observation profiles the average water levels and water level changes were recorded. Hydraulic gradients by using water level changes over the distance between each profiles are determined and tabulated as (Table 1).

The discharge of fresh water per unit width of shoreline is calculated

by Darcys law; \( \frac{Q}{W} = -Kb \frac{dh}{dl} \)

\( Q = \text{Discharge (L}^3\text{T}^{-1}) \)

\( W = \text{width of shoreline (L)} \)

\( K = \text{hydraulic conductivity (LT}^{-1}) \)

\( b = \text{aquifer thickness (L)} \)

\( \frac{dh}{dl} = \text{hydraulic gradient} \)

Ground water moved through the subsurface from the areas of higher hydraulic head (profile 1) to the areas of lower hydraulic head towards offshore region. Specific discharge or Darcy’s flux can be calculated by dividing the volumetric flow rates by cross sectional areas of flows; \( V = \frac{Q}{A} \) for the three electrical resistivity imaging pseudosections as 0.00002, 0.000005 and 0.000035 m$^3$/d. Flow through stratified media can be described by the definition of a hydraulically equivalent conductivity. Expression for horizontal and vertical equivalent in the study is generalized.

**Conclusion**

In the present study in-situ electrical resistivity imaging studies were carried to obtain the resistivity data to quantify the aquifer characters. It was evaluated the interconnectedness of the aquifer system. In the electrical resistivity imaging pseudosections of the profile 1, show vertical section for a width of 25 m with the increase of resistivity values at the centre represented more consolidated formation. The decrease of resistivities from the centre on either sides of the compact formation represents freshwater zone. This vertical compartmentalization cannot be considered faulted zones. In case if it was formed by faulting, it would have low resistivity zone at the center than the high resistivity zone. In the first electrical resistivity imaging, the width of the aperture or fracture zone is about 25 m and in the second, it is measured as 35 m, and in the electrical resistivity imaging section that surveyed at 1.5 m below the sea level exhibits the increase of space size to 70 m. Range of resistivity values (19 to 40 Ohmm) recorded clearly demarcates the freshwater discharge in the subsurface condition in the coastal zone. Aquifer zone identified in the profile 1 has increased into double the size of the first one within the short distances of 100 m from profile 1 to profile 3. In this section the saltwater wedge (1.43 to 8 Ohmm) that engulfed the freshwater aquifer implies the mixing of the lighter groundwater with denser saltwater. Cluster of freshwater wells with

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**Table 1. The discharge of fresh water per unit width of shoreline at Manapad.**

<table>
<thead>
<tr>
<th>Profile</th>
<th>W (m)</th>
<th>-K(m)</th>
<th>b(m)</th>
<th>( \frac{dh}{dl} )</th>
<th>Q (m$^3$/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>200</td>
<td>10</td>
<td>5</td>
<td>0.08</td>
<td>0.020</td>
</tr>
<tr>
<td>2</td>
<td>200</td>
<td>10</td>
<td>6</td>
<td>0.02</td>
<td>0.006</td>
</tr>
<tr>
<td>3</td>
<td>200</td>
<td>10</td>
<td>13</td>
<td>0.14</td>
<td>0.091</td>
</tr>
</tbody>
</table>

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**Fig. 5—A schematic diagram shows the Submarine Groundwater Discharge (SGD) in the coastal zone near Manapad headland, Tuticorin District.**
water tables of 3 m below the sea level within 15 m from the high water line in the same transect is the striking example to prove the relationship between the seawater intrusion into the terrestrial aquifers system and the submarine groundwater discharge is closely linked processes that directly affect each other. Even though the wells are located in the close proximity to the shoreline the entire village folk depends on these water sources for domestic needs. The upward movement of saline water is impeded due to discharge of submarine groundwater in this zone.

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References