Research Article **Open Access**

Application of Time Domain Electromagnetic (Tdem) Methods for Mapping of Salt Fresh Water Intrusions and Evaluate The Porosity in Carbyn's Cove, Wandoor and Khurumedhera Beaches in South Andaman

Vignesh A*, Ramanujam N, Swapan Kumar B and Rasool QA

Department of Disaster Management, Pondicherry University, Port blair – 744112, Andaman Islands, India

Abstract

Time Domain Electromagnetic (TDEM) methods are successfully used to delineate the geometry of different hydrogeological targets to determine porosity of saline and freshwater zones. TDEM can be used to determine both fluid resistivities (ρ_w) and bulk resistivities (ρ) which are required to calculate the porosity by applying Archie's equation. By studying saline water intrusion near coastal zone, where ρ_w and ρ can be determined very accurately by applying TDEM method. From the literature review, it is revealed that the TDEM method is the most suitable geophysical technique for seawater intrusion. TDEM technique is very sensitive to high conductive (low resistivity) zones hence this technique can be applied to study the saltwater intrusion into the fresh water aquifers. Therefore, the aim of the presence study is to find out the porosity of saline water zone for the EM data generated with TDEM technique in the areas of Carbyn's Cove, Khurumedhera and Wandoor beach of South Andaman The TDEM images shows the range of interface between saline water and fresh water at depth of 4 – 10 m from the shoreline to distance of 20 m in Carbyns cove beach, 7 – 18 m from 10m distance in Wandoor beach and 11 – 17 m from 30 m in Khurumedhera beach, indicating the varying amount of mixing of sea-water throughout the aquifer. The porosity of saltwater and freshwater shows that the low porosity indicates high salinity corresponds to salty brackish water with porous/ sandy or saturated clay and high porosity indicates low salinity corresponds to intermediate quality fresh water zone with Sand/gravel or minor clay. It is reasonably presumed from present field study, a close correspondence between the high resistivity zones that encompass with lower total dissolved solids concentration (fresh water) and lower resistivity region was incorporated with the higher amount of total dissolved solids concentration. TDEM soundings with Central Loop Technique appear to be a suitable tool to demarcate the transition zones between fresh water and salt water.

Keywords: Time Domain Electromagnetic (TDEM) method; Salt water intrusion; Porosity; Salinity; Andaman

Introduction

Time Domain Electromagnetic (TDEM) method is applied delineate the salt and freshwater interface along the shoreline to study seawater intrusion. In this technique a close connection between electrical conductivity/ resistivity and salt and fresh water salinity can be visualised. Many of the geophysical methods were focused to study the distribution of seawater intrusion, the depth to fresh – saline groundwater interface, etc. A variety of geophysical methods has been adopted in saltwater intrusion investigations. Conventional DC resistivity techniques have been used very long time to characterize shallow aquifers whereas the gravity and magnetic approaches were applied to reconstruct deep aquifers and the bedrock. Other applications have involved electromagnetic and seismic methods.

The TEM sounding is a proven successful and powerful technique for mapping of interfaces between fresh water and salt water, in which the electrical resistivity of the subsurface layers to several hundred meters of depth can be measured by increasing time duration [1].

We calculated the parameters needed for Archie's law from the TEM Section as: The theoretical basis for such investigations is being constituted by the empirical Archie's equation [2]:

$$rw/r = aFm \quad \text{..................................... (1)}$$

Where rw is the resistivity of water within the pore space, r is the bulk resistivity of the rock, F is the porosity of the rock (approximately representing the volume of water filling the pore space), a and m are material-dependent empirical factors, which are introduced to force the equation to fit the behavior of a rock in question. Since m increases with cementation, [2] named it cementation index, having the characteristic value of 1.3 for unconsolidated sands and varying between 1.8 and 2 for consolidated sandstones.

The detailed description of the method is given in numerous publications, including those devoted to groundwater exploration [3]. The present paper discusses only those features of the method that are relevant to the determination of the porosity of the aquifer. With empirical Archie's equation the relationship between porosity and salinity can be established [2,3].

$$\frac{\rho_w}{\rho} = \Phi^2 \quad \text{.................................. (2)}$$

Where ρ_w is the resistivity of water (From the TDS value, Conductivity of Water, we can calculate the Resistivity of water), ρ is the bulk resistivity of the rock, ϕ is the porosity of the rock.

Geological settings of study area

*Corresponding author: Dr. Vignesh A, Department of Disaster Management, Pondicherry University, Port blair – 744112, Andaman Islands, India, TEL: 0413 - 2655179 E-mail: vignesh@live.com.sg

Citation: Vignesh A, Ramanujam N, Kumar BS, Rasool QA (2015) Application of Time Domain Electromagnetic (Tdem) Methods for Mapping of Salt Fresh Water Intrusions and Evaluate The Porosity in Carbyn's Cove, Wandoor and Khurumedhera Beaches in South Andaman. J Coast Zone Manag 18: 413. doi: 10.4172/2473-3350.1000413

The Carbyn's Cove (11˚ 38' 36.353" N, 92˚ 44' 48.798" E) beach is located in the East coast of South Andaman bounded between the Port Blair Formation in North and West and Ophiolite suite exposed in the Brookshabad regions on South. On the Southern side fault controlled tidal mangrove creeks confluences with Andaman Sea in the East. The exposures of beach sediments upto 50 to 60m from the shoreline beyond that muddy, silt sediments derived from Port Blair Formation are extended upto 500m length. Carbyn's Cove is formed as graben structure between the two fault lines on South and North. The length of the beach in North – South trend is about 300m. The constitution of the Carbyn's cove sediments are mangrove soil, loose sand, shaly limestone and shaly conglomerate [4-6] (Figure 1).

The Wandoor (11˚ 37' 12.66" N, 92˚ 37' 2.717" E) and Khurumedhera (11˚ 39' 58.086" N, 92˚ 35' 42.024" E) beaches are located along the Bay of Bengal. These beaches are bounded with Port Blair Formation in all direction except Western part. The study areas are geographically plain in nature and developed between the faults controlled by cliffs. Sediments are assemblages at Wandoor and Khurumedhera are of sandstone, siltstone and shale (Figure 1).

The tectonic disequilibrium has direct impact on the development of geomorphic, hydrodynamic and sedimentary environment in this part of the study area. The low gradient of the submerged landmass after 2004 Earthquake is a paved way for sea water intrusion in coastal aquifers of prime agricultural land has increased soil salinity.

Methodology

The saltwater intrusion was studied by the geophysical techniques such as Resistivity, Induced Polarization, and Electromagnetic method. In the study area we carried out Electromagnetic Method using Central loop configurations with conductivity values.

Field procedures

Figure 2 shows a typical layout for a "Central loop" TDEM sounding. Field procedures involve placing a square loop of wire (typically 10×10 m², 20×20 m² and 30×30 m²) on the ground surface and measurements are made with a small receiver coil (typically 3×3 m², 9×9 m² and 15×15 m²) in the centre of the transmitter loop (Figures 3-5), as the induced electric current penetrate and diffuse through the earth. The investigation depth depends on the characteristics of the transmission and of the subsurface. The main advantages of this method are the good ratio of the penetration depth over the space required by the layout, and a high sensitivity to the well-conducting soil layers. The main disadvantages are a rather poor resolution obtained for the resistive layers as well as for the near surface layers.

TDEM measurements were carried out to detect saline water bodies within different aquifers and to delineate the interface between these saline bodies and the fresh ones. In order to quantitatively evaluate the ability of the TDEM method to both delineate geometrical features of seawater intrusion and characterize groundwater salinity, almost three TDEM measurements were performed.
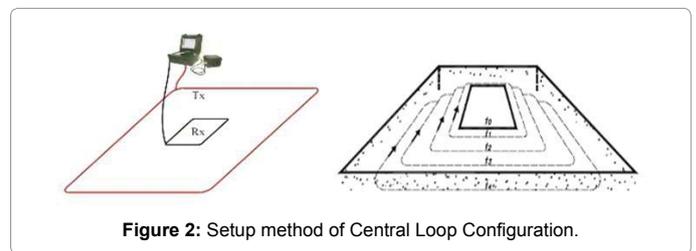

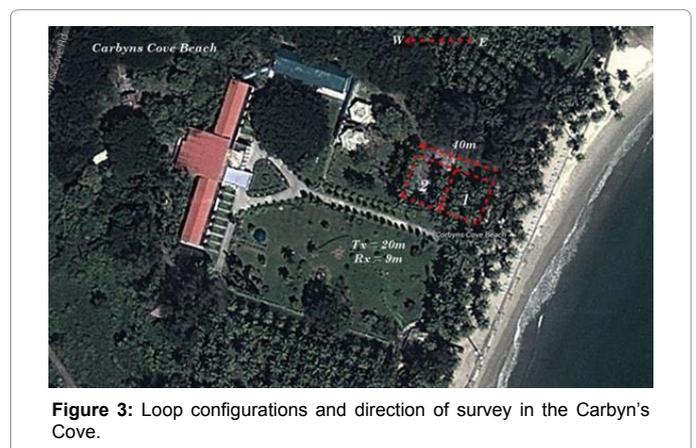**Figure 2:** Setup method of Central Loop Configuration.

Figure 3: Loop configurations and direction of survey in the Carbyn's Cove.

Figure 1: Location map of Study Area.
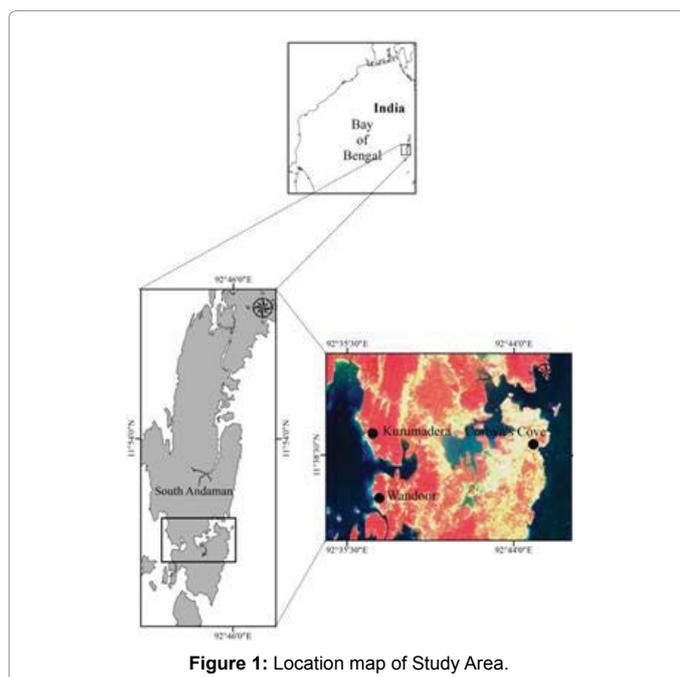

Figure 4: Loop configurations and direction of survey in the Wandoor.

Figure 5: Loop configurations and direction of survey in the Khurumedhera Resistivity – salinity calibration.

-	ϕ	ρ_w (Ohm – m)	ρ (Ohm – m)	Salinity (mg/l)	Sediment Rock
Carbyn cove	0.12	2.8	177.4	2499.9	Salty Brackish
Wandoor	0.03	0.9	657.2	7446.7	Salty Brackish
Khurumedhera	0.04	1.2	570.35	5833.3	Salty Brackish

Table 1: Salinity calculation at Salted water zone.

-	ϕ	ρ_w (Ohm – m)	ρ (Ohm – m)	Salinity (mg/l)	Sediment Rock
Carbyn cove	0.46	37.9	177.4	184.6	Intermediate quality Freshwater
Wandoor	0.25	41.91	657.2	167.0	Intermediate quality Freshwater
Khurumedhera	0.25	35.83	570.35	195.3	Intermediate quality Freshwater

Table 2: Salinity calculation at freshwater Zone.

The attempts to characterize groundwater salinity in the salinity ranges typical for fresh and brackish water using the interpreted TDEM resistivities. Tables 1 and 2 shows that the ability of TDEM to quantitatively characterize salt - groundwater – salinity. Indeed, if the salinity exceeds 10,000 mg /l (Saline water). The resistivity characterizing the brackish water salinity range (1,000 to 10,000 mg/l) vary in the range, between 0.9 to 2.8 Ωm and the freshwater salinities (below 1000mg/l) are characterized by resistivity range between 35.83 to 41.91 Ωm [1].

Porosity calculations

Based on the fact that resistivity below 10 ohm-m is uniquely indicative of seawater intrusion into the coastal aquifer [7-10].

Results and Discussion

Carbyn cove beach

The location of seawater / freshwater interface at the depth of approximately 6m. The shallow sequence from the surface to the depth of 16m exhibits high resistivities representing the underlying freshwater saturated aquifer. The thickness of the unsaturated zone at this site is only 4m. The intermediate zone between 6 and 16m exhibits resistivity values for aquifers saturated with brackish waters, salinity may vary in a wide range.

Profiles from the sea to landward direction exhibits the distribution pattern of hosted brines with the resistivity values 0.024 – 0.41 ohm-m and normal sea water concentrations shows as the resistivity values of 1.51 – 9.46 ohm-m. The fresh water aquifer with high resistivity values 16.3 – 59.5 ohm-m and the resistivity values for sand and gravel ranges upto 370.3 Ωm (Figure 6).

The very low resistivity layer reflects seawater intrusion. Applying equation (1), the porosity of the seawater (Study Area) was calculated for the intruded portion of the aquifer by using TDEM data. Thus the calculated porosity is ϕ = 0.12 and salinity = 2499.9 mg/l.

The shallow resistivity sequence, the porosity calculations of the fresh water in the area is ϕ = 0.46. Some additional semi – quantitative information can be also obtained regarding the groundwater salinity within the intermediate resistivity zone. This resistivity range corresponds to salinities 184.6 mg/l.

Wandoor beach

The location of seawater / freshwater interface at the depth of approximately 11m. The shallow sequence from the surface to the depth of 39m exhibits high resistivities representing the underlying freshwater saturated aquifer. The thickness of the unsaturated zone at this site is only 3m. The intermediate zone between 11 and 39m exhibits resistivity values for aquifers saturated with brackish waters, salinity may vary in a wide range.

Profiles from the sea to landward direction exhibits the distribution pattern of hosted brines with the resistivity values 0.05 – 0.10 ohm-m and normal sea water concentrations shows as the resistivity values of 1.25 – 2.39 ohm-m. The fresh water aquifer with high resistivity values 28.73 – 55.09 ohm-m and the resistivity values for sand and gravel ranges upto 10,000 Ωm (Figure 7).

The calculated porosity is ϕ =0.03 and salinity = 7446.7 mg/l. The shallow resistivity sequence, the porosity calculations of the fresh water in the area is ϕ = 0.25. Some additional semi – quantitative information can be also obtained regarding the groundwater salinity within the intermediate resistivity zone. This resistivity range corresponds to salinities 167.0 mg/l.

Khurumedhera beach

The location of seawater / freshwater interface at the depth of approximately 7m. The shallow sequence from the surface to the depth of 14m exhibits high resistivities representing the underlying freshwater saturated aquifer. The thickness of the unsaturated zone at this site is only 3m. The intermediate zone between 7and 14m exhibits resistivity values for aquifers saturated with brackish waters, salinity may vary in
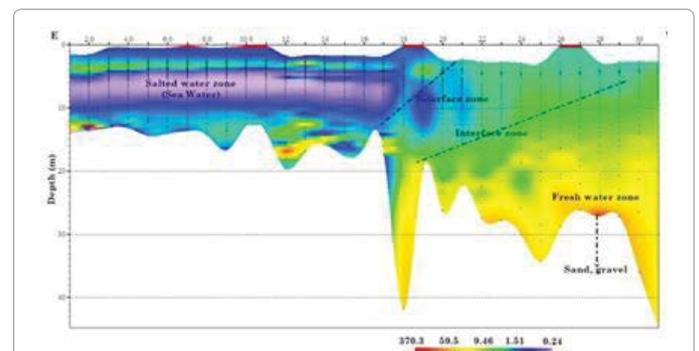

Figure 6: Fresh water aquifer in between the saline water aquifer in Carbyns cove beach. The low TDEM resistivities between 4 to 10m depth are in agreement with the high groundwater salinity.

a wide range.

Profiles from the sea to landward direction exhibits the distribution pattern of hosted brines with the resistivity values 0.09 – 0.185 ohm-m and normal sea water concentrations shows as the resistivity values of 1.57 – 2.96 ohm-m. The fresh water aquifer with high resistivity values 25.12 – 46.51 ohm-m and the resistivity values for sand and gravel ranges upto 5000 Ωm (Figure 8).

The calculated porosity is ϕ = 0.04 and salinity = 5833 mg/l. The shallow resistivity sequence, the porosity calculations of the fresh water in the area is ϕ = 0.25. Some additional semi – quantitative information can be also obtained regarding the groundwater salinity within the intermediate resistivity zone. This resistivity range corresponds to salinities 195.3 mg/l.

Conclusion

TDEM resistivity measurements allow accurate detection of the geometry and bulk resistivity of seawater intrusion into granular and carbonate coastal aquifers. This, in turn, facilitates more accurate estimation of porosity of seawater intruded parts of the aquifers, since both the bulk and the fluid resistivities are accurately determined in these parts. The obtained porosity, in most cases, adequately represents the entire aquifer or its major parts, since it is generally similar both above and below the freshwater/seawater interface.

Experience shows that the most suitable geophysical technique for the exploration of saline groundwater is the time domain electromagnetic (TDEM) method. Numerous measurements carried out in different granular clastic aquifers have proven that the bulk resistivity of saline water saturated portion of the aquifer is accurately detected by TDEM without any use of a priory information. Therefore, under favourable conditions, the porosity of the saline water saturated portion of the aquifer can be also accurately determined from the Archie's equation by using only geophysical data. The obtained porosity might be projected then to the freshwater saturated portion of the aquifer since it is reasonable to assume that hydraulic properties of the aquifer are essentially the same both below and above the freshwater/seawater interface.

Pattern of salt water distribution indicates that salt water intrusion into the fresh water zone from shoreline to adjoining lands. The TDEM images shows the range of interface between saline water and fresh water at depth of 4 – 10 m from the shoreline to distance of 20m in Carbyns cove beach, 7 – 18m from 10m distance in Wandoor beach and 11 – 17m from 30m in Khurumedhera beach. This suggest that the varying values of conductivity are indicating the varying amount of mixing of sea-water throughout the aquifer. The porosity of saltwater and freshwater shows that the low porosity indicates high salinity corresponds to salty brackish water with porous/ sandy or saturated clay and high porosity indicates low salinity corresponds to intermediate quality fresh water zone with Sand/gravel or minor clay. TDEM facilitates the porosity of seawater intruded parts and fresh water zones.

Some aspects affecting the resistivity values of a rock can be describing as follows [11]:

- Rocks are resulted from loose sedimentation show a low resistivity value when compared to compact rocks.

- Igneous and metamorphic rocks (dry rocks) having a high value in Wandoor (10000) and Khurumedhera (5000) areas.

- Wet rocks containing a lot of water and having a low resistivity value show very low values when found in wet lands with salt water.

- Mineral content in the surrounding area of a pack of rock influences the resistivity value of that rock.

Acknowledgement

Figure 7: Fresh water aquifer in between the saline water aquifer in Wandoor Beach. The low TDEM resistivities between 7 to 18m depth are in agreement with the high groundwater salinity.

Figure 8: Fresh water aquifer in between the saline water aquifer in Khurumedhera Beach. The low TDEM resistivities between 11 to 17m depth are in agreement with the high groundwater salinity.

References

1. Archie G (1942) The Electrical Resistivity Log as an Aid in Determining Some Reservoir Characteristics. Transactions of the American Institute of Mining and Metallurgical Engineers 146.

2. Bernard J (2003) Short note on the principles of geophysical methods for groundwater investigations. Terraplus.

3. Eddy Ibrahim (2008) International Journal of Science Engineering and Technology 3: 55-59.

4. Fitterman DV, Stewart MT (1986) Transient Electromagnetic Soundings for Groundwater. Geophysics 51: 995-1005.

5. Goldman M, Gilad D, Ronen A, Melloul A (1991) Mapping of seawater intrusion into coastal aquifer of Israel by the time domain electromagnetic method. Geoexploration 28: 153-174.

6. Goldman M, Kafri U, Yeachieli Y (2003) Application of the Time Domain Electromagnetic (TDEM) method for studying groundwater salinity in different coastal aquifers of Israel. In: Lopez-Geta JA, de Dios Gomes J, de la Orden JA, Ramos, Rodriguez L (Editors) Coastal aquifers intrusion technology: Mediterranean countries. The Institute of Geology and Mineralogy of Spain (IGME): 45-56.
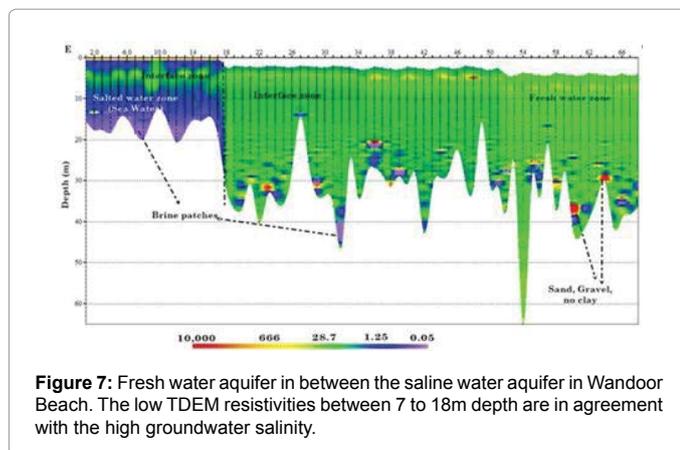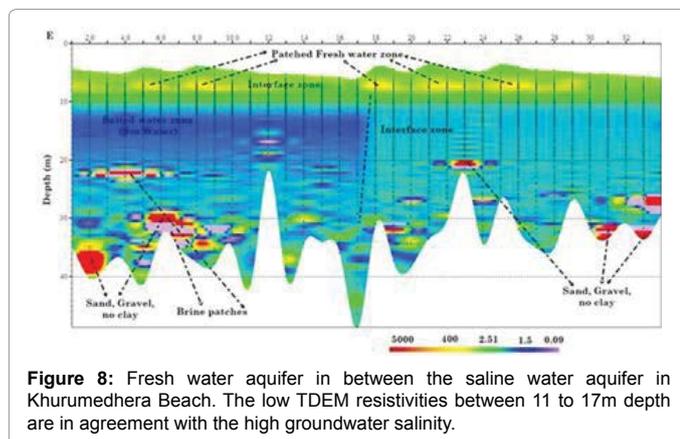
7. Goldman M, Kafri U (2004) The use of the time domain electromagnetic (TDEM) method to evaluate porosity of saline water saturated aquifers. 18 SWIM. Cartagena, Spain. (Editors). Araguas, Custodio and Manzano). IGME

8. Jafri SH, Balaram V, Ramesh SL (1990) Geochemistry of Andaman-Nicobar island basalts: A case for a possible plume origin. Journal of Volcanology and Geothermal Research 44: 339-347.

9. Pal T, Chakraborty PP, Gupta TD, Singh CD (2003) Geodynamic evolution of the outer-arc–forearc belt in the Andaman Islands, the central part of the Burma-Java subduction complex. Geological Magazine 140: 289-307.

10. Roy TK (1983) Geology and hydrocarbon prospects of Andaman–Nicobar basin, in Bhandari, L.L., ed., Petroliferous Basins of India: Petroleum Asia Journal 37-50.

11. Roy DK, Acharyya SK, Ray KK, Lahiri TC, Sen MK (1988) Nature of occurrence and depositional environment of the oceanic pelagic sediments associated with the ophiolite assemblage, South Andaman Island. Indian Mineralogy 42: 31-56.