International Journal of Geosciences, 2018, 9, 59-70
http://www.scirp.org/journal/ijg
ISSN Online: 2156-8367
ISSN Print: 2156-8359

Identification of Groundwater in Hard Rock Terrain Using 2D Electrical Resistivity Tomography Imaging Technique: Securing Water Scarcity at the Time of Seasonal Rainfall Failure, South Andaman

Maniruzzaman Sk*, N. Ramanujam, Vysakh Champoil, Swapan Kumar Biswas, Qazi Akhter Rasool, Chandrakanta Ojha

Department of Disaster Management, Pondicherry University, Puducherry, India
Email: *maniruzzamansk@gmail.com

How to cite this paper: Sk, M., Ramanujam, N., Champoil, V., Biswas, S.K., Rasool, Q.A. and Ojha, C. (2018) Identification of Groundwater in Hard Rock Terrain Using 2D Electrical Resistivity Tomography Imaging Technique: Securing Water Scarcity at the Time of Seasonal Rainfall Failure, South Andaman. *International Journal of Geosciences*, **9**, 59-70.
https://doi.org/10.4236/ijg.2018.91004

Received: December 3, 2017
Accepted: January 26, 2018
Published: January 29, 2018

Abstract

Like many of the tropical islands, the population of Andaman and Nicobar Islands, though not directly, relies predominantly upon rain water harvesting to quench their need and also depends on the groundwater sources. In the background of climate change, severity of hydrological cycle is much anticipated which may cause more extreme and unusual precipitation. It is quite essential to have other alternatives. Accordingly, groundwater could be exploited as a potential alternative. The present study intends to find out the potential groundwater source and estimate aquifer parameters in Kodiyaghat (KD) and Burmanallah (BN). As these areas are composed of very hard rock, Wenner-Schlumberger array has been used to carry out a 2D Electrical Resistivity Tomography survey to find out the fracture zone as well as to delineate the aquifer. KD and BN show maximum resistivity of 25,416 Ωm and 5985 Ωm indicate very hard rock terrain. Similarly, the minimum values of resistivity (21.6 Ωm and 30.4 Ωm) were observed at KD and BN define the presence of freshwater aquifers respectively. The aquifer identified was found to be at a depth of 5 m to 19.9 m at KD and 2.5 m to 20 m at BN. The calculated Hydraulic conductivity (14.85 m/day and 30.14 m/day), transmissivity (86.25 m^2/day and 271.27 m^2/day) and porosity (28.7% and 31.24%) values at KD and BN confirmed that, the located aquifer was of fresh ground water quality and can be utilized for drinking and house hold purposes. According to the results, almost 70% of the study area is hard rock terrain and 30% comes under potential aquifer zone. The results also show that, both the areas were characterized by Horst and Graben topography and suggest possible groundwater sources for future exploration.

Keywords

Aquifer, 2D Electrical Resistivity, Wenner-Schlumberger Array, Ground Water, South Andaman, Ophiolite

1. Introduction

Aquifers in fractured rocks are generally considered of minor importance compared to those in primary porous media, on which the attention has mainly been focused up until now. In fact, the amount of ground water available in fractures is generally limited, at least in arid and semi-arid regions. Nevertheless, this type of aquifer is a primary source of water for man in vast area throughout the world, where aquifers with primary porosity are practically non-existent and surface waters are ephemeral [1]. To find out groundwater potential, geophysical methods play a vital role. It is helpful to find out the hidden subsurface hydrogeological physiognomies adequately and accurately without drilling or bore holing. In hard rock environments fractures and overflowing streamlines are the main indicators of groundwater [2]. Both vertical and lateral fractures in hard rock areas influence and determine groundwater infiltration and migration. The resistivity imaging technique can detect vertical and lateral electrical resistivity variations related to fracture presence and intensity. The purpose of this study is to explore the capabilities of the resistivity imaging method for the detection of fractures and/or fractured zones buried an overburden by using 2D imaging methods, and demonstrating case study examples from experiments in hard rock environments in Kodiyaghat and Burmanallah where to meet the rising incapable demand of water of the island and surrounding areas.

2. Study Area

The data presented here were collected at Burmanallah (N.11˚34'-10" lat.: E.92˚43'-42.5" long) and Kodiaghat (N.11˚31'-53.6" lat.: E.92˚43'-22.2" long) respectively (**Figure 1**), situated on the southern-eastern side of the South Andaman Island along the western coast of Andaman Sea.

Profile Orientation:

The profile orientations were done with respect to the fault trending and the weak zone indicators like streams, fractures etc. In Kodiyaghat the stream orientation was East-West, so the 1st profile was made perpendicular to the stream, followed by second profile trending North-South. Whereas, in Burmanallah the stream oriented North-South direction and the profile was made perpendicular to it, South-East to North-West. Some of the common features of these regions like presence of perennial stream lines, subsided landmass and some open water sources have contributed to the ground trothing and profile orientations.

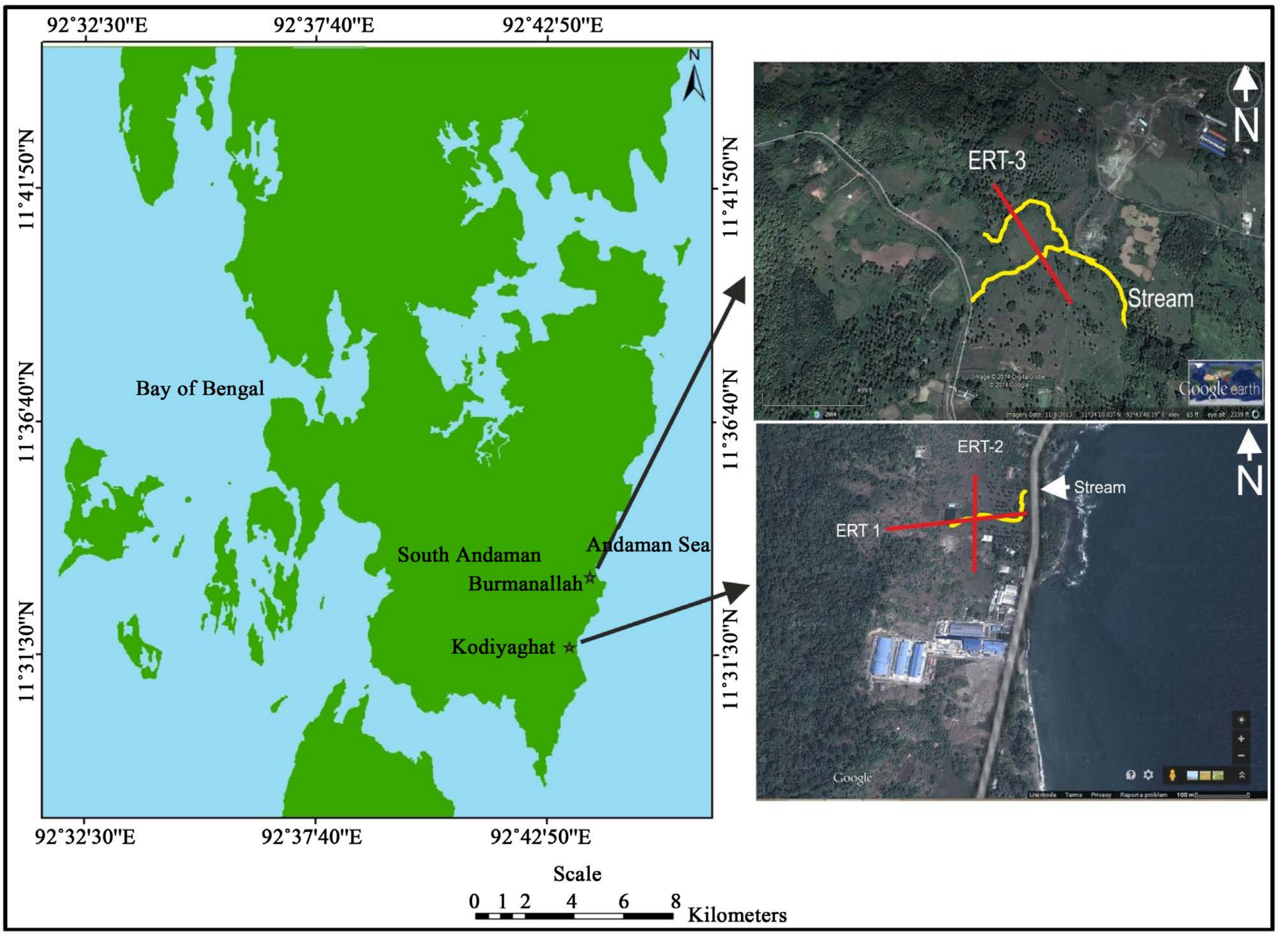

Figure 1. Study area.

Geological Settings:

Ophiolite occurrences are reported from almost all the major Andaman Islands, but are well-exposed in the south Andaman Island [3]. As the present study is concentrated on the southern part of south Andaman, only geology of this portion is presented here. Basalts are exposed all along the east coast of southern part of south Andaman. Noticeable exposures are encountered at Corbyn's cove, Ran-gachang, Bednabad, Kodiaghat, and Chidiya Tapu Burmanallah. For the present study, samples were collected from Kodiaghat and Burmanallah (Figure 2). Most of the basalt exposures show pillow structure. These basaltic exposures also show effect of shearing and shattering. At many places, they are intercalated by chert, shale, and marl and traversed by veins of calcite. An elongated N-S trending mafic-ultramafic body is exposed within the basaltic exposures [4]. This body consists of peridotite (mainly massive harzburgite), troctolite, and gabbro/olivine gabbro. As it is difficult to show these different mafic-ultramafic members on the map, these are classified as unclassified ophiolites. Sediments that mainly comprise ophiolite-derived material and pelagic material cover a major part of this region. All these rock types are surrounded by flysch material.

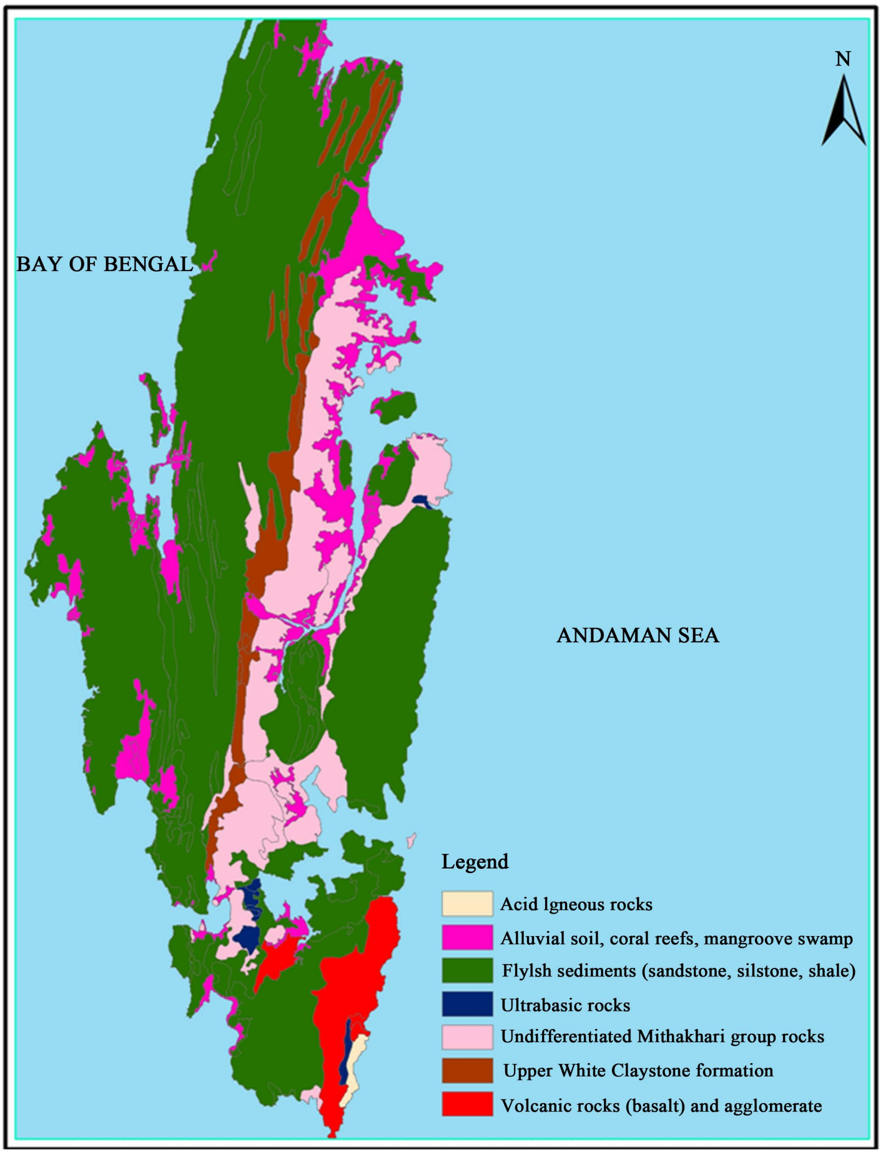

Figure 2. Geological map of the southern part of South Andaman.

3. Methodology

Among the various geophysical methods of groundwater investigation, the Electrical Resistivity Method has the widely applied for groundwater exploration [5] [6] [7] and [8]. This is due to the fact that the field operation is easy, the equipment is portable, less filled pressure is required, it has greater depth of penetration, and it is accessible to modern communication systems (*i.e.*, computer). It is an important technique to explore favorable groundwater condition in hard rock environment [2]. This is the method employed in the study presented here.

Three 2-D electrical resistivity tomography (ERT) surveys were conducted in Kodiaghat and Burmanallah areas. By using CRM500 system, the surveys used Wenner-Schlumberger array with 10 m and 5 m electrode spacing. Depth wise resistivity values are measured and calculated for Apparent Resistivity and interpreted using RES2DINV software on an inexpensive microcomputer.

Wenner-Schlumberger array is a new hybrid method used on a system with the electrodes arranged with constant spacing (**Figure 3**). Note that the "n" factor for this array is the ratio of the distance between the C1-P1 (or P2-C2) electrodes to the spacing between the P1-P2 potential pair. In areas where both types of geological features (horizontal and vertical) are expected, this array might be a good compromise between the Wenner and dipole-dipole array. The median depth of investigation for this array is about 10% larger than that for the Wenner array for the same distance between the outer (C1 and C2) electrodes. It also has a slightly better horizontal coverage compared with the Wenner array but narrower than dipole-dipole array.

Following steps were followed to estimate Aquifer Parameters [9] [10].

Water sample were collected from the respective study area and analysed.

TDS (Total Dissolved Solvents)

TDS (ppm) = (Alkalinity + hardness + chloride) × 1.2

Conductivity of Water

Conductivity of water (μS/cm) = TDS (ppm)/0.64

Resistivity of Water

Resistivity of water (Ωm) = 10^4/conductivity of water (μS/cm)

Formation Factor FF

Formation factor = aquifer resistivity (Ωm)/resistivity of water (Ωm)

Porosity (%) (Fracture or Secondary Porosity)

Porosity = $(1/\text{formation factor})^{1/2}$

Aquifer Conductivity

Aquifer conductivity (μS/cm) = 10^4/aquifer resistivity (Ωm)

Hydraulic Conductivity (m/dy)

Hydraulic conductivity (K) = cross sectional area of aquifer (m^2)/aquifer conductivity (μS/cm)

Transmissivity (m^2/dy)

Transmissivity = hydraulic conductivity (K) × aquifer thickness (h)

4. Result and Discussion

Profile 1—Kodiyaghat (KD)

Array Used: Wenner-Schlumberger, **Electrode Spacing:** 10 m, **Depth Covered**: 34.6 m.

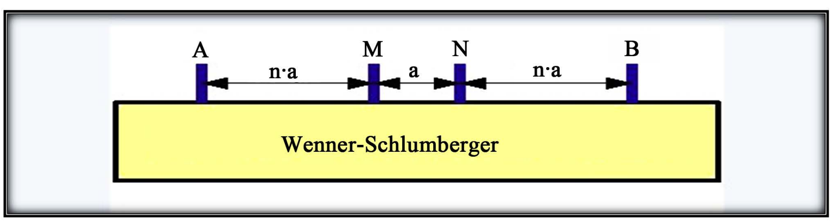

Figure 3. Wenner-Schlumberger array.

The profile 1st Wenner-Schlumberger trends East to West direction to a length of 320 m (Figure 4). Resistivity values from water layers show the variation from 29.5 Ωm to 25,416 Ωm and in the center part of the pseudo section the weak zone with weathered or fractured materials varies from 29.5 Ωm to 204 Ωm (Table 1). Total depth covered by the profile is 35 m.

The profile is characterized by:

1) Horst and Graben topography holding basin at both sides (Figure 5).

2) Deep vertical fracture zones with water bearing property along with hard rock intrusion towards the right side about 10 m width and 10 m length.

3) Two aquifers are marked on the extreme left side (60 m to 70 m electrode spacing) and middle (170 m to 180 m electrode spacing) of the profile.

Table 1. Zones identified with respect to resistivity ranges in Ωm.

Content	Resistivity Ranges (Ωm)	Depth Range (m)
Aquifer	29.5 - 204	7.75 -19.9
Weathered Rocks	535 - 1404	5 - 21
Hard Rocks	3686 - 25,416	7.75 - 34.6

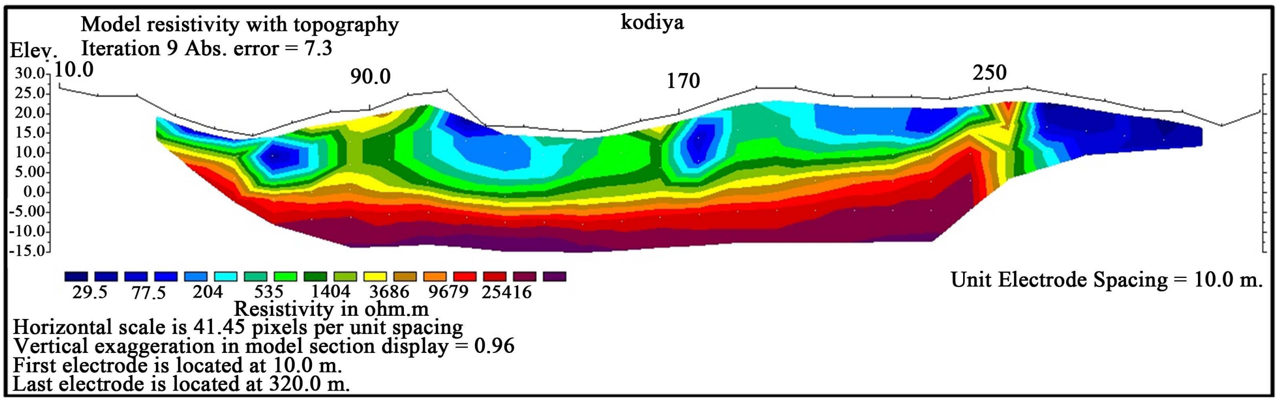

Figure 4. 2D ERT imaging pseudo section depicts distribution of groundwater aquifers.

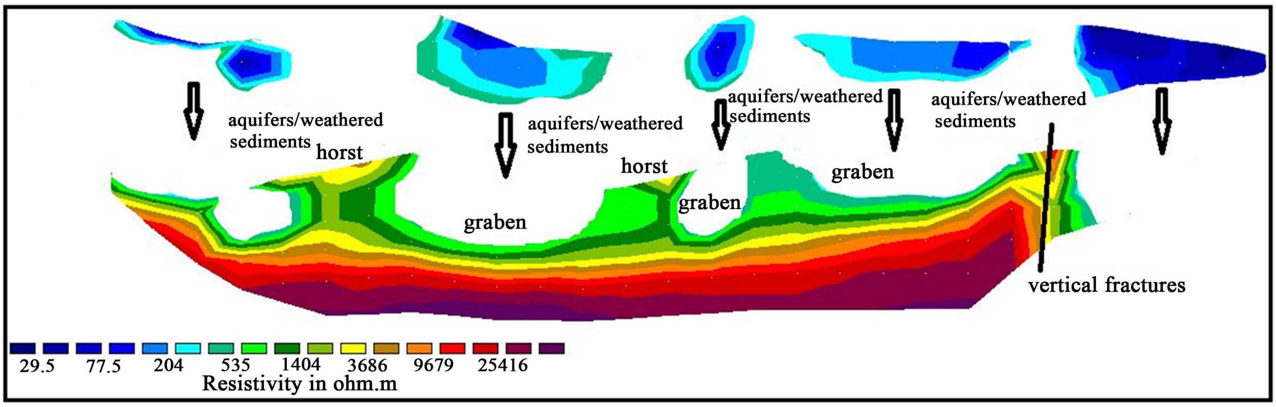

Figure 5. Morphological feathers of pseudo section.

Profile 2—Kodiaghat (KD)

Array used: Wenner-Schlumberger, **Electrode Spacing:** 5 m, **Depth Covered:** 30 m.

The profile 2nd Wenner-Schlumberger trends North to South direction to a length of 160 m. Resistivity values from water layers show the variation from 21.6 to 14,262 Ωm (Table 2) and at the length from 45 m to 60 m of the pseudo section (Figure 6) the hard rocks have been identified up to the depth of 5 m, shows the resistivity value 349 Ωm to 2232 Ωm. As well as at the right side of the pseudo we can identify the presence water layers shows the resistivity about 21.6 Ωm. Total depth covered by the profile is 30 m.

The profile is characterized by:

1) Successive Anticline and Syncline folds respectively cover the bedrock profile of pseudo section (Figure 7).

Table 2. Zones identified with respect to resistivity ranges in Ωm.

Content	Resistivity Ranges (Ωm)	Depth Range (m)
Aquifer	21.6 - 138	5 - 10
Weathered Rocks	349 - 883	10 - 14
Hard Rocks	2232 - 14,262	15 -30

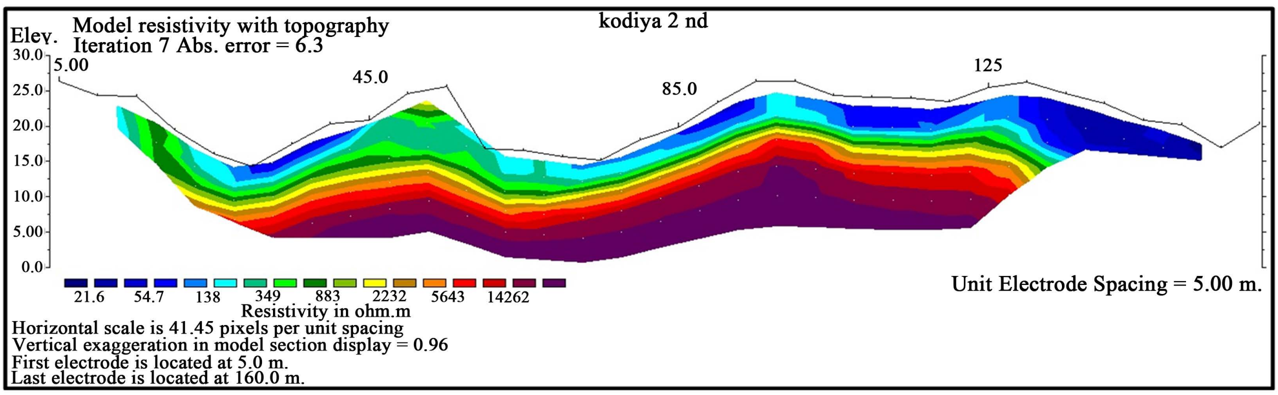

Figure 6. 2D ERT imaging pseudo section depicts the distribution of groundwater.

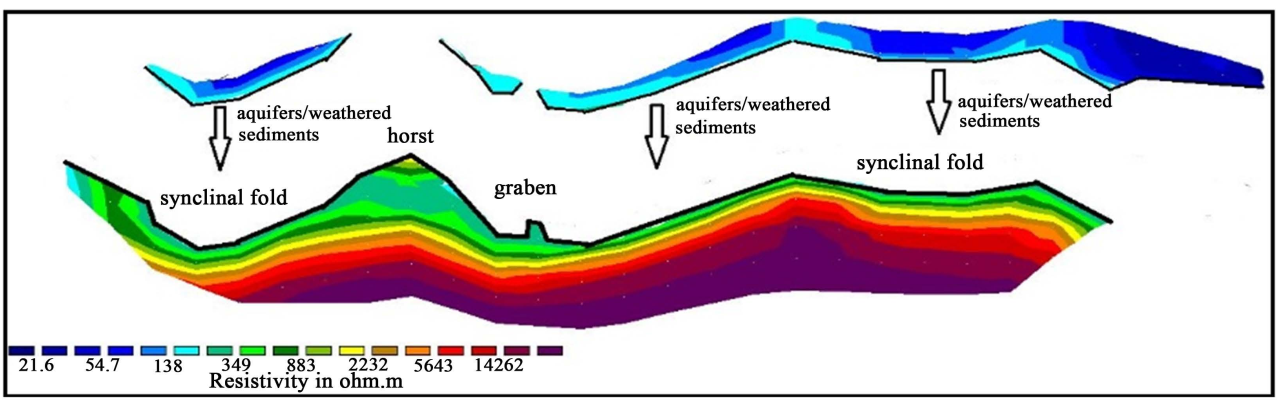

Figure 7. Morphological feathers of pseudo section.

2) Horst and Graben topography holding basin on both sides at 60 m to 100 m length.

3) Deep vertical fracture marked by hard rock intrusion towards the left side, almost above the anticline fold about 10m width and 5m length.

4) Small vertical fracture zones with water bearing property along with hard rock intrusion towards the middle side.

Profile 3—Burmanallah (BN)

Array Used: Wenner-Schlumberger, **Electrode Spacing:** 10 m, **Depth Covered:** 35 m.

The profile 3rd Wenner-Schlumberger trends North-West to South-East direction to a length of 320 m with 32 electrodes spacing 10 m (**Figure 8**). In the pseudo section, we can identify the presence of water layers showing the resistivity from 30.4 to137 Ωm (**Table 3**). Total depth covered by the profile is 35 m.

The profile is characterized by:

1) Horst and Graben topography characterized by tensional cracks resulting basins and rifting.

2) Open fresh water sources abundance almost from 15 m - 35 m, 70 m - 100 m, 130 m - 200 m, 210 m - 240 m, 260 m - 290 m electrode spacing (**Figure 9**).

3) Small vertical fractures and dipping in the bed rock strata.

The 2D ERT of study area shows maximum resistivity of 25,416 Ωm and 5985 Ωm indicate very hard rock terrain. Similarly, the minimum values of aquifer resistivity (21.6 Ωm and 30.4 Ωm) were observed at KD and BN define the presence of freshwater respectively. As the resistivity of fresh Groundwater water varies between 10 Ωm to 100 Ωm [11].

In accordance to parametrical analysis of identified aquifer, porosity value varies between 28.7% to 31.24%, which signifies the fresh water porosity zone for hard rock environments. According to Davis [12], weathering and fracturing of hard rocks increases the porosity up to 60%. The High formation factor shows more cementation whereas high hydraulic conductivity means more permeability in the region. The transmissivity values of the study area ranges from 86.25 m^2/dy to 271.27 m^2/dy (**Table 4**). The abundant aquifer thicknesses with greater transmissivity values reveal that the area is very potential for drilling productive boreholes [13]. In compare to Beodnabad (127 m^2/dy) and Calicut (139 m^2/dy) the study area has higher transmissivity value which are capable to cater the domestic needs of 10,000 rural populations [14]. The present investigation directs towards the alternate resource of fresh water for the island population which can be banked upon during the time of seasonal rainfall failure at South Andaman.

Table 3. Zones identified with respect to resistivity ranges in Ωm.

Content	Resistivity Ranges (Ωm)	Depth Range (m)
Aquifer	30.4 - 137	2.5 - 19.9
Weathered Rocks	292 - 1323	5 - 20
Hard Rocks	2813 - 5984	13.5 - 34.6

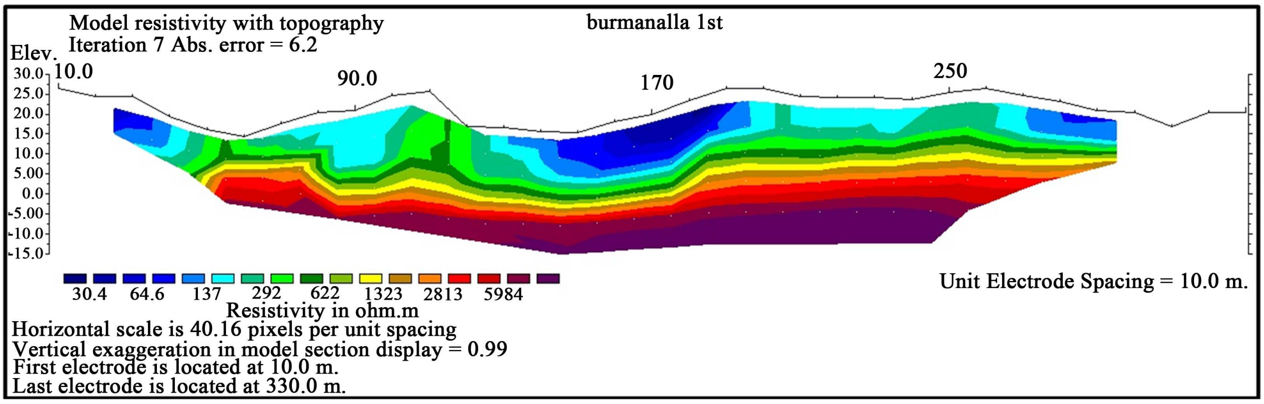

Figure 8. 2D ERT imaging pseudo section depicts the distribution of groundwater.

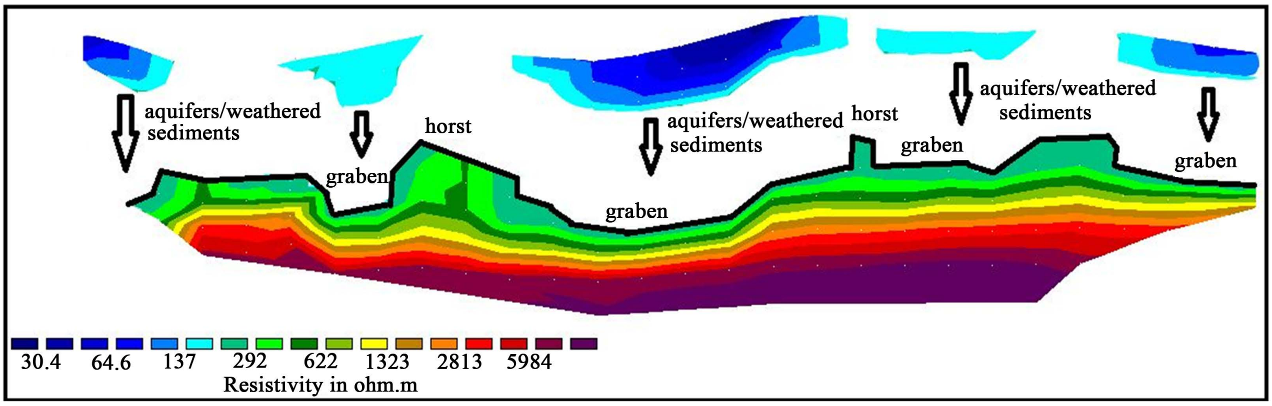

Figure 9. Morphological feathers of pseudo section.

Table 4. Aquifer parameters calculated from the total dissolved solvents (TDS) of collected water sample and profile resistivity.

Profile	Total Dissolved Solvents (ppm)	Conductivity of Water (μS/cm)	Resistivity of Water (Ωm)	Aquifer Thickness (m)	Formation Factor (FF)	Secondary Porosity (%)	Hydraulic Conductivity K (m/dy)	Transmissivity (m²/dy)
Prof-1	542.12 ± 3.14	858 ± 4.98	11.655 ± 0.06	10.5 ± 0.69	12.07 ± 3.43	28.7 ± 4.57	14.84 ± 3.59	155.82 ± 42.53
Prof-2	542.12 ± 3.63	858 ± 5.76	11.655 ± 0.07	5 ± 1.65	11.84 ± 1.43	29.06 ± 2.50	17.25 ± 3.02	86.25 ± 11.89
Prof-3	624 ± 13.72	975 ± 21.42	10.25 ± 0.22	9 ± 1.31	10.24 ± 3.47	31.24 ± 7.59	30.14 ± 3.35	271.27 ± 30.62

Further analysis, including permeability, production yield, water quality etc. has to be done to dig a bore well and extract the potential fresh water for drinking purpose.

5. Conclusions

Potential groundwater sources from secondary porosities in hard rocks were identified and located in the respective study areas using 2D Electrical resistivity technique. Some of the important conclusions are:

- The analysis of the pseudo section along the profile one to three clearly shows 3 broader divisions viz, aquifers (fresh water zone), hard rock and very hard rock region.

- Structural and tectonic factors (faults, fractures) play a vital role in locating potential groundwater sources and its movement. Overburden soil thickness is comparatively less so that ground water in this terrain is localized to fracture zone & rifted basins with the presence of Horst & Graben topography. The horst and graben topography that holds the basins is found to be a very good source for ground water. These features consolidate the fact that the study area belongs to a tectonically active region.
- The estimation of aquifer parameters has strengthened the evidences for locating fresh groundwater sources in the study areas. Favourable porosity values along with hydraulic conductivity and transmissivity values give appropriate groundwater source location and thereby, techniques for its extraction.
- The Profile 1 is very suitable for digging open wells and drilling Bore wells because the area comprises confined aquifer in addition to unconfined aquifers and streams. Profile 3 and 2 are appropriate location for open wells and reservoirs of fresh groundwater as the aquifer thickness is less compared to profile 1 and very few confined aquifers.
- In the hard rock area, it is difficult to locate the availability of ground water resources. Rock characteristics in the area show distribution of Ophiolite suite, mainly Basalt. Fractures and overflowing streamlines are the main indicators of groundwater in the hard rock environments. According to the results, almost 70% of the study area is hard rock terrain and 30% comes under potential aquifer. The application of electrical resistivity technique has helped to delineate the fractures and aquifer zones in the study area without making bore hole and conducting pumping tests, which are meant to be very expensive.
- The extracting groundwater can be supply for the house hold as well as agriculture purpose at the time of The Time of Seasonal Rainfall Failure.
- The 2D Electrical Resistivity Imaging technique, thus is a powerful tool for shallow subsurface groundwater investigation study in the hard rock environments.

Recommendation

The following recommendation can be inferred from the results and conclusions of the study:

- The 2D Electrical Resistivity technique can be recommended for groundwater exploration and study of aquifers characteristic in hard rock environments because it is easy to operate, low survey cost and the capability to distinguish between the saline and fresh water zones.
- Open wells, bore wells and reservoirs can be constructed in the suitable aquifer zones with reference to depth variations and type of aquifers present.
- Augmentation of groundwater resources is necessary where surface storage structures are inadequate to meet the demand or when annual exploitation of resources exceeds its replenishment in a given area.

- To maintain the sustainability of the fresh water bearing aquifer zones, large scale rain water harvesting can be advised to manage and control the groundwater resources for future.
- Hydro chemical study can be carried out in the area to determine the water quality for both municipal and industrial uses.
- Other advanced imaging techniques like Vertical Electrical Sounding (VES), Azimuthal Square array, Cross hole electrical tomography can be used in the area to validate this result.

Acknowledgements

The author would like to thanks Pondicherry University for providing the instrument and tools to this research work. Not forgotten, to Maulana Azad National Fellowship of Maniruzzaman SK for financial support. We would like to express our heartfelt thanks to Mr. Ravi Ranjan Kumar and Raj Kiran Lakra for helping us to improve the quality of manuscript. Mr. Gulam Rasool Bhatt especially recommended several modifications that tightened and strengthened the interpretations presented in this paper.

References

[1] Barrocu, G. (2002) Hydrogeological Parameters in Fractured Rock Aquifers. IAH Hardrock Hydrogeology Working Group, Middle and East Mediterranean Working Group, Abstract.

[2] Louis, I.F., Louis, F.I. and Grambas, A. (2002) Exploring for Favorable Groundwater Conditions in Hardrock Environments by Resistivity Imaging Methods: Synthetic Simulation Approach and Case Study Example. 2002 International Conference on Earth Sciences and Electronics. *Journal of Electrical & Electronics Engineering*, 1-14.

[3] Bandopadhyay, P.C. (2004) Discovery of Abundant Pyroclasts in the Namunagarh Grit, South Andaman: Evidence for Arc Volcanism and Active Subduction during the Palaeogene in the Andaman Area. *Journal of Asian Earth Sciences*, **25**, 95-107. https://doi.org/10.1016/j.jseaes.2004.01.007

[4] Saha, A., *et al.* (2010) Complete Preservation of Ophiolite Suite from Sout Andaman, India: A Mineral-Chemical Perspective. *Journal of Earth System Science*, **119**, 365-381. https://doi.org/10.1007/s12040-010-0017-6

[5] Afolayan, J.F., Olorunfemi, M.O. and Afolabi, O. (2004) Geoelectric/Electromagnetic VLF Survey for Groundwater in a Basement Terrain: A Case Study. *Ife Journal of Science*, **6**, 74-78.

[6] Ariyo, S.O. (2007) Hydro-Geophysical Investigations for Groundwater at Atan/Odosenbora Area, Southwestern Nigeria. *Ife Journal of Science*, **9**, 87-92.

[7] Barker, R.D. (2001) Imaging Fracture in Hardrock Terrain. University of Birmingham, Birmingham. http://www.bham.ac.uk/Earth Sciences/research/hydro/envgeo/

[8] Olorunfemi, M.O., Ojo, J.S. and Akintunde, O.M. (1999) Hydrogeophysical Evaluation of the Groundwater Potentials of the Akure Metropolis, Southwestern Nigeria. *Journal of Mining and Geology*, **35**, 201-228.

[9] Chachadi, G. and Pradip, D. and Gawas, A. (2012) Correlation Study between Geoelectrical and Aquifer Parameters in West Coast Laterites. *International Journal of Earth Science and Engineering*, **5**, 282-287

[10] Niwas, S. and Singhal, D.C. (1981) Estimation of Aquifer Transmissivity from Dar Zarrouk Parameters in Porous Media. *Hydrology*, **50**, 393-399. https://doi.org/10.1016/0022-1694(81)90082-2

[11] Nwankwo, L.I. (2011) 2D Resistivity Survey for Groundwater Exploration in Hard Rock Terrain: A Case Study of MAGDAS Observatory UNILORIN, Nigeria. *Asian Journal of Earth Sciences*, **4**, 46-53. https://doi.org/10.3923/ajes.2011.46.53

[12] Davis, S.N. (1969) Porosity and Permeability in Natural Materials in Flow through Porous Media. *Nigerian Journal of Mining Geology*, **26**, 279-284.

[13] Onuoha, K.M. and Mbazi, F.C.C. (1988) Aquifer Transmissivity from Electrical Sounding Data: The Case of Ajalli Sandstone Aquifers, South East of Enugu, Nigeria. In: Ofoegbu, C.O., Ed., *Groundwater and Mineral Resources of Nigeria*, Friedrich Vieweg & Sohn Publishers, Braunschweig, 17-29. https://doi.org/10.1007/978-3-322-87857-1_3

[14] Central Ground Water Board (2009) Experimental Artificial Recharge Studies in South Andaman. http://cgwb.gov.in/NEW/District_Profile/AandN/an%20brochure%202.pdf