CrossMark

ORIGINAL ARTICLE

Appraisal of groundwater resource in Holocene soil deposits by resistivity, hydrochemical and granulomerial studies in the Gulf of Mannar Coast from Southern India

A. Antony Ravindran[1] · Nepal Chandra Mondal[2] · N. Ramanujam[3] · K. Srinivasamoorthy[4] · P. Anbazhagan[5]

Abstract This article is aimed to delineate groundwater sources in Holocene deposits area in the Gulf of Mannar Coast from Southern India. For this purpose 2-D electrical resistivity tomography (ERT), hydrochemical and granulomerical studies were carried out and integrated to identify hydrogeological structures and portable groundwater resource in shallow depths which in general appears in the coastal tracts. The 2-D ERT was used to determine the two-dimensional subsurface geological formations by multi-core cable with Wenner array. Low resistivity of 1–5 Ω m for saline water appeared due to calcite at the depth of about 5 m below the ground level (bgl). Sea water intrusion was observed around the maximum resistivity as 5 Ω m at the 8 m depth, bgl in the calcite environs, but the calcareous sandstone layer shows around 15–64 Ω m at the 6 m depth, bgl. The hydrochemical variation of TDS, HCO_3^-, Cl^-, Na^+, K^+, Ca^{2+}, and Mg^{2+} concentrations was observed for the saline and sea water intrusion in the groundwater system. The granulometic analysis shows that the study area was under the sea between 5400 and 3000 year ago. The events of ice melting an unnatural ice-stone rain/hail among 5000–4000 years ago resulted in the inundation of sea over the area and deposits of late Holocene marine transgression formation up to Puthukottai quartzite region for a stretch of around 17 km.

Keywords Groundwater · Holocene soil deposits 2-D ERT · Hydrochemistry · Grain size · Gulf of Mannar Coast · Southern India

Introduction

The shallow alluvium coastal aquifer and geological structural features were mapped during the previous field and laboratory tests using the scientific investigations of Koike and Matsuda (2005). Studies of geological structures and sea water intrusion using 2-D electrical resistivity tomography (ERT) (Mondal et al. 2008; Gurunadha Rao et al. 2011; Antony Ravindran and Ramanujam 2014); hydrochemistry in shallow aquifer and mixing of sea water intrusion (Mondal et al. 2010); grain size, porosity and conductivity studies support for the groundwater movement (Aguilar 2013) have been carried in the coastal environments. The integration of geophysical properties, chemical characteristic of water and environmental analysis helps the estimation of shallow aquifer contamination due to sea water intrusion (Misonou et al. 2013). The coastal hydrogeological investigation is a needful study for developing groundwater quality management as well as estimating aquifer properties. Every year more quantity of freshwater both in shallow and deeper aquifers mixed with sea water (Revelle 1941). However, the shallow aquifer is mainly used for domestic purpose in the coastal area. This hydrogeological study depends upon the nature of

✉ A. Antony Ravindran
antonicogeo@gmail.com

1 Department of Geology, V. O. Chidambaram College, Manonmaniam Sunaranar University, Thoothukudi, Tamil Nadu, India

2 Aquifer Mapping Group, CSIR-National Geophysical Research Institute, Hyderabad 500007, India

3 Department of Coastal Disaster Management, Pondicherry Central University, Port Blair, Andaman, India

4 Department of Earth Science, Pondicherry University, Central University, Pondicherry, India

5 Department of Civil Engineering, Indian Institute of Science, Bangalore, India

Springer

environment and the properties of soil and rock formations (Frohlich et al.1994; Mondal et al. 2009). The factors, such as topography, soil type, elevation, evapotransporation, chemical changes, physical properties of the rocks and soil conditions, control the groundwater movements (Choudhury et al. 2001). The groundwater is easily contaminated due to the over evapotransporation in shallow aquifer and saline intrusion due to the wave and tidal influences (Edet and Okereke 2002). The palaeo-coastal morphological changes and marine transgressive and regressive controls on the freshwater marine environment also alter the groundwater quality. Groundwater flow depends upon the gradients of inland elevation (Selvam et al. 2014; Singa Raja and Shah 2006; Nicolas et al. 2011; Valentina et al. 2013). Sometimes reverse hydraulic gradient influences sea water intrusion in the coastal belt (Sankaran et al. 2012).

Thus, the coastal aquifer characteristic studies were carried out using 2-D ERT, groundwater quality, sieve of grain size and microscopic grain size analysis in a selected area, where the population is high in Thoothukudi city,

located in the Gulf of Mannar coast from Southern India (Fig. 1). The main purpose of this study is to assess groundwater resources in shallow aquifers and saline/sea water intrusion substantiate by: (1) using nine 2-D ERT profiles across the existing wells, (2) groundwater samplings for groundwater quality, and (3) core sampling for soil hydraulic properties in the Holocene deposits area using sieve and microscopic techniques.

Geology of the study area

The study area is under semi-arid and tropical climate. Air temperature data indicate that the hottest months are May–August, whereas the coolest months are December–February in every year. The mean annual temperature is about 28.3 °C and annual precipitation is about 676 mm. Major rainfall is received during the northeast monsoon period and the maximum rainfall has been observed during the month of November. The major soil types are black cotton,
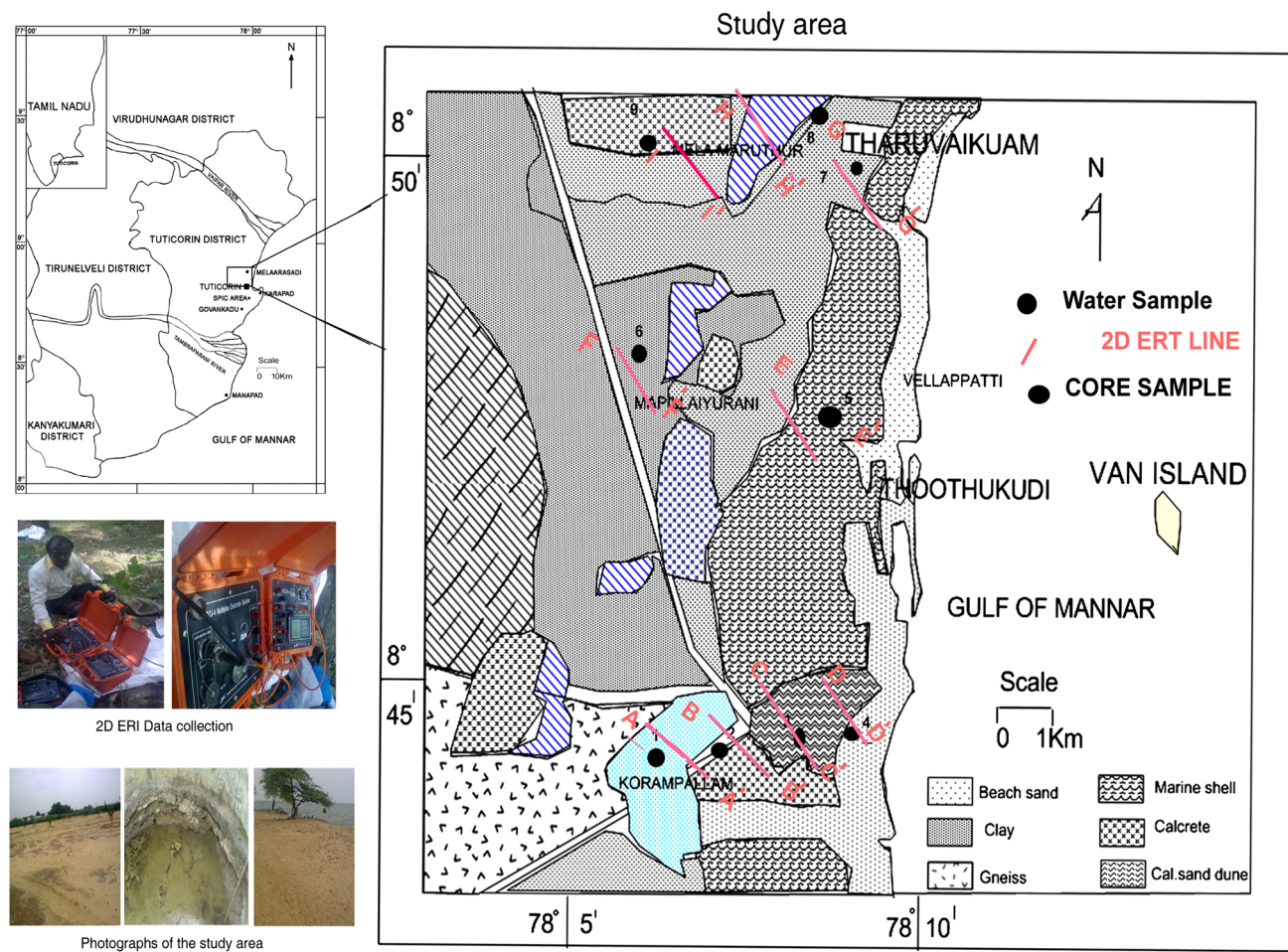

Fig. 1 Location maps of the study area in the Gulf of Mannar coast of Southern India and 2-D ERT lines with equipment used in the field site

shallow and deep red soils, river alluvium, strong calcareous soil, saline soil and saline mangrove soil.

The formations of the study area have been formed in Holocene coastal sand, river alluvium, laterite, red soil, calcite and calcareous sandstone; and shell fragments are observed on the litho logs. As the study area is one of the coastal belts in Southern India, the representative coastal features such as bays, lagoons, estuaries, cliffs, dunes, backshore width, beach width, wave cut features, etc., are common along this belt. The coastal aquifers are more porous and permeable calcarenite rocks in Korampallam, Thoothukudi, Velllappatti and Tharuvaikuam areas (Fig. 1) act as good aquifers source of potable water. Lens of portable water in these areas solve the water problems (Melloul and Collin 2006). Overuses at some places have caused the saline water intrusion. Groundwater exists under unconfined conditions in the weathered and fractured zones. The study area is covered by soil, sandstone, calcrete, gneiss rock and quartzite, and alluvium deposits. Coastal environment and aquifer characteristics are mainly controlled by the Holocene transgression and regression in the study area.

Materials and methods

Electrical resistivity tomography (ERT)

The electrical resistivity tomography (ERT) is a geoelectrical imaging technique which reflects different degrees of realism (Dahlin and Loke 1998). It involves measuring a series of constant separation traverse with an increase of electrode spacing with each successive traverse. The increase of electrode spacing increases the sounding depth, so that apparent resistivity measured at various depths is used to construct a pseudo-section. It gives better results in mapping of saline water intrusion and freshwater zones near shoreline in the different environments (Loke et al. 2003; Wilson et al. 2006). Thus, it was carried out at 9 sites (Fig. 1) with Wenner array of 2.0 m intervals. For this study, multi-core cables with terminals for the electrode connections, WTS-4 and specially designed switch panel with 30 sockets for electrode connections and 25 stainless steel electrodes were used. The 2-D ERT data along with the RES2DINV Ver. 3.56 software were used for preparation of resistivity pseudo-section (Griffth and Turnbull 1985). The bore well logs were also compared with the 2-D ERT pseudo-section for the interpretation.

Hydrochemical investigation

Because the Holocene marine transgression affects the groundwater, the groundwater sample analysis is an important part to investigate the changes of groundwater quality. In total 18 groundwater samples were collected and analyzed. Methods of collection and analysis of the collected samples were essentially the same as APHA (1985). Simultaneously the hydrophysical parameters, such as the electrical conductivity (EC) and pH were measured in situ using portable kits like conductivity and pH-meters. The samples were collected in 1-L capacity polythene containers from 0.5 m below the water table. Prior to collection the containers were thoroughly washed with diluted HNO_3 acid, and then with distilled water in the laboratory before filling containers with the samples. Each container was rinsed to avoid any possible contamination and other precautionary measures were also taken care. All concentrations are expressed in milligram per liter (mg/L), except pH and EC. The analytical precision for the measurements of cations and anions, indicated by the ionic balance error (IBE) was computed on the basis of ions expressed in me/L. The value of IBE was observed to be within a limit of ±5 % (Domenico and Schwartz 1990).

Sieve and microscopic studies

The mechanical sieving method is useful to determine the sedimentary formation and palaeo environmental deposits. The vertical depth soil samples were collected at the 9 bore holes for grain size analyses. The mechanical sieving method using a shaker was chosen for this analysis. The cumulative frequency curve was obtained by plotting of size (Phi) values vs. cumulative percentage for depositional environment (Friedman 1961; Folk 1974; Angusamy and Rajamanickam 2007; Joshua and Oyebanjo 2010). The mean values were used to determine the grain size (i.e., medium to coarse grained) in the study area. Further, the grain size and sorting were identified with the help of photomicroscopic study.

Results and discussion

Groundwater resource studies were carried out with the help of 2-D ERT, hydrochemistry and grain size distribution (porosity and hydraulic conductivity studies) in the Gulf of Mannar coast of Southern India. Water level fluctuation measurements were also carried out at the selected bore hole/open well pumping test. The results are summarized and discussed as follows.

Electrical resistivity tomography at nine sites

First profile A–A′ (at Koramppalam) is a length of 100 m oriented in the NW–SE direction. The upward trends of near SE part are a basin-like structure (resistivity ranges 8–18

Ω m) indicating the gneiss rock with highly water saturated zone. The resistivity of clay layer is about 1–5 Ω m, which indicates calcrete with highly compacted sediments (Fig. 2). Groundwater level had been observed at the depth of 4.7 m below ground level (bgl) with EC value of 1230 µS/cm (Fig. 3). Second profile B–B′ (at Medical College) water bearing zone was identified through the resistivity variation at the depth of 3.88–8.94 m, bgl and range of resistivity from 14 to 26 Ω m. The resistivity section of the top layer covered by the clay mixed with sandy layer (resistivity range 1–5 Ω m) ranges from 1.25 to 3.88 m, bgl depth. Groundwater quality was quite good as its EC value was 741 µS/cm. In the third profile C–C′ (at Millerpuram) the freshwater shallow aquifer resistivity varied from 10 to 15 Ω m, which indicates the highly porous sandy layer (Fig. 3). The profile D–D′ at Therspuram was taken in the NW–SE direction near to the shoreline. The shallow aquifer exists at a depth of around 3.0 m. The sandy dune having resistivity ranges of 19–45

Ω m (Fig. 2) forms shallow aquifer. But, the fully saturated ingress of saline water was displayed in the resistivity section (1–4 Ω m) at the depth of 4.0 m, bgl. The high saline water intrusion had been observed for the hydrostatic pressure of wave and tidal impacts.

The aquifer resistivity value ranges from 1 to 5 Ω m which indicates the sea water intrusion at the depth of 4.0 m, bgl on the fifth profile E–E′ (at Vellappatti) located near the coastline. The EC value about 5700 µS/cm was observed in the groundwater. The shallow aquifer was observed at the depth of 4.2 m, bgl, which is fallen on the profile F–F′ (at Tharuvaikullam). The intermixture layer of shell fragment by the sandy layer at a depth of 6.0 m (resistivity range 0.1–5 Ω m) indicates intrusion of the saline/sea water along with the groundwater EC value of 5700 µS/cm. The seventh profile G–G′ (at Pattinamaruthur) was selected near the clay and sand mixed rocky coast. The water bearing zone encountered at the 3.2 m
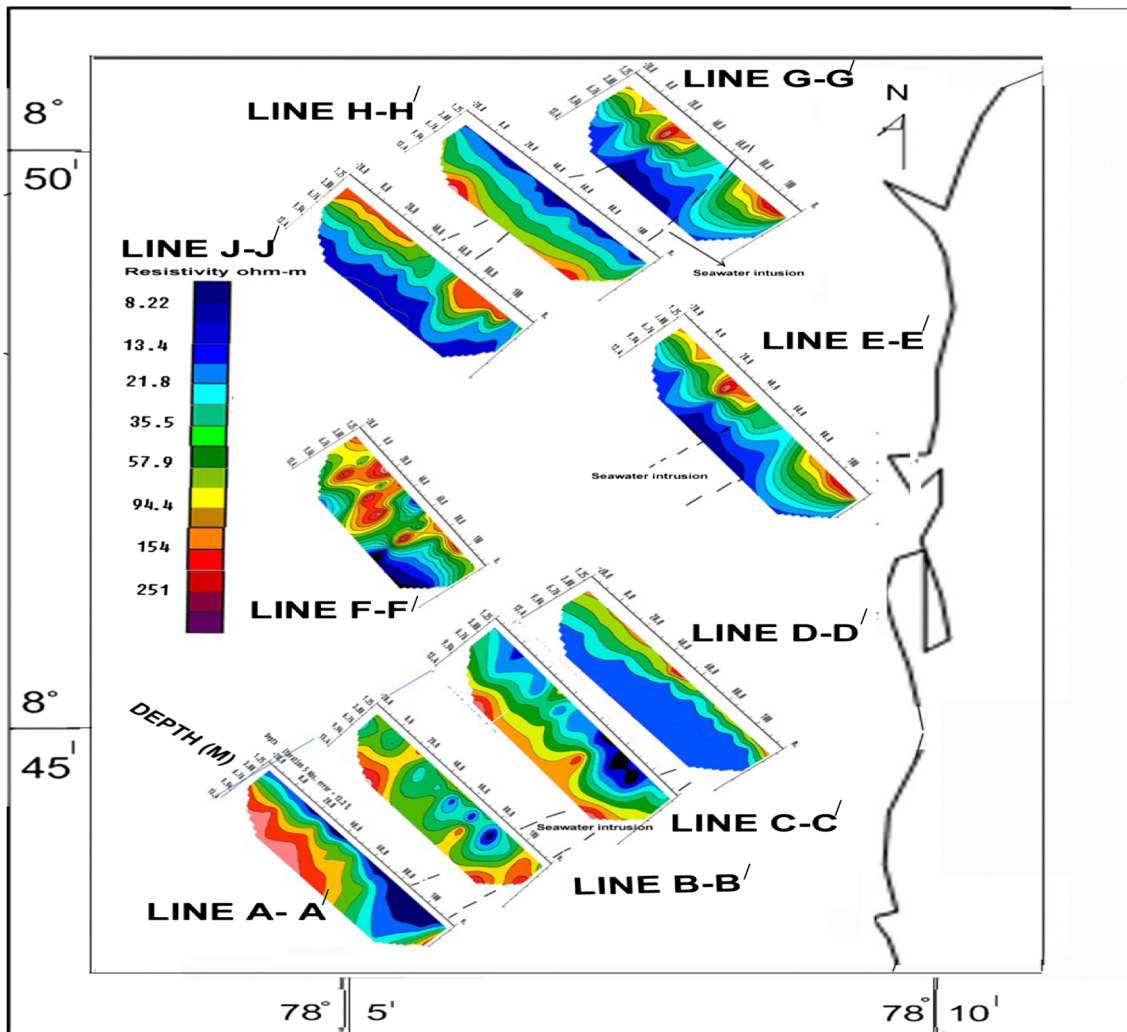

Fig. 2 Nine electrical resistivity images for resistivity distribution in Gulf of Mannar coast from Southern India
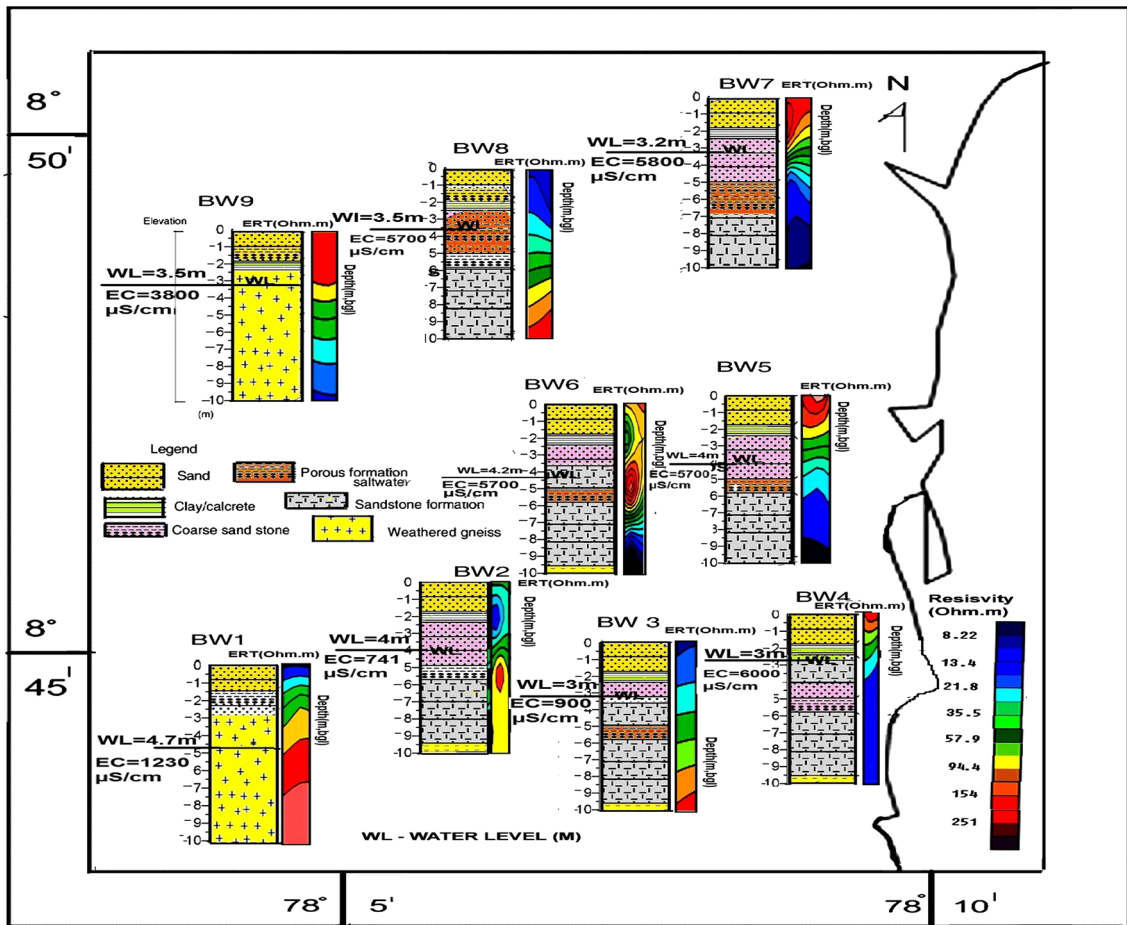
Fig. 3 Measured of groundwater level at nearby dug/open well and electrical conductivity (EC) of groundwater along with the resistivity values deduced from the electrical resistivity images and bore hole lithologs

depth and a distance of 40 m from this profile shows some mixing of water to the sea water (EC value = 5800 μS/cm). The sea water (resistivity range 0.14–5.0 Ω m) intrusion occurs at the depth of 6.7 m. The profile H–H′ at Melamaruthur was taken between the clay and teri sediment boundary. The clay mixed with calcrete layer was encountered with resistivity of 1–5 Ω m. The aquifer yield was good during the rainy season, but was observed as poor in summer due to high evapotransporation. The saline water aquifer having EC value of 5700 μS/cm was also observed on this profile. The last profile I–I′ at Mapillaiyurani resistivity image oriented NE–SW direction presented lateral variability in the resistivity distribution. The groundwater saturated zones in this area were identified with the low resistivity of 15 Ω m. The very low resistivity was observed at the SE corner (Fig. 2) which indicates the shell lime or calcrete formation with resistivity of 1–5 Ω m. But, the high resistivity range of 64–343 Ω m indicates weathered gneiss rock. In the shallow aquifer in teri

sediments with freshwater comparatively low resistivity of 12–28 Ω m was observed.

The range of resistivity from 1 to 5 Ω m indicates saline water/sea water intrusion in these profiles of the study area. The resistivity ranges from 5 to 10 Ω m suggested the existence of sandstone layer whereas the weathered gneiss rock has a high resistivity value of 200–465 Ω m. The resistivities of the palaeo-coastal formations change the fresh water into saline water due to low rainfall/low natural recharge and high evapotranspiration (Rangarajan et al. 2009; Mondal et al. 2011). The high sea water intrusion was identified near the shoreline of Therspuram (profile 4), Vellappatti (profile 5), Tharuvaikullam (profile 6), Pattinamaruthur (profile 7) and Melamaruthur (profile 8). The other parts of pseudo-sections suggest the fresh water in the shallow aquifer due to calcareous sandstone deposits near Medical College (profile 2) and Mapilliyurani (profile 9). The hard rock shallow aquifer occurs in Korampallam (profile 1) and Mapillaiyurani (profile 9) villages.

Hydrochemical characterization

Shallow aquifer resistivity is changeable with the movements of sea water and freshwater in the presence of coastal barriers (Misonou et al. 2013). In general, the fresh groundwater in the coastal area depends upon rainfall and low evapotransporation. For the evolution of groundwater quality, in total 18 samples were collected and analyzed separately for the periods of pre- and post-monsoons in 2012 from the dug wells (depths 5.5–15.0 m) in the study area. Statistical parameters, including minimum, maximum, mean and standard deviation, of different constituents of the samples for both the dry and wet seasons ($N = 18$) were computed, as shown in Table 1. Comparison of hydrochemical data with the World Health Organization (1984) drinking water standards showed that in the pre- and post-monsoons all the groundwater samples exceeded the guideline values for total dissolved solids (TDS: 500 mg/L), Chloride (Cl^-: 200 mg/L) and Sodium (Na^+: 200 mg/L) except Sulfate (SO_4^{2-}: 200 mg/L) about 33 % ($N = 3$) and 44 % ($N = 4$), respectively. The order of major cations and anions in groundwater samples obtained during the dry and raining seasons were $Na^+ > K^+ > Ca^{2+} > K^+ > Mg^{2+}$, and $Cl^- > HCO_3^- > SO_4^{2-}$, respectively.

This indicated that the groundwater quality has been significantly deteriorated. The degree of salinization in a well or a given area can be indicated by an increase in the TDS values. In particular, the TDS value in the pre-monsoon had a wide range between 373 and 3827 mg/L (mean 1407 mg/L) and in the post-monsoon the range

between 474 and 3840 mg/L (mean 2477 mg/L) which are shown in Table 1. Out of the total 9 well stations, three well area located nearby the profiles 1, 2 and 3 have TDS value less than 1500 mg/L where sea water intrusion was not observed in these ERT images (Sarma et al. 1982; Sarwade et al. 2007; Saxena et al. 2003). The ranges of Na^+ and Cl^- ions in the pre-monsoon were from 236 to 830 mg/L (mean 548 mg/L), and 35 to 135 mg/L (mean 87 mg/L), in the post-monsoon were from 256 to 910 mg/L (mean 674 mg/L) and 29 to 155 mg/L (mean 100 mg/L), respectively. The concentration of SO_4^{2-} in the pre-monsoon varied from 120 to 432 mg/L (mean 245 mg/L), in the post-monsoon varied from 121 to 455 mg/L (mean 287 mg/L).

The pH value varies from 7.1 to 8.3 (Fig. 4). It indicates that groundwater is in basic nature. The bicarbonate concentration ranges from 267 to 743 mg/L in the NE part of the study area (Fig. 10). Sample chlorine was normally high from 29 to 155 mg/L during both the seasons in the sea water intruded area. The major ion concentrations were derived from the fragment of shell and sedimentary rock types in Figs. 4, 5, 6, 7, 8, 9, and 10. The groundwater samples collected from Korampallam (profile 1), Medical College (profile 2) and Melamartgur (profile 8) villages indicate freshwater with less saline, whereas the samples collected from Therspuram (profile 4), Vellappatti (profile 5), Tharuvaikullam (profile 6), Pattinamaruthur (profile 7) and Melamaruthur (profile 8) were more saline due to the intrusion of saline water in Figs. 5, 6, 7, 8, 9, and 10. The spatial distribution of pH, TDS, Na^+, Mg^{2+}, Ca^{2+}, SO_4^{2-},

Table 1 Minimum, maximum, mean and standard deviation of groundwater samples in comparison with the worldwide average surface water and groundwater

Parameters	Periods								Standards for		
	Pre-monsoon in May 2012				Post-monsoon in September 2012				PLDW	SW	GW
	Minimum	Maximum	Mean	SD	Minimum	Maximum	Mean	SD			
Temperature	27.0	29.7	27.4	0.89	27.0	29.1	27.3	0.75	–	–	–
EC	584	5980	2202	1609	741	6000	3871	2360	750	–	–
TDS	373	3827	1407	1038	474	3840	2477	1510	500	–	–
pH	7.1	8.2	7.7	0.38	7.1	8.3	7.8	0.41	6.5–8.5	–	–
Na^+	236	830	548	252	256	910	674	275	200	5.20	30.00
K^+	128	980	367	253	73	780	298	210	100	1.30	3.00
Ca^{++}	40	135	101	45	42	145	105	45	75	13.40	50.00
Mg^{++}	14	135	89	47	21	135	90	49	30	3.40	7.00
Cl^-	35	135	87	44	29	155	100	44	200	5.80	20.00
SO_4^-	120	432	245	107	121	455	287	155	200	8.30	30.00
HCO_3^-	267	634	498	141	320	743	524	148	200	–	–

All ions in mg/L except EC in µS/cm at 27 °C, SD: standard deviation, pH: $-\log_{10}H^+$; collected 18 groundwater samples from dug wells in 2012

PLDW permissible limit for drinking water (WHO 1984), *SW* average surface water after Meybeck (1979), *GW* average groundwater after Turekian (1977)
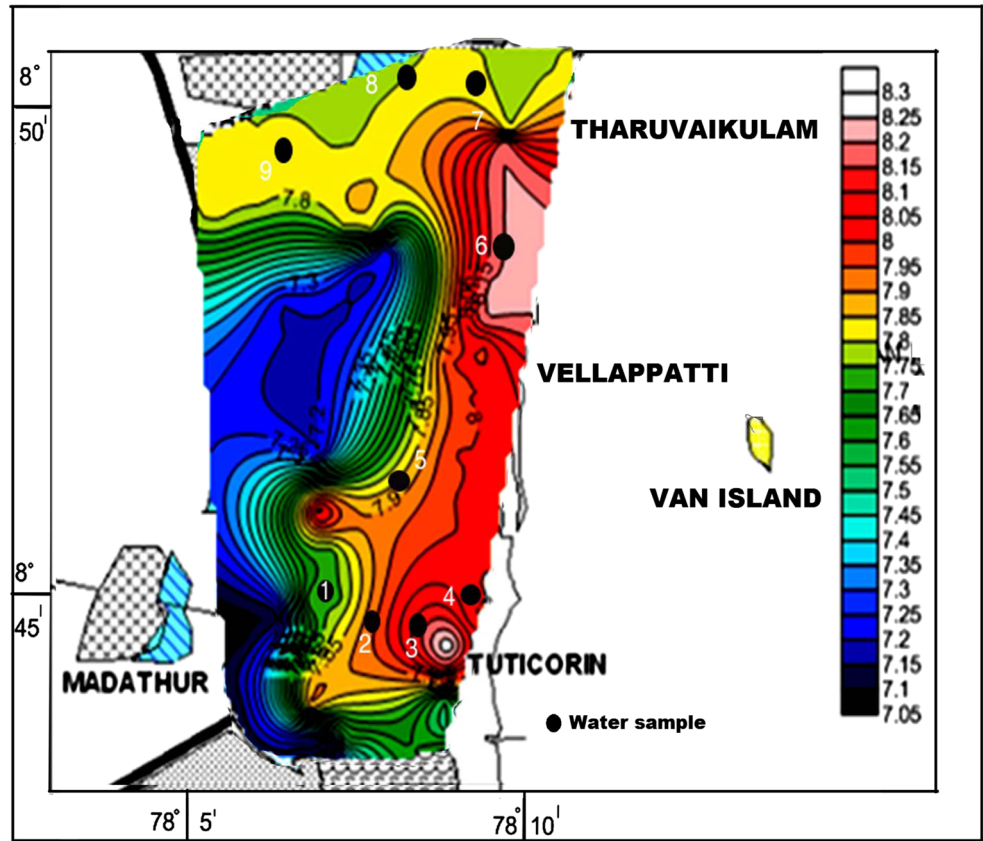
Fig. 4 pH distribution in the year 2012

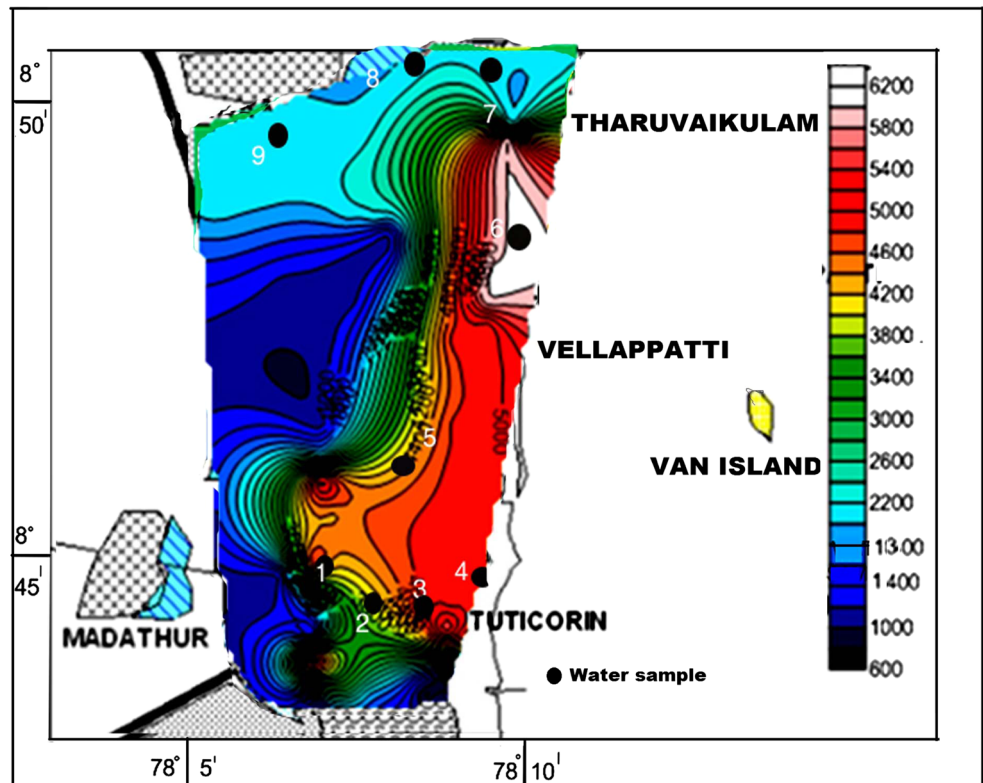**Fig. 5** Contour values of TDS (in mg/L) in the year 2012

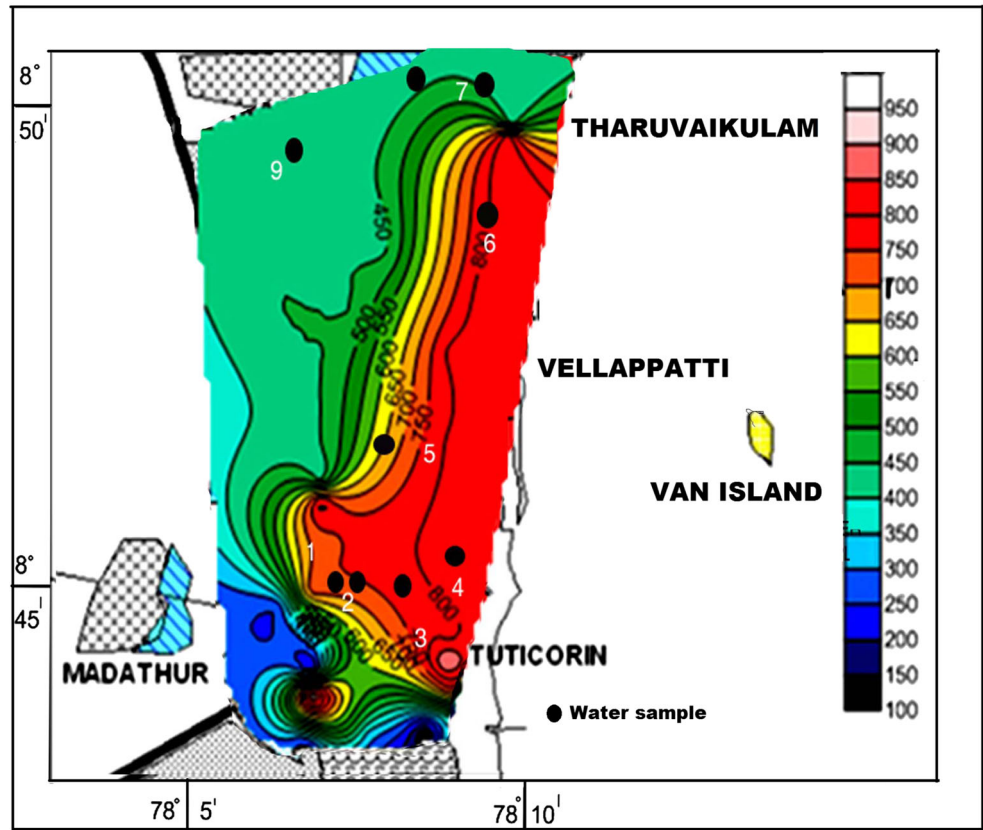**Fig. 6** Contour values of Na^+ (in mg/L) in the year 2012

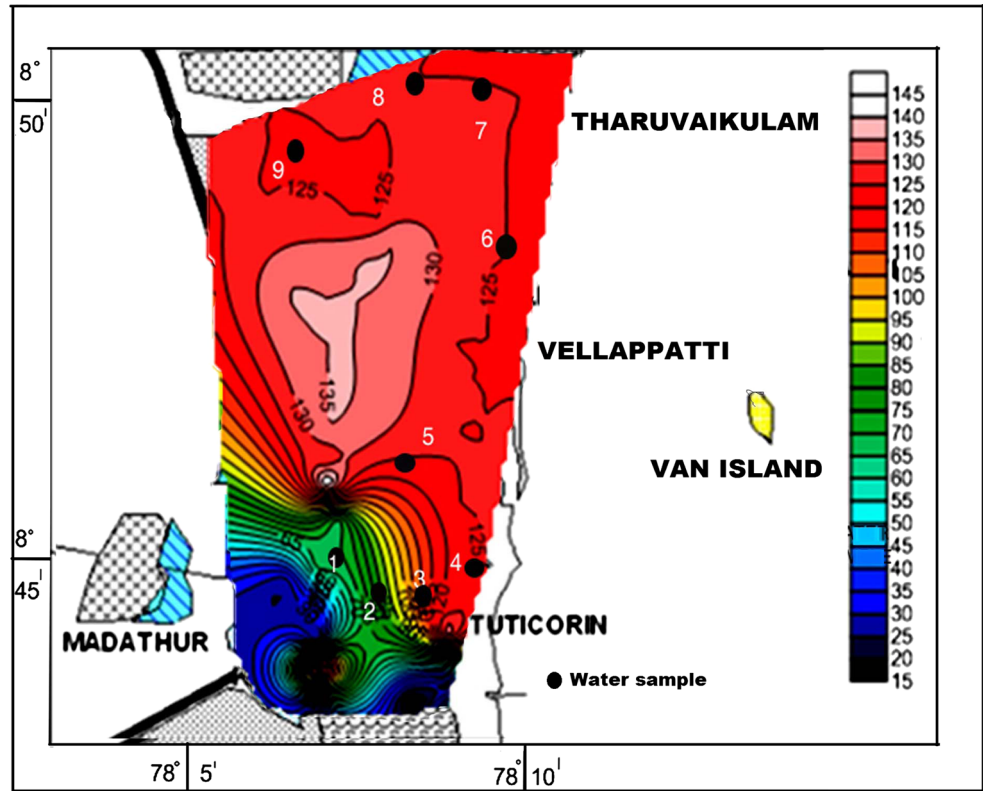**Fig. 7** Contour values of Mg^+ (in mg/L) in the year 2012

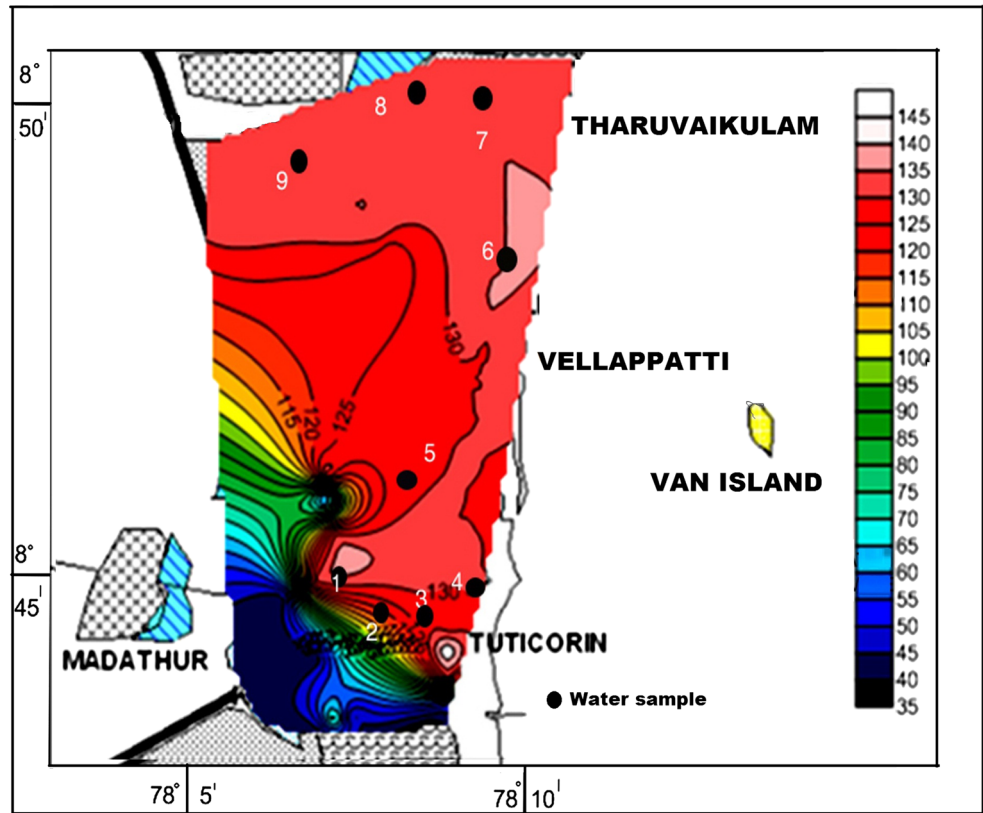Fig. 8 Contour values of Ca^{2+} (in mg/L) in the year 2012

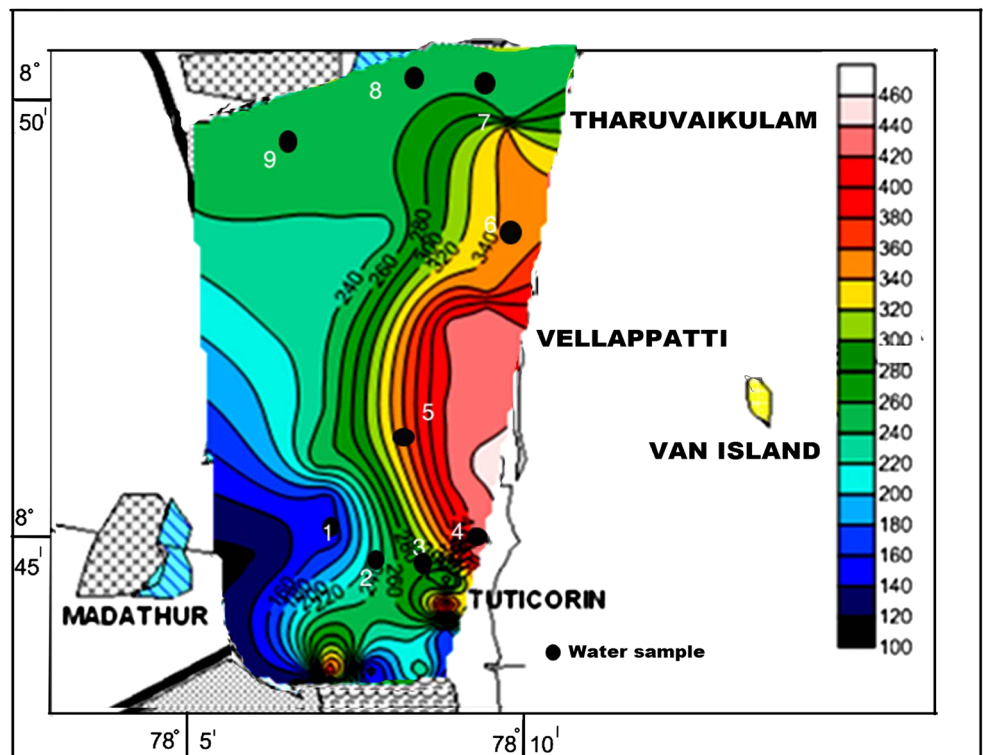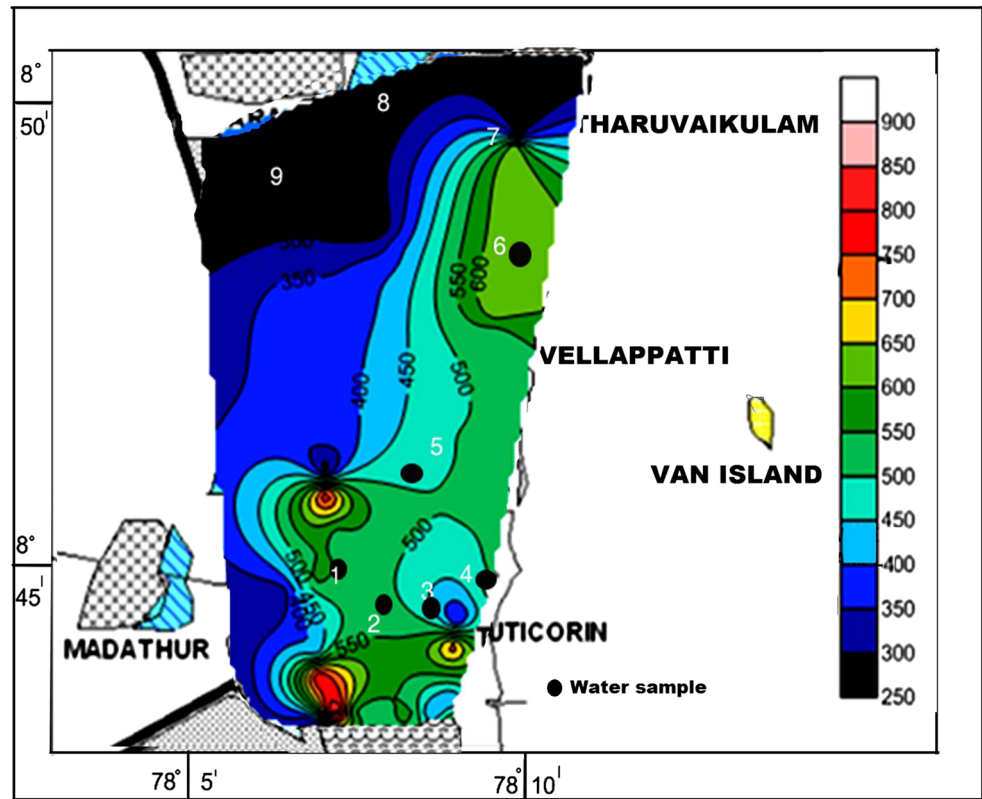Fig. 9 Contour values of SO_4^{2-} (in mg/L) in the year 2012

Fig. 10 Contour values of HCO_3^- (in mg/L) in the year 2012

and HCO_3^- constituents was plotted in Figs. 4, 5, 6, 7, 8, 9, and 10, which indicate clearly the deterioration of groundwater quality as well the occurrence of fresh groundwater at shallow depth.

The chemical analysis results of plagioclase (Na-rich) using Aquchem software employ the detailed environment of weathering sediments less than 0.2 and 0.8 in both the pre- and post-monsoons, respectively. It indicates rich gneiss rock in the elevated area. The molar ratios of (Na+K–Cl)/(Na+Cl) range from 0.2 to 0.8. The sodium concentrations were comparatively higher in the collected groundwater samples. The molar ratio of Na/(Na+Cl) is 0.5, which indicates the precipitation of calcium source of palaeo environment in the study area. The other samples with higher amounts of TDS were not used for domestic purposes. The ranges of TDS, Cl^-, Na^+ and HCO_3^- ratios indicate the saline water mixing at Therashpuram (profile 4), Vellappatti (profile 5), Tharuvaikulam (profile 6), Pattinamaruthur (profile7) and Melamaruthur (profile 8) villages in the study area.

Properties of core samples

Core samples were collected at 9 bore holes where the 2-D ERT profiles were taken. It was used to correlate and interpret the subsurface geological strata. The previous study of radio carbon dating that the Rameswaram and Keelakkarai terraces are 5440 ± 60, 4020 ± 160 and 3920 ± 160 years BP (Stoddart and Gopinatha Pillai 1972). The coastal terrace and sand dune in the recent formation of marine transgression and regression are in the mid-Holocene epoch (Krishna Kumar et al. 2012). Based on these results we conclude that Thoothukudi area was under the sea between 5400 and 3000 years ago. The events of ice melting and unnatural ice-stone rain/hail between 5000 and 4000 years ago resulted in the inundation of sea over this area and deposits of late Holocene marine transgression formation up to the Puthukottai Quartzite region for the stretch of around 17 km. The porosity, hydraulic conductivity and shallow aquifer depth were also used to identify about the status of groundwater in the study area. The withdrawal in open wells at Korampallam, Melamaruthur and Mapilaiyuram villages represented high yield of water supply from the gneiss rock. The shallow sandy formation acts as perched aquifer at Millerpuram, Medical College, Therspuram, Tharuvaikulam, Vellappatti, Mapilaiyurani and Patinamaruthur villages where freshwater exists at the depth of 4.5 m, bgl and is affected by sea water intrusion up to the depth of 10.0 m, bgl.

The grain size analysis was used to find out the weathering of sediments. The aim of this analysis was about the

Table 2 Results of grain size analysis of core samples for Holocene soil deposits

Grain size parameter	Observed value (in Phi)	Type of soil
Korampallam (BH_1)		
Graphical mean	4.2	Very fine sand
Inclusive graphical standard deviation	0.87	Moderately sorted
Inclusive graphical skewness	−0.087	Near-symmetrical
Graphic kurtosis	1.41	Leptokurtic
Medical College (BH_2)		
Graphical mean	2.1	Coarse sand
Inclusive graphical standard deviation	1.02	Poorly sorted
Inclusive graphical skewness	−0.57	Very coarse skewed
Graphic kurtosis	1.06	Platy kurtic
Millerpuram (BH_3)		
Graphical mean	2.13	Coarse sand
Inclusive graphical standard deviation	0.88	Moderately sorted
Inclusive graphical skewness	−0.5625	Very coarse skewed
Graphic kurtosis	0.928	Lepto kurtic
Therspuram (BH_4)		
Graphical mean	3.5	Fine sand
Inclusive graphical standard deviation	0.497	Well sorted
Inclusive graphical skewness	−0.221	Coarse skewed
Graphic kurtosis	1.229	Lepto kurtic
Vellappatti (BH_5)		
Graphical mean	2.56	Coarse sand
Inclusive graphical standard deviation	0.819	Moderately sorted
Inclusive graphical skewness	−0.512	Very coarse skewed
Graphic kurtosis	1.27	Lepto kurtic
Tharuvaikulam (BH_6)		
Graphical mean	2.66	Coarse sand
Inclusive graphical standard deviation	0.598	Moderately Well sorted
Inclusive graphical skewness	−0.295	Coarse skewed
Graphic kurtosis	1.27	Lepto kurtic
Pattinamaruthur (BH_7)		
Graphical mean	3.02	Very fine sand
Inclusive graphical standard deviation	1.25	Poorly sorted
Inclusive graphical skewness	−0.629	Very Coarse skewed
Graphic kurtosis	1.297	Lepto kurtic
Melamaruthur (BH_8)		
Graphical mean	2.4	Coarse grained
Inclusive graphical standard deviation	1.1	Poorly sorted
Inclusive graphical skewness	−0.424	Very Coarse skewed
Graphic kurtosis	1.297	Lepto kurtic
Mapillaiyurani (BH_9)		
Graphical mean	3.13	Very fine sand
Inclusive graphical standard deviation	1.09	Poorly sorted
Inclusive graphical skewness	−0.284	Coarse skewed
Graphic kurtosis	0.928	Meso kurtic

low and high tide environments during Holocene. The graphic mean, skewness and kurtosis of the grains are shown in Table 2 for the environmental status. The mean values of 3.02–2.56 Phi indicate about the fine, very fine and coarse sand at the BH_1 to BH_9. These sediments were derived from the palaeo-coastal environment. The

Fig. 11 Soil sample collection by a bore hole

sorting is very well, poorly and moderate. The most sorting ranging 81–2.60 indicates the glacial fluvial environments. The range of skewness values from 0.087 to 0.284 indicates the fine grain due to wave/tidal activity, but the coarse grains indicate the fluvial environment. The kurtosis varied from meso to platokurtic range about 40 % in the study area. It indicates that the sands are very comparable in occurrence (Swamy 2012), which are shown in Figs. 11 and 12.

In general, the electrical resistivity method has been used to investigate stratification of soil sediments/aquifer disposition, and their hydraulic condition (Mazac et al. 1985; Pozdnyakova et al. 2001). In the study area it was utilized to determine the groundwater occurrence, whereas the granulometric analysis in the soil profiles was used to determine the saline/sea water intrusion in the portable groundwater environment. The shallow groundwater was determined through the soil particle size and resistivity measurements (Chik and Islam 2012). The following conclusion is made based on the results of soil particle size distributions in conjunction with the electrical resistivity.

The grain size characteristic such as size and sorting having variation with depths changes at 9 bore hole samples analyzed mechanically (Table 2) and microscopic method. The mechanical method was to estimate the porosity and hydraulic conductivity for the coastal shallow alluvium deposits. The resistivity and grain size of variation for the fine, medium and coarse grains were determined the sequential seasonal variation sediment deposits. The grain variation deposits of sand dunes control the groundwater flow movement in shallow aquifer, and mixing of saline/sea and freshwater (Misonou et al. 2013). In the coastal area the loose sediments have low resistivity values of 10–20 Ω m and sand dunes have high resistivity of 150–200 Ω m.

The grain size and sorting (i.e., angular, sub-angular, rounded and sub-rounded) were observed by photomicroscopy. The results suggest depositional environment in the Holocene sediments such as wave and river deposits (Fig. 13). The porosity and hydraulic conductivity of 9 soil samples with different depths were calculated. The porosities vary from 30 to 35 % near Vellappatti, Tharuvaikulam, Medical College, Pattinamaruthur and Poolnayaganpettai. But, hydraulic conductivity ranges from 0.2 cm/h in a layer near clay bearing perched aquifer to 1.7 cm/h for sandy aquifer. The aquifer potentiality was determined by grain size distribution analysis and resistivity survey (Arshad et al. 2013). There is a good agreement between aquifer parameter calculated from the interpreted resistivity value of the aquifer and those deduced from grain size distribution and pumping test analysis. In general, the compact rocks expose low porosity with higher electrical resistivity, but loose sandy soil grain
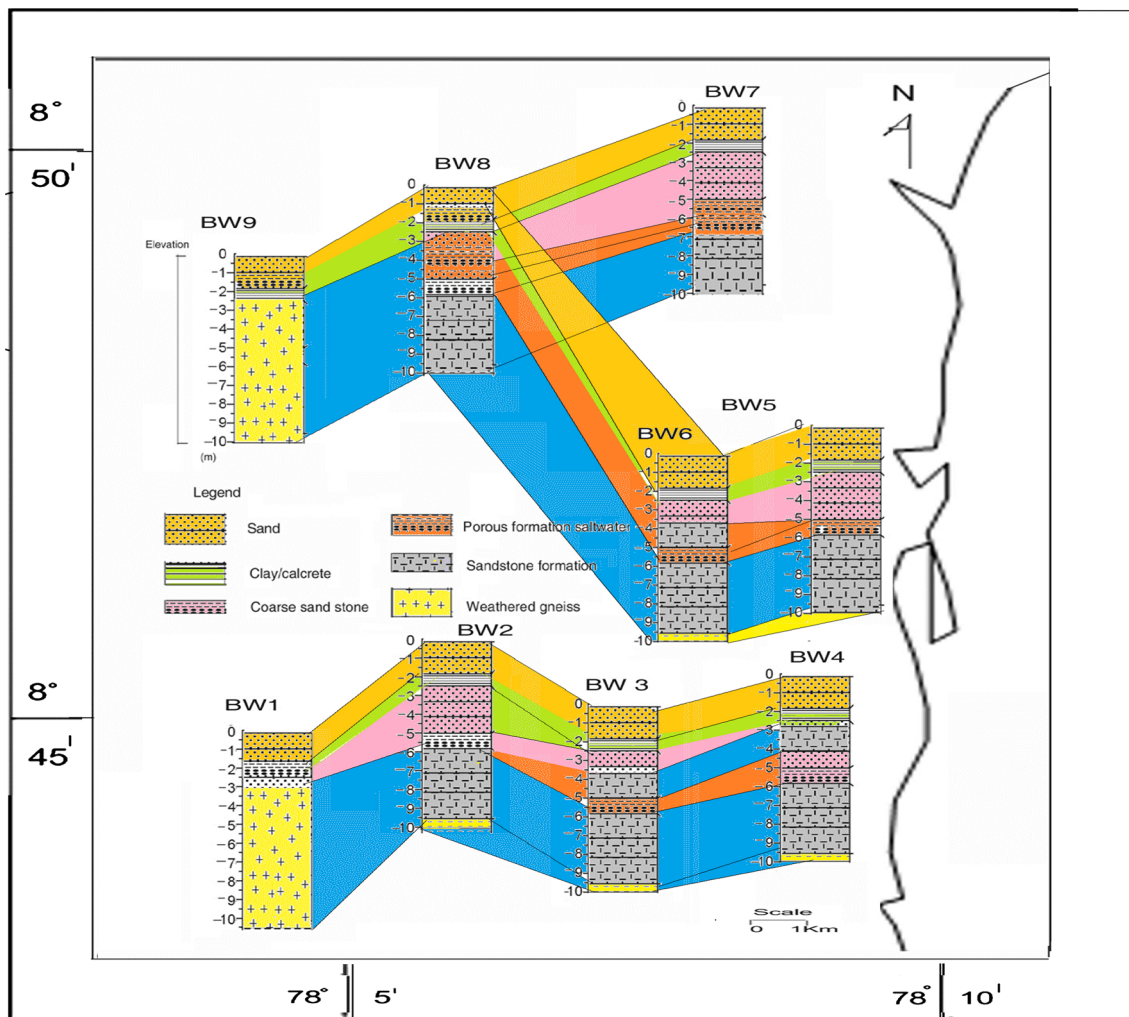
Fig. 12 Geologic columns collected from 9 bore holes and fence diagrams

porosity is less with lower electrical resistivity. The compaction of rocks reveals the lower porosity and sedimentary rocks as sandstone has high porosity due to loose soil package.

Conclusions

This study mainly focused on groundwater resource assessment in Holocene deposits in the Gulf of Mannar coast from Southern India. The 2-D ERT is a good tool for finding the contrast of the sediments. The low and high resistivity variations in the pseudo-section of resistivity indicate two zones, 1–5 Ω m for saline/sea water and 10–20 Ω m for sandy formation, respectively. On the contrary, the loose sediments have comparatively low resistivity values of 10–20 Ω m and sand dunes of 150–200 Ω m. The sea water intrusion of this coastal area by the sediment thickness is remarkable in NE, SW and middle

parts. However, in the W and NW parts, weathered gneiss rock completely covers. The middle part of the area is covered by the weathered gneiss rock. During off season the water supply in this part declines to the minimum and the groundwater quality deteriorated and becomes saline.

The grain size analysis and sorting of the Holocene sediment deposits reveals that porosities vary from 30 to 35 % whereas hydraulic conductivity ranges from 0.2 cm/h of clay bearing perched aquifer to 1.7 cm/h for the sandy aquifer. Overexploitation of groundwater shall not be done, otherwise saline water will rise. The maximum depth of bore hole in these areas recommended is up to 10 m for groundwater exploitation. The groundwater samples revealed the high range of saline sea water intrusion due to the hydrostatic pressure of wave and tidal impacts. The variation of the mean, sorting, kurtosis and skewness in the granulometric analysis shows near the Holocene deposits in the study area. Thus, this integrated approach in conjunction with Holocene soil deposits in Gulf of Mannar Coast
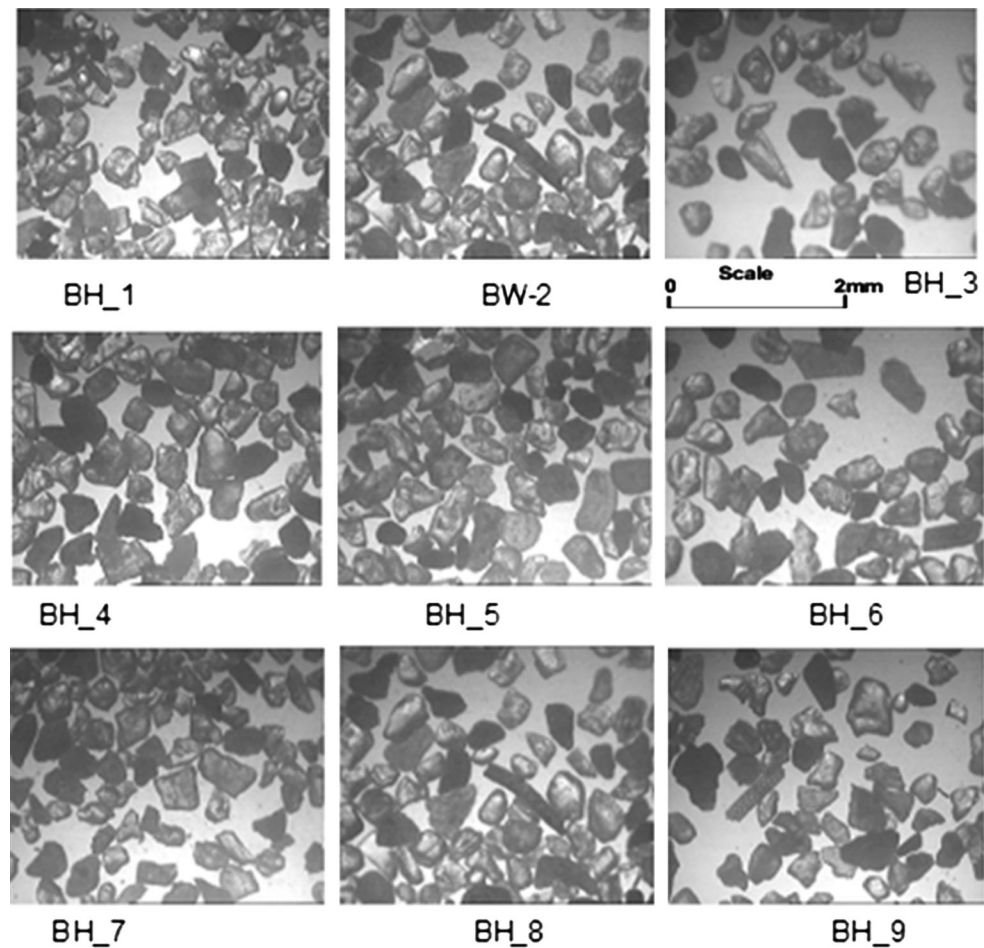
Fig. 13 Grain size analysis using microscope for the BH_1 (Korampallam), BH_2 (Medical College), BH_3 (Millerpuram), BH_4 (Thershpuram), BH_5 (Vellappatti), BH_6 (Tharuvaikulam), BH_7 (Pattinamaruthur), BH_8 (Melamaruthur), and BH_9 (Mapillaiyurani) samples

from Southern India provides confidence in identifying the fresh and saline groundwater zones as well as impact of palaeo-geography at shallow depths. The information obtained represents a base for the Holocene soil deposits that will help in the planning, protection and decision-making regarding sustainable groundwater management.

References

Aguilar JR (2013) Analysis of grain size distribution and hydraulic conductivity for a variety of sediment types with application to Wadi Sediments. Thesis for Master degree, King Abdullah University of Science and Technology, Thuwal, Kingdom of Saudi Arabia, p 134

American Public Health Association (APHA) (1985) Standard methods for the examination of water & waste. 16th edn. Am Public Health Assoc Washington DC, p 100

Angusamy NG, Rajamanickam V (2007) Coastal processes of Central Tamil Nadu, India: clues from grain size studies. Oceanologia 49(1):41–57

Antony Ravindran A, Ramanujam N (2014) Detection of submarine groundwater discharge to coastal zone study using 2-D electrical resistivity imaging study at Manapad, Tuticorin, India. Indian J Geo Mar Sci 43(2):224–228

Arshad M, Shakoor A, Ahmad I, Ahmad M (2013) Hydraulic transmissivity determination for the groundwater exploration using vertical electrical sounding method in comparison to the traditional methods. Pak J Agri Sci 50(3):487–492

Chik Z, Islam SMT (2012) Finding soil particle size through electrical resistivity in soil site investigations. Electro J Geotech Eng 17:1867–1876

Choudhury K, Saha DK, Chakraborty P (2001) Geophysical study for saline water intrusion in a coastal alluvial terrain. J Geophys 46:189–200

Dahlin T, Loke M (1998) Resolution of 2D Wenner resistivity imaging as assessed by numerical modelling. J Appl Geophys 38:237–249

Domenico PA, Schwartz FW (1990) Physical and chemical hydrogeology. Wiley, New York

Edet AE, Okereke CS (2002) Delineation of shallow groundwater aquifers in the coastal plain sands of Calabar area (Southern Nigeria) using surface resistivity and hydrogeological data. J Afr Earth Sci 35(3):433–443

Folk RL (1974) Petrology of sedimentary rocks. Hemphili Publication, Company, Austin, p 182

Friedman GM (1961) Distinction between dune, beach and river sands from their textural Characteristics. J Sediment Petrol 31(4):514–529

Frohlich RK, Urish DW, Fuller J, Reilley MO (1994) Use of geoelectrical method in groundwater pollution surveys in a coastal environment. J Appl Geophys 32:139–154

Griffth DH, Turnbull J (1985) A multi-electrode array for resistivity surveying. First Break 3:16–20

Gurunadha Rao VVS, Tamma Rao G, Surinaidu L, Rajesh R, Mahesh J (2011) Geophysical and geochemical approach for sea water intrusion assessment in the Godavari Delta Basin, A.P., India. Water Air Soil Pollut 217(1–4): 503–514

Joshua EO, Oyebanjo OA (2010) Grain-size and heavy mineral analysis of river Osun sediments sandstones. J Geol 70:737–753

Koike K, Matsuda S (2005) Spatial modeling of discontinuous geologic attributes with geotechnical applications. Eng Geol 78:143–161

Krishna Kumar S, Chandrasekar N, Seralathan P, Dajkumar Sahayam J (2012) Diagenesis of Holocene reef and associated beach rock of certain coral islands, Gulf of Mannar, India: implication on climate and sea level. J Earth Syst Sci 121(3):733–745

Loke M, Acworth I, Dahlin T (2003) A comparison of smooth and blocky inversion methods in 2-D electrical imaging surveys. Expl Geophys 34:182–187

Mazac O, Kelly WE, Landa I (1985) A hydrogeophysical model for relations between electrical and hydraulic properties of aquifers. J Hydrol 79:1–19

Melloul A, Collin M (2006) Hydrogeological changes in coastal aquifers due to sea level rise. Ocean Coast Manage 49:281–297

Meybeck M (1979) Concentrations des eaux fluviales en elements majeurs et apports en solution aux oceans. Rev Geol Dyn Geogr Phys 21:215–246

Misonou T, Asaue H, Yoshinaga T, Matsukuma Y, Koike K, Shimada J (2013) Hydrogeologic-structure and groundwater-movement imaging in tideland using electrical sounding resistivity: a case study on the Ariake Sea coast, southwest Japan. Hydrogeol J 21:1593–1603

Mondal NC, Rao VA, Singh VS, Sarwade DV (2008) Delineation of concealed lineaments using electrical resistivity imaging in granitic terrain. Curr Sci 94(8):1023–1030

Mondal NC, Singh VS, Rangarajan R (2009) Aquifer characteristics and its modeling around an industrial complex, Tuticorin, Tamil Nadu, India: a case study. J Earth Sys Sci 188(3):231–244

Mondal NC, Singh VP, Singh VS, Saxena VK (2010) Determining the interaction between groundwater and saline water through groundwater major ions chemistry. J Hydrol 388(1–2):100–111

Mondal NC, Singh VP, Singh S, Singh VS (2011) Hydrochemical characteristic of coastal aquifer from Tuticorin, Tamil Nadu, India. Environ Monit Assess 175(1–4):531–550

Pozdnyakova L, Pozdnyakov A, Zhang R (2001) Application of geophysical methods to evaluate hydrology and soil properties in urban areas. Urban Water 3:205–216

Rangarajan R, Mondal NC, Singh VS, Singh SV (2009) Estimation of natural recharge and its relation with aquifer parameters in and around Tuticorin town, Tamil Nadu, India. Curr Sci 97(2):217–226

Revelle R (1941) Criteria for recognizing sea water in groundwater. Am Geophys Union Trans 22:593–597

Sankaran S, Sonkamble S, Krishnakumar K, Mondal NC (2012) Integrated approach for demarcating subsurface pollution and saline water intrusion zones in SIPCOT area: a case study from Cuddalore in Southern India. Environ Monitor Assess 184(8):5121–5138

Sarma VVJ, Prasad NVBSS, Prasad R (1982) The geochemistry of groundwater along Visakhatnam–Bhimilipatnam coast with regard to their utility in drinking, domestic and irrigation purposes. J Expl Geophys 2(4):37–52

Sarwade DV, Nandakumar MV, Kesari MP, Mondal NC, Singh VS, Singh B (2007) Evaluation of sea water ingress into an Indian Attoll. Environ Geol 52(2):1475–1483

Saxena VK, Singh VS, Mondal NC, Jain SC (2003) Use of chemical parameters to delineation fresh groundwater resources in Potharlanka Island, India. Environ Geol 44(5):516–521

Selvam S, Manimaran G, Sivasubramanian P, Balasubramanian N, Seshunarayana T (2014) GIS-based evaluation of water quality index of groundwater resources around Tuticorin coastal city South India Environ. Earth Sci 71:2847–2867

Singa Raja V, Shah BM (2006) Holocene marine transgression in the Eleru Delta, East Godavari District, Andhra Pradesh. J Geol Soc India 67:605–608

Stoddart DR, Gopinatha Pillai CS (1972) Raised reefs of Ramanathapuram, South India. Trans. Inst of British Geographers. Pub., No. 56

Swamy ASR (2012) Sedimentary environments in the Godavari delta. In: ONGC Academy Sponsored Training Programme on "Modern Deltas—a Field Seminar" Organized by Delta Studies Institute, Andhra University, Visakhapatnam, 3–7 December, 2012, pp 165–175

Turekian KK (1977) Geochemical distribution of elements, 4th edn. Encyclopedia of Science and Technology, McGraw-Hill, New York, p 630

Valentina YH, Petra JM, Sergey K, Evgeny L (2013) Holocene marine transgression in the Black Sea: new evidence from the northwestern Black Sea shelf. Quatern Int. doi:10.1016/j.quaint. 2013.07.027

Wilson SR, Ingham M, McConchie JA (2006) The applicability of earth resistivity methods for saline interface definition. J Hydrol 316:301–312

World Health Organization (WHO) (1984) Guideline of drinking quality. World Health Organization, Washington, DC, pp 333–335