Integrated geophysical and geochemical assessment of submarine groundwater discharge in coastal terrace of Tiruchendur, Southern India

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Abstract

Submarine groundwater discharge (SGD) study is essential for groundwater in coastal terrace at Tiruchendur. The famous Murugan Temple is located in the area and around 25,000 people who visit this temple use the SGD well water at NaaliKinaru (a small open well) as holy water and drink it. The rock and soil type are sandy clay, silt, beach sand, calcarenite, kankar, gneissic rock and charnockite in base rock. Megascopic identification method was used to identify the porous and permeable rocks such as calcarenite, sandstone and kankar to support to increase SGD flux. Grain size study was used to identify the paleo-coastal estuarine environment with sediment deposits in the terrace. The square array electrical resistivity method was used to study the subsurface geology and aquifer depth. The 2d ERT technique was used to identify the subsurface shallow perched aquifer of freshwater. The magnetotelluric survey method was used to scan the entire subsurface geological and tectonic uplift, coastal ridges, rock folded subsurface structural features of continental and oceanic tectonism. Darcy's law was used to calculate the SGD flux rate in the above study area.

Keywords SGD · Calcarenite · Grain size · Estuarine · Aquifer · Magnetotelluric

Introduction

The submarine groundwater discharge (SGD) study plays a major play role in the coastal aquifer and water resources management. Taniguchi and Makoto (2002), Robb (1990), Peng et al. (2008), Land and Paull (2000). Studying the SGD discharge with flux rate estimation is essential one for coastal zones monitoring of freshwater environment. Porubsky (2014), Burnett et al. (2006), The SGD discharge with flux rate estimation is essential one for monitoring of freshwater environment in coastal zones. Zhang et.al (2020), Duque et.al (2020). The huge volume of the freshwater is discharged into the oceans regularly due to heavy rain. Therefore, aquifer characteristic study is essential for

SGD flux estimation. Prakash et al. (2018), Manivannan and Elango et al. (2019), Babu et al. (2009, 2021). An estimation of freshwater discharge using electrical resistivity methods of 2D ERT and magnetotelluric method. Ma and Zhang (2020), George et al. (2018), Jeyapaul et al. (2020), Ravindran et al. (2021). The main aim of discharge of freshwater is move through the sandstone formation. Geochemical studies were carried out by some researchers, Selvam et al. (2021a, b).

The study area is mostly covered with recent deposits of coastal alluvium, shell with marine environments of calcareous sandstone with shell material, Oolitic structure of lime, clay deposits in the study area. The terrace was formed due to the tectonic upliftment of coastal and continental movement. The Valli cave was formed by waves and is made up of lime calcareous kankar and calcarenite rocks. The terrace is completely made of calcareous materials. The “Naalli Kinaru” small open well is considered to be sacred and of divine origin. This is a small open well received the water from SGD discharge of water. A sub-stream of the Tamirabarani River once flowed toward the northern end of the Tiruchendur terrace.

The study area has semi-tropical climate condition. May to August is the hottest months. December to February is

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coolest months of the study area. The highest average temperature of around 35 °C is recorded in the month of June every year. The mean annual temperature is 28.3. The mean annual precipitation is 675 mm. Major rainfall is received during the northeast monsoon period between October and December. The maximum rainfall is usually received during November which is around 1131 mm.

The coastal zone tapers downwards towards the sea. The costal sediments assume different forms along the coastal belt due to Neotectonic activities. Raised beaches and cliffed shoreline are observed in Tiruchendur. These beach ridges or terraces are covered by aeolian sands and are undulated with calcareous cementing medium. There are many silted up lagoons behind the beach ridges during the rainy season and the lagoons are filled with freshwater but become hypersaline during summer.

The important coastal features are bays, lagoons, estuaries, cliffs, dunes, backshore width, beach width, and wave cut features. The cliff section of rock calcarenite is made by high energy wave action and is cut into notches and caves at different levels in the terrace. In Tiruchendur, wave pressure generates high energy for erosion activity. The study focuses on the coast terrace of Tiruchendur. It is tectonically connected by the tributaries of the Tamirabarani channel. The study area Tiruchendur terrace is located in the middle part of the Gulf of Mannar coast.

Material and methods

The present study focuses on the discharge of freshwater into subsurface through hydraulic connection of sea bottom in the coastal terrace of Tiruchendur coast. The 2D electrical resistivity imaging (2D ERI), Electromagnetic, Geotechnical logging, Aquifer system, Topographical study, Tectonic settings of faulted movement through the satellite imagery wave were used for the aquifer characteristic study.

The 2D electrical resistivity imaging technique is used to find out the subsurface geological and hydrogeological aquifer thickness. The multicore cable with resistivity meter was used for the data collection in imaging study. The Werner configuration was used for this survey. The collected data were plotted in the Res2DINV software for pseudosection preparation with data interpretation.

In the present study, SGD flux estimation was studied with the help of 2D electrical resistivity, magnetotelluric, Bore hole drilling, grain size Granulometric study, Microscopic and Megascopic study of rocks. In thin section identification study was used for megascopic identification of rock with Quartz grains and association of Magnetite, Ilmenite, Zircon embedded to consolidate with cementing matrix of calcareous material.

Megascopic Identification

The petrological study of the rock revealed megascopically fine and oolitic texture of calcareous cemented sandstone, ferrous rich calcareous limestone, and oolitic texture with coarse and fine grained porous siliceous material cemented with lime material. Most of the parent rock is intergrowth and porous filling magnetite, illuminate mineral enriched. The paleo-river sediments and sandstone deposits are completely altered into metamorphic sheared grains from granitic rock with accessory minerals. The garnet, illuminate, embedded quartz and feldspar grains are seen in the entire rock. The Arkose rock contains feldspar and quartz type of mineral intergrowth in step like terrace (Barnard et al. 2013). The grains texture in the top to bottom level of the terrace is low to high sorting. The temperature variation and upliftment of shearing grain calcarenite are recorded in the stone. (Fig. 2).

The Valli Cave is made up of porous and permeable formation of calcarenite, sandstone and Kankar formation that is identified in the microscopic study.

Microscopic identification

In the microscopic identification of mineral and quartz with cementing matrix material, the followings were observed: the shape and size of minerals, grains with porous medium are also measured in the microscopic study.

Electrical resistivity method (VES)

Vertical Electrical Sounding (VES) method and SGD study have been carried out in various coasts of world. Burnett et al. (2006), Yadav (2019), Viso et al. (2010), Swarzenski and Izbicki et al. (2009), Henderson et al. (2010).

Five VES profiles were taken near the beach of Tiruchendur. The Azimuthal square array method was used to identify the deeper aquifer system and compare it with bore well litho log data. The aquameter is used for the data collection, the four copper electrodes, wire spool, with equal short interval of 1.75 m depth is followed for shallow aquifer identification. Azimuthal square array is a scientific method to cover more depth of penetration compare to Wenner configuration. Spacing (A) is equal to the depth of penetration. $pa = \frac{k \times v}{i}$; Pa = apparent resistivity, K = Geometric factor for the array, V = Potential differences in volt.

I = Current magnitude in amperes, K = Geometrical factor for square array formula.

$$K = \frac{2\pi A}{2-(2)^{1/2}} = k \text{ factor calculation formula of side length}$$
 of the square array method.

Square Array method electrode arrangement (Habberjam 1972; Habberjam and Watkins 1967; Antony Ravindran 2012).

Fig. 1 Location map of the study area

Fig. 2 (a) Calcareenite rock (b) Beach rock exposure (c) Calcareenite in compact nature (d) Oolitic nature of calcarenite rock (e) Valli cave entrance (f) Valli cave below 15 m MSL

Fig. 3 (a) Feldspar+quartz matrix (b) Feldspar+biotite (c) Quartz cemented in feldspar (d) quartz+feldspar+biotite grains (e) rutile+feldspar (f) pyroxene grain+quartz (g) quartz class embedded

by calcareous material (h) fossil in sandstone (i) angular shape quartz (j) quartz matrix with other minerals (k) feldspar+quartz matrix presents in quartz (l) garnet grains with quartz

Fig. 4 (a) Quartz+feldspar (b) quartz+biotite (c) aggregate of quartz+feldspar+biotite (d) feldspar alteration (e) quartz cementing medium (f) shell material (g) garnet+apatite (h) milky quartz from

quartzite area (i). wave sorted quartz grain (j) Rutile+apatite (k) quartz grain weathered from quartzite ridge (l) well sorted quartz grain from estuarine environment (m) Rutile (n) Zircon mineral (o) quartz

Fig. 5 Azimuthal square array data collection and electrode arrangements in Tiruchendur terrace

Fig. 6 Azimuthal square array electrical resistivity sounding profile 1

The shallow depth of resistivity is 10 ohms, and this is indicating the freshwater SGD flow in 10 m depth. The depth of 40, 70 m is a freshwater resistivity range of 4 ohms. The seawater or saline interface is identified in the resistivity of 0.1–3 Ω .

2D electrical resistivity imaging (ERI) study

The 2D electrical resistivity imaging is a useful tool for SGD path study. The subsurface geology, freshwater and saline water studies were carried in the the 2D ERT equipment with multicore cable, 40 copper electrode, 12 V battery. The two ERT profiles were carried out from parallel to the

coast of dunal area and near shoreline area covers a 300 m distance.

Profile1

Profile 1 covered a length of 300 m with Wenner–Schlumberger configuration. The subsurface geology showed the freshwater perched aquifer in the dunal area at depth of 6–8 m resistivity ranging from 4.00 to 5.00 Ω .m and this seen in the middle part of the area. The uplift of weahtered gneissic rock and its resisitivity is 5.00–700 Ω .m. The low resisitiity is obtained from 2d ERI pseudosection due to the seawater intrusion by dynamic wave action in the depth of 14 m (Fig. 10).

Fig. 7 Azimuthal square array electrical resistivity sounding profile 2

Fig. 8 Azimuthal square array electrical resistivity sounding profile 3

Fig. 9 Azimuthal square array electrical resistivity sounding profile 4

Fig. 10 Electrical resistivity imaging (ERI) Profile1

Profile 2

Profile 2 is covering 300 m distance of NE-SW direction of shoreline area. The upliftment of coastal granitic rock is intruded from the deeper level to top. The beach exposure is clearly seen in the 2D ERT pseudosection at an apparent resistivity of $2.38 \Omega.m$. The low resistivity of seawater intrusion at shallow level is $0.863 \Omega.m$. In the depth of 31.3 m, an apparent resistivity is $4 \Omega.m$ which indicates SGD. The

freshwater is moving from highly elevated continental area to oceanic plate of coastal shore line area. (Fig. 11).

Magnetotelluric method

Magnetotelluric method is used to identify the subsurface geology, formation and freshwater discharge, Li and Jie (2017), Vozoff and Keava (1991), Abdelzaher et al. (2012),

Fig. 11 Electrical resistivity imaging (ERI) Profile 2

Fig. 12 Tiruchendur coastal shoreline area

deGroot-Hedlin (1990), Jones and Alan (1988), Duque and Carlos (2008), Falgàs (2009), Demirci and İsmail (2017), Albouy et al. (2001). The magnetotelluric method has been used by ADMT-300S, equipment with the help of M, N copper probe continuously shifted by equal distance and depth of coverage which was also changed to cover 300 m. The resistivity variation clearly demarcates the different soil, rock types and coastal boundaries. The fresh/saline water interface was also distinguished with the help of magnetotelluric images.

The magnetotelluric method is useful for subsurface deep or aquifer study. The aquifer thickness, freshwater movement, saline intrusion, folded and faulted tectonic movement of landscapes Geomorphologic changes of the river and coastal sediment into meta-sedimentary rock were studied.

The petrological study of the soil type and rock type in the area showed that it was mostly covered by the shell, sandstone, calcareous sandstone, sandy loam, clay loam, shell with lime material, calcareous limestone and paleo-marine clay deposits in the study area.

Fig. 13 Magnetotelluric method profile 1 at Tiruchendur coast

Tiruchendur profile 1

Profile 1 is at a distance of 130 m parallel to the coast of Tiruchendur terrace. The other side of terrace has highly intrusive rock from deeper level range of 0.27–0.33 Ω .m.

Fig. 14 Magnetotelluric method profile 2 at Tiruchendur coast

The temple of Murugan is placed on the hard terrace. The lowest value of 0.03–0.06 Ω .m is indicating the SGD flow. The SGD discharge is at the depth of 30 m, 60 m, 80 m and 120 m depth in the magnetotelluric method. (Fig. 13).

Tiruchendur profile 2

Tiruchendur profile 2 covers a stretch of east to west a distance of 170 m the range of resistivity 0.03–0.07 and this indicates the high seawater intrusion in the highly weathered granitic, gneissic rock. The range of resistivity 0.14 to 0.317 ohms is also indicating the highly lithified meta-sedimentary rock associated with Charnockite. The freshwater SGD is occurring at the depth of 60 m at a resistivity of 0.03–0.04 Ω . (Fig. 14).

Tiruchendur profile 3

Profile 3 is measured in Tiruchendur coast E-W direction for a distance of 173 m. The high rock has been completely sheared by oceanic and continental plate movements and the coastal terrace layer was scanned in magnetotelluric method.

Fig. 15 Magnetotelluric method profile 3 at Tiruchendur coast

Table 1 Magnetotelluric Profile in Tiruchendur Terrace and SGD flow rate Estimation using Darcy's law

Locations	SGD depth(m)	dh/dl	Hydraulic Conductivity of the rock	Q (m/day)
Profile1	3	0.083333	$1 \times 10^{-3.6}$	0.622
	5	0.166667	1×10^{-6}	0.1727
Profile2	10	0.166667	$1 \times 10^{-3.6}$	0.0691
	20	0.333333	1×10^{-8}	0.2073
Profile 3	10	0.5	$1 \times 10^{-3.6}$	0.0518

The hard and compact rock of gneissic, Charnockite is massively formed in 30 m, 60 m, and 90 m depth and freshwater is discharged in the same depth. (Fig. 15).

The Darcy's flow rate calculation formula was used to estimate the SGD flow rate. Ravindran and Ramanujam (2014).

In the Darcy's law, is $Q = ki$; Where, Q: Flow rate, m/s; k: Hydraulic conductivity, in m/s; I: Hydraulic gradient, dimensionless; A: Flow cross section area, in m^2 .

$$Q = kiA$$

Fig. 16 Continental and Oceanic plate margin and coastal ridge formation

Fig. 17 Magnetotelluric method profile 1, 2 parallel coast compile map Coastal aquifer and coastal terrace map at Tiruchendur coast

BW data collection for rock/soil identification

In the study area in two places near Tiruchendur, beach sampling was collected by depth-wise change of subsurface soil, lithology study. The geotechnical study was done with the help of hand auguring and hammering techniques, the collected samples were analyzed using sieve techniques, and

the soil properties for the construction in near coastal area were studied.

Profile 1 geotechnical study of soil variation shows fine sand, silty-clay, sandy loam, coarse sand with water table depth is used to correlate the resistivity data. Profile 1 is well graded and silty mixture with silty-clay-sandy mixture up to 6ft is expensive clay rich area. Profile 2 was near the coastal

Fig. 18 Depth-wise soil of Soil sandy-silt-clay soil, well sorted sediments, shell material and gneissic rock

and estuarine area and the well logging estuarine site was high well and had fine graded sand, coarse sand with water column at depth of 9ft around 3.3 m depth. The clay with shell material at depth of 15ft occurs in this area due to river, wave and tidal depositional environment.

This systematic sieve method has adopted for twenty-four soil samples and they were collected from in and around Tiruchendur coast. The grain size study using mechanical sieving method with systematic analysis using sieve involves a column of sieve wire mesh cloth and a different sieve size.

Fig. 19 Depth-wise soil classifications

The size-wise grain separately settled in the upper to lower opening sieve size. The sieve shaker is equipment used for the experimental test. The collected sample was analyzed mechanically by sieving method using sieve shaker for the size and shape of soil grains (Fig. 20).

The geotechnical grain size textural characteristic study supported the identification of sorting geomorphology, marine, ocean, and estuarine, and the earlier studies have been agreed by Friedman (1961a, b, 1978), Nitsche et al. (2007), Chen et al. (2013), Komar et al. (1984), Guillen and Palanques (1996). The statistical grain size distribution of statistical analysis grandstat has studied in previous work done by Blott and Pye (2001), Makaske and Augustinus (1998). Flemming (2007) An Indian estuarine and associated geomorphologic study was carried out by Venkatraman, S, et al. 2011; the coastal geomorphology of dune and associated textural study had done by Friedman (1961). Folk and Ward (1957), Watson (2013), Punzo et al. (2017), Venkatraman et al. (2011).

The graphical representation of the Kurtosis value is plotted in the lower side of graph which indicated the mesokurtic, platykurtic, and melanokurtic sizes. The mean value of the grains min 1.8 and max 2.2 is obtained from the graph. The sorting of grains is 0.164–0.0781 and kurtosis 0.517–1.373. The fine sand formation occurred in the sampling point of 1,2,6,7, and medium sand is found in the samples of 3, 4, 9, 10.

Sieve analysis of terrace sediments was analyzed with the mechanical sieve analysis of grains. The excel worksheet plotted in the percentage-wise and used to explain the size in the terrace area.

The statistical analysis mean, median, mode, skewness, kurtosis values obtained from the sieve analysis. The sorting of the grain is used to identify the depositional environment of shallow marine, beach, and environments. The lagoon stagnant water altered to hypersaline water and becomes shallow marine deposition.

Water geochemistry

The geochemical study of water samples in NaaliKinaru and the adjoining area of Tiruchendur terrace was used to identify the SGD in the terrace. The cation and anion concentration study of water samples from open well, bore well and push point was done with the help of water sampling from the beach shoreline side (Srinivas et al. 2020). The systematic water sample collection was followed in the study. The water bottle is completely sealed and monitored the cation and anion in the collected water samples. The major ion and cation concentrations were analyzed in the laboratory of V.O. Chidambaram College, Thoothukudi.

The hydrochemical facies of Ca^{2+} , Mg^{2+} , Na^+ , K^+ , HCO_3^- , SO_4^{2-} , Cl^- , NO_3^- values range for maximum and minimum 21–136; 13–42 and 11–36; 27–75; 132–156.

Result and discussion

The study area is tectonically associated with the Achaean–tertiary contact in the trends of NNE–SSW linear fault of Tamirabarani River. The microscopic and megascopic showed rock and minerals such as calcarenite, Kankar, shell limestone, clay, sandy soil, sandy clay, sandy loam, sandstone, calcareous limestone, gneissic rock and the Charnockite basement was formed in the folded nature (Figs. 1, 2, 3, 4). The Azimuthal square array method is a supporting tool for indirect identification the depth of soil, rock type, seawater, freshwater (10 $\Omega\cdot\text{m}$, 10 m depth) in shallow perched aquifer and (4 $\Omega\cdot\text{m}$ in 70 m depth) (Figs. 5, 6, 7, 8, 9). The 2D ERI profiles1 SGD was recognize at 10 m resistivity of 4–5 $\Omega\cdot\text{m}$, in profile 2 is 4 ohms at depth of 13 m (Figs. 10, 11, 12).

In the magneto telluric profile1 SGD is found in the depth of 30, 60, 80, 120 m and resistivity was 0.03–0.06 $\Omega\cdot\text{m}$. The profile 2 SGD flow is located at a depth 10, 30 m of

Fig. 20 Cumulative frequency curve for phi values (vs.) grain size from samples

Table 2 Grain size analysis and statistical analysis

Stations	Mean	Sorting	Skewness	Kurtosis	Mean	Sorting	Skewness	Kurtosis
1	2.112	0.569	0.205	0.806	Fine Sand	Moderately Well Sorted	Fine Skewed	Platykurtic
2	2.269	0.678	0.164	0.537	Fine Sand	Moderately Well Sorted	Fine Skewed	Very Platykurtic
3	1.981	0.543	0.355	0.833	Medium Sand	Moderately Well Sorted	Very Fine Skewed	Platykurtic
4	1.794	0.450	0.335	0.846	Medium Sand	Well Sorted	Very Fine Skewed	Platykurtic
5	1.831	0.554	0.443	1.133	Medium Sand	Moderately Well Sorted	Very Fine Skewed	Leptokurtic
6	2.130	0.712	0.517	0.584	Fine Sand	Moderately Sorted	Very Fine Skewed	Very Platykurtic
7	2.029	0.626	0.394	1.373	Fine Sand	Moderately Well Sorted	Very Fine Skewed	Leptokurtic
8	2.062	0.695	0.480	0.590	Medium Sand	Moderately Well Sorted	Very Fine Skewed	Very Platykurtic
9	1.940	0.721	0.781	0.584	Medium Sand	Moderately Sorted	Very Fine Skewed	Very Platykurtic
10	1.906	0.504	0.555	0.942	Medium Sand	Moderately Well Sorted	Very Fine Skewed	Mesokurtic

Table 3 Hydrochemical facies evolution diagram

Wells	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	HCO ₃ ⁻	SO ₄ ²⁻	Cl ⁻	NO ₃ ⁻	Phase	Facies
T1	21	29	17	19	660	132	159	0.001	Fresh	Mg-HCO ₃
T2	77	128	36	22	758	143	66	0.001	Fresh	Mg-HCO ₃
T3	29	31	18	11	457	122	81	0.002	Fresh	Mg-HCO ₃
T4	143	27	19	13	571	223	138	0.002	Intrus	Ca-HCO ₃
T5	57	55	42	36	464	439	196	0.001	Fresh	MixMg-MixSO ₄
T6	101	25	21	11	305	342	128	0.002	Intrus	Ca-MixSO ₄
T7	56	112	36	26	417	519	112	0.003	Intrus	Mg-SO ₄
T8	22	45	34	15	596	288	88	0.001	Fresh	Mg-HCO ₃
T9	37	153	13	23	275	567	162	0.001	Intrus	Mg-SO ₄
T10	136	32	55	12	705	278	53.4	0.002	Fresh	Ca-HCO ₃

Fig. 21 Hydrochemical facies evolution diagram of Tiruchendur coast

resistivity 0.03–0.04 Ω .m. In Profile 3, freshwater resistivity is ranging from 0.05–0.06 Ω .m at depth of 30, 60, 90 m (Fig. 13, 14, 15).

The SGD flux of the flow rate Q is measured using the Darcy's law of two different flows in the aquifer formation of water through the hydraulic gradient with rock types or hydraulic conductivity of formation. Profile 1 in shallow aquifer water system was 0.6220 m³/day; it was 0.17279 m³/day in Profile 2 is having 0.057 m³/day and profile 3 is 0.1156 m³/day (Table 1) (Figs. 16, 17 18).

The grain size analysis is used to find out the fine sand, medium sand in dune, beach, and estuarine environment in and around the terrace area (Figs. 19 and 20) Table 2.

The groundwater quality and geochemical facies was studied using the scientific method freshwater (Na, Mg surface), seawater (Na, Mg defects). The proper systematic geochemical analysis showed the cation and anion value of water at the minimum and maximum value of Ca, Mg, Na, K, HCO₃, SO₄, NO₃, and freshwater phase of 1, 2, 3, 5, 8, 10 and saline/seawater zone 4, 6, 7, 9, intrusion of seawater (Table 3). The hydrochemical plot of diagram of samples is T1, T2, T3, T5, T8 and T10 which are plotted to the freshwater zone. Then, remaining samples T4, T6, T7, and T9 plot of seawater intrusion zone. The facies of Mg²⁺, HCO₃⁻ is a freshwater zone (Fig. 21). The Ca²⁺, HCO₃⁻ seawater intrusion zone of the study area. The shallow aquifer well acts as a permeable layer of perched aquifer lens of water table available in "Nallikinaru." The open small freshwater well is utilized for Murugan Temple pleasing water for 25,000 people visiting every day this temple. The bore well soil and rock sampling was used to validate the azimuthal square array, magnetotelluric and 2D ERI data identified the soil and rock of the study area. The geophysical and geochemical assessment to find out the Calcarinite rock which act as leaky aquifer from Avudaiyur Kulam (Western side of the Terrace) in to Sea shore area. It is a useful study for SGD flux rate for public using up of groundwater in coastal aquifer system.

Conclusion

The study has analyzed the submarine groundwater discharge flows that take place in Tiruchendur by subsurface water penetration into the sea. It is used to investigate the type of rock, the quality and quantity of soil and groundwater. This study focuses on SGD in porous sandstone with water permeability for public utility. Since the density of freshwater is much lower than that of seawater, freshwater floats to the surface in coastal areas. The floating of freshwater (SGD in the form of perched aquifer) oozed out to occur in the seaside area of the Murugan Temple in Tiruchendur. The cliffs and rocky coasts are formed due to

uplift, and freshwater springs can be seen under the sea. The porous sandstone and sand bar are of sandy nature with dunes area occurring in Tiruchendur beach. SGD study has been conducted using electrical resistivity and geochemical groundwater parameters, as well as particle size analysis of water behavior in the soil and rocks; resistivity studies were based on the information from VES profiles, 2D profiles and magnetotelluric profiles of SGD under the sea is at a level of 10 feet 30 feet 60 feet 90 feet. Samples of groundwater in dug, open, bore wells were collected from the study area, for water quality and quantity of SGD water for public utility. Groundwater quality and geochemical phases were adopted as scientific methods for analyzing freshwater (Na, Mg surface) and seawater (Na, Mg defects). The minimum and maximum values of Ca, Mg, Na, K, HCO₃, SO₄, NO₃ were seen on fresh water phase 1, 2, 3, 5, 8, 10 and where salt water/sea water 4, Areas 6, 7, and 9 where the sea water invades. The water chemistry diagram of the chart plotted the samples T1, T2, T3, T5, T8, and T10 into the freshwater area. Then, the remaining samples T4, T6, T7 and T9 showed seawater intrusion in the area map. The SGD in the coastal environment of water is mixed with fresh, saline and seawater. The significant variation of water geochemistry and electrical resistivity has been the method used to find out SGD flow in porous sandstone in Tiruchendur area.

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Compliance with ethical standards

Conflict of interest No conflict of interest is confirmed.

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