Ground Water Quality Maps of Paravanar River Sub Basin, Cuddalore District, Tamil Nadu, India

Aravindan.S · Shankar.K

Abstract Ground water is an excellent solvent, which dissolves chemicals ions as it moves through rocks and subsurface soil. This leads to more mineralization in groundwater than surface water. The objective of the present study is to examine the groundwater quality of the Paravanar River Sub-basin, Cuddalore district, Tamil Nadu, India. The Electrical Conductivity (EC) values ranges between 160 and 2,580 µS/cm in groundwater samples. The highest value of 2,580 µS/cm was recorded in wells near the coast. pH values ranges from 7.2 to 8.6. NNE and southern part of the study area has low pH values, rest of the area represents the alkaline nature of groundwater. In south eastern part of the study area alkali values are slightly higher but it is within WHO's tolerable limits. The spatial distribution of chloride concentration shows that Meenatchipettai, Vazhisothani palayam and Allapakkam represents maximum Cl_2 concentration of 527, 320 and 374 ppm, which is above ISI drinking standards of 250 ppm. Increase in isochlore is observed from the coast up to the Neyveli lignite mine. Nitrate concentration of groundwater samples ranges from 0.1 mg/l to 64 mg/l. As most of the study area is cultivated, fertilizers used for agriculture may be the cause for increase in concentration of nitrates in few concentrated locations.

Aravindan.S (✉) · Shankar.K
Department of Earth Sciences, Annamalai University,
Annamalai Nagar - 608 002, India
e-mail: aravindan_rs@yahoo.com

Introduction

Ground water is an excellent solvent that dissolves chemical ions, as it moves through rocks and subsurface soil. This leads to more mineralization in groundwater than surface water. Earth surface is acting as an effective filtrate to filter out particulate matters like leaves, soils, bugs, dissolved chemicals and gases. Above matters also occur in large concentrations to change the physico-chemical properties of groundwater. To understand the above process, hydrogeochemical studies were attempted in the Paravanar basin in Tamil Nadu to monitor the concentration of various major and minor constituents present in groundwater.

The conventional techniques of histograms and trilinear techniques (Dalton and Upchurch 1978) such as Stiff and Piper plots consider only the major and minor ions with equal emphasis to interpret the group of variables to evaluate the chemical nature of groundwater has several limitations. In order to overcome these limitations conventional method of factor analytical technique has been used to understand geochemical processes by several professionals (Dawdy and Feth 1967; Lawrence and Upchurch 1976, 1983; Razack and Dazy 1990; Olmez et al. 1994; Subbarao et al. 1996; Jayakumar and Siraz 1997; Bakac 2000).

Remote Sensing is very useful for geologists and hydrologists. The raw remote sensing data cannot be used directly for geological application because it does not contain the subsurface information for visualization. Indirect evidences for subsurface structure, geodynamics, geomorphic units and drainage can be used for various themes in GIS analysis. In the present study satellite imagery of the study area is used to interpret the geological units, and drainage pattern. Visual interpretation techniques were used for identification and interpretation of different geomorphological features from satellite data.

GIS has been used by scientists of various disciplines for spatial queries, analysis and integration for the last three decades (Burrough and McDonnell 1998). A number of studies were conducted to determine potential sites for groundwater exploration in diverse geological set ups using remote sensing and GIS techniques (Kamaraju 1997; Srivastava et al. 1997; Srivastava and Bhattacharya 2000; Aravindan et al. 2006).

Geographic information system (GIS) is an efficient and effective tool in solving problems where spatial data are important. Therefore, it is widely used for assessment of water quality and developing solutions for water resources related problems (Chaudhary et al. 1996). GIS based spatial distribution mapping and suitability of groundwater quality evaluation for domestic and agricultural purpose (Goyal et al. 2010). Anbazhagan and Nair (2004) used GIS to represent and understand the spatial variation of various geochemical elements in Panvel Basin, Maharashtra, India. Aravindan et al. (2010) and Shankar et al. (2010) has applied GIS to understand the behavior of various geochemical elements spatially in Upper Gadilam, River basin of Vizhupuram district and Paravanar basin of Cuddalore district Tamil Nadu. Therefore, groundwater quality plays a major role in planning water supply, water quality management, public health management, and environmental management.

In the present study GIS was used to prepare Geology & Geomorphology map and spatial interpolation with the aim to evaluate the groundwater quality of Paravanar River basin, by generating and amalgamating the groundwater quality data of Paravanar River sub basin. The objective of the present study is to examine the groundwater quality of the Paravanar River Sub-basin.
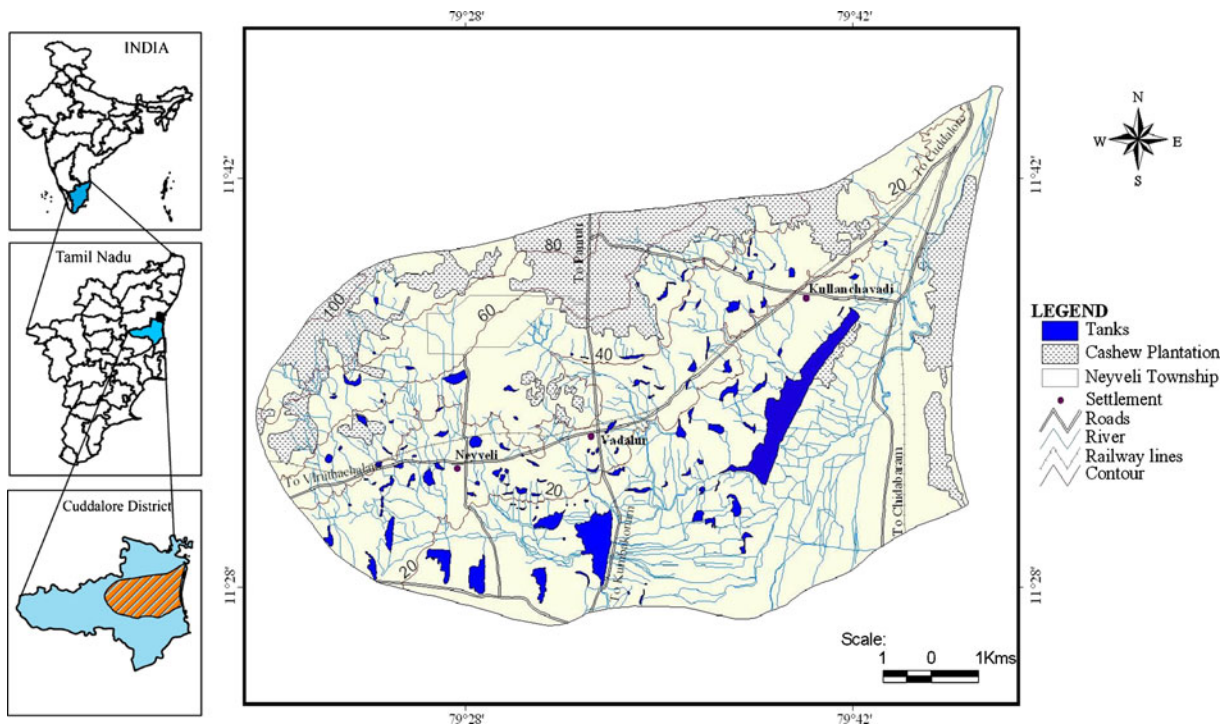
Study Area

The study area (Fig. 1) Paravanar sub-basin lies partly in Virudhachalam, Panruti, Chidambaram and in Cuddalore taluks of Cuddalore District. It is bounded on the north by the main Gadilam river basin, on the south by the Vellar basin, on the east by Bay of Bengal. Most part of the study area is a flat plain, slopping very gently towards the sea on the east. The uplands are only on the northwestern border, with the Capper Mound or the Red Plateau running parallel to the sea with an elevation of <25 m above M.S.L., forming part of red lateritic "Cuddalore Sand Stones". The area has a tropical climate with the highest and lowest temperatures recorded in May and January respectively. The precipitation of this study area mainly depends upon North East monsoon, which is cyclonic in nature and attributed to the development of low pressure in the Bay of Bengal. This area receives an annual rainfall of 1,162 mm. The study area includes two large (Mines I and II) and one small (Mine IA) opencast lignite mines and associated industries are (two thermal power plants) that are operated by Neyveli Lignite Corporation Ltd. (NLC), a government of India public sector under taking.

Geology

The study area is underlined by geological formations, ranging in age from the Tertiary to recent alluviual sediments (Fig. 2). Geological map of the study area was checked with field investigations and with the help of geological map of the Cuddalore District, which was published by Geological Society of India (Subramanian and Selvan 2001). The River Paravanar originates from the Cuddalore sandstone of Tertiary age. This formation is completely composed of mottled argillaceous sandstone (Balasundar 1968). The Cuddalore sandstone occurs at capper plateau south of cuddalore town and is made up of sandstone, clay and silt (Table 1). The lower Cuddalore sandstone is unconsolidated at few places. The sandstones is found intercalated with clay lenses and covered by lateritic formation (Selvaraj and Ramasamy 1998). Major lineation of Cuddalore sandstone and laterite was NNE to SSW and major dip

Fig. 1 Location map of study area

is due SE. The major soil types found in this basin are Inceptisol, Entisol, Alfisol and Vertisol.

Tertiary Formation

Gopurapuram formation Overlying the cretaceous formation are the Gopurapuram formations of Eocene age and the Cuddalore formation of Mio-Pliocene age. The Gopurapuram are essentially argillaceous, comprising silts, claystones, calcareous sandstones, siliceous limestones and algal limestones (Table 1). They are also considered essentially as a transitional formation from Cretaceous to Tertiary and placed equivalent to Niniyur stage of Trichinopoly Creta-ceous group. The exposures of this formation are seen as a narrow belt and sometimes also as inliers in Cuddalore sandstones.

Cuddalore sandstone The Cuddalore sandstone for-mations are exposed in major part of the study area and are charcterised by lateritic cover at exposures. The Cuddalore sandstone formation is formed in the western part of the study area around Mudanai and Perperiyankuppam. The Cuddalore sandstones are

often ferrugenious and consist of pebble beds, sands and clays with seams of lignite (Table 1). The sandstones are variegated in colour (whitish, pinkish, reddish or mottled) and are friable. Pebble bearing sandstones are seen near Caper mount, Kottusagai and pankulam. Lenticular beds of white or mottled clay are observed occasionally in associ-ation with sandstones. Lignite has been found to occur in association with Cuddalore sandstone at North and South Neyveli.

Quaternary Formation

The Quaternary formations in the study area consist of sediments of fluvial, fluvio-marine and marine facies. It includes various types of soils, fine to coarse grained sands, silts, clays, laterite and lateritic gravels. The fluvial sediments occupy the flood plains of the Uppanar River. It consists mainly sands, sandy loams or clayey loams (Table 1). The thickness of Paravanar alluvium near Tiruthunainagar is 24 m.

Laterite and lateritic gravels occur in major part of the study area covering the Cuddalore sandstones.
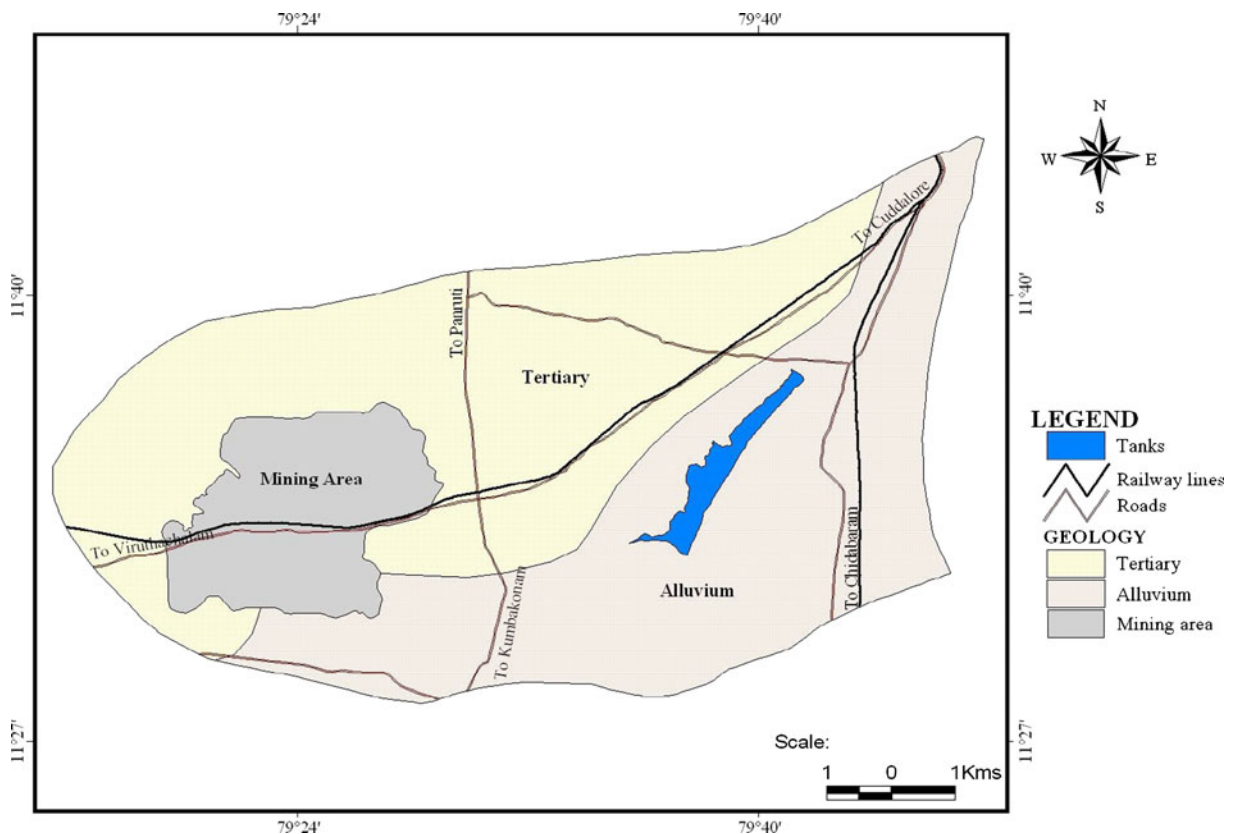
Fig. 2 Geology of study area

The Laterites are generally ferruginous and sometimes extensive in occurrences near Vadalur and Madurai-kuppam. Laterites are dark brown, yellowish, hard and assumes metallic luster. Along the coast in the study area, windblown sands of 1.5 to 3.0 km width are commonly occurring in the form of low and flat topped sand dunes excepting at the confluence of the nallas with sea. Irregular mounds of 10 to 15 m height are prominent feature due to wind action near Cuddalore.

Geomorphology Mapping

Geomorphology was demarcated on the basis of image interpretation keys such as size, shape, texture etc., with their distinguishing characteristics and other Geotechnical elements. Geomorphology is the science of landforms and it is inter relative description of relief features of the earth. Landforms develop through the combined influence of exogenous and endogenous process. Climate has a pronounced effect on the development of landforms. Space imagery provides the best means of identifying landforms and process.

Geomorphology of study area show gentle slopes towards southeast and east, and not drained by any major river except the ephemeral Paravanar River flowing from west to east. This carries mine water, industrial effluents with natural water and discharge into the Walaja and Perumal Lake east of lignite mines. The geomorphology of the Paravanar River sub-basin is interpreted using IRS P6 LISS-III data of path 102 and row 65 acquired on 12th may 2005 (Fig. 3). The major hydrogeomorphic features along this coastal tract comprises of upland plain, flood plain and coastal plains. The coastal plain has a width of 6 km. The river course is almost gentle plain from apex of the basin to Bay of Bengal. The major geomorphological units interpreted and categorised in the high lands of Tertiary upland are, **i) Denudation Landforms**: Tertiary Upland; **ii) Fluvial Geomor-**

Table 1 Stratigraphy of the Paravanar River Sub basin

Era	Period	Geological Age (Epoch)	Formation	Thickness in m	Lithology	Environment	Typical area
Cenozoic 20 km	Quaternary (1.8 Ma to Present)	Recent to Sub recent	Alluvium	05.36	Soils, alluvium, brown sanda laterite and Kankar	Fluvial	South East Basin
					Unconformity		
	Tertiary (65–1.8 Ma)	Upper Miocene	Cuddalore	62.660	Argillaceous Sandstones, Pebbles bearing sand stones, Grits, Sands, Clays with pebbles and lignite beds.	Continental fluvial parallic deltaic to near shore	Neyveli Lignite field
					Probable Unconformity		
		Eocene	Gopurapuram		Black Clays or Shales, grey coloured sandstones and shales and siliceous lime stones with fossils	Marine, near shore to inner shelf	Adiamankuppam
					Unconformity		
Mesozoic 50 km	Cretaceous (145–65 Ma)		Virudhachalam	550–3500	Shell lime stone, siliceous lime stone, marls etc.,	Marine outer shelf to bathyal	As an in layer from 220 to 330 mbgl in and around Neyveli

phology: Alluvial plains, Flood plain; **iii) Coastal Geomorphology**: Coastal Plain, Beach, Beach ridges, Sand dunes and Swales.

Denudation Landforms

Tertiary Upland In the west and northern side of the basin, uplands of Tertiary age is occupied. It occupies nearly 26% of the basin. Tertiary upland is the older sedimentary geomorphic units of this basin, having very gentle slope towards east composed of sands, ferruginous sand stone, gravels, clay and clay stones popularly known as Cuddalore sand stones which is the most potential aquifer system of this basin. This geomorphic unit can be observed in and around Neyveli, Vadalur, Kurinjippadi, Kattugudalur areas. The eastern side of the unit boundary is bounded towards North of Perumal Eri in the east.

Here, the groundwater occurs in shallow phreatic aquifer, deep water table aquifer and perched water table aquifer. Layers of potential confined aquifers occur below the lignite seams and artesian aquifer occured once around Neyveli. First two confined aquifers occur immediately below the lignite seams within the depth of 122 mbgl and the third aquifer occurs between 122 m and 305 mbgl. This area is characterized by cashew plantation and prone to erosion.

Fluvial Geomorphology

Alluvial plains When the river attains old stage it loses all its energy to carry the bed load and deposits all the materials on either side of the river and forms the alluvial plains. These are associated with major streams/rivers which are identified by sparse surface drainage. It is a leveled tract bordering river on which alluvium is deposited. Here the groundwater occurs under phreatic and semi confined aquifers in the alluvial area of Pravanar river under Quaternary formations.this geomorphic unit was found in around Kullanchavadi, Maruvai, Adur kanadi and sedapalayam.

Flood plain When the river floods, it spills over on either banks of the river and dumps lot of sediments. Such flood plains express remarkable tone in the images owing to the moisture influx and also due to thick vegetation. However certain rivers show devel-
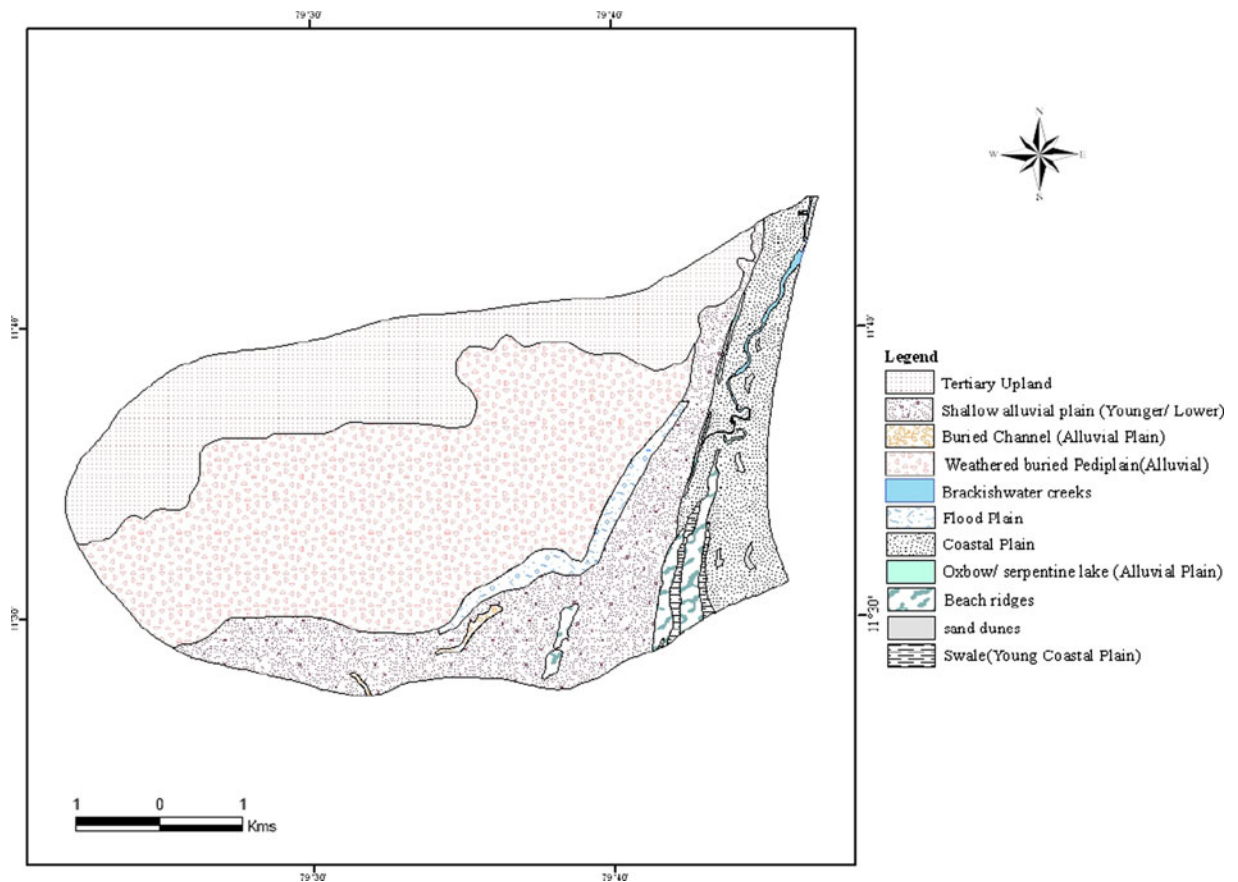
Fig. 3 Geomorphology of the study area

opment of such flood plains only on one side of the banks which indicate the preferential shifting of the river in one direction. This also indicates that river once had a wide spread floodplain; Subsequently either due to depletion of incoming water or due to latter rejuvenation a narrow and restricted flood plain i.e. younger flood plain occur. The younger flood plains are preferable for groundwater prospects. Floodplains are conspiques in this basin.

Coastal Geomorphology

Coastal Plain Coastal zone or coastal plain is a delicate transitional zone situated in between land and sea. The coastal process develops the coastal geomorphic features as poly zonal in character. In the coastal plain, the major geomorphic agents are waves, currents and tides working in the back ground defined by the structure of rock, climatic conditions, vegeta-

tion cover and man. Sea level oscillations too have to be looked into for explaining the coastal landform. The shoreline of the study area is more or less smooth and curvilinear. Dominance of northeast monsoon results in strong wave action in transverse/oblique direction of the shore. It has almost entirely eliminated the protuberance and given wall like straightness to the shore (Ahmed 1972).

The presence of Oxbow lake and meandering in the course of Uppanar and Paranavar represents the low relief nature of the coastal plain. Some of the coastal geomorphic units developed in this basin are exposed in the area of small hamlets like Pundiankuppam, Sangolikuppam and Kudikkadu in the eastern side of the basin.

Beach Beach and sand bars are the dominant depositional landforms along the coast. Beaches develop in the gently sloping areas and they are the accumulation

of a temporary deposit of sand, which are subjected erosion depending upon wave, tides and currents. Gravels and pebbles on the shore are found between the low tide level and the coastline. Beaches grow in size during the periods of less active wave attack but may get destroyed by waves during storm. In this basin, beach is long, narrow and developed under active deposition. Silver beach from little north of study area (Dhevanampattinum) to Cuddalore port (old town) is the second larged beach in Tamil Nadu next to Marina which stretches to a total length of 4 Kms.

Beach ridges This land form is found to be very near to coast in low tidal shorelines composed of beach. Marine process with the intercalations of river deposits formed series of beach ridges parallel to the coast, which is predominant. This indicates the emergence of coastal plain. A long narrow beach ridge traversing from NE – SW direction, passing through Mettupalayam, Mettur, Anaiyampettai, East of Karaikkadu in Palvattunnam and Manikollai is observed.

High rate of sedimentation and landforms in the coastal plain suggests that the coastal plain would have been under a deltaic plain of Paravanar. Marine depositional landforms like beach ridges and the sand dunes causes Uppanar river course as the inter dunal depression.

Beach and the coastal plains of this river basin are now under severe anthropogenic impact due to its high ground water potentiality, its proximity to the east coast and to the cuddalore port.

Sand dune Along the beach ridges there are a number of migrating and stabilized sand dunes composed of sand parallel to the coast. Along the seashore, sand is brought from the shore face and backshore region by wave action. The sand located above sea level is exposed to wind activity and sand is reworked into dunes (Reineck and Singh 1980). After the emergence of coastal plain, the aeolian action has intensified and sand dunes are formed. Some of the sand dunes are still under migration while the others are stabilized due to vegetal cover. These types of sand dunes are observed south of Thiruchopuram and east of Pettankuppam.

Swale This land forms are between beach ridges or between point bars and some time occupied with water. Such landform is observed in west of Tachchanchavadi and east of Karaikkadu.

The characteristics of each geomorphic unit and lithology units are described in the table below.

Sl. No.	Geomorphic units	Lithology	Description
1	Tertiary uplands	Mainly lateritic capping occur over Digenetic sediments,	Occupying elevated land, medium to coarse texture with less drainage density. Infiltration and permeability are good. Prone to erosion.
2.	Flood plain	Primarily comprises of unconsolidated materials like gravels, sand and silt.	A flat surface adjacent to stream composed of unconsolidated fluvial sediments. Permeability is good.
3.	Buried channel	Comprises of unconsolidated material like gravels, sand and silt.	A linear low lying surface parallel or in connection with the existing river or streams. Intensive cultivation practices are seen.
4.	Beach	Un consolidated sand/silt deposited by tidal waves.	Narrow stretch of unconsolidated sand/silt deposited by tidal waves along the shore line.
5.	Beach Ridge	Unconsolidated sand/silt.	A linear ridge of unconsolidated sand/silt parallel to the shore line. Infiltration and permeability are good in this landforms
6.	Sand Dunes	Sands of different shapes and sizes	Heaps of sand of different shapes and sizes formed by wind action.

Methodology

To achieve the objectives, various data generated in the field were converted into information in the lab. (Table 2).

17 wells were selected for this study (Fig. 4) and these wells are widespread in the study area. Groundwater was sampled in the month of June 2007 (Table 2). Water samples were collected mostly from observation wells of PWD.

Table 2 Hydrogeochemical data (Post monsoon of 2007) of the Paravanar river sub-basin

S.No.	LOCATION	EC micro-mhos/cm	pH	Ca	Mg	Na+K	HCO$_3$	CO$_3$	SO$_4$	Cl	NO$_3$	TDS
1	Annadanapettai	360	8.3	24	0.2	23	73	12	14	36	6.12	196.7
2	Meenakshipettai	1860	8.6	40	2	222	153	15	29	527	12	1008.6
3	Kullanchavadi	760	8.3	20	0.5	0.5	134	12	48	149	6	471.8
4	Puliyur	580	7.7	28	1.3	54	116	0	53	114	0	374
5	Sathankuppam	570	7.7	26	0.6	58	128	0	4.8	114	25	364.1
6	Ramapuram	503	7.2	14	1.2	62	67	0	62	110	31	354.4
7	Vallichothanaipalayam	1080	8.2	38	0.12	200	244	42	38	320	37	927.3
8	Kanarapettai	870	8.3	76	28	60	183	12	115	106	6	594.3
9	Vadalur	480	8.4	24	0.9	46	116	6	10	71	50	332.3
10	Abaddhapuram	300	8.4	30	1	17	123	6	0	28	0	213.4
11	Jubleeclub	2580	8.1	28	2.4	253	187	72	250	178	62	1042.5
12	Alapakkam	2176	8.39	52	3.3	187	287	57	53	374	0.4	1022
13	Marungur	230	7.8	10.02	40.86	32.18	16.5	0	40.8	38.99	0	129
14	Muthandikuppam	160	7.9	8.02	4.86	19.59	73.2	0	17.72	20.65	9.3	88
15	Maruvai	451	7.74	16	8.2	17.1	42	0	29	34	26	316
16	Sorathur	230	7.9	24.05	9.75	6.89	95.52	0	1	14.18	25.63	126
17	perpriyankuppam	700	8.3	18.04	21.88	98.85	170.84	30	28.22	77.98	120.2	370

Except EC and pH all others parameters are expressed in mg/l.

The water samples were collected in 500 ml polyethylene bottles. Before collection sampled bottles were soaked with 1:1 HNO$_3$, washed using a detergent and rinsed using double distilled water. At the time of sampling, the sampling bottles were thoroughly rinsed two or three times using the groundwater to be sampled. The hydrogeochemical characteristics of groundwater and its potability were obtained through physiochemical parameters like Temperature, Electrical Conductivity (EC) and hydrogen-ion concentration (pH) using in situ pH meter. Samples were tightly packed and transported to the laboratory for chemical analysis on the same day.. The pH electrode was calibrated using 2 buffer solutions (pH 7 and pH 10). Since there was automatic temperature compensation probe, the readings was recalculated considering the temperature of water during collection as 25°C. EC, salinity and Total Dissolved Solids (TDS) were measured using a pre-calibrated portable meter. Readings were taken for the above parameters at each 17 sites.

These water quality parameters are interpolated to make spatial variation of these parameters.

Method used for interpolation is krigging technique by multi quadrilateral means as the sampling was done by stratified random method and the distribution of four adjacent sampled wells was arranged like quadrilateral in the above technique. As coarse sampling was done to represent a fair representation within study area quadrilaterals were found to be more realistic in interpolating the contours rather than by bilinear mode.

The collected groundwater samples were filtered and acidified with nitric acid for analysis. The samples were analyzed for concentrations of major elements like bicarbonate (HCO$_3$) and chloride (Cl$_2$) ions. The analytical procedures used were adopted from APHA (1995). During the analyses, blanks and standards were run to check the reliability of the methods adopted. After completion of the analysis of major ions, the ionic balance error was calculated. In general, ion balance error was within 10%. The collected groundwater samples were analyzed for major ions by following the standard analytical methods and the accuracy of chemical analyses were checked as per the procedure listed by Richards (1954).
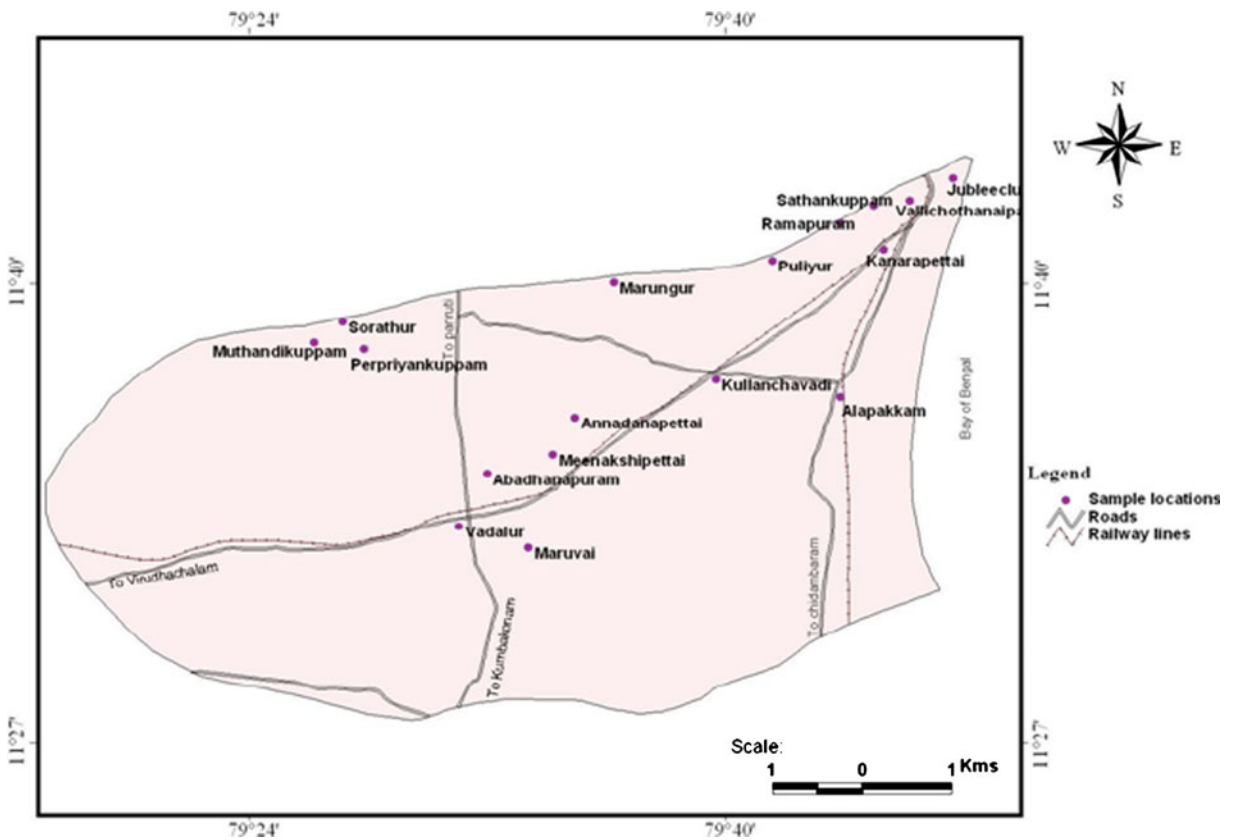
Fig. 4 Observation well location in the study area

Results and Discussion
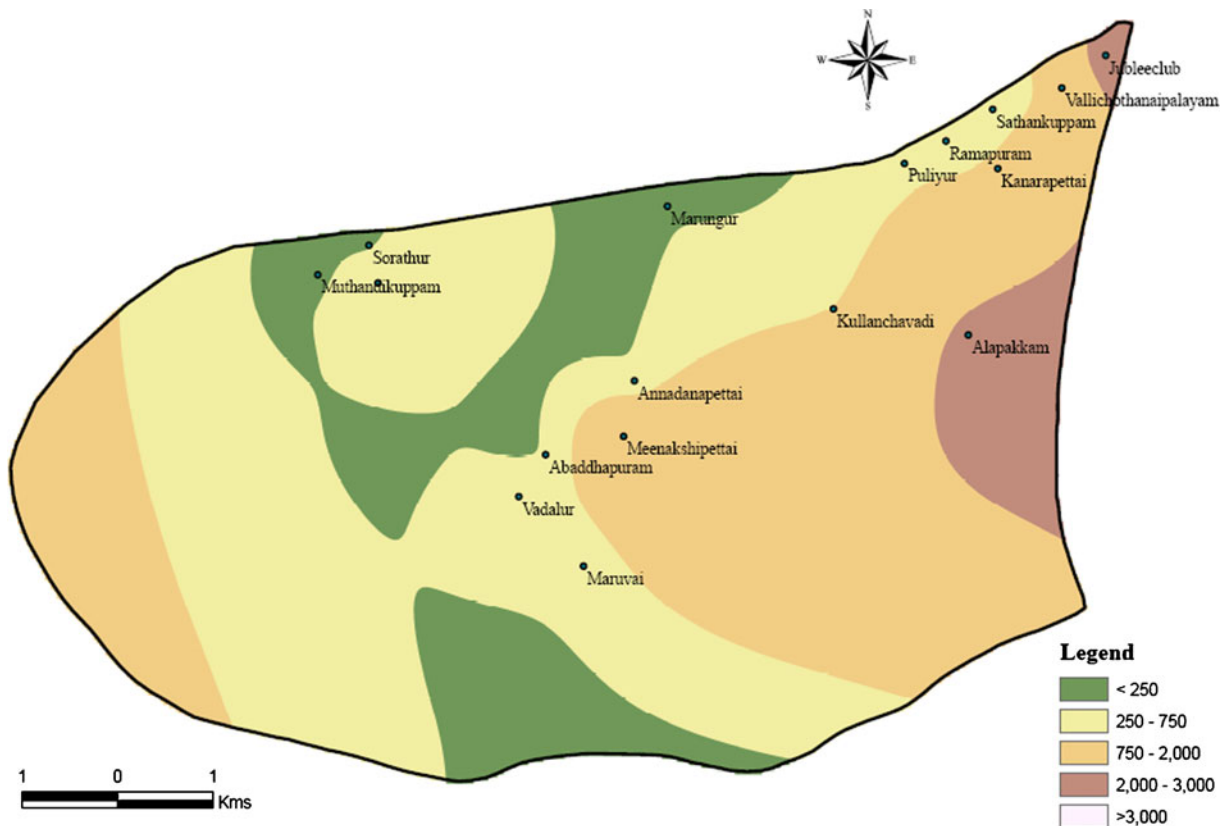
Physical Parameters

Electrical Conductivity

Electrical conductivity (EC) is a measure of the total salt content of water based on the flow of electrical current through the sample. The higher the salt content, greater will be the flow of electrical current. Measured EC values range from160 to 250 microsiemens/cm at 25°C in tertiary upland in muthandikuppam in th west to Marungur in NE (Fig. 5). The highest value of 2580 microsiemens/cm is found in the sample near the coast in Alapakkam which represents coastal plain (Fig. 5). Jublee club in NE and area in and around Alapakkam in the eastern part of the study area represents the doubtful water class (Fig. 5) as the concentration of EC has exceeded 2000 μS/cm to represent the connate nature of groundwater adjacent

to the coast also to indicate its increasing age. (Table 3)

Hydrogen Ion Concentration (pH)

Most groundwater found in the Paravanar river sub basin has pH value of less than 7.5 in and around Ramapuram in north east comprising of Teriary formation and all along the coast from kannarapettai to Alapakam a narrow fringe of land adjacent to coast found to have pH value of more than 8.5 (Fig. 6). The regional distribution of pH in groundwater is shown in Fig. 6. East Central part of the study area in and around Meenkshipettai has high pH value of above 8.5 which may be due to closed industrial activity around vadalur and due to mining and other allied activity of NLC with in the tertiary rocks (Fig. 6). Rest of the basin has pH value from 7.5 to 8.5 due to acidification of lateralized sandstone as a host rock and mixing of saline water from the coast to nutralize the acids of uplands to be alkaline the and saline in east and cental part (Fig. 6).

**Fig. 5** Spatial variation of EC (µS/cm) in Paravanar River Sub basin

Chemical Parameters

Stiff Diagram

Pattern diagrams, first suggested by Stiff, for representing chemical analyses by four parallel axes, are illustrated in Fig. 7. Concentrations of cations are plotted to the left of a vertical zero axis and anions to the right, all values are represented in milliequivalent per liter. The resulting points, when connected, form an irregular polygonal pattern; water of a similar quality defines a distinctive shape. The STIFF plots for groundwater illustrate that there are two end-members, representing water dominated by sodium-potassium and bicarbonate-carbonate and water with low TDS. The STIFF plots for the remaining samples appear to fall somewhere between these two end-members and may represent a mixing of the two waters.

Table 3 Quality of groundwater based on electrical conductivity

EC (micro mhos/cm)	Water class	Representing wells	Total no. of wells
<250	Excellent	13, 14 and 16 (Sorathur)	3
250–750	Good	1, 4, 5,6,9,10,15 & 17	8
750–2000	Permissible	2, 3, 7 & 8 (Kanarapettai)	4
2000–3000	Doubtful	11 & 12 (Alapakkam)	2
>3000	Unsuitable	Nil	Nil
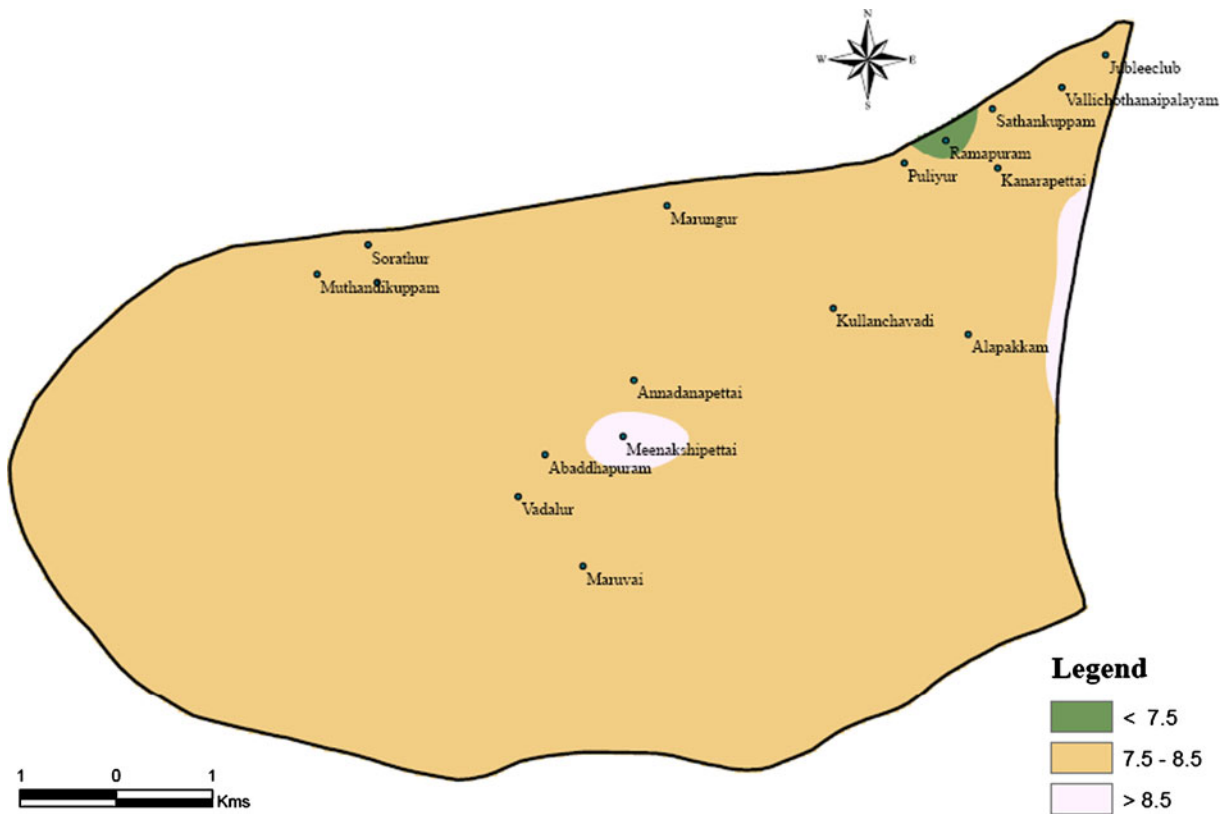
Fig. 6 Spatial variation of pH values in the Paravanar River Sub- basin

The plot shows that most of the groundwater samples were collected during July 2008 to fall in the field of mixed Ca–Mg–Cl$_2$ type of water (Fig. 8). Some samples are also represented in Ca–Cl$_2$ and Na – Cl$_2$ types. From the plot, alkaline earths (Ca^{2+} and Mg^{2+}) significantly exceed the alkalis (Na$^+$ and K$^+$) and strong acids (Cl$_2$) and (SO$_4$) exceed the weak acids (HCO$_3$) and (CO$_3$).

Bicarbonate

The primary source of bicarbonate ions in ground water is the dissolved CO$_2$ in rain water that on entering in the soil dissolves more Carbon- di -oxide. An increase in temperature or decrease in pressure causes reduction in the solubility of CO$_2$ in water Decay of organic matter and SO$_4$ reducing bacteria may also release CO$_2$ for dissolution. Water charged with CO$_2$ dissolved carbonate minerals, passes through soil and rocks, to give bicarbonates. Weathering of silicate mineral also has the possibility of bicarbonate liberation. HCO$_3$ concentration is classified based on WHO's (1983) standard with

concentration <100 ppm is categorized as poor zone, which is suitable only for industrial activity (Table 4) where Cuddalore industrial complexex are located.

Northern and southern parts of the study area (Fig. 9) represent minimum amount of hardness to neutralize acids, hence above part is categorized as poor zone <100 ppm. Moderate zone is found to occur in northwest, west, southwest and in central part comprising Tertiaries and lower alluvial plain of the study area by considering the concentration of <250 ppm (Fig. .9). Good zone is found to occur in eastern part of the study area as the concentration is >250 ppm along beach ridges and in coastal plains.

Chloride

The chloride ions occur in natural water in fairly low concentration, usually <100 mg/l unless the water is brackish or saline. Chloride is used by human beings in many applications and can be added to the subsurface via industrial discharges, sewage, animal wastes and road salting. The chloride ions are not absorbed into the

**Fig. 7** Chemical parameters in Stiff Plot
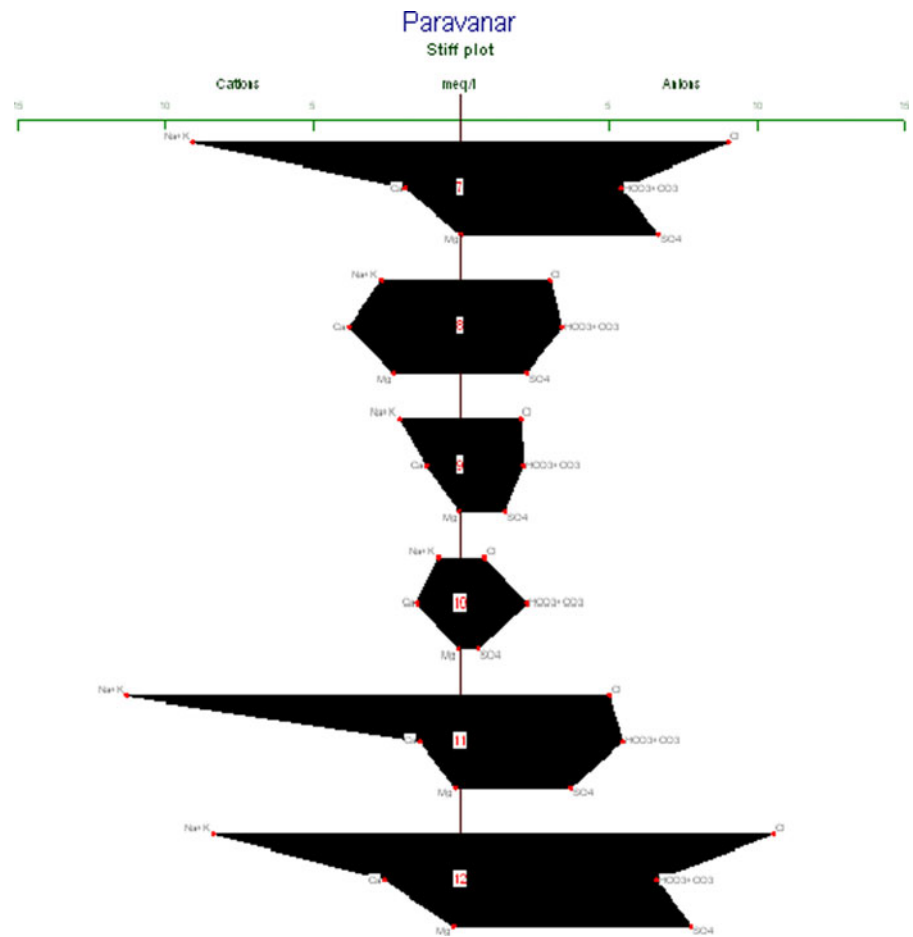
mineral or organic surface, and do not form insoluble precipitates. Chloride-bearing minerals such as sodalite and chloro-apatite, which form very minor constituents of igneous, metamorphic rocks and liquid inclusions comprises very insignificant fraction of the rock volume and form as minor sources of chloride in ground water. The distribution of chloride ion concentration individually reflects the water interaction with rocks, permeability variations of aquifer and inters transmissivity of rock (Hem 1970).

Based on ISI standard, chloride concentration is classified <100 ppm as good zone suitable for drinking. Moderate ground water suitable zone is categorized under the class of 100–250 ppm (Table 5). Above 250 ppm zones were classified as poor ground water suitable zones. The chloride ion concentration in the study area varies between 28 mg/l at Abathanapuram in cuddalore sand stone and 527 mg/l at Meenatchipettai in shallow alluvial plain. The spatial distribution of chloride concen-

tration in groundwater of the study area is illustrated in the Fig. 10. Meenakchipettai and Allapakkam in the east represents the maximum Cl_2 concentration of 527 and 374 ppm respectively represents older to coastal alluvium as geomorphic units and which is more than ISI standard of 250 ppm for drinking.Vazhichothanaipalayam in the NE comprising tertiary formation has the concentration of 320 ppm

Eastern part of study area adjacent to the coast is found to suffer from chloride and saline hazard. Increase in isochlore is observed from the coast upto Abathanapurm which is 2 Km east of the Neyveli lingnite mine 1A. Such increase in isochlore (Fig. 10) indicates the possible migration of chloride ion from the coast upto the Neyveli mine may be due to depressurization of neyveli aquifer, which is in the cental part of the study area (Fig. 10). Chloride contour pinching axis the south central part of the study area (Fig. 10) may be due to

Fig. 8 Chemical parameters in Stiff Plot
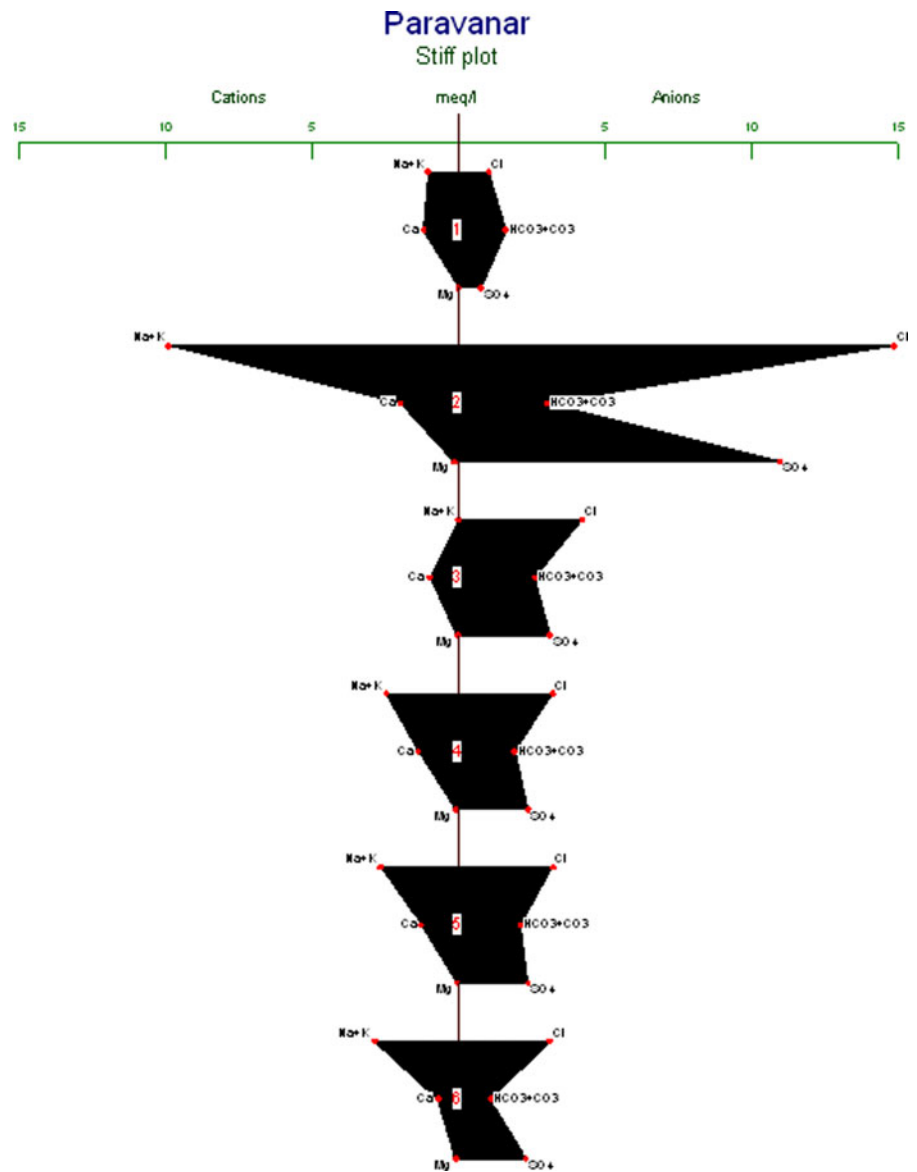
the effect of chloridization of aquifer for the past half a centuary and also due to upwelling of connate water from the deeper aquifer as a result of depressurization of Neyveli aquifer.

**Table 4** Suitability of drinking quality of Bicarbonate ions

Concentration of HCO$_3$ in ppm	Suitable Zone
<100	Poor
100–250	Moderate
>250	Good

Nitrate

The largest anthropogenic input of nitrogen into the nitrogen cycle is fertilizers (Panel on Nitrates 1978). The impact on the nitrogen cycle results in pollution problems such as toxic amounts of nitrate in drinking water, eutrophication in lakes, rivers or coastal waters, all of which posses possible health and environmental consequences.

Globally, nitrogen fixation and the mineralization of organic nitrogen by biological processes produce the largest amount of inorganic nitrogen, usually in the form
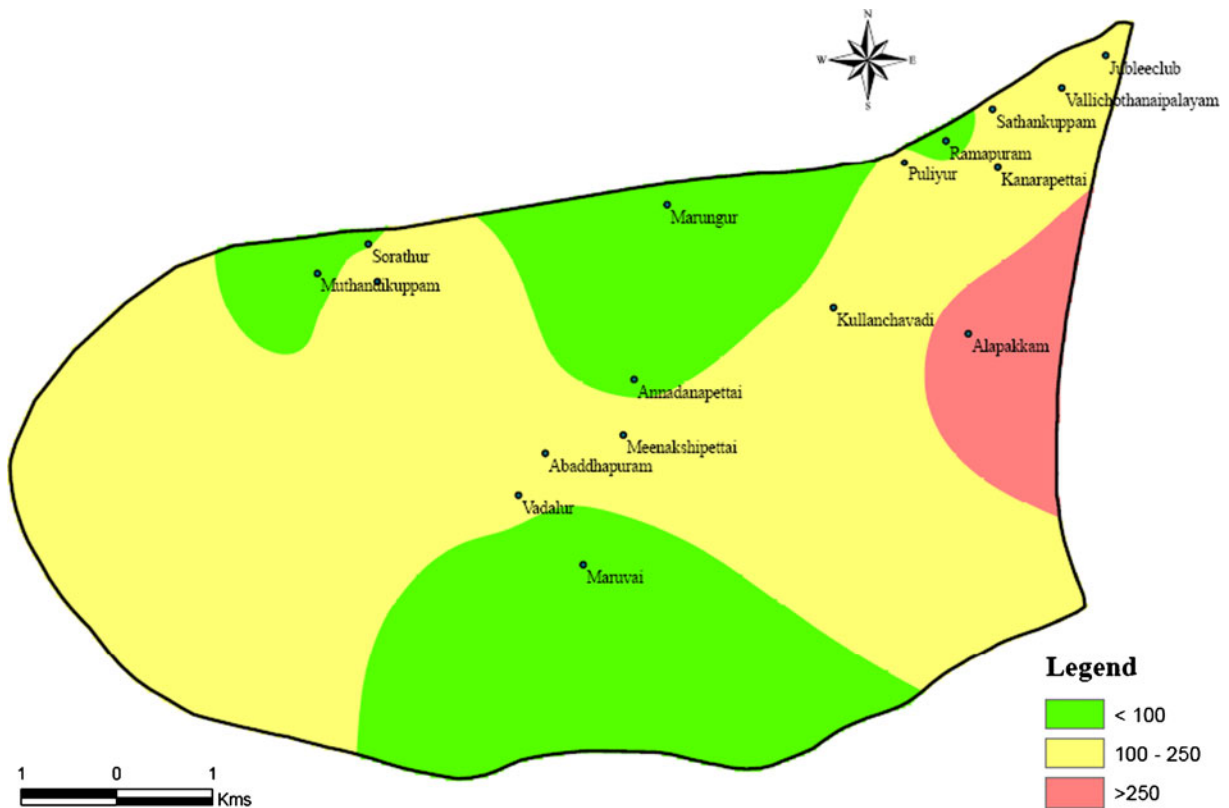
Fig. 9 Spatial variations of HCO_3 ion (ppm) in the Paravanar River Sub-basin

of nitrate. However, on a local scale, nitrogen inputs from agricultural activities in the form of fertilizers usually exceed those of natural sources. When this occurs, there could be an excessive amount of nitrogen that is not utilized by the plants. This excess amount of nitrogen is usually leached down into the soil by irrigation water or precipitation and has the potential to seriously pollute groundwater and eventually surface waters. Nitrogen is originally fixed from the atmosphere and then mineralized by soil bacteria into ammonium. Under aerobic conditions, nitrogen is finally converted into nitrate by nitrifying bacteria (Tindall et al. 1995).

Another activity that generates nitrogen input and hence, has the potential to degrade water quality is waste

material from livestock, such as cattle, swine and poultry. The forms of nitrogen that livestock produce are usually urea or uric acid. There are four possible fates for this nitrogen once it reaches the soil surface: 1) it may accumulate in the soil; 2) be leached down to the subsoil as ammonium; 3) be denitrified; or 4) be lost as volatiles into the atmosphere (Stewart 1970). All of this surplus nitrogen may seriously affect water quality and air quality.

When more nitrate accumulates in the soil than the plants can use, water from irrigation and precipitation can carry it down through the soil in a process known as 'leaching'. Most of the excess nitrate eventually finds its way to the groundwater. Though nitrate is non-toxic to humans, when nitrate enters the body, bacteria inside the stomach will convert nitrate to nitrite. Infants are at high risk, as an infant's stomach provides an excellent condition for bacteria to convert the nitrate into nitrite. Once the nitrite is formed, it would be absorbed by the intestines and enters the circulatory system, eventually forming a complex with the hemoglobin, whereby the nitrite oxidizes

Table 5 Suitability of drinking quality of Chloride ions

Concentration of Chloride in ppm	Suitable Zone
<100	Good
100–250	Moderate
>250	Poor
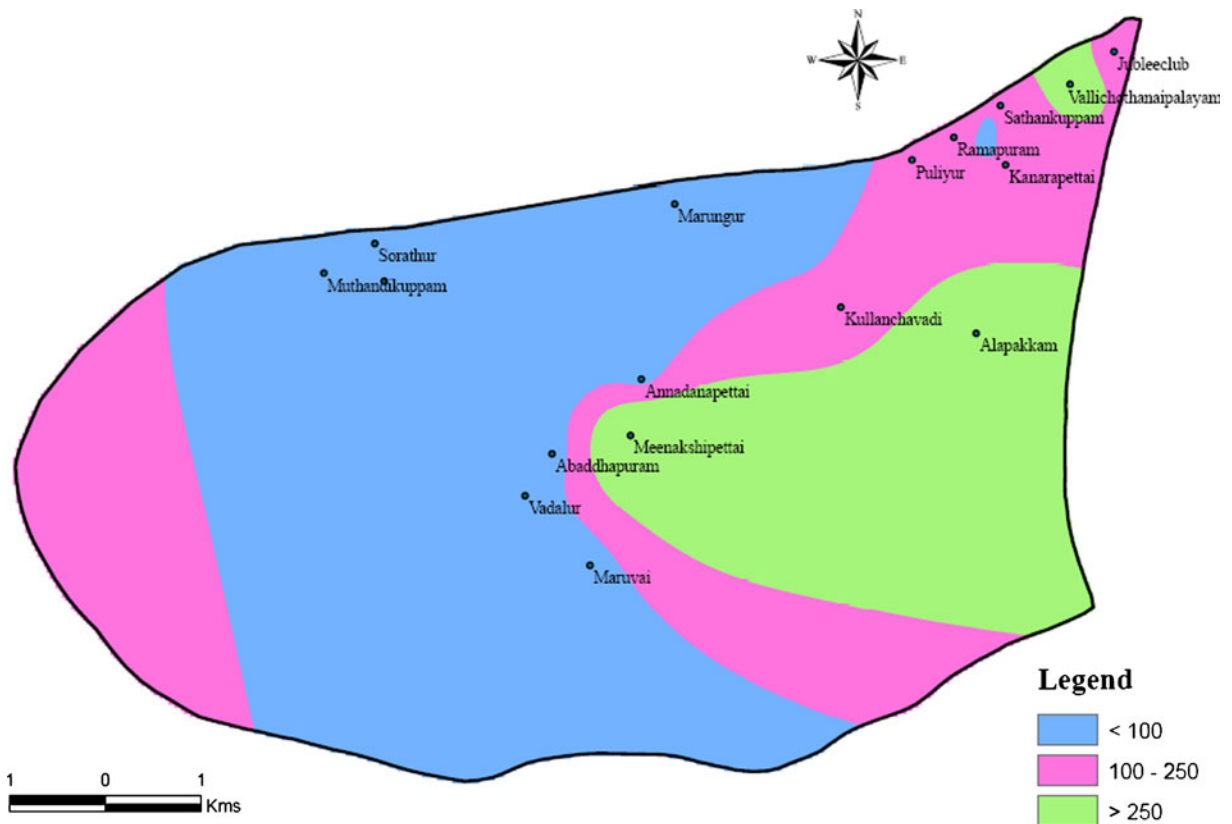
Fig. 10 Spatial variations of Cl_2 ions (ppm) in the Paravanar River Sub-basin

the iron of the hemoglobin to the ferric state (+3), changing it to methemoglobin. Since methemoglobin cannot carry oxygen and the reverse reaction is much slower, the infant would have oxygen starvation which results in a bluish discoloration of the body.

Another serious health problem that can arise from nitrate pollution is stomach cancer. As nitrate itself is not toxic; however, nitrite produced from nitrate could pose serious health hazard. Studies have shown that nitrite produced from nitrate could react in the stomach with an organic compound that comes from the breakdown of meat called secondary amine. Result of these two combined forms what is known as an N-nitroso compound. It is the N-nitroso compound that is able to alter certain components of DNA, leading to cancer (Addiscott et al. 1991).

Nitrate concentration in groundwater samples ranges from 0 mg/l to 120.2 mg/l in Abathanapuram there is no concentration of NO_3 due to geomorphological units of Alluvial plain. As most of the study area in the northern part is cultivated by natural and chemical fertilizers which may be the source for the elevated concentration of nitrate in a few selected locations in the north. Spatial variation of nitrate in the groundwater of the basin is represented in Fig. 11. It shows that the concentration of nitrate in and around the village Perperiyankuppam is about 120.2 mg/l east of Muthandhikuppam (Fig. 11). Perperiyankuppam represents sand stone of tertiary age, which act as an effective filtrate for such point source pollution in the near vicinity due to the application of natural fertilizers to cultivate dry crops like cashew nut, jack fruits and ragi etc.In the eastern part of the study area from Knnarapettai to Abathanapuram are relatively free from No_3 pollution (Fig. 11)

Conclusions

The major conclusions derived from this study, carried out in the Paravanar River sub-basin are as follows. The EC value ranges from 160 μS/cm in cuddalore

sandstone to 2,580 μS/cm in groundwater samples of coastal Alluvium. The highest value of 2,580 μS/cm was recorded in wells near the coast. pH value ranges from 7.2 to 8.6. Central and eastern part of the study area has high pH values, which represents the alkaline nature of groundwater at west and saline in eastern part of the study area.

In south eastern part of the study area alkali values are slightly higher but it is with in WHO's (1983) tolerable limits. The spatial distribution of chloride concentration shows that Meenatchipettai, Vazhisothani palayam and Allapakkam represents maximum Cl_2 concentration respectively of 527, 320 and 374 ppm, which is above ISI drinking standards of 250 ppm. Meenatchipettai is found in shallow alluvial plain and vazhisothanai palayam in buried alluvial plain. Increase in isochlore is observed from the coast up to the Neyveli Lignite mine. Such increase in isochlore indicates the possible migration of chloride ion from the coast up to the Neyveli mine due to depressurization of Neyveli aquifer.

Nitrate concentration of groundwater samples ranges from 0 mg/l to 120.2 mg/l. In marungur and puliyur there is no signature of No_3 abundance as they were found to be in tertiary upland without much stress by Anthropogens. As most of the study area is intensively irrigated, natural and chemical fertilizers used for agriculture may be the cause for increase in concentration of nitrates in Periperiyankuppam of about 120.2 mg/l. Northern and southern parts of the study area represent minimum amount of hardness to neutralize acids; hence the above part is categorized under 'poor zone' 'Moderate zone' is found to occur in northwest, west, southwest and in central parts of the study area as concentration is <250 ppm.

In cuddalore port (Jublee club) and in Alapakkam doubtful class of EC in coastal Alluvium represents the connate nature of groundwater to conform its increasing age. Increase in pH concentration in central and eastern part may be due to the presence of alkalies in tertiary and salinity in coastal alluvium and may be also due to connate nature of groundwater in the east. Increase in
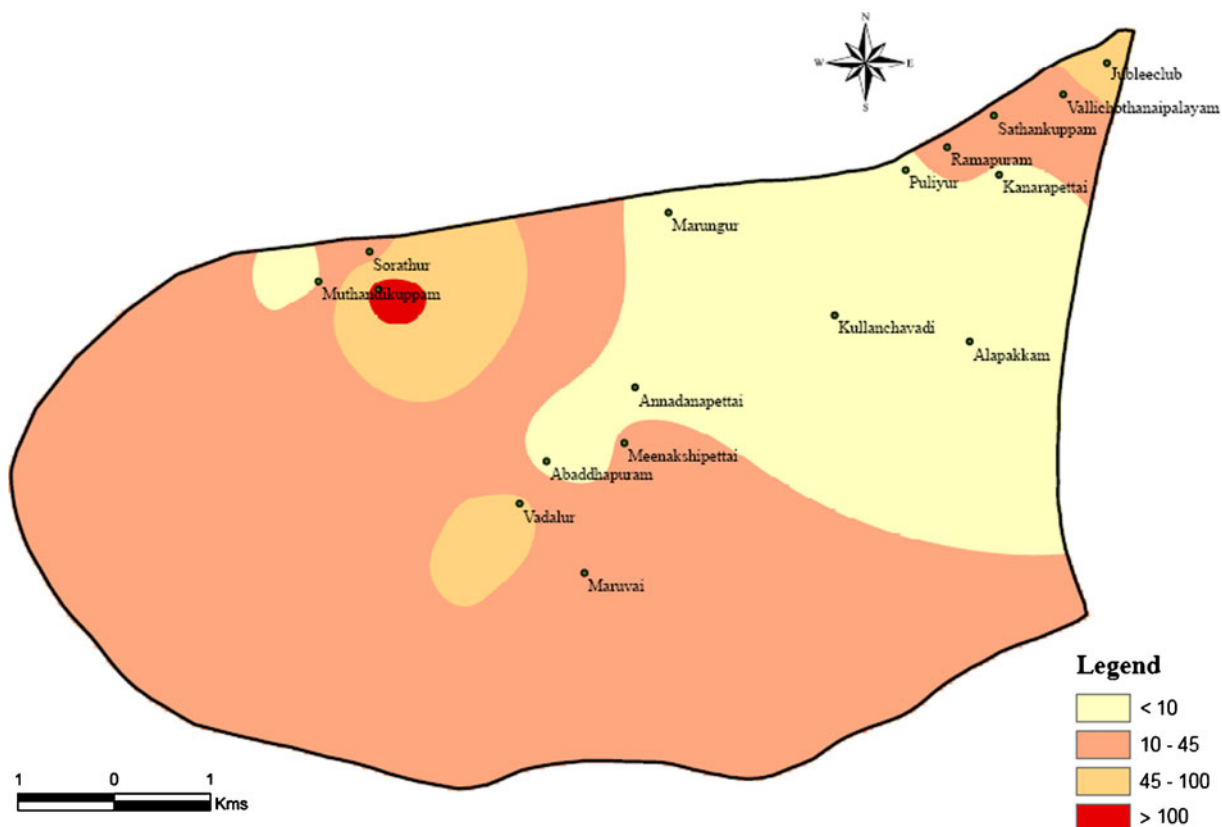
Fig. 11 Spatial variations of NO_3 ions (ppm) in the Paravanar River Sub-basin

Isochlore indicates the possible upwelling of connate water from the deeper aquifer of neyveli mines in the central part. However increase in nitrate concentration at Periperiyankuppammay is due to application of vermi-composite for agriculture operation by anthropogens.

References

Addiscott, T. M., Whitmore, A. P. & Powlson, D. S. 1991. Farming, Fertilizers and the Nitrate Problem. C.A.B. International. Wallingford, Oxford, United Kingdom.

Ahmed, E. (1972). *Coastal geomorphology*. New Delhi: Orient Longman.

Anbazhagan, S., & Nair, A. M. (2004). Geographic information system and groundwater quality mapping in Panvel Basin, Maharashtra, India. *J Environ Geol, 45*, 753–761.

APHA. (1995). *Standard methods for the examination of water and wastewater* (19th ed.). Washington: American public Health Association.

Aravindan, S., Patak, S., & Sekar, C. (2006). Groundwater targeting in the hard rock region of Gadilam river basin using remote sensing and GIS, Tamil Nadu. *Indian Jr. of Applied Hydrology, 19*(1 & 2), 84–93.

Aravindan, S., Shankar, K., Bhuvaneswari, M., & Rajendran, S. (2010). Groundwater geochemical mapping in the hard rock area of Gadilam river basin, Tamil Nadu. *Indian Jr. of Applied Geochemistry, 12*(2), 209–216.

Bakac, M. (2000). Factor analysis applied to a geochemical study of suspended sediments from the Gediz River, western Turkey. *Environmental Geochemistry and Health, 22*(2), 93–111.

Balasundar, N.K. (1968) Tertiary deposits of Neyveli Lignite field. Geol. Soc. India, Mem. No.2, pp.256–262.

Burrough, P. A., & McDonnell, R. A. (1998). *Principles of Geographical Information Systems* (p. 333). Oxford: Oxford University Press.

Chaudhary, B. S., Kumar. M., Roy, A. K., & Ruhal, D. S. (1996) Applications of RS and GIS in groundwater investigations in Sohna block, Gurgaon district, Haryana, India. International Archives of Photogrammetry and Remote Sensing, 31, B-6, Vienna, Austria. pp 18–23

Dalton, M. G., & Upchurch, S. B. (1978). Interpretation of hydrochemical facies by factor analysis. *Ground Water, 10*, 228–233.

Dawdy, D. R., & Feth, J. H. (1967). Applications of factor analysis in study of chemistry of groundwater quality, Mojave River Valley, California. *Water Resour Res, 3*, 505–510.

Goyal, S. K., Chaudhary, B. S., Singh, O., Sethi, G. K., & Thakur, P. K. (2010) GIS based spatial distribution mapping and suitability evaluation of groundwater quality for domestic and agricultural purpose in Kaithal district,

Haryana state, India. *Environmental Earth Sciences* doi:10.1007/s12665-010-0472-z

Hem, J. D., (1970). Study and interpretation of the chemical characteristics of natural water, USGS., Water supply paper 1473.

Jayakumar, R., & Siraz, L. (1997). Factor analysis in hydro-geochemistry of coastal aquifers—a preliminary study. *Environmental Geology, 31*, 174–177.

Kamaraju, M. V. V. (1997). Ground-water potential evaluation of West Godavari district, Andhra Pradesh State, India- A GIS approach. *Ground Water, 34*(2), 318–334.

Lawrence, F. W., & Upchurch, S. B. (1976). Identification of geochemical patterns in groundwater by numerical analysis. In Z. A. Saleem (Ed.), *Advances in groundwater hydrology* (pp. 199–214). USA: American Water Resources Association.

Lawrence, F. W., & Upchurch, S. B. (1983). Identification of recharge areas using factor analysis. *Ground Water, 20*, 680–687.

Olmez, L., Jack, W. B., & Villaume, J. F. (1994). A new approach tounderstanding multiple-source groundwater contamination:factor analysis and chemical mass balance. *Water Research, 28*, 1095–1101.

Panel on Nitrates of the Co-ordinating Committee for the Scientific and Technical Assessments of Environmental Pollutants. (1978). Nitrates: An environmental assessment. National Academy of Sciences, Washington, DC.

Razack, M., & Dazy, J. (1990). Hydrochemical characterization of groundwater mixing in sedimentary and metamorphic reservoirs with combined use of piper's principal and factor analysis. *Journal of Hydrology, 114*, 371–393.

Reineck, H. E., & Singh, I. B. (1980). *Depositional sedimentary environments with reference to terrigenous clastics* (2nd ed.). Berlin, Heidenberg: Springer Verlag.

Richards LA (1954) Diagnosis and improvement of saline alkali soils. US Department of Agriculture, Hand Book 60, pp 160

Selvaraj, K., & Ramasamy, S. (1998). Depositional environment of Cuddalore sandstone formation, Tamil Nadu. *Jr. Geol. Soc. India, 51*, 803–812.

Shankar, K., Aravindan, S., & Rajendran, S. (2010). GIS based groundwater quality mapping in Paravanar River Sub-Basin, Tamil Nadu, India. *International Journal of Geomatics and Geosciences, 1*(3), 282–296.

Srivastava, P. K., & Bhattacharya, A. K. (2000). Delineation of groundwater potential zones in a hard rock terrain of Bargarh district, Orissa using IRS Data. *Photonirvachak- J Indian Soc Remote Sens, 28*(2), 129–140.

Srivastava, A., Tripathi, N. K., & Gokhale, G. K. (1997). Basement topography and aquifer geometry around Ken Garden, India. *International Journal of Remote Sensing, 20*(11), 2295–2305.

Stewart, B. A. (1970). Voliatization and nitrification of nitrogen from urine under simulated cattle feedlot conditions. *Environmental Science and Technology, 4*, 579–582.

Subbarao, C., Subbarao, N. V., & Chandu, S. N. (1996). Characterisation of ground water contamination using factor analysis. *Environmental Geology, 28*, 175–180.

Subramanian, K. S., & Selvan, T. A. (2001). Geology of Tamil Nadu and Pondicherry. Geological Society of India, Bangalore.

Tindall, J. A., Petrusak, R. L., & McMohan, P. B. (1995). Nitrate transport and transformation process in unsaturated porous media. *Journal of Hydrology, 169*, 51–94.

WHO. (1983). *Guidelines to drinking water quality* (p. 186). Geneva: World Health Organisation.