IJEP 30 (10) : 793-813 (2010) (Received on June 11, 2010)

Hydrogeological Studies Along the Coastal Area of Kanyakumari to Colachel After Tsunami, South Tamil Nadu

S.Bhagavathi Perumal, P.Thamarai and L. Elango

The Rajaas Engineering College, Department of Civil Engineering, Vadakangulam, Tirunelveli - 627116

INTRODUCTION

Hydrogeology of the Kanyakumari to Colachel aquifer was brought out by systematic hydrogeological, lithological and hydrological studies. Intensive field work was carried out to study the geomorphic and geologic variations within the study area. These studies included water level monitoring and surface and groundwater chemical analyses. Detailed lithological surveys were carried out to demarcate the vertical variations in aquifer lithology. Spatial and temporal analysis of the groundwater head revealed about the flow, recharge and discharge conditions of the aquifer. In this chapter, the hydrological aspects of the Kanyakumari Colachel study area derived from the interpretation of the results obtained from the above mentioned surveys are presented. These studies will form the basis to achieve the objectives of this research and will be utilised to develop a conceptual groundwater flow model of the Kanyakumari Colachel aquifer is presented.

The study area is under Agastheeswaram taluk which is having the salient features of 20 villages, 10 villages in Agastheeswaram block and 10 villages in Rajakkamangalam block. The eastern side of this area is bounded by the Bay of Bengal, the southern side area is bounded by Indian Ocean and the western side is bounded by Arabian sea. The average maximum temperature recorded during April and May is about 35.93°C. The average minimum temperature is about 23.85°C recorded usually during the months of November and December. The average annual rainfall of the basin is about 1448.6 mm. The northeast monsoon from October to December contributes almost 538.6 mm and the southwest monsoon from June to September contributes almost 538.3 mm, during hot whether period from March to May rainfall is 326.3 mm and during winter January and February the rainfall is 45.4 mm in the study area. The main river basin in the study area is Pazhayar river. The climate condition is subtropical. There are 248 lakes/ponds, 5 channels and 1 perennial Pazhayar river and 1 non perennial Valliyar river is passing through the area. A well-developed dendrite type of drainage system indicates the occurrence of rocks of uniform resistance. Banana, paddy, groundnut, tobacco, flower plants, rubber and coconut are the common crops. Cultivations are due to perennial river basins, like Pazhayar, Valliyar (Kodaiyar channel) and Tamiraparani (Thovalai channel). Numerous small ponds are present in the depressed parts of the undulating topography of the study area.

Study area

Kanyakumari district coastal belt is approximately between latitudes 8° 05′ 30" to 8° 34′ 30" and longitudes 77° 06′ 30" to 77° 35′ 00". Kanyakumari district covers an area of 167184 ha in which along the coastal belt approximately 70 km length and 18 km width Kanyakumari to Colachel coastal belt of 860 km^2 area is taken as study area after Tsunami in 26th December 2004 (Figure 1). The average annual rainfall of the basin is about 1448.6 mm. The climate condition is subtropical. Types of soil available are sandy clay, river alluvium, red soil, laterite soil and coastal alluvium.

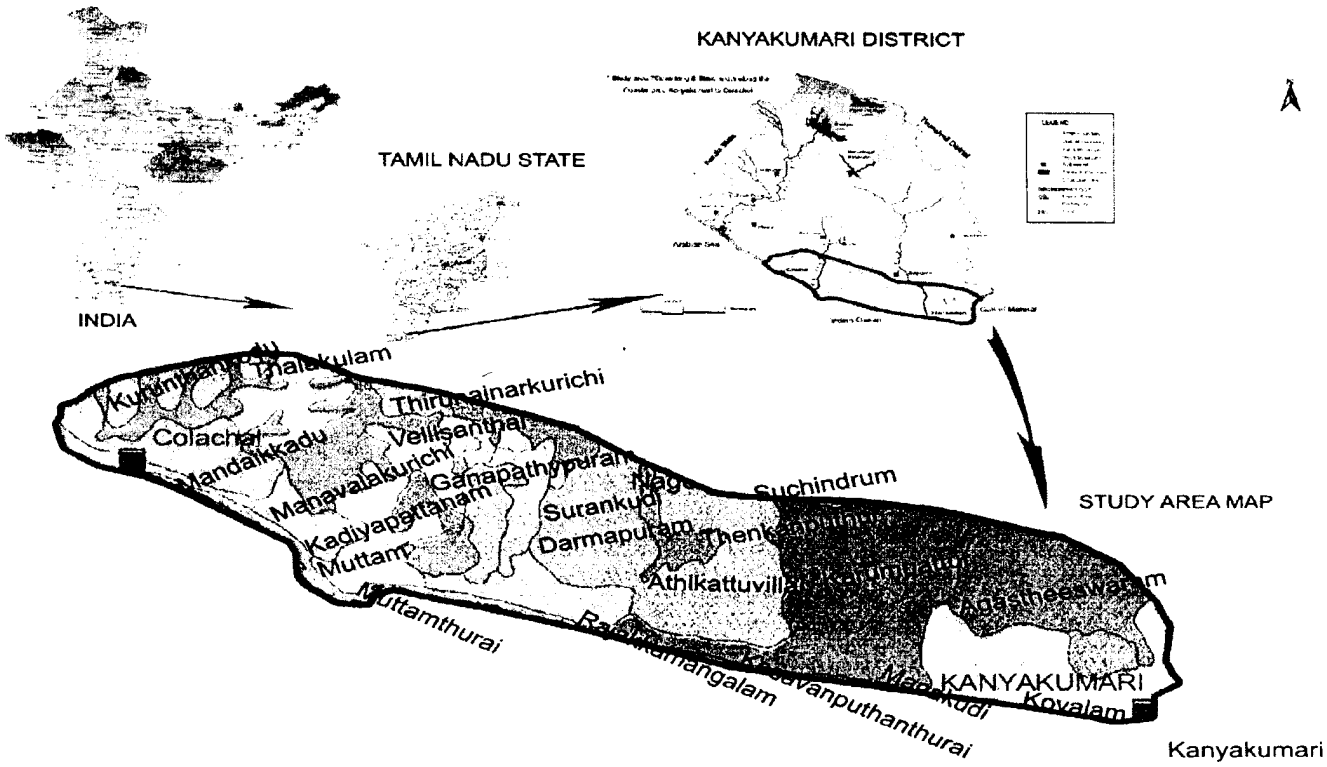


Figure 1. *Study area map (Kanyakumari to Colachel coastal area-860 km²)*

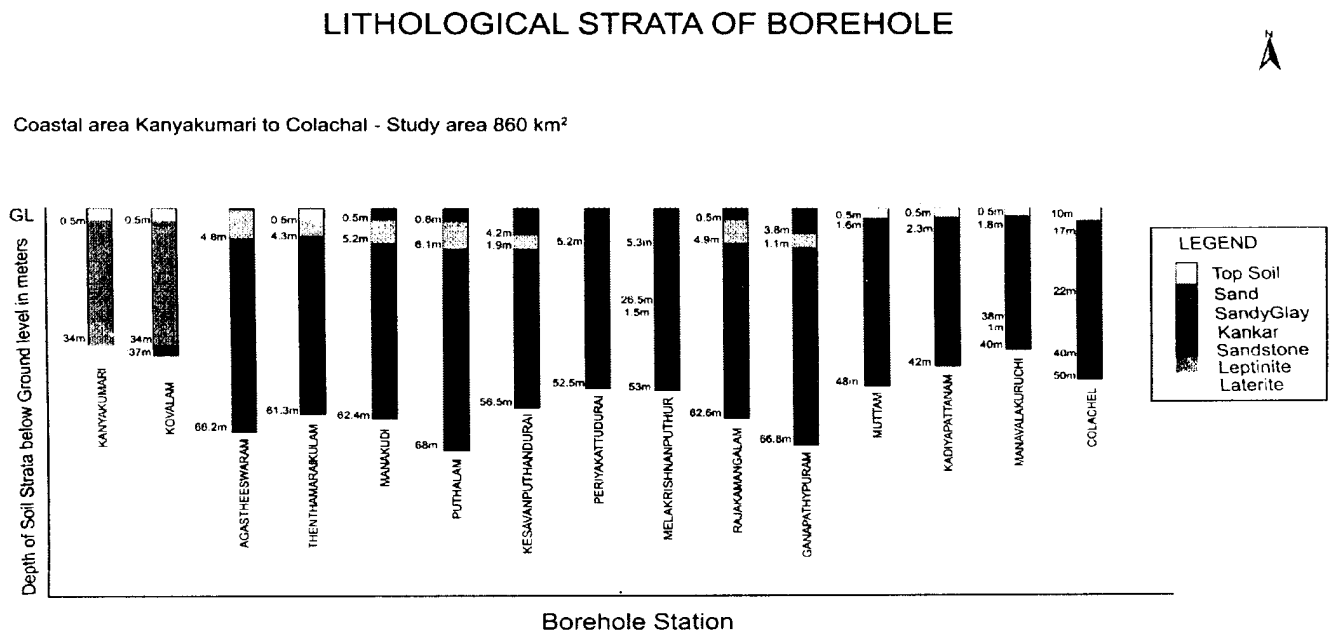


Figure 2. *Borehole lithology of the study area*

The basement of the study area consists of charnockite, granite gneiss, leptinite, leptinite gneiss, peninsular gneiss, laterite, warkalai sandstone, variegated clay, sandy clay, river alluvium, etc. Alluvium occurs as the upper layer and is characterized by sand, gravel and sandy clay. Its thickness ranges from 1m to 20m along the coastal area. The alluvium and weathered crystalline charnockites function as an unconfined aquifer system. Groundwater occurs under unconfined conditions. Depth of groundwater from

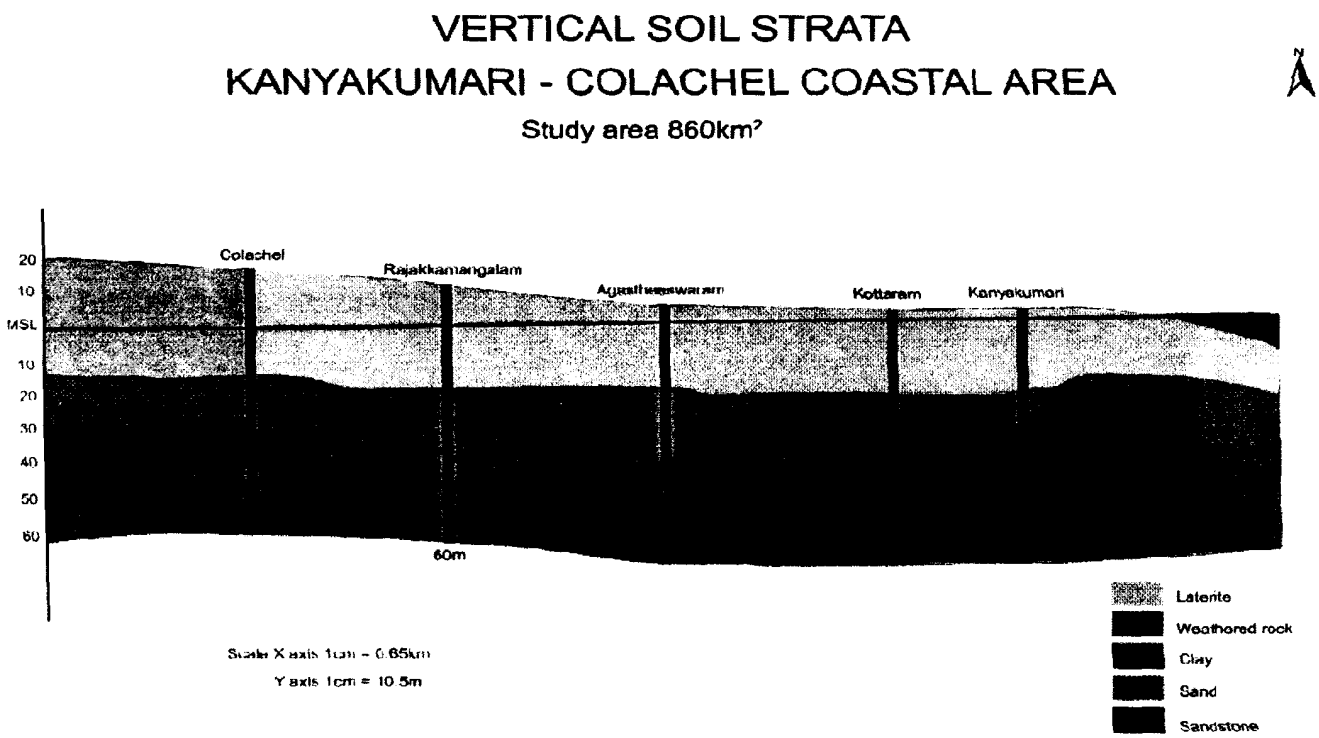


Figure 3. *Borehole soil strata of the study area*

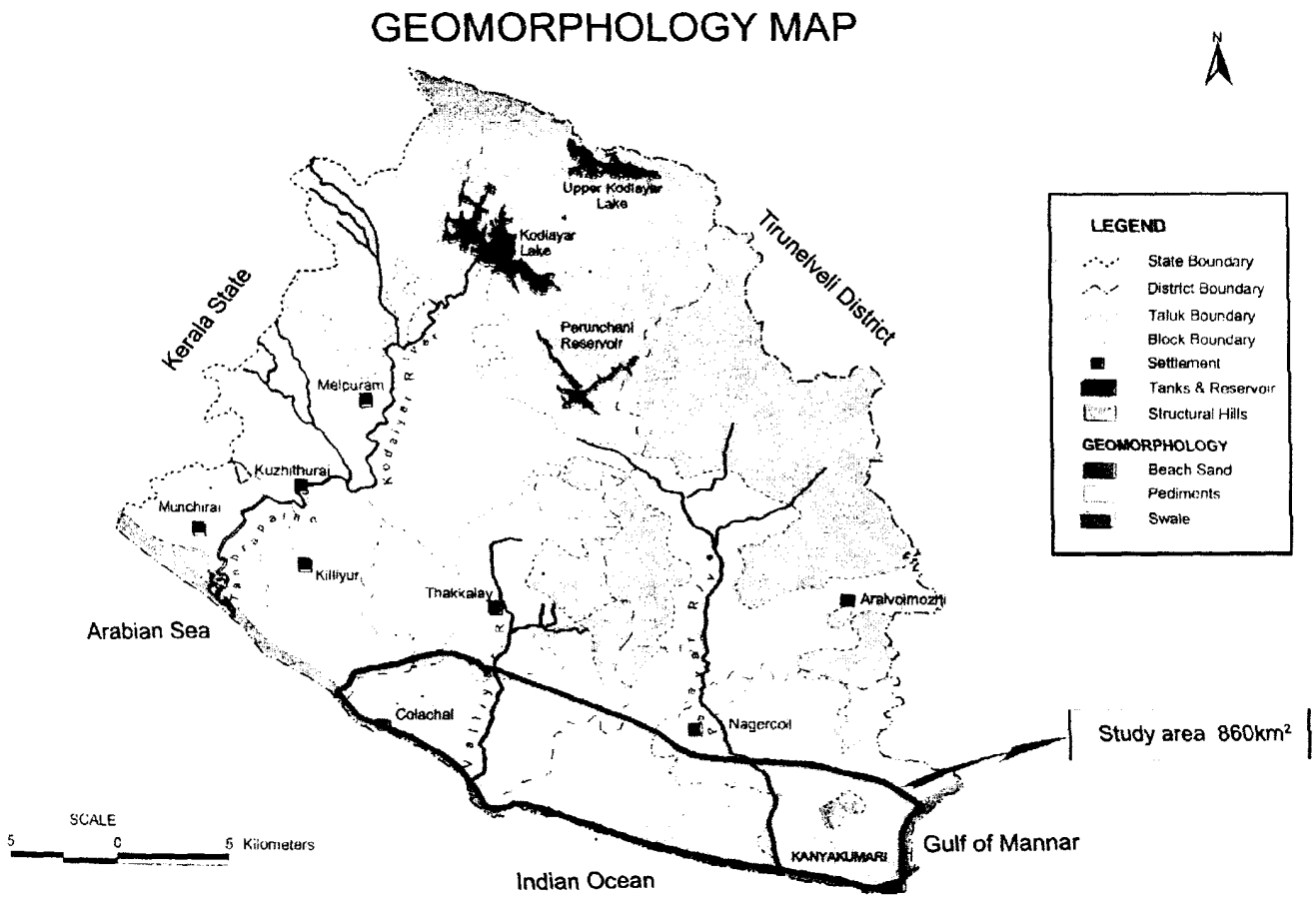


Figure 4. *Geomorphology of the study area*

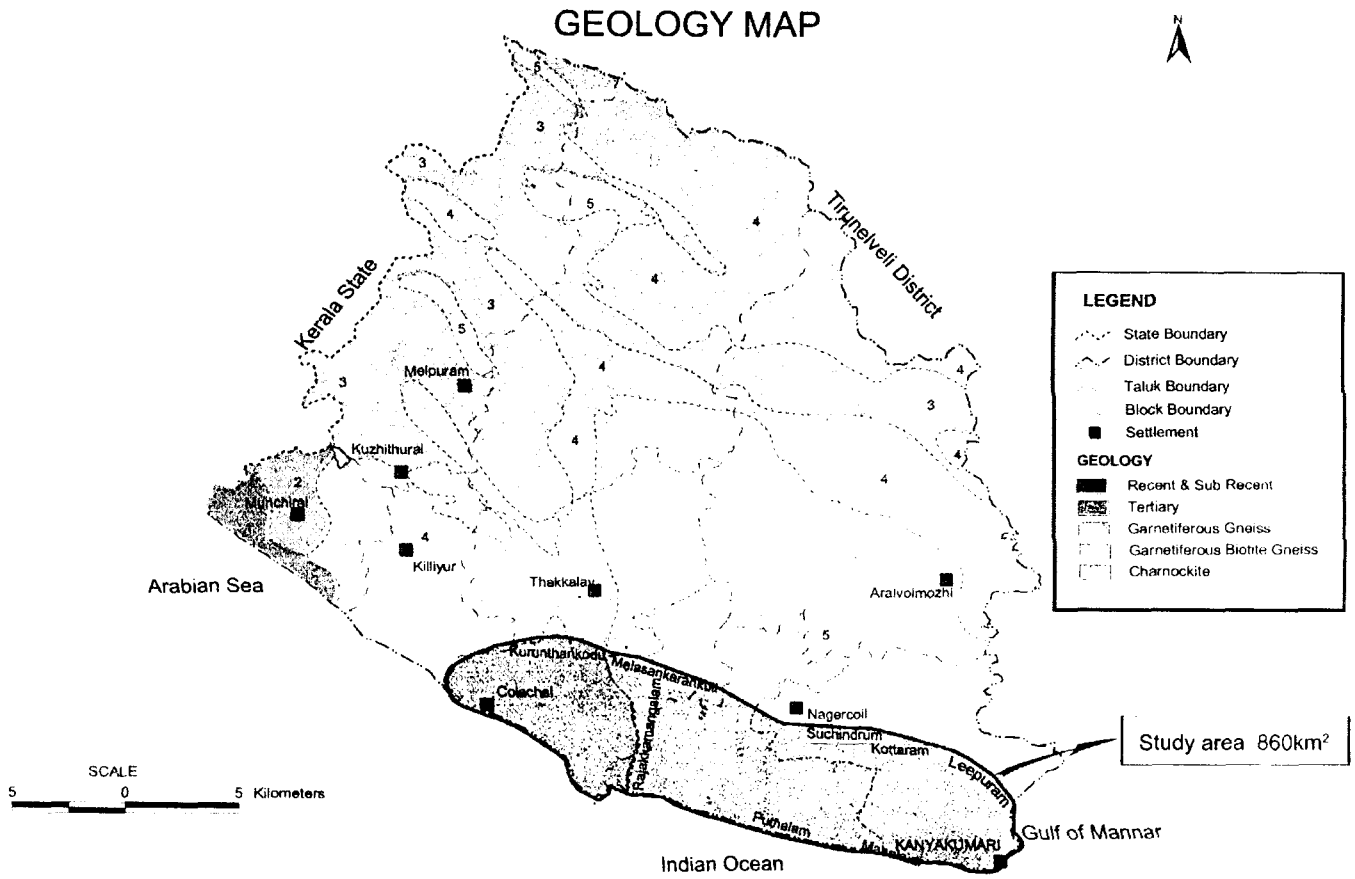


Figure 5. *Geology of the study area*

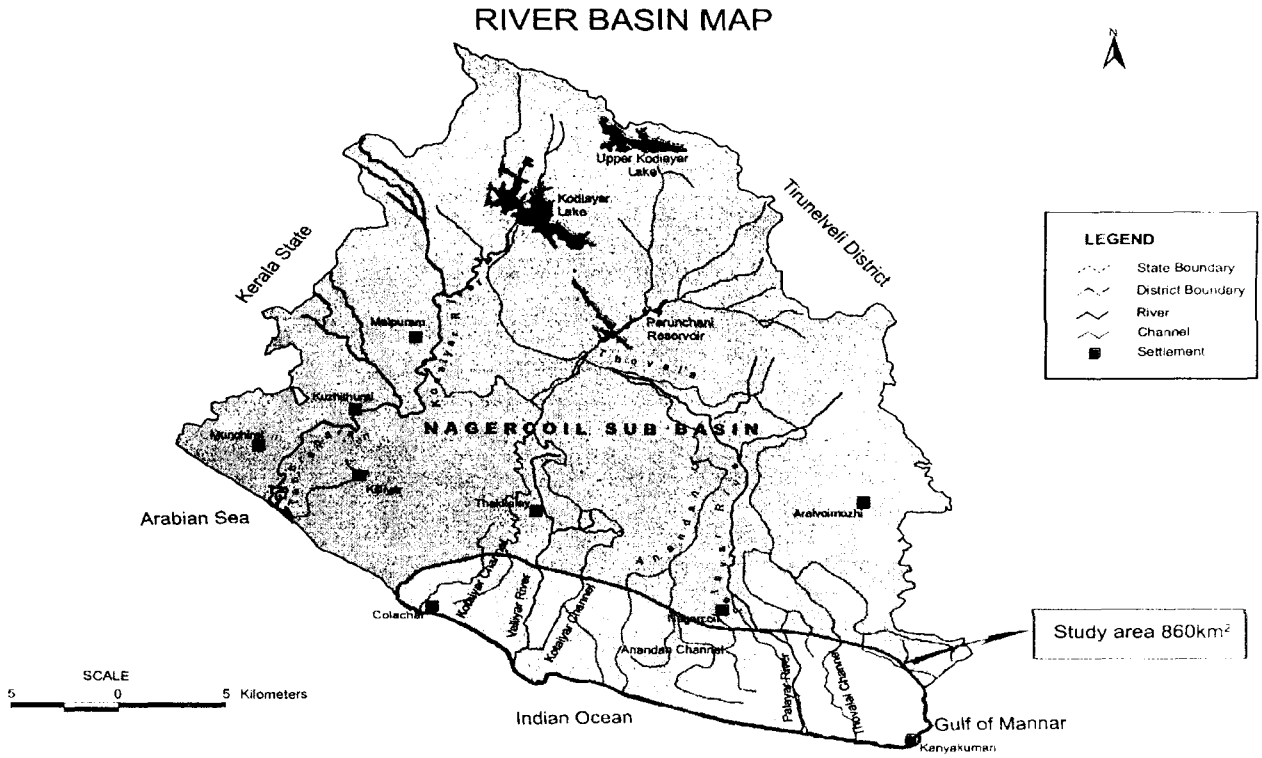


Figure 6. *River basin map in the study area*

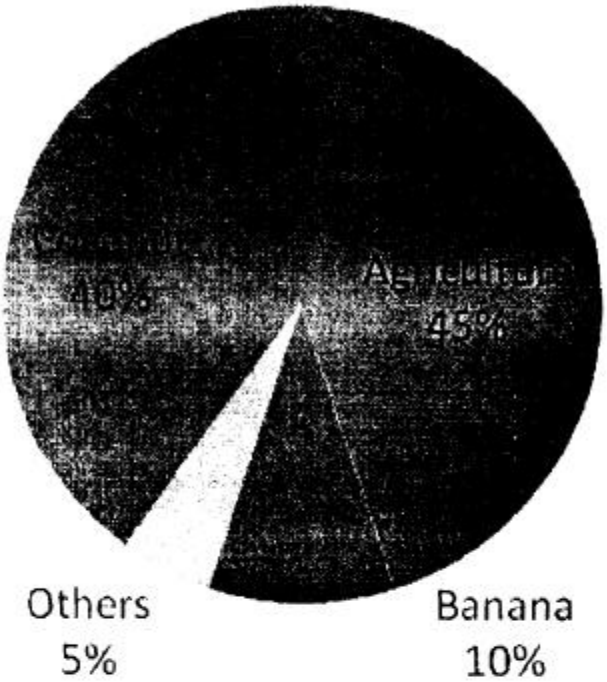


Figure 7. *Land use pattern for irrigation purpose in the study area*

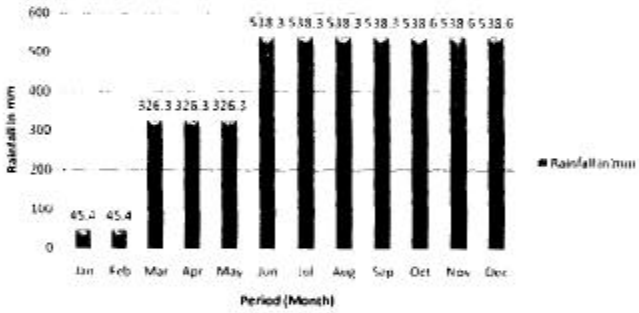


Figure 8. *Intensity of rainfall the study area*

monitoring wells varies in the range of 0.5m to 10m above MSL, and 5m to 11m below ground level. The hydraulic conductivity of the alluvium is 30.0 m/day (PWD, 2000). The specific yield value is 0.2 (PWD, 2000).

MATERIAL AND METHOD

Geology and hydrogeology

The basement of the study area consists of charnockite, granite gneiss, leptinite, leptinite gneiss, peninsular gneiss, laterite, warkalai sandstone, variegated clay, river alluvium, etc. The study of structural and tectonic history indicates several episodes of deformation, which caused repeated folds,

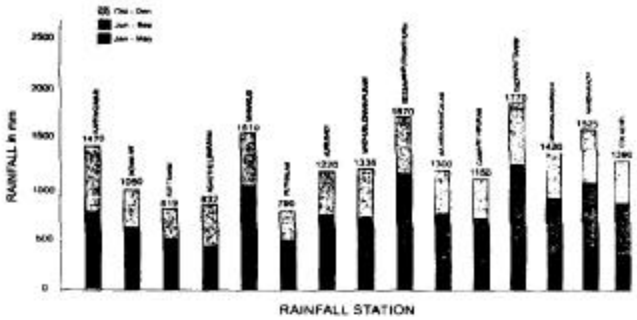


Figure 9. *Histogram of normal annual rainfall in the study area (1996-2007 years average)*

faults, joints and fracture systems. The basement rocks are overlain by red soil, lateritic soil, clayey soil, river alluvium and coastal alluvium, black, red and red sandy soils of thickness ranging from 1m to 1.5 m in most places. The area is underlain by the peninsular gneissic terrain of India. Sediments of miocene were also deposited and identified as the warkalai sandstones. Also, the sands of recent origin are noticed along the coast. Penisular gneisses occupy the largest area in the study places. The general trend of the strike of the area is N-NW to S-SE. Garnetiferous sillimanite, graphite gneisse and garnetbiotite gneiss is the two major groups identified in this area. The charnockite group of rocks is well exposed around Rajakkamangalam area.

The warkalai beds of tertiary age are exposed as the cappings, south-west region near the coast. Sub-recent origin of calcareous limestone is noticed near Kanyakumari. Lateral deposits or bay deposits of sand, zircon, rutile, illemanite and garnet are very common phenomena along the entire sea coast of Kanyakumari. Near Manavalakurichi monazite are deposited. The trend of foliation in gneisses is N 20 W-S 30 E with steep dips on the eastern side. The peculiar deposition of feldspathic granites over a large portion of this area is suggestive of the fact that rocks have been sharply folded isoclinally causing repetition of bands. The trend of folds is aligned in NW-SE direction. Subsequently, this might have been subjected to cross folding. Also coastal sand is seen

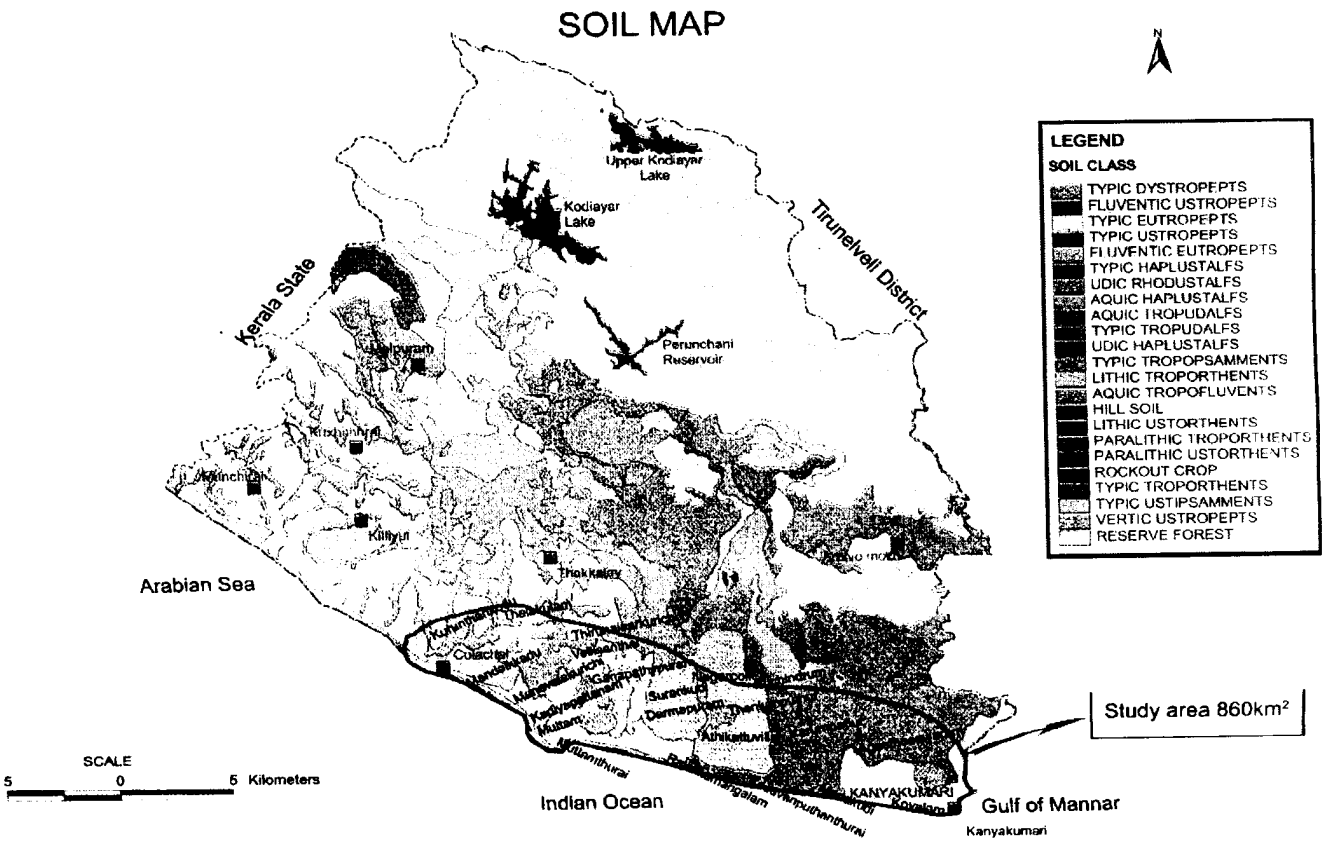


Figure 10. *Soil map of the study area*

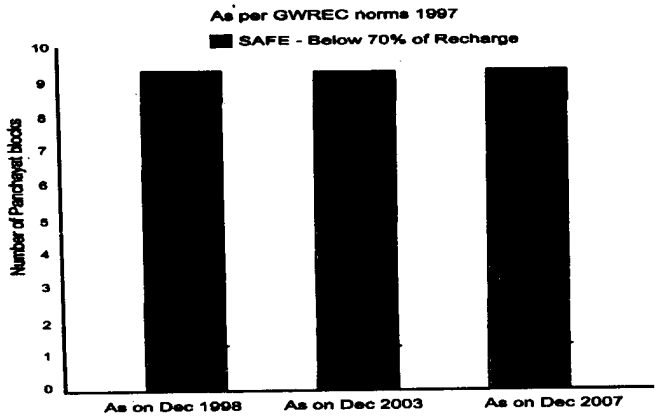


Figure 11. *Stages of groundwater development in the study area*

in the entire coastal belt of Kanyakumari coastal area. Borehole lithology records reveal that the thickness of alluvial deposits is more in Bazada and valley fills (about 10 –15 m). Weathered and fractured zones are areas for groundwater occurrence. Intensity of weathering is not uniform in space and depth. It is considerably higher in gneissic rocks than in charnockite.

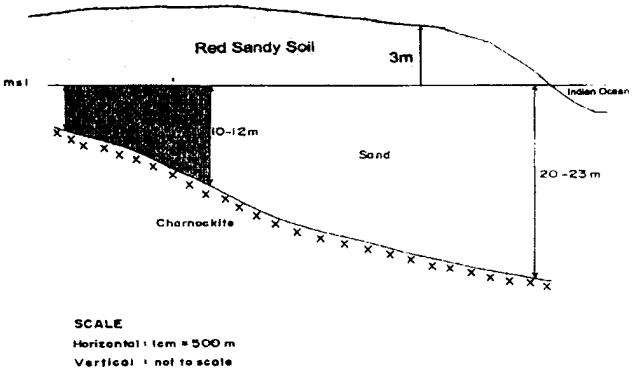


Figure 12. *Aquifer geometry*

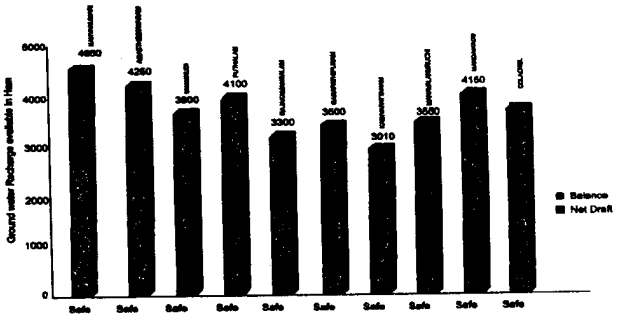
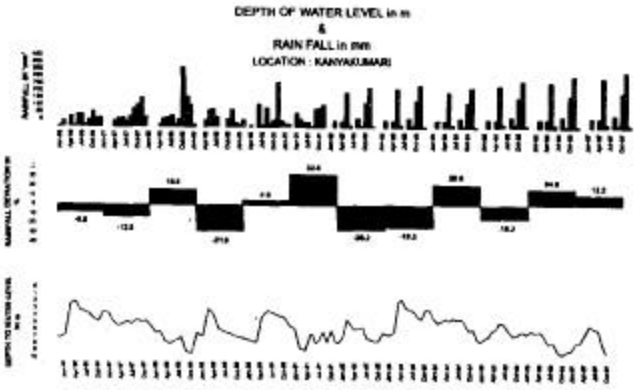
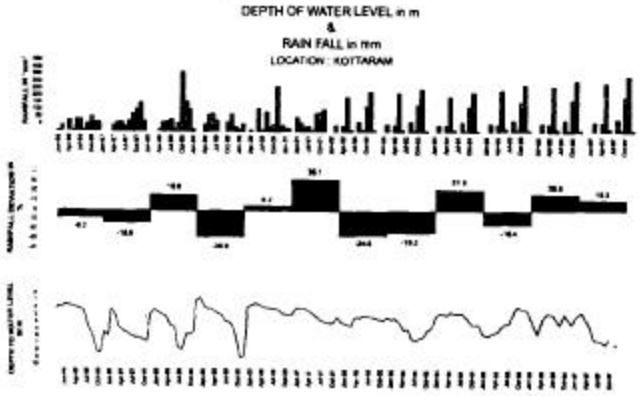


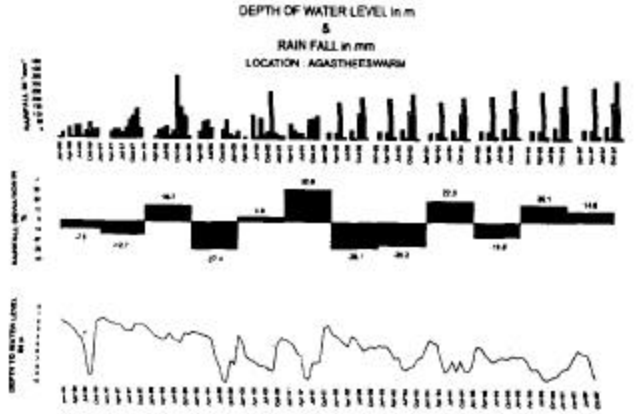
Figure 13. *Ground water potential as on January 2007 based on GWREC norms 1997*



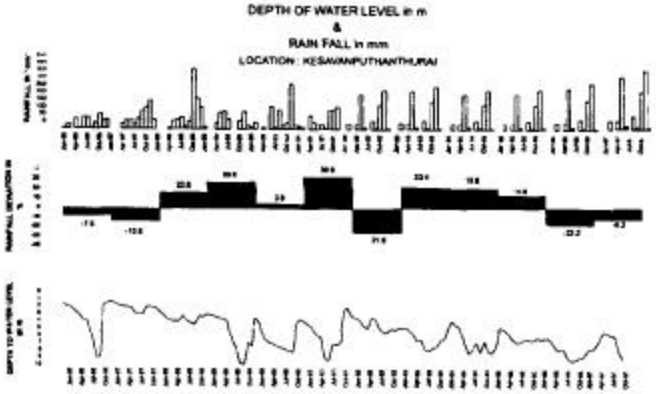
Time in month
(a) Kanyakumari



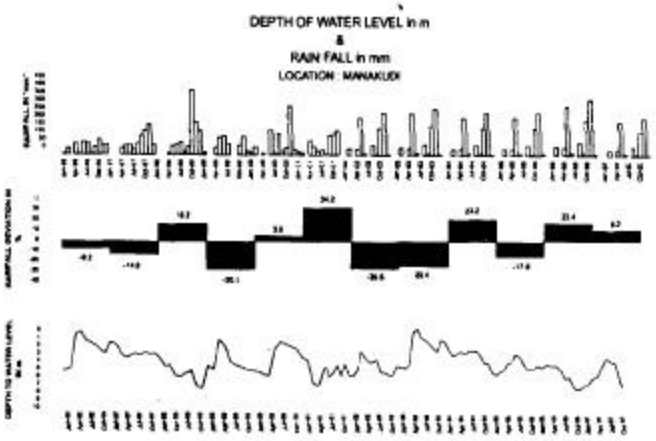
Time in month
(b) Kottaram



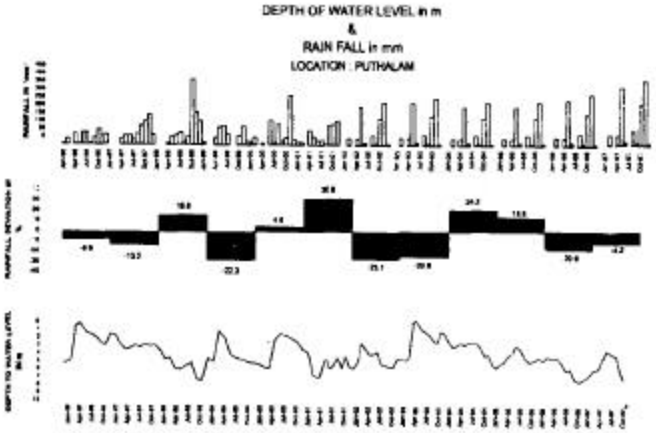
Time in month
(c) Agastheeswaram



Time in month
(d) Kesavanputhanthurai



Time in month
(e) Manakudi

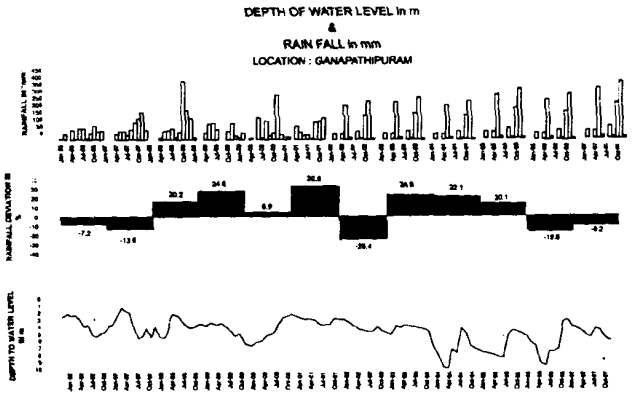


Time in month
(f) Puthalam

Figure 14. *Continued*

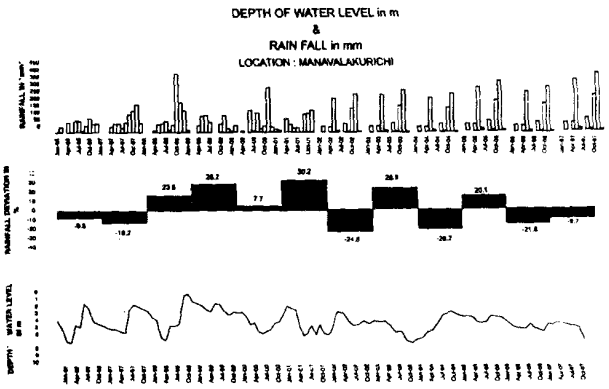
Weathered zone thickness of the study area generally ranges from 10 to 35 m below ground level. The groundwater of the area occurs under unconfined conditions. Rainfall infiltration and seepage of water from surface water bodies are responsible for groundwater actuation. Most of the wells used for irrigation are shallow and partially penetrating because once a considerable depth of water column is reached, farmers stop further deepening of wells. Hydro-

Figure 14. *Continued*



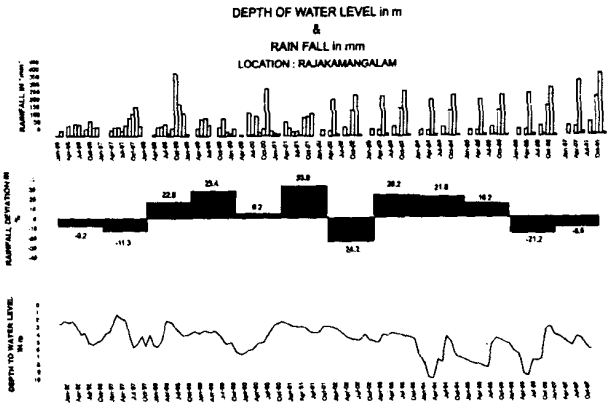
Time in month

(g) Ganapathypuram



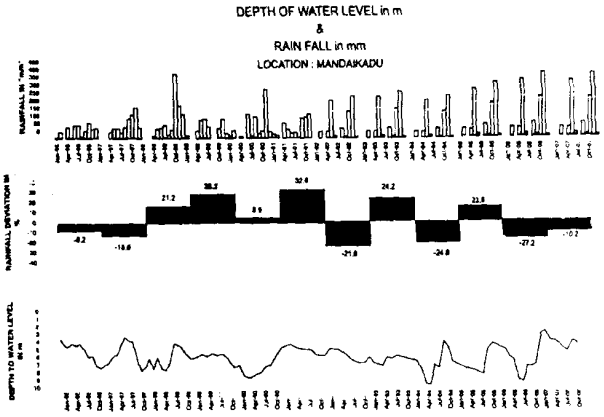
Time in month

(j) Manavalakurichi



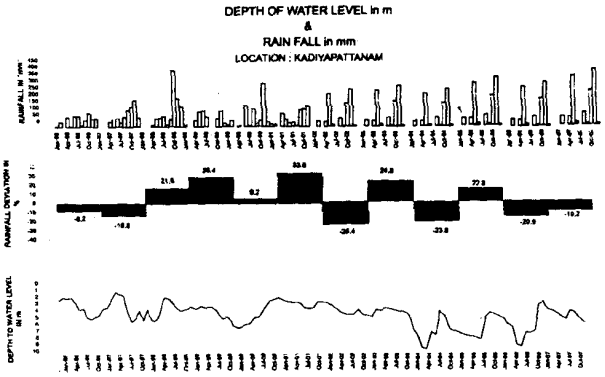
Time in month

(h) Rajakkamangalam



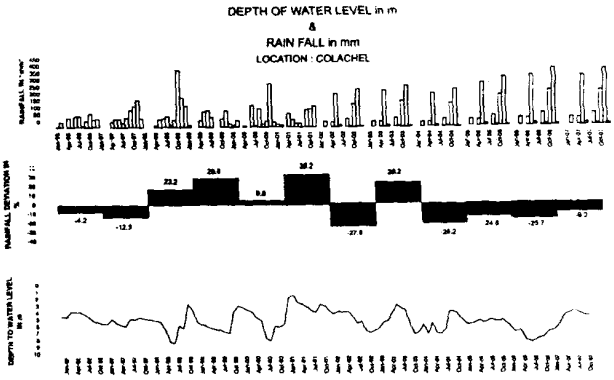
Time in month

(k) Mandaikadu



Time in month

(i) Kadiyapattinam



Time in month

(l) Colachel

Figure 14. *Comparison between water level and rainfall*

graphs indicate that the groundwater table tends to rises during October and December to reach peak and starts receding from February onwards to the end of August to September. However, a slight raising trend is seen during July because of southwest

Table 1. *Description of land forms and groundwater occurrence in the study area*

Geomorphic	Characteristics	Hydrogeology	Groundwater potential
Bazada (BZ) (Rajakkamangalam to Colachel)	Coalescence of alluvial cones and fans formed at the break of composite slopes boundary	More infiltration recharge zone comprised of colluvio-fluvial materials	Very good
Valley fill (VF) (west part of Colachel)	Comprised of cobbles, pebbles and detridal materials, like sand silt, kankar and friable clay. Formed in linear depression along the stream/ drainage	Infiltration is good-recharge is from stream and rivers	Good
Flood plain (FP) (near Pazhayar river)	It is gentle plain adjacent to river comprising of river Alluvium. Indicate the maximum flood level. Comprise both younger and older flood plain	High infiltration recharge mainly from river and other hydrogeological features	Good
Pediment (P) (Manakudi area)	It forms outcrops with or without soil cover	Run off zone	Poor
Shallow buried pediment (BPS) (Muttam area)	Intermediate zone between pediment and deep buried pediment weathering thickness is appreciable	Moderate infiltration-recharge, influenced by hydrological features	Moderate
Deep buried pediment (BPD) (normally in all parts of the area)	Shallow depressed low relief area with good drainage networks. Weathering thickness is more	Infiltration moderate to good-recharge by hydrological feature storage complemented by secondary fractures	Good
Coastal plain (CP) (Coastal area)	Unstabilised and stabilised sand dunes and comprising of medium to fine sandy wind blown particles	Recharge zone with good infiltration	Good
Lineament (L) (Kanyakumari area)	Linear feature may be a geological contact/fault/ sheared or fractured jointed zone.	Infiltration is good in fracture jointed lines and in geological contact.	Good

Table 2. *Stratigraphical successions of geological formations*

Era	Age	Stage	Lithology
Quaternary	Recent	Cuddalore sandstone	Sand, sandy clay
Cenozoic	Middle miocene		Warkalai sandstones
Archaean			Peninsular gneisses
			Charnockites, granites and pegmatite's

Table 3. *Seasonwise normal rainfall (70 year) at selected rain gauge station*

Season	Period	Rainfall, mm	Percentage
Winter	Jan and Feb	45.4	3.13
Hot weather period	March to May	326.3	22.53
South west monsoon	June to Sep	538.3	37.16
North east monsoon	Oct to Dec	538.6	37.18
	Total	1448.6	100.00

Table 4. *Seasonal normal rainfalls for selected rain gauge stations, in mm*

Rain gauge station	Jan to Feb	Mar to May	June to Sep	Oct to Dec	Normal annual rainfall	Average year
Kanyakumari	34.0	282.7	466.1	468.4	1251.2	70
Kottaram	37.7	251.3	381.0	450.9	1120.9	70
Colachel	40.5	342.1	546.4	540.6	1469.6	70

Table 5. *Soil categorisation in the study area*

Category	Differentiations characters
Order	Soil forming process as indicated by the presence on absence of major diagnostic horizons
Sub order	Sub divisions of order according to presence or absence of properties associated with wetness, soil moisture, parent materials and vegetation effect
Group	Sub divisions of sub orders according to similar kind arrangement and degree of expression of horizons bass status, soil temperature and moisture regime
Sub group	Integration to other great groups, sub orders and orders
Family	Properties important for plant growth broad soil textual, mineralogical and soil temperature class
Series	Kind and arrangement of horizons, colour texture, consistency, regarding chemical and mineralogical properties of horizons

monsoon rain.

Lithological details of study area

Analysing the lithological details of 15 bore holes (PWD, 1970-2005) in the study area of Kanyakumari to Colachel, at Kanyakumari GL-0.5 m is top soil, 0.5 m-5.5 m is sandy clay, 5.5 m-9.5 m is leptinite, 9.5 m-34 m is leptinite weathered, at Agastheeswaram Gl-4.8 m laterite, 4.8m-66.2 m sandy clay, at Thenthamaraikulam GL-0.5 m top soil, 0.5m-4.3 m laterite, 4.3 m-61.3 m sandy clay, at Manakudi GL-0.5 m is sand, 0.5 m-5.2 m is laterite, 5.2 m-62.4 m sandy clay, at Puthalam GL-0.6 m sand, 0.6 m-6.1 m laterite, 6.1 m-68 m sandy clay, at Kesavanputhanthurai GL-4.2 m sand, 4.2 m-56.5 m sandy clay, at Periyakattudurai GL-5.2 m sand, 5.2m-52.5m sandy clay, at Melakrishnanputhur GL-5.3 m sand, 5.3 m-26.5 m sandy clay, 26.5m-27 m sandsatone, 27 m-53 m sandy clay, at Rajakamangalam GL-0.5 m top soil, 0.5 m-62.6 m sandy clay, at Ganapathypuram GL-3.8 m sand, 3.8 m-4.9 m laterite, 4.9 m-66.8 m sandy clay, at Mutam GL-0.5 m top soil, 0.5 m-1.6 m sand, 1.6 m-48 m sandy clay, at Kadiyapattanam GL-0.5 m top soil, 0.5 m-2.3 m sand, 2.3 m-42 m sandy clay, at Manavalakuruchi-GL-1 m top soil, 1 m-47 m sandy clay, at Mondaymarket GL-7 m laterite, 7 m-48 m sandy clay, and at Colachel GL-7 m is top

Table 6. *Major type of soils in Kanyakumari to Colachel area*

Soil subgroup	Common name	Local name
Inceptisol-Order		
Tropepts-Sub-order		
Typic dystropepts	Slightly developed, low fertile deep, brown soils in high rainfall area	Valarman
Fluventic ustropepts	Very weakly developed, deep, stratified, brown soils	Vandal, Valarman
Typic entropepts	Slightly developed, highly fertile, deep, brown soils in high rainfall area	Aasal Vandal
Typic ustopepts	Slightly developed, deep brown soil	Aasal Valarman
Fluventic entropepts	Very weakly developed, deep, stratified brown soils in high rainfall zone	Satha Vandal
Alfisol-Order		
Ustalfs Sub-order		
Typic happlustalfs	Moderately developed deep, calcareious brown soils	Sukkan Paalseval
Udic rhodustalfs	Moderately developed deep, non calcareious red soils	Asal Seval
Aquic haplustalfs	Moderately developed deep, ill drained brown soils	Machacha Paalseval
Aquic tropudalfs	Moderately developed deep, ill drained brown soils in high rainfall zone	Aasal Paalseval
Typic tropudalfs	Moderately developed deep, brown soils in high rainfall zone	Seval
Udic rhodudalfs	Moderately developed, deep non calcareious red soils in high rainfall zone	Aasal Seval
Mentisal-Order		
Summents-Sub-order		
Typic tropopsmments	Pedogenically young coastal sandy soil in high rainfall zone	Kadalmanal
Entisal-Order		
Lithic troporthents	Pedegenically eroded, shallow soils in high rainfall zone	Kaliman Vandal

Table 7. *Irrigation sources*

Taluk	Canal	Reservoir	Number of irrigation survey tanks			% of tanks in each taluk
			With Ayacut above of 40 ha and above	With Ayacut less than 40 ha	Total	
Agastheeswaram	36	-	80	168	248	15.45

soil, 7 m-30 m is sandy clay, 30 m-70 m is Kankar (Figures 2 and 3), respectively.

Geomorphology

Geomorphologically the area slopes towards the east and south directions from the central elevated portion. The other portion which lies towards the west has topographic elevation varying between 1.0 and 10.0 m above MSL. The topography in this region gently slopes towards the sea with higher elevation of 25.0 m above MSL along the

Table 8. *Groundwater potential as on January 2007 in the area of Kanyakumari to Colachel*

Total groundwater recharge MCM	Net Groundwater availability MCM	Domestic and industrial draft at year 25 MCM	Irrigation draft projected to Jan. 2003 MCM	Total draft MCM	Balance groundwater available MCM	Stage of development as on Jan. 2007
289.1803	260.2623	22.5098	19.5830	42.0928	218.1695	16%

Table 9. *Categorisation as per GWREC norms 1997*

Safe	Extraction is less than 70% of recharge
Semi-critical	Extraction is between 70 and 90% of recharge
Critical	Extraction is between 90 and 100% of recharge
Over exploited	Extraction is above 100%

western boundary of the study area. The geomorphic and land use patterns existing in the study area are the beach sand, pediments, sand dunes, beach terraces, mudflats, saline tracts, water bodies, etc. Sand dunes form a characteristics geomorphic feature of the study area and exist as a narrow band of approximately about 100 m width along the topographically high areas. The sandy tract exists parallel to the coastal margin and has elevation ranging between 4 m and 6 m above MSL. Dwellings and other human settlements exist towards the western margin of the area. The area under irrigation that exists around Agastheeswaram village and adjoining areas has very less aerial extent and lies about 2.5 to 4.0 m above the MSL (Figure 4) (PWD, 1970-2005).

The coastal region is a narrow strip of plain region along the coast with a width of 1 to 2.5 km. The coastline has narrow stretches of beaches and sand dunes. The rear adjoining the coast is characterised by laterite capping. The whole area is generally undulated with ups and downs slopping towards different directions. All major rivers originate from the western ghats and flows towards southeast. Wind velocity generally reach maximum in July-August indicating the setting of monsoon over the district. The maximum wind speed of 17.74 km/hr is recorded during August and the minimum wind speed of 5.53 km/hr is recorded during December. Humidity in the area is generally high recorded during May of 95% where as the minimum during February of 45%. Remote sensing techniques using satellite and aerial photographs are effective modern tools for terrain analysis and for evaluation of natural resources. These techniques are applied to study the geomorphological features and other technical features, like lineaments. The thematic maps prepared on geomorphology and lineaments help to target good groundwater sources are macro level. Limited Geomorphological field checkup has been carried out in this area using 1:50,000 scale.

Geomorphological maps help to identify the various geomorphic units and groundwater occurrence in each unit. Selected and limited field checks are carried out in the field to verify the different geomorphic units. An overall appraisal of groundwater occurrence in each geomorphic unit and the significance of its hydrogeological characters in the area are furnished in table 1. Even though the groundwater potential zones are demarcated based on remote sensing techniques and the subsequent field checks, the present extraction of groundwater has to be taken into consideration before implementing further groundwater schemes. The south and southwestern part of the area is covered by buried pediplain. Shallow pediments occur as small patches near Manakudi Rajak-kamangalam, Muttam and Colachel areas. The coastal sand is seen in the entire coastal belt of Kanyakumari Colachel area with valuable minerals.

GEOLOGY

The geology of the study area is brought out by bore hole lithological studies. In general, the study area comprises of unconsolidated sandy formation of different depositional environment belonging to quaternary age. The geology of the study area is shown in figure 5 (PWD, 1970-2005). The alluvial deposits are comprised of interlayer clay, silt, sand, gravel and pebble beds. Borehole lithology depicts that the aquifer material comprises of fine to coarse grain sand, sandy clay, clayey sand and small patches of clay occurring as lenses. The clay that exists as thin lenses or small patches was mostly deposited in fluvial and shallow marine environments. These formations overlie the charnockites of archean age. charnockites existing below this sandy formation function as impermeable strata or bed rock.

Geological formation between Kanyakumari to Rajakkamangalam-Charnockite and alluvium formations and Rajakkamangalam to Colachal-Granite gneiss - N-NW to S-SE (garnetiferous biotite gneiss). Beach sand- lateran deposits of sand, zircon, rutile, illemanite and garnet. Kanyakumari to Colachel area is underlain by the peninsular gneissic terrain of Indian. Within the area, sediments of middle miocene were also deposited and identified as the Warkalai sandstones. Also, the sands of recent origin are noticed along the coast. The stratigraphical succession of the geological formations met with in this area is given in table 2.

Peninsular gneiss

The peninsular gneiss occupies the largest area. The general trend of the strike of this area is the N-NW to S-SE, garnetiferous sillimanite, graphite gneisses and garnetbiotite gneiss are the two major groups identified in the area.

Charnockite

The charnockite group of rocks is well exposed around Rajakkamangalam, Manakudi, Muttam, Manavalakuruchi areas. Charnockite group consists mainly of charnockite, pyroxene granulite and their associated migma-tites. Charnockites also are exposed within the gneisses as bands and lenses. Granites and pegmatites are the derivations from the migmatites of the peninsular gneisses.

Warkalai sandstone

The Warkalai beds of tertiary age are exposed as the cappings, southwest of Colachel near the coast; it is equivalent of the Cuddalore sandstone.

Alluvium

Sub-recent of Calcareous lime shell is noticed near Kanyakumari. All along the west coast from Kanyakumari, Colachel area is covered by the thick lateritic soil dotted with a few rocky outcrops.

Beach sands

Lateral deposits or Bay deposits of sand, zircon, rutile, illemanite and garnet are very common phenomena along the entire sea coast of Kanyakumari Colachel area. Near Manavalakurichi monazite is seen in addition to the above deposits.

Structure

The trend of foliation in gneisses is N 20°W-S30°E with steep dips on the eastern side. The peculiar deposition of feldspathic granites over a large portion of this area is suggestive of the fact that rocks have been sharply folded isoclinically causing repetition of bands. The trend of folds is aligned in NW-SE direction. Subsequently, this might have been subjected to cross folding. The straight west coastline without any break is itself suggestive of faulted one and faulting would have taken place during the pliocene period.

PHYSIOGRAPHY

Physiographically, this area can be broadly classified into : (1) Hilly regions represent-

ing western ghat mountains, (2) coastal region and (3) undulating regions.

Hilly regions representing western ghat mountains

The north of north western side of the area is completely occupied by western ghat mountains with a maximum elevation of 1658 m (Mahendragiri peak).

Coastal region

The coastal region is a narrow strip of plain region along the coast with a width of 1 to 2.5 km. The coastline has narrow stretches of beaches and sand dunes. The area adjoining the coast is characterised by laterite cappings.

Undulating region

The whole area is generally undulated with ups and downs slopping towards different directions. All major rivers originate from the western ghats and flows towards southeast. River Tamirabarani has a vast catchment area and the two important reservoirs, namely Petchiparai and Perunjani have been constructed across its flow tract. Throughout the year flow of water has been noticed in this river because of the contribution by both northeast and southwest monsoon rain. The water from these two reservoirs are not directly let into the river but taken out through channels to distant places for irrigation purposes, so that this forms a network of channel system, a quite different drainage system, when compared with other districts. The river confluence is seen near Thengapattinam which is away from the study area and are shown in figure 6 (PWD, 1970-2005). It runs a distance of 40 km from its origin of 1600 m height above MSL in the western ghats.

Perennial river, like Pazhayar river originates at an altitude of 1300 m above MSL in the Mahendragiri hills and the river water is taken away through channels for irrigation. The river is benefited by both SW-NE monsoons. Throughout the year water is flowing in the river because of high intensity of rainfall. It completes its 20 km journey after joining the Arabian sea. Its creek can be seen near Manakudi, 12 km south of Nagercoil. River Valliyar originates at an altitude of 950 m above MSL at Vallimalai Hills and has a very limited irrigation system. Period of flow of water in this river is for 6 month. Near Manavalakurichi the river joins the Arabian sea. The length of the river is nearly 29 km. The general flow trend is mainly southwards for all these rivers.

LAND USE PATTERN

The land use pattern of the Kanyakumari Colachel area depends mainly on topography, landform, soil cover, etc., out of the total geographical area of 860 km^2, 45% is used for agricultural use, 40% is coconut trees, 10% is banana and 5% is for other types plants and are shown in figure 7. The net area shown more than once is 12%.

CLIMATE AND RAINFALL

Temperature

Normally, sub tropical climate prevails over the Kanyakumari Colachel area. Maximum temperature prevails during May and minimum temperature prevails during January of every year. The mean annual temperature is 29.89 °C. The mean minimum temperature is 23.85 °C and the mean maximum temperature is 35.93 °C.

Wind velocity

Wind velocity in the area generally reach maximum in July-August indicating the setting of monsoon over this district. The maximum wind speed of 17.74 km/hr is recorded during August and the minimum wind speed of 5.53 km/hr is recorded during December. Wind velocity is low from October to December.

Sunshine hours

March to April forms the average bright sunshine hours. The maximum of 12.74 hr/day

has been recorded during April and the minimum of 5.74 hr/day is recorded during November.

Relative humidity

As the Kanyakumari Colachel coastal area is very close to sea, humidity is generally high. The highest humidity is generally recorded during May with the value of 95 % whereas the minimum of 45% is recorded during February.

RAINFALL

The average annual rainfall of this district, 70 year is 1448.6 mm, the variation are shown in figure 8. The season wise rainfalls at selected rain gauge stations are given in table 3. There are 3 rain gauge stations spread over the area are selected as 70 year rainfall data are available. A general overall view of rainfall pattern recorded in the different rainfall stations indicate that the precipitation varies from 764.30 to 208.30 mm. Most of the rainfall occurs during NE and SE monsoon periods. The seasonal normal rainfalls for selected rain gauge stations are furnished in table 4. From table 4 it is observed that the quantum of precipitation during the southwest and northeast monsoon is more or less equal. The contribution of southwest monsoon and northeast monsoon are 37.16 and 37.18 % of the annual rainfall, respectively.

Analysis of seasonal and annual rainfall data for 70 year (1935-2005) indicates that the coefficient of variation of annual rainfall is in the range of 764.3 to 2083.3 mm. The variability of seasonal rainfall is comparatively much higher and is shown in figure 9. As per meteorological standards deviation of plus 20 % or more is excess minus 19 % or plus 19 % is normal minus 20 % to minus 60 % is deficient and less than minus 60 % is scanty.

SOIL TYPES

Soil types of the area are more important, since it is the main criteria in the agricultural production and in the recharge of groundwater. Different types of soils are derived from a wide range of geological formations. Knowledge about the type of soils, its extent and occurrence is of primary importance for agricultural planning to maximize production and for the groundwater recharge. Types of soil in the study area are red soil, lateritic soil, clayey soil, river alluvium, coastal alluvium which is given in table 5. The soil map of the study area is shown in figure 10 (PWD, 1970-2005). The soils of the area can be classified into red loams, red lateritic soil and pale reddish in colour. They are derived from lateritisation of gneisses. The soils derived from gneisses are mostly brownish. The lateritic type of soil occurs in blocks of Rajakkamangalam. The mixed type of red and alluvial soil occur in Agastheeswaram block. The coastal sand occurs in the western side of the area. The coastal alluvium sand is of high fertility.

Generally the soils are highly acidic in the area. This is mainly due to heavy rainfall and heavy leaching of basic rock in hilly area. Soils of Kanyakumari Colachel area are mapped based on All India soil and land use survey organisation and the USDA (1978) soil survey manuals by soil survey and land use organisation, India. Under new system of classification, ten soil orders, namely entisols, inceptisols, alfisols, ultisols, axisols, vertisols, mollisols, spodosols, histosols and aridisols are recognised. Out of them only three soil orders occur in Kanyakumari Colachel area. Importance soil sub groups that occur in Kanyakumari Colachel area are shown in table 6.

IRRIGATION BY SURFACE AND GROUNDWATER

This area is irrigated by the network of channel systems and tank. The main channels are Ananthanar, Thovalai, Kodaiyar. Open well and energised well irrigation plays small role in this area. Less extraction of groundwater keeps the water table high in the

area.

Irrigation by groundwater

In this area usage of groundwater is limited due to the availability of surface water. Surface water from river, channels, canals and tanks are used for agricultural purposes. Therefore, less extraction of groundwater is used for irrigation in the area.

Irrigation by surface water

The entire area is irrigated by surface water because of its availability. A good network in irrigation system, surface water from the rivers, channels, canals, tanks are used for agricultural purposes. The details of minor irrigation (surface water) source in this area under Agastheeswaram block is shown in table 7.

OCCURRENCE OF GROUNDWATER

Groundwater occurs in almost all the geological formations in the area, namely crystalline rocks, sedimentary formations, quaternary alluvium and beach sands and is developed by dug wells, dug-cum-bore wells and bore wells.

Hard rock formations

The entire Kanyakumari to Colachel area is covered by hard rock formation, like charnockite and gneisses. The groundwater occurrence is limited to only weathered mantle of the hard rock. The weathered thickness ranges generally from 10 to 35 m below ground level. The groundwater occurrence is also limited 1 to 10 m above MSL. Weathering is quiet higher in granite gneissic rock rather than charnockite. Hence the groundwater occurrence is also higher in gneiss than charnockite.

Bazada and valley-fill sediments

The groundwater occurs under water table conditions in valley-fill sediments area. These bazada and valley-fill area have alluvial deposit for a depth of 10 to 15 m followed by highly weathered formation upto 20 to 30 m below groundwater level. The water table is very shallow.

River alluvial deposits

In alluvial formation, the groundwater occurs under water table conditions. These formations are highly porous and permeable. However, the thickness of alluvium is very shallow.

Drilling of boreholes

The occurrence and movement of groundwater is restricted to open system of fractures, and joints in unweathered portion and also in the porous zones of weathered formation. Generally in hard rock regions the occurrence of weathered thickness is discontinuous both in space and depth. Hence the recharge of groundwater is influenced by the intensity of weatherings. In general weathering thickness is higher in gneissic rock than that of charnockite. It varies from 10 to 35 m below ground level.

AQUIFER PARAMETER

In order to evaluate the characteristics of shallow phreatic aquifer, yield tests were conducted (PWD, 1970 - 2005) on selected open wells during the systematic hydrogeological surveys, by referring the yield test results, yield of open wells varied from 150 to 200 m^3/day for a drawdown of 1 to 3 m with a pumping period of 2 to 4 hr. From the yield tests, transmissivity of shallow phreatic aquifer is within the range of 3 to 15 m^3/d and the specific yield is around 1 to 4%.

WATER TABLE FLUCTUATION

By establishing a network of observing wells spread over the area, the fluctuation in groundwater level is monitored every month. The groundwater level reached the lowest level in the area or hottest periods after which it starts rising to reach highest peak, a little the end of rainy seasons. The rise and fall depends upon the amount, duration and intensity of precipitation, depth of weathering, specific yield of the formation,

etc. A general overall view of the water level fluctuation suggests that the water level trends to rise during October to December to reach the peak and starts receding from February onwards to the end of August to September, hydrographs. However, a slight raising trend is seen during July because of southwest monsoon rain.

GROUNDWATER POTENTIAL

Estimation of groundwater potential

The blockwise groundwater potential and utilisation of groundwater resources for irrigation as on January 2007 were estimated by the groundwater wing of PWD in accordance with the methodology recommended by the Government Estimation Committee (1997) setup by Government of India. Out of the total groundwater recharge some amount is kept reserved to meet domestic and industrial requirements. The balance is earmarked as utilizable groundwater recharge for further development of irrigation. For Kanyakumari Colachel area, the details are given in table 8. The groundwater recharge, net extraction and balance groundwater available have been estimated separately for the area. While assessing the dynamic groundwater resource, the different geological formation is considered as a single principal aquifer. The specific yield of geological formation in each Panchayat union has been worked out by taking into account the number of energised wells, diesel driven wells and other types of wells. Based on cropping pattern, the annual draft for each block has been worked out. By deducing the draft from groundwater recharge, the balance groundwater potential for future development has been estimated. The probable number of wells feasible in each Panchayat union is evolved taking into consideration 70% of the balance groundwater potential available.

STAGES OF GROUNDWATER DEVELOPMENT

The stage of groundwater development in the area can be defined as the ratio of net draft to net recharge available for irrigation. As per 1997 new methodology, the above categorisation is modified as safe, semi-critical, critical and over exploited is given in table 9. In Kanyakumari Colachel coastal area is in two blocks, like Agastheeswaram and Rajakkamankalam. In all the two blocks groundwater head fall in safe category since the extraction in all these blocks is below 70% of total groundwater recharge. As per GWREC norms 1997, the stages of groundwater development in the study area is shown in figure 11.

AQUIFER CHARACTERISTICS

Aquifer geometry and boundary conditions

The sandy clay unconsolidated quaternary formation occurring over the Archeans function as an excellent aquifer system. The total depth of the aquifer system comprising the aquifer matrix ranges among 3 and 23 m. The cross section of the aquifer obtained through the analysis of borehole lithology investigation along the section is shown in figure 12. The lateral extent and the thickness of the aquifer vary from west to east. The thickness of the aquifer is least towards the western margin (2-3m) and gradually increases towards the east coast (10-12m), where the aquifer meets the sea. The hydraulic contact with the aquifer along the eastern, southern and western margin surrounded by sea forms a constant head boundary and the inner land is variable boundary.

Aquifer parameters

The hydraulic conductivity (k) of the sandy aquifer ranges between 25 and 75 m/day (GSI, 1972). In general, the hydraulic conductivity of the aquifer lying west has values between 25 and 35 m/day while the sub-basin along the east of the canal has high hydraulic conductivity with values ranging between 45 and 75 m/day. The low hydraulic conductivity (k) value along the west part is attributed to the presence of sandy clay

and clay. The specific yield (s) of the alluvial aquifer ranges from 0.17 to 0.23. The specific yield of the aquifer existing between the coast and the canal ranges between 0.21 and 0.23, while the other portion of the canal has values ranging between 0.17 and 0.19.

Recharge and discharge patterns

The major hydrological stress exerted on the aquifer is by pumping and rainfall recharge. The discharge from the aquifer is mainly by the withdrawal of water by pumping for domestic supply, mainly for drinking purposes, and for industries, both by private and government agencies. Seepage to the sea and canal also forms the major outflow. Substantial quantity of output occurs by evapotranspiration during the non-monsoon periods. Rainfall forms the only source of aquifer replenishment of the aquifer.

Groundwater abstraction

Due to continuous rainfall in SW monsoon and NE monsoon in the area and less extraction of groundwater, there is no such problem arises as groundwater abstraction in the area. The groundwater head is always stable due to the storage of surface water in tanks in the area.

Groundwater recharge

The study area receives an average annual rainfall (70 year normal) of about 1446.8 mm. Comparison between the water level and rainfall reveals that the water level rises in correspondence with the monthly rainfall showing that rainfall is the major source of aquifer replenishment of the study area (PWD, 1970-2005) are shown in figure 13. The study area receives maximum rainfall during SW and NE monsoons. The rate of rainfall recharge varies within the study area is based on the soil types, geomorphic pattern, land use and topography.

REGIONAL GROUNDWATER HEAD

Spatial variation

In general, the water table is shallow and synchronizes with the topography of the study area. The groundwater head is high along the central portion between the canal and the coast and dips gradually on both sides. The head towards the western region gently dips towards the canal. The spatial variation of the groundwater head of the study area ranges from 3 to 5.5 m during post monsoon period, during pre-monsoon period; it varies between 1.5 to 3 m. High water table was observed in the inner land of the study area (10.0 m above MSL) while low groundwater heads (1.0 m above MSL) occur along the coast and adjoining areas. Comparison between the spatial distributions of water level the water table trends were found to be similar over a period of time (1996-2007).

Temporal variation

The hydrograph provides a good aerial and temporal representation of head throughout the study area. The hydrograph of the representative observation wells reveals that the water table fluctuates between 1.0 m (minimum) and 3.25 m (maximum) with the average fluctuation of 1.5 m in most of the observation wells. The water level fluctuations are in response to recharge and discharge. The water table is shallow during June-September and October-December, average in March-May and deeper in January-February. Comparisons of the hydrographs of all the wells over a period of time show that the rise and fall are almost identical. As such no consistent long term trend of water table rise or decline was observed. Groundwater level in all wells in the area varies from 1.0 to 10.0 m above MSL. The water levels in all aquifer are good in all periods of monsoon as such there is no decline profile of water level in the area and are shown in figure 14 (a-l).

GROUNDWATER FLOW CONDITIONS

The groundwater flow of the study area is

influenced by the differences in hydraulic head produced by topographic relief and the unconsolidated formation comprising the aquifer material that has finite permeability facilitating water to move both laterally and vertically. The differences in hydraulic head produced by topographic relief are the most of the observation wells. The water level fluctuations are in response to recharge and discharge. The groundwater flow of the study area is influenced by the differences in hydraulic head produced by topographic relief and the unconsolidated formation comprising the aquifer material that has finite permeability facilitating, water to move both laterally and vertically. The differences in hydraulic head produced by topographic relief are the most significant driving force for groundwater flow in this region since the relief ranges from 1.0 to 1.10 m above MSL within a span of 3 km. The regional flow direction within this aquifer is from south to east. Topographically high area flow towards the coast and the river. The western part of the aquifer has flow towards the Arabian sea, eastern part of the aquifer has flow towards the Bay of Bengal and the inland part of the aquifer has flow towards Indian Ocean.

The subsurface outflow is along the southern boundary and the Pazhayar river. In general, flow to the southern boundary (Indian Ocean) and Pazhayar river occurs throughout the year, since the groundwater potential is higher than the river and the sea. The discharge along the sea coast (Indian Ocean) is expected to be high due to high permeable character (K = 10-30 m/day) of the sediments. The subsurface outflow is computed in the model by applying the fixed head boundary condition and is discussed in chapter 6 on flow simulation.

CONCEPTUAL MODEL OF THE STUDY AREA

From the above study and analysis, the conceptual model of the study area was constructed. The inference of the study reveals that the study area comprises of consecutive layers of sand (fine to coarse grained), sandy clay, clay, silty clay and silt of unconsolidated nature though they are of depositional environments. The clay that exists as thin lenses or small patches existing within hydraulic conductivity of the aquifer and hence the aquifer functions as single layered.

The hard rock (charnockites) existing below this alluvial aquifer function an impermeable strata or bed rock and thus form the zero flow boundary beneath. The east-Bay of Bengal, south-Indian Ocean, west-Arabian sea functions as constant head boundary and the Pazhayar river functions as an internal constant head boundary. Rainfall forms the only source of aquifer replenishment while seepage to sea and river and pumping are the major sources of outflows from the aquifer system. The hydraulic characteristics permeability range between 10-30 m/day, porosity is 0.22 and specific yield is 0.23, respectively.

CONCLUSION

The basement of the study area consists of charnockite, granite gneiss, leptinite, leptinite gneiss, peninsular gneiss, laterite, warkalai sandstone, variegated clay, river alluvium, etc. The study of structural and tectonic history indicates several episodes of deformation, which caused repeated folds, faults, joints and fracture systems. The basement rocks are overlain by red soil, lateritic soil, clayey soil, river alluvium and coastal alluvium, black, red and red sandy soils of thickness ranging from 1 to 1.5 m in most places.

The area is underlain by the peninsular gneissic terrain of India. Sediments of miocene were also deposited and identified as the warkalai sandstones. Also, the sands of recent origin are noticed along the coast. Penisular gneisses occupy the largest area in the study places. The general trent of the strike of the area is N-NW to S-SE. Garnetiferous sillimanite, graphite gneisse and garnetbiotite gneiss are the two major gro-

ups identified in this area. The charnockite group of rocks is well exposed around Rajakkamangalam area. The warkalai beds of tertiary age are exposed as the cappings, south-west region near the coast. Sub-recent origin of calcareous limestone is noticed near Kanyakumari.

Lateral deposits or Bay deposits of sand, zircon, rutile, illemanite and garnet are very common phenomena along the entire sea coast of Kanyakumari. Near Manavalakurichi monazite are deposited. The trend of foliation in gneisses is N 20 W-S30 E with steep dips on the eastern side. The peculiar deposition of feldspathic granites over a large portion of this area is suggestive of the fact that rocks have been sharply folded isoclinally causing repetition of bands. The trend of folds is aligned in NW-SE direction. Subsequently, this might have been subjected to cross folding. Also coastal sand are seen in the entire coastal belt of Kanyakumari coastal area.

Borehole lithology records reveal that the thickness of alluvial deposits is more in bajada and valley fills (about 10-15 m). Weathered and fractured zones are areas for groundwater occurrence. Intensity of weathering is not uniform in space and depth. It is considerably higher in gneissic rocks than in charnockite. Weathered zone thickness of the study area generally ranges from 10 to 35 m below ground level. The groundwater of the area occurs under unconfined conditions. Rainfall infiltration and seepage of water from surface water bodies are responsible for groundwater actuation.

Most of the wells used for irrigation are shallow and partially penetrating because once a considerable depth of water column is reached, farmers stop further deepening of wells. Hydrographs indicate that the groundwater table tends to rises during October and December to reach peak and starts receding from February onwards to the end of August to September. However, a slight raising trend is seen during July because of southwest monsoon rain.

REFERENCE

Ahmed, S.S. and Q.H. Mazumder. 2002. Hydrochemistry and classification of groundewater, Rajshahi City Corporation Area, Bangladesh. *J. Geol. Soc. India*. 60 :411-418.

Anbazhagan, S. and A.M. Nair. 2004. Geographic information system and groundwater quality mapping in Panvel Basin, Maharashtra. *J. Env. Geol.,* 45 : 753-761.

APHA. 1995. Standard methods for the examination of water and wastewater (19th edn). American Public Health Association, Washington, D.C.

APHA. 1998. Standard methods for examination of water and wastewater (20th edn). American Public Health Association, Washington. D.C.

Ballukraya, P.N. and R. Ravi. 1999. Characterisation of groundwater in the unconfined aquifer of Chennai city. *J. Geological Society of India.* 54 : 1-11.

Chandrasekharan, H., *et al.* 2007. Variability of soil-water quality due to Tsunami-2004 in the coastal belt of Nagapattinam district, Tamil Nadu. *J. Env. Manage.,* Online.

Elango, L. 1992a. Hydrogeochemistry and modeling of multiplayer auifers. Ph.D. Thesis. Anna University, Chennai.

Elango, L. 1992b. Hydrogeochemistry and mass balance modelling of multilayered aquifers. Ph.D. Thesis. Anna University, Chennai.

Elango, L., S. Ramachandran and Y.S.N. Chowdary. 1992. Groundwater quality in coastal regions of south Madras. *Indian J. Env. Health.* 34(4) : 318-325.

Elango, L., N. Rajmohan and D. Ganasundar. 1998. Groundwater quality monitoring in internsively cultivated regions of Tamil Nadu. **In** Groundwater sustainable solution. **Ed** T.R. Weaver and C.R. Lawerence. Australia. Proceedings, pp 637-643.

Elango, L., R. Kannan and M. Senthil Kumar. 2003. Major ion chemistry and identifica-

tion of hydrogeochemical processes of groundwater in a part of Kancheepuram district, Tamil Nadu. *Env. Geosci.,* 10(4) : 157-166.

AUTHOR

1*. Dr. S. Bhagavathi Perumal, Principal and Professor in Civil Engineering, The Rajaas Engineering College, Vadakangulam, Tirunelveli-627 116.

2. Dr. P. Thamarai, Assistant Professor, Department of Civil Engineering, Government College of Engineering, Salem-11.

3. Dr. L. Elango, Professor, Department of Geology, Anna University, Chennai - 600 025.