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Geoenvironmental Resource Assessment Using Remote Sensing and GIS: A Case study from Southern Coastal Region

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Abstract

This article describes the aspect of geoenvironment and portable groundwater zone of a watershed located in coastal tract around Tuticorin Corporation, Tamil Nadu, India, using remote sensing and GIS. Initially, based on satellite imagery, topographical, geomorphological and hydrogeological features, an area of about 206 sq.km was demarcated as a promising zone for groundwater exploration in the study area. The problem of the study is a representative case of overexploitation of groundwater resources, leading to the continuous exhaustion of the grained as well as the groundwater aquifer. In such situations topographic, landuse, geology, hydrogeological and geomorphological features provide useful clues for the selection of suitable areas. Identifying a good site for groundwater exploration in coastal terrain is a challenging task. From the fluctuation map it is found that maximum recharge in deeper water level is found in the central and southern part of the present study area. Eastern and Northern part of the study area shows minimum rise of water level of less than 4 m. The water level fluctuation of the study area compounds is considered for components of recharge. In general, the coastal terrain formations do not have good groundwater potential. Still, integrated studies help to ascertain the presence of hidden water bearing formations.

Keywords: Groundwater recharge, remote sensing and GIS, coastal terrain, geology, water bearing formations.

Introduction

Ground water is the last component of the hydrologic cycle to realize the benefits of remote sensing. Ground water scientists have been late to embrace satellite data for an obvious reason: ground water lies in the subsurface, and current air- and satellite-based radar and radiometers can normally penetrate only a few centimeters into the ground. In spite of this apparent roadblock, remote sensing holds tremendous potential for regional ground water flow studies. Previous, current, and future remote sensing efforts that are applicable to shallow ground water systems are reviewed in this article. Ways in which remote sensing can be more effectively used for future ground water studies are suggested. The rapidly expanding human population, large scale changes in landuse / landcover and burgeoning development project and improper use of watersheds has all caused a substantial decline of wetland resources of the country[1-7]. Absence of reliable and updated information and data on extent of wetland, their conservation values and socioeconomic importance has greatly hampered development of policy, legislation and administrative intervention by the state[8,9]. Increasing population and modern industrial and agricultural activities are not only creating more demand for groundwater resources due to the inadequate availability of surface water resources, but are also polluting groundwater resources by releasing untreated wastes. Consequently, these activities have resulted in an increase of research, not only with regard to groundwater resources, but also with an emphasis on locating groundwater of good quality for human consumption[10,11,12]. While our country accounts for 2% of the world's geographical area and 4% of its fresh water, it has to support 17% of the world's population and 15% of its livestock. The present case study focuses attention on the study of the geomorphology and geology of the sipcot area in the strategically close to the East-West International sea routes on the Southeast coast of India. Major problem with the study area can be identifies as are rapid growth of population and unplanned growth of the city both horizontally in all direction. Many of the developments have come up in the recent years, which have affected the study area in a drastic way. So there is a need for proper planning for the careful handling of this alarming situation. The study focuses on development of remote sensing and GIS based analysis and methodology in groundwater recharge studies in coastal region[13,14]. As a result, nowadays, GIS is widely used for spatial modelling of hydrogeological prospect of a large area with more reliability. Examples from recent literature spotlight several uses of GIS as applied to ground water exploration[15-17]. According to conserve to next generation people consider going the present work is attempt towards this direction.

Study area: The study area is located in the coastal tract of southern Tamilnadu. The coastal stretch between Tuticorin and Thiruchendur extends over a distance of about 60 km. Tuticorin is in South Tamilnadu about 540 km south west of Chennai and is geographically located in the Gulf of Mannar. The area has been selected for its under developed nature and also for its varied lithological conditions, hydrological characteristics, geomorphology and geology and nature of rocks etc. The study area covers geographical area of 206 sq.km and lies between 8° 43' - 8° 51' N latitude and 78° 5' - 78° 10' E longitude (figure 1). Topographic elevation varies from 27 m (amsl) to a few meters (amsl) near Tuticorin town and slopes from west to east. The slope is gentle in the western and the central part and nearly flat in the eastern part. The coast of Tuticorin encompasses 4 small islands located an average distance of 4km away from the mainland. These islands are built up of calcareous framework of dead corals and coral reefs. The area is endowed with a combination of ecosystem including mangroves, coral reefs, sea grass and seaweeds[18].

Material and Methods

The method used in this study for mapping geoenvironment, groundwater recharge and discharge areas incorporated GIS and remote sensing mapping techniques to link catchment features with groundwater recharge and discharge processes. Various thematic maps such as were prepared for the study area by using survey of India of Toposheet no 58H/13, 58H/14, 58L/1 and 5, 58L/2 on a 1:50,000 scales and IRS-1C geocoded satellite imagery. The drainage network for the study area was scanned from Survey of India (SOI) toposheets and digitized in ArcGIS 9.3 platform. Drainage study through the survey of India toposheets at the scale of 1:50,000. The land use map and geomorphic maps of the area have been prepared using the above data on a scale 1:50,000. Extensive fieldwork was carried out for ground checks and verifications of the geological, stuructural and geomporphic features interpreted by the remote sensing data.

Results and Discussion

Geology: The Tuticorin area 90% is made up of sedimentary rocks of Tertiary to Recent age comprising of Shell limestone and Sand, Tuffaaceous Kankar, Sand (Aeolian deposits) etc., and the remaining area is covered by mixed and composite Genesis of proterozoic age of crystalline rocks (figure 2). The Archaean groups of formation are crystalline and metamorphic and finely foliated with general NW-SE trend described by Balasubramanian et al and Selvam[19,6]. The general Tuticorin district stratigraphic succession is presented below (table-1).

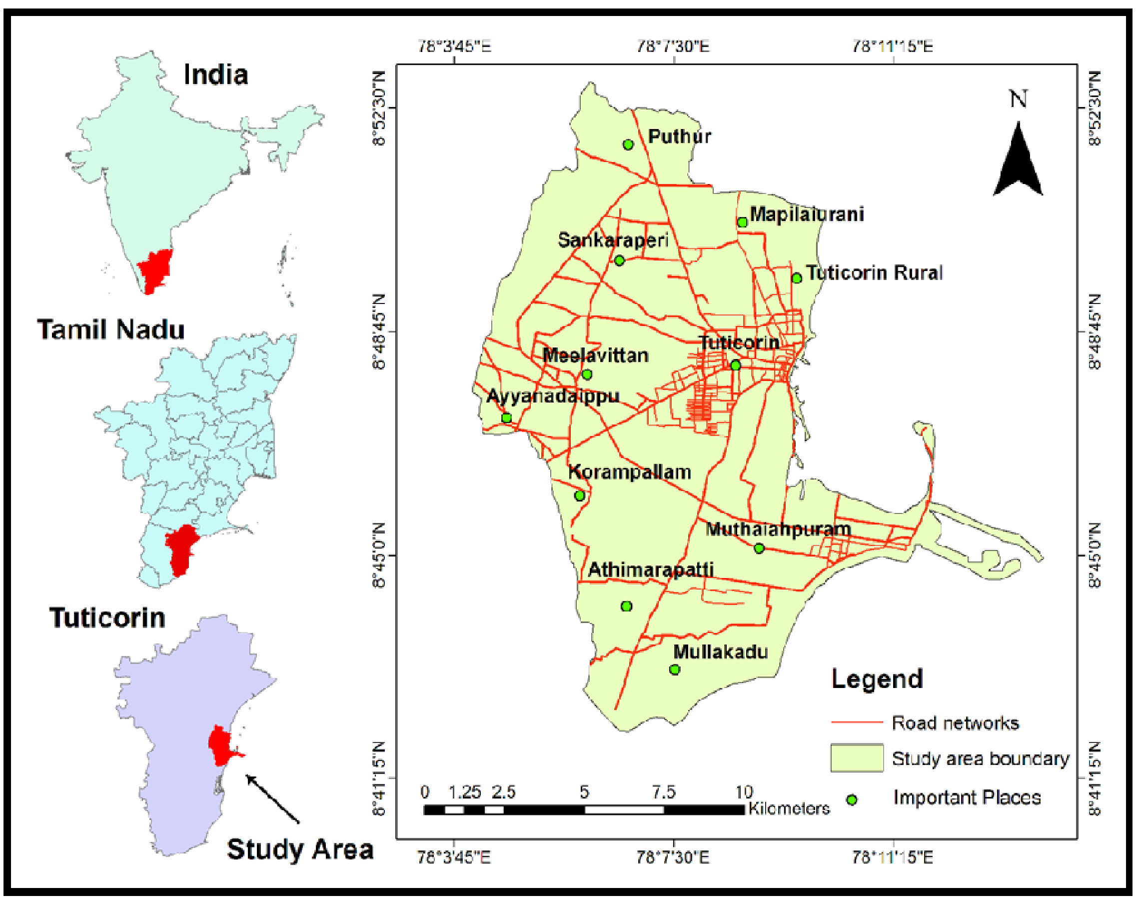

Figure-1
Location map of the study area

Table-1
Tuticorin district geology

Period	Age	Formation	Lithology
Quaternary	Holocene to Recent	Alluvium Colluvium	Red soil, Coastal sand, Clay, River Alluvium, Laterite Red Teri, Kankar, Tuffaceous Kankar, Shell limestone Calcareous Sandstone
Tertiary	Mio-Pliocene	Panamparai Sandstone	Hard, compact, Calcareous sandstone, Shell Limestone
Proterozoic	Precambrian	Crystalline complex	Charnockite , Mixed and composite Genesis Peliticgneiss, Calc-granulite, Quartzite

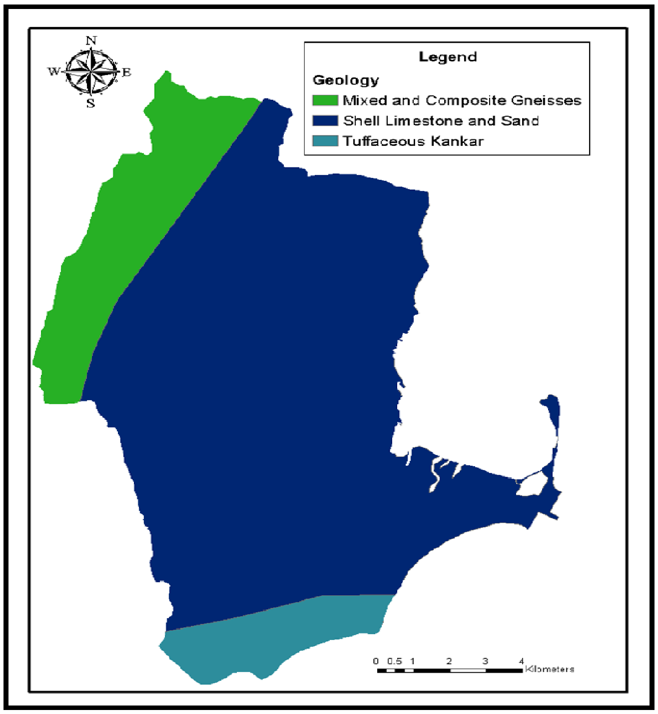

Figure-2
Geology map of the study area

Soil: The study area soil types are more important, since it is the main criteria in the recharge of groundwater and agricultural production. The area is covered with sandy clay in the Sankarapari area (western part) red soil (Sandy loam to Sandy soil) in the central part and alluvial sandy soils (Coastal area) in the eastern part (figure 3). The maximum soil thickness is about 3m. The sandy soils originated from sandstones and these have low soil moisture retentivity. The alluvium soils are wind-blown sands and shells constitute beach sand and coastal dunes, which have very low soil moisture retentivity[20]. The porous formation in the study area includes sandstone and clays of Recent to Subrecent (Quaternary) and Tertiary age. The recent formations compraising mainly sads, clays and gravel are confined to major drainage course of in the district.

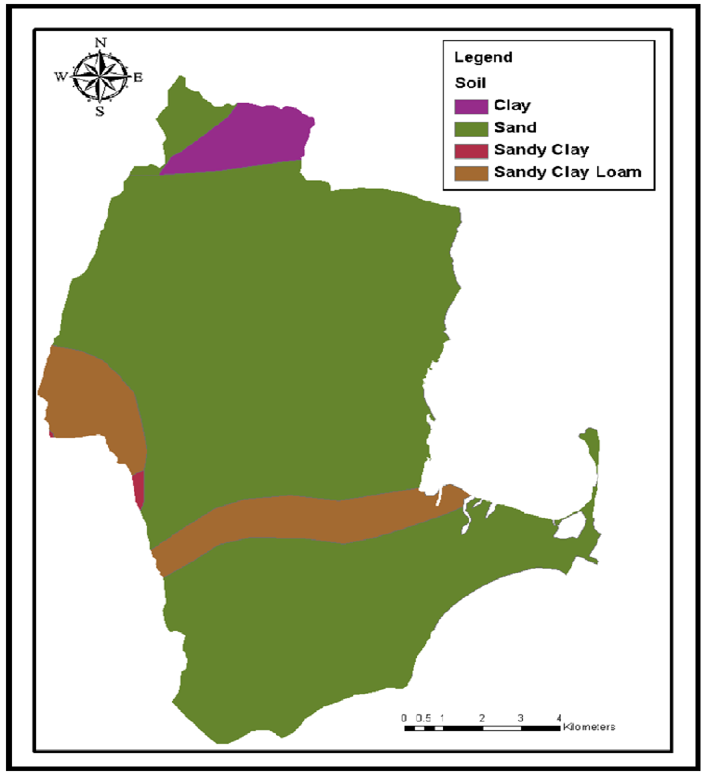

Figure-3
Soil map of the study area

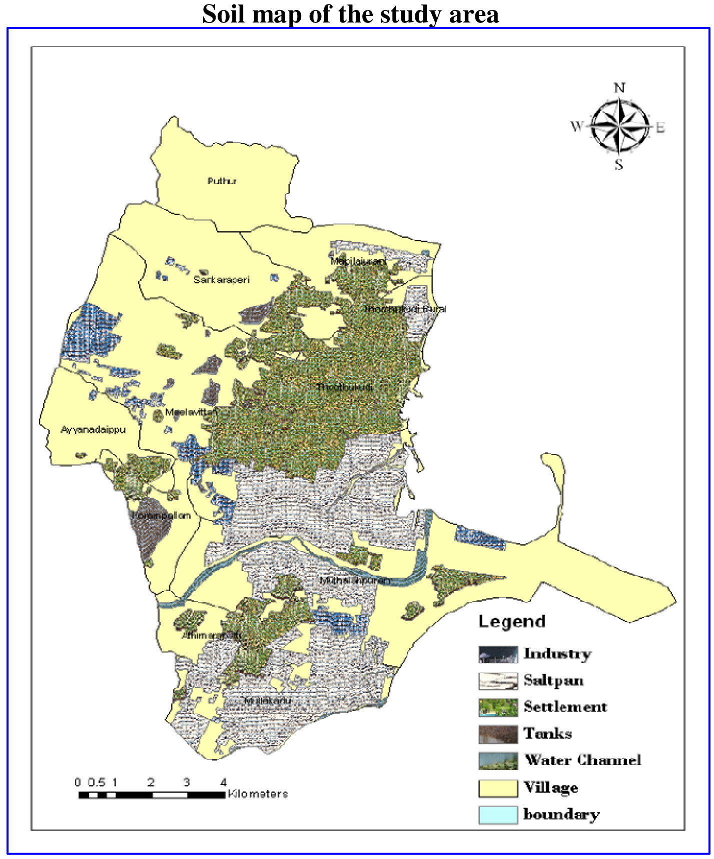

Figure-4
Geomorphology map of the study area

Irrigation tanks: Tamiraparani river has a number of canal systems in Murappanad and Srivaikundam. In recent years farmers draw out the groundwater along the river banks and around the irrigation tank though large diameter dugwell and dug-cum bore well. Korampallem tank is an important irrigation tank in the study area (figure 4).

Intertidal Environment: These are the narrow zones influence by terrestrial environments and as well as by marine environment. These are strand plain of depositional system. Salt marshes, Mangroves and Tidal flat over run the intertidal environments of Tuticorin harbour (with in the study area) on either sides of Tamiraparani deltaic region. These environments are admixture with fine mud, shell material; sand sized terrigenous particle and plants materials. In some areas these environments are converted into salt pans and aqua farms.

Sandy beach: Sandy beaches are the product of waves interacting with a sandy beach at the shoreline. The sandy beaches are extensively developed along the entire coast of study area except at some places. The study area is covered by long and extensive sandy beach. It trends in North-South direction. Well developed sandy beach is identified below south harbour break water. This beach is dominated by an admixture of quartz, feldspars and mica minerals.

Spits: A spit is a small point of low tongue or narrow bankment, commonly consisting of sand or gravel deposited by a long-shore drifting and having one end attached to the mainland and other terminating in the open sea. Two spit formations have been observed in south of the urban coast. Normally the formation of spit has been attributed to the movement and deposition of materials by long shore current. The spit near Tuticorin is 0.75 to 2 km long and tongue shaped. Tuticorin spit has resulted by long shore currents during monsoon and the sediments discharged by Tamiraparani River.

Beach ridges: Beach ridges are moderately undulating terrain features of marine depositional type, formed during Pleistocene to recent age, in the plains of the study area. They are low, essentially continuous beach or beach dune materials (sand, gravel and shingle) heaped up by the action of wave and currents on the backshore of a beach beyond the present limit of storm waves or the reach of ordinary tides, and occurring as a single or as one of a series of approximately parallel deposits. Beach ridges of Tuticorin are highly reworked.

Mudflat: Mudflat is a flat area containing a fluid to plastic mixture of finely derived particles of solid material mainly silt and clay water. They are always associated with silted environments like lagoons, estuaries and other embankments. Mudflats are formed by the deposition of fine inorganic material and organic debris in particulate form. Mud flats are wide expense of deposit of clay, silt, ooze, etc. Mudflats are well developed at the river mouth of Koramballam Oodai, an estuarine environment. They appear as dark black tone in satellite imagery.

Dune complex: Dune complex is an important geomorphic unit comprising of active and loose sediment heaps with negligible amount of vegetation. In this zone, the aeolian activity is reportedly high resulting in migration without a major change in their shapes. It indicates the age of late Pleistocene to Recent. Tuticorin is situated in dune complex.

Teri dune complex: Teri dune complex is an undulating terrain having loose heaps of red color sand and silt dust of aeolian origin. They represent Pleistocene to Recent age of formation. They appeared as round to oval shaped mounts with dense vegetation. It is assumed that the fierce and continuous winds of south west monsoon by sweeping up vast clouds of dust from the dry surface of the red loam, exposed at the base of the hills must have brought and deposited their load of sediments near the coast over the plain to form Teri dune complex. All dune complexes in this area are trending in the northeast to southeast direction. In recent years, these Teri dune complexes are being utilized for cultivation also. It is identified in greenish yellow color in satellite imagery.

Landuse/Land covers: The landuse map for the study area was prepared with the help of image interpretation keys such as tone, texture, drainage, structure fabric and relief using both toposheets as well as geocoded data[21,22]. Further demarcated areas were confirmed though ground truth data. The various landuse found in the study area and their map overlay technique is consent of GIS. In the Tuticorin Corporation 40% of the area is covered by salt pans. Settlement occupies 39% of the area and Industry cover is 20%. Marginal area is occupied by tanks, water, channel and others (figure 5).

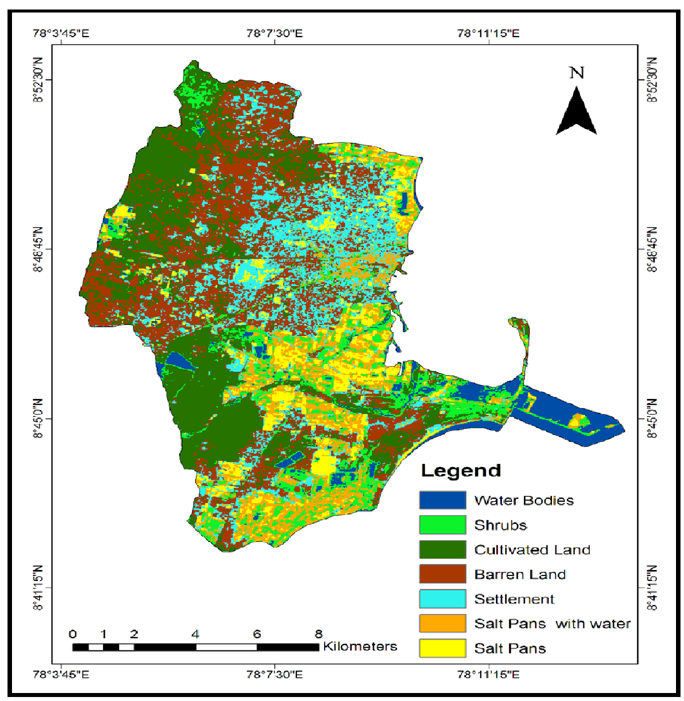

Figure-5
Land-use and Land Cover map of the study area

Land with or without shrubs: In the imagery these lands were identified with pale yellowish tint as well as coarse to smooth texture. In the study area these type of land is available nearby western portion of the study area.

Water bodies: In the study area many number of tanks are present which get water from the korampalam channel in the area which flows from north-south direction. In the imagery tanks are identified with blue tint (shallow water) and black tint (deep water).

Saltpan: In Tuticorin Corporation thousands of acres of land is utilities for production of salt. Originally salt was found in sea water but later it was found that the underground water contains more salt. Now they have bored holes into the earth through which the underground water is pumped to the surface. The ground is leveled with a slight slope towards one direction. The land is divided into squares of 20-25 feet called `pans' and from one pan the water drains into the other pan. The underground water comes into the first pan in the field where by evaporation it becomes more concentrated and its specific gravity gradually increases. It is let out into the second and subsequently into the third and fourth pans in the field. In the last pan where its specific gravity is high, sodium chloride separates into crystals. In the first pan magnesium crystals precipitate and appear like white, needlelike crystals. This is collected and sent for use for other industries. As the production of salt remains disrupted owing to incessant rainfall, there is a mismatch between supply and demand for salt. In the imagery tanks were identified with light to dark yellowish tint.

Groundwater Condition: The porous and permeable calcarienites rocks in Tuticorin areas act as good aquifers source of portable water. Lense of portable water in these zones solve the water problem. In the laterite and the alluvial areas groundwater is in unconfined state in shallow aquifers and in confined state below a blanket of clay of varying thickness in deeper aquifers. Prior to 1930 Tuticorin people quenched their thrust from the perched water in tuticorin are, people used to dug shallow wells and extracted the water then closed them is and when they had gone saline.

In 1936 the drinking water scheme to Tuticorin from Tamiraparani river through infiltration well was launched by the effort of Mr. Gruz Fernando then Municipal chairmen for bothing and other domestic purpose. Korampalam irrigation tank water was distributed through the network of submerged lined canal system in Tuticorin Corporation. Now the supply of water from korampalam was abolished due to damage of the cannel system[23].

Althrough the annual rainfall in the watershed is relatively moderated the availability of groundwater is problematic because of the following reasons, i. Low recharge rate, ii. Generally high runoff mainly, iii. Unsuitable aquifer conditions over the parts of coastal areas, iv. Low and hot dry seasons, v. Excess with drawls of groundwater in parts of the eastern alluvial tract, for irrigation purposes have causes continuous lowering of the groundwater label over the years.

Water table: Groundwater level data has been collected from 36 observation wells in the study area. It is a well established fact that the occurrence and movement of groundwater depends upon geology, landforms and the structure[24,25]. If these factors are favorable then the aquifer condition holds good for good groundwater potentiality. A good aquifer is one which can be recharged during the period of monsoon when rain water gets infiltrated and recharged. This means that during the pre monsoon period the aquifer used to have a deep water table condition compared to post monsoon period. The difference in water table can be calculated once the water table of both seasons recorded. Wells are found to be fairly distributed throughout the study area. From the water level data, existing 36 wells are considered for both pre and post monsoon seasons (figure 6).

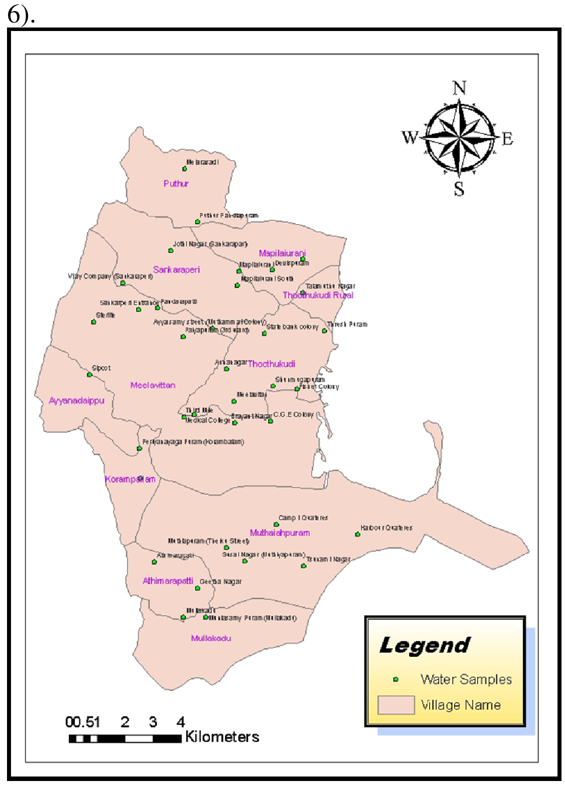

Figure-6
Well location map of the study area

Pre-monsoon water table: Water level data of pre monsoon period was collected for the year 2010. Depth to water table from ground surface was measured with the help of measuring tape. Altitude is measured with the help of GPS. These water level data is converted to mean sea level referenced data by using altitude value. After getting the MSL referenced to water level data, water table contour map is prepared with the help of Arc GIS 9.3. The pre monsoon water table contour varies between 4.4 m to 30 m (figure 7). Shallow water tables are found in eastern part; whereas deeper water values are found in the southern and northern part. Average water table depth from ground is 14 m water in tertiaring formation is found to be in confined conditions results they were at deeper depth and found to be occurring below.

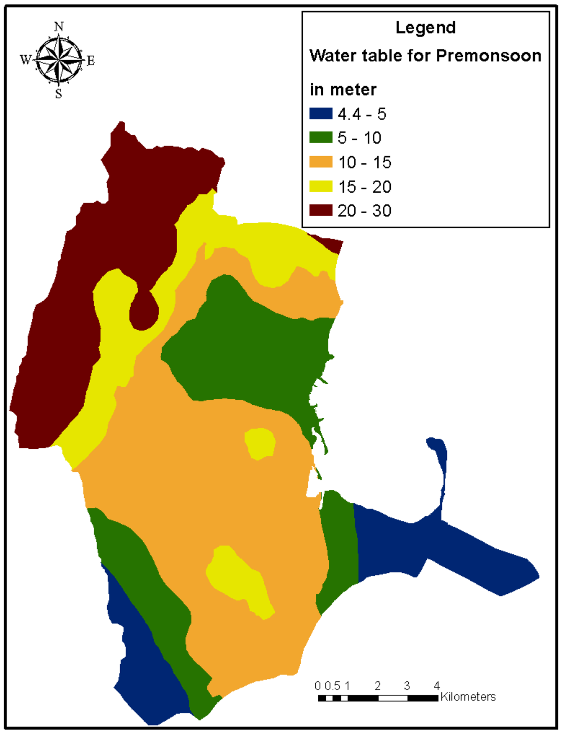

Figure-7
Water table (Pre-monsoon) map of the study area

Post monsoon water table: Post monsoon water level data was collected for January 2011. Depth to water table is measured from the respective observation wells. Similar procedures are adopted as similar to pre monsoon. Post monsoon water table map was carried out using Arc GIS 9.3 for post monsoon water table contours are prepared (figure 8). Post monsoon water table varies in the range of 1 m to 25 m. Similar to pre monsoon water level eastern part shows shallow water table where as southern part shows deeper water table. Reason is water in recent formation is found to be in unconfined condition as s result they are at shallow depth as they are found to be in a plain country. Overall average water table depth from ground is 25 m.

Water table Fluctuation: There are various methods in use for the quantitative evaluation of groundwater recharge e.g i. Groundwater level fluctuation and specific yield method ii. Soil moisture balance, method iii. Rainfall infiltration method[26,27]. Measurement of groundwater recharge requires proper understanding of the recharge and discharge prices and interrelationship with geological, geomorphologic, soil and landuse. In the present study the groundwater level fluctuation and specific yield method is used for the quantitative estimate of groundwater recharge in the Tuticorin Corporation.

In the case of conventional methods like rainfall infiltration method or water level fluctuation method average values of rainfall or water level fluctuation is taken for a part of the land. The study area receives rainfall under the influence of both S-W and N-E monsoons. The N-E monsoon chiefly contributes to the rainfall in the Tuticorin Corporation[28]. The S-W monsoon rainfall is highly erratic and summer rains are negligible. In this study the average of 10 years (2001-2010) are utilized in the annual fluctuation of water level. The spatial variability in the components of recharge is considered. In case of Remote sensing and GIS based method spatial distribution of the variable are taken into accounts, thus preparing an information is required for estimation on recharge.

Water table fluctuations map is prepared using the difference in level of pre and post monsoon water level data. Water level fluctuation map is prepared using spatial analysis of Arc GIS software (figure 9). Physical, chemical and biological features in reservoirs are influenced by seasonal surface-level fluctuations, which are significantly associated with anthropogenic utilization. From the above map I could find the cone of depression or abstraction is more in south central part of the study area due to abstraction in Korampalam channel. As a result ground water flow is towards the north direction. Generally water table has a configuration similar to that of land surface; however, depth to water levels are deeper in uplands recharge area rather than in the area adjacent to the river valley and discharge areas.

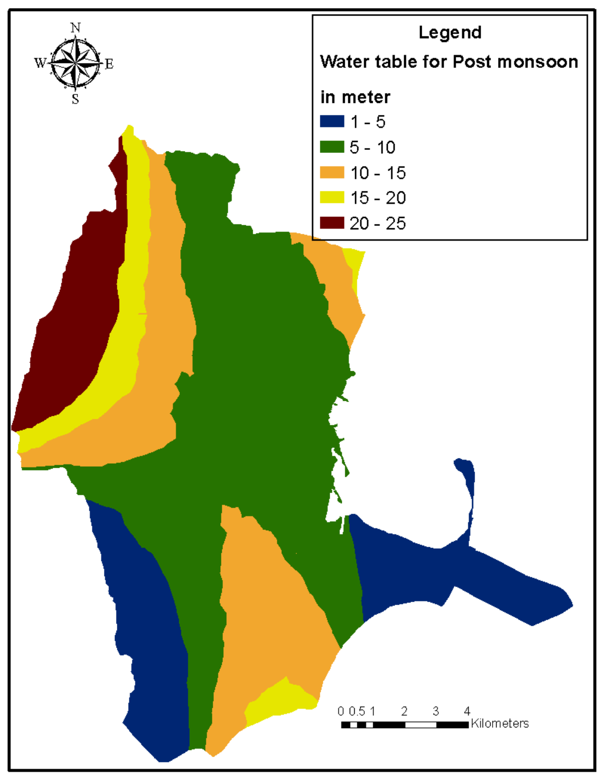

Figure-8
Water table (Post-monsoon) map of the study area

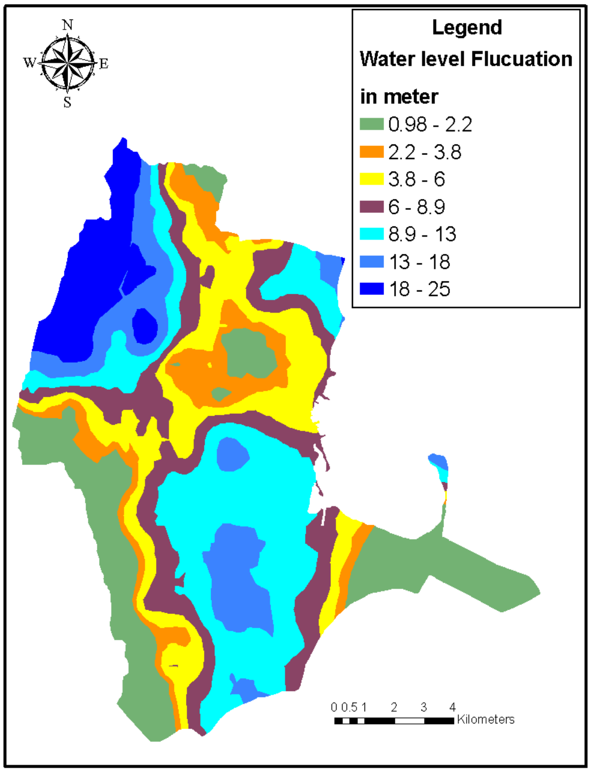

Figure-9
Water level Fluctuation map of the study area

Conclusion

Groundwater is most important precious resource of ecological system. Recently there has been overall development in various fields such as agriculture, industry and urbanization in India. This has lead to increase in the dement of water supply which is met mostly from exploitation of groundwater creating a water stress condition. Groundwater identification program needs a large volume of data from various sources. As demonstrated successfully in this study that integrated remote sensing and GIS can provide the appropriate platform for convergent analysis of large volume of multidisciplinary data and decision making for groundwater studies. IRS-1C satellite imageries provide information related to geology, geomorphology, landuse will be helpful in knowing the nature and water potentiality of different geomorphic unit. The following conclusion are drawn from the above study, i. In the present study area an integrated remote sensing and GIS based methodology has been developed and demonstrated for evaluation of groundwater resources. ii. Recently the areas nearer to the place are newly created settlements area and small scale industries. Recently the monsoon and irrigation system have failed so the agricultural cultivation is low and increase in urbanization and industrialization had its repercussions on agriculture and the allied categories of landuse practices. iii. Korampalam tank and korampalam channel are the important water irrigation in Tuticorin Corporation. Moderately high resolution remote sensing data provide details of the area as well as a synoptic overview to visualize the general groundwater conditions indirectly. iv. The water level fluctuation of the study area compounds is considered for components of recharge. v. Owing to its synoptic coverage, high resolution, temporal data availability, satellite remote sensing techniques followed by GIS analysis and image processing techniques give desirable results for making opposite plans for resources assessment in general and groundwater targeting.

References

1. Alaguraja P., Durairaju S., Yuvaraj D., Sekar M., Muthuveerran P., Manivel M. and Thirunavukkarasu A., Land Use and Land Cover Mapping – Madurai District, Tamilnadu, India Using Remote Sensing and GIS Techniques, *International journal of Civil and Structural Engineering*, **1**, 91-100 **(2010)**

2. Dar I.A., Sankar K. and Dar M.A., Deciphering groundwater potential zones in hard rock terrain using geospatial technology, *Environmental Monitoring and Assessment*, **173**, 597-610 **(2010)**

3. Hemapriya R., Sankar K. and Imran A. Dar., Geologic and Geomorphologic Investication of Gadilam River Basin (India), *Journal of Environmental Research and Development*, **4**, 750-757 **(2010)**

4. Jain S.K., Land use mapping of Tawi catchment using satellite data. Report No. CS72, National Institute of Hydrology, Roorkee, 52 **(1992)**

5. Shankar M.N.R. and Mohan G., Assessment of the groundwater potential and quality in Bhatsa and Kalu river basins of Thane district, western Deccan Volcanic Province of India, *Environmental Geology*, **49**, 990-998 **(2006)**

6. Selvam S., Use of Remote Sensing and GIS Techniques for Land Use and Land Cover Mapping of Tuticorin Coast, Tamilnadu, *Universal J of Envi Res and Tech*, **4**, 233-241 **(2012a)**

7. Akther H., Ahmed M.S., Rasheed K.B.S., Spatial and Temporal Analysis of Groundwater Level Fluctuation in Dhaka City, Bangladesh, *Asian Journal of Earth Sciences*, **4** , 222-230 **(2010)**

8. Chandrasekar N. and Sivasubramanian P. and John Prince Soundranayagam, Ecological Consequences of Rapid Urban Expansion: Tirunelveli, India, *African Journal of Basic & Applied Sciences*, **2**, 167-176 **(2010)**

9. Karwariya Sateesh and Goyal Sandip, Land use and Land Cover mapping using digital classification technique in Tikamgarh district, Madhya Pradesh, India using Remote Sensing, *International Journal of Geomatics and Geosciences,* **2**, 519-529 **(2011)**

10. Magesh N.S., Chandrasekar N. and Soundranayagam J.P., Morphometric evaluation of Papanasam and Manimuthar

watersheds, parts of Western Ghats, Tirunelveli district, Tamil Nadu India: a GIS approach, *Environmental Earth Science*, **64**, 373-381 **(2011a)**

11. Magesh N.S., Chandrasekar N. and John Prince Soundranayagam, Delineation of groundwater potential zones in Theni district, Tamil Nadu, using remote sensing, GIS and MIF techniques, *Geoscience Frontiers*, **3**, 189-196 **(2012b)**

12. Mondal N.C., Singh V.P., Singh V.S. and Saxena V.K., Determining the interaction between groundwater and saline water through groundwater major ions chemistry, *J Hydrol*, **388**, 100–111 **(2010)**

13. Sivasubramanian P. and Balasubramanian N., John Prince Soundranayagam, Chandrasekar, N., Hydrochemical characteristics of coastal aquifers of Kadaladi, Ramanathapuram District, Tamilnadu, India, *Appl Water Science*, DOI 10.1007/s13201-013-0108-z, **(2013)**

14. Antony Ravindran. A. and Mohd. Abdul Kadar Prabhu. H., Groundwater exploration study using Wenner-Schlumberger electrode array through W-4 2D Resistivity Imaging systems at Mahapallipuram, Chennai, Tamilanadu, India, *Research Journal of Recent Sciences*, **11**, 36-40, **(2012)**

15. Selvam, S. Sivasubramanian, P., Groundwater potential zone identification using geoelectrical survey: A case study from Medak district, Andhra Pradesh, India, *International Journal of Geomatics and Geosciences*, **3**, 55-62, **(2012b)**

16. Manimaran D., Groundwater Geochemistry Study Using GIS in and Around Vallanadu Hills, Tamilnadu, India, *Res.J.Recent Sci*, **1**, 52-58 (**2012**)

17. Biswas Arkoprovo. Jana Adarsa. and Sharma Shashi Prakash., Delineation of Groundwater Potential Zones using Satellite Remote Sensing and Geographic Information System Techniques: A Case study from Ganjam district, Orissa, India, *Res.J.Recent Sci*, **9**, 59-66, **(2012)**

18. Selvam, S. Manimaran, G. Sivasubramanian, P., Hydrochemical characteristics and GIS-based assessment of groundwater quality in the coastal aquifers of Tuticorin Corporation, Tamilnadu, India, *Applied water Sci*, **3**, 145-159, **(2013a)**

19. Balasubramanaian, A. R. Thirugnana, S. Chellaswamy, R. and Radhakrishnan, V., Numerical modeling for prediction and control of saltwater enchroment in the coastal aquifers of Tuticorin, Tamil Nadu (21). Tech. Report, **(1993)**

20. Rangarajan, R. Mondal, N,C, Singh, V.S. Singh, S.V. Estimation of natural recharge and its relation with aquifer parameters in and around Tuticorin town, Tamil Nadu. India, *Curr Sci*, **97**, 217–226, **(2009)**

21. John Prince Soundranayagam. Sivasubramanian, P. Chandrasekar, N. Durairaj, K.S.P., An analysis of landuse pattern in the industrial development city using high resolution satellite imagery, *J.Geogr.Sci*, **21**, 79-88, **(2011)**

22. Caleb Adwangashi Tabwassah. and Gabriel Ike Obiefuna., Geopysical and Geotechnical Investigation of Cham Failed Dam Project, Ne Nigeria, *Res.J.Recent Sci*, **2**, 1-18, **(2012)**

23. Selvam,S. Iruthaya Jeba Dhana Mala,R .and Muthukakshmi,V., A Hydrochemical analysis and Evaluation of groundwater quality index in Thoothukudi district,Tamilnadu, South India, *International Journal of Advanced Engineering Applications,* **2**, 25-37**, (2013b)**

24. Selvam, S. Seshunarayana, T. Manimaran ,G. Sivasubramanian, P. Manimaran, D., Groundwater Investigation using Geoelectrical Survey: A case study from Kanukunta Village, Andhra Pradesh, *India journal of Outreach*, **IV**, 59-62, **(2010)**

25. Selvam, S. Chindam Narsimhulu. Manimaran, G. Sivasubramanian, P., Geomorphological and textural characteristics of sediments of St. Marys Island Western continental shelf, India, *Archives of Applied Science Research,* **3**, 480-487, **(2011)**

26. Sander, P. Chesley, M.M. Minor, T.B., Groundwater assessment using remote sensing and GIS in a rural groundwater project in Ghana: lessons learned. *Hydrogeol J*, **4**, 40–49, **(1996)**

27. Murhekar Gopalkrushna Haribhau., Trace Metals Contamination of Surface Water Samples in and Around Akot City in Maharashtra, India, *Res.J.Recent Sci*, **7**, 5-9**, (2012)**

28. Selvam S., Manimaran G., Sivasubramanian P., Balasubramanian N. and Seshunarayana, T., GIS-based Evaluation of Water Quality Index of groundwater resources around Tuticorin coastal city, south India. *Environ Earth Sci,* DOI 10.1007/s12665-013-2662-y, **(2013c)**