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RESEARCH ARTICLE

Spatial Analysis of Groundwater Potential using Remote Sensing and GIS in the Kanyakumari and Nambiyar Basins, India

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Keywords Ground water potential · Inter-correlation Matrix · Multi-criterion.

Abstract Remotely sensed data can provide useful information in understanding the distribution of groundwater, an important source of water supply throughout the world. In the present study, the modern geomatic technologies, namely remote sensing and GIS were used in the identification of groundwater potential zones in the Kanyakumari and Nambiyar basins of Tamil Nadu in India. The multivariate statistical technique was used to find out the relationship between rainfall and groundwater resource characteristics. It has been found out that groundwater not only depends upon rainfall, but various other factors also influence its occurrence. Eight such parameters were considered and multi criterion analysis has been carried out in order to find out the potential zones. Accordingly, it had been concluded that the Kanyakumari river basin has more ground water potential, whereas the Nambiyar basin has less potential. Thus surface investigation of groundwater has proved to be easier, time consistent and cheaper using the geomatic technologies.

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Introduction

Groundwater is an important source of water supply throughout the world. The areas that are prone to excessive withdrawal, result in the shortage of groundwater, emphasize the need for the accurate estimates of the available subsurface resources and the importance of proper planning to ensure the continued availability of water. Although groundwater cannot be directly seen on the earth's surface, a variety of techniques can provide information about its availability. Remote sensing from aircraft or satellite has recently become a valuable tool for understanding the sub-surface water conditions. The remotely sensed data of geomorphology, drainage, geological litho units and lineaments, soil, land use and the other related characteristics of an area can be spatially integrated by means of geographic information system and finally groundwater potential zones can be identified. In this field, attempts have been already made in different parts of the country by scholars like Obi Reddy *et al.* (1994), Krishnamurthy *et al.* (1992), Reddy *et al.* (1996), Rao *et al.* (1996), Goyal *et al.* (1999), Goyal *et al.* (2004), and Sikdar *et al.* (2004). Some other scholars like Vaidyanathan (1964), Das *et al.* (1997), Kumar and Tomas (1998), Tomas *et al.* (1999), Pratap *et al.* (2000) and Subba Rao *et al.* (2001) have arrived at the groundwater prospects by considering the geomorphological aspects that have been derived out of satellite images. The present investigation has made an attempt to make use of the modern techniques namely, remote sensing, Global Positioning System (GPS) and Geographic Information System (GIS) for the purpose of evaluating and delineating the groundwater potential zones of the present study area.

The following research hypotheses have been framed appropriately for the study of groundwater resources. The characteristics of groundwater resources are associated with following hydro-geomorphological facets such as:

- Groundwater is dependent upon the rainfall and the sub-surface conditions
- Highly porous, plain regions enhance the groundwater conditions
- Fractured hard rock litho unit is also high in groundwater potential
- Higher groundwater potential produces less fluctuation

Materials and Methodology

Study area

The two adjacent river basins namely Kanyakumari and Nambiyar that lie between latitude 8° 04' N to 8° 34' N and longitudes 77° 05' E to 77° 57' E with an area of about 2,918 km^2 in the southern most part of Tamil Nadu in Peninsular India have been chosen for the present study (Fig. 1). They are coastally located and are mainly drained by Kodayar and Nambiyar rivers. These river basins fall under the district level administrative units such as Kanyakumari district and a part of Tirunelveli district that comprises Nanguneri and Radhapuram taluks. Although these two river basins are adjoining to each other, they geo-hydrologically differ with one another in many aspects. The satellite image clearly depicts the contrasting nature of the study area (Fig. 2).

Methods

The quantitative database required for the groundwater study was the groundwater level data observed directly from the observation wells located in the area under study collected by the Groundwater Division of Public Works Department. In fact, the State Surface and Groundwater Resources Data Center, Chennai, has all these recorded data, and in the present investigation, data pertaining for a period of 30 years between 1971 and 2001 had been collected. The rainfall data measured in the selected nearest rain gauge stations located in the study area for the same period was also collected from the Meteorological Department. The spatial locations of the selected observation wells and the rain gauge stations have been arrived at by using GPS. The spatial data pertaining to geology, soil and slope has been derived from Geological Survey of India (GSI) map, soil map and Survey of India toposheets respectively. The geomorphology, surface water resource characteristics and land use have been derived from the digitally enhanced IRS LISS III and PAN merged data product acquired during the year 2001 and were verified in the ground by using GPS.

Statistical tools and techniques used

The rainfall forms the basic input for both surface and ground water resources. The relationship

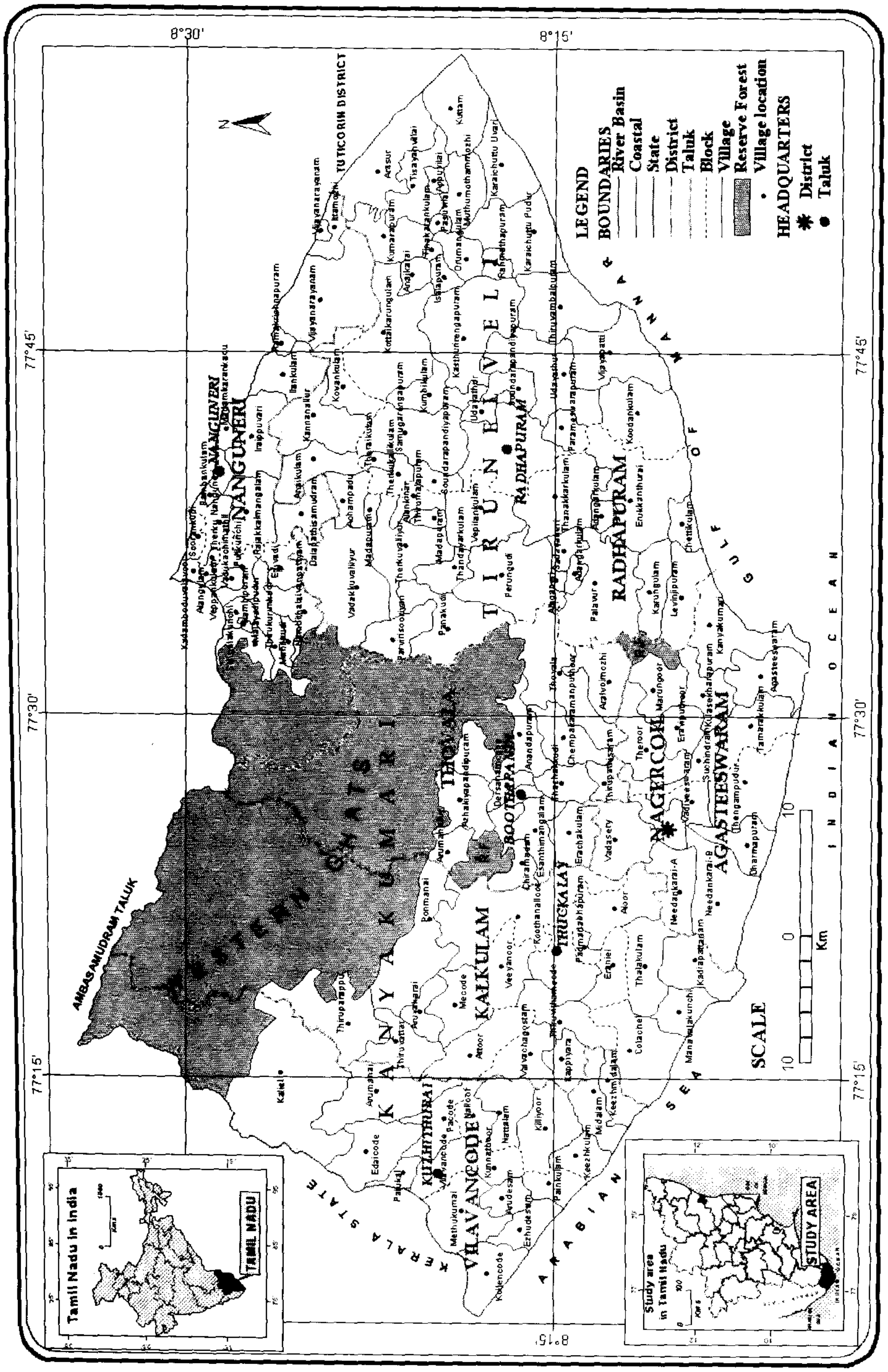

Fig. 1. Study area - Kanyakumari and Nambiar River basins

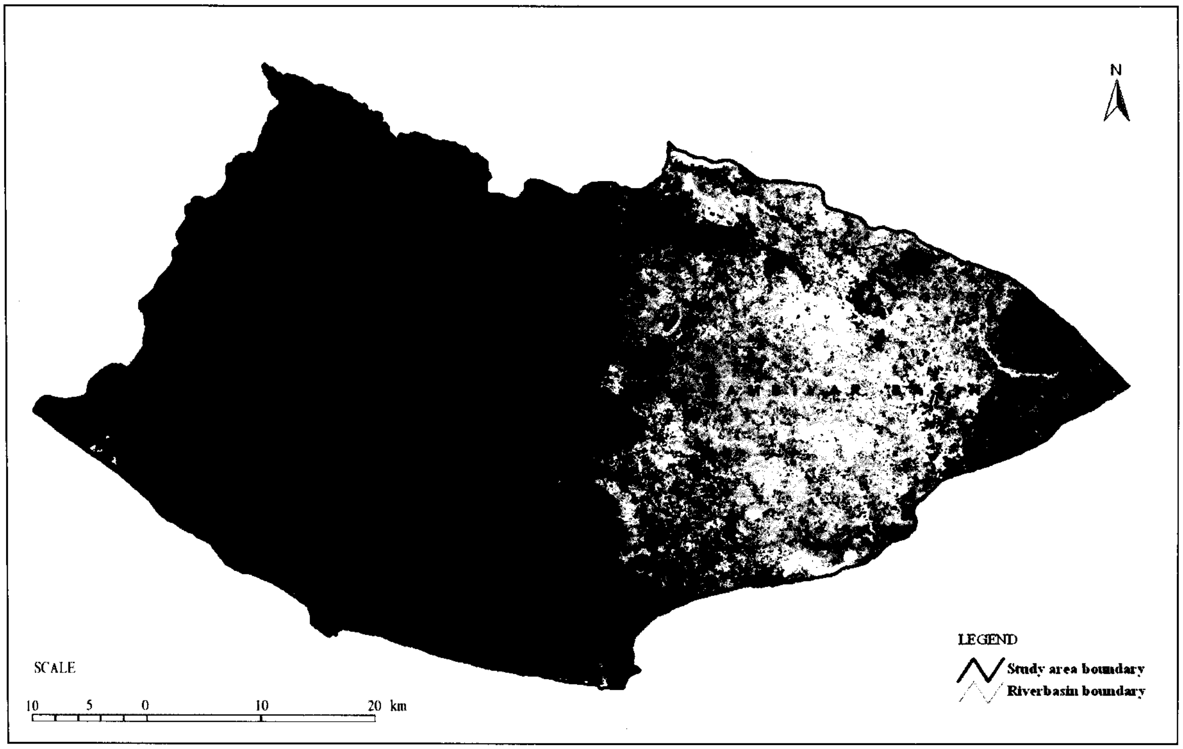

Fig. 2 IRS1D LISS III FCC of study area

between the groundwater characteristics and rainfall, a surface water resource characteristics were analysed by advanced multivariate inter-correlation technique using the steps followed by Yeats (1968). It is to be noted at this stage that various workers like Sawant (1992 Sawant and Suryawanshi, 1998), Ramasamy *et al.* (1995), Jeyakumar (1996) and Raghuvanshi *et al.* (2001) have already used this advanced statistical technique to solve problems related to both quality and quantity of ground water resources in their area of study. The characteristics of the ground water resources for a period of 30 years between 1971 and 2001 were analysed on the basis of groundwater level, fluctuation and deviation in association with rainfall of the area. For this purpose, an inter-correlation matrix of 15 × 15 variables pertaining to both the aspects that have been derived from 30 pairs of observations, was considered for the analysis with the aid of Statistical Package for Social Scientists (SPSS) version 10.0. The available data regarding the ground water draft/pumpage/exploitation was insufficient and deriving these observations was costlier in the hard rock terrain. Even though it is an important factor in determining the ground water occurrence, it was not considered in the present study because the surface water resources are utilized more rather than the ground water resources.

The inter-correlation matrix at the outset highlighted the existing significant (positive) correlation between the ground water resources and rainfall characteristics. The result, further indicates, that groundwater resource characteristics not only depend on the rainfall of a particular region, but also on other factors that control the infiltration of this precipitated water. Studies by Sawant (1992, 1998), Shrivastava (1995) and Raghuvanshi *et al.* (2001) which related groundwater aspects with certain morphological characters, also emphasized the above fact. A similar attempt in the present investigation had become essential. Hence, the present study analyses the groundwater potential zones of the study area, considering the factors controlling the groundwater resource by using the geo-spatial database, which were derived by both remote sensing and GIS techniques.

Application of GIS and derivation of groundwater potential zones

Among various factors responsible for groundwater resource potential, the notable factors considered for the present analysis were geomorphology, slope, geological lineaments and litho units, rainfall, drainage, soil and land use/land cover. The geomorphology, lineament, land use/land cover and drainage are derived from the digitally enchanced IRS LISS III PAN merged data; slope map is derived from the SOI toposheets; the geology and soil are derived from the GSI and Soil maps respectively whereas the rainfall data is collected from the meteorological department.

Multi-criterion evaluation (MCE) technique allows map layers to be weighted to reflect their relative importance (Voogd 1983, Eastman *et al.* 1995, Eastman 1996 and Navalgund 1997). Saaty's (1980) analytic hierarchy process is the most widely accepted method for scaling the weight of parameters whose entries indicate the strength with which one element dominates over the other in relation to the relative criterion. The basic input is the pair-wise comparison matrix of n parameters constructed based on the Saaty's scaling ratios which could be of the order ($n \times$ n), and is in the form of

$$A = [a_{ij}] \quad \text{where } i, j = 1,2,3,\ldots n.$$

The matrix A has generally the property of reciprocality and consistency. This is mathematically given as, $a_{ij} = 1/a_{ji}$, and $a_{ij} = a_{ik}/a_{jk}$ for any i, j and k.

Thus, multiplying A with weighing vector W of order ($n \times 1$) size yields

$$(A\text{-}nI)\,W = 0$$

where, I is an identity matrix of order ($n \times n$). According to the matrix theory, if the matrix A has the property of consistency, the system of equations has a trivial solution. The matrix A is, however, a judgement matrix and it may not be possible to determine the elements of A accurately to satisfy the property of consistency. Therefore, it is estimated by a set of linear homogenous equations

$$A^* \times W^* =_{\max} W^*$$

where, A^* is the estimate of A, and W^* is the corresponding priority vector and $_{\max}$ is the largest eigen value for the matrix A. The above equation yields the weightages W which are normalized to unity for further purposes.

After determining the weightages for the parameters, it is necessary to rank each category of the parameters for the suitability analysis. The ranks of the individual categories are assigned in such a way that higher the rank, higher is the suitability and lesser are the limitations. For determining the inter-class/inter-map dependency, a probability weighed approach was adopted that allows a linear combination of probability weights of each thematic map (W) with individual impact value (Sarkar and Deota 2000). The thematic maps have been ranked in a scale of 0 to 5 depending upon their suitability to hold groundwater. The rank of each map has been converted to a probability weight using Bayesian Decision Theory (Haan, 2002). Similarly, different categories of derived thematic maps were assigned scores in a numeric scale 0 to 5, depending upon their capability to store and transmit water. These scores were again converted into capability values.

These capability values (cv_i) were then multiplied with the respective probability weight of each thematic map to arrive at the final weight map. Integration analysis was carried out using overlay – intersect method and a composite groundwater potential map was generated. The composite potentiality index was obtained by multiplying weightages with rank numbers of each category and by summing up the values of all categories.

Mathematically this can be defined as:

$$GWP = F\,(Geom, Sl, Lin, Lith, Ra, Dd, Sol, Lu)$$

where, *GWP* refers to groundwater potential, *Geom* – Geomorphology, *Sl* – Slope, *Lin* – Lineaments, *Lith* – Lithology, *Ra* – Rainfall, *Dd* – Drainage density, *Sol* – Soil and *Lu* – Land use

Groundwater potential map values can be expressed as

$$GWP = \Sigma W_i \times cv_i$$

where W_i - map weight
cv_i - capability value

The algorithm used in the derivation of groundwater potential zones was as follows:

$$gwp = 0.19 \times [cv_{geom}] + 0.19 \times [cv_{slope}] + 0.15 \times [cv_{lin}] + 0.11 \times [cv_{litho}] + 0.11 \times [cv_{rain}] + 0.11 \times [cv_{drain}] + 0.07 \times [cv_{soil}] + 0.07 \times [cv_{lu}]$$

where *gwp* – groundwater potential

cv_{geom} – Geomorphic layer with capability value
cv_{slope} – Slope layer with capability value
cv_{lin} – Lineament density layer with capability value
cv_{litho} – Lithounits layer with capability value
cv_{rain} – Rainfall layer with capability value
cv_{drain} – Drainage density layer with capability value
cv_{soil} – Soil layer with capability value
cv_{lu} – Land use layer with capability value.

The resultant final map indicates the potentiality of groundwater occurrence in the study area. This map was then classified into four categories based on the mean and standard deviation values namely very good, good, moderate, and poor groundwater potential.

Results and Discussion

Relationship among the characteristics of the groundwater resources and rainfall

The relationship between the groundwater characteristics and rainfall had been clearly brought out with the help of the inter-correlation statistically. The output of 15 variables viz., well average water level, winter deviation, summer deviation, south west monsoon deviation, north east monsoon deviation, winter fluctuation, summer fluctuation, south west monsoon fluctuation, north east monsoon fluctuation, average well fluctuation, winter rainfall, summer rainfall, south west monsoon rainfall, north east monsoon rainfall and average annual rainfall pertaining to 30 pair of observations form 15 × 15 inter-correlation matrix. The correlation results derived out of the matrix are presented in Table 1. The table clearly depicts the existing relationship among the 15 derived variables of groundwater resources with that of the seasonal and annual rainfall variables.

The groundwater resource characteristics show significant positive correlation to that of the rainfall at 0.05 level of significance. In fact, among the groundwater variables the average level of the observation - wells is positively related to both seasonal and annual rainfall. Its correlation coefficient is notably higher with regard to winter rainfall (0.642); and it is moderately high with that of northeast rainfall (0.505); followed by less significant with that of average annual rainfall (0.418) as well as southwest rainfall (0.381). But, at the same time it is to be noted that the summer rainfall shows positive correlation of 0.321, least significant with that of average annual groundwater level. In fact, the strength of relationship notably

Table 1 Correlation between the seasonal rainfall with that of the groundwater resource characteristics in Kanyakumari and Nambiyar basins (significance at 0.05 level).

Rainfall/Ground water resource Characteristics	Winter rainfall	Summer rainfall	South west monsoon rainfall	North east monsoon rainfall	Average annual rainfall
Well average level	0.642	0.324	0.381	0.505	0.418
Winter deviation	-0.153	-0.032	0.028	-0.078	-0.016
Summer deviation	0.210	0.450	0.541	0.545	0.532
South west monsoon deviation	0.021	-0.159	-0.252	-0.205	-0.219
North east monsoon deviation	-0.211	-0.426	-0.513	-0.484	-0.497
Winter fluctuation	0.094	0.028	-0.006	0.066	0.022
Summer fluctuation	0.441	0.061	0.052	0.187	0.098
South west monsoon fluctuation	0.184	0.141	0.064	0.12	0.104
North east monsoon fluctuation	0.174	0.123	0.092	0.193	0.129
Average well fluctuation	0.418	0.185	0.149	0.273	0.201

varies in this regard, owing to the nature of the monsoon rainfall that slowly recharges the groundwater, which is the maximum at the end of monsoon and at the beginning of the winter season. In contrast, the summer rains do not increase the groundwater level resulting in the less significant value. Similarly, with regard to the seasonal deviation of water level, summer deviation is predominant showing highly significant positive coefficients with southwest monsoon (0.541), northeast monsoon (0.545) and annual rainfall (0.535). The deviation of groundwater level in summer season was more and even if there was rain, it is not sufficient to recharge the already exploited water resource and this results in positive correlation. Whereas during the other seasons namely, the winter, southwest monsoon and northeast monsoon, the water level show negative deviation due to the fact that in these seasons there is more rainfall, and therefore, more will be the recharge and this reduces the deviation in groundwater level. As soon as the excess of water exploitation occurs, recharge becomes obvious and hence there is neither rise nor fall in aquifer water level maintaining the level constant. The seasonal and annual fluctuation in the water level show very little significant positive correlation, owing to the almost similar seasonal and annual rainfall.

On the whole, seasonal and annual groundwater level and its deviation significantly respond to the intercepting rainfall. But it is clearly evident that the rainfall alone was not the only determining factor as its seasonal variation was mostly uncorrelated for the groundwater resource base. In fact, there are certain other related factors, which determine the changing levels of groundwater. Hence, the determination of other governing factors for the identification of groundwater potential zones becomes essential at this stage. The following section discusses in detail, the groundwater characteristics, the factors influencing them, and the process of identification of groundwater potential zones.

Spatial distribution and pattern of groundwater potential zones

All the eight parameters namely the geomorphic units, slope, lineament. litho units, rainfall, drainage density,

Table 2 Thematic layers, their categories, weights and area

Sl. No	Thematic layer	Layer Rank	Map weight (W_i)	Category	Category Rank	Capability value (CV_i)	Area km²	Percent to total area
I	Geomorphology	5	5/27=0.19	**Structural landforms**				
				Ridge valley complex	2	0.07	614.52	21.05
				Composite slope	1	0.03	223.85	7.67
				Denudational landforms				
				Inselberg	1	0.03	15.34	0.53
				Pediment	2	0.07	480.77	16.47
				Deep pediment	3	0.10	7.67	0.26
				Buried pediment	2	0.07	564.32	19.33
				Shallow buried pediment	2	0.07	69.34	2.38
				Depositional landform(fluvial)				
				Valley fill	4	0.14	168.82	5.78
				Uplands	2	0.07	556.32	19.06
				Pediment zone	3	0.10	50.97	1.75
				Coastal landforms				
				Coastal plain	3	0.10	107.46	3.68
				Sand beach	3	0.10	12.06	0.41
				Aeolian landform				
				Stabilised sand dune	1	0.03	47.41	1.62
II	Slope (in degrees)	5	0.19	<1° Nearly level	5	0.33	523.61	17.94
				1°-3° Very gentle	4	0.27	734.28	25.16
				3°-5° Gentle	3	0.20	718.54	24.62
				5°-10° Moderately steep	2	0.13	420.11	14.39
				10°-15° Steep	1	0.07	189.10	6.48
				>15° Very steep	0	0.00	333.22	11.42
III	Lineament (m/sq.km)	4	0.15	>60 Highly dense	4	0.40	22.49	0.77
				40-60 Dense	3	0.30	80.21	2.75
				20-40 Moderately dense	2	0.20	930.33	31.87
				<20 Less dense	1	0.10	1885.82	64.61
IV	Lithology	3	0.11	**Archaen age**				
				Charnockite	1	0.04	783.10	26.83
				Garnet biotic Gneiss	2	0.09	105.80	3.62
				Garnet biotic Sillimenite Gneiss	2	0.09	403.64	13.8
				Garnetiferous biotite Gneiss	2	0.09	1153.20	39.5
				Garnetiferous Sillimenite Gneiss	2	0.09	308.36	10.56
				Miocene				
				Cuddalore sandstone	4	0.17	25.15	0.86
				Loose and Gritty Calcareous Sandstone	4	0.17	90.65	3.11
				Recent				
				Alluvium	5	0.22	23.61	0.8
				Kankar and Tuffaceous limestone	1	0.04	25.34	0.87
V	Rainfall (mm/year)	3	0.11	>2000 Very high	5	0.33	333.22	11.42
				1500-2000 High	4	0.27	475.25	16.28
				1000-1500 Moderate	3	0.20	601.81	20.62
				500-1000 Low	2	0.13	1508.58	51.68
				<500 Very low	1	0.06	-	
VI	Drainage density (km/km²)	3	0.11	<1 Very coarse	4	0.40	718.06	24.6
				1-2 Coarse	3	0.30	1323.32	45.34
				2-3 Moderate	2	0.20	544.25	18.65
				>3 Fine	1	0.10	333.22	11.4

Table 2 (Continued) ...

Sl. No	Thematic layer	Layer Rank	Map weight (W_i)	Category	Category Rank	Capability value (CV_i)	Area km²	Percent to total area
VII	Soil infiltration (mm/hr)	2	0.07	Sandy loam	5	0.36	287.54	9.85
				Loamy sand	4	0.29	1545.36	52.94
				Sandy clay	3	0.21	730.89	25.04
				Forest	2	0.14	355.06	12.16
VIII	Land cover/Land use	2	0.07	Built up	1	0.03	132.33	4.53
				Dry agriculture	3	0.11	297.37	10.19
				Wet agriculture	5	0.18	741.29	25.39
				Forest	3	0.11	759.89	26.03
				Water body	5	0.18	68.79	2.36
				Dry tank	2	0.07	96.66	3.31
				Waste land with scrub	2	0.07	347.49	11.91
				Waste land without scrub	1	0.03	361.48	12.38
				Sandy area	1	0.03	58.89	2.02
				Rocky exposure	1	0.03	36.04	1.24
				Beach	3	0.11	12.81	0.44
				Salt pan	1	0.03	15.83	0.2

soil and land use/land cover were subjected to multi-criterion evaluation by following Saaty's importance scale. The summation of the product of all the map weights of the thematic layer, each with the related capability value of corresponding categories (see Table 2), finally depicts the groundwater potential zones. For this, the polygons in each of the eight thematic layers were overlaid by using *intersect method* of *map overlay option* in GIS.

Accordingly, the resultant polygons that were derived out of the overlaid theme by using the weighted value, reflect all the eight parameters that influence the groundwater potential of an area. The spatial distribution of all these categories of groundwater potential zones is depicted in Fig. 3. Very good zones of groundwater potential occur in the places where all the eight themes are more favourable to groundwater. From the figure, it is clear that very good groundwater potential category is seen in the places with rich surface water bodies that enhance the infiltration whereby the area becomes potential. The second category of zones with good groundwater potential is predominantly seen all over the Kanyakumari basin in the present study area. On the other hand, moderate as well as poor groundwater potential category of zones were notably seen in the Nambiyar basin. A few pockets of poor groundwater potential zones were also found in Kanyakumari basin, wherein dense area of urban settlements occurs. In fact, the northwestern part of the study area, having the geomorphic unit of ridge valley complex with dense lineaments and granite rock group, registered mostly moderate groundwater potential. Even though this region receives very high rainfall, the occurrence of dense lineaments and forest land use with porous soil. The groundwater potential is notably moderate due to the steep slopes of the terrain with fine drainage density. The southwestern side, which is of moderate slope with predominant upland geomorphic unit, has good groundwater potential. Similar is the case with regard to the southwestern coastal region with gentle slope, which have upland geomorphic unit underlaid by a variety of rocks belonging to different geological age groups. This area with coarse drainage density and agricultural land use notably influence infiltration, whereby this zone has a good groundwater potential. In the southern region, even though the geomorphic unit is of composite slope with charnokites as bedrocks, the denser lineaments increases the infiltration of surface water to the ground; and the drainage density is moderate with loamy soil and agricultural land use, and so the groundwater

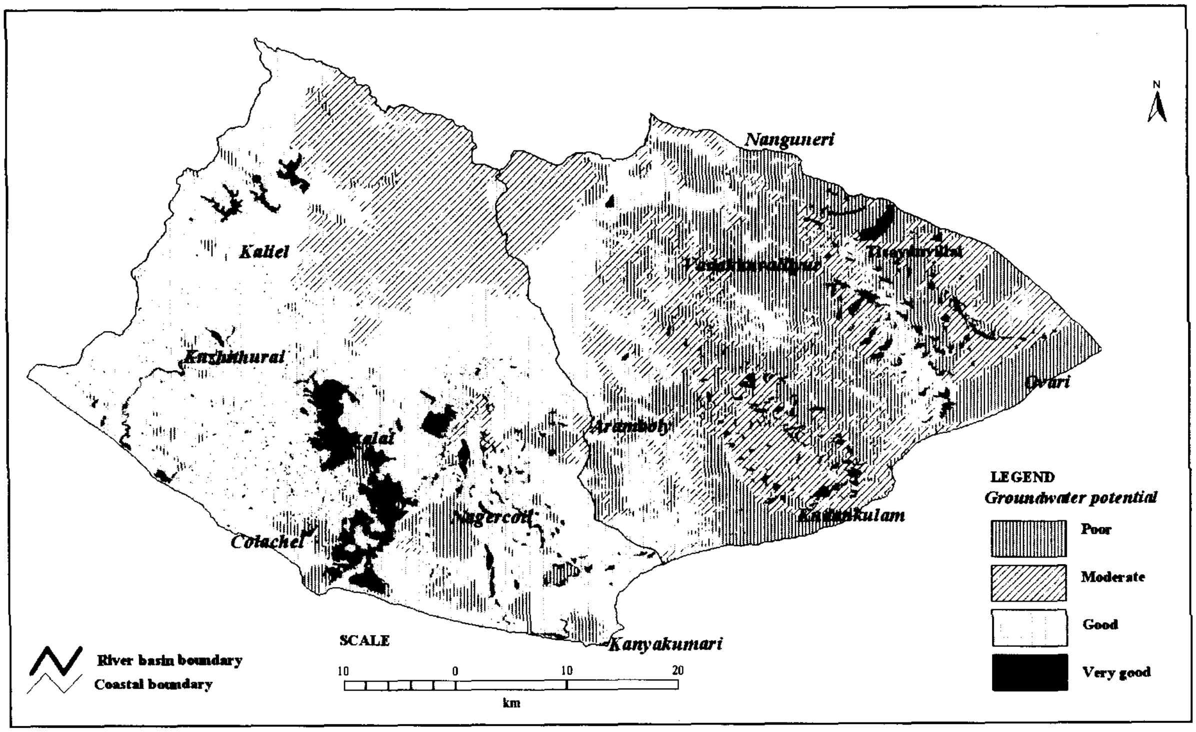

Fig. 3 Spatial pattern of ground water potential

potential of this zone is good. The southeastern region have a favourable geomorphic unit namely, valley fill, with notable pediments and gentle to very gentle slope and therefore contributes to good groundwater potential. In spite of their charnockite bedrock with less dense lineaments and moderate rainfall, these areas have good groundwater potential. It is to be noted that the dense built-up area of this region like Nagercoil, Rajakkalmangalam and Kanyakumari have poor groundwater potential.

Almost all the areas of Nambiyar basin except Upper Nambiyar portion are of very gentle slope to nearly level, with low rainfall. The predominant land use here is wastelands. Pediments with loamy soils dominate in this region thereby increasing the groundwater potential..Still, the groundwater potential is moderate to poor except for the surface water bodies and along the river course. In the coastal plain region, the rainfall and geomorphic unit namely the buried pediment, favour groundwater potential. The piedmont zone with moderately dense lineaments in the catchment area, moderate drainage density and loamy soil favour groundwater whereby the groundwater potential is moderate. The *kankar* and tuffaceous limestone with wastelands make the region a moderate to poor groundwater potential zone. In the catchment region, the geomorphic units, lineaments, drainages and lithounits favour groundwater potential; but loamy, and silt loamy soil in which the infiltration is low brings the region under moderate to poor groundwater potential zone. The eastern region shows moderate groundwater potential due to the favourable geomorphic unit and the river course. Thus, various factors influence the groundwater potential of the study area, showing disparity in the distribution and pattern of groundwater.

In Kanyakumari basin, various geomorphic units like uplands, pediments, coastal plains, valley fills and ridge valley complex show moderate to high groundwater potential; but a small portion of the geomorphic unit namely inselberg and composite slope reduces infiltration. On the whole, the geomorphic units favour groundwater potential in that area. The lineaments are also comparatively more, enhancing groundwater. Rainfall is also high, favouring the groundwater recharge. Drainage density is comparatively coarse in the coastal sub-watersheds which increases the groundwater potential. Kanyakumari basin is mostly of loamy type of soils in the foothill region, while sandy and clay loam in the coastal region favouring groundwater potential. Likewise, the land use/land cover is dominated by forest and agricultural land which increase infiltration. In the Nambiyar basin, the dominant geomorphic units like pediments, buried pediments, shallow buried pediments show moderate groundwater potential. Slope is nearly gentle to level which increase the infiltration and reduce the surface runoff. The northwestern part of the basin has moderate lineaments, which favours recharge. The coarse drainage density in the parts of Nambiyar basin increases the groundwater potential. Mostly this river basin is covered by loamy type of soil enhancing infiltration and consequently increasing the groundwater potential. Although all the above factors favour groundwater potential, the comparatively less rainfall and the predominant wastelands reduce infiltration. Hence moderate to poor groundwater potential prevails in this part of the study area.

Conclusion

The relation between the seasonal rainfall and groundwater characteristics has been studied by using multivariate inter-correlation techniques. The results reveal that the groundwater characteristics not only depend upon the rainfall but also on other factors like geomorphic units, drainage, lithounits, lineaments, slope and land use. By incorporating all these factors, a weighted index model could be created for identifying the groundwater potential zones. Suitable models derived out of these techniques, including remote sensing and GIS have been applied in an appropriate manner in order to understand the real potentiality of groundwater resources in the present study area. The surface investigation of groundwater potential using remote sensing and GIS platform has proved to be an easier as well as a challenging method in identifying groundwater resources. Multi-criterion evaluation has been performed by assigning weights to all the chosen parameters and the result derived out of MCE, has been endorsed to assess the entire study area. Accordingly, the Kanyakumari basin has good and moderate groundwater potential zones, compared to that of the Nambiyar basin.

References

Das S, Behera SC, Kar A, Narendra P and Guha S (1997) Hydrogeomorphological mapping in groundwater exploration using remotely sensed data - A case study in Keonjhar district in Orissa. *J Indian Soc. Remote Sen.* 25(4): 247–259

Eastman JR (1996) *Multi-criteria Evaluation and Geographical Information Systems* Eds. Longley PA, Goodchild MF, Magurie DJ and Rhind DW, Second edition,1 (John Wiley and sons, New York): 493–502

Eastman JR, Jin W, Kyemi PAK and Toledano J (1995) Raster procedure for multi-criteria/multi-objective decisions. *Photogrammetric Engineering and Remote Sensing* 61: 539–547

Goyal R and Arora AN (2004) Use of remote sensing in groundwater modeling. Map Asia 2004. Beijing International Convention Centre, Beijing, China. www.GIS@development.net

Haan CT (2002) Statistical Methods in Hydrology. Second Edition, Iowa State University Press, 2121 State Avenue, Ames, Iowa: 378

Jayakumar R (1996) Groundwater level fluctuation analysis using trend surface in Upper Vellar Basin BHU-JAL News: 5–10

Krishnamurthy J, Manavalan P and Saivasan V (1992) Application of digital enhancement techniques for ground water exploration in a hard rock terrain. *International Journal of Remote Sensing* 13: 2925–2942

Kumar A and Tomas S (1998) Groundwater assessment through hydrogeomorphological and geophysical survey – A case study in Godaveri sub-watershed, Giridih, Bihar. *J Indian Soc. Remote Sen.* 26(4): 177–184

Navalgund RR (1997) Revised Development plan of Ahmedabad Urban Development Authority Area – 2011. Ahmedabad Urban Development Authority and Space Applications Centre, Ahmedabad, India, Technical Report 1 SAC/RSAG/TR/12/AUG/1997:142

Obi Reddy GP, Suresh BR and Rao Sambasiva M (1994) Hydrogeology and hydrogeo-morphological conditions of Anantapur district using remote sensing data. *Indian Geographical Journal,* 69(2): 128–235

Pratap K, Ravindran KV and Prabakaran B (2000) Groundwater prospect zoning using remote sensing and geographical information system – A case study in dala-Renukoot area, Sonbhadra district , Uttarpradesh. *J Indian Soc. Remote Sen.* 28(4): 249–263

Raghuvanshi R, Bharathi R, Padmakar C and Yadava RN (2001) Morphometric analysis of Dudhi river basin, Begamganj block, Raisen district, Madhya Pradesh, India using remote sensing techniques. *Journal of Hydrology*: 330-337

Ramasamy SM, Athithan DSP, Jayakumar R and Vasudevan S (1995) Groundwater quality monitoring through remote sensing – A mathematical approach. *Journal of Applied Hydrology* 8(1-4):19–27

Rao DP, Bhattacharya A and Reddy PR (1996) Use of IRS-1C data for geological and geographical studies. *Current Science*, IRS 1C, 70(7): 619–623

Reddy PR, Vinod Kumar K and Seshadri K (1996) Use of IRS-1C data in ground water studies. *Current Science* Special session, IRS 1C 70(7) 600–605

Goyal S, Bhardwaj RS and Jugran DK (1999) Multicriteria analysis using GIS for groundwater resources evaluation in Rawasen and Pili watershed. U.P. Proc. Map India 99, New Delhi, India

Saaty TL, (1980) *The Analytic Hierarchy Process.* (Mc Graw Hill, New York)

Sarkar BC and Deota BS (2000) A geographic information system approach to ground water potential of shamri micro-watershed in the Shimla Taluk, Himachal Pradesh. Unpublished Project Report submitted for NNRMS sponsored course on GIS; Technology and Applications, IIRS, NRSA, Dehradun, India, 24

Sawant PT (1992) Ground water potential of Bhagawati river basin. Solapur district, Maharastra, India. *Journal of Applied Hydrology* 12(1) 1–9

Sawant PT and Suryawanshi RA (1998) Hydrological studies of Terna river basin, Latur-Osmanabad districts, Maharastra. *Journal of Applied Hydrology* 11(1) 36–48

Shrivastava VK and Mitra D (1995) Study of drainage pattern of Raniganj coal field (Burdwan district) as observed on Landsat - TM/IRS LISS II Imagery. *J Indian Soc.* Remote Sen. 23(4) 225–235

Sikdar PK, Chakraborty S, Enakshi A and Paul PK (2004) Land use/Land cover changes and groundwater potential zoning in and around Raniganj coal mining area, Bardhaman District, West Bengal- A GIS and Remote Sensing Approach. *Journal of Spatial Hydrology,* 4 (2 Fall 2004): 1–24

Subba Rao N, Chakradhar GKJ and Srinivas V (2001) Identification of groundwater potential using remote sensing techniques in and around Guntar town, Andhra pradesh, India. *J Indian Soc. Remote Sen.* 29(1 & 2): 69–78

Tomas A, Sharma AK, Manoj KS and Sood, A. (1999) Hydrogeomorphological mapping in assessing groundwater by using remote sensing data - A case study in Lehra Ganga block, Sangrur district, Punjab. *J. Soc. Remote Sens.* 27(1): 31–42

Vaidyanathan R (1964) Geomorphology of Cuddapah basin. *Journal of Indian Geosciences Association* 4: 29–36

Voogd H (1983) Multi-criteria Evaluation for Urban and Regional Planning. Pion, London

Yeats MH (1968) An introduction to quantitative analysis in human geography. Mc Graw Hill, New York