Geo-spatial Information Science 14(1):17-26
DOI 10.1007/s11806-011-0422-2

Volume 14, Issue 1
March 2011

Article ID: 1009-5020(2011)01-017-10

Document code: A

Groundwater Potential Zoning in Thirumanimuttar Sub-Basin Tamilnadu, India—A GIS and Remote Sensing Approach

MURUGESAN Vasanthavigar[1], **KRISHNARAJ Srinivasamoorthy**[1],
KANNUSAMY Vijayaragavan[1], **SELVARAJ Gopinath**[1], **SUBRAMANYA Sarma**[2]

1. Department of Earth Sciences, Annamalai University, Annamalai Nagar – 608 002, Tamil Nadu, India
2. National Geophysical Research Institute (NGRI), Uppal Road, Hyderabad – 500 007, India

Abstract The main objective of the study is to identify groundwater potential zones in Thirumanimuttar basin with an integrated approach using Remote Sensing and geographical information system (GIS). FCC Image of Landsat TM 30 m resolution data and topographic maps has been used to generate thematic maps like geology, geomorphology, lineament and lineament density, drainage, drainage density, and slope map of the study area. A number of geomorphic units such as Denudational hills, structural hills, Bajadas, Colluvial plain, Pediplain, Deep Pediment and Alluvial plains have been observed. A composite groundwater potential map has been generated as very high, high, medium, low and very low based on the groundwater availability area. The upper, middle and downstream of the basins have been identified as potential zones for groundwater exploration. The regions of lineaments and intersecting lineaments proved for groundwater potential zones. The data generated was validated with field checks and observed to be in conformity with the same.

Keywords geomorphology; groundwater; Landsat; potential zones; remote sensing; GIS

CLC number P208;P237.3

Introduction

Groundwater is an important natural resource in present day, but of limited use due to frequent failures in monsoon, undependable surface water, and rapid urbanization and industrialization have created a major threat to this valuable resource. A groundwater development program needs a large volume of multidisciplinary data from various sources. In order to ensure a judicious use of groundwater, its proper evaluation is required for optimal utilization. With groundwater occurrence being a subsurface phenomenon, its identification and location are based on indirect analysis of some direct observable terrain features like geology, geomorphology and their hydrologic characters. In the last few decades, Remote Sensing (RS) and Geographical Information System (GIS) techniques have been used in different field of sciences in which it provides an opportunity for better observation and more

---

► Received on September 7, 2010.

► Supported by the Major Research Project Under University Grants Commission, India (No.32-335/2006).

► MURUGESAN Vasanthavigar is a University Grants Commission (UGC), New Delhi, India sponsored research fellow. He is currently pursuing Ph.D. in applied geology from Annamalai University. His current research interests include hydrogeochemistry, groundwater vulnerability, water quality, pollution studies, remote sensing and GIS, and isotope geochemistry.

► E-mail: moorthy_ks@yahoo.com,breezevasanth@gmail.com systematic analysis of various identification and demarcation of groundwater resources.

RS and GIS are playing a rapidly increasing role in the field of hydrology and water resource development.[1-5] In developing accurate hydrogeomorphological analysis, monitoring, ability to generate information in spatial and temporal domain and delineation of land features are crucial for successful analysis and prediction of groundwater resources.[6,7] However, the use of RS and GIS in handling large amount of spatial data provides to gain accurate information for delineating the geological and geomorphological characteristics and allied significance, which are considered as a controlling factor for the occurrence and movement of groundwater[8-10] used IRS LISS II data on 1: 50000 scale along with topographic maps in various parts of India to develop integrated groundwater potential zones by qualitative analysis in terms (i.e., good to very good, moderate to good and poor)[11], used GIS for the analysis of lineament data derived from SPOT imagery for groundwater potential mapping. For the assessment of groundwater resources of Northwest Florida, we took the advantage of GIS for spatial analysis and data visualization.[12] Developed a GIS-based model for delineating groundwater potential zones of Marvdaiyar basin, Tamil Nadu, India, by integrating different thematic layers derived from remote-sensing data. Same types of studies were applied in different parts of India by Ref.[5,8,13,14].

Water resources in India are very unevenly distributed both spatially and temporally. Idiosyncrasies of monsoon and diverse physiographic conditions give rise to unequal distribution of water. Over the years, population growth, urbanization and agricultural expansion have exacerbated the situation. The aftermath of unscientific exploitation of groundwater is that we are moving towards the water shortage condition. Even now, some parts of the country are facing acute water crisis. Despite being a very important part of the nation’s growth, water resource analysis has been fragmentary. An integrated study covering the aspect of identification of groundwater potential zones is a crucial requirement of the present day. We enhance the efficiency and performance of planning, utilization, administration, and management of the groundwater resources.[15, 16] The present work is an attempt to integrate RS and GIS-based analysis and methodology in groundwater potential zone identification in hard rock terrains. It is necessary to understand different types of landforms and their characteristics, rock types, geological structures and how they evolved with respect to each other, hydrological characteristics and slope in order to demonstrate the integrated remote sensing and GIS-based methodology for identification of groundwater potential zones, Thirumanimuttar sub basin, which forms the integral part of the Cauvery basin, has been taken as the study domain.

1 Study area

Thirumanimuttar Sub-basin is a major tributary of river Cauvery, which lies between North latitudes 10°58' and 11°48' and East longitudes 77°53' and 78°21' (Fig. 1). It originates at Manjavadi in Salem district and configures in river Cauvery at paramati Velur in the Namakkal district of Tamilnadu. The river course is about 102 km with a total drainage of 2438 km^2. Thirumanimuttar forms an important groundwater province in south India, facing serious scarcity in groundwater quantity.[17] The serious problem in the area is rapid growth population and intensive industries, and economic activity has increased. Generally, the basin is precarious for surface flow but receives meager flow during rainy season. It acts as a major sink for domestic and industrial effluents along with agricultural return flow. Thus, groundwater as the only water source has extensively been used to meet the increasing demand for domestic, irrigational and industrial requirements.

1.1 Geology

The study area is entirely underlined by Archean crystalline metamorphic complexes. The rocks of this group are highly weathered, jointed and covered by recent valley fills and soil covers at some places (Fig. 2). A wide range of rock types occurs which is found to be experienced by recurring tectonic and magmatic activities in Precambrian period which resulted in complicated structure and geology. The study area composed of many folds, faults, lineaments, shears and joints. The geology of the area is underlined by rocks

Fig. 1 Location map of the study area

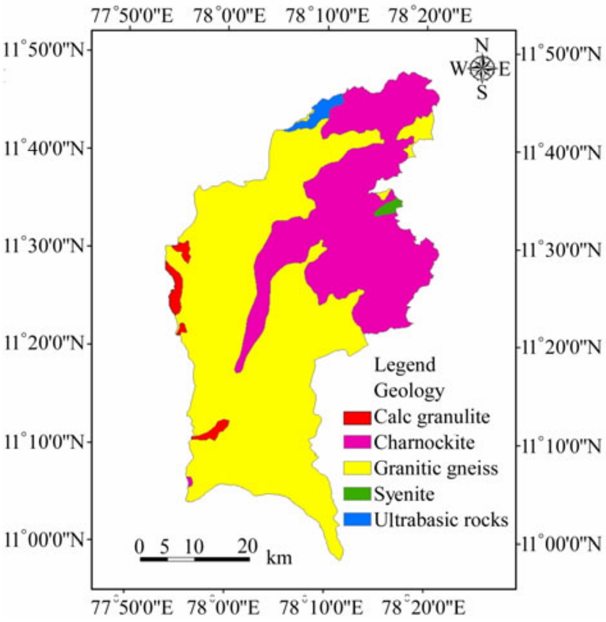

Fig. 2 Geology map of the study area

representing metasediments of Achaean age with Charnockites, granitic gneiss, calc granulites, syenites and ultra basics as major exposures.

1.2 Meteorology and hydrology

The area enjoys sub-tropical climate. The mean temperature varies from 33℃ to 45℃. The study area comes under a rain shadow region with an annual rainfall of about 1590 mm. The area receives major part of rainfall from southwest monsoon (47%), followed by northeast (33%), post monsoon (19%) and summer (1%).[18] The mean annual temperature for the study area is 27.8℃. Relative humidity is generally higher during June to November. The evaporation varies from 7 mm to 9 mm per day in different months. Thirumanimuttar is a sub basin of Cauvery basin and is ephemeral in nature. Drainage pattern is dentritic to sub-dentritic.

The occurrence and movement of groundwater in hard rock areas mainly controlled by the secondary porosity and groundwater occur under water table to semi confined conditions. Groundwater generally occurs in weathered portions of the rocks along joints and fractures. The occurrence and movement of groundwater in the study area are restricted to an open system of fractures like fissures and joints in unweathered portion and also the porous zones of weathered formations. The weathered layer in gneissic terrain of the study area varies from 2.2 to 50 m. In Charnockite, thickness was ranging between 5.8 and 55m. At contacts of gneiss and Charnockite, thickness ranges between 9.0 and 90.8 m indicating good groundwater potential zones. Groundwater fluctuation ranges from 0.2 m to 13.5 m BGL. It reaches the lowest level during summer (March-June), and after that, it starts rising till the end of the monsoon season (August-January). Groundwater flow was noted in the North East direction and, along with downstream flow, is due west to east which generally coincides with the topography of the study area. The study area falls under a semiarid climatic type, and the areas over and adjacent to Shervaroy hills and Kolli hills are of dry to moist sub humid climatic types.

2 Methodology

For the groundwater resource development in an area, the following methodology may be undertaken which integrates remotely sensed data. The survey of India toposheets may be used for the preparation of the base map. The methodology of generation of thematic maps such as lithology, hydro-geomorphology, drainage and lineaments of the study area requires visual interpretation of satellite remote-sensing data. Identification and delineation of various units on the thematic maps are based on the colour, tone, texture, size, pattern and association. Survey of India (SOI) topographic maps (No. 58I/1, 58I/2, 58I/3, 58I/4, 58I/5, 58I/6, 58I/7, 58E/14, 58E/15, 58E/16 of scale 1:50000) were used for the preparation of base maps. Geology, geomorphology, drainage and lineament maps are generated from FCC Image of Landsat 7 TM. Drainage density, lineament density and groundwater prospects maps were prepared by ARC GIS (Version 9.1) software. The methodology adopted is tabulated below (Fig.3).

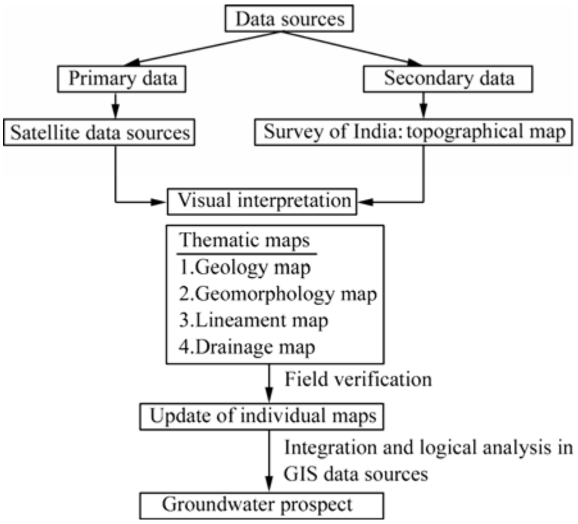

Fig. 3 Flowchart for evaluating groundwater resources by integrated remote sensing and GIS techniques

All the thematic maps are verified through field checks. The thematic details thus finalized are transferred to the base map prepared from the survey of India toposheets. A typical method used in GIS modelling is to compute numerical values for each spatial feature in a theme and classify the numerical values on an interval basis known as Weighted Index Overlay Analysis. This method takes into consideration the relative importance of the parameters and the classes belonging to each parameter. There is no standard scale for a simple weighted overlay method. For this purpose, criteria for the analysis should be defined, and each parameter should be assigned importance.[19] The result of the overlay analysis compared with manual evaluation has been made during the period of the study.

3 Results and discussion

3.1 Hills/denudational hills (DH)

The denudational hills (Fig. 4) mainly consist of highly fractured rocks covered with big pebbles and sparse vegetation occurring superficially due to the accumulation of moisture holding soils.[20, 21] The badland topography of this region is due to the erosion of fine material from the bottom of the denudational hill to the plain region, leaving the rock exposed. This zone has geological potential for groundwater because of occurrence of fractured rocks through which rainwater percolates and groundwater is recharged. But the groundwater flows away towards the adjacent plains. Therefore, groundwater prospecting is less feasible than in the surrounding plains. Thus, the groundwater potential is moderate to poor.

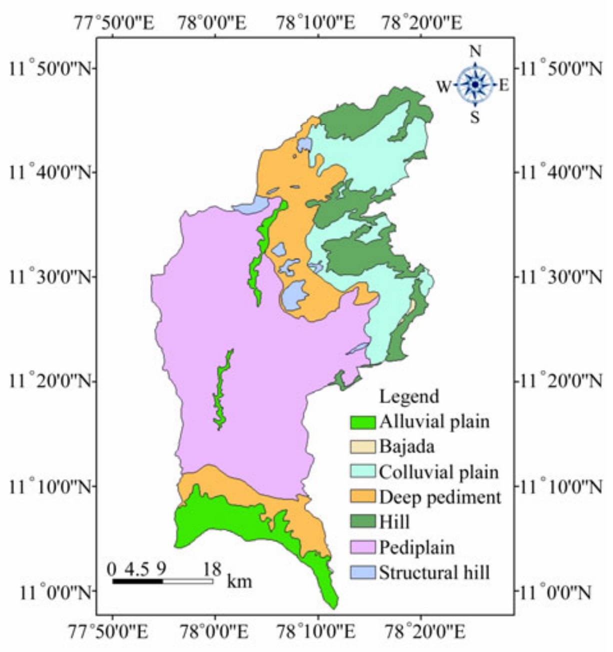

Fig. 4 Geomorphology map of the study area

3.2 Bajadas (B)

Bajada represents geologic conditions that are excellent for obtaining groundwater in large quantities from wells. Water infiltrates readily in the coarse materials at the heads of the fans and moves down the bajada under a hydrostatic head. Bajadas are the main geomorphic units that are present very close to the foot hills of the study area. Generally, the bajada zone is excellent for groundwater targeting especially in the hilly region. Bajadas are located along the Eastern side, and it has occupied a very small portion of the area.

3.3 Deep pediments (DP)

Deep pediments are mainly due to high weathering of the Granitic gneisses under semi-arid climatic conditions. It is characteristically defined as a gently sloping topography; when deep, its infiltration is moderately good. The thickness of the weathered zone varies from 10 m to 20 m and favors a good amount of water to circulate within this zone before reaching the deeper fracture zone. Deep pediments are found as a detached unit throughout the study area. The groundwater potential zone is good to moderately good.

3.4 Structural hills (SH)

Structural hills are the linear or arcuate hills exhibiting definite trend lines and Charnockites and Granitic gneiss formations. These hills are structurally controlled with numerous joints/fractures which facilitate some infiltration and mostly act as run-off zones. The structural trend of the hills ranges in the southwest to northwest direction with slight deviation towards the eastern part of the study area. The slope of the hills ranges from 2° to 4°. The distribution of lineament is comparatively less, and hence, the groundwater availability is moderate to poor.

3.5 Pediplain (P)

Pediplains are developed by continuous processes of pedimentation. Pediplain with meta-sedimentary rock exposures (Granitic Gneiss and Charnockite) is to be found in the central part of the area. This is formed due to intensive weathering of rock materials under semi arid climatic conditions, representing the final stage of the cyclic erosion.[22, 23] In the study area, 48.07% of the area is mainly covered with Pediplain. Groundwater prospect in a pediplain region is good when associated with lineament interaction.[24] Pediplains with lineament interaction have been identified in the centre of the study area.

3.6 Colluvial plain (CP)

Any material that has been transported for short distances from the source essentially by gravity and especially near the foot hills is considered as colluvial or colluvial deposit. CP is composed of sandy, silt and gravel in different proportions. The CP slowly merges with the river built plain, and the zone of contact of the two is often found to be a transitional one. CP is identified in the foot hill area along the north-eastern part of the study area with very high groundwater availability.

3.7 Alluvial plain (AP)

AP is defined as a level plain, gently sloping with slightly undulating land surfaces. It is encompassed of alluvial type of deposits like sand, silt and clay materials. These are the fluvial depositional plains built on either side of a river course due to the shifting of the river course during its long geological history. AP is marked as a zone of good groundwater prospects because of their good recharging capacity. The APs are identified as small pockets along the middle and down course of the study area with invariably good groundwater potential zones.

3.8 Lineaments

A lineament is defined as a large-scale linear feature, which expresses itself in terms of topography of the underlying structural features and relatively straight tonal alignments visible in satellite images. The satellite data of Landsat TM Image of FCC (False color Composites) have been visually interpreted to identify the lineaments of the basin. The data have been checked by field studies, and they act as pathways for groundwater movement in hard rock areas.[25-27] In general, lineaments are considered as good potential zones for groundwater targeting, as they reflect high porosity and hydraulic conductivity of the underlying materials.[14,28,29] Most of the lineaments are confined to the locations where Pediplain, Deep Pediment and Colluvial Plain are exposed. The lineaments trending NNE-SSW, NE-SW, NW-SE and NS are identified in the study area indicating regions of good groundwater availability (Fig. 5).

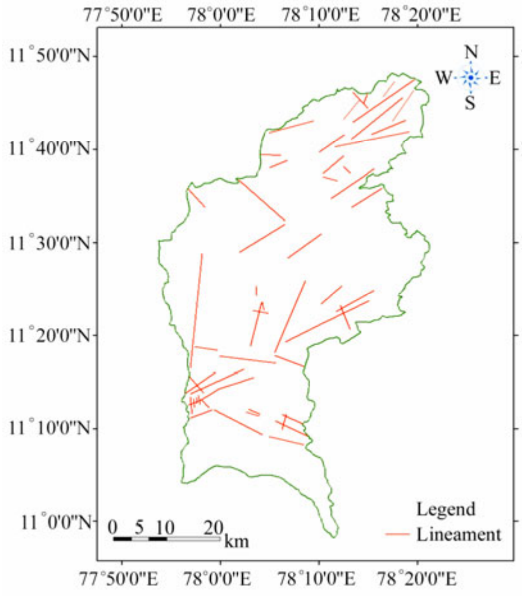

Fig. 5 Lineament map of the study area

3.9 Lineament density

To determine the lineament density in the study area, the total study area is subdivided in a number of grids of dimension 1 km × 1 km. The density of the lineaments of a single grid is obtained from the values of the total length of the lineaments in a single grid (ΣL). Calculation of the density of the lineaments in the area involves the ratio of ΣL to A. By calculating the value of $\Sigma L/A$ for each grid and locating the value at the centre of that grid, the density of the lineaments of the study area is calculated. These values are joined by isolines to prepare a lineament density map using GIS software. High lineament density (Fig. 6) is observed in over the hilly terrain, pediplain and deep pediment and moderate-to-low lineament density over the colluvial plains. This shows that the hills are structurally controlled. Lineament interceptions were observed at a few regions in Pediplain with potential zones for groundwater.

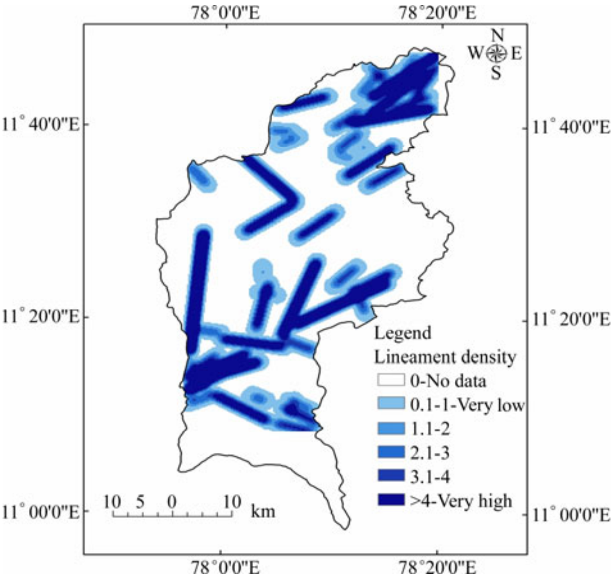

Fig. 6 Lineament density map of the study area

3.10 Drainage

A drainage map is a plan of all streams or river systems in a drainage basin. Drainage analysis involves a detailed examination of the drainage patterns, drainage texture and stream patterns. The drainage pattern map has been prepared from a survey of India toposheets. The drainage type is mainly dentritic, and a few locations have the trellis type. It is also observed that, in almost all watersheds, new drainages have come up, and a stream has changed its course in the southern side of the study area. Stream orders are classified on the basis of its origin.[11,30] The main stream has the highest order from river-mouth to the head of a stream, and the largest tributary has lower stream order by 1 than the stream. Generally, stream order increases, the numbers and the mean gradient of streams decrease in an inverse geometric ratio and the mean length of streams and the mean area of drainage basin increase. The study area streams have the shortest, and the steepest streams have the smallest drainage basins. A first-order stream network was observed in the majority of the area (Fig. 7).

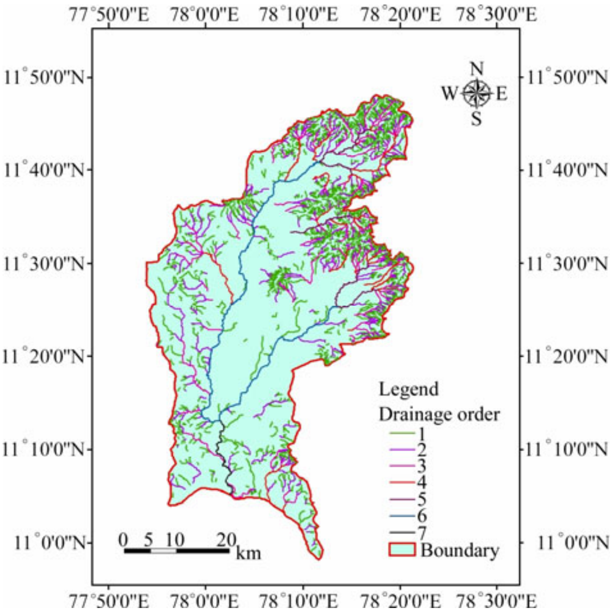

Fig. 7 Drainage map of the study area

A hilly terrain with closeness in the drainage pattern is proved as zones of poor groundwater potential, as a major part of the water poured over them during rainfall is lost as surface runoff with little infiltration. On the contrary, a low drainage density area permits more infiltration with greater potential for groundwater. The structural analysis of a drainage network helps to assess the characteristics of the groundwater recharge zone. Drainage is noted more in the hilly regions when compared with the rest of the area, indicating poor groundwater potentials. But along the northern side of the area lineaments are more, indicating favorable locations for groundwater potential zones.

3.11 Drainage density (DD)

It is noted as one of the prime indicators for the location of groundwater potential zones in hard rock terrains like the study area. It is also an indirect measure of porosity and permeability of a terrain. DD is defined by the total length of the streams in a given drainage basin, divided by the total area, indicating an expression of the closeness of spacing of channels. DD provides a quantitative analysis of the average length of stream channels stretching the entire part of the basin. The DD values were grouped into eight categories with value ranges from 0 to 550 (Fig. 8). Higher values are confined to the hilly terrains with low groundwater availability; the higher value is noted from the hilly terrain. Hence, in this region, groundwater availability may be very low.

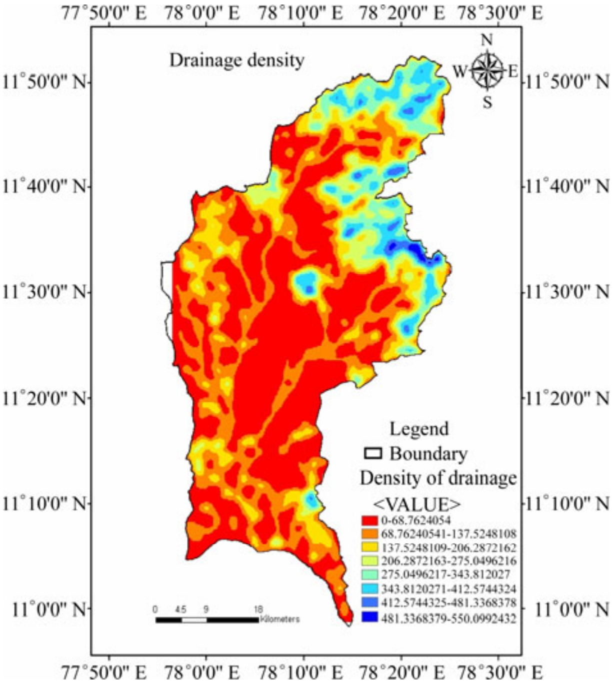

Fig. 8 Drainage density map of the study area

3.12 Slope

Slope is also a crucial parameter for occurrence and recharging conditions of groundwater in a particular area. The slope is measured in degrees[31]. A layout grid of 2 cm has been prepared and overlaid on the topographic map, and the average slopes have been delineated. General slope track is NE-SW direction of the study area (Fig. 9).

The identified slope categories vary from 1° to more than 85° in the study area (Table 1). Slope degree has been classified on the basis of water availability in the study area.[21] On the basis of the above classification, 0° to 1° and 1° to 3° are observed along the river flow direction. 5° to 10° degrees is noted in upstream and middle of the basin which indicates good potential is present in the area. A high degree (>35°) is confined to the hilly region which, in turn, indicates that groundwater availability is poor to nil.

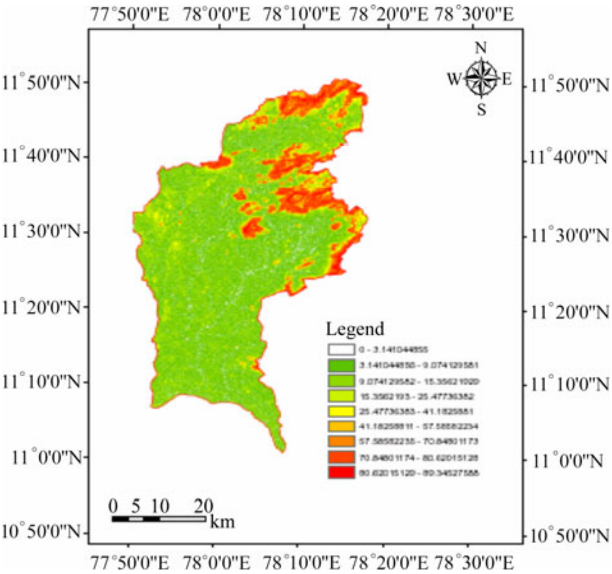

Fig. 9 Slope map of the study area

Table 1 Classification of slope degree on the basis of groundwater availability

Slope degree in range	Category
0°-1°	Excellent
1°-5°	Very good
5°-10°	Very good
10°-15°	Good - moderate
15°-35°	Moderate to poor
> 35°	Poor to nil

Table 2 Different hydrogeomorphological units, their characteristic and groundwater potentiality

Hydrogeomorphic units	Area (km^2)	Description symbol	Soils	Drainage	Lineament	Groundwater availability
Alluvial plain	184.85 (7.58%)	Level plain, gently sloping with slightly undulating land surfaces.	Gravel, sand, silt and clay materials.	Medium	Nil	Very high to high
Bazadas	2.69 (0.11%)	It is formed by series of stream deposition along the foot hill.	Thin layer of soil and gravel	Medium	Nil	High to low
Colluvial plain	354.8 (14.55%)	Any material that has been transported for short distances from the source essentially by gravity and especially near the foot hills is considered as Colluvial deposit.	Sandy-silty-gravel in different proportions	Medium to Poor	High	Medium to high
Deep pediment	394 (16.16%)	Gently sloping topography; very deep	Sand, sandy silt and clay	Moderate to good	High	Very low to medium
Denudational hills	267.73 (10.96%)	Fractured rocks covered with big pebbles	Sand, silt, clay and Hill soils	Good	Low to High	Moderate to poor
Pediplain	1,172 (48.07%)	Moderately sloping plain with <10m thickness of weathered zone	Shallow weathered Granitic and Charnockite	Medium	High	Medium to high
Structural hill	61.93 (2.57%)	The linear or arcuate hills exhibiting definite trend lines and Charnockites, Granitic gneiss formations.	Hill soils	Very good	Low	Low to very low

4 Generation of groundwater prospect map

Finally, the groundwater prospect maps (Fig. 10) have been prepared by integrating information from all the thematic maps like geomorphology, lineament and LD, drainage, DD and slope. In this method, the total weights of the integrated polygons that were ultimately formed were derived as a sum or product of the weight that had been assigned to the different layers according to their groundwater suitability.[32-34] Then the polygons of the final integrated layer were reclassified as very high, high, medium, low and very low/not suitable based on the weight ranges obtained from logical conditions that had been established. Very high and high zones are observed in regions of colluvial plains, high drainage density, lineament density and along the lineament interaction indicating the availability of water in the subsurface. Medium zones are confined to 70% of the study area with low drainage density and with meager or absence of lineaments. Low and very low zones are confined to the hilly regions, scarp slopes, pediments, pediplains and structural hills which do not favor much infiltration and with less groundwater availability.

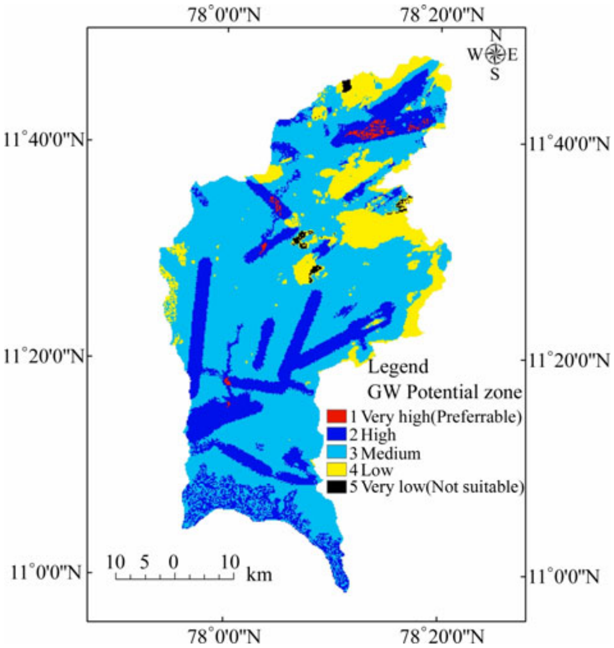

Fig. 10 Groundwater prospects map of the study area

5 Conclusion

Mapping of groundwater resources has been increasingly implemented in recent years because of increased demand for water. The importance of the study is, instead of taking only one characteristic to identify potential groundwater zones, integrating the thematic maps prepared from conventional and remote sensing using GIS gives more and accurate results. Presence of colluvial plain, high drainage density and interaction of lineaments were identified as prospective zones for groundwater exploration and development in the study area. The presence of intersecting lineaments in the area enhances the potential of groundwater.

Acknowledgements

The authors express great gratitude to UGC. The authors wish to express thanks to Mr. B. Poovalinga Ganeshfor the preparation of maps. Many thanks for the Annamalai University for offering support during the hydrogeological measurements.

References

[1] Chatterjee R S, Bhattacharya A K (1995) Delineation of the drainage pattern of a coal basin related inference using satellite remote sensing techniques[J]. *Asia Pacific Remote Sens.*, 1:107-114

[2] Horton R E (1945) Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology[J]. *Geol. Soc, Am, Bull.*, 56: 275-370

[3] Ravindran K V, Jeyaram A (1997) Groundwater prospects of Shahbad Tehsil, Baran district, eastern Rajasthan: a remote sensing approach[J]. *J. Ind. Soc. Remote Sens.,* 25(4): 239-246

[4] Sridevi P D, Srinivasalu S, Kesava Raju K (2001) Hydrogeomorphological and groundwater prospects of the pageru river basin by using remote sensing data[J]. *Environ. Geol.,* 40:1088-1094

[5] Sharma D, Jugran D K (1992) Hydrogeomorphological studies around Pinjaur-Morni-Kala Amb area, Ambala district (Hariyana) and Sirmour district (Himachala Pradesh)[J]. *J. Ind. Soc. Remote Sens*., 20(4): 187-197

[6] Saraf A K (1999) A report on Landuse modeling in GIS for Bankura District[R]. DST, NRDMS

[7] Kumar, Ashok, Srivastava S K (1991) Geomorphological unit, their geohydrological characteristics and vertical electrical sounding response near Munger, Bihar[J]. *J. Ind. Soc. Remote Sens*., 19(4): 205-215

[8] Dubey N, Trivedi R K (1994) Application of LANDSAT TM imagery and aerial photographs for evaluating the hydrogeological conditions around Damoh M.P. [J]. *Bhujal News Faridabad* ,9(2):1-4

[9] Ganapuram S, Vijaya Kumar G T, Murali Krishna I V, et al. (2009) Mapping of groundwater potential zones in the musi basin using remote sensing data and GIS[J]. *Advan. Eng. Soft.,* 40: 506- 518

[10] Jain P K (1998) Remote sensing techniques to locate ground water potential zones in upper Urmil river basin, district Chatarpur-central India[J]. *J. Ind. Soc. Remote Sens*., 26(3): 135-147

[11] Gustafsson P, Pasadena C A (1993) High resolution satellite data and GIS as a tool for assessment of groundwater potential of semi arid area[C]. IXth Thematic Conference on Geologic Remote Sensing, 1: 609-619

[12] Krishnamurthy J, Venkatesa Kumar N, Jayaraman V, et al.

(1996) An approach to demarcate groundwater potential zones through remote sensing and geographic information system[J]. *Inter. J. Remote Sens.*, 17: 1867-1884. DOI: 10.1080/ 01431169608948744

[13] Ravi Shankar M N, Mohan G A (2005) GIS based hydrogeomorphic approach for identification of site-specific artificial-recharge techniques in the Deccan Volcanic province[J]. *J. Earth Sys. Sci.*, 114(5): 505-514

[14] Sahai B (1993) Remote sensing of deserts, the Indian experience[J]. *J. Arid Environ.*, 25(1): 173-185

[15] Millington A C, Townshed J R G (1986) The potential of satellite remote sensing for geomorphological investigations–an overview[M]. Inter. Geomor, V.Gardiner (part ii. Eds.) Hoboken, New Jersey :John Wiley & Sons

[16] Prithvi Raju K N, Vaidyanadhan R(1984) Photohydrogeomorphology of the Sarada river basin in Visakhapatnam District[J]. *Asso. Explor. Geophy.*, 4(3): 31-39

[17] Vasanthavigar M, Srinivasamoorthy K, Vijayaragavan K, et al. (2009) Hydrogeochemistry of Thirumanimuttar Basin: An Indication of weathering and anthropogenic impact[J]. *International Journal of Environmental Research*,3(4): 617-628

[18] Vasanthavigar M, Srinivasamoorthy K, Vijayaragavan K, et al. (2010) Application of water quality index for groundwater quality assessment: Thirumanimuttar sub-basin, Tamilnadu[J].*India Environmental Monitoring Assessment*. DOI: 10.1007/s10661- 009- 1302-1

[19] Saraf A K, Chowdhury P R (1998) Integrated remote sensing and GIS for groundwater exploration and identification of artificial recharge sites[J]. *Inter. J. Remote Sens.*, 19(10): 1825-1841

[20] Jagadeeswara Rao P, Harikrishna P, Suryaprakasa Rao B (2004) An integrated study on ground water resource of pedda gedda watershed[J]. *J. Ind. Soc. Remote Sens.*, 32(3):307-311

[21] Murthy K S R, Amminedu E, Venkateswara Rao V (2003) Integration of thematic maps through GIS for identification of groundwater potential zones[J]. *J. Ind. Soc. Remote Sens.*, 31(3): 197-210

[22] Knig L C (1950) The study of the world plain lands. A new approach in geomorphology[J]. *Quat. Geol. Soc. Lon.*, 106: 101-103

[23] Sparks B W (1960) Landforms in arid and semi-arid climates[M]. Geomorphology, London:longman Group Ltd

[24] Prakash S, Ravi Mishra D (1993) Identification of groundwater prospectives zones by using remote sensing and geoelectrical methods in and around saidnagar area, Daker block, Jalaum District, U.P[J]. *J. Ind. Soc. Remote Sens.*, 21(4): 217-227

[25] Das D (1996) Environmental appraisal for water resource development proceedings[C]. Inter. Confer. on Disaster Man. (icodim) Guwahati, India

[26] Das D (1990) Satellite remote sensing in subsurface water targeting[C]. Proceeding ACSM-ASPRS Annual Convention, Denver

[27] Sankar K (2002). Evaluation of groundwater potential zones using remote sensing data in upper vaigai river basin, Tamil Nadu, India[J]. *J. Ind. Soc. Remote Sens.*, 30(3): 119-129

[28] Sahai B, Bhattacharya A, Hedge V S (1991) IRS-1b application for groundwater targeting[J]. *Curr. sci.,* 61(3&4): 172-179

[29] Subba Rao N, Prathap Reddy R (1999) Groundwater prospects in a developing satellite township of Andhra Pradesh, India using remote sensing techniques[J]. *J. Ind. Soc. Remote Sens.*, 27(4): 193-203

[30] Strahler A N (1957) Quantitative analysis of watershed geomorphology[J]. *Trans. Am. Geophy. Uni.,* 38:913-920

[31] Wentworth C K (1930) A simplified method of determining the average slope of land surfaces[J]. *Am. J. sci.*, 5(20): 184-194

[32] Dipankar saha Y R, Dhar Vittala S S (2009) Delineation of groundwater development potential zones in parts of marginal Ganga alluvial plain in south Bihar, eastern India[J]. *Environ. Monitor. Assess.* DOI: 10.1007/s10661-009-0937-2

[33] Srinivasa rao Y, Jugran K D (2003) Delineation of groundwater potential zones and zones of groundwater quality suitable for domestic purposes using remote sensing and GIS[J]. *Hydrol. Sci. J.*, 48: 821-833

[34] Prasad R K, Mondal N C, Pallavi Banerjee, et al. (2008) Deciphering potential groundwater zone in hard rock through the application of GIS[J]. *Environ. Geol.*, 55: 467-475. DOI: 10.1007/s 00254-007-0992-3