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Mapping of groundwater potential zones in Sarabanga Sub-basin, Cauvery River, South India using remote sensing and GIS techniques

KEYWORDS Groundwater potential zones, Remote sensing and GIS, Drainage density, Lineament density, Geomorphology, Geology, Land use, Sarabanga sub-basin.

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ABSTRACT *This study proposes to introduce the remote sensing and GIS Techniques in the augmentation of groundwater. Remote sensing and GIS techniques are used to map the groundwater potential zones in Sarabanga sub-basin, Cauvery River, Tamil Nadu, India. Fissile hornblende biotite gneiss and Charnockites are the major rock types in this region. Dunites and peridodites are the ultramafic rocks which cut across the foliation planes of the gneisses and are highly weathered. The thickness of weathered zone varies from 2.2 to 50 m in gneissic formation and 5.8 to 55 m in charnockite. At the contacts of gneiss and charnockite, the thickness ranges from 9.0 to 90.8 m favouring good groundwater potential. Therefore it is essential to map the groundwater potential zones for proper management of the aquifer system. Satellite imageries are also used to extract lineaments, hydrogeomorphic landforms, drainage patterns and land use, which are the major controlling factors for the occurrence of groundwater. Various thematic layers pertaining to groundwater existence such as geology, geomorphology, land use / land cover, lineament, lineament density, drainage, drainage density are generated using GIS tools. By integrating all the above thematic layers based on the ranks and weightages, eventually groundwater potential zones are demarcated.*

INTRODUCTION

Remote sensing techniques and Geographic Information System (GIS) have opened new paths in groundwater studies (Krishnamurthy et al. 2000). Remote sensing with its advantages of spatial, spectral and temporal availability of data covering large and inaccessible areas within short time has become a very useful tool in collecting, storing, transforming, retrieving, displaying and analyzing spatial data and is used for various purposes such as feasibility of recharge sites, evaluation of ground and surface water resources, identifying contaminated sites etc. Satellite imageries provide quick and useful baseline information on the parameters like lineaments, geology, geomorphology, drainage, land use/land cover etc (Saraf and Choudhuray 1998). Remote sensing and GIS techniques have successfully applied for groundwater prospecting and recharge sites (Goyal et al. 2010 and Karanth 1987) and integrated remote sensing and GIS techniques have been used to delineate groundwater potential zones (Krisnamurthy et al. 1992; Anuradha et al. 2010; Srinivasa Rao et al. 2003 and Balachander et al. 2010). Various thematic maps prepared using remote sensing and GIS techniques have been used by Subramani et al. (2013) for the computation of groundwater resources in Chithar River basin, Tamil Nadu, India. In hard rock terrains, availability of groundwater is of limited extent. Occurrence of groundwater in such rocks is essentially restricted to fractured and weathered horizons (Binay Kumar et al. 2010).

STUDY AREA

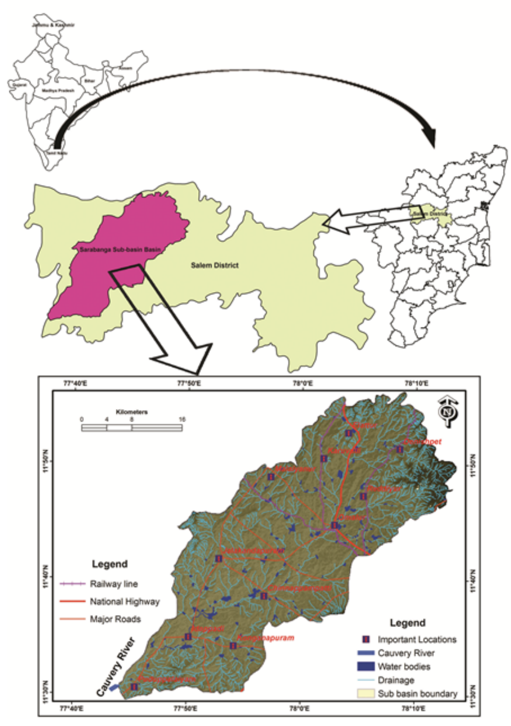

Figure 1: Location map of Sarabanga sub-basin, Cauvery River

The study area lies between the latitudes 11°46' N to 12°09'39" N and longitudes 78°12'27" E to 78°36'65" E covering an area of 1175.44 Km2. Out of which plain land covers an area of 1015.79 km2 (Fig.1). The study area falls in Salem district of Tamil Nadu. The climate of the study area is mainly sub-tropical climate with moderate humidity and temperature. The weather is quite pleasant from No-

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vember to February and becomes hot from March to June. The maximum temperature ranges from 24°C to 40°C and the minimum temperature ranges from 13°C to 28°C with a mean annual rainfall of 852 mm of which nearly 80% is received during the southwest and northeast monsoon period (June–December).The study area is underlain by the Archaean crystalline rocks surrounded by wavy hills and hillocks.

METHODS AND MATERIALS

The groundwater potential zones in the study area has been demarcated by integrating different thematic maps using remote sensing and GIS techniques. Geological map of the area was prepared from Geological Quadrangle Map published by Geological Survey of India (GSI). Other thematic maps such as drainage, drainage density, geomorphology, lineament, lineament density and land use/land cover are prepared from satellite imageries using GIS. By integrating all the thematic layers groundwater potential zonation map was prepared. Integration of various thematic maps are carried out using GIS in three steps such as (i) Spatial data base building (ii) Spatial data analysis and (iii) Data integration (Schot et al. 2009).

Spatial data base building: All the thematic maps are created using GIS software by adopting digitization of scanned maps, editing for errors, topology building, attributes assignment and projection (Sharma et al. 2012).

Spatial data analysis: The groundwater prospect map is prepared by integrating the hydrogeomorphic, lineament and geological maps along with drainage patterns in the area (Mohanty et al. 2010). Each theme is considered and assigned a weightage depending on its degree of influence on groundwater recharge and storage. By combining all these thematic maps and incorporating limited data on groundwater level, groundwater prospect map was prepared. Different geological formations developing a variety of landforms such as structural hill, pediments, buried pediments and valley fills possess different capacity of water holding thereby showing varied aquifer qualities.

Data Integration: Each thematic map such as geology, geomorphology, drainage, drainage density, lineament and land use/land cover provides certain information on groundwater occurrence. Each theme was overlaid on another theme to find the intersecting polygons. By this way a new map was obtained by integrating two thematic maps. Subsequently this composite map was overlaid on a third thematic map, and so on. So that a final composite map was produced. In the final map, weightage to each polygon was assigned using simple arithmetic model and the groundwater potential zones were demarcated and categorized into four zones namely (i) Very good (ii) Good (iii) Moderate and (iv) Poor. The methodology adopted in this study is presented in the Figure 2.

RESULTS AND DISCUSSION

Geology

The geology map was collected from Geological Survey of India (GSI). The map was traced, scanned, digitized and then taken to GIS. In the field, the rock samples were collected and identified to assess the quantity characteristics of groundwater. The sub-basin lies mainly over the Archaean crystallines rocks (Fig. 3 and Table 1), and the groundwater occur under pharetic conditions in the weathered and fractured zones of the hard-rock aquifers. The area is made up of high-grade supracrustals of Archaean age, comprising Charnockite group, Satyamangalam group, Younger intrusive alkaline and Syenite complex, ultramafics, basic and acid rocks. The Charnockite group occupying the northern part of the study area. Shevroy hills is altered to bauxite and laterite. The rocks of Satyamangalam group comprising fuchsite quartzite and amphibolite occur in a linear zone surrounding the Chalk hills. The litho unites occur as dismembered lensoids in the fissile hornblende gneiss, known as Bhavani gneiss and in the granite. The study area is endowed with economically exploitable deposits of iron ore, tin, mica, limestone, magnesite, talk/steatite, bauxite, and feldspar.

Magnesite: Essentially in Chalk hills.

Iron Ore: It occurs as bands of magnetite quartzite near Kanjamalai.

Bauxite: It is found capping the Shervaroy hills.

Mica: Large books of mica extracted from the pegmatite veins in Kullampatti area.

Quartz and feldspar: The pegmatites occurring in Jalakandapuram-Idappadi contain ceramic grade quartz and feldspar which are extracted for use in the ceramic industries.

The Fissile hornblende Biotite gneiss vein (727.87 km2) occupies in more or less the entire portion of the sub-basin followed by Charnockite (277.04 km2) this type of rock occurs in northeastern part of the study area, Granite (104.75 km2) and Syenite (39.39 km2) occupied in many patches in and around Jalakandapuram. The development of drainage networks mainly depends on the underlying geology, precipitation, exogenic and endogenic processes of the area. The drainage pattern of the basin ranges from dendritic to sub-dendritic at higher elevations and parallel to sub parallel in the lower elevations. A radial drainage pattern was also observed in the areas with isolated hillocks. Based on the drainage orders, the Sarabanga river basin has been classified as sixth order river basin.

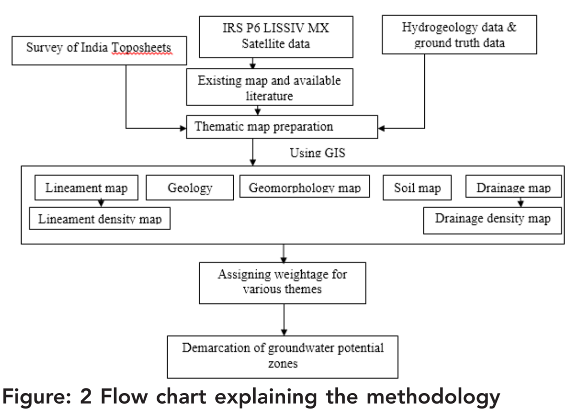

Figure: 2 Flow chart explaining the methodology

TABLE-1

SPATIAL DISTRIBUTION RESULT OF GEOLOGY		
Sl.No.	Class	Area in Km2
1	Amphibolite	1.48
2	Charnockite	277.04
3	Dunite	14.88
4	Fissile hornblende biotite gneiss	727.87
5	Fuchsite Quartzite	2.88
6	Granite	104.75
7	Laterite	2.71
8	Pegmatite	3.22
9	Peridotite	1.21
10	Syenite	39.39

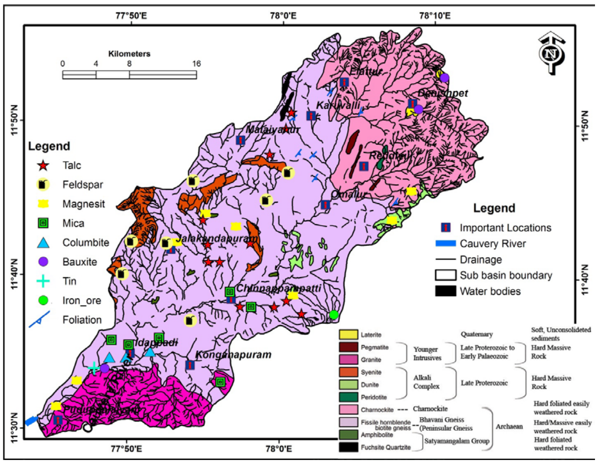

Figure: 3 Geology map of Sarabanga sub-basin, Cauvery River

TABLE-2
SPATIAL DISTRIBUTION RESULT OF DRAINAGE DENSITY

Sl.No.	Drainage density zones (m/km)	Area in km²
1	Very low drainage density (< 1000 m/Sq.km)	320.97
2	Low drainage density (1000 to 3000 m/Sq.km)	775.76
3	Moderate drainage density (3000 to 5000 m/Sq.km)	43.07
4	High drainage density (5000 to 7000 m/Sq.km)	25.84
5	Very high drainage density (> 7000 m/Sq.km)	9.75
	Total	**1175.44**

TABLE-3
AREA STATISTICS OF GEOMORPHOLOGICAL UNITS

Sl.No.	Class	Area in Km²	Area in %
1	Denudational hills	25.56	2.17
2	Structural hills	1012.69	86.15
3	Pediplain	137.18	11.67

Drainage

Sub-surface hydrological condition of any area is controlled by the drainage characteristics of the basin that leads to decipher the groundwater condition. The drainage density can indirectly indicate the groundwater potential of an area due to its relation to surface runoff and permeability (Pradhan 2009). The drainage map of the study area along with different tributaries was prepared from the SOI topographical maps on 1:50,000 scale and updated using the satellite imageries. Dendritic pattern is generally observed in the study area (Figure 4). It is influenced by factors like initial slope, differences in rock resistance, structural controls, and morphological history of the basin (Sharma et al. 2012). Drainage pattern is most helpful in interpreting the geomorphic features and tracing the evolution of landforms. The map was further used for the preparation of drainage density map (Figure 5). Drainage density was measured and ranged as <2000, 2000-4000, 4000-6000, 6000-8000, 8000-10000, 10000-12000 and >12000 m/km (Table 2). The zones of high drainage density will have poor groundwater prospects and gradually the zones of lower and lower drainage density zones will have better groundwater prospects (Balachandar et al. 2010). An area of high drainage density also increases surface runoff compared to a low drainage density area (Biswas Arkoprovo et al. 2012). The lower drainage density zones in the area indicate relatively higher permeability and the presence of more fractured rock.

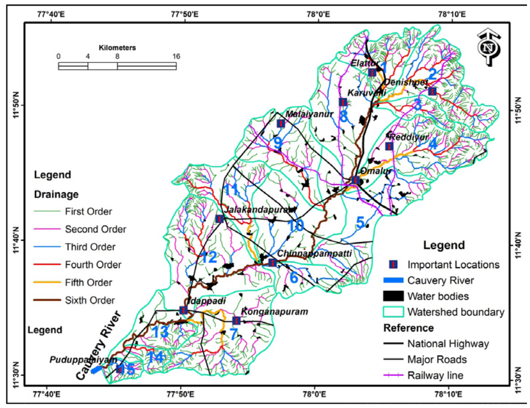

Figure: 4 Drainage map of Sarabanga sub-basin, Cauvery River

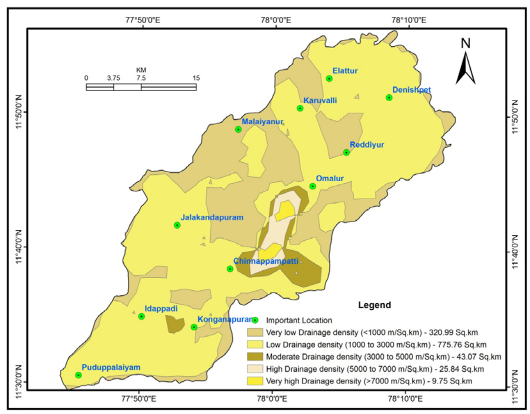

Figure: 5 Drainage density map of Sarabanga sub-basin, Cauvery River

Hydrogeomorphology

Geomorphological map (Figure 6) is generally used to identify the various geomorphological units and the scope of the groundwater occurrence in each unit (Biswajeet Pradhan 2009). Hydrogeomorphological study shows that there is a close relationship between the hydrogeomorphic units and groundwater resources (Subba Rao 2003). A systematic study of various landforms and geomorphic units helps to demarcate the potential zones of groundwater in the study area. Geomorphological units are extremely helpful for selecting groundwater potential zones and artificial recharge sites (Elango et al. 2003). The prominent geomorphic units identified in the study area through interpretation of satellite imageries are denudational hills, structural hills pediplain (Table 3). The aerial extent of various geomorphological units of the study area is presented in Table 4. These landforms act as groundwater storage reservoirs and some of them act as recharge and run-off zones (Jagannadha Rao et al. 2003, Madan K Jha 2007). The occurrence and movement of groundwater in the study area are restricted to open system of fractures like fissures and joints in un weathered portion and also the porous zones of weathered formations (Amaresh Singh et al. 2004).

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TABLE-4
AREA STATISTICS OF LINEAMENT DENSITY

Sl.No.	Lineament density (m/km)	Area in km^2
1	Very low lineament density (< 3000 m/Sq.km)	458.38
2	Low lineament density (3000 to 6000 m/Sq.km)	483.74
3	Moderate lineament density (6000 to 9000 m/Sq.km)	144.71
4	High lineament density (9000 to 12000 m/Sq.km)	49.86
5	Very high lineament density (> 12000 m/Sq.km)	38.74
	Total	1175.44

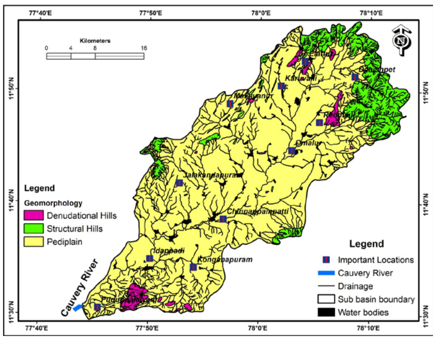

Figure: 6 Geomorphological map of Sarabanga sub-basin, Cauvery River

Lineaments

Lineaments are the weaker zones of bed rock which are formed due to the movement of the earth intersection of lineaments are considered as good occurrence of groundwater potential zones (Rao et al. 2003). Lineaments occur as linear, curvilinear and rectilinear lines in satellite imageries. Salem city and its vicinity fall within the NE–SW trending numerous lineaments in the study area identified from the satellite imagery are illustrated in the Figure 7. These extend over a length of less than 1 km to more than 5 km. Most of the lineaments trend in the direction of NNE-SSW to ENE–WSW with medium to steep reversal of dips from SW to NE indicating a series of tightly packed antiform and synforms. These lineaments were classified into two groups, major and minor lineaments depending on the nature and aerial extent. Keeping the lineament map as the base map, a lineament density map (Figure 8 and Table 4) was prepared (Balachander et al. 2010) using GIS. It was observed in the field that water level fluctuations were low in the regions having higher lineament density.

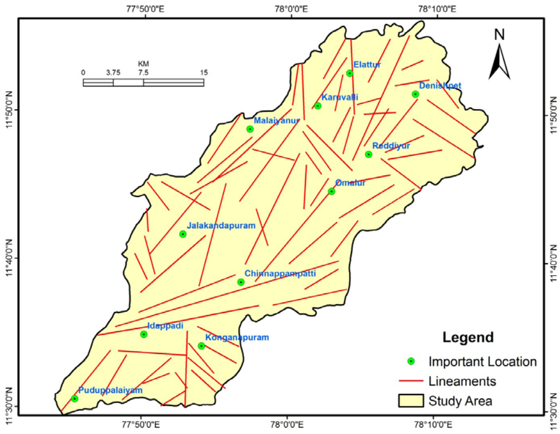

Figure: 7 Lineament map of Sarabanga sub-basin, Cauvery River

Slope

The slope map of the study area has been prepared by adopting the widely used Wentworth's average slope method. The various slope classes and their spatial distribution are shown in the Figure 9. The slope degree of the area is given in the Table 5. Less degree of slope is considered as favourable for groundwater possible and recharge zone. For the construction of check dam, below 15° of slope is considered as favourable zones.

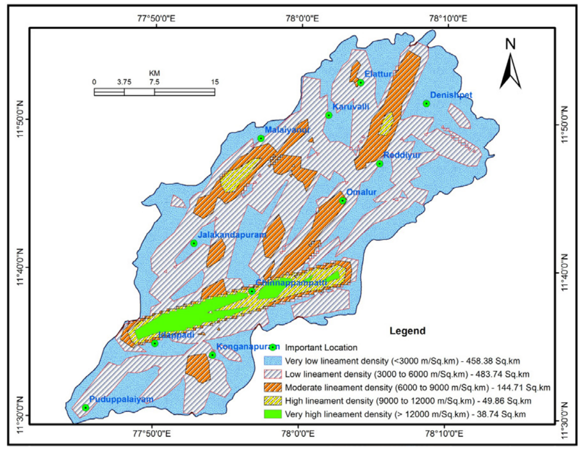

Figure: 8 Lineament density map of Sarabanga sub-basin, Cauvery River

Slope map shows that the major portion of the study area fell along gentle slope (< 10°). South-eastern parts of the study area have very steep slope (> 30°) to steep slope (15° to 30°), whereas the other areas have nearly level topography. Less than 5° is highly suitable for construction of artificial recharge structures.

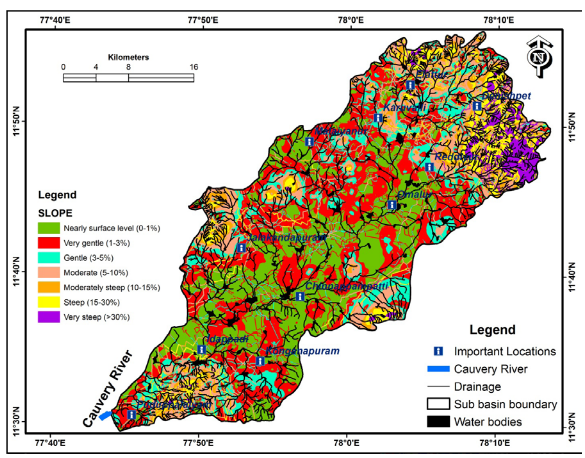

Figure: 9 Slope Map of Sarabanga sub-basin, Cauvery River

TABLE-5
AREA STATISTICS OF SLOPE

Sl.No.	Class	Area in Km^2	Area in %
1	Nearly surface level (0-1%)	342.83	29.17
2	Very gentle (1-3%)	361.25	30.73
3	Gentle (3-5%)	148.86	12.66
4	Moderate (5-10%)	149.56	12.72
5	Moderately steep (10-15%)	63.92	5.44
6	Steep (15-30%)	74.75	6.36
7	Very steep (>30%)	34.26	2.91
Total Area		**1175.44**	**100**

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Weighted Index Overlay Analysis

The identification of groundwater potential zones involves an integrated approach taking into account on various parameters like geology, geomorphology, drainage density, lineament density and slope (Mamadou Samake et al. 2011). By using remote sensing and GIS techniques, thematic data has been integrated for evaluation of groundwater potential zones of the study area. The groundwater prospect map is also prepared by integrating the geological map, hydrogeomorphic map, slope, lineament density map, and drainage density map of the areas with limited information on groundwater level. Different geological features in a variety of landforms such as structural hill, Denudational hills and pediplain bear different capacities to hold water thereby showing varied aquifer qualities. Weighted index overlay analysis (WIOA) is a simple and straightforward method for a combined analysis of multiclass maps. The advantage of this method is that the human judgment can be integrated with this analysis. A weight represents the relative importance of a parameter and the objective. There is no standard scale for a simple weighted overlay method. For this purpose, criteria for the analysis are defined and each parameter is given its due importance (Saraf and Choudhury 1998). Thematic maps on geology, geomorphology, lineament density, slope and drainage density provide valuable information on the occurrence of groundwater. In order to get all these information unified, it is necessary to integrate these data with proper factor and it is also possible to superimpose this information manually (Horton 1945). Therefore, numerically this information is integrated through the application of GIS. Various thematic maps are reclassified on the basis of weightage assigned.

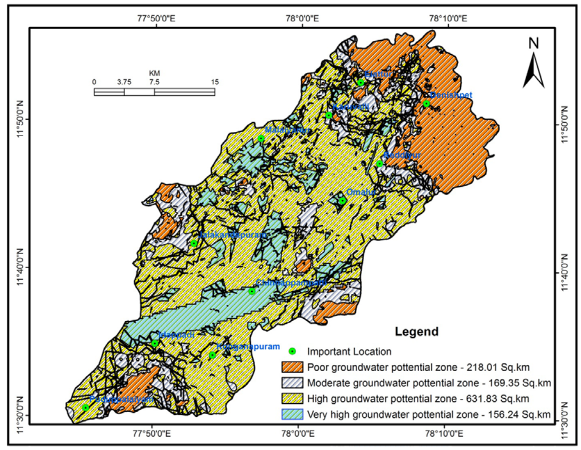

Fig. 10 Groundwater prospect map of Sarabanga sub-basin, Cauvery River

Depending on the groundwater potentiality, each theme geomorphology, lineament density, geology, slope and drainage density are qualitatively placed into the following categories viz., (i) Very good (ii) Good (iii) Moderate and (iv) Poor. Suitable weightage on a scale of 'Six' was given to each class of a particular thematic layer based on their contribution towards groundwater potentiality.

TABLE-6

RANK, WEIGHT AND SCORES FOR VARIOUS CATEGORIES OF GEOLOGY, GEOMORPHOLOGY, LINEAMENT DENSITY, DRAINAGE DENSITY AND SLOPE WITH RESPECT TO GROUNDWATER PROSPECT

Geomorphology		Lineament density		Geology		Drainage density	Slope		
Weight # 35	Rank	Weight # 30	Rank	Weight #15	Rank	Weight # 10	Rank	Weight # 10	Rank
Denudational hills	1	Very low lineament density (< 3000 m/Sq.km)	1	Amphibolite	2	Very low drainage density (< 1000 m/Sq.km)	5	Nearly surface level (0-1%)	7
Structural hills	1	Low lineament density (3000 to 6000 m/Sq.km)	2	Charnockite	1	Low drainage density (1000 to 3000 m/Sq.km)	4	Very gentle (1-3%)	6
Pediplain	4	Moderate lineament density (6000 to 9000 m/Sq.km)	3	Dunite	2	Moderate drainage density (3000 to 5000 m/Sq.km)	3	Gentle (3-5%)	5
		High lineament density (9000 to 12000 m/Sq.km)	4	Fissile hornblende biotite gneiss	2	High drainage density (5000 to 7000 m/Sq.km)	2	Moderate (5-10%)	4
		Very high lineament density (> 12000 m/Sq.km)	5	Fuchsite Quartzite	3	Very high drainage density (> 7000 m/Sq.km)	1	Moderately steep (10-15%)	3
				Granite	2			Steep (15-30%)	2
				Laterite	3			Very steep (>30%)	1
				Pegmatite	5				
				Peridotite	2				
				Syenite	3				

All the thematic maps were then registered with one another through ground control points and integrated (Vasanthakumaran et al. 2002) by normalized aggregation method in GIS for computing groundwater potential index of each feature. The weight and rank assigned to different classes of all the themes are presented in Table 10. The groundwater conditions in crystalline hard rock terrain are multivariate due to the heterogeneous nature of the rock formations displaying varying composition, compaction and degree of weathering.

Final integration output map (Groundwater potential map) Figure 10 was prepared based on the above techniques. From that it is observed that the good potential zones possess suitable surface and subsurface conditions such as occurrence of lineaments and permeable formations. Villages falling in various groundwaters potential categories are given in Table 7.

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TABLE-7
RESULT OF FINAL INTEGRATED GROUNDWATER POTENTIAL ZONE

Sl.No.	Class	Area in Km2	Area in %
1	Poor groundwater potential zone	218.01 Sq.km	18.55
2	Moderate groundwater potential zone	169.35 Sq.km	14.41
3	high groundwater potential zone	631.83 Sq.km	53.75
4	Very high groundwater potential zone	156.24 Sq.km	13.29
Total Area		1175.44	100

CONCLUSION

In the present study, qualitative analysis was carried out using map overlaying techniques to demarcate the groundwater potential zones. Integrated remote sensing techniques with GIS has proved an efficient tool to find the groundwater prospects in Sarabanga sub-basin, Cauvery river area, Salem, Tamil Nadu, India. Considering the influence of different geomorphic and lithological units on groundwater regimes, four groundwater prospect zones such as (i) Very good (ii) Good (iii) Moderate and (iv) Poor zones were identified. Very good groundwater potential zones are found in plain areas due to the presence of highly fractured and weathered rocks. It shows that high potential zones occur within very low drainage density. The study concludes that 'High' potential zones (Very Good category) cover an area of 156.24 km2 (13.29% of the study area). 'Good' potential zones occupy 631.83 km2 (53.75% of the study area) which are in and around the plain region. In the plain region, usage of water for irrigation and domestic purposes is nil and recharge from the nallas in this region leads to augment the groundwater resources. 'Moderate' potential zones spread over an area of 169.35 km2 (14.41 %) and fall in the hilly region. 'Poor' groundwater potential zones are confined to mostly the hilly terrain which acts as runoff zone. It occupies an area of 218.01 km2 (18.55 %) of the study area.

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