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RESEARCH ARTICLE

SPATIAL ANALYSIS OF GROUNDWATER POTENTIAL ZONES USING REMOTE SENSING, GIS AND MIF TECHNIQUES IN UPPAR ODAI SUB-WATERSHED, NANDIYAR, CAUVERY BASIN, TAMIL NADU

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ABSTRACT

Groundwater is a natural resource of the earth that sustains and supports domestic, agricultural and industrial activities. Over half of the world's population depends on groundwater for drinking water supplies. Its usage is increasing due to rapid population growth, high rate of urbanization, industrial growth and agricultural utilizations. This has resulted to rapid depletion of groundwater which leads to water stress and degradation of these resources. The situation is further worsened by inadequate information on groundwater resource which has been and is still a big obstacle to the proper management of these resources. Remote sensing and GIS techniques have emerged as very effective and reliable tools in the assessment, monitoring and conservation of groundwater resources. In the present paper, various groundwater potential zones for the assessment of groundwater availability in Uppar odai sub-watershed, Nandiyar, Cauvery Basin, Tamil Nadu have been delineated using remote sensing and GIS techniques. Survey of India toposheets and IRS-1C satellite imageries are used to prepare various thematic layers viz. lithology, slope, landuse/land cover, lineament, drainage, geomorphology, soil, and rainfall were transformed to raster data using feature to raster converter tool in ArcGIS 10.1. The raster maps of these factors are allocated a fixed score and weight computed from multi influencing factor (MIF) technique. Moreover, each weighted thematic layer is statistically computed to get the groundwater potential zones. The groundwater potential zones thus obtained were divided into four categories, viz., excellent, good, moderate and poor zones. The result depicts the groundwater potential zones in the study area and found to be helpful in better planning and management of groundwater resources.

INTRODUCTION

Remote sensing and GIS methods permit rapid and cost effective natural resource survey and management. Moreover, remotely sensed data serve as vital tool in groundwater prospecting (Sharma and Jugran, 1992; Chatterjee and Bhattacharya, 1995; Tiwari and Rai, 1996; Ravindran, 1997; Horton, 1945). The remote sensing data helps in fairly accurate hydrogeomorphological analysis and identification and delineation of land features (Kumar and Srivastava, 1991). With sufficient ground data, hydrological characteristics of geomorphological features can be deciphered. Integration of remote sensing with GIS for preparing various thematic layers, such as lithology, drainage, lineament, geomorphology, rainfall, slope, soil, and landuse/land cover with assigned weightage in a spatial domain will support the identification of potential groundwater zones. Therefore, the present study focuses on the identification of groundwater potential zones in Uppar Odai Sub-Watershed, Nandiyar, Cauvery Basin, Tamil Nadu using the technology of remote sensing and GIS for the planning, utilization, administration, and management of groundwater resources.

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Study area

The study area is centrally located in Tamil Nadu, India. This sub-watershed falls in Perambalur and Tiruchirappalli Districts of Tamil Nadu. This sub-watershed falls in Thuraiyur, Musiri, Manachanallur and Lalgudi taluks of Tiruchirappalli district in the southern part and Alathur, Perambalur taluks of Perambalur district in the northern part of the research area. The sub-watershed lies between 10° 54′ and 11° 15′ North latitudes and 78° 36′ and 78° 49′ East longitudes and it forms a part of the Survey of India (SOI) topographic sheets 58/I-12, 58/I-16, 58/J-9 and 58/J-13 in 1:50,000 scale. The Sub-watershed covers a total geographical area of about 520.38 sq.km. The annual average rainfall in the study area is 823.76mm. The maximum temperature of the study area is 45°C and a minimum temperature is 29°C. The topography of the study area is an undulating plain with irregular charnockitic hillocks and hornblende biotite gneissic rocks. The relief of the area varies between 600 and 400 m above mean sea level (Fig.1)

MATERIALS AND METHODS

The methodology adopted for the present study is shown in Fig. 2. The base map of Uppar odai sub-watershed was prepared based on Survey of India topographic maps (58/I-12, 58/I-16, 58/J-9 and 58/J-13) on a 1:50,000 scale. The drainage network for the study area was scanned from Survey of India (SOI) toposheets and digitized in ArcGIS 10.1 platform. The slope map was prepared from ASTER DEM data in ArcGIS Spatial Analyst module. The rainfall map was prepared using the data obtained from the Indian Meteorological Department (IMD) gauge stations. These data were then spatially interpolated using Inverse Distance Weighted (IDW) method to obtain the rainfall distribution map. The drainage density and lineament density maps were prepared using the line density analysis tool in ArcGIS 10.1software. Satellite images from IRS-1C, LlSS-III sensor, on a scale of 1:50,000 have been used for delineation of thematic layers such as land use / land cover, lithology and lineament. These thematic layers were converted into a raster format (30 m resolution) before they were brought into GIS environment. The groundwater potential zones were obtained by overlaying all the thematic maps in terms of weighted overlay methods using the spatial analysis tool in ArcGIS 10.1software (Shaban *et al*., 2006). During weighted overlay analysis, the ranking was given for each individual parameter of each thematic map, and weights were assigned according to the multi influencing factor (MIF) of that particular feature on the hydro-geological environment of the study area.

Multi influencing factors of groundwater potential zones

Eight influencing factors, such as lithology, slope, landuse/land cover, lineament, drainage, geomorphology, soil, and rainfall have been identified to delineate the groundwater potential zones. Interrelationship between these factors and their effect is shown in Fig. 3. Each relationship is weighted according to its strength. The representative weight of a factor of the potential zone is the sum of all weights from each factor. A factor with a higher weight value shows a larger impact and a factor with a lower weight value shows a smaller impact on groundwater potential zones. Integration of these factors with their potential weights is computed through weighted overlay analysis in ArcGIS 10.1 software.

RESULT AND DISCUSSION

Weightage Calculation

The multi influencing factors for groundwater potential zones namely lineaments, drainage, geomorphology, lithology, slope, landuse/land cover, rainfall and soil were examined and assigned an appropriate weight and are shown in Table 1. The effect of each influencing factor may contribute to delineate the groundwater potential zones. Moreover, these factors are interdependent. The effect of each major and minor factor is assigned a weightage of 1.0 and 0.5 respectively (Fig. 3). The cumulative weightage of both major and minor effects are considered for calculating the relative rates (Table 1). This rate is further used to calculate the score of each influencing factor. The proposed score for each influencing factor is calculated by using the formula.

$$(A+B)*100/\sum (A+B)$$

Where,

A is major interrelationship between two factors and
B is minor interrelationship between two factors.

The concerned score for each influencing factor was divided equally and assigned to each reclassified factor (Table 2).

Lithology

Lithology is major factor controlling the quantity and quality of groundwater occurrence in a given area. It is represented by the distribution of different rock units characterizing the area under study. Various lithological units exposed in the area belong to Charnockite Group belonging to Southern Granulite Complex of Archaean age and Peninsular Gneissic Complex – II of Archaean to Palaeoproterozoic age. In general, the hills in the northwest part of the study area are made up of hard resistant rock namely charnockite. Hornblende biotite gneisses are spread almost in central part of the study area (Fig. 4). Around 37 percent of the total area is covered with Hornblende biotite gneisses followed by charnockite.

Landuse / Land Cover

The major land-use types in the study area are agriculture crop land, forest, barren land and settlements. These landuse classes are delineated from IRS-1C, LlSS-III data for the study area. These images were selected for this study because they provided suitable cloud-free spatial coverage with relatively high spatial and spectral resolutions. Around 71percent of the total area is under cultivation, followed by forest, barren land and built up area. (Fig. 5)

Lineament Density

Lineaments are structurally controlled linear or curvilinear features, which are identified from the satellite imagery by their relatively linear alignments. These features express the surface topography of the underlying structural features. Lineaments represent the zones of faulting and fracturing resulting in increased secondary porosity and permeability. These factors are hydro-geologically very important as they provide the path ways for groundwater movement. Lineament density of an area can indirectly reveal the groundwater potential, since the presence of lineaments usually denotes a permeable zone, Areas with high lineament density are good for groundwater potential zones (Haridas *et al*., 1998). The lineament density map of the study area is shown in Fig. 6, and it reveals that high lineament density is observed in the northern part of the study area with a value ranging above 3 km/km^2. The lineaments especially those representing geologically weak zones like fractures, joints, faults and sheer zones are good rechargeable zones. If the density of the lineaments is more, then the possibility for groundwater recharge is more and this characteristic was considered to assign weightage for different lineament density zones of the study area. Areas with highest lineament density (>3 km/km^2)

Table 1. Effect of influencing factor, relative rates and score for each potential factor

Factor	*Major Effects (A)*	*Minor Effect(B)*	*Proposed Relative Rates (A+B)*	*Proposed Score of each influencing factor (A+B)*100/∑(A+B)*
Lineaments	1 (D) + 1 (LULC)	0.5 (Geo)	2.5	12.0
Landuse/Land Cover	1 (D) + 1 (R)	0.5 (Sl) + 0.5 (Geo) + 0.5 (Lin) + 0.5 (Lith)	4.0	20.0
Lithology	1 (D) + 1 (Lin) + 1 (LULC) + 1 (So)	0.5 (Geo)	4.5	22.0
Drainage	1 (LULC)	0.5 (Geo) + 0.5 (So) + 0.5 (Lin)	2.5	12.0
Slope	1 (R) + 1 (D)	0.5 (LULC)	2.5	12.0
Rainfall	1 (D)	0.5 (LULC) + 0.5 (So)	2.0	10.0
Soil	1 (LULC)		1.0	5.0
Geomorphology		0.5 (LULC) + 0.5 (So) + 0.5 (D)	1.5	7.0
			∑= 20.5	∑100

Abbreviations: D-Drainage Density, LULC-Landuse / Land Cover; R-Rainfall, So-Soil, Sl-Slope, Lin-Lineament Density; Lith-Lithology, Geo-Geomorphology

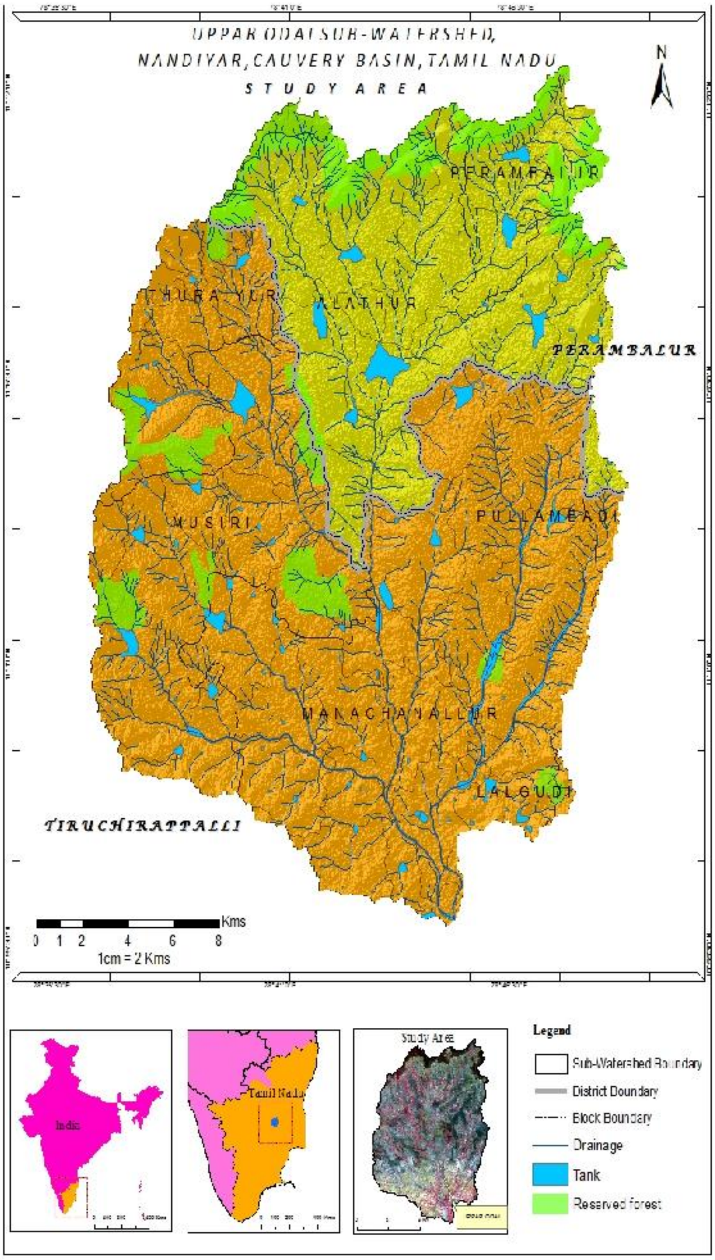

Fig.1. Location of Uppar odai sub-watershed, Nandiyar, Cauvery Basin

Table 2. Classification of weighted factors influencing the potential zones

Factor	*Domain of Effect*	*Weightage*
Landuse/Land Cover	Agriculture, Current shifting cultivation	7
	Agriculture, Fallow	5
	Agriculture, Crop land	7
	Agriculture, Plantation	7
	Barren/Wasteland, Barren rocky	5
	Barren/Wasteland, Salt affected land	5
	Barren/Wasteland, Scrub land	5
	Barren/Wasteland, Gullied/ravenous	5
	Barren/Wasteland, Sandy area	5
	Built up, Mining	2
	Built up, Urban	2
	Forest evergreen/semi evergreen	6
	Forest, Deciduous	6
	Forest, Scrub forest	2
	Forest, Forest plantation	6
	Grass, Grazing	2
	Wetland/Water bodies	7
Lithology	Amphibolite	2
	Banded magnetite quartzite	3
	Biotite gneiss	4
	Calc granulite with limestone	6
	Charnockite	3
	Granite	2
	Gypseous clay	2
	Hornblende-biotite gneiss	4
	Meta pyroxenite	4
	Pegmatite	2
	Pink gneiss	4
	Pyroxene granulite	2
	Quartz vein	2
	Sand stone	6
Soil	Black clayey soil	6
	Clayey soil	7
	Gravelly soil	9
	Loamy soil	5
	Red loam soil	5
Geomorphology	Dome type denudational hills (Large)	2
	Dome type residual hills	2
	Eroded pediplain with shallow basement	8
	Inselberg	2
	Linear ridge / Dyke	2
	Moderately weathered/Moderately buried pediplain	5
	Pediment/Valley floor	4
	Ridge type structural hills (Large)	2
	Shallow weathered/Shallow buried pediplain	8
Lineament Density	< 1	2
	1 – 2	4
	2 – 3	6
	> 3	8
Drainage Density	< 1	2
	1 – 2	4
	2 – 3	6
	> 3	8
Slope gradient	<1	9
	1-3	9
	3-5	9
	5-10	8
	10-15	6
	>15	4
Rainfall	<600	2
	600-700	4
	>700	6

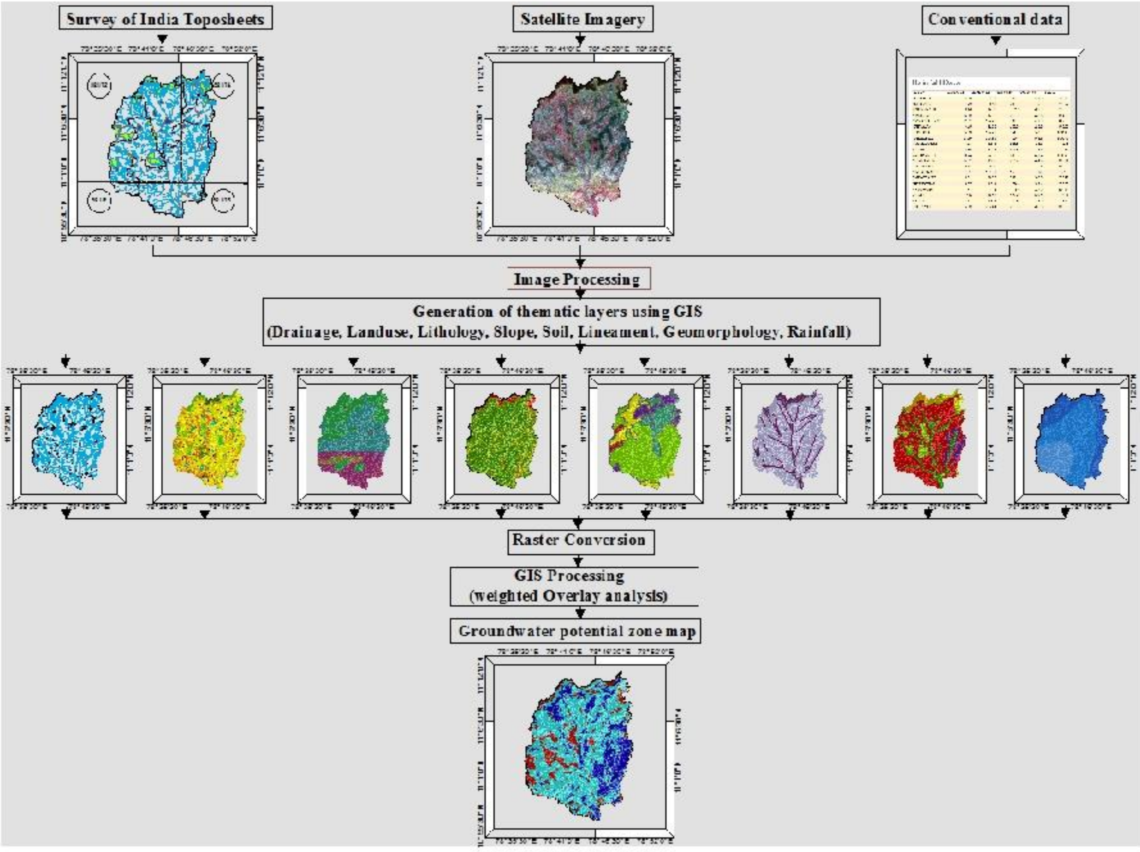

Fig.2. Flowchart for delineating the groundwater potential zone

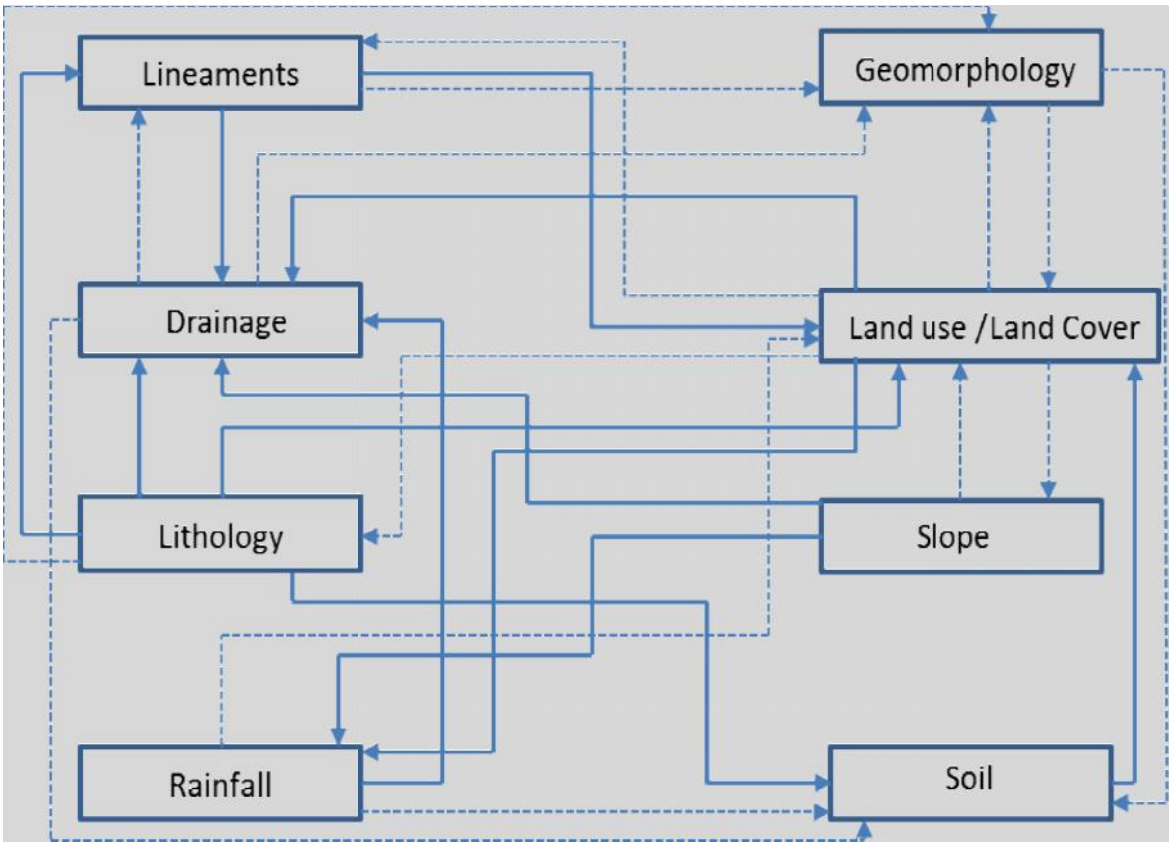

Fig. 3. Interrelationship between the multi influencing factors concerning the groundwater potential zone

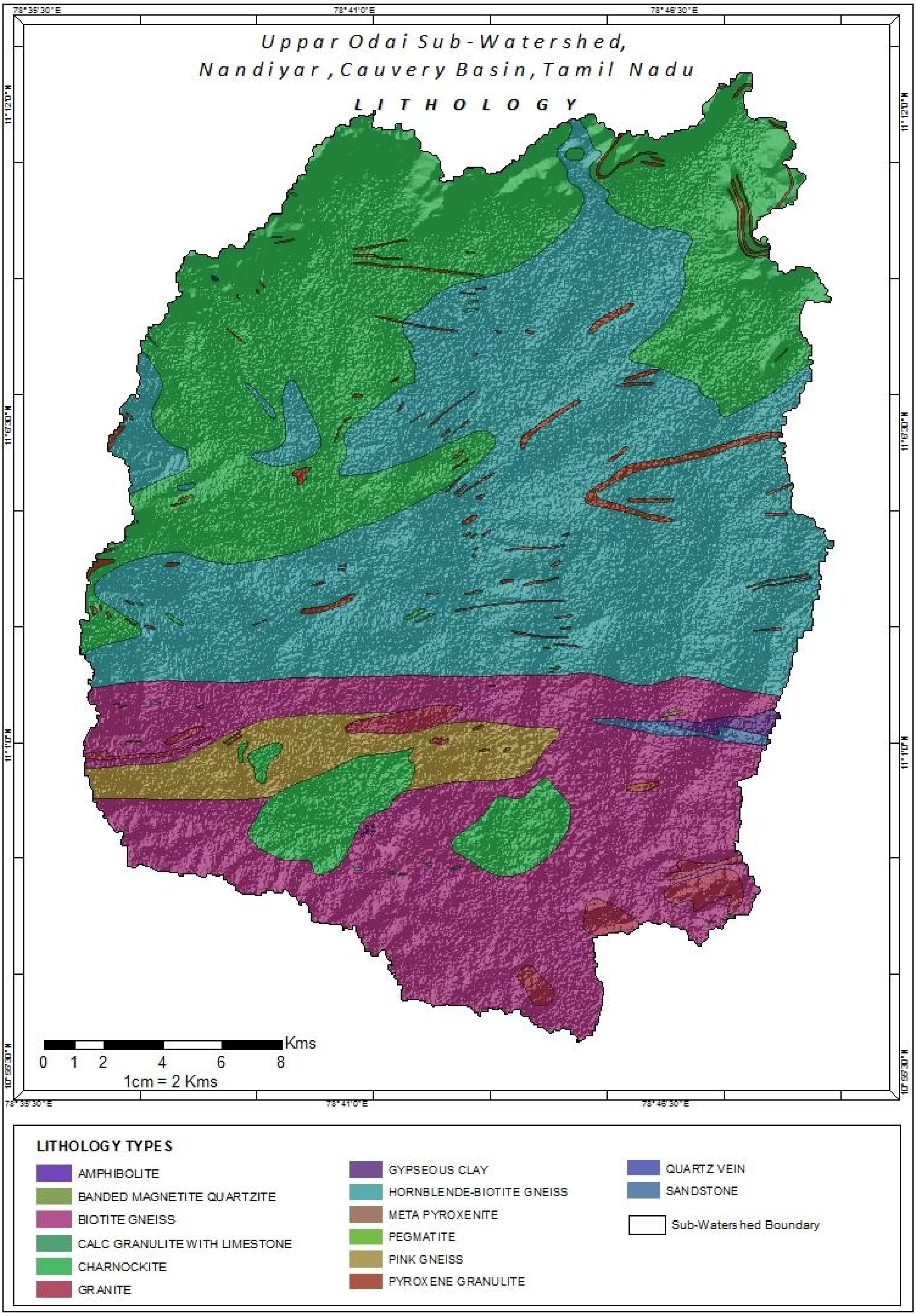

Fig.4. Lithology of Uppar odai sub-watershed, Nandiyar, Cauvery Basin

was assigned the maximum weightage (8) and progressively lower weightages were assigned for the lineament density classes of 2-3 km/km^2 (6), 1-2 km/km^2 (4), and the least weightage was assigned to the lineament density class of < 1 km/km^2 (2).

Drainage Density

Drainage density is defined as the closeness of spacing of stream channels. It is a measure of the total length of the stream segment of all orders per unit area. The drainage density is an

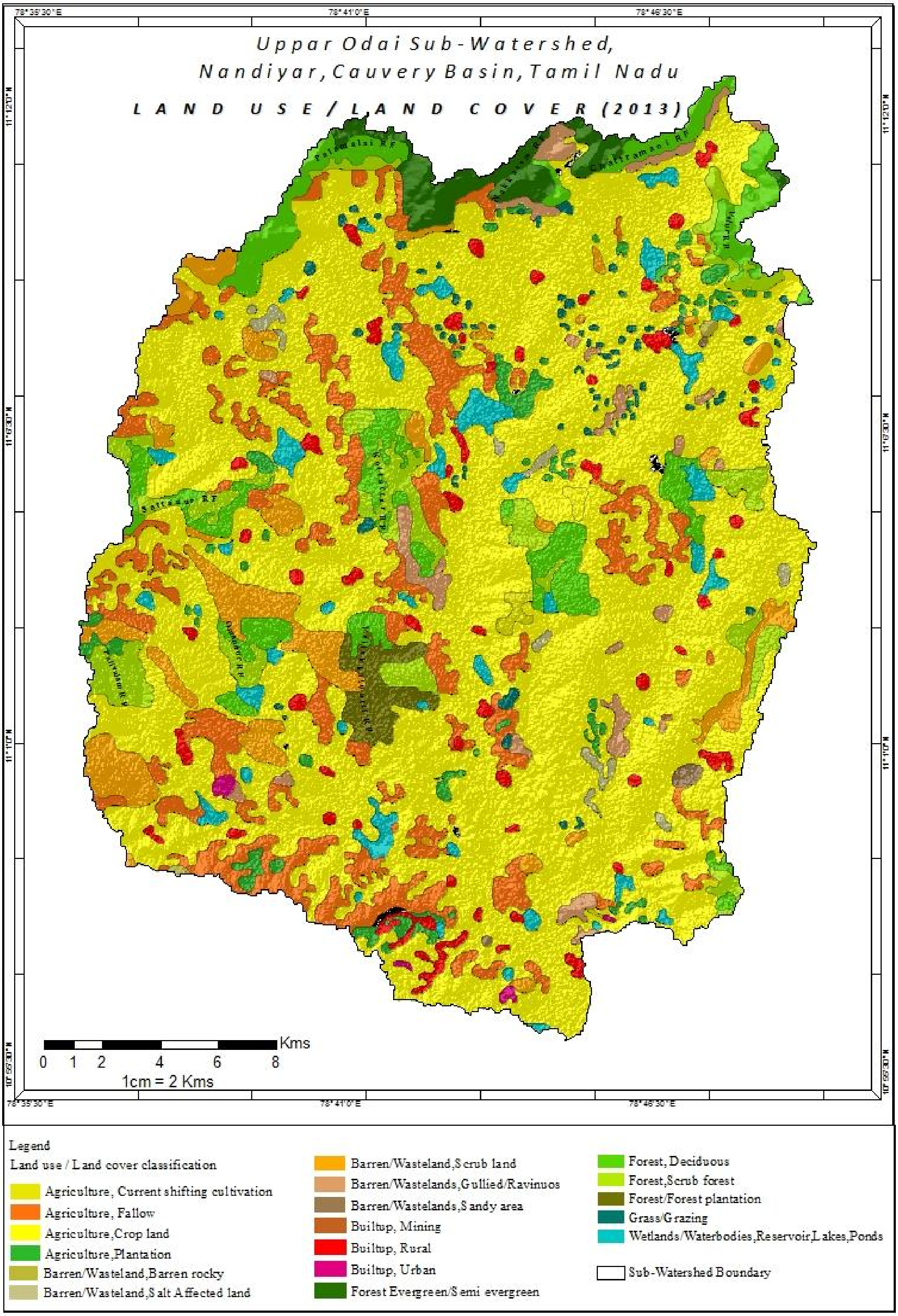

Fig. 5. Landuse/Land Cover of Uppar odai sub-watershed, Nandiyar, Cauvery Basin

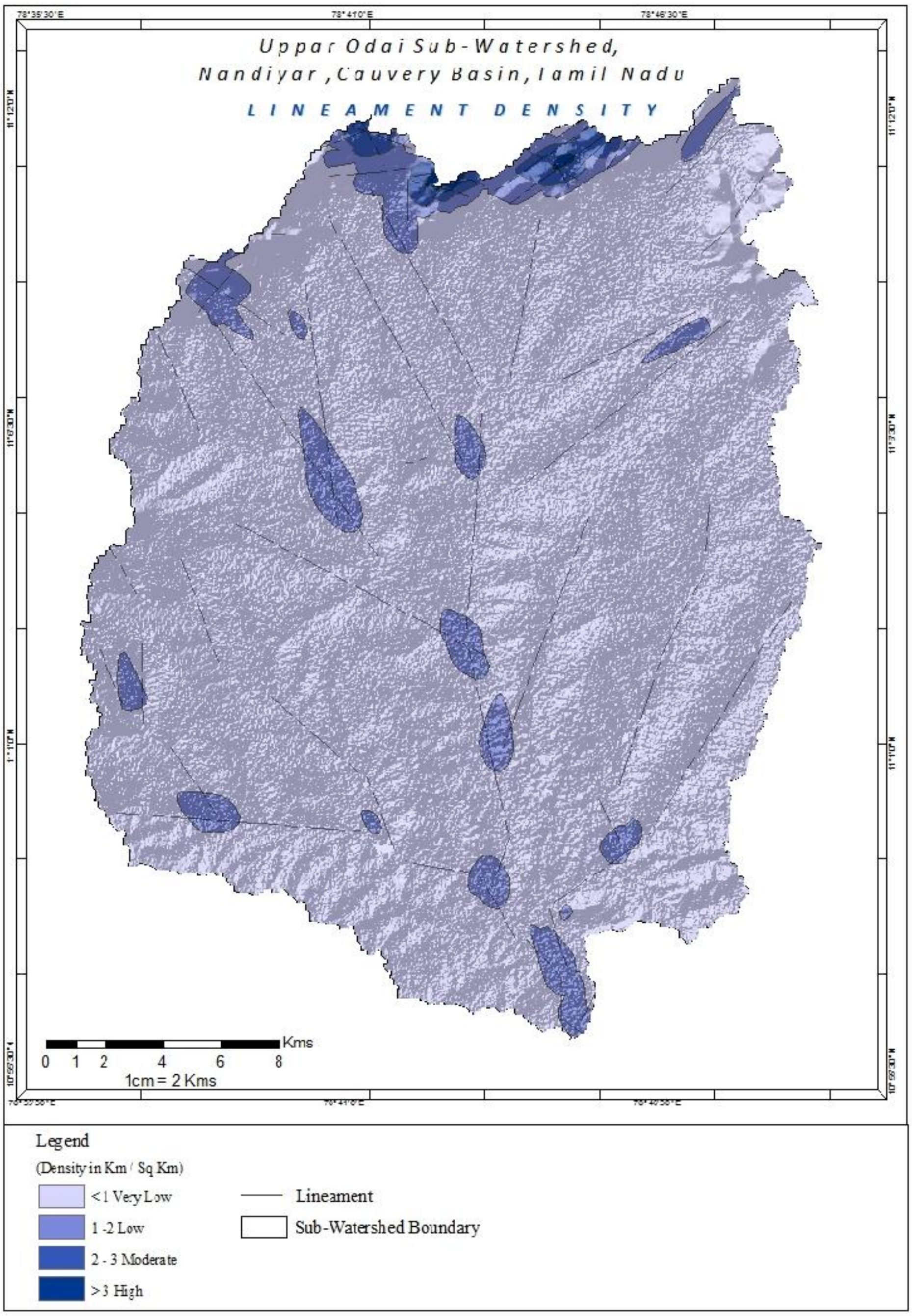

Fig. 6. Lineament Density of Uppar odai sub-watershed, Nandiyar, Cauvery Basin

inverse function of permeability. The less permeable a rock is, the less the infiltration of rainfall, which conversely tends to be concentrated in surface runoff. Drainage density of the study area is calculated using line density analysis tool in ArcGIS 10.1 software. The study area has been grouped into four classes. These classes have been assigned to 'high (> 3 km/km^2), 'moderate' (2 to 3 km/km^2), 'low' (1 to 2 km/km^2) and 'very low' (< 1 km/km^2) respectively. This fact was considered in assigning the weightages for various drainage density classes in the study area. (Fig.7) Drainage density class of less than 1 km/km^2 was assigned the minimum weightage value (2) and progressively increasing weightages were assigned to the drainage density classes.

Slope

Slope is an important factor for the identification of groundwater potential zones. Higher degree of slope results in rapid runoff and increased erosion rate with feeble recharge potential (Magesh *et al*., 2011).The slope map of the study area was prepared using ASTER DEM data (Fig.8). The slope map of the study area has been derived by using Spatial Analyst module of ArcGIS 10.1 software, the module uses the basic algorithm to calculate the slope is:

$$Slope\_Radians = ATAN (\sqrt{([dz/dx]^2 + [dz/dy]^2)})$$

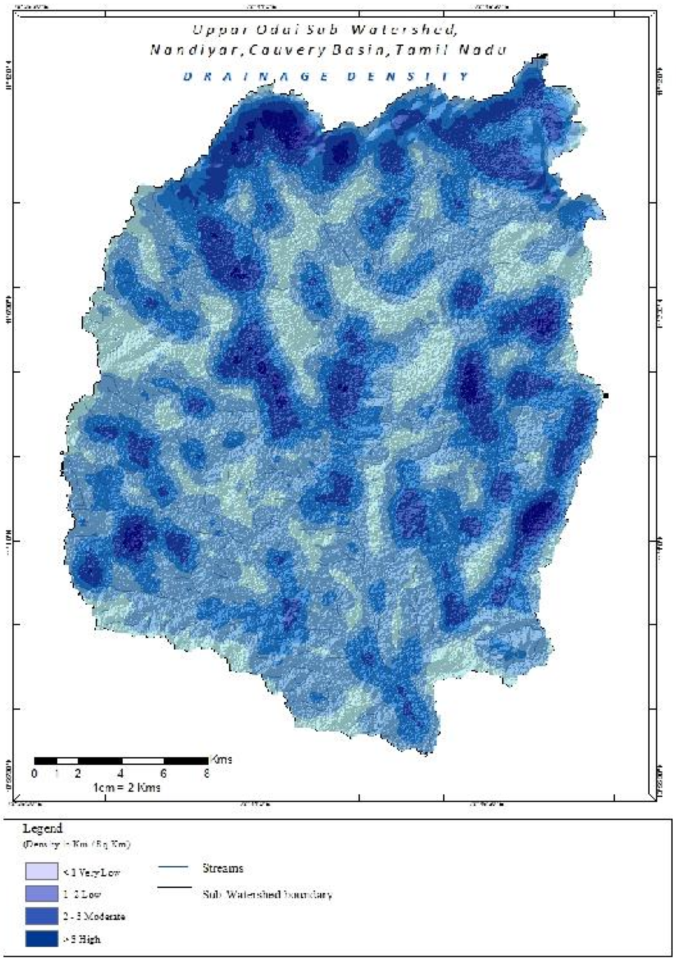

Fig.7 Drainage Density of Uppar odai sub-watershed, Nandiyar, Cauvery Basin

rates of change (delta) of the surface in the horizontal (dz/dx) and vertical (dz/dy) directions from the center cell determine the slope (Burrough, 1986). Based on the slope values, the study area was divided into six zones viz., areas with below 1% slope(nearly level), 1-3%(very gently sloping), 3-5%(gently sloping), 5-10%(moderately sloping), 10-15(strongly sloping %, and 15-35%(steep sloping). In general, the slope gradually decreases towards south. The Palamalai hill located in the northern part of the study area are found to possess steeper slope. The degree of slope will determine the infiltration rate of surface water into ground, in areas with higher slopes, the water, which flows on the surface rapidly, drains off immediately and greatly reduce the chances of water infiltrating into the ground. On the other hand, in flat areas/plains, water which flows on the surface with lower velocities and hence the possibility of water infiltrating into the ground is more and hence it is natural to expect plain areas contain higher groundwater than areas with higher degrees of slopes. This fact was considered while assigning the weightage for various slope classes. Thus areas with slopes of 0-5 degree were assigned higher weightage (9) and progressively lower weightages were assigned to other slope classes.

Soil

Soil is an important factor for delineating the groundwater potential zones. Soil characteristics invariably control penetration of surface water into an aquifer system and they are directly related to rates of infiltration, percolation and permeability The analysis of the soil type reveals that the study area is predominantly covered by clayey soil 56.7 % with black clayey soil 16.6 %, gravelly soil 14.4 %, red loamy soil 9.8% and loamy soil 2.3% at some places as shown in Fig.9. The weightage has assigned based on the medium of porosity.

Geomorphology

Climate and geomorphological characteristics of an area affect its response to a considerable extent. There are ten different types of landforms present in the study area. It involves the identification and characterization of various landforms and structural features. Many of these features are favorable for the occurrence of groundwater and are classified in terms of groundwater potentiality. The prominent geomorphic units such as structural hills, denudational hills, residual hills, pediplain, pediment, are identified in the Uppar odai sub-watershed through the interpretation of satellite images using IRS-P6 LISSIII (Fig.10). Apart from the satellite data, topographic sheets of 1:50,000 scale and information obtained from the field study were also used.

Rainfall

Rainfall distribution along with the slope gradient directly affects the infiltration rate of runoff water hence increases the possibility of groundwater potential zones**.** Rainfall data pertaining to the last 30 years for the twenty rainfall stations located in and around the sub-watershed have been considered for the present study. The average rainfall computed for southwest monsoon is 252.68 mm, which is about 31 per cent of the average annual.

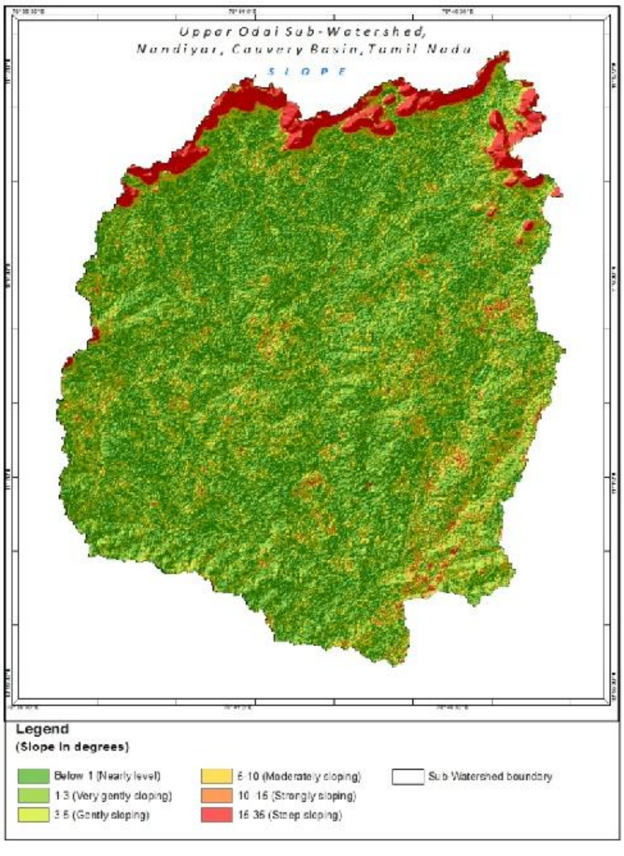

Fig. 8. Slope of Uppar odai sub-watershed, Nandiyar, Cauvery Basin

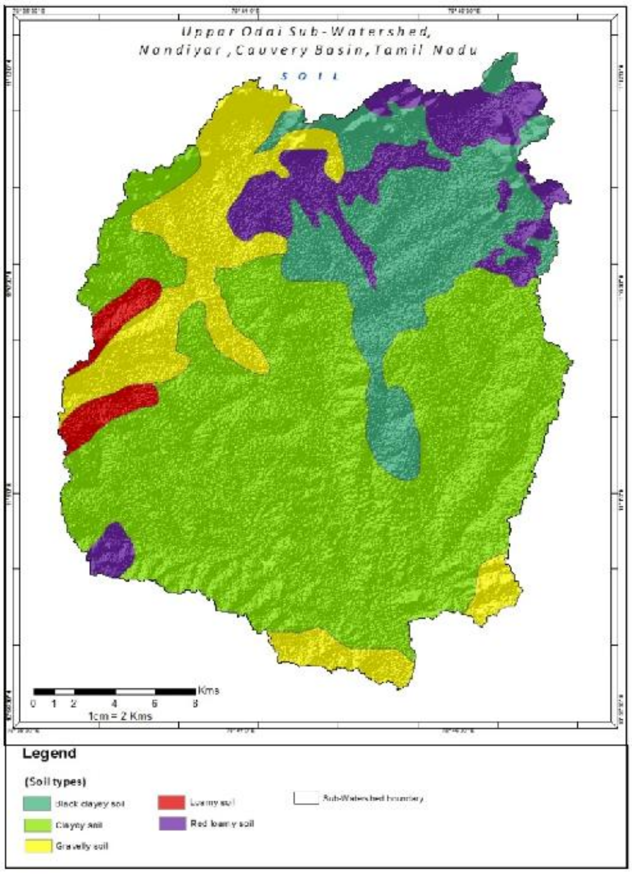

Fig. 9. Soil of Uppar odai sub-watershed, Nandiyar, Cauvery Basin

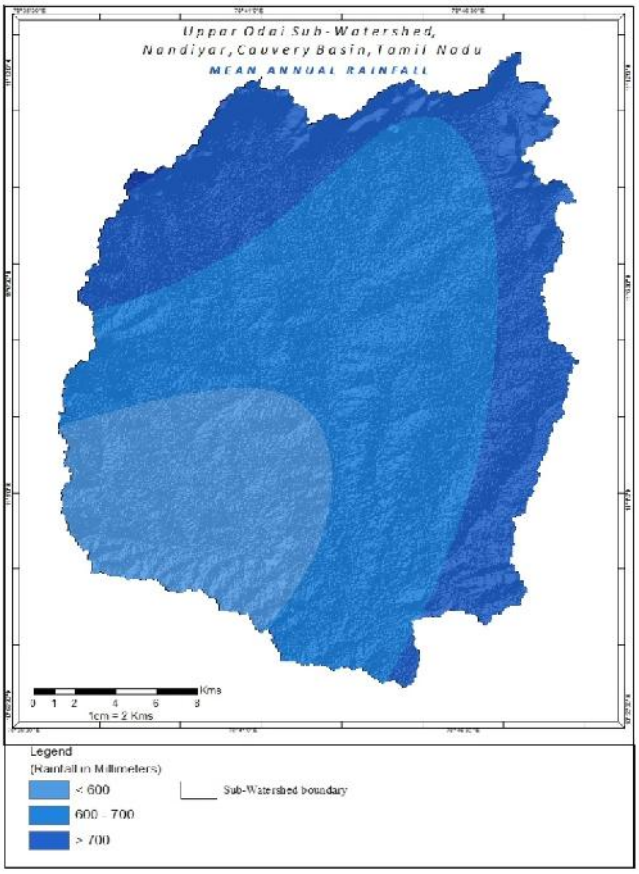

Fig.11. Mean annual rainfall of Uppar odai sub-watershed, Nandiyar, Cauvery Basin

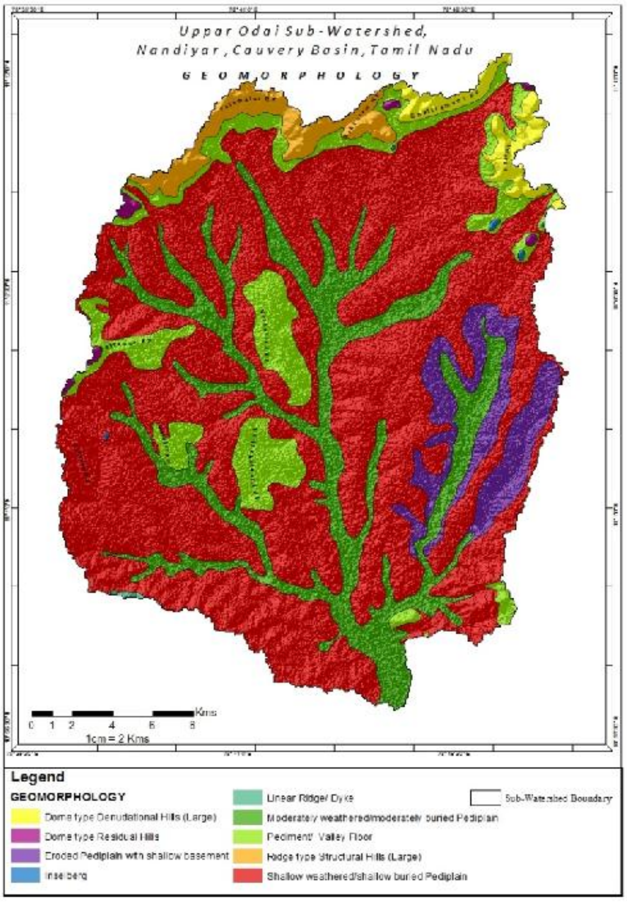

Fig.10. Geomorphology of Uppar odai sub-watershed, Nandiyar, Cauvery Basin

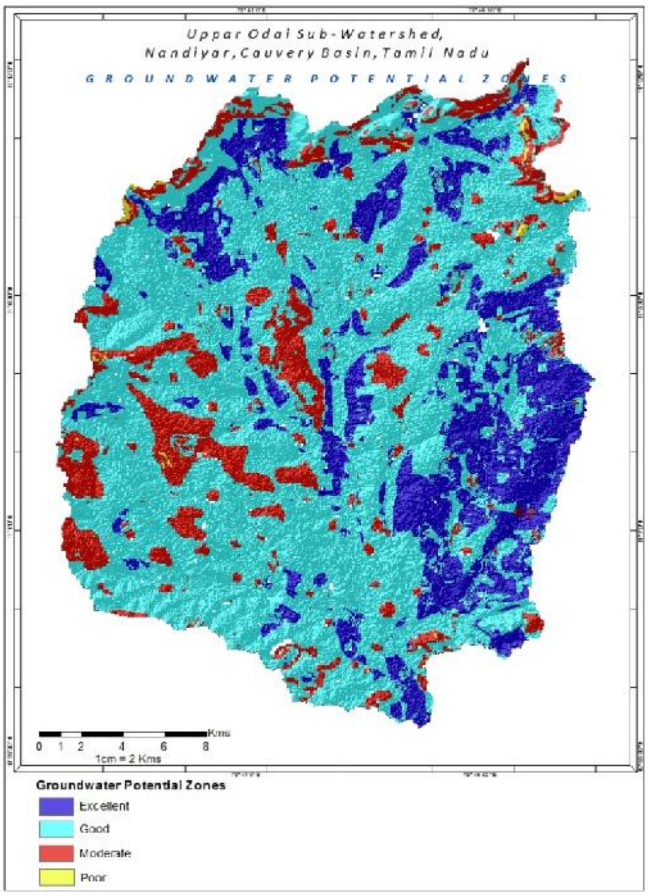

Fig.12. Groundwater potential zone of Uppar odai sub-watershed, Nandiyar, Cauvery Basin

The maximum rainfall during this season is found in Lalgudi (330.7 mm) and minimum in Thatangarpet (175.3 mm). The average rainfall computed for northeast monsoon is about 435.1mm, which is about 52 per cent of the average annual rainfall. The maximum rainfall received during the season is found in Nandiyar (581.4 mm) and minimum in Pulivalam (263.9 mm). In general the rainfall received during the season is relatively high (>500 mm) in Siddhamalai, Pullambadi,Nandiyar,Thirumanur and Lalgudi. The average rainfall computed for winter season is 10.62 mm, which is about 1 per cent of the average annual rainfall. The maximum rainfall during the season is found in Siddhamalai (35.5 mm) and minimum in Pulivalam (0.45 mm). The average rainfall for the summer season is 129.09 mm, which is 16 per cent of the average annual rainfall. Rainfall during the season is found maximum in Thuraiyur (206.4 mm) and minimum in Pulivalam (84.63 mm). Based on the mean annual rainfall distribution, the study area has classified into three classes, they are, less than 600mm, 600-700mm, and greater than 700mm and weightage has been assigned as 2, 4, and 6 respectively (Fig.11).

Groundwater Potential Zones

The groundwater potential zone of this study area can be divided into four grades, namely excellent, good, moderate and poor. The groundwater potential map (Fig. 12) demonstrates that the excellent groundwater potential zone is concentrated in the Manachanallur Block and northern part of Thuraiyur Block. This indicates that, it is due to eroded pediplain and agricultural land with high infiltration ability. Moreover, during south-west monsoon, the western part of study area receives very good rainfall which drains these regions. The excellent zones contribute 20 per cent of the total area. The Blocks like Manachanallur, Musiri, Thuraiyur of Tiruchirappalli district and blocks like Alathur and Perambalur of Perambalur district falls under moderate to good groundwater potential zone. This is mainly due to gentle slope and fairly distributed clayey soil and agriculture land with good amount of infiltration. Seventy eight per cent of groundwater potential falls in category of moderate to good. Poor potential zone is found in eastern part of the sub-watershed which accounts for only two percent of the total area.

Conclusion

Groundwater is one of the precious natural resource. Due to rapid growth in population and urbanization the demand of potential groundwater zone identification increases in the country as well as throughout the world. The collective use of the remote sensing and GIS based potential zone analysis has brought a new path in this field. Thus, the combination of remote sensing, GIS and MIF techniques has been employed in the present study and proved to be a powerful tool to understand the behavior of groundwater in any area. The weighted index overlay model has also been found to be very useful in the mapping of groundwater prospective zones. According to the groundwater potential zone map, Uppar odai sub-watershed is categorized into four different zones, namely 'excellent, 'good', 'moderate', and 'poor'. Thus, the results will be useful in better organization and supervision of groundwater resources of the present study area.

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