

Drainage morphometry and its influence on landform in a crystalline terrain, Sarabanga Sub-basin, Cauvery River, South India – a remote sensing and GIS approach

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Abstract

An attempt has been made to study drainage morphometry and its influence on landform characteristics in Sarabanga sub-basin Cauvery river basin of crystalline terrain (Archaean age), Salem district, Tamil Nadu, South India. High Spatial Resolution Indian Remote Sensing Satellite (IRS)-P6 Linear Image Self Scanning (LISS)-IV sensor data of 23 May 2012 in conjunction with Survey of India (SOI) topographical sheets (1:50,000 scale) were used for systematic analysis of various morphometric, geology and landform characteristics of the river basin. Morphometric analysis was carried out at micro watershed level using spatial analysis system (ArcGIS ver. 9.3.1) Geographic information system to analyze the influence of drainage morphometry on landforms, drainage and geological characteristics. Four distinct landforms were identified in the basin based on visual interpretation of satellite sensor data. These are structural hill, denudational hills, pediplain and water bodies. Sarabanga sub basin is one of the tributaries of Cauvery River, drained in the middle of the sub basin. It is 6th order drainage basin and drainage pattern, mainly in subdendritic to dendritic type. It is observed that the drainage density value is low, which indicates the basin is highly permeable soil and thick vegetative cover. The circularity ratio value reveals that the basin is strongly elongated and highly permeable homogenous geologic formations. The study demonstrates that remotely sensed data and GIS based approach is found to be more appropriate than the conventional methods in evaluation and analysis of drainage morphometry, landforms and land resources and to understand their inter-relationships for planning and management at a micro watershed level.

Key words: Morphometry; Crystalline terrain; Geology; Geographic Information System (GIS); Spatial analysis; Remote sensing; Micro watershed.

Introduction

Surface drainage characteristics of many river basins and sub basins in different parts of the globe have been studied using conventional methods (Horton, 1945; Strahler, 1952,

1957, 1964; Morisawa, 1959; Leopold and Miller, 1956; Krishnamurthy et al., 1996). Morphometric studies involve evaluation of streams through the measurement of various stream properties. River basins comprise a distinct morphologic region and have special relevance to drainage pattern and geomorphology (Doornkamp and Cuchlaine, 1971; Strahler, 1957). Horton's law of stream lengths suggests a geometric relationship between the number of stream segments in successive stream orders and landforms (Horton, 1945). Evaluation of morphometric parameters necessitates the analysis of various drainage parameters (viz., ordering of the various streams and measurement of area of basin, perimeter of basin, length of drainage channels, drainage density (Dd), drainage frequency, bifurcation ratio (Rb), texture ratio (T) and circulatory ratio (Rc) (Kumar et al., 2000). Quantitative description of the basin morphometry also requires the characterization of linear and areal features, gradient of channel network and contributing ground slopes of the drainage basin. Detail analysis of drainage parameters is of great help in understanding the influence of drainage morphometry on landforms and their characteristics.

The aim of the study was to demonstrate the potential use of remotely sensed data and geographical information systems (GIS) in evaluation of linear, relief and areal morphometric parameters and to analyze their influence on the genesis and processes of landforms. Visual interpretation of satellite sensor data in analysis of landforms in conjunction with the drainage patterns, facilitates effective delineation of distinct features to evaluate the influence of drainage morphometry on landform characteristics and their processes. Remote sensing and GIS techniques are being used in determining the quantitative description of the basin geometry (Biswas et al., 1999). The high spatial resolution remotely sensed data coupled with topographical data analysis procedures have made satellite sensor data-based morphometric analysis a highly effective tool to understand and manage the natural resources (Srinivasan, 1988). It provides the real time and accurate information related to distinct geological formations, landforms and helps in identification of drainage channels, which are altered by natural forces or human-induced activities. Multispectral satellite sensor data provides a convenient means to analyze drainage and distinct landform characteristics at various scales.

The basin morphometric characteristics of the various basins have been studied by many scientists using conventional methods (Horton, 1945; Smith, 1950; Strahler, 1957) and remote sensing and GIS methods (Krishnamurthy and Srinivas, 1995; Srivastava and Mitra, 1995; Agarwal, 1998; Biswas et al., 1999; Keller et al., 1982; Mayer, 1990; Cox, 1994; Merriitts, et al., 1994; LupiaPalmieri et al., 1995 and 2001; Currado and Fredi, 2000; Pike, 2002; Della Seta, 2004; Della Seta et al., 2004. The fast emerging spatial information technology (SIT) viz. remote sensing and GIS. GIS is an effective tool to analyze spatial and non-spatial data on drainage, geology and landforms to understand their inter-relationships. Integration of remotely sensed data and GIS thereby provides an efficient way in analysis of morphometric parameters and landform characteristics for resource evaluation, analysis and management. An attempt has been made to utilize the interpretative techniques of GIS to find out the relationships between the morphometric parameters at micro watershed level and identifying zones for artificial recharge.

Study Area

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 1175.44Km². 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 November 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 underlaid by the Archaean crystalline rocks surrounded by wavy hills and hillocks.

Methodology

The Indian Remote Sensing (IRS)-P6 Satellite Linear Image Self Scanning (LISS)-IV sensor data of 23 May 2012 were collected and registered to Survey Of India (SOI) topographical sheets at 1:50,000 scale in the ERDAS Image processing ver. 9.1. The Sarabanga sub-basin, Cauvery river basin of Salem district has been delineated based on the water divide line concept

The drainage network of the basin was traced on transparency and digitized as available on toposheets nos. 57L/4, 8, 58 I/1, and 5 of (1:50,000) and some of the first-order streams were updated with the help of satellite sensor data. A few of the drainage lines were extended through water bodies with the help of collateral data to facilitate the measurement of different drainage parameters. The digital elevation model (DEM) was generated based on the contour values of 20 m interval to generate height and slope maps. The Sub basin was divided into 15 micro watershed and morphometric analysis was carried out at a micro watershed level in the spatial analysis system (ArcGIS ver. 9.3.1). The drainage channels were classified into different orders using Strahler's (1964) classification. In GIS, drainage channel segments were ordered numerically as order number 1 from a stream's headwaters to a point downstream. The stream segment that results from the joining of two first order streams was assigned order 2. Two-second order streams formed a third-order stream and so on. The primary basin parameters such as basin area, basin perimeter, basin length and stream length were obtained, which were further used to obtain the derived parameters such as drainage density, Drainage Texture, Bifurcation Ratio, Stream length Ratio, Stream Frequency, Form Factor, Elongation Ratio and Circulatory Ratio. The evaluated morphometric parameters were grouped as linear, relief and areal parameters.

Visual interpretation techniques have been followed in delineation of geology, landforms, slope based on the tone, texture, shape, drainage pattern, color characteristics of the satellite imagery in conjunction with drainage morphometry and collateral data. Subsequently, detailed landform analysis has been carried out based on their genesis, relief and their morphometric characteristics. Finally, to identify the suitable locations for artificial recharge structure's construction.

Results and Discussion

Elevation

The digital elevation model map of the study area reveals that higher elevation of 1929 m above mean sea level is associated with dissected hills and escarpments in the western, northern and southeastern parts of the study area (Fig. 2 and Table 1). The elevation ranging from 390 to 470 m above msl is mainly confined to isolated mounds, linear ridges, plateau spurs and upper parts of rolling plains. The elevations above 470 m above msl are structural hills with wavy mountains and upper part of this region are very steep slope. The elevation ranging from 190 to 270 m above msl is mainly associated with lower plain area.

The elevation ranging from 270 to 390 msl is mainly composed with middle parts of foot slopes, narrow valleys and main valley floor.

The majority of areas fall and parts of area in the micro watershed nos. 5–15 is under nearly surface level to very gentle slope (0–3%) and occupy about 59.90% of the total geographical area (TGA) (Fig. 3 and Table 2). These slopes cover almost all the sub basins except the 10th and 11th sub basins. Much less drainage density and low stream frequency are observed on these slopes covering the central, northeastern and southeastern parts of the study area. The moderately steep to very steep (more than 10%) of the upland areas and isolated places in the micro watershed nos. 1-4 occupy 14.71% of the TGA. Moderate to gentle slopes (3–10%) are observed in undulating terrain and intermittent valley zones covering 25.39% of the total area.

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 crystalline rocks (Fig. 4 and Table 3), and the groundwater occur under phreatic 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 lithounites 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 Chaik hills.

Iron ore: it occurs as bands of magnetite quartzite near Kanjamalai.

Bauxite: it is found capping the Shervroy 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 Jalagoundapuram. 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.

Linear parameters

Stream order analysis shows that the main sub basin is fall under sixth order category. Based on the network pattern it has been further sub divided into fifteen micro watersheds. The micro watershed no. 13 were identified second order stream, three watersheds (5,6,15) under third order stream, three watersheds (3,9, and 14) under fourth order stream, five

watersheds (1,2,7,11,13) under fifth order stream and three watersheds (8,10,12) under sixth order stream (Fig. 5 and Table 4). The sixth order stream is found in the unclassified area. Analysis of cumulative length of streams (L) shows that micro watershed 2, 4 and 11 have the highest L value, whereas, micro watersheds 6, 13 and 15 have the lowest L value. The existence of high (L) value is due to structural complexity, high relief and impermeable bedrock. Analyses of bifurcation ratio (Rb) shows lower (Rb) values in the micro watersheds 3, 6 and 9 are attributed to the characteristics of fewer structural disturbances which, in turn, has not distorted the drainage pattern (Strahler, 1964). Whereas, the higher (Rb) values in the micro watersheds 5, 7 and 14 indicate high structural complexity and low permeability of the sub surface strata.

Areal parameters

Drainage density indicates that the low Dd exists in micro watersheds 4, 8, 9, 10 and 13 having high permeable sub surface material and are under dense vegetation cover and low relief (Fig. 5 and Table 5). In contrast, high Dd values are observed in micro watersheds 2, 14 and 15 may be due to the presence of impermeable sub surface material, sparse vegetation and elevated relief. Basin relief (Bh) aspects of the sub basins play an important role in drainage development. Surface and sub-surface water flow, permeability and landforms development properties of the terrain. The analysis reveals that the sub basins 1, 2, 3, 4, 5, 6, 7, 9, 10, 12, 13 and 14 are having the relief more than 250 m (Table 4). The high Bh value indicates the gravity of water flow, low infiltration and high runoff conditions. The measurement of drainage density provides a numerical measurement of landscape dissection and runoff potential. Analysis of stream frequency (Fu) shows low values of Fu existing in micro watersheds 8 and 10, 13, which are having high permeable geology and low relief.

Where elevated value of Fu is noticed in 1 and 2 micro watersheds, where impermeable sub-surface material, sparse vegetation and high relief conditions prevail. Texture ratio (T) indicates that highest T values are found in micro watersheds 1, 2 and 4 whereas the lowest T values are noticed in micro watersheds 6, 10 and 13. Thus, it can infer that T values depend on the underlying geology, infiltration capacity of bedrock and relief aspects of the individual micro watersheds. Analysis of the form factor (Rf) reveals that micro watersheds having low Rf have less side flow for smaller duration and high main flow for longer duration and vice versa.

This condition prevails in micro watersheds 3, 4 and 13. High Rf exists in micro watersheds 1, 5 and 15 with high side flow for longer duration and low main flow for shorter duration causing high peak flows in a shorter duration. Circulatory ratio (Rc) values approaching 1 indicates that the basin shapes are like circular and as a result, it gets scope for uniform infiltration and takes long time to reach excess water at the micro watershed outlet, which further depend on the existing geology, slope and land cover. The micro watersheds 5 and 15 are having highest Rc value of 1.01 and 0.66 respectively, which support the above concept. Analysis of an elongation ratio (Re) indicates that the areas with higher Re values have high infiltration capacity and low runoff. The micro watersheds 5 and 15 are characterized by high Re and 3, 4 and 11 micro watersheds have low Re respectively. The micro watersheds having low Re values are susceptible to high erosion and sedimentation load. Constant of channel maintenance (C) depends on the rock type, permeability, climatic regime, vegetation cover and relief as well as duration of erosion (Schumm, 1956). The micro watersheds 3 and 14 have low C values of 0.43 and 0.37 respectively. It indicates that these micro watersheds are under the influence of high structural disturbance, low permeability;

steep to very steep slopes and high surface runoff. The micro watersheds of 5 and 13 have highest C values of 1.94 and 1.46 respectively and are under very fewer structural disturbances and fewer runoff conditions.

Drainage morphometry and its impact on landform characteristics the underlying geology, exogenic and endogenic activities, drainage morphometry and considerable changes in climate during the Quaternary, influences the genesis and morphology of landforms (Subramanyan, 1981). In this study area, the denutiation hills are located in the micro watersheds (4, 7, 11, 14, 15) pediplain covers nearly 60 percentages of the sub basin. The structural hills found in the following micro watersheds (1, 2, 3, 4, 7, 11) are identified and mapped as major landforms on the upper reaches. These landforms are associated with high drainage density, high bifurcation ratio and high cumulative length of first, second and third-order streams. Rolling plains, foot slopes, narrow valleys and main valley floors are analyzed and mapped as landforms of the Sarabanga sub basin (Fig. 6 and Table 6). Which are formed by the influence of permeable geology, moderate to nearly level plains, medium to low drainage density (<2.0), low cumulative length of streams having fourth and fifth order streams. Landforms of upper reaches. The fluvio-denudational geomorphological processes are actively involved in landscape reduction processes at upper reaches. The physio-chemical weathering and multiple slope dissections under the influence of steep slopes, high drainage density and precipitation conditions lead to the development of ridge-valley land systems in the North Eastern and North Western part of the area. The occurrences of alluvium and colluvium deposits at places are dissected by incoming third and fourth order streams. They are noticed in the upper parts of micro watershed nos. (1, 2, 3, 4, 5, 8). Foot slopes are low in relief and consist of deposited sediments that are regularly carried out from upland catchments. The deposited sediments are admixed with sandy loam and clay. The majority of these landforms are noticed in micro watershed nos. 7, 13, 14 and 15 of the study area.

Conclusions

The study reveals that remotely sensed data and GIS based approach in evaluation of drainage morphometric parameters and their influence on landforms and land characteristics at a micro watershed level is more appropriate than the conventional methods. Interpretation of multi-spectral satellite sensor data is of great help in analysis of drainage parameters and delineation of distinct geological and landform units, relief and slope. GIS based approach facilitates analyzing different morphometric parameters and to explore the relationship between the drainage morphometry on one hand and properties of landforms and geology on other hands. Geomorphology spatial variation in the upper parts of micro watershed nos. (1, 2, 3, 4, 5, 8). Foot slopes are low in relief and consist of deposited sediments that are regularly carried out from upland catchments. The majority of these landforms are occupied in the micro watershed nos. 7, 13, 14 and 15 of the study area. The sixth order stream is found in the unclassified area. Analysis of cumulative length of streams (L) shows that micro watersheds 2,4 and 11 have the highest L value, whereas, micro watersheds 6,13 and 15 have the lowest L value. The existence of high (L) value is due to structural complexity, high relief and impermeable bedrock.

The micro watersheds 3 and 14 have low C values of 0.43 and 0.37 respectively. It indicates that these micro watersheds are under the influence of high structural disturbance, low permeability; steep to very steep slopes and high surface runoff. The micro watersheds of 5 and 13 have highest C values of 1.94 and 1.46 respectively and are under very fewer structural disturbances and fewer runoff conditions. The present scenario where water

resources are becoming scarce, this exercise of calculating the various attributes of a drainage basin plays a significant role in locating sites for artificial recharge structures.

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TABLE CAPTIONS

Table. 1. The various height of the Sarabanga sub basin results are given in the table.

Table. 2. Results of the Slope of the Sarabanga sub basin are given in the table.

Table 3. Results of the Geological features area in km² of the study area.

Table 4. Micro watershed level Linear and Relief morphometric parameters, it is calculated for the various guide line (Formulas) are given in the table.

Table 5. Micro watershed level Areal morphometric parameters, it is calculated for the various guide line (Formulas)are given in the table.

Table 6. GIS SpatialResults of Geomorphological features are given in the table.

FIGURE CAPTIONS

Fig. 1 Location of the Sarabanga Sub basin and the digital elevation model with drainages and water bodies of the study area details are given in figure.

Fig. 2 Detailed elevation map of the study area.

Fig. 3 Slope of the study area with spatially represented and land marks.

Fig. 4 Geology and mineral identification of the study area with spatially represented and land marks.

Fig. 5 detailed drainage order wise like 1st, 2nd, 3rd upto 6th order with micro watershed boundary and road network railway track of the study area with spatially represented and land marks.

Fig. 6 Geomorphological features of the study area with spatially represented and land marks.

Table 1 Elevation class with area of the Sarabanga sub basin

| Sl.No. | Class | Area in Km ² |
|--------|-----------|-------------------------|
| 1 | 190 - 210 | 1.88 |
| 2 | 210 - 230 | 10.88 |
| 3 | 230 - 250 | 46.70 |
| 4 | 250 - 270 | 52.40 |
| 5 | 270 - 290 | 97.69 |
| 6 | 290 - 310 | 115.93 |
| 7 | 310 - 330 | 142.19 |
| 8 | 330 - 350 | 110.95 |
| 9 | 350 - 370 | 104.57 |
| 10 | 370 - 390 | 77.69 |
| 11 | 390 - 410 | 60.40 |
| 12 | 410 - 430 | 54.36 |
| 13 | 430 - 450 | 40.61 |
| 14 | 450 - 470 | 38.42 |

| | | |
|----|---------------|--------|
| 15 | 470 - 490 | 220.76 |
| 16 | More than 490 | 0.001 |

Table 2 Slope class with area of the Sarabanga sub basin

| 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 |

Table 3 Geology with area of the Sarabanga sub basin

| Sl.No. | Class | Area in Km ² | Area in % |
|--------|--|-------------------------|-----------|
| 1 | Charnockite | 2.12 | 0.2 |
| 2 | Granite | 280.15 | 23.8 |
| 3 | Purple conglomerate, sandstone and shale | 90.13 | 7.7 |
| 4 | Quartz vein | 759.71 | 64.6 |
| 5 | Shales with bands limestone | 43.30 | 3.7 |

Table 4. Linear and Relief parameters of micro watersheds

| micro watershedno. | Basin Length Lb (km) | Perimeter P (km) | Drainage Order (in Number) | | | | | | Total Number N | Cumulative Length L (km) | Bifurcation Ratio Rb | Basin height Bhm |
|--------------------|----------------------|------------------|----------------------------|----------------|----------------|----------------|----------------|----------------|----------------|--------------------------|----------------------|------------------|
| | | | N ₁ | N ₂ | N ₃ | N ₄ | N ₅ | N ₆ | | | | |
| 1 | 11.09 | 38.57 | 129 | 68 | 25 | 17 | 2 | 0 | 241 | 353.00 | 3.65 | 627 |
| 2 | 16.41 | 54.37 | 216 | 117 | 52 | 46 | 7 | 0 | 438 | 660.00 | 2.95 | 1309 |

| | | | | | | | | | | | | |
|----|-------|-------|-----|----|-------|----|---|---|--------|--------|------|------|
| 3 | 12.33 | 27.09 | 47 | 25 | 11 | 9 | 0 | 0 | 92 | 137.00 | 1.79 | 895 |
| 4 | 23.04 | 56.02 | 183 | 94 | 53 | 19 | 8 | 2 | 359 | 535.00 | 2.58 | 1260 |
| 5 | 29.67 | 55.62 | 51 | 30 | 29.91 | 0 | 0 | 0 | 111.91 | 172.82 | 5.08 | 673 |
| 6 | 11.91 | 31.36 | 22 | 8 | 9 | 0 | 0 | 0 | 41 | 60.00 | 1.21 | 456 |
| 7 | 18.93 | 51.48 | 149 | 65 | 22 | 2 | 1 | 0 | 239 | 329.00 | 4.56 | 389 |
| 8 | 18.47 | 50.35 | 47 | 19 | 11 | 1 | 3 | 1 | 82 | 117.00 | 3.71 | 243 |
| 9 | 17.87 | 44.36 | 126 | 54 | 17 | 11 | 0 | 0 | 208 | 290.00 | 2.35 | 257 |
| 10 | 20.25 | 60.57 | 41 | 7 | 7 | 3 | 2 | 1 | 61 | 81.00 | 2.54 | 603 |
| 11 | 19.07 | 48.41 | 135 | 58 | 28 | 20 | 5 | 0 | 246 | 357.00 | 2.45 | 121 |
| 12 | 20.89 | 55.55 | 143 | 67 | 32 | 4 | 1 | 1 | 248 | 353.00 | 3.45 | 381 |
| 13 | 15.23 | 47.80 | 23 | 6 | 0 | 0 | 0 | 0 | 30 | 37.00 | 3.83 | 405 |
| 14 | 5.82 | 17.61 | 37 | 14 | 2 | 1 | 0 | 0 | 54 | 71.00 | 3.88 | 430 |
| 15 | 4.94 | 14.69 | 21 | 10 | 2 | 0 | 0 | 0 | 33 | 45.00 | 3.55 | 156 |

Table 5. Areal Morphometric parameters of micro watersheds

| micro watershed no. | Area A (km ²) | Stream Frequency Fu | Drainage density Dd | Texture Ratio T | Form factor Rf | Circulatory Ratio Rc | Elongation Ratio Re | Constant of channel Maintenance C |
|---------------------|---------------------------|---------------------|---------------------|-----------------|----------------|----------------------|---------------------|-----------------------------------|
| 1 | 57.40 | 4.20 | 2.18 | 3.34 | 0.47 | 0.48 | 0.77 | 0.46 |
| 2 | 92.24 | 4.75 | 2.33 | 3.97 | 0.34 | 0.39 | 0.66 | 0.43 |
| 3 | 23.51 | 3.91 | 2.02 | 1.73 | 0.15 | 0.40 | 0.44 | 0.50 |
| 4 | 107.54 | 3.34 | 1.95 | 3.27 | 0.20 | 0.43 | 0.51 | 0.51 |
| 5 | 103.08 | 2.2 | 2.18 | 1.4 | 0.56 | 1.01 | 1.17 | 1.94 |
| 6 | 36.22 | 1.13 | 1.12 | 0.70 | 0.26 | 0.46 | 0.57 | 0.89 |
| 7 | 122.48 | 1.95 | 1.46 | 2.89 | 0.34 | 0.58 | 0.66 | 0.68 |
| 8 | 116.28 | 0.71 | 0.69 | 0.93 | 0.34 | 0.58 | 0.66 | 1.45 |
| 9 | 94.33 | 1.92 | 0.99 | 2.60 | 0.34 | 0.58 | 0.66 | 1.01 |
| 10 | 124.97 | 0.49 | 0.72 | 0.68 | 0.30 | 0.43 | 0.62 | 1.40 |
| 11 | 74.43 | 3.31 | 1.67 | 2.79 | 0.20 | 0.40 | 0.51 | 0.60 |
| 12 | 147.22 | 1.43 | 1.14 | 2.30 | 0.40 | 0.56 | 0.71 | 0.88 |
| 13 | 53.36 | 0.43 | 0.68 | 0.45 | 0.30 | 0.34 | 0.62 | 1.46 |

| | | | | | | | | |
|----|-------|------|------|------|------|------|------|------|
| 14 | 14.19 | 3.81 | 2.69 | 2.10 | 0.42 | 0.57 | 0.73 | 0.37 |
| 15 | 11.29 | 2.92 | 2.35 | 1.43 | 0.46 | 0.66 | 0.77 | 0.43 |

Table 6 Geomorphological features with area of the Sarabanga sub basin

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

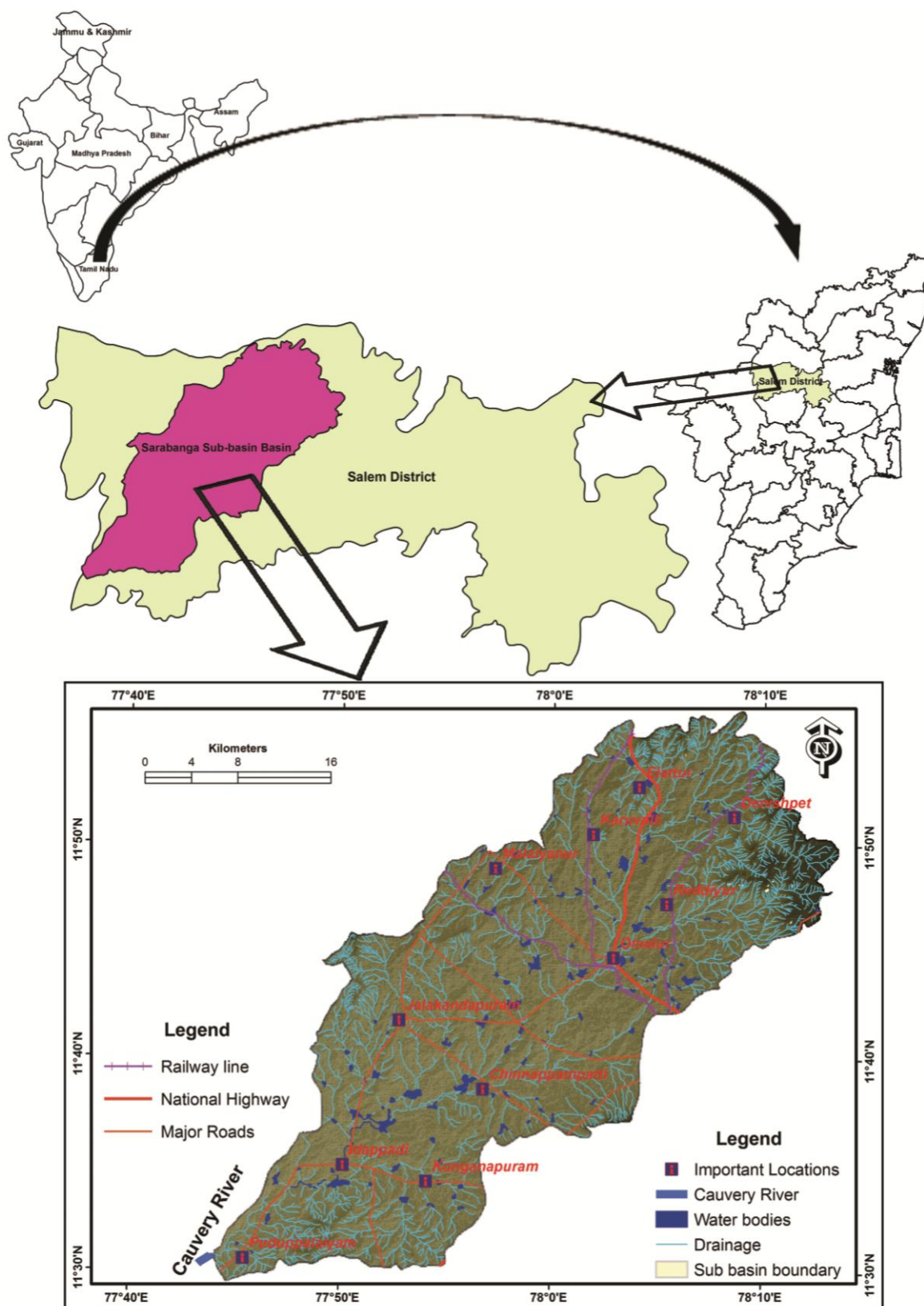


Fig.1 Study Area Map of Sarabanga Sub-basin with stream networks and water bodies

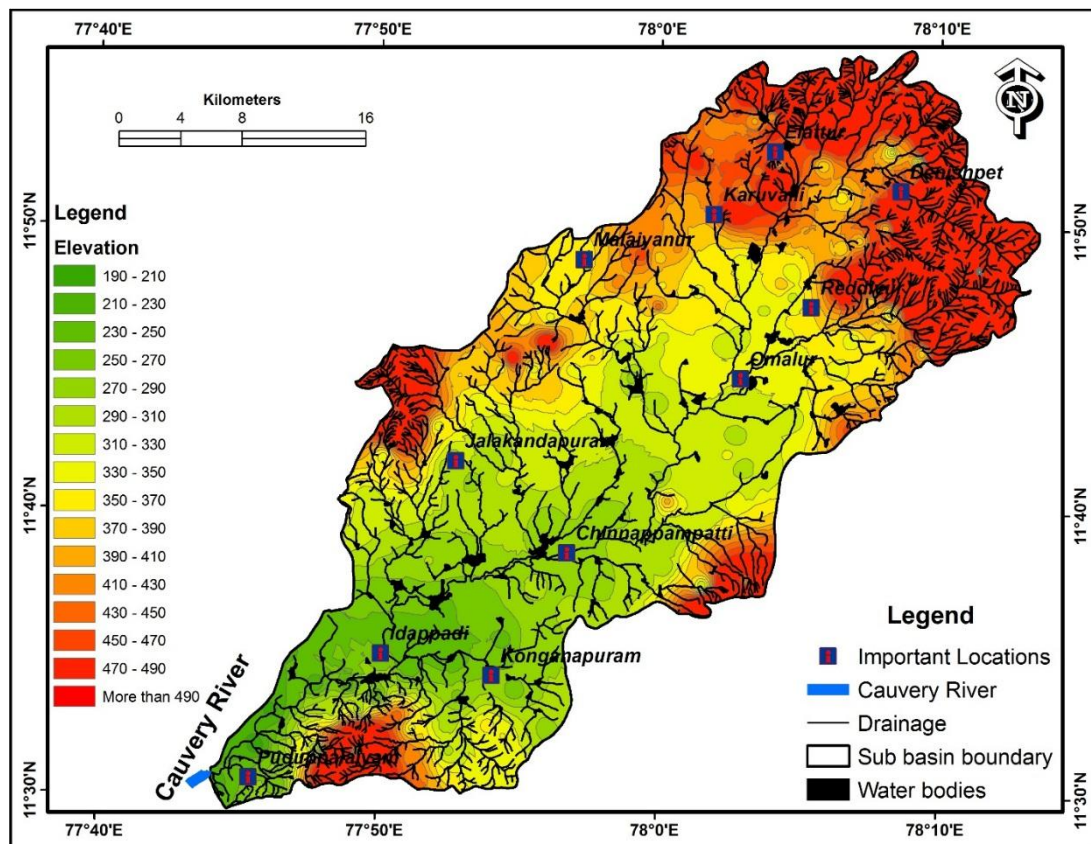


Fig. 2 Elevation map of Sarabanga sub basin

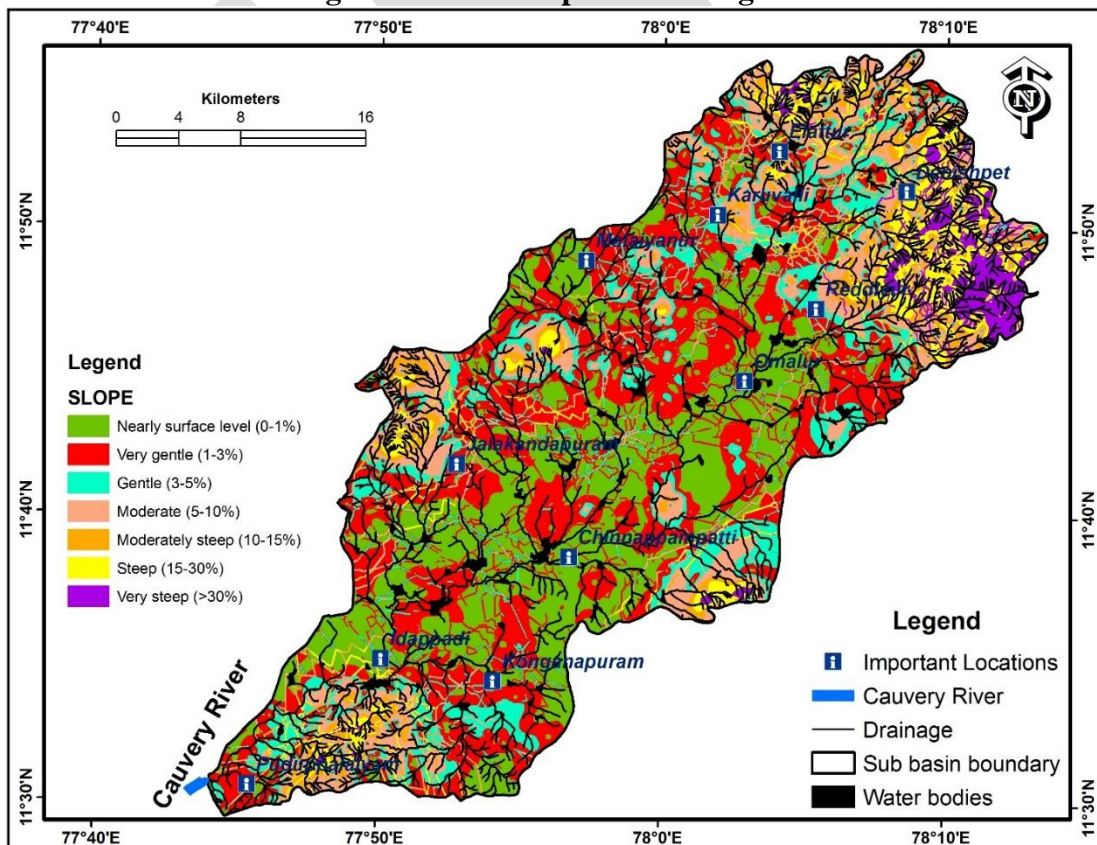


Fig. 3 Slope map of Sarabanga sub basin

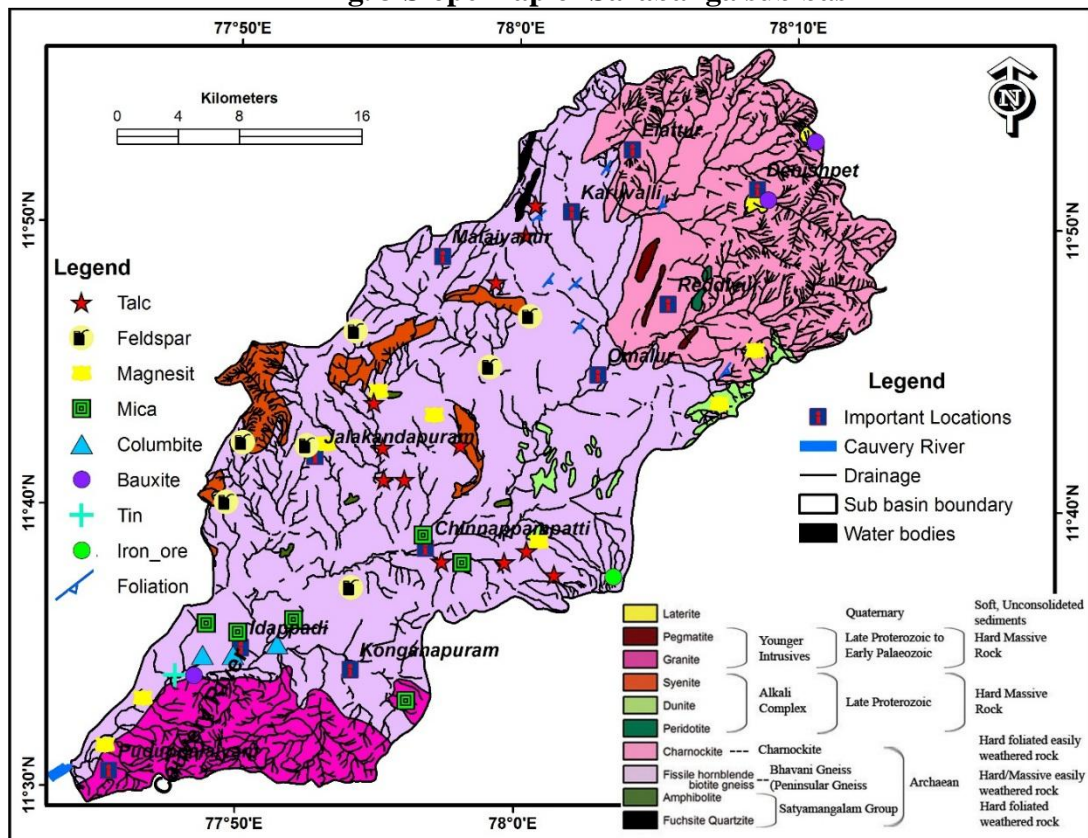


Fig. 4 Geology map of Sarabanga sub basin

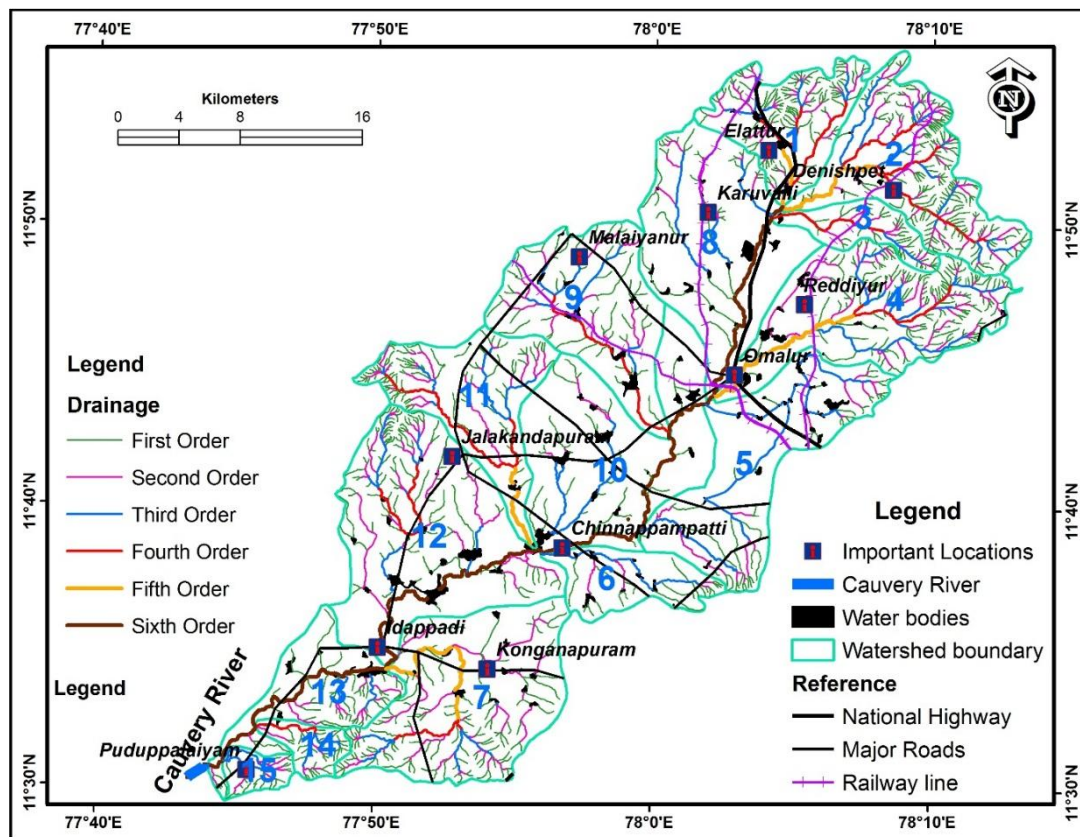


Fig.5. Micro watersheds and stream orders of Sarabanga sub basin

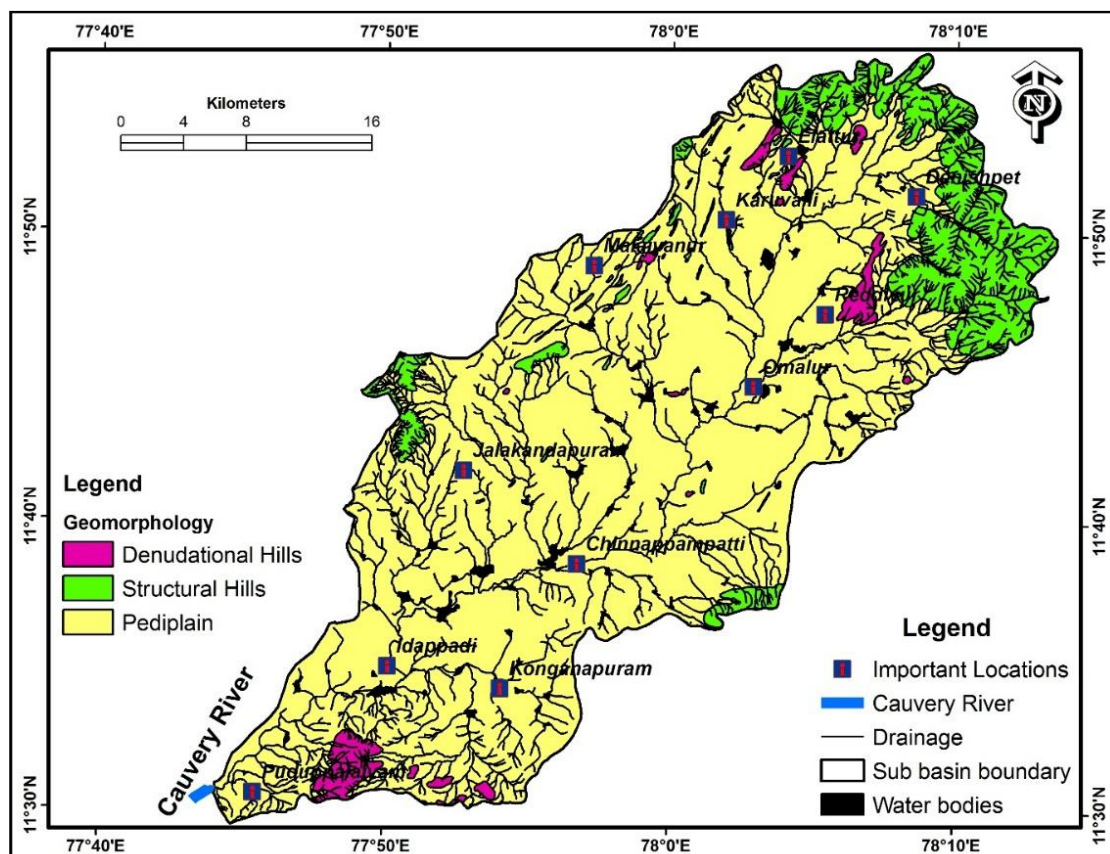


Fig.6. Geomorphology of the Sarabanga sub basin

