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IMPORTANCE OF MORPHOMETRY STUDIES, LAND FORM PROCESSES TO FIND PRIORITIZE AREAS WHERE FLOOD CONTROL - USING REMOTE SENSING AND GIS FOR TAMIRAPARANI SUBBASIN, TIRUNELVELI DISTRICT, TAMIL NADU, INDIA

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ABSTRACT

In addition to standard methods, efforts are being created to explore the importance of morphometry by incorporating Remote Sensing information and techniques into a GIS platform. In order to determine the drainage features using GIS method, a morphometric assessment of the Tamiraparani sub basin was performed. The study proved the prospective use of remotely sensed data and geographic information systems (GIS) in calculating linear, relief and areal morphometric parameters and analyzing their impact on the genesis and processes of landforms and soil parameter characteristics such as texture, drainage and soil erosion conditions. Visual interpretation of satellite information in the assessment of the characteristics of geology, landforms and soil erosion in combination with drainage patterns promotes the efficient delineation of separate characteristics to assess the impact of drainage morphometry. The model offers a drainage basin after implementation with the categorized flow network of Strahler backed by thematic layers such as aspect, slope, relief, and soil density. The developed model demonstrates that this subbasin's drainage area is 734.84 km^2 and shows a subdendritic drainage pattern to dendritic. The basin involves a stream of sixth order, mostly dominated by lesser stream order. The study area's slope varies from 0 ° east to 61 ° west. Western Ghats ' presence is the main controlling factor for variation in the slope. In addition, local lithology and erosion cycles control the slope variety. The bifurcation ratio shows that the geological structures have little impact on the drainage networks, and the drainage density shows that the subsurface strata are permeable.

KEY WORDS: *GIS, land form, morphometry, relief, remote sensing, slope, Tamiraparani river basin*

I. INTRODUCTION

Morphometric surveys require assessing streams by measuring the different characteristics of the stream. Analysis of different drainage parameters: arrangement of different streams and measurement of basin region, basin perimeter, drainage channel length, drainage density (Dd), drainage frequency, bifurcation ratio (Rb), texture ratio (T) and circulatory ratio (Rc) [1].

The evaluation of a drainage basin's hydrological features is a mandate for any basin management system. It involves a thorough morphometric assessment that includes basin size, shape, drainage zone slope, drainage density, tributary size and length, etc. The delineation of drainage networks within a basin or sub basin can be accomplished using traditional techniques such as field observations and topographic maps or using sophisticated techniques using remote sensing and GIS. [2, 3, 4, 5 and 6]. The main drawback of traditional method is its tedious attempt to examine all stream networks from field observations because of their extent across a vast region. GIS and image processing techniques have been adopted to identify morphological characteristics and analyze their Lower Gostani River Basin (LGRB) properties in Andhra Pradesh, India.

Using Remote Sensing, compared to standard morphometry research, allows existing ground reality inputs to evaluate changes in drainage patterns, soil density features, Landuse changes, and real-time landforms.

In this context High Spatial Resolution Indian Remote Sensing Satellite (IRS)-P6 Linear Image Self Scanning (LISS)-4 sensor data of 7 July 2002, Survey of India (SOI) topographical sheets (1:50,000 scale) and field verification data were used for systematic analysis of various Geomorphic processes, hydrological and landform characteristics of the study area. Drainage Network analysis was carried out at basin level using Spatial Analysis GIS System (ArcGIS) to identify the influence of drainage morphometry on landforms, drainage, and land erosion characteristics. The research shows that embedded strategy based on Remote Sensing and GIS is more suitable and helpful than standard techniques. The research aims to use GIS ' interpretation capacities to determine the relationship between morphometric parameters at sub basin level on the one side and landforms on the other side, soil physical and eroded soil characteristics. The research complements attempts to comprehend the interrelationship between different interactive planning, biodiversity management and disaster-prone zoning variables. Surface drainage characteristics of many river basins and sub basins in different parts of the globe have been studied using conventional methods [7, 8, and 9].

The region of research is located in the Western Ghats, a fragile eco-region known for its wealthy biodiversity. This region's two main watersheds are Papanasam and Manimuthar, contributing almost 400 km2. These two watersheds morphometric details are well researched by [10] but no significant work regarding the morphometry of Tamiraparani subbasin was reported elsewhere. On the other hand, [11] has explained the eco-regions using water quality patterns for the entire Tamiraparani basin with the help of morphometric analysis.

High spatial resolution remote sensed information combined with topographical data analysis processes have made morphometric analysis based on satellite sensor information a extremely efficient tool for understanding and managing natural resources (Srinivasan, 1988). It offers real-time information and accuracy linked to different geological formations, landforms, and helps identify drainage channels that are changed by natural forces or anthropogenic activities. Multispectral satellite sensor information offers a convenient means of analyzing drainage and separate landform features at different scales. GIS is an efficient instrument for analyzing spatial and non-spatial information on parameters of drainage, geology, landforms and soil to know their interrelationships. Geo-coded resource database produced in the heart of GIS on drainage, landforms and soil parameters offers an outstanding way to store, retrieve and analyze river basin-level information to determine their connection. It also offers a strong mechanism for upgrading and monitoring morphometric parameters, as well as for the spatial analysis of other related resources databases. The integration of remote sensed information and GIS thus offers an effective way for resource assessment, assessment and management to analyze morphometric parameters and landform features. An attempt was made to use GIS's interpretative techniques to determine the relationship between, on the one hand, the morphometric parameters at sub basin level and, on the other hand, the characteristics of land, soil physics and eroded lands.

II. STUDY AREA

Tirunelveli, the name was composed of three Tamil phrases i.e. "Thiru-Nel-Veli" i.e. "Sacred Paddy Hedge." This district is fertile because of the Tambaraparni River. This district's history is linked to that of the Pandya, just like Madurai and Ramanathapuram.

The Ambasamudram research zone, passing through the district of Tirunelveli in Tamil Nadu, India. Located between 8.7 ° N 77.47 ° E, as of 2001, the entire taluk had a population of 392.226, with 42.5 percent being categorized as rural. Area coverage of 142187 population density is 734.84sq.kms. The Manimuthar river lies between 8o 40'57"N at latitude 8o 68'25"N and 77o 23'15"E at longitude 77o38'75"E. The total running length of the river is 85 km. The command of the Ambasamudram has a gross area of 11652 Ha research area Fig 1.

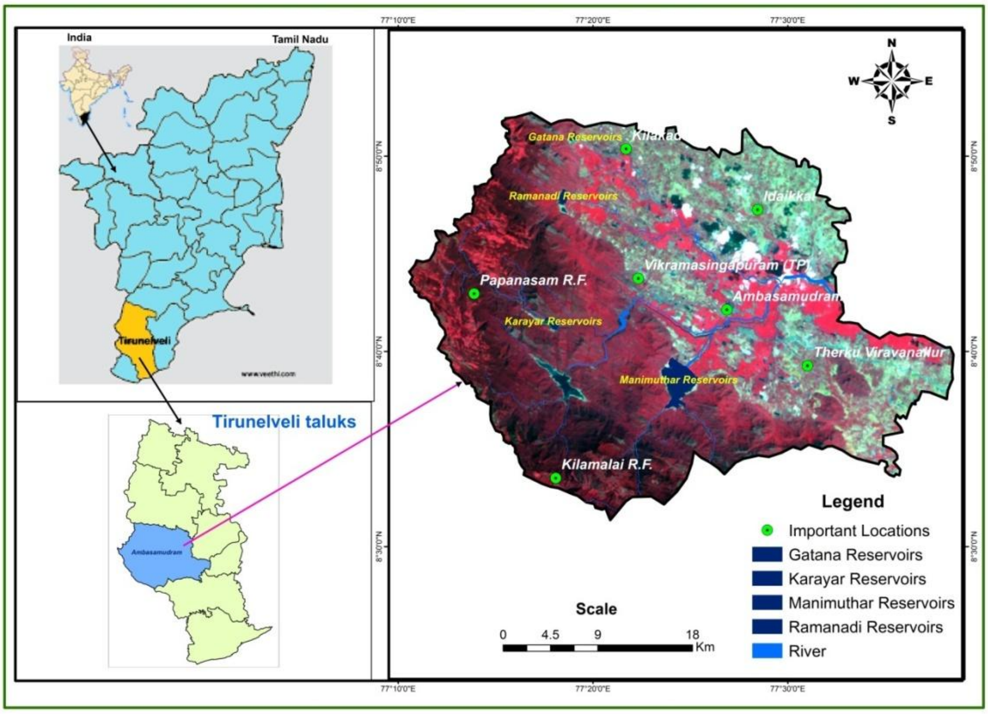

Fig.1 Location Map of the Study Area

III. METHODOLOGY

The Indian Remote Sensing (IRS)-P6 Satellite Linear Image Self Scanning (LISS) – III sensor data were collected and registered to Survey of India (SOI) topographical sheets at 1:50,000 scale in the ERDAS image analysis system version. 9.2. The Tamiraparani subbasin of Tirunelveli district was delineated based on the water divide line concept. The drainage network of the basin was traced on transparency and digitized as available on toposheets

(1:50,000) and some of the first order steams were updated with the help of satellite sensor data. The elevation model was generated based on the contour values of 500 m interval to generate height and slope maps. The morphometric analysis was carried out at sub basin level in the Spatial Analysis GIS System (ArcGIS) methodology flow chart (Fig. 2). Some areas have been left out in the process of delineation of sub basins and were considered as unclassified. Based on the drainage order, the drainage channels were classified into different orders (Strahler, 1964). 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 sub basin area, perimeter, cumulative length of streams and basin length were measured in GIS and are expressed as A, P, L and Lb respectively. Parameters such as ruggedness number (Rn), drainage density, bifurcation ratio, stream frequency (Fu), texture ratio, form factor (Rf), circulatory ratio (Rc), elongation ratio (Re) and constant of channel maintenance (C) were evaluated with established mathematical equations [9] (Table 1). The Study was contacted for Ambasamuthram sub basin of Tirunelveli district. Base information is extracted from toposheets. Satellite data (2019) was used to extract landform characteristics.

The evaluated morphometric parameters were grouped as linear, relief and areal parameters. Delineation of landforms, soil boundaries and degraded lands identified based on image color, texture, size, shape, drainage pattern and association recognition elements in the satellite data like Differential erosion characteristics of the satellite imagery in conjunction with drainage morphometry and collateral data has been used. Subsequently detailed landform analysis has been carried out based on their genesis, relief and their morphometric characteristics. The detailed methodology adopted is shown in Fig. 2.

Table 1 Morphometric parameters and their mathematical expressions

Sl. No.	Morphometric parameter	Formula	Description
1	Cumulative length of streams (L)	$L = \sum Nu$	L was calculated as the number of streams in each order and total length of each order was computed at sub basin level
2	Bifurcation ratio (Rb)	$Rb = Nu/(Nu + 1)$	Rb was computed as the ratio between the number of streams of any given order to the number of streams in the next higher order
3	Basin relief (Bh)	$Bh = h_{max} - h_{max}$	Bh was defined as the maximum vertical distance between the lowest and the highest points of a sub basin
4	Ruggedness number (Rn)	$Rn = Bh \times Dd$	Rn was calculated as the product of the basin relief and its drainage density
5	Drainage density (Dd)	$Dd = L/A$	Dd was measured as the length of stream channel per unit area of drainage basin
6	Stream frequency (Fu)	$Fu = N/A$	Fu was computed as the ratio between the total number of streams and area of the basin
7	Texture ratio (T)	$T = N(1/P)$	T was estimated as the ratio between the first order streams and perimeter of the basin
8	Form factor (Rf)	$Rf = A/(Lb)^2$	Rf was computed as the ratio between the basin area and square of the basin length
9	Elongation ratio (Re)	$Re = (2/Lb) \times A/\sqrt{A}/P\pi$	Re was computed as the ratio between the diameter of the circle having the same area as that of basin) and the maximum length of the basin
10	Constant of channel maintenance (C)	$C = km^2/km$	C is expressed as the inverse of drainage density

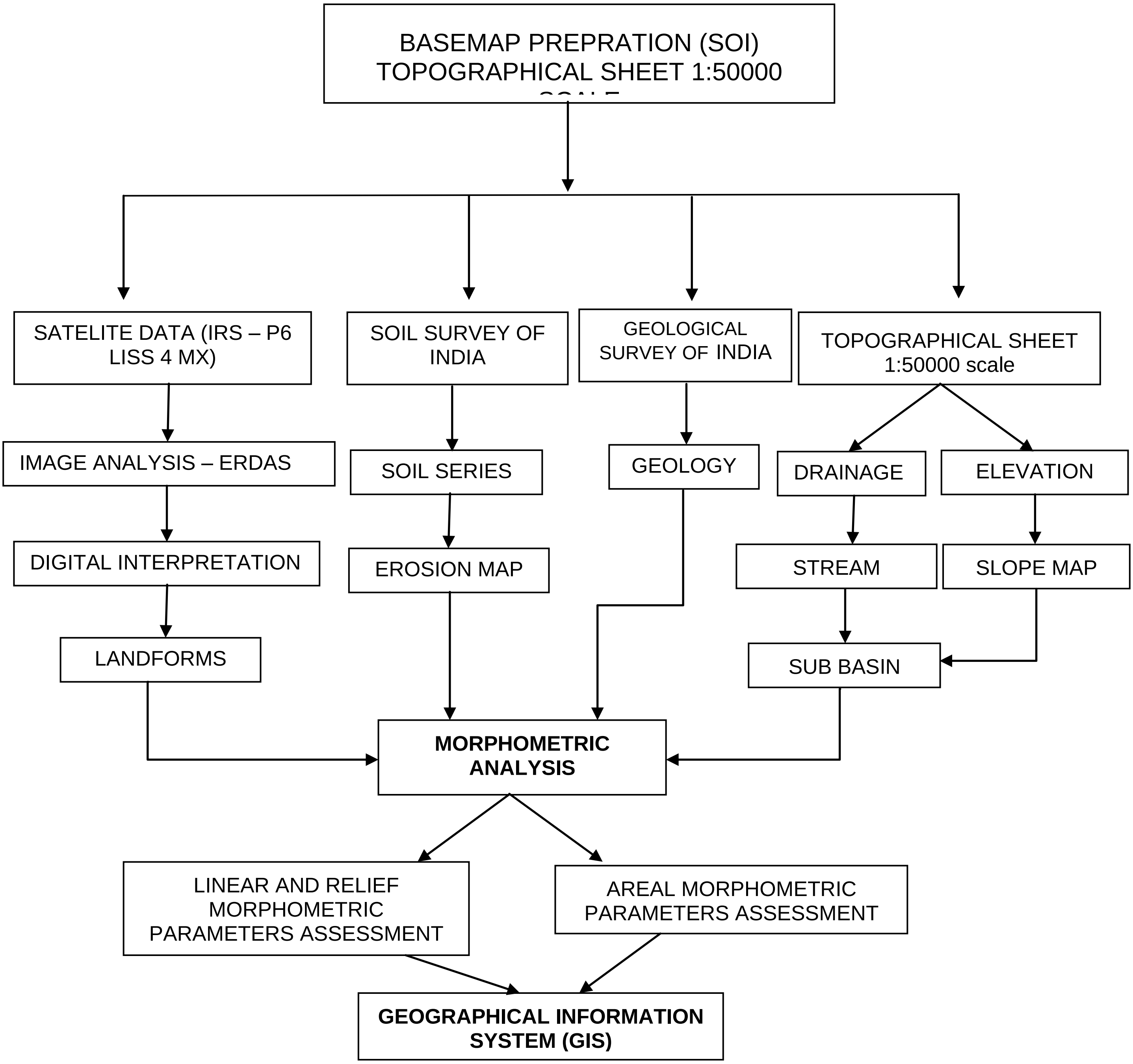

Fig. 2 Flow Chart - Methodology Adopted for Drainage Morphometry Studies

RESULTS AND DISCUSSION

I. Regional Geology

The geology of the study area is predominantly underlain by crystalline rocks of Archean age, which consists of gneisses, charnoc kites, granites, and basic and acidic intrusive rocks. Archean series gneisses and charnoc kites are typical Western Ghats crystalline rocks. Hornblende biotite gneisses and blended gneisses connected with migmatites are found in the south eastern portion of the subbasin. On the other side, the western part is characterized by Khondalitic migmatic assemblage of garnetiferous biotite gneisses and garnetiferous sillimanite graphite gneiss assemblages are found in the northwest areas. In connection with charnoc kites and garnetiferous biotite gneiss, some tight bands of calc-granulites are seen. These bands differ in length from 5 to 15 m and width from 1 to 5 m. The geological features are digitized from Geological Survey of India map using ArcGIS software. The detailed geological map of the study area is shown in Fig 3.

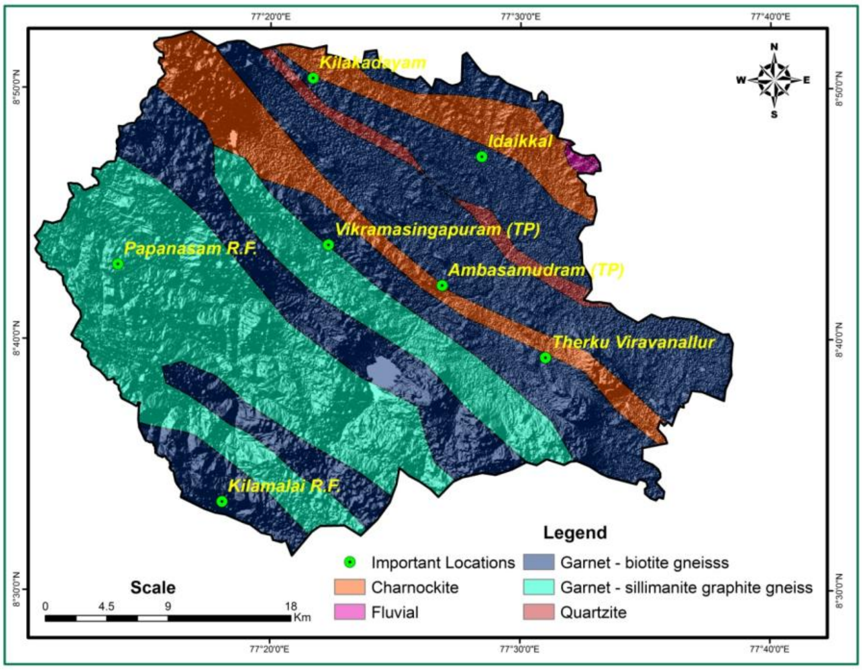

Fig. 3 Geology Spatial Distribution Map

II. Evaluation of morphometric parameters

A complete drainage area of 734.84sq.kms is covered by the Tamiraparani sub basin. The SRTM DEM has been achieved with a 90 m pixel size covering the entire region of research. The growth of drainage networks relies, apart from exogenic and endogenous factors, on geology and precipitation. A basin's morphometry is the measurement and mathematical assessment of the Earth's landform surface, shape and size. This assessment can be accomplished by measuring linear, aerial and relief elements of the contributions to the basin and slope. Assessing the growth of the study area's drainage networks can provide some hints for understanding the study area's geomorphic procedures and hydrological features. The parameters of the linear elements are stream order, flow number, bifurcation ratio, basin length and perimeter.

III. ELEVATION AND SLOPE

Elevation and slope play a major role in managing a terrain's stability. The slope affects the direction and quantity of surface runoff or underground drainage that reaches a site. Slope has a dominant impact on rainfall's contribution to stream flow. It regulates overland flow length, infiltration, and underground flow. The combination of the corners of the slope basically describes the shape of the slope and its relation to the lithology, structure, soil type and drainage. A smooth / flat surface that enables the water to flow rapidly is a disadvantage and creates flooding, while a greater roughness of the surface may slow down the flood reaction.

Steeper slopes are more prone to runoff on the ground, while flat ground is prone to water logging. Compared to high gradient slopes, low gradient slopes are extremely susceptible to flood events. In an region where the slope gradient is generally small, rain or excessive river water always collects. Areas with elevated gradients of slope do not allow water to accumulate and cause flooding. If the primary problem is the flood induced by the river, the difference in elevation of the different DEM cells from the river could be regarded, whereas it would be more essential for local pluvial flood depressions, i.e. DEM cells with reduced altitude than the surrounding ones. This means that the association between elevation and danger is crucial.

The slope map was prepared in this research using ArcGIS software's digital elevation model (DEM) and slope generation instruments. In the research fields, the recognized slope category is different from 0 ->600. Fig.5 shows the slope courses and their map of spatial distribution.

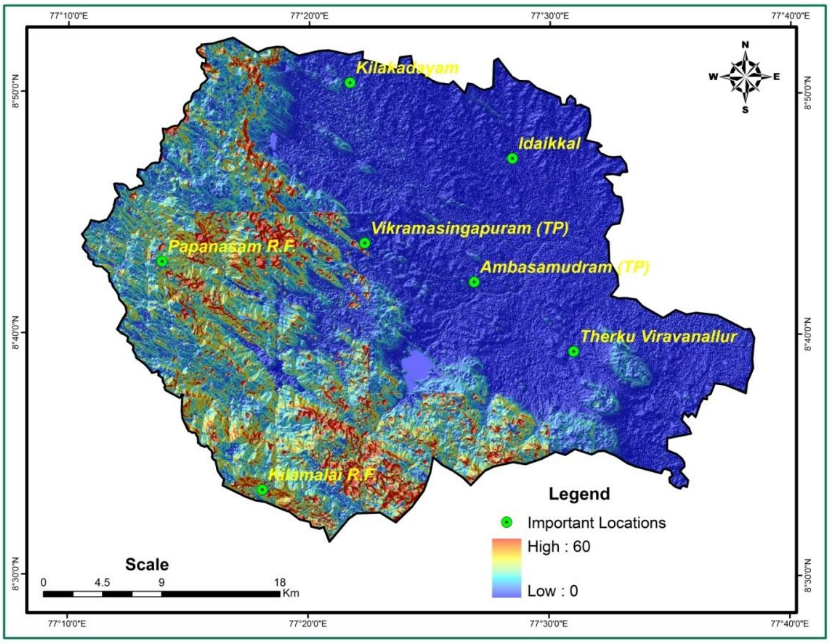

Fig. 5 Slope Spatial Distribution Map

MORPHOMETRIC PARAMETERS

I. Relative relief

Relative relief is an significant morphometric variable used to evaluate any topography's morphological features. The complete study area relief is 1,776 m. In the western portion of the study region, which contains the Western Ghats, the elevated relief value is noted and shows the gravity of water flow, low infiltration and elevated flood conditions.

II. Stream order (U)

The flow order is a precondition for any watershed assessment and is based on a systematic hierarchical stream ranking. The flow order of the Tamiraparani subbasin was categorized by Strahler [9] classification scheme in the current research. The stream without tributaries is defined as a stream of the first order, and when two streams of the first order join, they become second order, and so on. Table 2 shows the order-wise flow figures. For the research region, the largest stream order corresponds to the sixth order of the map shown in Fig.6. The assessment shows that the features of the stream confirm Horton's first law [7] "Law of stream numbers," which states that the amount of streams in a specified drainage basin tends tightly to approximate an inverse geometric ratio. The fluid order and sub-basin differences are mainly due to the region's physiographic and structural circumstances. In the case of first order streams and then for second order, the maximum stream order frequency is observed. It is therefore observed that the frequency of the stream is decreasing as the order of the stream rises and vice versa.

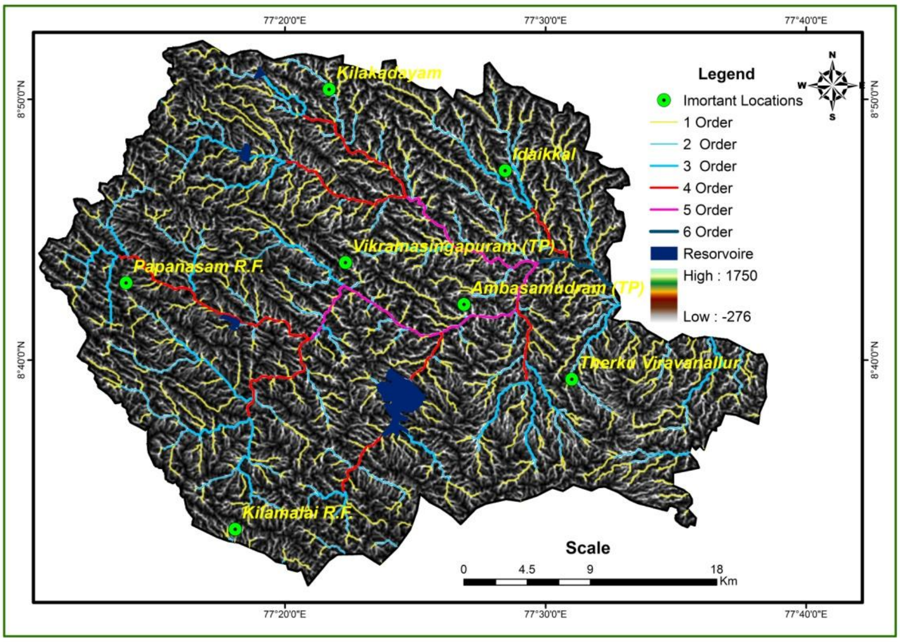

Fig.6. Drinage map

III. Stream number (Nu)

The count of stream channels in each order is termed as stream order. As per Horton's law [7] of stream numbers, the number of streams of different orders in a given drainage basin tends closely to approximate as inverse geometric series of which the first term is unity and the ratio is the bifurcation ratio.

The number of streams counted for each order is plotted on a logarithmic scale on the y axis against arithmetic scale order on the x axis, according to this law. In GIS platforms, the number of streams of various orders and the total number of streams in the basin are counted and calculated. The amount of streams current in a basin is the complete amount of streams. It is evident that as the stream order rises, the complete amount of streams gradually reduces. The complete amount of streams of each order has been calculated using GIS instruments and is shown in Table 2.

IV. Stream length (Lu)

According to Horton [7], stream lengths delineate the total stream segment lengths of each of a basin's successive orders tend to approximate a direct geometric series where the first term is the average stream length of the first order. The length of the stream is a measure of the bedrock's hydrological features and the magnitude of drainage. Wherever the rock and the structure are permeable, only a tiny amount of comparatively longer streams are created in a well drained watershed, a big amount of smaller streams are created in which the rocks and formations are less permeable.

Table 2 shows the outcome of the order-wise stream duration. It is observed that in first-order streams the cumulative stream duration is greater and reduces as the order of the stream rises. The largest stream order is 64.32 kilometers long.

V. Mean stream length (Lsm)

Mean flow duration (Lsm) shows the distinctive size and contributing surfaces of a drainage network elements [9]. The Lsm is a characteristic property associated with the size of parts of the drainage network and its contributing basin surfaces. The Lsm was calculated by separating in the order the complete stream length of order "u" and number of segment streams (Table 1). The Lsm values differ between 0.72 and 64.32 km in the study region. It is noted that Lsm is greater than that of the lower order of any given order and less than that of its next higher order in the subbasin.

VI. Stream length ratio (RL)

Stream length ratio (Rl) is the proportion of one order's mean length to the next reduced flow segment order [7]. The length ratio of the subbasin stream was calculated using the formula shown in Table 1. The subbasin value of Rl ranges from 1.33 to 6.08 (Table 2). Rl between consecutive stream orders differs owing to variations in slope and topographical circumstances and has a beneficial connection with the sub-basin ground flow discharge and erosional phase.

VII. Bifurcation ratio (Rb)

The word bifurcation ratio can be described as the ratio of the amount of stream sections of a specified order to the amount of sections of the next greater order, according to [12]. This is a very significant parameter expressing the extent of the drainage network's ramification. The bifurcation ratio indicates a tiny variety of variations for various areas in distinct settings except where strong geological control prevails [8]. The subbasin Rb values range from 3.14 to 7.00 and are shown in Table 2. In the study area, the higher Rb value indicates a strong structural control in the drainage pattern while the lower value indicates that structural disturbances affect the subbasin less. [9]. The Rb values are observed to fluctuate from one order to the next. These changes rely on the drainage basin's geological and lithological growth.[9]. However, between fifth / sixth-order streams there is a steep reduction in Rb values (Table 2). This can be ascribed in the plain fields due to minimal structural disturbances. The mean bifurcation ratio (Rbm) for a basin typically varies from 3.0 to 5.0 when the impact of geological structures on the drainage network is negligible (Verstappen 1983). Rbm of the study area is 4.77, which indicates that the geological structures have little influence on the drainage networks.

Table 2 Results of morphometric analysis of Tamiraparani subbasin

S. no.	Parameters	Stream orders					
		I	II	III	IV	V	VI
1	Stream order (u) (Total)	10,028	2,096	463	98	22	7
2	Stream length (LU)	3,796.65	1,517.72	803.24	385.80	174.46	74.00
3	Mean stream length (km) (Lsm)	0.38	0.72	1.73	3.94	7.93	10.57
4	Stream length ratio (RL)		1.91	2.40	2.27	2.01	1.33
5	Bifurcation ratio (Rb)		4.78	4.53	4.72	4.45	3.14
6	Mean bifurcation ratio (Rbm)	4.77					
7	Perimeter (P) (in km)	227.67					
8	Basin length (Lb) (km)	67.85					
9	Basin area (km2)	2,055.02					

10	Total relief (R) (m)	1,776.00					
11	Relief ratio (Rh)	0.0261					
12	Elongation ratio (Re)	0.75					
13	Length of over land flow (Lg)	0.60					
14	Drainage density (D) (km/km2)	3.32					
15	Stream frequency (Fs)	6.19					
16	Texture ratio (Rt)	20.52					
17	Form factor (Rf)	0.45					
18	Circulatory ratio (Rc)	0.50					

VIII. Relief ratio (Rh)

The relief ratio is described, according to [12] as the horizontal distance along the basin's shortest dimension parallel to the main drainage line. Rh is an indicator of erosion process intensity working on the slopes and a drainage basin's general steepness. The research area's value of' Rh' is 0.0261. It is an indicator of the intensity of erosion procedures that operate on the basin slopes

IX. Drainage density (Dd)

Drainage density (Dd) is a measure of a specified basin's complete stream length to the complete basin region [9]. Factors that regulate the characteristic length of the watershed affect the drainage density. Drainage density is associated with multiple landscape dissection characteristics such as valley density, channel head source region, relief, weather and vegetation [13], soil and rock properties [14] and landscape evolution processes. The quantity of precipitation and gradient of the slope directly affects the surface runoff quality and characteristics. The subbasin's water density is 3.32 km2 which suggests that the subsurface strata's nature is permeable because the density values are less than 5.0 km2. The research area's Dd map is shown in Fig. 7.

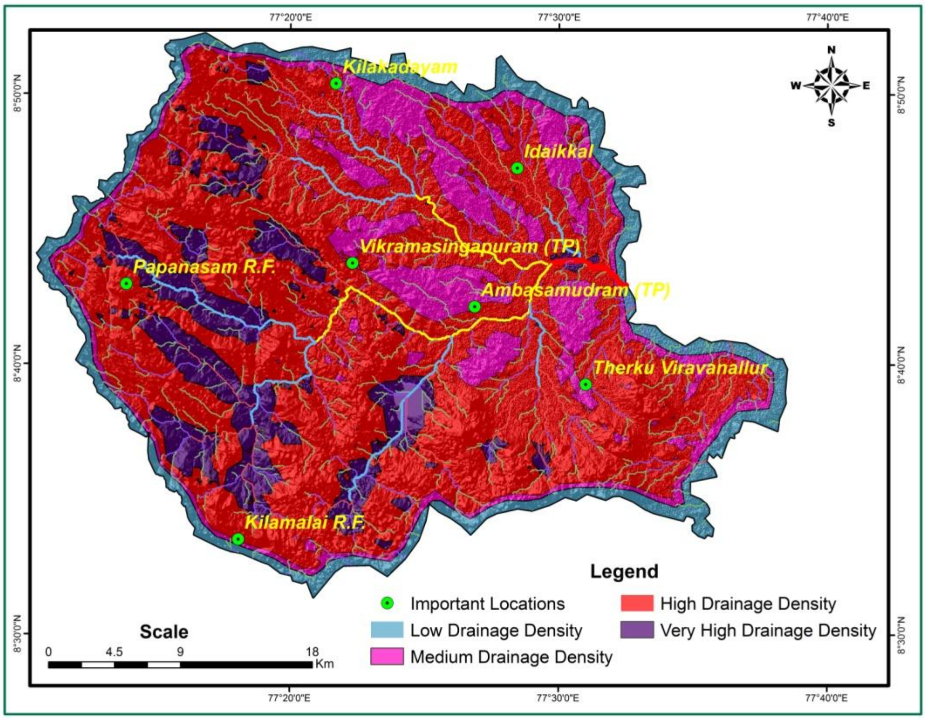

Fig.7 Drainage Density Map

X. Elongation ratio (Re)

The elongation ratio (Re) is described as the diameter ratio of a circle with the same region as the basin and the maximum length of the basin [12]. It is a measure of the river basin's form and depends on the kinds of weather and geology. In runoff discharge, a circular basin is more effective than an elongated basin [15]. Re' values vary from 0.6 to 1.0 across a broad range of climatic and geological kinds. Very low relief basins have values close to 1.0, while elevated relief and steep slope basins have values ranging from 0.6 to 0.8. (Strahler 1964). These values can be grouped into three categories, namely (a) circular (>0.9), (b) oval (0.9–0.8), and (c) less elongated (<0.8). The 'Re' value of the study area is 0.75 (Table 2), which indicates that the subbasin is less elongated with high relief and steep slope.

XI. Stream frequency (Sf)

A basin's flow frequency can be described as the complete amount of flow orders per region per unit. It relies primarily on the basin's lithology and represents the drainage channels ' texture. The research area's Fs is 6.19 km / km2. It is noted that the stream frequency is strongly associated with the subbasin's drainage density value. This shows that the rise in the population of streams is linked to the rise in drainage density. High Fs show the high relief and elevated ability of the bed rocks to infiltrate. Channel frequency density serves as a instrument for determining the erosion procedures running over an region ; more specifically, the same in relation to stream orders and their features offers information that can shed light on the sequences of relief events and the degree of roughness in the region. [16].

XII. Form factor (Rf)

The shape factor is described as the basin area proportion and basin length square. The value of the form factor will be greater than 0.78 for a perfectly circular basin and the lower value indicates that the basin is longer. The research area's' Ff' value is 0.45 which shows that the sub-basin is slightly elongated and subcircular.

XIII. Circularity ratio (Rc)

Circulatory ratio is the proportion of the basin region to the circumference region of a circle equal to that of the reservoir perimeter [17]. It is affected by the basin's width, stream frequency, and lithology. It is an important proportion that shows a basin's dendritic phase. Its low, medium and high values are reflective of the basin's life cycle's youth, mature, and ancient phases. The research area's' Rc' value is 5.0 which shows that they are less elongated and distinguished by elevated to mild relief and structurally controlled drainage system.

CONCLUSION

GIS modeling application merged with remote sensing has proved to be an effective instrument for landscape morphometry. The Tamiraparani subbasin's computed morphometric features show that this area is dominated by lower-order streams. A sixth order drainage basin with a maximum flow order length of 74.00 km is displayed in the research region. The gradient of the incline varies from 0 to 61 °, and the western portion of the study region shows a large degree of slope. Floods are natural phenomena that can not be avoided. However, human activity contributes to an rise in the probability of severe flood occurrences and negative effects. First, the scale and frequency of floods are likely to rise owing to climate change, which will bring greater rainfall intensity and rising sea levels, as well as inadequate river management and construction in flood plains, which will reduce their ability to absorb flood waters. Second, there is a continuing increase in the amount of individuals and financial resources in flood risk areas. The research area aspect map shows the predominance of the east-facing slopes in the western portion. As a result, the slopes to the east have a greater humidity content and a reduced evaporation rate than the slopes to the west in the south. The elevated moisture content of the eastern slope may be subject to elevated weather conditions as compared to the dry slopes and this situation may change the morphology of the stream channel. The variation in the length ratio of the flow may be due to variations in slope and topographical circumstances. The bifurcation ratio in the research region shows that the geological structures have little impact on the drainage networks and the drainage density suggests that the subsurface strata are permeable with a very good drainage texture. The elongation and circulatory proportion shows that with elevated stability and steep slope, the sub basin is less elongated. The current research is useful for sub-basin level landscape management in Tamil Nadu and the extraction model for any basin morphometric assessment will be useful for time-efficient research.

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