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MORPHOMETRIC AND HYPSOMETRIC ANALYSIS OF LOKAPAVANI RIVER BASIN USING ARCGIS

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Abstract: Morphometric analysis is one of the important aspects of planning for implementing watershed management programmes. The present study evaluates the morphometric characteristics of the Lokapavani River basin in Mandya District of Karnataka by the use of Cartosat-1 data (CartoDEM) using ArcGIS. The aerial, linear, and relief morphometric parameters of the watershed have been evaluated. The drainage map of the study area reveals a sub-dendritic drainage pattern with a fifth-order stream network with an area of 483.44 km². The Mean bifurcation ratio of the basin is 3.251 which indicates that the geological structures do not disturb the pattern of the drainage. The drainage density of the Lokapavani river is 0.988 km/km2 which indicates very coarse texture, higher infiltration, and permeability with sparse vegetation and moderate to low relief. The Elongation ratio of 0.565 and the form factor of 0.25 signifies the basin to be an elongated shape. The geologic stage of development and erosion proneness of the basin is quantified by hypsometric integral (HI) bearing value as 0.5 for lokapavani basin, indicating the landscape to be uniform and in the mature stage. The use of ArcGIS in the present study is proved to be highly useful in extracting the characteristics for the evaluation and analysis of watershed characteristics.

***Keywords*– Morphometric analysis, CartoDEM, Hypsometric integral value, ArcGIS.**

I. INTRODUCTION

The earth's surface have been structured into watersheds, naturally on which Hydrologists and Geomorphologists are interested in the study of spatial variability in a watershed. Morphometric parameters are of great utility in lake basin evaluation, watershed prioritization, soil and water conservation, and natural resources management .These can be better studied and explained through quantitative analysis. Drainage morphometric analysis gives overall view of the terrain information like hydrological, lithological, relief, variations in the watershed, ground water recharge, soil characteristics, flood peak, rock resistant, permeability and runoff intensity and is useful for geological, hydrological, ground water projection, civil engineering and environmental studies. These parameters affect catchment stream flow pattern through their influence on concentration time (Jones, 1999). The significance of these landscape parameters was earlier pointed out by Morisawa (1959), who observed that stream flow can be expressed as a general function of geomorphology of a Watershed. Morphometric analysis provides quantitative description of the basin geometry to understand initial slope, structural controls, geological and geomorphic history of drainage basin.The Morphometric analysis is mathematical calculation of the linear, areal and relief parameters. It is the measurement and mathematical analysis of the configuration of the earth’s surface, shape, dimension of its landforms (Clarke, 1966). Morphometric analysis requires measurement of linear features, gradient of channel network and contributing ground slopes of the drainage basin (Nautiyal 1994). Morphometric analysis provides quantitative description of the basin geometry to understand initial slope, the rock hardness, structural controls, geological and geomorphic history of drainage basin (Strahler 1964). Morphometric analysis is a significant tool for prioritization of sub watersheds even without considering the soil map (Biswas et al., 1999). Morphometric analysis of drainage basins thus provides not only an stylish description of the landscape, but also serve as a powerful means of comparing the form and process of drainage basins that may be widely separated in space and time (Easterbrook, 1993). Geographical Information System (GIS) techniques have been used for assessing various terrain and morphometric parameters of the drainage basins and watersheds as they provide a flexible environment and a powerful tool for the manipulation and analysis of the spatial information, particularly for the future identification and extraction of the information for better understanding. The available surface and ground water resources are inadequate to meet the growing water demands due to rapid urbanization and increasing population. The demand for water has increased over the years, due to which the assessment of quantity and quality of water for its optimal utilization is necessited.

Hypsometric analysis is the relationship of horizontal cross-sectional drainage basin area to elevation. The hypsometric curve has been termed the drainage basin relief graph. Hypsometric curves and hypsometric integrals are important indicators of watershed conditions (Ritter, 2002). Differences in the shape of the curve and hypsometric integral values are related to the degree of disequilibria in the balance of erosive and tectonic forces (Weissel, 1994). Hypsometric analysis was first time introduced by

Langebein (1947) to express the overall slope and the forms of drainage basin. The hypsometric curve is related to the volume of the soil mass in the basin and the amount of erosion that had occurred in a basin against the remaining mass (Hurtrez, 1999). It is a continuous function of non-dimensional distribution of relative basin elevations with the relative area of the drainage basin (Strahler, 1952). This surface elevation has been extensively used for topographic comparisons because of its revelation of three-dimensional information through two-dimensional approach (Harrison, 1983; Ro-senblatt and Pinet, 1994). Comparisons of the shape of the hypsometric curve for different drainage basins under similar hydrologic conditions provides a relative insight into the past soil movement of basins. Thus, the shape of the hypsometric curves explains the temporal changes in the slope of the original basin. Strahler (1952) interpreted the shape of the hypsometric curves by analysing numerous basins and classified the basins as young (convex upward curves), mature (S-shaped hypsometric curves which is concave upwards at high elevations and convex down-ward at low elevations) and peneplain or distorted (concave up-ward curves) as shown in figure 1. 1. There is frequent variation in the shape of the hypsometric curve during the early geomorphic stages of development followed by minimal variation after the watershed attains a stabilized or mature stage. The integration of the hypsometric curve gives the hypsometric integral (HI),which is equivalent to the elevation-relief ratio (E) as proposed by Pike and Wilson (1971). Based on the values obtained from the hypsometric integral cycle of erosion can be divided into the three stages that is, monadnock (old) (HI <0.3), in which the watershed is fully stabilized; equilibrium or mature stage (HI 0.3 to 0.6); and in equilibrium or young stage (HI > 0.6), in which the watershed is highly susceptible to erosion (Strahler, 1952). The cycle of erosion is the total time required for reduction of land area to the base level Hypsometric curves and hypsometric integral is important watershed health indicator. The hypsometric Integral Employing Geographical Information System (GIS) techniques in hypsometric analysis of digitized contour maps helps in improving the accuracy of results and save time.

II. STUDY AREA

The analysis is carried out for Lokapavani river, which is one of the tributary of river Cauvery. The Lokapavani river originates at Honakere in Nagamangala taluk and takes a course flowing through Nagamangala, Pandavapura, Srirangapatna and Mandya taluk and it joins Cauvery at Sangam near Srirangapatna. Two dams have been constructed across this river, one near Uyyanahalli of Nagamangala taluk and the other at Bolenahalli of Melkote hobli. The catchment is located between the 12º30′ N and 12º45’N and 76º25′ E and 76º50′ E geographically. The Lokapavani river has an area of 483.4 km² and the perimeter of 123.3 km (fig.2.1).

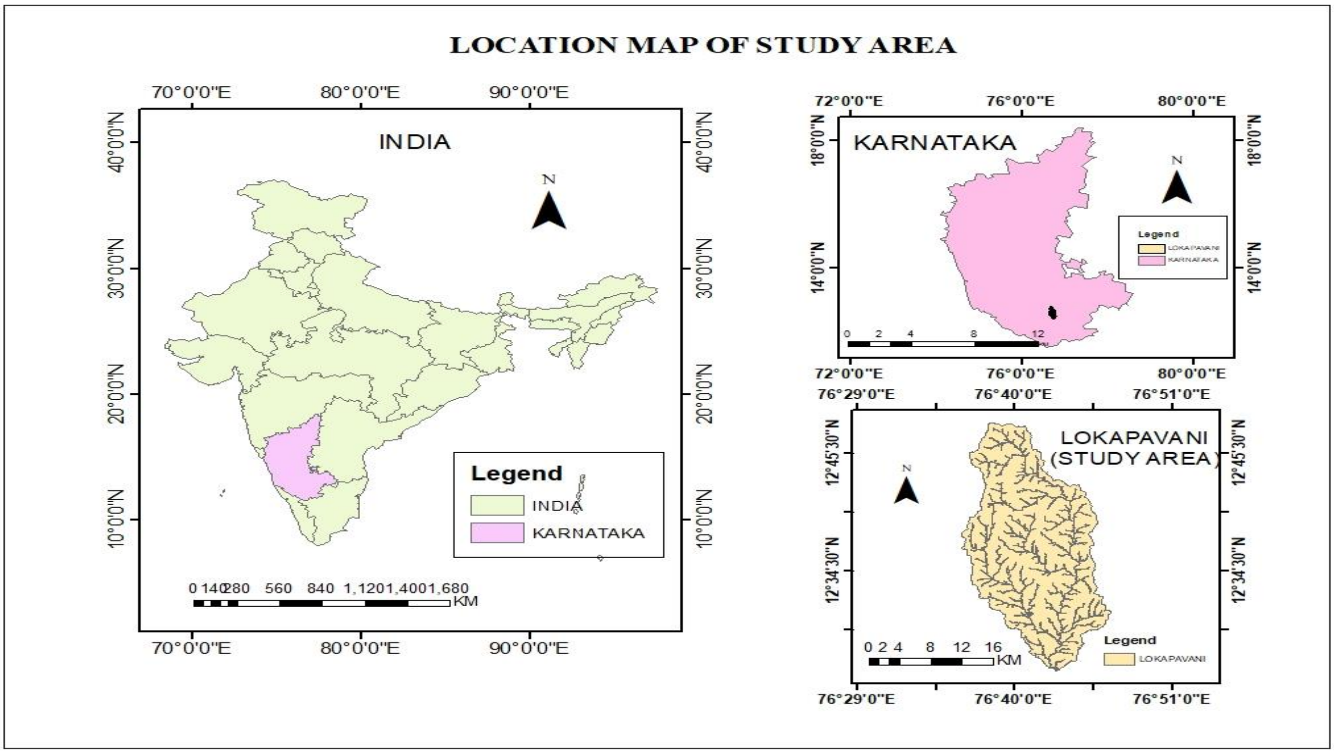


Fig 2.1 : Location map of Lokapavani river basin.

The annual rainfall in the catchment is about 600 mm to 800 mm. The catchment is divided into two zones. In the first zone, 35% of the total catchment area is irrigated by Vishweswarayya Canal and Chikkadevaraya Sagar Canal (CDS) from KRS reservoir. Remaining is the rainfed zone. The major crops in the study area are sugarcane, paddy, mulberry, coconut, jowar, finger millet, maize and betel nut. People grow both kharif and rabi crops in the command area.

III. MATERIALS AND METHODOLOGY

The boundary of Lokapavani river basin has been found using Survey of India (SOI) topographical maps No. 57D/13, 57D/15, 57D/14, 57D/11, 57D/10, 57D/9, 57D/5, 57D/7 and 57D/6 at 1:50,000 scale were used. The morphometric parameters and hypsometric parameters of a basin, i.e., extraction of river basin boundary and extraction of drainage/stream network from the Lokapavani river is carried out using CartoDEM obtained from Cartosat-I. The CartoDEM was downloaded from the BHUVAN website.

The methodolgy for the present study involes the automatic extraction techniques for evaluating the parameters of the Lokapavani River basin, using DEM, ArcGIS and georeferenced SOI toposheets. All the topographical maps were mosaiced and georeferenced with the help of ArcGIS version 10.3. After georefrencing of the images, they are rectified and re sampled into a Universal Transverse Mercator projection WGS 1984, Zone 43 North. Arc-Hydro tools in ArcGIS 10.3 have been used to derive basin boundary, drainage pattern and watersheds within the basin to understand the morphological parameters. The determination of the morphometric analysis involves the process from filling the sinks in DEM. Following the DEM fill, flow direction was calculated. In order to generate a drainage network, flow accumulation has been taken into account based on the direction of flow of each cell. The watersheds were delineated by giving pour points where water flows out of an area. The longest drainage length was digitized and converted to vector data using ArcGIS 10.3. The derived basin boundary was then converted to vector data called "shapefile" and named as watershed polygon from which the area and perimeter of Lokapavani river basin was calculated in attribute table of ArcGIS. Stream order was determined accordance with Strahler (1964) and stream length for each order in Lokapavani river basin were determined using ArcGIS 10.3. as shown in fig. 4.3.The stream numbers were found using the editor tool that is by merging the streams segments of the same order leading to next next higher order.These morphometric parameters are useful in understanding the hydrological process of the drainage basin. The methodology of the morphometric analysis is as shown in the flowchart below.

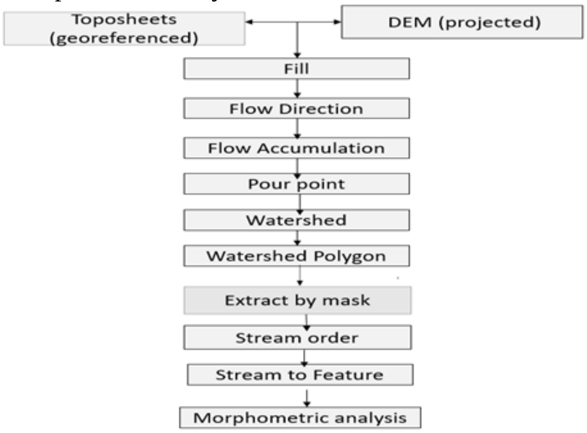


Fig 3.1 : Flowchart of Morphometric Analysis

Hypsometric analysis aims at developing a relationship between horizontal cross-sectional area of the watershed and its elevation. The digital contour map was used to generate the data required for relative area and elevation analysis The hypsometric analysis for the Lokapavani area is carried out using ArcGIS tools. The hypsometric curve is typically represented as distribution of the relative height (e/E) with relative area (a/A) (Strahler 1952). The contours were digitized to generate the line feature class in Arc-GIS which was further processed using the spatial analyst, the hydrology tool of spatial analyst module. The attribute tables of the georefrenced feature classes representing the contours and their enclosed area with the watersheds boundary contained the elevation and length of contours and their respective area and perimeter values. The attribute feature classes containing these values were used to plot the hypsometric curve of the watersheds as shown in the flowchart 3.2.The hypsometric curves for the basin were prepared based on Strahler (1952) method. Hypsometric integrals of the basins have been calculated by Elevation-relief ratio using empirical formula proposed by Pike and Wilson (1971).

The relationship of elevation-relief ratio method is given by,

$$E = \frac{\text{Emean} - \text{Emin}}{\text{Emax} - \text{Emin}}$$

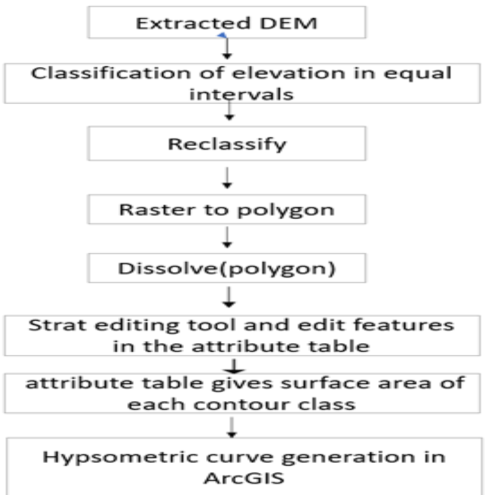


Fig 3.2 : Flow Chart for Generation of Hypsometric Curve

IV.RESULTS AND DISCUSSION

4.1 MORPHOMETRIC ANALYSIS

The morphometric analysis of Lokapavani catchment is carried out using ArcGIS which is a suitable tool to derive the morphometric parameters. The analysis was carried out through measurement of linear, aerial and relief aspects of basins. The morphometric parameters were useful in understanding the hydrological processes of the drainage basin.

4.1.1 Linear aspects

Linear aspects include the measurements of linear features of drainage such as stream order, stream length, stream length ratio, bifurcation ratio, length of overland flow and drainage pattern.

Stream order

The stream order is a measure of degree of stream branching within a watershed. The stream ordering is calculated using Strahler's(1984) method where every fingertip stream is the first-order stream while the second-order stream forms just below the junction where the two first-order streams join together. Thus, according to Strahler's, the two same order streams join to form a next order stream and the process continues till the trunk stream of the highest order. The Lokapavani river is a 5th order river (fig 4.1)

Stream number

The order wise total number of stream segment is known as the stream number. The Lokapavani river is a fifth order stream including the number of streams as 241,50,8,2 and 1 as first, second, third, fourth and fifth order streams respectively. The data reveals that the number of stream segments decreases with increase in stream order (fig 4.2). The decrease in the number of stream segments is experienced because when a channel of lower order joins a channel of higher order, the channel downstream retains the higher of the two orders (Chow et al, 1988).

Stream length

Stream length is one of the most significant hydrological features of the basin as it reveals surface runoff characteristics. Horton's law of stream lengths supports the theory that geometrical similarity is preserved generally in watershed of increasing order. Stream length is one of the important hydrological feature of the basin which reveals the surface runoff characteristics. Streams with relatively short lengths are representative of areas with steep slopes and finer textures whereas longer lengths of stream are generally indicative of low gradients.in the present study, results show that the total length of stream segments is more in case of first order streams and decreases with the increase in the stream order as shown in the table 1 and figure 4.3. This discrepancy is attributable to variations in relief andlithology. It is noticed that stream segments of 1st and 2nd order are characterized by steep to moderate slopes while the 3rd , 4th and 5th order stream segments occur in comparatively plain lands.

Mean stream length

It is a dimensional property revealing the characteristic size of components of a drainage network and its contributing watershed surfaces. It is obtained by dividing the total length of stream of an order by total number of segments in the order. Generally, it is observed that the mean stream length of any given order is greater than that of the lower order but less than that of the next higher order.

Stream length ratio

Horton states that the length ratio is the ratio of the mean of segments of order to mean length of segments of the next lower order which tends to be constant throughout the successive orders of a basin. Horton law of stream lengths refers that the mean stream lengths of stream segments of each of the successive orders of a watershed tend to approximate a direct geometric sequence in which the first term (stream length) is the average length of segments of the first order.In the present study, the mean stream length ratio of the stream order is not constant as shown in the table 1.

Bifurcation ratio

It is defined as the ratio of the number of the stream segments of given order to the number of segments of the next higher orders,Schumm(1956). The bifurcation ratio is a dimensional property and it ranges between 3 and 5 for watersheds in which the geologic structures do not distort the drainage pattern. According to Strahler, in a region of uniform climate and stage of development, the ratio tends to remain constant from one order to next order. The irregularities of the drainage basin depend upon lithological and geological development, leading to changes in the values from one order to the next. An elongated watershed has higher bifurcation rtaio than the normal watershed and circular watershed. In the present study, it is 3.251 the lower value which indicates Lokapavani river basin is not affected by structural disturbances.

Length of overland flow

The length of overland flow is a measure of erodibility, and is one of the independent variable affecting both the hydrologic and physiographic development of the drainage basin. The length of overland flow is approximately equal to one half of the reciprocal of the drainage density. The shorter the length of overland flow, the quicker the surface runoff from the streams. The overland flow of the lokapavani river is 0.506 which indicates low surface runoff.

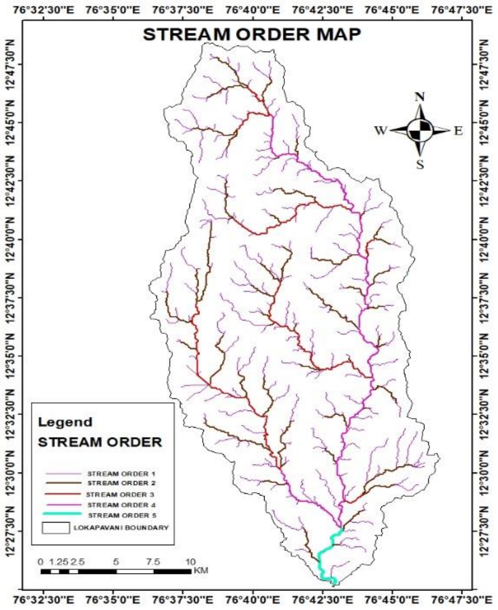
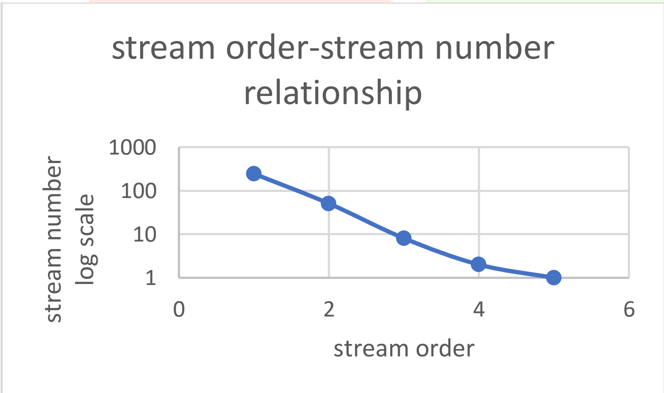


Fig 4.1 : Stream Order Map of Lokapavani River

Sl No	stream order	stream number	stream length (km)	Mean stream length(km)	Bifurcation ratio	Mean bifurcation ratio	stream length ratio	Cumulative stream length	Basin length (km)
1	1	241	247.451	1.027	2.099			247.451	
2	2	50	117.915	2.358	2.174		2.297	365.366	
3	3	8	54.258	6.782	1.066	3.251	2.877	419.624	43.92
4	4	2	50.929	25.465	7.664		3.755	470.553	
5	5	1	6.646	6.646			0.261	477.199	

Table 1 : Linear Parameters of the Lokapavani River



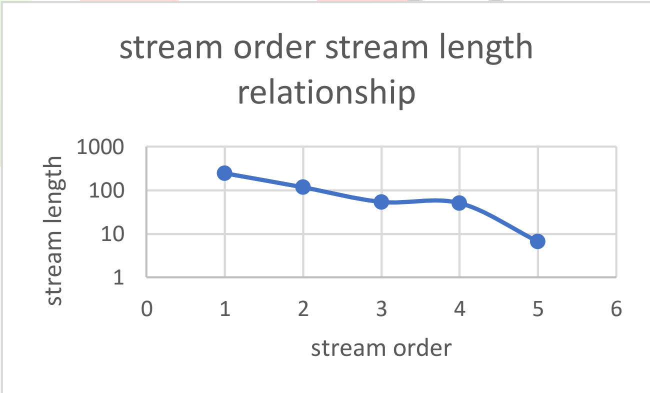


Fig 4.2 : Stream Order and Stream Number Relationship

Fig 4.3 : Stream Order and Stream Length Relationship

4.1.2 Areal aspects

Area and perimeter of a watershed are two important parameters in quantitative morphometry..The area and perimeter of the Lokapavani river basin is 483.44km^2 and 123.2km respectively. The aerial aspects of the drainage basin such as basin area, drainage density, stream frequency, elongation ratio, circularity ratio and form factor ratio, constant of channel maintenance are calculated and results have been given in Table 2**.**

Drainage density

Drainage density is defined as the total length of streams of all orders to total drainage area. Low drainage density generally results in the areas of highly resistant or permeable sub-soil material, dense vegetation and low relief. High drainage density is the result of weak or impermeable sub-surface material, sparse vegetation and mountainous relief. Low density leads to coarse drainage texture while high drainage density leads to fine drainage texture.If the drainage density is less than 1.24, the texture is very coarse. If it is 1.24-2.49 then has coarse texture,2.49-3.73 then the texture moderate.If the value is 3.73-4.97 then, the texture is fine while less than 4.97 it is very fine. The drainage density of lokapavani river is 0.988km/km^2 indicating very coarse texture and high infiltration.

Stream frequency

It is the ratio of a total number stream of all order of the drainage basin and the area of the drainage basin. It is an index of various stages of landscape development and depends on the nature and amount of rainfall, the nature of rock and soil permeability of the region. The stream frequency of the Lokapavani river is 0.625/km^2 indicating the low frequency and higher permeability.

Elongation ratio

It is the ratio of the diameter of a circle of the same area as the watershed to the maximum length of the watershed (Schumm, 1956). If the ratio is 0.9, then it is circular and if 0.8-0.9 then, it is oval. If it has the ratio of 0.7-0.8 then it is less elongated and elongated if 0.5-0.7 while more elongated if less than 0.5. The elongation ratio of the Lokapavani river is 0.565 indicating the elongated shape.

Circulatory ratio

Circulatory ratio is defined as the ratio of basin area to the area of the circle having the same parameter as the basin(Miller). It is a dimensionless parameter. A circular basin has a maximum runoff while, an elongated basin has the least. The circulatory ratio for the Lokapavani river is 0.401, indicates the elongated shape.

Form factor

Form factor is defined as the ratio of the area of the basin and square of the basin length (Horton, 1932). The value of the form factor varies from 0 which indicates highly elongated shape to the 1 which indicates circular shape.The form factor for the lokapavani basin is 0.25 which indicates it is a elongated shape and thus it has a lower peak flow.

Constant of channel maintenance

Constant of channel maintenance is the inverse of drainage density(schumm, 1956). It not only depends on rock type permeability, climatic regime, vegetation, relief but also as the duration of erosion and climatic history. The constant is extremely low in areas of close dissection.The constant of channel maintanenace of the Lokapavani river basin is 1.013km.

Compactness coefficient

Compactness coefficient is the perimeter of the basin to the circumference of a circle whose area is equal to the area of the watershed.The compactness coefficient of the lokapavani river is 1.581 indicating that the basin is not in circular shape.

Form factor	0.25
Compactness coefficient	1.581
Circulatory ratio	0.401
Elongation ratio	0.565
Constant of channel maintenance	1.013
Stream fequency	0.625
Drainage density (km/km2)	0.988

Table 2 : Areal Parameters of the Lokapavani River

4.1.3 Relief aspects

The relief aspects of the drainage basin involves the study of three dimensional features involving area, volume and altitude of vertical dimension of landforms. The relief aspects of the basin has been given in the table 3.

Basin relief

Basin relief is the difference in elevation between the remotest point in the water divide line and the discharge point of the basin. The highest relief in the basin is found to be 975m above the mean sea level and the lowest relief is 579m above the mean sea level. The basin relief calculated for the basin is 0.396 km indicating low denudational rates.

Relief ratio

Relief ratio is the ratio of maximum watershed relief to the horizontal distance along the longest dimension of the watershed parallel to the principal drainage line (Schumn, 1956). It measures the overall steepness of a watershed and is an indicator of the intensity of erosion processes operating on slopes of the watershed. The relief ratio of the lokapavani river is 0.01 therefore has gentle slope.

Relative relief

Relative relief is defined as the ratio of the maximum basin relief to the perimeter of the watershed. The relative relief of the lokapavani river is 0.0079.

Ruggedness number

It is defined as the product of the basin relief and drainage density, Strahler (1958). An extremely high value of ruggedness number occurs when both basin relief and drainage density are large and the slope is generally steep. The ruggedness number for lokapavani river is 0.39 thus, the slope is gentle.

Basin relief	0.396km
Relief ratio	0.01
Relative relief	0.0079
Ruggedness number	0.39

Table 3 : Relief Aspects of the Lokapavani River

4.2 HYPSOMETRIC ANALYSIS

The coordinates of the hypsometric curve of the Lokapavani river basin is obtained and plotted as shown in Fig 4.4. It was observed from the hypsometric curves, that the drainage system is in Mature or Equilibrium stage. It was also observed that there was a combination of convex-concave and S-shape of the hypsometric curves for the Lokapavani basin which might be due to soil erosion resulting from the incision of channel beds, down, washout of the soil mass and cutting of streams.The parameters required for plotting the hypsometric curve and hypsometric integral is given in table 4. The hypsometric integral was found using the relation given by Pike and Wilson (1971) and it was found that the hypsometric integral value was found to be 0.5 indicating the mature or equilibrium stage of soil.The elevation map of the lokapavani river is shown in fig 4.5.

Sl no	Elevation reclassified	Elevation (m)	area (a)	Cumulative area (A)	e	e/emax	a/A	Hypsometric integral	Geological stage
		975	32.1604	32.1604	396	0.406154	0.066529	0.5	Mature or equilibrium stage
1	579-623	931	87.0254	119.1858	352	0.361026	0.180025		
2	623-667	887	102.794	221.9798	308	0.315897	0.212645		
3	667-711	843	91.226	313.2058	264	0.270769	0.188715		
4	711-755	799	52.7657	365.9715	220	0.225641	0.109154		
5	755-799	755	35.6928	401.6643	176	0.180513	0.073836		
6	799-843	711	40.2953	441.9596	132	0.135385	0.083357		
7	843-887	667	34.7436	476.7032	88	0.090256	0.071873		
8	887-931	623	6.70283	483.40603	44	0.045128	0.013866		
9	931-975	579							

Table 4 : Hypsometric Curve and Hypsometric Integral Calculations Of Lokapavani River

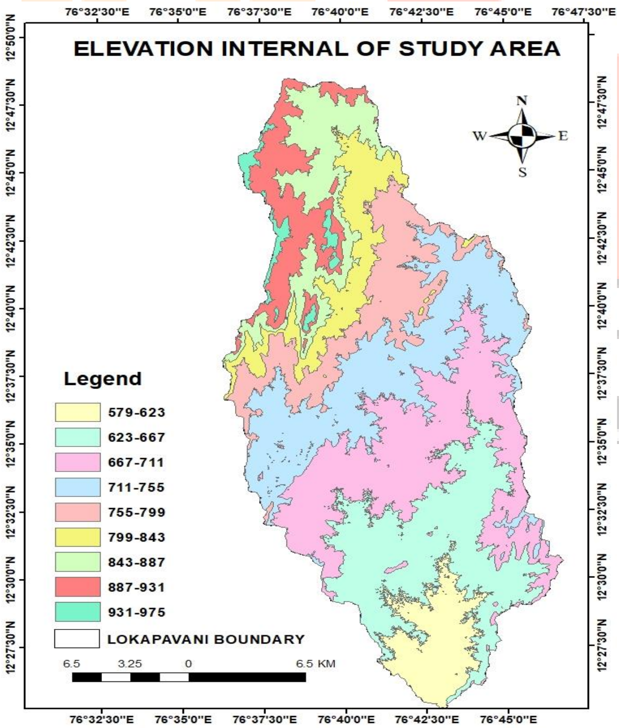


Fig 4.4 : Elevation Interval Map Of Lokapavani Area

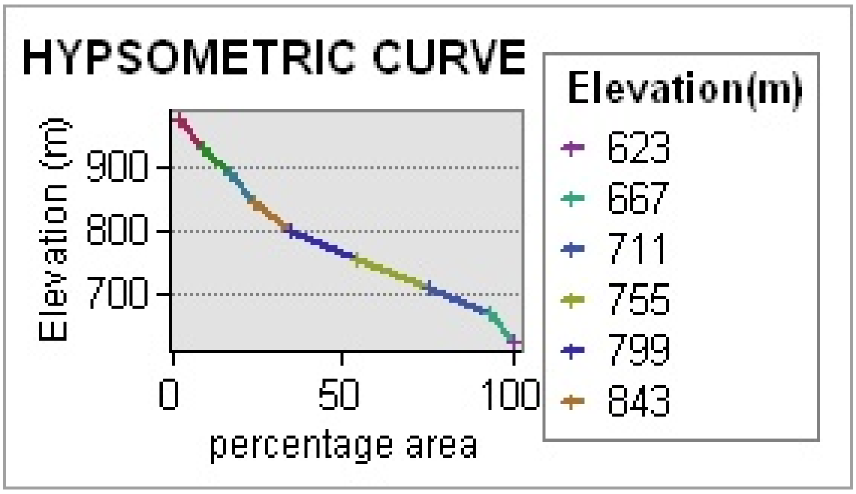


Fig 4.5 : Hypsometric Curve of Lokapavani River

V.CONCLUSION

The Morphometric and Hypsometric analysis of the Lokapavani river reveals that ArcGIS based approach is more appropriate and time saving than the conventional methods. It is observed that morphometric parameters were carried out through linear, areal and relief aspect of the Lokapavani river basin and found out that drainage network of this basin shows sub-dendritic pattern, which indicates the homogeneity in texture and the bifurcation ratio of the study area is not same from one order to its next order. It is found out that drainage density of 0.988 km/km2 was indicated that the basin is not much affected by structural, geological disturbances and indicates the very coarse texture of the watershed. The drainage frequency for the basin was indicated low relief and permeable sub surface material, while very coarse drainage texture indicates good permeability of sub-surface rocks and soils with high infiltration. The form factor, circularity ratio and elongated ratio suggest the basin shape as elongated and lesser relief and slope are characterized by moderate value of relief ratios. Hypsometric curve obtained from hypsometric analysis clearly shows that the watershed is in equilibrium or mature stage and the Hypsometric integral value works out to be 0.5 from Elevation Relief ratio method.

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