

RESEARCH ARTICLE

MORPHOMETRIC ANAYSIS OF THE MAJOR VALLEY SYSTEMS AROUND BENGALURU

Pavithra C.J¹, Balakrishna H B² and Aravinda P.T³

- 1. Reseach Scholar, Bangalore Institute of Technology, Bengaluru, Karnataka, India.
- 2. Professor and Head, Department of Civil Engineering, Bangalore Institute of Technology, Bengaluru, Karnataka, India.
- 3. Assistant Professor, Government Engineering College, Ramanagara, Karnataka, India.

..... Manuscript Info

Abstract

..... Manuscript History Received: 25 May 2021 Final Accepted: 29 June 2021 Published: July 2021

Key words:-

Hebbal Valley, Kormangala-Valley(K-C Challaghatta Valley), Morphometry, Vrishabhavathi Valley(V-Valley)

The three major Valley systems of Bengaluru namely Vrishabhavathi Valley, Hebbal Valley and Kormangala-Challaghatta Valley houses many lakes and play a very important role in its hydrological processes. The morphometric analysis helps us to learn about the characteristics of the underlying rock type, pervious nature of soil, slope gradients, runoff behavior and water retention potential within the Valley systems. Morphometric analysis was carried out for Linear, areal and relief aspects. The Survey of India topographical maps and Digital Elevation Model data were used to prepare the base map and the drainage maps with the help of GIS software. The Strahler system of stream ranking was adopted. Among the three Valleys, Vrishabhavathi Valley is observed to be the largest Valley in terms of area and perimeter. Vrishabhavathi Valley basin has sixth order stream as the highest stream order where as the other two Valleys have fifth order stream as the highest order. The drainage pattern formed within the Vallev systems was observed to be dendritic. The watershed shape factor showed that the Vrishabhavathi Valley is elongated in shape where as the K-C Valley and the Hebbal Valleys are less elongated in shape comparatively. The drainage density of the three Valleys revealed that they fall under coarse drainage density classification. The relief aspects of the three Valleys exhibit low reliefs indicating a flat surface. This helps in designing a sustainable management plan for the three major Valley systems in terms of their conservation and also ensure sustainable soil and water usage within the Valley systems.

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Introduction:-

Bengaluru, popularly called as "The City of Lakes" is located in the semi-arid peninsular plateau in the southeastern part of Karnataka. Bengaluru and its surrounding regions are not supported by perennial river system, but has three major Valley systems namely Vrishabhavathi Valley, Hebbal Valley and Kormangala-Challaghatta Valley and few minor Valleys. These three major Valleys play an important role in Bengaluru's hydrological processes. Morphometric analysis is very important to analyse the physical, characteristics, hydrological processes and drainage patterns in the study area. Linear aspects, areal aspects and relief aspects of the catchment area are considered for the morphometric analysis. Morphometric analysis helps to obtain the mathematical relationships

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Corresponding Author:- Pavithra C J

Address:- Reseach Scholar, Bangalore Institute of Technology, Bengaluru, Karnataka, India.

between various attributes of streams. It also helps to understand the relationship of various aspects within a drainage basin and compare various basins developed under different topographical and geo-morphological regimes. The Linear aspects include stream order, stream length, bifurcation ratio etc. Areal aspects include area, perimeter, watershed shape factor, drainage density, drainage texture, stream frequency etc. Relief aspects include watershed relief, relief ratio, relative relief, ruggedness number etc. Remote sensing and Geographic information systems are powerful systems which are very useful for carrying out the morphometric analysis.

Materials and Methods:-

Preparation of the Base Map

The road networks, railway lines, water bodies, stream networks were digitized using the Survey of India (SOI) Topographical map of 1:50,000 scale using ArcGIS Software. Satellite data was used to update the data in the preparation of the base map.



Figure 1 :-Base Map of the study area

Morphometric analysis

Morphometric analysis was carried out to analyze the physical characteristics, hydrological processes and drainage patterns in the three Valley systems. Linear, areal and relief aspects were considered for the analysis.

Linear aspects

Linear aspects include the measurements of linear features of drainage such as stream order, stream length, stream length ratio etc and are discussed below.

Stream order (N_u)

The drainage map was first prepared using SOI Topographical map and SRTM (Digital elevation model) satellite data. Stream ordering is very important for the drainage basin analysis and systematic mapping of any river system/streams. Strahler system of stream ranking [22] was followed in the present study and ArcGIS Spatial Analyst Hydrology tool was used for stream ordering. Strahler system of stream ordering is a "top down" approach where stream segments are ordered numerically from stream's headwater to a desirable point downstream called an outlet. In this system, the ordering begins with the tributaries at the stream's headwaters being assigned as one(smallest, outermost, unbranched tributaries). When the two-first order stream joins, a second-order stream is formed. When two second-order stream segments meet, a third-order stream is formed and so forth. The higher order stream is always associated with the high discharge, The stream segment of the highest order called the trunk stream/principal stream. It is the one through which all the discharge of sediments and water passes.

Bifurcation ratio(**R**_b)

Bifurcation ratio is defined as the ratio of number of segments of a given order (N_u) to the number of streams of the next higher order (N_{u+1}) by Schumm [18]. According to Horton, the bifurcation ratio varies from a minimum of 2 in

"flat or rolling drainage basins" to 3 to 4 in "mountains or highly dissected drainage basins". Bifurcation ratio is a prime parameter in the drainage basin analysis of the Valley systems because it helps to link the hydrological regime of the watershed under topological and climatic conditions. It helps in interpreting the shape of the catchment and its runoff behavior. The following expression was used to calculate the Bifurcation ratio

$$R_b = \frac{N_u}{N_{(u+1)}}$$

Where, $R_b = Bifurcation ratio;$ $N_u =$ number of stream segments of u or $N_{(u+1)} =$ number of streams of the (u+1) order.

Stream length(Lu)

Stream length is the total length of streams in the given catchment area or any watershed. The length of the stream is an indication of the contributing area of the catchment. The streams of various order were counted and their lengths measured using ArcGIS software. The total length of stream segments decreases with increasing order of the streams. Deviation from this general behavior indicates that the terrain is characterized by moderately steep slopes and/or high relief, underlain by varying lithology and probable uplift across the basin (Singh and Singh 1997)[19]. Steep well drained areas have numerous small tributaries.

Mean Stream length(L_u)

The mean stream length is calculated by dividing the total stream length of order $u(L_u)$ by the number of streams(N_u). The unit of mean stream length is represented in Kms. It indicates the characteristic size of the components of a drainage network and its contributing basin surfaces. Topography of the catchment has influence on the mean stream length. The following equation was used to calculate the mean length of the channel.

$$\overline{L_u} = \frac{\sum_{i=1}^{N} L_u}{N_u}$$

3.7

Where $\overline{L_u}$ is the Mean length of channel of order u in Km Lu is the total stream length of order u i Nu is the total number of stream segments of order u.

Stream length ratio (L_u)

It is defined as the ratio of the stream length of any stream order to the next lower order of the stream segments (Horton, 1945). Horton also states that the stream length ratio will remain constant throughout the successive orders of the stream and the variation is mainly due to the slope as well as topographical changes in the basin area. The equation used to calculate the stream length ratio is expressed as

$$R_L = \frac{\overline{L_u}}{\overline{L_{(u-1)}}}$$

Where L_u = Average length of the stream length of order u in Km L (u-1) = Average length of stream of next lower order in Km

Length of Overland Flow (L₀)

Length of overland flow is the flow of water over the surface before it gets drained into a definite stream channel. The length of overland flow is a measure of its erodibility. It is one of the independent variables affecting both the hydrologic as well as physiographic development of the drainage basin. Horton[7] defined the length of overland flow as the length of flow path, projected to a horizontal plane of the rain flow from a point on the drainage divide to

a point on the adjacent stream channel. It is approximately equal to one half of the reciprocal of the drainage density. The shorter the length of the overland flow, the surface runoff is more faster. It is inversely related to the average slope of the channel.

Areal Aspects

Areal aspects of a watershed or basin is defined as the total area projected upon a horizontal plane contributing overland flow to the channel segment/streams of the given order and includes all tributaries of lower order. Areal aspects include area and perimeter of the drainage basin, drainage pattern, drainage density, stream frequency etc.

Area and Perimeter

The area and perimeter of the Valley basins were directly measured with the help of ArcGIS software using calculate geometry tool.

Drainage Pattern

A drainage system is the pattern formed by the rivers, streams and lakes in a particular fashion in the drainage basin. It is the planimetric arrangement of streams on the land surface forming a drainage system. The drainage pattern may reflect the bedrock type (hard rock or soft rock), the original slope and structure, landforms, modification of the earth surface(uplift depression, tilting etc), structural elements (faulting, folding, warping etc) and soil characteristics. It is also controlled by the topography of the land, structural and lithological aspects. The drainage pattern may be dendritic or deranged, parallel, rectangular, radial, trellised, annual, angular and centripetal.

Watershed shape factor

Watershed shape is the shape of projected surface on the horizontal plane of the watershed map. The shape of a watershed has a profound impact on the runoff and sediment transport process. The shape of the catchment also regulates the rate at which water enters the stream. The quantitative expression can be characterized in terms of form factor, compaction coefficient, circularity ratio, and elongation ratio. Form factor (R_f)

Horton[7] defined form factor as the ratio of the area of the watershed to the square of the watershed length and is expressed as;

Form factor(
$$R_f$$
) = $\frac{A}{L^2}$

Where, Rf = Form factor A = Area of the watershed in sq.km L =Length of the watershed in km

Compactness coefficient (Cc)

Compactness coefficient of a watershed is the ratio of perimeter of watershed to the circumference of circular area, which is equal to the area of that watershed. The Cc is independent of size of watershed and depends only on the slope. A circular watershed is most susceptible to runoff from a drainage stand point as it yields the shortest time of concentration before peak flow occurs in the watershed. Compactness coefficient is directly proportional to elongation of the basin and a perfectly circular basin has its Cc as unity.

Compactnes s coefficien $t = \frac{Perimeter of the watershed}{Circumfere nce of a circle whose area is}$ equal to the area of the watershed

Compactness Coefficient =
$$\frac{P}{2\sqrt{\pi A}}$$

Where, P = Perimeter of the watershed in km

A= Area of the watershed in sq. km

Circularity ratio (R_c)

Circularity ratio is the ratio of the area of watershed to the area of circle having the same circumference as that of the perimeter of the watershed (Miller, 1953)[11]. The value of Circularity ratio ranges from 0.2 to 0.8. Lower Rc values indicate strongly elongated basin. It is expressed as

$$R_c = \frac{4\pi A}{P^2}$$

Where, Rc = circularity ratioA = watershed area in sq. km P = Perimeter of watershed in km

Elongation ratio (Re)

The elongation ratio is defined as the ratio of diameter of a circle of the same area as the watershed to the maximum watershed length (Schumm, 1956)[17]. It is expressed as

$$R_e = \frac{2\sqrt{A/\pi}}{L}$$

Where, Re is the elongation ratio A is watershed area in sq. km L is length of the watershed in km

The value of the elongation ratio ranges from 0.4 to 1, lesser the value, more is the elongation of the watershed. We can find many classifications and the one mentioned in the table 1 below is used in the present study.

Table 1:-Watershed shape ratio

Watershed	Shape ratio
Circular	0.9
Oval	0.8-0.9
Less elongated	0.7-0.8
Elongated	0.5-0.7
More elongated	<0.5

Drainage density (D_d)

 $\sum_{i=1}^{N} L_{u}$

Drainage density is defined as the ratio of total length of all streams to the area of the basin or watershed. It represents the closeness of the spacing of channels. It is expressed as km/Sq.km. It is one of the important indications of the linear scale of landform elements in stream eroded topography and it varies inversely with the length of the overland flow. In the areas of higher drainage density the infiltration is less and runoff is more. The wells in this region of low drainage density will have good water potential leading to higher specific capacity of wells. Thus, it indirectly indicates the groundwater potential. Drainage density is collectively influenced by climate, topography, soil infiltration capacity, vegetation, and geology. It is mathematically expressed as:

$$D_{d} = \frac{\sum_{i=1}^{N} L_{u}}{Dranage \ density}(D_{d}) = \frac{Cumulative length \ of \ all \ the \ stream \ segment}{Area \ of \ the \ watershed}$$

Where = Cumulative length of all streams in km. A = Area of watershed in sq. km.

Drainage texture

Drainage texture is the total number of stream segments of all the orders in a river basin/catchment to the perimeter of the basin. Unit of drainage texture is km-1.

Constant of channel maintenance (c)

Constant of channel maintenance is defined as the inverse of drainage density (Schumm, 1956)[17]. It indicates number of Sq.km of watershed required to sustain one linear Km of channel and is expressed as sq km/km. It depends on relief, rock type permeability, vegetation, climatic regime along with the duration of erosion. The equation can be expressed as

$$C = \frac{1}{D_d} \quad Sq.km/km$$

Where, $D_d =$ Drainage density.

Stream frequency (S_f)

$$S_f = \frac{\sum_{i=1}^{K} N_u}{A}$$

Horton (1932) defined the stream frequency or channel frequency as the total number of stream segments of all orders per unit area. Stream frequency is dependent on lithology of the basin and the drainage texture. The equation used is given as

$$\sum_{i=1}^{K} N_{u}$$

Where, = Total no. of stream segments, A = Total area of watershed in Sq. km

The pattern of stream frequency based on number of streams/Sq. km. given by Horton is shown in table 2 below

Stream frequency	No. of streams/Sq.kms
Low	0-5
Moderate	5-10
Moderate high	10-15
High	15-20
Very high	20-25

Table 2:- Stream frequency pattern based on Number of streams/ Sq. km

Relief Aspects

Relief aspects are the significant parameters which help to understand the denudation processes within the catchment and are also the indicator of the water flow direction.

Watershed relief (H)

Watershed relief is the difference in the elevation between the highest point of a watershed and the lowest point on the Valley floor or watershed. It can be either measured on contour map or satellite derived DEM or field measurements. It is expressed by the following equation

H= Elevation of the highest point of watershed - Elevation at the watershed outlet

Relief ratio (Rh)

Relief Ratio is the ratio of maximum watershed relief to the horizontal distance along the longest dimension of the basin parallel to the principal drainage line (Schumm, 1956)[17]. It measures the overall steepness of the drainage

basin and is an indicator of the intensity of erosion processes happening on the slopes of the basin. The high relief ratio indicates high relief and steep slope, where as the low value of relief ratio is mainly due to the resistant basement rocks in the basin and low degree of slope (Mahadevaswamy G. et. al)[9]. It is expressed by the following equation

$$R = \frac{H}{L}$$

Where, H = Total catchment relief in k L = Maximum length of the catchment in km.

Relative relief (R_r)

Relative relief is defined as the ratio of the maximum watershed/catchment relief to the perimeter of the watershed. It is expressed by the equation

$$R_r = \frac{H}{P}$$

Where R_r = Relative relief H = Maximum relief in km. P = Perimeter in km.

Ruggedness number (R_n)

Ruggedness number is defined as the product of the watershed relief and drainage density (Strahler 1964)[22]. It combines steepness of the slope with its length. Larger values of the ruggedness is due to high relief and high drainage density. The lower value of ruggedness number implies that the area has intrinsic structural complexity and is less prone to erosion. It also indicates low relief and drainage density.

$$R_n = HD_d$$

Where $R_n = Ruggedness$ number H = Watershed relief in km. $D_d = Drainage$ density in km/Sq.km.

Results and Discussion:-

The various morphometric parameters computed based on the above mentioned criteria are tabulated in the table 3 below.

Sl No	Morphometric parameter	MorphometricUnitVrishabhavathiHebbal ValleparameterValley		Hebbal Valley	Kormangala- Challaghatta Valley
Ι	Linear aspects				
1	Stream Order				
	Highest stream order	-	Sixth	Fifth	Fifth
	First order streams	-	647	295	302
	Second order streams	-	170	75	74
	Third order streams	-	41	17	19
	Fourth order streams	-	9	5	7
	Fifth order streams	-	2	1	1
	Sixth order streams	-	1	=	-
2	Total number of	-	870	393	403
	streams				
3	Mean Bifurcation ratio	-	3.80	4.17	4.42
4	Cumulative stream length	Km	721.48	365.61	387.58

Table 3:- Morphometric parameters of the three major Valley system.

5	Length of overland flow	Km	0.265	0.426	0.373
II	Areal aspects				
1	Area of the delineated Valley system	Sq.Km	382.5	311.26	289.68
2	Perimeter of the Valley system	Km	136.36	133.97	118.71
3	Basin elongation	Km	34.6	28	25.26
4	Drainage pattern	-	Dendritic	Dendritic	Dendritic
5	Watershed shape factor	-			
	Form factor	-	0.320	0.397	0.454
	Compactness	-	3.130	2.519	2.203
	coefficient				
	Circulatory ratio	-	0.258	0.218	0.258
	Elongation ratio	-	0.638	0.711	0.760
6	Drainage density	Km/Sq.Km	1.886	1.175	1.338
7	Drainage texture	Per Km	6.380	2.933	3.395
8	Constant of channel	Sq.Km	0.530	0.851	0.747
	maintenance	/Km			
9	Stream frequency	No/Sq. km	2.275	1.263	1.391
III	Relief aspects				
1	Total relief	Km	0.280	0.095	0.105
2	Relief ratio	-	0.008	0.003	0.004
3	Relative relief	-	0.002	0.001	0.001
4	Ruggedness number	-	0.528	0.112	0.140

In the present study, the Vrishabhavathi Valley is measured as the largest Valley in terms of area and perimeter. It has sixth order stream as its highest order where as Hebbal and Kormangala-Challaghatta Valleys have fifth order stream as their highest order. The total number of streams respectively in the V-Valley are 870, in the Hebbal Valley 393 and in K-C Valley 403. The stream order map of the three Valleys are shown in the below figures 2, 3 and 4 and the stream order numbers are represented in the above table 3. The bifurcation values calculated for all the three Valleys stay within normal values indicating less structural disturbance and are tabulated in table 4. All the three Valleys exhibit a dendritic drainage pattern. The pattern of the drainage formed in the study area shows well integrated pattern formed by a main stream with its tributaries branching and re-branching freely in all the directions. The dendritic drainage pattern indicates the semi-pervious nature of the soil.





Figure 2:- Stream order map- Vrishabhavathi Valley.





Figure 4:- Stream order map- Kormangala-ChallaghattaValley.

Table 4:-Bifurcation	ratios	of the	three	major	Valley s	ystem
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Sl No	Vrishabhay	vathi Valley	Hebba	al Valley	Kormangala-Challaghatta Valley		
	Number of	Bifurcation	Number of Bifurcation		Number of	Bifurcation ratio	
	streams	ratio	streams	ratio	streams		
1	647	3.80	295	3.93	302	4.08	
2	170	4.15	75	4.41	74	3.89	
3	41	4.56	17	3.40	19	2.71	
4	9	4.50	5	5.00	7	7.00	
5	2	2.00	1	-	1	-	
6	1	-	-	-	-	-	

The stream lengths, mean stream lengths and stream length ratios calculated for the three major Valley system are mentioned in the below table 5.

Table 5:- Stream lengths, mean stream lengths and Stream length ratios of the three major Valley system

Strea m Order	a Vrishabhavathi Valley er				Hebbal Valley				Kormangala-Challaghatta Valley			
	Numb	Strea	Mean	Lengt	Numb	Strea	Mean	Lengt	Numb	Strea	Mean	Lengt

	er of	m	strea	h	er of	m	strea	h	er of	m	strea	h
	stream	length	m	ratio	stream	length	m	ratio	stream	length	m	ratio
	s	(Kms	lengt		S	(Kms	lengt		S	(Kms	lengt	
)	h)	h)	h	
			(Kms				(Kms				(Kms	
)))	
1	647	365.8	0.47	-	295	174.1	0.59	-	302	192.4	0.64	-
2	170	171.7	1.01	0.47	75	93.9	1.25	0.54	74	90.4	1.22	0.47
3	41	83.4	2.04	0.48	17	48.5	2.85	0.52	19	55.60	2.93	0.62
4	9	67.7	7.53	0.81	5	22.2	4.44	0.46	7	28.27	4.04	0.51
5	2	7.6	3.80	0.11	1	26.8	26.78	1.21	1	20.84	20.83	0.74
6	1	25.2	25.23	3.32	-	-	-		-	-	-	-

The watershed shape factor was calculated in terms of form factor, Compactness coefficient, circulatory ratio and elongation ratios. The form factor value of Vrishabhavathi Valley is 0.320, Hebbal Valley is 0.397 and Kormangala-Challaghatta Valley is 0.454. All the three Valleys are elongated in nature and flow for longer duration. The compactness coefficient for Vrishabhavathi Valley is 3.130, Hebbal Valley is 2.519 and Kormangala-Challaghatta Valley is 2.203. The results indicate Vrishabhavathi Valley is elongated and the other two Valleys are less elongated comparatively. The value of Circularity ratio for Vrishabhavathi Valley is 0.258, Hebbal Valley is 0.218 and Kormangala-Challaghatta Valley is 0.258. These values also indicate that the Valleys are elongated in nature. In the present study, the value of elongation ratio for Vrishabhavathi Valley is 0.638 which also indicates that the Valley is elongated. The elongation ratios of Hebbal Valley and Kormangala-Challaghatta Valley are 0.711 and 0.760 respectively, which also indicate that these Valleys are less elongated in shape comparatively.

The drainage density value obtained for Vrishabhavathi Valley is 1.886 Km/Sq.km, Hebbal Valley is 1.175 Km/Sq.km and Kormangala-Challaghatta Valley is 1.338 Km/Sq.km. All the three values have low drainage density values which may be due to low relief and permeable/semi-permeable sub-soil materials. The V-Valley exhibits moderate to fine drainage texture and the other two Valleys coarse drainage texture. This is a collective result of all the geo-morphological and the geological processes. Low value implies low risk of soil erosion. The value of Constant of channel maintenance for Vrishabhavathi Valley is 0.530 Sq.km/km, Hebbal Valley is 0.851 Sq.km/km and Kormangala-Challaghatta Valley is 0.747 Sq.km/km. The result here indicates the less lithological control in the region. The values also depends on rock permeability. relief, vegetation and duration of the rainfall. For the current study areas of Vrishabhavathi Valley, Hebbal Valley and Kormangala-Challaghatta Valley, the stream frequency values are 2.275, 1.263 and 1.391 respectively. The stream frequency of the study exhibit low values and indicates a positive co-relation drainage density.

The total relief calculated for the delineated Vrishabhavathi Valley is 0.280Kms, Hebbal Valley is 0.095Kms and Kormangala-Challaghatta Valley is 0.105Kms. All the three Valleys have low reliefs indicating almost a pediplain or a flat surface as a whole. The value of the relative ratio for Vrishabhavathi Valley is 0.008, Hebbal Valley is 0.003 and Kormangala-Challaghatta Valley is 0.004. The results show that the Slope in the Valley regions vary from nearly level to gentle slope or very gentle slope. The relative relief value of Vrishabhavathi Valley is 0.002, Hebbal Valley is 0.003 and Kormangala-Challaghatta Valley is 0.001. The results show that the Slope in the Valley regions vary from nearly level to gentle slope or very gentle slope. (In few points within the Valley we can notice moderate slope and steep slope). The values of the ruggedness number computed for Vrishabhavathi Valley is 0.528, Hebbal Valley is 0.112 and Kormangala-Challaghatta Valley is 0.140. Low values of ruggedness number indicate low relief and coarse drainage density.

Conclusions:-

Morphometric analysis was carried out for linear aspects, areal aspects and relief aspects. Among the three Valleys, Vrishabhavathi Valley is larger in geographical area and perimeter compared to the other two Valley systems. Vrishabhavathi Valley basin has the sixth order stream as its highest stream order where as the other two Valleys have fifth order stream as their highest order. The mean bifurcation ratios stay within normal values indicating less structural disturbance. The watershed shape factor calculated in terms of form factor, compaction coefficient, circularity ratio and elongation ratio indicates that the Vrishabhavathi Valley is elongated in its shape, where as the K-C Valley and the Hebbal Valley are less elongated in their shape. Drainage density reflects land use and land

cover pattern, which affects the infiltration process and the watershed response time between the precipitation and discharge. It measures how well or poorly a watershed or basin is drained by the stream channels. The V-Valley exhibits moderate to fine drainage texture and the other two Valleys coarse drainage texture. Low Values indicate permeable to semi-permeable subsoil material and low relief. The drainage pattern formed within the Valley systems is dendritic, characterized in irregular branching of tributary streams in all the directions. The dendritic drainage is an indication of lack of structural control. The dendritic drainage pattern is formed in areas with flat and uniform bedrock type(that has not been folded). This drainage pattern indicates that the soil is semi-pervious in nature. The relief aspects of the three Valleys exhibit low reliefs indicating almost a pediplain or a flat surface as a whole. The results show that the Slope in the Valley regions vary from nearly level to gentle slope or very gentle slope. (with few points moderate to steep slope). Relief and drainage density contribute to the ruggedness number. Low values of ruggedness number indicate low relief and coarse drainage density. The morphometric analysis helps us to learn about the characteristics of the underlying rock type, the pervious nature of soil, the slope gradients, the runoff behavior and the water retention potential within the Valley systems. This helps in designing a sustainable management plan for the conservation of three major Valley systems and ensure sustainable soil and water usage within the Valley systems.

Acknowledgment:-

I acknowledge and thank Bangalore Institute of Technology, Karnataka for giving me the opportunity and facilities to conduct my research work.

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