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RESEARCH ARTICLE

Morphometric Analysis of Penna sub-basin in Nellore District using RS and GIS

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Abstract

The study of morphometric analysis of Penna sub-basin has been conducted based on the secondary source, the SRTM data has been downloaded from GLCF website. The downloaded data has been analyzed using ArcGIS software, to study the Linear, Relief and Arial aspects of drainage basin retrieved that, total numbers of streams are 443, in that 181 are first orders, 158 are second orders, 57 are third orders, 45 are fourth orders and 2 are fifth order streams. The streams have been formed in dendritic drainage pattern. The length of stream segments is maximum for first order stream and decreases as the stream order increases. The result of drainage density shows the value 0.286 per square kilo meters in study area, which suggesting that there is more possibility of infiltration, and less surface runoff, highly permeable subsoil and vegetation.

INTRODUCTION

The study of stream order in drainage basin helps to identify the natural environment of a place. The Geographers, Geoscientist, Hydrologist and Geologists study stream order in drainage basin to get idea of the size and strength of specific waterways within stream networks and important component to water management. Stream orders have been classified based on its relative position in the stream network, which helps us to understand the similarities and differences between them. Different types of stream order classification system has been developed, in that one of the earliest method and most commonly used method was developed by Strahler in 1952. The study of streams and waterways in general is known as surface hydrology and is a core element of environmental geography. In recent years development of Geographical Information Systems helps the researchers and scientist to study the stream order accurately and easily. The current study also has been done using GIS technique to analysis the Pennar sub-basin.

Study area

The Penna is a river of southern India which rises on the hill of Nandi Hills in Chikballapur District of Karnataka state, and runs north and east through the state of Andhra Pradesh to empty into the Bay of Bengal. It is 597 kms (371 mi) long, with a drainage basin 55,213 kms^2 (21,318 sq. mi) large. This river basin occupies nearly 55,213 km^2 area. Penna is an interstate river with 6,937 km^2 and 48,276 km^2 river basin area located in Karnataka and Andhra Pradesh respectively. The river basin receives 500 mm average rainfall annually. The river basin lies in the rain shadow region of Eastern Ghats. The present study area is a sub basin of the pennar basins which is in Nellore district of Andhra Pradesh State and cover an area of 3025km^2. The geographical location of drainage basin (Fig.1) is from 79^O22”2.27’ E to 80^O4”58.94’ E and 13^O52”51.12’ N to 14^O25”29.352’ N.

Material and Methods

The study is based on the secondary data. The Shuttle Radar Topographic Mission data has been downloaded from Global Land Cover Facility website. The ArcGIS software has been used to analysis the stream order of drainage basin. The contour map has been prepared from the downloaded topographic elevation data. The Triangulated Irregular Network (TIN) map has been created from the prepared contours, using TIN as an input file the output Digital Elevation Model (DEM) derived. The created DEM has been corrected using FILL tool (which removes the errors such as sinks and eliminates discontinuities) in ArcGIS Hydrology toolset. Flow Direction (Creates a raster of flow direction from each cell to its steepest downslope neighbor), Flow Accumulation (Creates a raster of accumulated flow into each cell. A weight factor can optionally be applied), Stream Order tool in Strahler method (Assigns a numeric order to segments of a raster representing branches of a linear network) and Stream to feature tools have been used to find out pattern of stream in study area. Pour points were selected to delineate the watershed boundary from the main river. Number of stream orders has been calculated using raster file itself and length of each stream have been calculated using the feature (.shp) file in ArcGIS. The length, perimeter and area of drainage basin have been calculated using suitable tools in software. When the necessary data have been collected from the software the Linear, Relief and Arial properties of drainage basin have been analyzed using the method shown in Table 1.

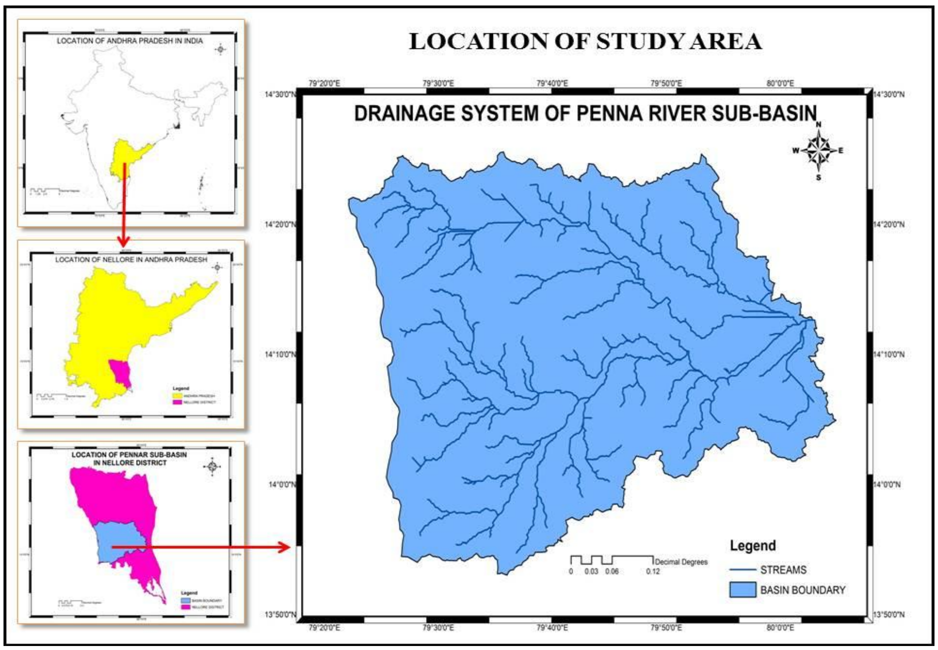

Fig.1: Location of the study area

	Table:1 Methods of Calculating Morphometric parameters of Drainage basin		
	Morphometric Parameters	**Methods**	**References**
LINEAR	Stream order (U)	Hierarchical order	Strahler,1964
	Stream length (L_u)	Length of the stream	Horton, 1945
	Mean stream length (L_{sm})	$L_{sm} = L_u/N_u$ where, L_u=Stream length of order 'U', N_u=Total number of stream segments of order 'U'	Horton, 1945
	Stream length ratio (R_L)	$R_L=L_u/L_{u-1}$; where Lu=Total stream length of order 'U', Lu- 1=Stream length of next lower order.	Horton, 1945
	Bifurcation ratio (R_b)	$R_b = N_u/ N_{u+1}$; where, N_u=Total number of stream segment of order'u'; N_{u+1}=Number of segment of next higher order	Schumn,1956

RELIEF	Basin relief (B_h)	Vertical distance between the lowest and highest points of watershed.	Schumn,1956
	Relief ratio (R_h)	R_h=B_h/L_b; Where, B_h=Basin relief;L_b=Basin length	Schumn,1956
	Ruggedness number (R_n)	R_n= B_h × D_d Where, B_h =Basin relief; D_d=Drainage density	Schumn,1956
ARIAL	Drainage density (D_d)	D_d = L/A where, L=Total length of streams;A=Area of watershed	Horton, 1945
	Stream frequency (F_s)	F_s = N/A where, N=Total number of streams; A=Area of watershed	Horton, 1945
	Texture ratio (T)	T = N_1/P where,N_1=Total number of first order streams; P=Perimeter of watershed	Horton, 1945
	Form factor (R_f)	R_f=A/$(L_b)^2$;where, A=Area of watershed, L_b=Basin length	Horton, 1945
	Circulatory ratio (R_c)	R_c=4πA/P^2 ;where, A=Area of watershed, π=3.14, P=Perimeter of watershed	Miller, 1953
	Elongation ratio (R_e)	R_e=2√(A/π)/L_b ;where, A=Area of watershed, π=3.14, L_b=Basin length	Schumn,1956
	Length of overland flow (L_g)	L_g = 1/2D_d where,D_d=Drainage density	Horton, 1945
	Constant channel maintenance (C)	L_{of} = 1/D_d where, D_d=Drainage density	Horton, 1945
	Shape factor (S_f)	S_f=Lb^2/A where, L_b=Basin length, A = Area of the basin	Horton (1945)
	Drainage texture (D_t)	D_t=N_u/P where, N_u= total number of stream segments of all orders, P = Perimeter of study area	Horton (1945)
	Compactness coefficient (C_c)	C_c=0.2841*P/$A^{1/2}$ where, P= perimeter of the basin, A= Area of the basin	Gravelius (1914)

Result and Discussion

The result of the Linear, Relief and Arial properties of Tungabhadra drainage basin are given below.

Table: 2 Results of Morphometric Analysis

Morphometric Parameters	Result
Basin Area (Km^2)	3025
Perimeter (Km)	306
Basin Order	5
Basin Length(L_b) Km	101.13
Relief ratio (R_h)	2.51
Basin relief (B_h) m	254
Ruggedness number (R_n)	72.64
Mean Bifurcation Ratio (R_b)	6.92
Drainage Density D_d (km/km^2)	0.29
Stream frequency (F_s)	0.15
Texture ratio (T)	0.59
Form factor (R_f)	14.96

Circulatory ratio (R_c)	0.41
Elongation ratio (R_e)	0.61
Length of overland flow (L_g)	1.75
Constant channel maintenance (C)	3.50
Shape factor (S_f)	3.38
Drainage texture (D_t)	1.45
Compactness coefficient (C_c)	1.28

LINEAR ASPECTS

The linear aspects of morphometric analysis of drainage basin include stream order, stream length, mean stream length, stream length ratio and bifurcation ratio.

Stream order (U)

Differentiate the stream order in basin is the first step in drainage basin analysis and expresses the hierarchical relationship between stream segments, their connectivity and the discharge arousing from contributing catchments. The Strahler's method has been followed in this study; according to his definition the smallest head water tributaries are called first order treams. Where two first order streams meet, a second stream is created. Where two second order streams meet, a third stream is created and so on. It has retrieved that the highest order in the study area is four. The total numbers of streams are 443, in that 181 are first orders, 158 are second orders, 57 are third orders, 45 are fourth orders and 2 are fifth order streams. The calculated number of streams in number of orders retrieved that number of stream segments are decrease as the stream order is increase. Horton (1945) laws of stream numbers states that the number of stream segments of each order forms an inverse geometric sequence against plotted order. Most drainages show linear relationship with small deviation from a straight line. Plotting the logarithm of the number of streams against stream's order shows a straight line which states the number of streams usually decreases as the stream order increases.

Stream Length (L_u)

The stream length is calculated on the basis of the law proposed by Horton (1945). The length of various orders in drainage basin has been calculated using ArcGIS. The length of first order is 426.609 km, Second order is 242.06 km, third order is 135.20 km, four order is 58.41 km and fifth order is 2.79 km. the length of stream segments is maximum for first order stream and decreases as the stream order increases.

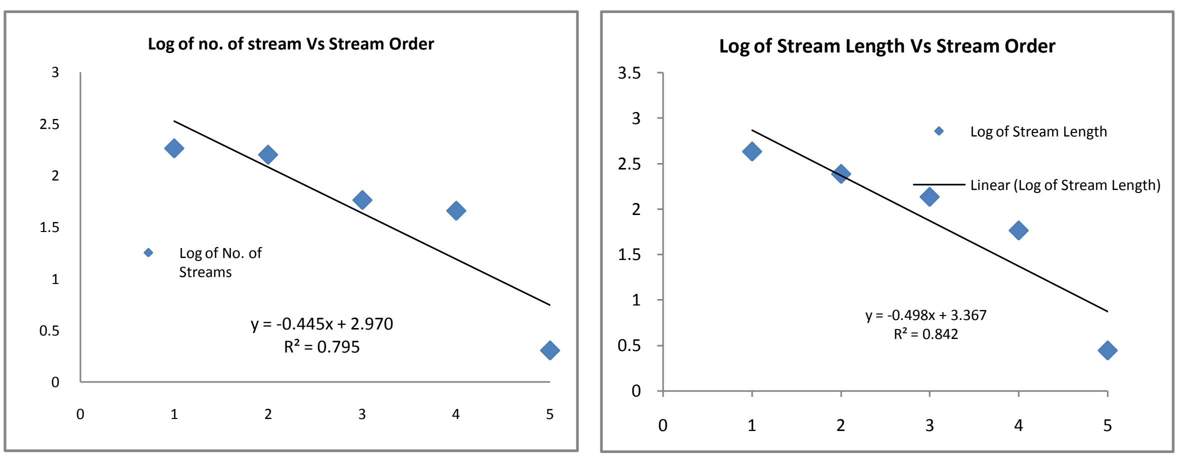

Fig.2 (a) Graph showing relation between Logarithmic of no. of streams to stream order. (b): Graph showing the relation between logarithmic of stream length to stream order.

If there is any deviation from its general behavior indicates that the terrain is characterized by high relief/moderately steep slopes, underlain by varying lithology and probable uplift across the basin. From the relation, the number of streams of a given order, when plotted against the order, the points lie on and near to the straight line. (Fig 2(a) & 2(b))

Mean Stream Length (L_{sm})

The mean stream length of a channel is the characteristic size of drainage network components and its contributing basin surface. It is calculated by dividing the total stream length of order "u" by the number of stream of segments in the order. The mean stream length of the study area is approximately same for order one and third (2.36, 2.37), fourth and fiveth (1.30, 1.39), while slight change in second orders (1.53).

Table: 3 Results of Morphometric Analysis

Stream Order	Number of streams	Bifurcation ratio (R_b)	Stream Length (L_u) (km)	Stream length ratio (R_L)	Mean stream length (L_{sm})
1	181	1.15	426.61	_	2.36
2	158	2.77	242.06	0.57	1.53
3	57	1.27	135.20	0.56	2.37
4	45	22.50	58.41	0.43	1.30
5	2	_	2.79	0.05	1.39
	443#	**6.92***	**865.07#**		

Note: # - Sum of all values, * Mean of all values

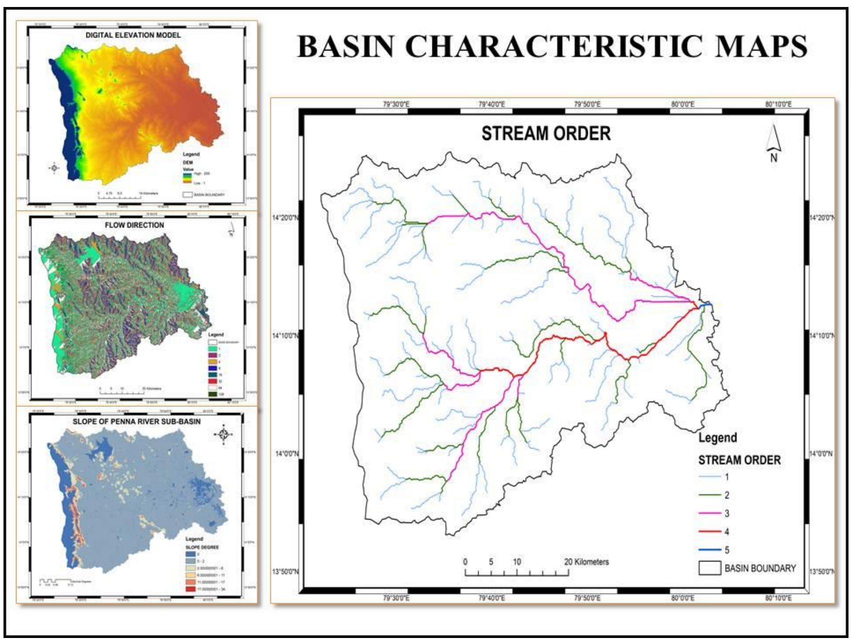

Fig.3: Drainage characteristics of the study area

Stream Length Ratio (R_L)

The stream length ratio can be defined as the ratio of the mean stream length of a given order and having important relationship with surface flow and discharge. The ratio between order in the study area differs from one order to another, which indicates late youth to mature stage of geomorphic development.

Bifurcation Ratio (R_b)

The ratio of number of the stream segments of given order 'Nu' and the number of streams in the next higher order (Nu+1) is called bifurcation ratio. Horton (1945) has well-thought-out the Rb as index of relief and dissertation. The Rb is dimensionless property and generally ranges from 3.0 to 5.0. In the present sub-basin, it is observed that Rb is not same from one order to its next order as these irregularities are dependent upon the geological and lithological development of the drainage basin (Strahler, 1952). The higher values of Rb (Table 3) in the basin indicates a strong structural control on the drainage pattern, while the lower values are indicative of basin that are not affected by structural disturbances.

RELIEF ASPECT

The relief aspects determined include relief ratio, relative relief and ruggedness number.

Relief Ratio (R_h)

The relief ratio is the ratio of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line is termed as relief ratio (Schumm, 1956). The Rh normally decreases with the increasing area and size of sub-basin of a given drainage basin (Gottschalk, 1964). The relief ratio of study area is 2.51.

Ruggedness number (R_n)

It is the product of maximum basin relief (H) and drainage density (D), where both parameters are in the same unit. An extreme high value of ruggedness number occurs when both variables are large and slope is not only steep but long as well (Strahler,1956). The value of ruggedness number in present basin is 72.64. The result shows that the study area is extremely rugged with high relief and high stream density. It is also reveals that the study area is prone to soil erosion.

ARIAL ASPECT

The aerial aspects include drainage density, drainage texture, stream frequency, form factor, circularity ratio, elongation ratio and length of overland flow, shape factor, Compactness coefficient, and relative perimeter.

Drainage Density (D_d)

Drainage density is the total length of all the streams in the watershed to the area of watershed. It helps in determining the permeability and porosity of the watershed and an indicator of landform elements in stream eroded topography. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture. Low drainage density generally result in the area of highly resistant or permeable subsoil material and high drainage density is the resultant of weak or impermeable subsurface material. The result shows the value 0.286 per square kilometers in study area indicating moderate drainage densities. The Moderate drainage density indicates the basin is highly permeable subsoil and vegetative cover (Nag, 1998).

Stream Frequency (F_s)

The stream frequency is defined as the total number of stream segment of all order per unit area. A large basin may contain as many fingertip tributaries per unit of area as a small drainage basin, and in addition, it usually contains a larger stream or streams (Horton 1945). he stream frequency of study area is 0.15 per square km. The value of stream frequency for the basin exhibit positive correlation with the drainage density value of the area indicating the increase in stream population with respect to increase in drainage density.

Texture Ratio (T)

Texture ratio (T) is an important factor in the drainage morphometric analysis which is depending on the underlying lithology, infiltration capacity and relief aspect of the terrain. The result of study shows the value of texture ratio is 0.59. The low value of texture ratio is described in the high hydrological potential zone because it is depend on the drainage density. Low value of texture ratio is also represent the low drainage density, means low surface runoff.

Form Factor (R_f)

Form factor is be defined as the ratio of basin area to square of the basin length (Horton 1932). The value of form factor would always be less than 0.7854 (for a perfectly circular basin). Smaller the value of form factor, more elongated will be the basin. The basins with high form factors have high peak flows of shorter duration, whereas, elongated sub-watershed with low form factors have lower peak flow of longer duration. It has been observed from the study that 14.96 is the value of form factor in study area. Which indicates that the basin is very less elongated in shape and has the flow of shorter duration.

Circulatory Ratio (R_c)

Circularity ratio is the ratio of the basin area to the area of a circle having the same circumference perimeter as the basin, which is dimensionless and expresses the degree of circularity of the basin (Miller 1953). He described the basin of the circularity ratios range 0.4 to 0.5 which indicates strongly elongated and highly permeable homogenous geologic materials. The value of circulatory ratio of present study is 0.41, which shows basin is stongly elongated in shape and highly permeability of the subsoil condition.

Elongation Ratio (R_e)

It is the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin (schumm S.A, 1956). A circular basin appear to more efficient in the discharge of run-off than that of an elongated basin (Singh and Singh, 1997). The Re values generally ranges between 0.6 and 1.0 over a wide variety of climate and geologic types. Values near to 1.0 are the characteristics of the region of very low relief, while values in the range of 0.6 - 0.8 usually occur in the areas of high relief and steep ground slope (Strahler 1964). These values are further categorized as circular (>0.9), oval (0.9-0.8) and less elongated (<0.7). The Re value of study area is 0.61, which indicates the drainage basin is high relief and steep ground slope.

Length of overland Flow (L_g)

Length of Overland Flow It is the length of water over the ground before it gets concentrated into definite stream channels. This factor relates inversely to the average slope of the channel and is quite synonymous with the length of sheet flow to a large degree. It approximately equals to half of reciprocal of drainage density (Horton 1945). The study found that Lg value of study area is 1.75, which shows less surface runoff of the study area.

Constant Channel Maintenance (C)

Schumm (1956) used the inverse of drainage density or the constant of channel maintenance as a property of landforms. The constant indicates the number of Kms^2 of basin surface required to develop and sustain a channel 1 Km long. The constant of channel maintenance indicates the relative size of landform units in a drainage basin and has a specific genetic connotation (Strahler, 1957). Channel maintenance constant of the watershed is 3.50 Kms^2/Km.

Shape factor (S_f)

According to Horton (1945) the shape factor is the ratio of the square of the basin length and basin area. Sf is inversely proportionate to the Form factor ratio (Rf). The Sf value of the study area is 3.38.

Drainage texture (D_t)

Horton (1945) has expressed the drainage texture as the total number of stream segments of all orders per perimeter area (Dt=Nu/P). Smith (1938) has classified drainage texture into five different textures as very coarse (<2), coarse (2-4), moderate (4-6), fine (6-8) and very fine (>8). The drainage texture value of the Sarada basin is calculated as 1.45, which indicates a fine drainage texture.

Compactness coefficient (C_c)

As per Gravelius (1914) compactness coefficient is the ratio of perimeter of basin and circumference of circular area (Cc=0.2841*P/A1/2). The Cc is independent of size of the basin and dependent on the slope. The Cc value for basin is calculated as 1.28.

Conclusions

The study of morphometric analysis of Tungabhadra using GIS retrieved that, Geographical Information System helps the researchers to analysis the drainage basin easily and accurately. The study of linear aspects of drainage basin result shows that, the basin has been formed in dendritic pattern with fourth order stream, plotting the logarithm of number of streams against stream's order shows a straight line which states the number of streams usually decreases as the stream order increases. The result of relief aspect shows the study area is extremely rugged with high relief and high stream density, the result of arial aspect shows the texture of drainage is less and the result of elongation ratio indicates the drainage is high relief and steep ground slope.

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