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Geographical Information System Based Morphometric Analysis of Halia Drainage Area, Nalgonda District, Andhra Pradesh, India

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Abstract: Morphometric analysis is important in any hydrological investigation and it is inevitable in development and management of drainage basin. The linking of the geomorphological parameters with the hydrological characteristics of the basin provides a simple way to understand the hydrologic behaviour of the different basins particularly of the ungauged basins because the hydrologic and geomorphic effects of natural and human process with in a catchment are focused at its outlet. The development of morphometric techniques was a major advance in the quantitative description of the geometry of the drainage basins and its network which helps in characterizing the drainage network. The geomorphological properties which are important from the hydrological studies point of view include the linear, aerial and relief aspect of the watersheds. In the present study a morphometric analysis of Halia river drainage area has been carried out using geoprocessing techniques in GIS. This technique is found relevant for the extraction of river basin and its drainage networks. The extracted drainage network was classified according to Strahler's system of classification and it reveals that the terrain exhibits dendritic to sub-dendritic drainage pattern. The various linear parameters (Stream order, Stream number, Stream length, stream length ratio, Bifurcation ratio, Drainage density, Texture ratio, Stream frequency) and shape factors (Compactness coefficient, Circularity ratio, Elongation ratio, Form factor) of the drainage area were computed. Hence, it is concluded that GIS techniques proved to be a competent tool in morphometric analysis.

Keywords: Morphometric analysis, drainage area, GIS, ungauged basins, dendritic

I. INTRODUCTION

The development of a drainage system over space and time is influenced by several variables such as geology, structural components, geomorphology, soil and vegetation of an area through which it flows. Geomorphometry is the measurement and mathematical analysis of earth's surface and its dimensions of the landforms Clarke (1996). Morphometric analysis of a river basin provides a quantitative description of the drainage system, which is an important aspect of the characterization of basins Strahler (1964). It is important in any hydrological investigation like assessment of groundwater potential, groundwater management, basin management and environmental assessment. Various hydrological phenomena can be correlated with the physiographic characteristics of a drainage basin such as size, shape, slope of the drainage area, drainage density, size and length of the contributories, etc. Rastogi and Sharma(1976). The morphometric analysis can be performed through measurement of linear, aerial, relief, gradient of channel network and contributing ground slope of the basin Nautiyal (1994), Nag and Chakraborty (2003). The dynamic nature of runoff is controlled by the geomorphologic structure of the catchment area and the induced runoff is

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very sensitive towards the morphometric characteristics of the contributing area Rudraiah et al. (2008). In India, National Institute of Hydrology (1993) has carried out hydro-geomorphological studies of various basins and their analyses were based on linear, aerial and relief aspects using different mathematical equations. Various morphometric parameters such as drainage pattern, stream order, bifurcation ratio, drainage density and other linear aspects are studied using remote sensing technique and topographical map Mesa (2006). The surface runoff and flow intensity of the drainage system can be estimated using the geomorphic features associated with morphometric parameters Ozdemir and Bird (2009). Pioneer work on basin morphometry has been carried out by Horton (1932), Horton (1945) and Miller (1953). Based on their ideology, similar work has been emerged throughout the world by different researchers using different techniques. In India, morphometric studies of various drainage basins have been carried out by using GIS and remote sensing technique for the estimation of morphometric parameters because the results obtained were reliable and accurate. Geographical information systems (GIS) have been used for assessing various basin parameters, providing flexible environment and powerful tool for determination, interpretation and analysis of spatial information related to river basins. Geology, relief and climate are the primary determinants of a running water ecosystem functioning at the basin scale John Wilson et al. (2012). Thus, detailed morphometric analysis of a basin is of great help in understanding the influence of drainage morphometry on landforms and their characteristics. The present study depicts the process to evaluate the various morphometric parameters of Halia river in Nalgonda District of Andhra Pradesh using geoprocessing techniques in ArcGIS. The linear, relief and aerial parameters were computed mathematically to analyze the characteristics of different morphometric parameters for planning and development of the river basin.

II. STUDY AREA

The Halia river is one of the tributary of river Krishna which is flowing in the Nalgonda district. The length of the flow of the river is 112 km. The study area chosen is located in Nalgonga district between 17^0 N - 17 15^1 N latitude and 78^0 45^1E - $79^0 15^1$ E longitude covering an area of 1,510 km^2. The study area covers eight mandals of Nalgonda district namely Marriguda, Chandur, Kangal, Narayanpur, Chityal, Munugode, part of Choutuppal and Nalgonda. The average annual rainfall in the Halia drainage area is 637 mm. The South West Monsoon sets in by middle of June and withdraws by the middle of October. About 90% of annual rainfall is received during the Monsoon months, of which more than 70% occurs during July, August and September. The study area falls in the Survey of India toposheet Nos. 56K, 56L, 56O and 56P. The location map of the study area is shown in Fig.1.

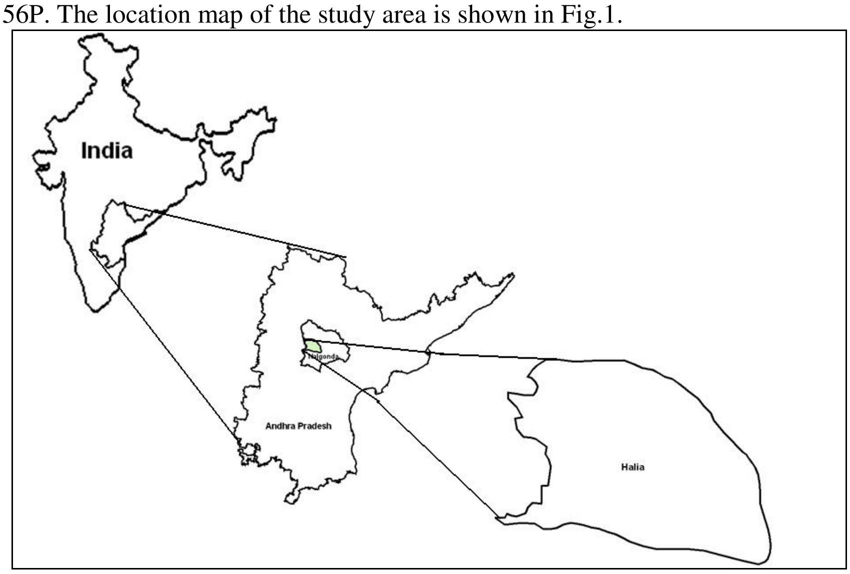

Fig.1 Location Map of the Study Area

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III. MATERIALS AND METHODS

The study area was delineated using the Survey of India topographic maps to a scale of 1:2, 50,000. The ridgelines in the toposheets were identified, which act as dividing lines for the runoff. Keeping in mind the functional area requirement of the study area, the stream network was digitized. The various steps employed in the study are given in Fig. 2.

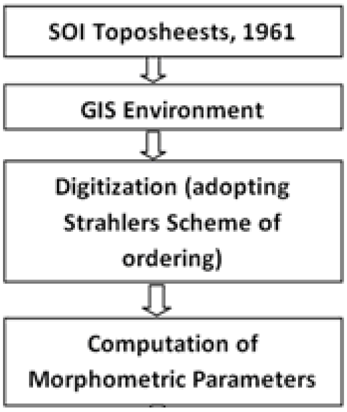

Fig. 2 Steps of Methodology

The first step in the quantitative analysis of drainage basin is designation of stream order. The term "stream order" is a measure of the position of a stream in the hierarchy of tributaries. In the present study, the channel segment of the drainage basin has been ranked according to Strahler's stream ordering system. According to Strahler (1964), the 1st order streams are those, which have no tributaries. The 2nd order streams are those, which have tributaries only of 1st order streams, where two 2nd order channels join, a segment of 3rd order is formed. When two 3rd order segments join, a 4th order channel is formed and so on. Morphometric analysis was carried out for the Halia drainage area. The parameters computed in the present study using GIS technique includes stream order, stream length, bifurcation ratio, drainage density, stream frequency, form factor, circulatory ratio, elongation ratio, relief ratio and ruggedness number. The input parameters for the present study such as area, perimeter, elevation, stream length etc. were obtained from digitized coverage of drainage network map in GIS environment. The morphometric parameters were computed using the standard formulae which are presented in Table 1.

Table 1 Methods of Calculating Morphometric Parameters

	Morphometric Parameters	Methods	References
Linear Parameters	Stream order (U)	Hierarchical rank	Strahler (1964)
	Stream length (Lu)	Length of the stream	Horton, 1945
	Mean stream length (Lsm)	Lsm = Lu/Nu where, Lu=Stream length of order 'U' Nu=Total number of stream segments of order 'U'	Horton, 1945
	Stream length ratio (Rl)	Rl=Lu/Lu-1; where Lu=Total stream length of order 'U', Lu-1=Stream length of next lower order.	Horton, 1945
	Bifurcation ratio (Rb)	Rb = Nu/ Nu+1; where, Nu=Total number of stream segment of order'u'; Nu+1=Number of segment of next higher order	Schumn,1956
Relief Parameters	Basin relief (Bh)	Vertical distance between the lowest and highest points of watershed	Schumn, 1956
	Relief ratio (Rh)	Rh=Bh/Lb; Where, Bh=Basin relief; Lb=Basin length	Schumn, 1956
	Ruggedness number (Rn)	Rn = Bh × Dd Where, Bh =Basin relief; Dd=Drainage	Schumn, 1956

		density	
Aerial Parameters	Drainage density (Dd)	Dd = L/A where, L=Total length of streams; A=Area of watershed	Horton, 1945
	Stream frequency (Fs)	Fs = N/A where, N=Total number of streams; A=Area of watershed	Horton, 1945
	Texture ratio (T)	T = N1/P where,N1=Total number of first order streams; P=Perimeter of watershed	Horton, 1945
	Form factor (Rf)	Rf=A/(Lb) 2 ;where, A=Area of watershed, Lb=Basin length	Horton, 1932
	Circulatory ratio (Rc)	Rc=4πA/P2 ;where, A=Area of watershed, π=3.14, P=Perimeter of watershed	Miller, 1953
	Elongation ratio (Re)	Re=2√(A/π)/Lb ;where, A=Area of watershed, π=3.14, Lb=Basin length	Schumn,1956
	Length of overland flow (Lof)	Lof = 1/2Dd where, Dd=Drainage density	Horton, 1945
	Constant channel maintenance (C)	Lof = 1/Dd where, Dd=Drainage density	Horton, 1945

IV. RESULTS

The study carried out has been divided into three sections, the first section deals with applicability of Horton's laws of stream numbers and stream lengths in the study area. The second section deals with the various linear and shape morphometric parameters. The total drainage area of Halia is 1,510 km^2. The drainage pattern is dendritic to sub-dendritic in nature and it is influenced by the general topography of the area. The stream orders of Halia drainage area varies from 1 to 4 and the total number of stream segments of all orders recorded was 142. Orders of stream network indicated 108 of 1st orders, 27 of 2nd order, 6 of 3rd order and 1 of 4th order. The drainage map of the study area is shown in Fig. 3.

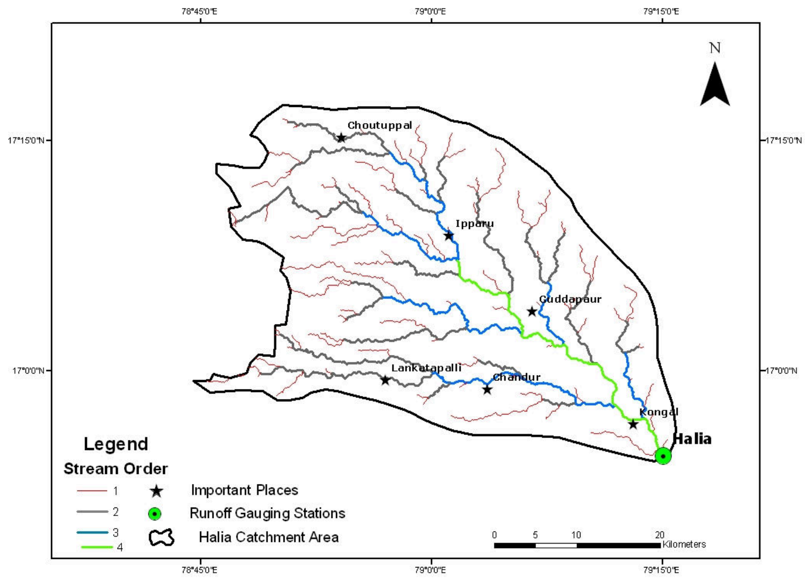

Fig. 3 Drainage Map of the Halia Drainage Area

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The values of different geomorphological parameters were calculated by using the methodology as discussed in materials and methods.

Stream order (u): The concept of stream order was introduced by Horton in 1932. Stream ordering is a widely applied method for stream classification in a river basin. Stream ordering is defined as a measure of the position of a stream in the hierarchy of tributaries Leopold et al. (1964) and the streams of Halia drainage area have been demarcated according to the Strahler's system of stream ordering. The stream order and the total number of stream segments in each order for the area are shown in the Table 2. Based on the Strahler's system of stream ordering, the area has been designated as a fourth-order drainage area. The first-order streams are those that do not have any tributary and these channels normally flow during the wet weather Chow et al (1988). Moreover, the presence of large number of streams in the basin indicates that the topography is still undergoing erosion and at the same time, less number of streams indicates mature topography. The calculated result matched with Strahler (1964), which described that the total number of streams gradually decreases as the stream order increases.

Stream number (Nu): With the help of GIS, the number of streams of different orders and the total number of streams in the basin are counted independently. Generally, the number of streams gradually decreases as the stream order increases; the variation in order and size of tributary basins is largely depends on physiographic and structural condition of the region. The total stream segments in the study area are 142. High values of first-order streams indicate that there is a possibility of sudden flash floods after heavy rainfall in the down streams Chitra et al. (2011).

Stream length (Lu): Stream length is indicative of chronological developments of the stream segments including interlude tectonic disturbances. The stream length is measured from mouth of the river to the drainage divide near the source. 'Lu' has been computed on the basis of Horton's law of stream length, which states that geometrical similarity is maintained in the basins of increasing orders. The stream length of various orders is presented in the Table 2. Generally, the total length of stream segments is the maximum in first-order streams and decreases with an increase in the stream order. The law holds true in the present case study. The results reveal that the first-order streams are short in length and are found in the upstream area. Streams with relatively short lengths are representative of areas with steep slopes and finer texture, whereas longer lengths of stream are generally indicative of low gradients Strahler (1964).

Mean stream length (Lsm): Mean stream length (Lsm) reveals the characteristic size of components of a drainage network and its contributing surfaces. It has been computed by dividing the total stream length of order 'u' by the number of stream segments in the order. The Lsm values for the Halia drainage area vary from 2.63 to 43.20 km with a mean Lsm value of 17.93 km. It is noted that Lsm of any given order is greater than that of the lower order and less than that of its next higher order in the basin. The Lsm values differ with respect to different basins, as it is directly proportional to the size and topography of the basin. Strahler (1964) indicated that the Lsm is a characteristic property related to the size of drainage network and its associated surfaces.

Stream length ratio (R_L): It is the ratio between the lengths of streams in a given order to the total length of streams in the next order. The R_L values for the Halia drainage area vary widely from 1.25 to 2.40 and are strongly dependant on the topography and the slope. Similar observations are noted in Aiyar basin and it shows an important relationship with the surface flow discharge and the erosional stage of the basin John Wilson et al (2012).

Bifurcation ratio (R_b): The term 'bifurcation ratio (R_b) was introduced by Horton in 1932. R_b is related to the branching pattern of a drainage network and is defined as the ratio of the number of streams of any given order to the number of streams in the next higher order in a drainage basin. It is a dimensionless property and shows the degree of integration prevailing between streams of various orders in a drainage basin. R_b shows a small range of variation for different regions or for different environments except those where the powerful geological control dominates. The R_b for the Halia drainage area varies from 4.0 to 6.0 with a mean R_b of 4.83. The mean bifurcation ratio (R_{bm})

characteristically ranges between 3.0 and 5.0 for a basin when the influence of geological structures on the drainage network is negligible Verstappen (1983). The analysis showed that the R_b is not same for all orders. Geological and lithological development of the drainage basin may be the reason for these variations. Low R_b value indicates poor structural disturbance and the drainage patterns have not been distorted whereas the high R_b value indicates high structural complexity and low permeability of the terrain. This shows that the geologic structures within the drainage area do not distort the drainage pattern. It also indicates that the basin has mature topography due to the result of the process of drainage integration.

Table 2 Stream Parameters of the Halia Drainage Area

Stream order(U)	No. of streams (N_u)	Length of Streams (L_u)	Mean stream length (L_{sm})	Bifurcation ratio (R_b)	Stream length ratio (R_L)
1	108	283.59	2.63	4.0	1.25
2	27	226.83	8.40	4.5	2.16
3	6	104.95	17.49		
4	1	43.20	43.20	6.0	2.40

VI.1 Linear and Shape Morphometric Parameters

The linear and shape parameters of the study area are shown in Table 3.

Basin length (L_b): The basin length (Lb) is the longest length of the basin from the headwaters to the point of confluence Gregory and Walling (1973). The basin length determines the shape of the basin. High basin length indicates elongated basin. The L_b of the basin is 64.78 km.

Relief (R): The relief (R) is defined as the differences in elevation between the highest and the lowest points on the valley floor of a basin. Basin relief is an important factor in understanding the denudational characteristics of the basin and plays a significant role in landforms development, drainage development, surface and sub-surface water flow, permeability and erosional properties of the terrain. From the morphometric study, it should be noted that the maximum relief value of Halia drainage area is 480.00 m and the high relief value of basin indicates the gravity of water flow, low infiltration and high runoff conditions.

Table 3 Morphometric Parameters of the Halia Drainage Area

S.No	Morphometric Parameters	Values	S.No	Morphometric Parameters	Values
1	Area of the drainage area in km^2	1,510.05	10	Circularity ratio	0.55
2	Perimeter in km	185.64	11	Elongation ratio	0.68
3	Axial length in km	64.78	12	Form factor	0.36
4	Breadth in km	32.77	13	Compactness factor	1.35
5	Drainage density	0.44	14	L_{min} scale ratio	0.69
6	Constant channel maintenance	2.29	15	Maximum watershed relief	480.00
7	Stream Frequency	0.09	16	Relief ratio	7.41
8	Length of overland flow in Km	0.22	17	Relative relief	2.59
9	Time of overland flow in hr	10.88	18	Ruggedness number	209.36

Relief ratio (Rh): The relief ratio has been widely accepted as a effective measure of gradient aspect of the basin, despite uncertainties surrounding definition of its component measurements and may be unduly influence by one

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isolated peak within the basin Sharma (1981). Schumm (1956) defined relief ratio as the ratio of maximum relief to horizontal distance along the longest dimension of a basin parallel to the main drainage line and it measures the overall steepness of the river basin. The value of relief ratio in the Halia drainage area is 7.41.

Drainage density (Dd): Drainage density (Dd) is one of the important indicators of the landform element and provides a numerical measurement of landscape dissection and runoff potential (Chorley 1969). Dd is defined as the total stream length in a given basin to the total area of the basin (Strahler 1964). Dd is related to various features of landscape dissection such as valley density, channel head source area, relief, climate and vegetation, soil and rock properties and landscape evolution processes. A low drainage density indicates permeable sub-surface strata and has a characteristic feature of coarse drainage, which generally shows values less than 5.0. Strahler (1964) noted that low drainage density is favoured where basin relief is low and vice versa. The Dd of the Halia drainage area is 0.44, which indicates that the study area has a weak or permeable subsurface material with intermediate drainage and low relief.

Stream frequency (Fs): According to Horton (1945), stream frequency is defined as the ratio of the total number of stream segments of all the orders in the basin to the total area of the basin. 'Fs' is an index of the various stages of landscape evolution. The occurrence of stream segments depends on the nature and structure of rocks, vegetation cover, nature and amount of rainfall and soil permeability. The stream frequency for the Halia drainage area is 0.09. The stream frequency is dependant more or less on the rainfall and the physiography of the region.

Form factor (Ff): Horton (1932) defined form factor (Ff) as the ratio of the basin area and square root of the basin length. Long-narrow basins have larger lengths and hence smaller form factors. Circular basins have intermediate form factors, which are close to one. For a perfectly circular basin, the value of the form factor will be greater than 0.78. Short-wide basins have the largest form factors. Halia drainage area is an elongated basin with lower peak flows of longer duration due to lower Ff value 0.36.

Circulatory ratio (Rc): Miller (1953) defined circularity ratio (Rc) as the ratio of the area of a basin to the area of a circle having the same circumference as the perimeter of the basin. The 'Rc' is influenced more by the lithological characteristics of the basin rather than anything else. The low, medium and high values of the circulatory ratio are indications of the youth mature and old stages of the life cycle of the tributary basins. Halia drainage area is in the youth stage of its development with a circulatory ratio of 0.55. The result showed that the study area has Rc value\0.55, indicating elongated shape. In addition, Miller (1953) described Rc as a significant ratio that indicates the dendritic stage of a watershed. This is mainly due to the diversity of slope and relief pattern of the basin.

Elongation ratio (Re): Elongation ratio (Re) is defined as the ratio of diameter of a circle having the same area as of the basin and maximum basin length (Schumm 1956). It is a measure of the shape of the river basin and it depends on the climatic and geologic types. Generally, the Re values vary from 0.6 to 1.0 for most of the basins. The value ranges from 0.6 to 0.8 for regions of high relief and the values close to 1.0 have very low relief with circular shape. These basins are efficient in the discharge of runoff than the elongated basin because concentration time is less in circular basins. The Re value of Halia drainage area is 0.68, which indicates moderate relief with steep slope and elongated in shape.

Length of overland flow (Lg): Length of the overland flow (Lg) is the length of water over the ground before it gets concentrated into definite stream channels. 'Lg' can be defined as the mean horizontal length of flow path from the divide to the stream in a first-order basin and is a measure of stream spacing and degree of dissection and is approximately one-half the reciprocal of the drainage density (Chorley 1969). From the morphometric analysis, the Lg value for Halia drainage area is 0.22. The low Lg value indicates that the rainwater had to travel relatively shorter distance before getting concentrated into stream channels (Chitra et al. 2011).

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V. CONCLUSIONS

The present study has proved that the geoprocessing technique used in GIS is an effective tool for computation and analysis of various morphometric parameters of the basin and helps to understand various terrain parameters such as nature of the bedrock, infiltration capacity, surface runoff, etc. The Halia drainage area is well drained in nature with the stream order varying from 1 to 4. The basin is dominated by lower order streams and the total length of stream segments is maximum in first order streams. Halia drainage area is an elongated basin with moderate relief and steep slope due to the lower elongation ratio 0.68. Stream frequency and drainage density are the prime criterion for the morphometric classification of drainage basins, which certainly control the runoff pattern, sediment yield, and other hydrological parameters of the drainage basin. The Dd appears significantly lower in Halia drainage area, which is an indicative of existence of impermeable rocks and moderate relief, causing more infiltration and high groundwater prospects. The quantitative analysis of linear, relief and aerial parameters using GIS is found to be of immense utility in river basin evaluation, basin prioritization for soil and water conservation and natural resource management. The geoprocessing techniques employed in this study will assist the planner and decision makers in basin development and management studies.

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