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Morphometric Analysis of a Drainage Basin using Geographical Information System: A Case study

M.L.Waikar[1] and Aditya P. Nilawar[2]

[1]Professor and Head, [2]P.G. student, Department of Civil & Water Management SGGS Institute of Engineering and Technology, Vishnupuri, Nanded, India

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Abstract

Geographical information system (GIS) has emerged as an efficient tool in delineation of drainage pattern and ground water potential and its planning. GIS and image processing techniques can be employed for the identification of morphological features and analyzing properties of basin. The morphometric parameters of basin can address linear, areal and relief aspects. The present study deals mainly with the geometry, more emphasis being placed on the evaluation of morphometric parameters such as stream order (N_u), stream length (L_u), bifurcation ratio (R_b), drainage density (D), stream frequency (F_s), texture ratio (T), elongation ratio (R_e), circularity ratio (R_c),and form factor ratio (R_f) etc.. Study area is Charthana, geographically located between 76° 30′, 76° 40′ E longitudes, and 19°30′, 19°45′ N latitudes located in Parbhani district of Maharashtra state in India. The GIS based Morphometric analysis of this drainage basin revealed that the Charthana is 4 th order drainage basin and drainage pattern mainly in sub-dendritic to dendritic type thereby indicates homogeneity in texture and lack of structural control. Total number of streams is 148, in which 95 are first order, 37 are second order, 12 are third order and 4 are fourth order streams. The length of stream segment is maximum for first order stream and decreases as the stream order increases. The drainage density (D_d) of study area is 1.45 km/km^2.This study would help the local people to utilize the resources for sustainable development of the basin area.

Keywords: *Morphometric analysis, River basin, GIS, RS.*

1.0 Introduction

Remote Sensing and GIS techniques are the proven efficient tools in the delineation, updating and morphometric analysis of drainage basin. The drainage basin analysis is important in any hydrological investigation like assessment of groundwater potential and groundwater management. Various important hydrologic phenomena can be correlated with the physiographic characteristics of drainage basins such as size, shape, slope of drainage area, drainage density, size and length of the tributaries etc. (Rastogi et al., 1976). Remote sensing data can be used in conjunction with conventional data for delineation of ridgelines, characterization, priority evaluation, problem identification, assessment of potentials and management needs, identification of erosion prone areas, evolving water conservation strategies, selection of sites for check dams and reservoirs etc.,(Dutta et al.,2002). The present paper describes the drainage characteristics of Charthana area in Parbhani district obtained through RS GIS based morphometric analysis. It is felt that the study will be useful to understand hydrological behavior of basin.

2.0 Literature

Ramu, B.Mahalingam and P.Jayashree, (2013) have conducted morphometric analysis of Tungabhadra drainage basin based on secondary source i.e. the SRTM data.

Rao, L.A.K et al., (2009) demonstrated the dynamic equilibrium that has been achieved due to interaction between matter and energy to understand the prevailing geo-hydrological characteristics of the drainage basins. Further analysis has been carried out using remote sensing and Geographical Information System (GIS) techniques to assess the geo-hydrological characteristics of four sub-watersheds of Agra district, Uttar Pradesh.

R.K. Somashekar and P.Ravikumar., (2011) carried out quantitative morphometric analysis for Hesaraghatta watershed, and the four sub watersheds, Banglore independently by estimating their various aerial, linear, relief aspects.

G.TammaRao,V.V.S. and GurunadhaRao., (2012) Remote Sensing (RS) and Geographical Information System (GIS) techniques were used to update drainage and surface water bodies and to evaluate linear, relief and aerial morphometric parameters of the two sub-watersheds, West Godavari district, A.P.. In the present study an attempt has been made to analyses the morphometric analysis of two sub-watersheds under different physiographic conditions.

SangitaMishra.S and Nagarajan.R., (2010) have carried out study in Odisha, area recurring drought coupled with increase in ground water exploitation results in decline in the groundwater level. The compound parameter value is calculated and the sub-watershed with the lowest compound parameter is given the highest priority.

M.L.Waikar andAjay Chavadekar., (2014) carried out Investigations on spatial and temporal land use/land cover (LULC) changes at regional scales. A case study related to Chandpur reservoir area in Maharashtra state is presented.

3.0 Study area

The present study area is located in the Parbhani district of Maharashtra. Parbhani district has natural boundaries of the Penganga River with a stretch of 160.93 km. (100 miles) in the north-east, and of the Godavari River with 64.37 km. (40 miles) in the south-west. Administratively, it is bounded on the north by Buldhana and Akola, on the east by Yeotmal and Nanded, on the south by Nanded and Bhir, and on the west by Aurangabad districts. The Godavari River, the Purna, the Dudhana, the Karpara River and their tributaries mainly drain the study area. The climate of the district is Semiarid, humid and subtropical. The average annual rainfall in the district is about 909 mm and temperature goes up to 42°C in summer and comes down to 11°C in winter season. The Charthana area is geographically located between 76° 30′, 76° 40′ E longitudes, and 19°30′, 19°45′ N latitudes. In the Survey of India toposheet, it forms part of 56 A/10 on 1:50000 scale. (Fig.1).

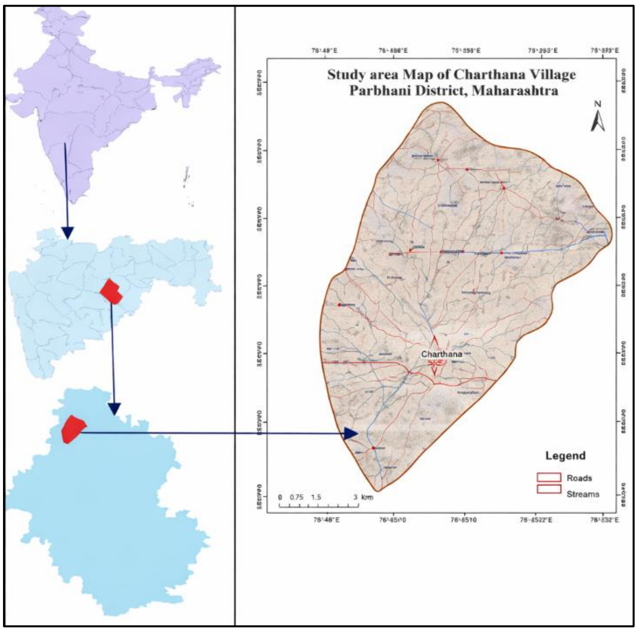

Fig.1. Study area map of basin

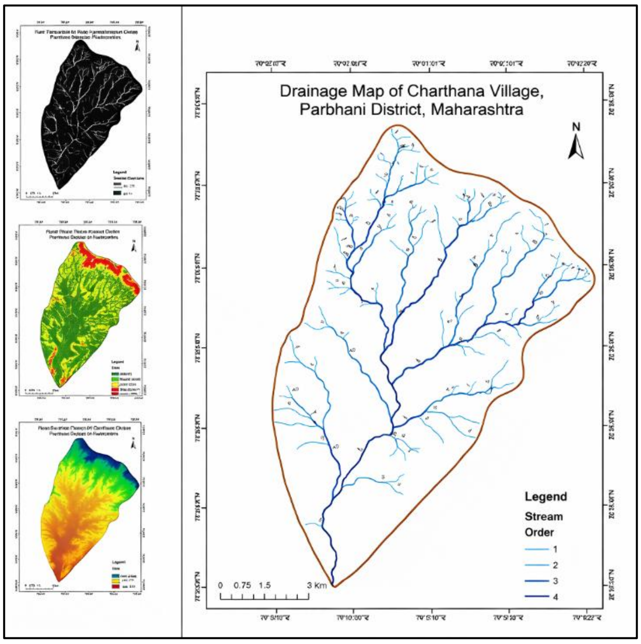

Fig.2. Drainage map of basin

4.0 Methodology

In present study, morphometric analysis and priorization of basin is based on the integrated use of remote sensing and GIS technique. The remotely sensed data is geometrically rectified with respect to Survey of India (SOI) topographical maps at 1:50000.The digitization of dendritic drainage pattern is carried out in Arc GIS 10.1 software. (Fig.2) For stream ordering, Horton's law is followed by designating an un-branched stream as first order stream, when two first order streams join it is designated as second order. Two second order steams join together to form third order and so on. The number of streams of each order are counted and recorded. The drainage map along with basin boundaries are digitized as a line coverage giving unique id for each order of stream. The digitized map is edited, and saved as line coverage in Arcview GIS Software. Morphometric parameters under linear and shape are computed using standard methods and formulae (Horton 1932, 1945; Smith 1954; Strahler, 1964).The fundamental parameter namely; stream length, area, perimeter, number of streams and basin length are derived from drainage layer. The values of morphometric parameters namely; stream length, bifurcation ratio, drainage density, stream frequency, form factor, texture ratio, elongation ratio, circularity ratio and compactness constant are calculated based on the formulae suggested by Horton (1945), Miller (1953), Schumn (1956), Strahler(1964), Nookaratm (2005) .

5.0 Morphometric analysis of basin

The following paragraphs describe the physical meaning of various morphometric parameters. Further values of these parameters are obtained as per methods proposed by various researchers for the study area and indicated in respective descriptions.

5.1 Linear Aspects

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

5.1.1 Stream Order (U)

There are four different system of ordering streams that are available [Gravelius(1914), Horton (1945), Strahler (1952) and Schideggar (1970)]. Strahler's system, which is a slightly modified of Hortons system, has been followed because of its simplicity, where the smallest, un-branched fingertip streams are designated as 1st order, the confluence of two 1^{st} order channels give a channels segments of 2^{nd} order, two 2^{nd} order streams join to form a segment of 3rd order and so on. When two channel of different order join then the higher order is maintained. The trunk stream is the stream segment of highest order. It is found that Karpara river tributaries are of 4^{th} order. In all 148 streams were identified of which 95 are first order, 37 are second order, 12 are third order, and 4 in fourth order. Drainage patterns of stream network from the basin have been observed as mainly of dendritict type which indicates the homogeneity in texture and lack of structural control. The properties of the stream networks are very important to study basin characteristics (Strahler, 2002).

5.1.2 Stream Length (L_u)

The stream length (L_u) has been computed based on the law proposed by Horton. Stream length is one of the most significant hydrological features of the basin as it reveals surface runoff characteristics. The stream of relatively smaller length is characteristics of areas with larger slopes and finer textures. Longer lengths of streams are generally indicative of flatter gradient. Generally, the total length of stream segments is maximum in first order stream and decreases as stream order increases. The numbers of streams are of various orders in a watershed are counted and their lengths from mouth to drainage divide are measured with the help of GIS software. The length of first order stream is 59.68 Km, second order stream is 42.04 Km, third order stream is 22.61 Km, and fourth order stream is 9.7 Km. The change may indicate flowing of streams from high altitude, lithological variation and moderately steep slopes (Singh 1997).The observation of stream order verifies the Horton's law of stream number i.e. the number of stream segment of each order forms an inverse geometric sequence with order number.

5.1.3 Mean Stream Length (L_{sm})

The mean stream length is a characteristic property related to the drainage network and its associated surfaces (Strahler, 1964). The mean stream length (L_{sm}) has been calculated by dividing the total stream length of order by the number of streams. The mean stream length of study area is 0.63 for first order, 1.14 for second order, 1.88 for third order, 2.43 for fourth order. The mean stream length of stream increases with increase of the order.

5.1.4 Stream Length Ratio (R_L)

The stream length ratio can be defined as the ratio of the mean stream length of a given order to the mean stream length of next lower order and has an important relationship with surface flow and discharge (Horton, 1945). The R_L values between streams of different order in the basin reveal that there are variations in slope and topography.

5.1.5 Bifurcation Ratio (R_b)

Bifurcation ratio (R_b) may be defined as the ratio of the number of stream segments of given order to the number of segments of the next higher order (Schumn 1956). Horton (1945) considered the bifurcation ratio as an index of relief and dissections. Strahler (1957) demonstrated that the bifurcation ratio shows a small range of variation for different regions or different environmental conditions, except where the geology dominates. It is observed that R_b is not the same from one order to its next order. In the study area mean R_b varies from 2.56 to 3; the mean R_b of the entire basin is 2.88. Usually these values are common in the areas where geologic structures do not exercise a dominant influence on the drainage pattern.

5.2 Relief Aspects

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

5.2.1 Relief Ratio (R_h)

The relief ratio, (R_h) is ratio of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line (Schumm, 1956). The R_h normally increases with decreasing drainage area and size of watersheds of a given drainage basin (Gottschalk, 1964). Relief ratio measures the overall steepness of a drainage basin and is an indicator of the intensity of erosion process operating on slope of the basin (Schumm, 1956). The value of R_h in basin is 9.80 indicating moderate relief and moderate slope.

5.2.2 Relative Relief (R_{bh})

This term was given by Melton (1957). In the present study area it is obtained by visual analysis of the digital elevation model prepared from SRTM data. The elevation varies from 431m to 585m which represent the land has gentle to moderate slope.

5.2.3 Ruggedness number (R_n)

It is the product of maximum basin relief (H) and drainage density (D_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 steep (Strahler, 1956). The value of ruggedness number in present basin is 223.3. (Schumm, 1956).

5.3 Aerial Aspects

It deals with the total area projected upon a horizontal plane contributing overland flow to the channel segment of the given order and includes all tributaries of lower order. It comprises of drainage density, drainage texture, stream frequency, form factor, circularity ratio, elongation ratio and length of overland flow.

5.3.1 Drainage density (D_d)

Horton (1932), introduced the drainage density (D_d) is an important indicator of the linear scale of land form elements in stream eroded topography. It is the ratio of total channel segment length cumulated for all order within a basin to the basin area, which is expressed in terms of Km/Km^2.The drainage density, indicates the closeness of spacing of channels, thus providing a quantitative measure of the average length of stream channel for the whole basin. It has been observed from drainage density measurement made over a wide range of geologic and climatic type that a low drainage density is more likely to occur in region and highly resistant of highly permeable subsoil material under dense vegetative cover and where relief is low. High drainage density is the resultant of weak or impermeable subsurface material, sparse vegetation and mountainous relief. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture (Strahaler, 1964).The drainage density (D_d) of study area is 1.45 Km/Km^2 indicating moderate drainage densities. The Moderate drainage density indicates the basin is highly permeable subsoil and vegetative cover (Nag, 1998).

5.3.2 Stream Frequency (F_s)

Stream frequency (F_s), is expressed as the total number of stream segments of all orders per unit area. It exhibits positive correlation with drainage density in the watershed indicating an increase in stream population with respect to increase in drainage density. The F_s for the basin is 1.59. (Horton, 1932)

5.3.3 Texture Ratio (T)

Drainage texture ratio (T) is the total number of stream segments of all orders per perimeter of that area (Horton, 1945). It depends upon a number of natural factors such as climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and stage of development. In the present study the texture ratio of the basin is 2.37 and categorized as moderate in the nature.

5.3.4 Form Factor (F_f)

Form factor (F_f) is defined as the ratio of the basin area to the square of the basin length. This factor indicates the flow intensity of a basin of a defined area (Horton, 1945). The form factor value should be always less than 0.7854 (the value corresponding to a perfectly circular basin). The smaller the value of the form factor, the more elongated will be the basin. Basins with high form factors experience larger peak flows of shorter duration, whereas elongated watersheds with low form factors experience lower peak flows of longer duration. The F_f value for study area is 0.378, indicating elongated basin with lower peak flows of longer duration than the average.

5.3.5 Circulatory Ratio (R_c)

Circularity Ratio is the ratio of the area of a basin to the area of circle having the same circumference as the perimeter of the basin (Miller, 1953). It is influenced by the length and frequency of streams, geological structures, land use/ land cover, climate and slope of the basin. The R_c value of basin is 0.724 and it indicating the basin is characterized by moderate to low relief and drainage system seems to be less influenced by structural disturbances. The high value of circularity ratio shows the late maturity stage of topography.

5.3.6 Elongation Ratio (R_e)

Schumm (1956) defined elongation ratio as the ratio of diameter of a circle of the same area as the drainage basin and the maximum length of the basin. Values of R_e generally vary from 0.6 to 1.0 over a wide variety of climatic and geologic types. R_e values close to unity correspond typically to regions of low relief, whereas values in the range 0.6–0.8 are usually associated with high relief and steep ground slope (Strahler 1964). These values can be grouped into three categories namely (a) circular (>0.9), (b) oval (0.9-0.8), (c) less elongated (<0.7). The Re values in the study area is 0.7 indicating moderate to slightly steep ground slope and area when collaborated with Strahler's range seem to suggest an elongated shape.

5.3.7 Length of overland flow (L_g)

The Length of Overland Flow (L_g) is the length of water over the ground surface before it gets concentrated into definite stream channel (Horton, 1945). L_g is one of the

Table.1 Method of Calculating Morphometric Parameters of Drainage basin

	Morphometric Parameters	Formula/Defination	References
LINEAR	Stream order (U)	Hierarchical order	Strahler,1964
	Stream Length (L_U)	Length of the stream	Hortan, 1945
	Mean stream length (L_{sm})	$L_{sm}=L_u/N_u$; Where, Lu=Mean stream length of a given order (km), Nu=Number of stream segment.	Hortan, 1945
	Stream length ratio (R_L)	R_L= Lu / Lu-1 Where, Lu= Total stream length of order (u), Lu-1=The total stream length of its next lower order.	Hortan, 1945
	Bifurcation Ratio (R_b)	R_b = Nu / Nu+1 Where, Nu=Number of stream segments present in the given order Nu+1= Number of segments of the next higher order	Schumn,1956
RELIEF	Basin relief (B_h)	Vertical distance between the lowest and highest points of basin.	Schumn,1956
	Relief Ratio (R_h)	R_h = Bh / Lb Where, Bh=Basin relief, Lb=Basin length	Schumn,1956
	Ruggedness Number (R_n)	R_n=Bh×DdWhere,Bh= Basin relief, D_d=Drainage density	Schumn,1956
AERIAL	Drainage density (D_d)	D_d=L/A Where, L=Total length of stream, A= Area of basin.	Hortan, 1945
	Stream frequency (F_s)	F_s=N/A Where, L=Total number of stream, A=Area of basin	Hortan, 1945
	Texture ratio (T)	T=N_1/P Where, N_1=Total number of first order stream, P=Perimeter of basin.	Hortan, 1945
	Form factor (R_f)	$R_f=A/(Lb)^2$ Where, A=Area of basin, Lb=Basin length	Hortan, 1945
	Circulatory ratio (R_c)	$R_c=4\pi A/P^2$Where A= Area of basin,π=3.14, P= Perimeter of basin.	Miller,1953
	Elongation ratio (R_e)	$R_e=\sqrt{(Au/\pi)}/ Lb$ Where, A=Area of basin, π=3.14, Lb=Basin length	Schumn 1956
	Length of overland flow (L_g)	$L_g=1/2D_d$ Where, Drainage density	Hortan, 1945
	Constant channel maintenance(C)	Lof=1/D_d Where, D_d= Drainage density	Hortan, 1945

Table.2 Result of morphomatric analysis

Stream order	Number of stream Nu	Bifurcation ratio	Total length of stream Lu (Km)	Log Nu	Log Lu	Mean of Bifurcation ratio
1	95	2.56	59.68	1.977	1.775	
2	37	3.08	42.04	1.568	1.623	2.88
3	12	3	22.61	1.079	1.354	
4	4	-	9.7	0.986	0.986	

most important independent variables affecting hydrologic and physiographic development of drainage basins. The length of overland flow is approximately equal to the half of the reciprocal of drainage density. This factor is related inversely to the average slope of the channel and is quiet synonymous with the length of sheet flow to a large degree. The L_g value of study area is 2.9.

5.3.8 Constant channel maintenance (C)

Schumm (1956) used the inverse of drainage density as a property termed constant of stream maintenance C. This constant, in units of square feet per foot, has the dimension of length and therefore increases in magnitude as the scale of the land-form unit increases. Specifically, the constant C provides information of the number of square feet of watershed surface required to sustain one linear foot of stream. The value C of basin is 0.69.It means that on an average 0.69 sq.ft surface is needed in basin for creation of one linear foot of the stream channel.

6.0 Conclusion

GIS and Remote sensing techniques have proved to be accurate and efficient tool in drainage delineation and their updation. Bifurcation ratio, length ratio and stream order of basin indicates that the basin is fourth order basin with dendritic type of drainage pattern with homogeneous nature and there is no structural or tectonic control. Relief ratio, Ruggedness number and visual interpretation of DEM of study area indicate moderate and high relief, low run off and high infiltrations with early mature stage of erosion development.

Table.3 Result of morphomatric analysis

Sr. no	Parameter	Value
1	Basin Area $(Km)^2$	93.24
2	Perimeter (Km)	40.22
3	Basin order	4
4	Drainage density(D_d) (Km/Km^2)	1.45
5	Stream frequency (F_s) $(Km)^2$	1.59
6	Relief Ratio (R_h)	9.80
7	Texture ratio(T) (Km)	2.37
8	Basin Length(L_b) (Km)	15.71
9	Basin Relief(B_h) (m)	154
10	Ruggedness number (R_n)	223.3
11	Mean Bifurcation ratio (R_b)	2.88
12	Form Factor (R_f)	0.378
13	Circulatory ratio (R_c)	0.724
14	Elongation Ratio (R_e)	0.7
15	Length of overland flow (L_g) (Km)	2.9
16	Constant channel maintenance (C) (Km)	0.69

Drainage density, texture ratio, circulatory ratio and elongation ratio shows that texture of basin is moderate and shape of basin almost elongated. The complete morphometric analysis of drainage basin indicates that the given area is having good groundwater prospect. The formulae used for evaluating morphometric parameter are tabulated in Table 1. Results of this analysis are tabulated in Table 2 and Table 3.

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