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Research Article

GIS-BASED MORPHOMETRIC ANALYSIS OF PENCH RIVER BASIN

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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 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. The study indicates that analysis of morphometric parameters with the help of geographic information system (GIS) would prove a viable method of characterizing the hydrological response behaviour of the watershed. In the present study a morphometric analysis of Pench river basin area has been carried out using geoprocessing techniques in GIS. In this study, Pench River basin a tributaries of Kanhan River has been selected for detailed morphometric analysis. Morphometric parameters viz; stream order, stream length, bifurcation ratio, drainage density, stream frequency, form factor, circulatory ratio, etc., are calculated. Pench River Basin covers an area of 4865 sq. km. Total number of streams are 3621, of this, first order stream segments accounts for78.65%. Since, the bifurcation ratio value is 2.00 to 5.40. It is concluded that GIS techniques proved to be a competent tool in morphometric analysis.

INTRODUCTION

Drainage basin analysis is one of the important criteria for any hydrological investigations. It provides valuable information regarding the quantitative description of the drainage system, which is an important aspect of the characterization of a basin (A.N. Strahler 1964). The term 'Morphometry' literally means measurement of forms introducing quantitative description for landform (Horton, R.E 1945). Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Clarke 1996; Agarwal 1998; Obi Reddy *et al*. 2002). This analysis requires measurement of linear features, aerial aspects and gradient of channel network of the drainage basin (Nautiyal, 1994). Drainage characteristics of many river basins and sub-basins around the globe have been studied using conventional methods (J. Krishnamurthy *et. al*. 1996). Various hydrological phenomena can be correlated with the physiographic characteristics of any drainage basin such as size, shape, slope of the drainage area, drainage density, size and length of the contributories, etc. (Rastogi and Sharma 1976; Magesh *et al*. 2012a).

Hydrologic and geomorphic processes occur within the watershed and morphometric characterization at the watershed scale reveals information regarding formation and development of land surface processes (Singh 1995; Dar *et al*. 2013). Drainage basins are the elementary units to comprehend geometric characteristics of fluvial landscape, such as topology of stream networks, and quantitative picture of drainage texture, pattern, shape and relief features (G.P. Obi Reddy *et.al*. 2004, and Subba Rao, 2009).

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 Rastogi and Sharma 1976, Nautiyal 1994, Magesh *et al.* 2012a, b, John Wilson *et al.* 2012, and Magesh and Chandrasekar 2012. Application of remote sensing provides a reliable source for the preparation of various thematic layers for morphometric analysis. The digital elevation data can be used for generating the elevation model

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of a landscape to any extent. The resolution of the image may vary with respect to the satellite sensors. The processed DEM can be used for generating the stream network and other supporting layers (Mesa 2006; and Magesh *et al.* 2011). Identification of drainage networks in a basin can be achieved using traditional methods such as field observation and topographic maps alternatively by advanced methods like remote sensing and extracting features from digital elevation models (D.R. Maidment 2002).

Objective

The main objective of this study is - To calculates Morphometric parameters viz; stream order, mean stream length, stream length ratio, bifurcation ratio, mean bifurcation ratio, basin Relief, relief ratio, drainage density, stream frequency, texture ratio, form factor, circularity Ratio, elongation ratio etc. of the Pench River Basin through GIS.

MATERIALS AND METHODS

Study Area

Pench River basin is located 21^{0}15’57.861” N to 22^{0}23’47.485” N latitude and 78^{0}30’17.268” E to 79^{0}31’51.037” E longitude. It is an important tributary of the River Kanhan. The total geographical area of pench basin is 4865 sq. km. It flows all the way through Madhya Pradesh and Maharastra (Fig.1). Pench River originates at tamiya tehsil of District Chhindwara (MP). It flows towards North West to South and made the political boundary of Chhindwara and seoni district. Total length of river 274.71 km. Total 214.40 km. flows in Madhya Pradesh and only 60.31 km. in Maharastra. Elevation of basin is 190 to 1152 m.

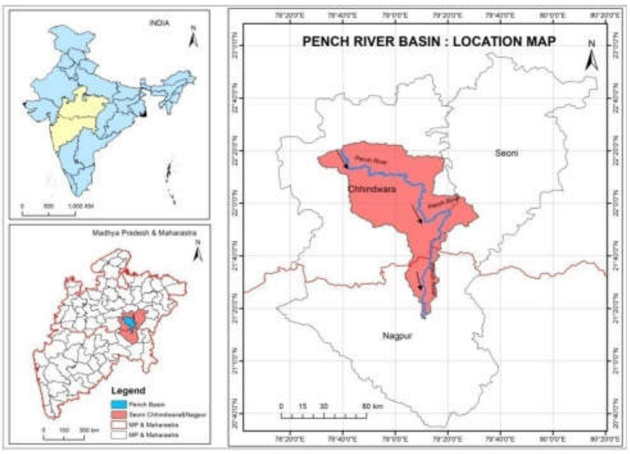

Fig. 1 Location Map

METHODOLOGY

The present study is based on satellite geo-reference data. Aster (dam) data has been downloaded from USGS earth explorer website. Aster Dem data is freely available for modeling physical feature. The different morphometric parameters were determined by using the standard methodologies. The drainage network of the Pench basin is extracted from a series of geo processing tools in ARC GIS- 10.2. The output of this method is a basis for creating a stream/ drainage network grid with stream order based on Strahler’s 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. Highest seventh stream order has been identified in Pench basin. The output of the drainage network is smoothened using a smooth line tool in ArcGIS- 10.2. The parameters computed in the present study using ArcGIS (10.2) technique includes stream order, stream number, stream length, stream length ratio, bifurcation ratio, basin length, basin area, drainage density, stream frequency, relief ratio, ruggedness number, aspect, hill shade.

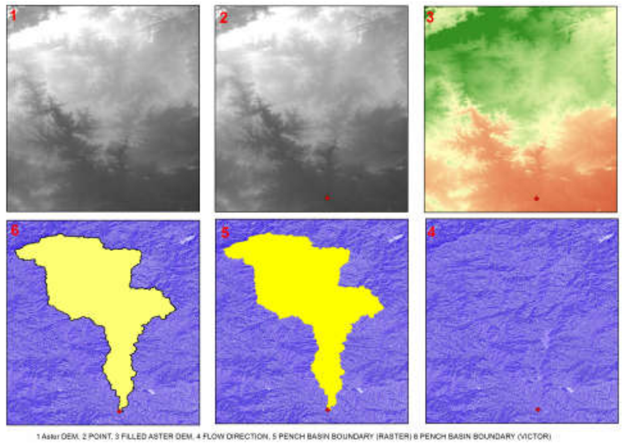

Fig. 2 Extract Basin Boundary

RESULT AND DISCUSSION

The total basin are of pench river basin is 4865 sq. km2. The details of stream characteristics confirm with Horton’s (1932) “law of stream numbers” which states that the number of streams of different orders in a given drainage basin tends closely to approximately an inverse geometric ratio. Aster DEM is used to prepare slope and aspect maps.

Stream order

In the present study, ranking of streams has been carried out based on the method proposed by Strahler (1964). 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). Stream orders are classified up to seventh orders in the Pench river basin. The maximum stream order frequency is observed in case of first-order streams and then for second order. Hence, it is noticed that there is a decrease in stream frequency as the stream order increases (Fig.4).

Stream number (Nu)

After assigning stream orders, the segments of each order are counted to get the number of segments of the given order (u). In the study area, the total streams segments present are 3621 of which 78.65 % are first order streams having 2848 segments (Table.1). The second order stream segments are 613 and account for 16.93 %; Third order stream segments are 125 and accounted 3.45%; Fourth order stream segments are 27 and account for 0.75 %; fifth order stream segments are 5 and account for 0.14%; sixth order stream segments are 2 and account of 0.06% and seventh order stream are 1 and account of 0.03%.

Table 1 Methods of Calculating Morphometric Parameters

S. No.	Morphometric Parameter	Symbols/Formulas	References
1	Stream order (U)	Hierarchical rank	Strahler (1964)
2	Mean stream length (Lsm)	$Lsm = \frac{Lu}{Nu}$ Lu=Stream length of order 'U' Nu=Total number of stream segments of order 'U'	Strahler (1964)
3	Stream length ratio (RL)	$RL = \frac{Lu}{(Lu-1)}$ where Lu=Total stream length of order 'U', Lu-1=Stream length of next lower order.	Horton (1945)
4	Bifurcation ratio (Rb)	$Rb = \frac{Nu}{(Nu+1)}$ where, Nu=Total number of stream segment of order'u'; Nu+1=Number of segment of next higher order	Schumm (1956)
5	Mean bifurcation ratio (Rbm)	Rbm = average of bifurcation ratios of all order	Strahler (1957)
6	Basin Relief (Bh)	Vertical distance between the lowest and highest points of watershed	Hadley and Schumm (1961)
7	Relief ratio (Rr)	$Rr = \frac{R}{L}$ Where, R=basin relief L = Basin length	Schumm (1963)
8	Drainage density (Dd) (in km.)	$Dd = \frac{Lu}{A}$ where, Lu=Total length of streams; A=Area of watershed	Horton, 1945
9	Stream frequency (Fs)	$Fs = \frac{Nu}{A}$ where, Nu =Total number of streams; A=Area of watershed	Horton (1945)
10	Texture ratio (T)	$T = \frac{Nu}{P}$ where,Nu1=Total number of first order streams; P=Perimeter of watershed	Horton, 1945
11	Form factor (R_f)	$Rf = \frac{A}{(Lb^2)}$ Where, A = area of the basin, km2; and Lb = length of the basin, km.	Harton (1932)
12	Circularity Ratio (Rc)	$Rf = \frac{P_c}{P} = \frac{2\sqrt{\pi A}}{P}$ Where, A = area of the basin, km2; P= basin perimeter, km2; and Pc= perimeter of the circle having equal area as that of the drainage basin, km.	Miller (1953)
13	Elongation ratio (Re)	$Re = \frac{2\sqrt{A/\pi}}{Lb}$ where, A=Area of watershed, π=3.14, Lb=Basin length	Schumn (1956)
14	Length of Overland Flow (Lof)	$Lof = \frac{1}{2}Dd$ Where, Lof= Length of Overland Flow Dd= Drainage Density	Horton (1945)

Stream Length

According to Horton (1945), Stream length is the total length of stream segment of each of the consecutive order in the basin tends approximate a direct geometric series in which the first term is the average length of the first order. It is the quantification of hydrological characteristics of bedrock and the drainage extent. When bedrock is of permeable character then only subtle numbers of relatively longer streams are formed in a well drained basin area (Kulkarni, 2015, Sethupathi *et al.* 2011). Table 2 is shown stream order wise length of pench river basin. It is clearly identified that the stream length is higher in first-order streams and decreases as the stream order increases i.e., first order stream length is 2819.61 km., second order stream length is 1397.67 km., in third order 677.50 km., in fourth order 307.51km., in fifth order stream length 106.00 km. after in six order stream length is increased 115.78 km. stream length is calculated in this order, than after this order stream length is decrease in seventh order. This order stream length is 103.44 km.

Stream Length Mean (LuM)

Stream length Mean reveals the size of component of drainage network and its contributing surface (Strahler, 1964). It's directly proportional to the size and topography of drainage basin (Kulkarni, 2015). It has been computed by dividing the total stream length of order 'u' by the number of stream

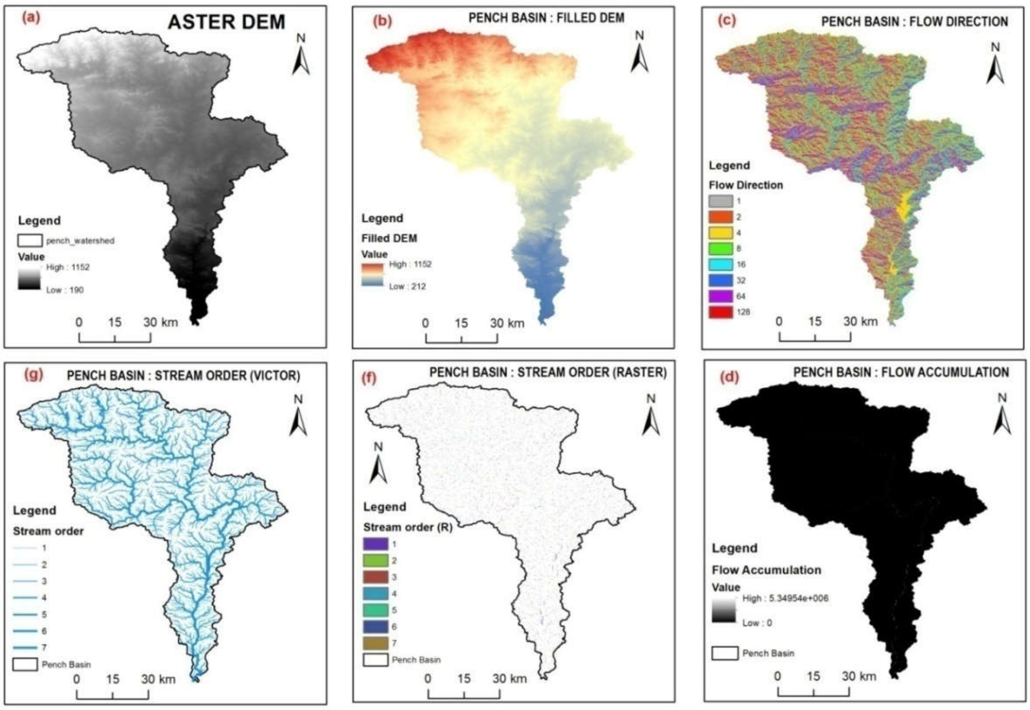

Fig. 3 Stream order Creation

segments in the order (Table 2). Strahler (1964), indicated that the Stream length means is a characteristic property related to the size of drainage network and its associated surfaces. Stream length means values for the Pench river basin range from 0.99 to 103.44 km. with a mean Lsm value of 29.67 km.

Stream length ratio (RL)

Horton's law of stream length states that mean stream length segment of each of the consecutive of a basin tends to approximate a direct geometric series with stream increasing towards higher order of stream.

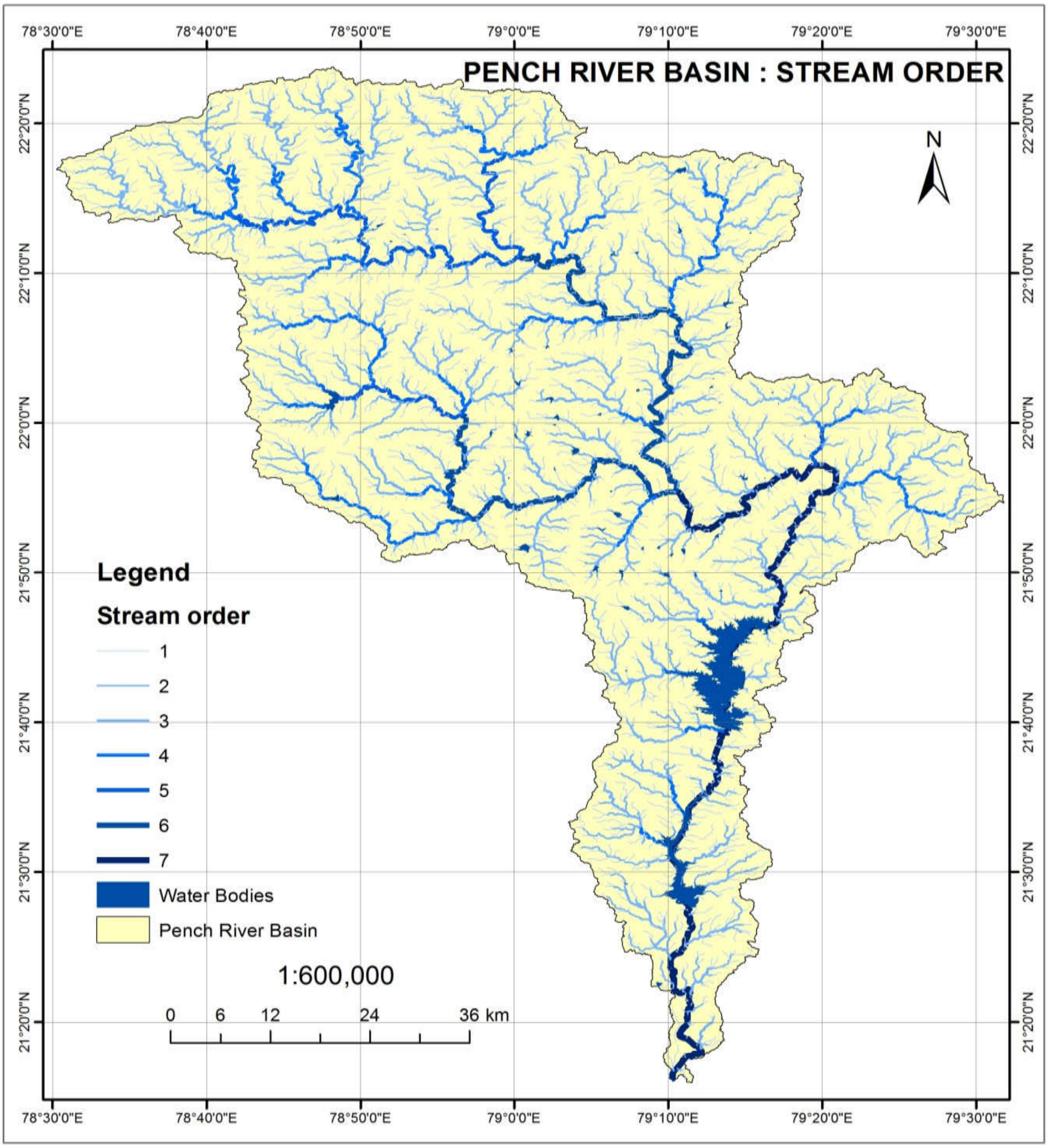

Fig 4 Stream Order of Pench River Basin

Table 2 Linear aspect of drainage network of Pench Basin

River Basin	Stream Order (U)	Stream Numbers (Nu)	Stream Length in km. (Lu)	Stream Length Mean in km. (Lu)	Cumulative Stream Length Mean in km. (Lu)	Stream Length Ratio (RL)	Bifurcation ratio (Rb)	Mean bifurcation ratio (Rbm)
Pench Basin	I	2848	2819.61	0.99	0.99	0.50		4.01
	II	613	1397.67	2.28	3.27	0.48	4.65	
	III	125	677.50	4.73	8.00	0.45	4.90	
	IV	27	307.51	11.39	19.39	0.34	4.63	
	V	5	106.00	21.20	40.59	1.09	5.40	
	VI	2	115.78	57.89	98.48	0.89	2.50	
	VII	1	103.44	103.44	201.92		2.00	
Total		3621	4850.01					

The stream length ratio has important relevance with surface flow and discharge and erosion stage of the basic (Horton, R.E, 1945 and Obi Reddy *et, al*. 2002). The stream length ratio (RL) of Pench river basin showed an increasing trend. The RL values are also presented in Table 2; it is vary widely from 0.34 to 1.09 km. and is strongly dependant on the topography and the slope.

Bifurcation ratio (Rb)

Bifurcation ratio is the ratio of the number streams of an order to the number streams of next higher order (Horton, 1945, Strahler, 1964). It is a dimensionless property and shows the degree of integration prevailing between streams of various orders in a drainage basin (Magesh *et. al.*, 2013). According to Strahler (1964), the values of bifurcation ratio characteristically range between 3.0 and 5.0 for drainage basin in which the geological structures do not disturb the drainage pattern. Rb shows a small range of variation for different areas or for different environments except those where the powerful geological control dominates. In the Pench River basin the higher value of Rb indicate a strong structural control in the drainage pattern. The Rb for the Pench river basin area varies from 2.00 to 5.40.

Mean Bifurcation ratio (Rbm)

The mean bifurcation ratio (Rbm) 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 Rb is not same for all orders. Geological and litho-logical development of the drainage basin may be the reason for these variations. Low Rb value indicates poor structural disturbance and the drainage patterns have not been distorted whereas the high Rb 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. The Rbm of Pench river Basin is 4.01 km.

Basin Area

The area of entire basin is 4865 sq.km. If a basin size is small it is likely that rainwater will reach the main channel more rapidly than in a larger basin, where the water has much further to travel (Waugh, 1996).

Basin length (Lb)

The length (L) 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 length of the basin is 131.4 km.

Basin 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 study area. Basin relief is an important factor in understanding the Denudational characteristics of the basin and plays a important role in landforms, drainage development, surface and sub-surface water flow, permeability and erosion properties of the terrain. From the morphometric study, it should be noted that the maximum relief value of Pench River Basin is 962 m. and the high relief value of basin indicates the gravity of water flow, low infiltration and high runoff conditions.

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 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. In the study area, the relief ratio computed was 0.007 m.

Form Factor (Rf)

It is the ratio of a basin area (A) (Horton, 1932) to the square of the basin length (Lb). The basins with high form factor value have high peak flow for short duration whereas elongated basin with low form factor will have a flatter peak flow of longer duration. Flood flows in elongated basins are easier to manage than that of the circular basins (Nautiyal, 1994). The factor value of 0 indicates a highly elongated shape and the value of 1.0, a circular shape. The value of form factor of the Pench River basin is 0.28km.

Circularity Ratio (Rc)

Circularity Ratio is defined as the ratio of basin area (A) to the area of circle having the same perimeter (P) as the basin (Miller, 1953). It is influenced more by the length, frequency and gradient of streams of various orders rather than slope conditions and drainage pattern of the basins. The value 0.0 indicates a highly elongated shape and the value 1 is a circular shape. Circulatory ratio in the Pench river basin is 0.43 km hence, it is moderately elongated shape basin.

Elongation Ratio (Re)

It is the ratio of the diameter of a circle of the same area as the basin to the maximum length of the basin (Schumm's, 1956). It is a very significant index in the analysis of basin shape which helps to give an idea about the hydrological character of a drainage basin. Elongation ratio of the study area is 0.60 km.

Table 3 Morphometric Parameters of the Pench River Basin

S.No.	Parameter	Estimated Value
1	Area (sq. km)	4865
2	Perimeter (km.)	573
3	Basin Length (Lb) (in km)	131.4
4	Drainage density (Dd) (in km.)	1.00
5	Stream frequency (Fs)	0.75
6	Stream order (U)	7
7	Stream length (Lu)	4850.01
8	Mean stream length (Lsm)	1.34
9	Stream length Ratio (RL)	0.34 to1.09
10	Bifurcation ratio (Rb)	2.00 to 5.40
11	Texture Ratio (T)	4.97
12	Basin Relief (R)	962 m
13	Relief ratio (Rh)	0.007 m
14	Form factor (R_f))	0.28 km
15	Circularity Ratio (Rc)	0.43 km
16	Elongation ratio (Re)	0.60 km.
17	Length of Overland Flow (Lof)	0.50

Length of Overland Flow (Lg)

It is one of the most important variables that affect both hydrological and physiographic development of the drainage basins (Horton 1945). It is the distance covered by surface runoff before turning into a stream channel. In the development of drainage basins, length of overland flow (Lg) is usually equal one half reciprocal of the drainage density. The length of overland flow is 0.50 km in the Pench river basin.

Aspect

Aspect generally refers to the direction to which a mountain slope faces. The aspect of a slope can make very significant influences on its local climate because the sun's rays are in the west at the hottest time of day in the afternoon, and so in most cases a west-facing slope will be warmer than sheltered east-facing slope. This can have major effects on the distribution of vegetation in the Pench River Basin. The value of the output raster data set represents the compass direction of the aspect (Magesh *et al*. 2011). The aspect map of Pench river basin is shown south east facing characteristic (Fig.5.)

Slope

Slope analysis is an important parameter in geomorphological studies for watershed development and important for morphometric analysis. The slope elements, in turn, are controlled by the climatomorphogenic processes in areas having rock of varying resistance (Magesh *et al.* 2011; Gayen *et al.* 2013). A slope map of the study area is majored on the bases of ASTER DEM data using the spatial analysis tool in ARC GIS-10.2. The slope in Pench River Basin is shown in Fig.6. The degree of slope of Pench river basin is varied from 2^{o} to 50^{o}

CONCLUSION

The present study has proved that the geo-processing 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. In the present study, morphometric analysis of the Pench River basin has been delineated, based on several drainage parameters using satellite data and latest GIS tools for drainage analysis. The Pench River basin is well drained with the stream order varying from 1 to 7 U. In the given area, the mean Bifurcation Ratio of the basins ranges from 2.00 to 5.40 Rb values indicates that the Pench River Basin has suffered less structural disturbance. 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 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 geo-processing techniques employed in this study will assist the planner and decision makers in basin development and management studies. This study will be useful in developing functional relationships between geo-morphological parameters and hydrological variables.

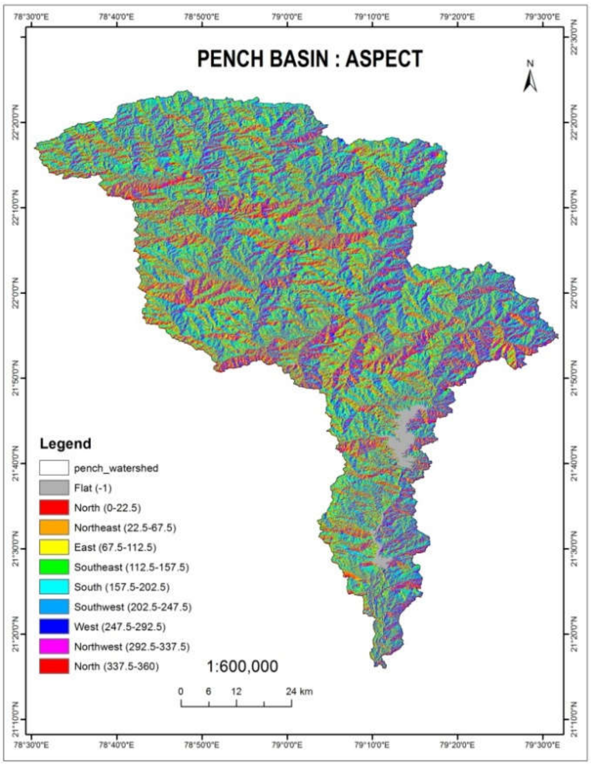

Fig. 5 Aspect of Pench River Basin

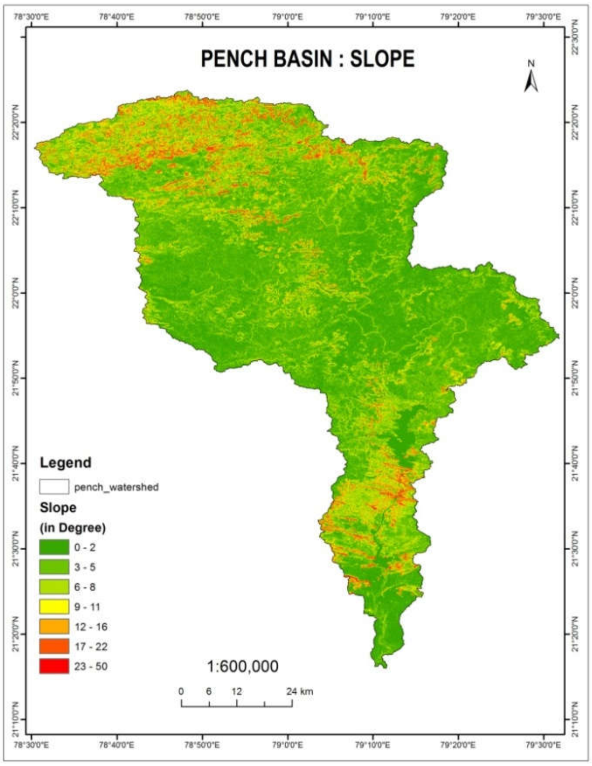

Fig. 6 Slope of Pench River Basin

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