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Morphometric aspects of a small river system of Mirzapur District, Uttar Pradesh, India: A case study of Barhi river system

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Abstract
The Barhi watershed is a small river system passing through a highly vegetated region of Mirzapur district, Uttar Pradesh, India. Morphometric analysis has been carried to determine the spatial variations in the drainage characteristics using the Survey of India toposheet 63L/13 and Landsat 8 imagery data. The study revealed that the area consists of forth order drainage system and lower orders dominating the river system. The soil over the area has been derived from the parent rocks include limestone, schist, sandstone, slate, gneiss, phyllite and granite. The region is hilly terrain so mostly rainfed rivers are there. The morphometric analysis of the region provides a significant insight to the terrain characteristic and hydrological behavior which gives a proper base for a comprehensive management to tackle the water issues of the area.

Keywords: Morphometry, Barhi watershed, Mirzapur

Introduction
The morphometric assessment helps to understand about the primary details of hydrological aspect of any watershed area in order to predict approximate behavior in terms of geomorphology and geology of the related area (Esper 2008) [5]. From the early research investigation made by eminent workers on the drainage analysis parameters in nineties like Horton (1945) [16], Thornbury (1945) and Strahler (1964) [45] showed its relevant importance to understand the structural, lithological, geomorphological aspects of the related area under discussion.
In Indian context, the morphometric analysis has been employed for characterizing major and minor watershed (Nag, 1998, Ratnam *et al.*, 2005) [30, 33] and for the development of groundwater resources (Sredevi *et al.*, 2004, 2009) [39, 40]. Various studies have been carried out in the North Indian drainage system. Now, the trend of computer based analysis are proving easier, time- efficient tool with reliable results to gain important information about the concerned area. The present study employed some field and mostly computer based morphometric analysis of the study area. The data generated using Landsat 8 imagery and Survey of India toposheet number 63L/13.

Study Area
The study area lies between 82°54′E to 83°E latitude and 24°54′N to 25°N longitude. The climate is tropical monsoon type, with the year divisible into winter (November-February), summer (April- Mid June) and rainy (Late June- October) seasons. The monthly minimum mean temperature ranges between 13.4 °C to 30.7 °C. About 9 month of the year are dry and 3 month are moist, the later receiving about 87% of the total annual rainfall (mm) due to south west monsoon. The average rainfall varies between 850 and 1300 mm. About 85% of the annual rainfall occurs during the rainy season from the SW monsoon. The Barhi river passes through densely vegetated reserve forests where Khoradih reserve forest and Jangal Mahal reserve forest present in its east and west respectively except some of its lower part which flows in the agricultural region. The river flows from south to north showing slope of the region as in the direction of flow. The soils developed in the Mirzapur district are derived from the underlying bedrock consisting of Archaean to Proterozoic sandstones, limestone, phyllites, shale, slate and granite. They are products of erosion, deposition, weathering and leaching over a long period of time.

Methodology
The stream network has been digitised using toposheet map in Arc GIS version 10.1 after its subset has been created using the watershed area boundary map and simultaneously drainage has been extracted from the satellite data. Both the drainage networks were compared for proper understanding of the major and minor streams of the study area. The drainage network generated was then analysed using Horton (1945) [16], Strahler (1964) [45], Smith (1950) [37], Schumm (1956) [34], etc. for various parameters. The basic parameters have been derived and extracted using various mathematical equations (table no. 1).

Result and Discussion
The drainage network of the area has been digitized as shown in the figure 1.

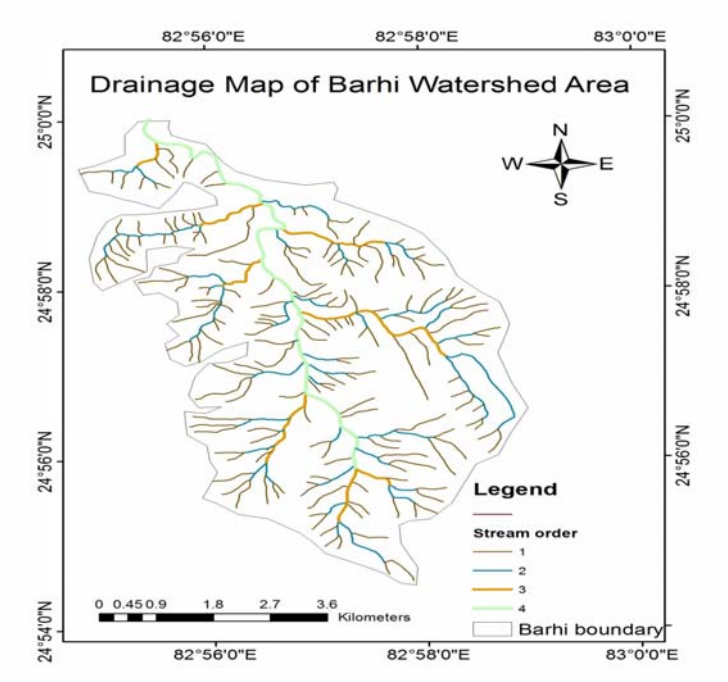

Fig 1: Drainage map of Barhi watershed area

The morphometric parameters have been categorized into three parts: linear, areal and relief aspects which have been discussed:

Table 1: Morphometric parameters used for the morphometric analysis.

LINEAR ASPECT				
Sl. No.	**Parameter**	**Definition**	**Unit**	**References**
1.	Perimeter (P)	Length of the watershed boundary	Km	
2.	Basin length (Lb)	Maximum length of the watershed measured parallel to the main drainage line	Km	
3.	Stream order(Nu)	Hierarchical ordering	Dimensionless	Strahler (1957) [43]
4.	Stream length (Lu)	Length of the major stream	Km	Horton (1945) [16]
5.	Bifurcation ratio (Rb)	Rb=Nu/N(u+1), where Nu is number of streams of any given order and N(u+1) is number in the next higher order.	Dimensionless	Horton (1945) [16]
6.	Stream length ratio (RI)	Rl=Lu/L(u-1), where Lu is stream length order u and L(u-1) is stream segment length of the next lower order.	Dimensionless	Horton (1945) [16]
7.	Rho coefficient (ρ)	ρ=Rl/Rb	Dimensionless	Horton (1945) [16]
AREAL ASPECT				
8.	Area (*A*)	Area of watershed	Km^2	
9.	Drainage density (Dd)	$Dd = \frac{\sum Lt}{A}$, Where ∑Lt is the total length of all the ordered streams	$Km\ Km^{-2}$	Horton (1945) [16]
10.	Stream frequency (Fs)	$Fs = \frac{\sum Nt}{A}$, Where Nt is total length of all the ordered streams	Km^2	Horton (1945) [16]
11.	Drainage texture (T)	$T = Dd \times Fs$	$Km\ Km^{-4}$	Smith (1950) [37]
12.	Length of overland flow (Lg)	$Lg = \frac{1}{2}$ Dd	Km	Horton (1945) [16]
13.	Constant of channel maintenance (C)	$C = \frac{1}{Dd}$	Km	Schumm (1956) [34]
14.	Form factor (Ff)	$Ff = \frac{A}{Lb^2}$	Dimensionless	Horton (1945) [16]
15.	Elongation ratio (Re)	$Re = \frac{1.128\sqrt{A}}{Lb}$	Dimensionless	Schumm (1956) [34]
16.	Shape index (Sw)	$Sw = \frac{1}{Ff}$	Dimensionless	Horton (1945) [16]
RELIEF ASPECT				
17.	Basin relief (R)	R= H-h, where H is maximum elevation and h is minimum elevation	Km	Schumm (1956)

		within the basin		[34]
18.	Relief ratio (Rr)	$Rr=\frac{R}{Lb}$	Dimensionless	Schumm (1956) [34]
19.	Ruggedness number (Rn)	$Rn= R \times Dd$	Dimensionless	Strahler (1958) [44]
20.	Gradient ratio (Rg)	$Rg= Es-\frac{Em}{Lb}$, where Es is the elevation at the source, Em is the elevation at the mouth	Dimensionless	Sreedevi *et al.* (2004) [40]
21.	Melton ruggedness ratio (MRn)	$MRn = H-\frac{h}{A^{0.6}}$	Dimensionless	Melton (1965) [27]

Table 2: Results of calculated morphometric parameters

S. No.	Parameters	1st Order	2nd Order	3rd Order	4th Order	Total
1.	Perimeter					39.4617 km
2.	Basin length					10.867504 km
3.	Stream length	81.26345km	28.140935 km	11.367491 km	10.213213 km	130.985 km and 0.5798 km
4.	Number of streams	178	39	8	1	
5.	Bifurcation ratio		4.564	4.875	8	5.813 (Mean)
6.	Stream Length ratio		0.346	0.4039	0.898	0.549 (Mean)
7.	Rho coefficient		0.075	0.0828	0.112	0.089 (Mean)
8.	Area					37.867 km^2
9.	Drainage density					3.459 km^{-1}
10.	Stream frequency					5.9682km^{-2}
11.	Drainage texture					20.644 km^{-3}
12.	Length of overland flow					0.147 km
13.	Constant of channel maintenance					0.289
14.	Form factor					0.32
15.	Elongation ratio					0.6387
16.	Shape index					3.11885566
17.	Basin relief					216 m (Highest relief-316m and lowest relief-100m)
18.	Relief ratio					19.876
19.	Ruggedness number					0.747
20.	Gradient ratio					0.017
21.	Melton ruggedness ratio					0.035

Linear Aspects

Perimeter (P): The data on perimeter of Barhi is 39.4617 Km.

Basin length (Lb): The Lb of Barhi is 10.867504 km.

Stream Order (Nu): The classification of stream based on the number and type of tributary junctions, has proven to be a useful indicator of stream size, discharge, and drainage area (Strahler 1957) [43]. Order (*u*) with specific number of stream (N) is written in result and discussion. Barhi is designated as one forth order watershed with eight third order tributaries.

Stream length (Lu): The mean and total stream length of Barhi watershed is 0.5798 km and 130.985 km respectively.

Bifurcation ratio (Rb): Bifurcation ratio, a measure of the degree of ramification of drainage network (Mesa 2006) [28], exercises a significant control over the 'peakedness' of runoff (Chorley 1969) [2]. The Rb values usually fall in the range of 3.0 and 5.0 for networks formed on the homogeneous rock (with least/minimum structural disturbances), on the one hand and hits values higher than 10.0, where structural control play dominant roles on the other (Mekel 1970, Chow *et al.* 1988) [26, 3]. The shape of watersheds also exert a significant control on Rb (Verstappen 1983) [49]. The variation in Rb values are a reflection of the differences in the shape of stream network (Ghosh and Chhibber 1984) [8]. In case of Barhi, Rb attains a value range 5.8.

Stream length ratio (RI): Stream Length Ratio of 2nd Order- 0.34, 3rd Order- 0.40, 4th Order- 0.89 and mean RI is 0.549. The variability in RI among successive stream order is a reflection of differences between slope and topography and hence it has an important control on discharge and erosional stage of watershed (Sreedevi *et al.* 2004) [40]. It must also be associated with either as downstream extension of the higher order segment or an upward extension of tributaries or inception. The high positive correlation of mean RI with A indicates the higher erosional activity and consequent tendency for a more rapid bifurcation of streams and development of higher order streams.

Rho coefficient (ρ): The Rho coefficient is an important relating drainage density to physiographic development of a watershed which facilitate evaluation of storage capacity of drainage network and hence, a determinant of ultimate degree of drainage development in a given watershed (Horton 1945) [16]. The climatic, geologic, geomorphologic, and anthropogenic factors determine the changes in this parameter. The mean value of ρ is 0.089.

Areal Aspects

Area (A): The Barhi watershed area is 37.8673 square Km.

Drainage density (Dd): Drainage density is a parameter sensitive to the erosional development and provides a link

between form attribute of a watershed and processes operating along the stream course (Strahler 1954, Gregory and Walling 1973) [42, 11]. According to Verstappen (1983) [49], Dd measures the degree of fluvial dissection and is under the influence of numerous factors, but the resistance to erosion of rock, infiltration capacity of land and climatic condition rank high. The Dd of Barhi watershed is 3.45 km^{-1}, suggesting that terrain is moderately steep, comparatively impervious and moderately dissected as well as region receives good precipitation.

Stream frequency (Fs): The stream factor for Barhi is 5.9km^{-2}.

Drainage texture (T): Smith (1950) [37] suggested that drainage texture is a measure of relative channel spacing in a fluvial-dissected terrain, which is greatly influenced by climate, vegetation, lithology, soil type, relief, and stage of development of a watershed. The drainage texture of Barhi watershed is 20.64. Smith (1950) [37] is identified five different texture classes based on Dd values viz., very coarse (<2), coarse (>2), moderate (4-5), fine (6-8), very fine (>8). Thus Barhi watershed falls under the category of very fine texture.

Length of overland flow (Lg): Length of overland flow is the length of water over the ground before it gets concentrated into definite stream channels which affect both hydrologic and physiographic development of drainage basins (Horton 1945) [16]. The Barhi watershed report Lg value of 0.14 km. suggesting mature geomorphic stage.

Constant of channel maintenance(C): The *C* value of Barhi watershed is 0.28. Most of the sub-watersheds with low values indicate the region with close dissection and these are moderately influenced by structural parameters (Vijith and Satheesh 2006) [50]. Barhi watershed characterized value implies significantly moderate infiltration rates.

Form factor (Ff): Ff is a parameter used to predict the flow intensity of a watershed of a defined area and this has a direct linkage to peak discharge (Horton 1945, Gregory and Walling 1973) [16, 11]. The Ff of Barhi watershed is 0.32 which implying a more elongate plan view of a watershed and suggesting consequent flatter peak flow of longer duration.

Elongation ratio (Re): The Re of Barhi watershed is 0.63. Based on the classification by (Strahler 1964) [45], oval shape has a range (0.90>Re>0.80) and less elongate has a range (0.80>Re>0.70) and elongated has (Re<0.70). Hence, Barhi watershed falls under the category of elongated shape with a smooth hydrograph which explained by greater time lag for water from upper regions of the catchment to reach outlet.

Shape index (Sw): The Sw of Barhi watershed is 3.1 suggesting the channel more developed along its length.

Relief Aspects

Basin relief (R): R is a parameter that determines the stream gradient and influences flood pattern and volume of sediment that can be transported (Hadley and Schumm 1961) [13]. It may be unduly influenced by one isolated peak within the watershed. Basin relief is an important factor in understanding denudational characteristics of a basin (Sreedevi *et al.* 2004) [40]. The basin relief of Barhi watershed is 216 meters.

Relief ratio (Rr): Rr is a dimensionless height to length ratio, i.e. basin relief and widely accepted as an effective measure of gradient aspects of the watershed (Schumm 1956) [34]. The Rr of Barhi watershed is 0.08 (Rr<0.10) indicating the exposure of basement rocks as small ridges and mounds with lower slope value (Vittala *et al*., 2004).

Ruggedness number (Rn): The ruggedness number is expressed as the product of basin relief and drainage density (Strahler 1958) [44]. The Rn for Barhi watershed is 0.745 so the low value shows the region to be less prone to soil erosion (Vijith and Satheesh, 2006) [50].

Gradient ratio (Rg): Gradient ratio is indicator of channel slope which enables assessment of the runoff volume (Sreedevi *et al*. 2004) [40]. Barhi watershed has an Rg of 0.02. The large Rg value reflects the mountainous nature of the terrain. The main stream maximally flows through the plateau and the relative low values of Rg confirm the same.

Melton ruggedness number (MRn): The MRn is a slope index that provides spatialized representation of relief ruggedness within the watershed (Melton 1965) [27]. Barhi watershed has an MRn of 0.04

Conclusion

The morphometric analysis is an immense tool used in evaluating river basin and the watershed preference for soil, conservation of water and resource management. It is of great importance in understanding hydrological behavior of basin. The analysis carried out for the catchment basin depicts that the basin is tending towards elongated shape. The infiltration in the region is not high as due to presence of fine sediments in abundance. The Dd value provide sufficient explaination of geology as less impervious and moderate slope helps to check higher erosion. The river is rainfed so water level fluctuates due to seasonal variation, lower in summers and higher in rainy season. Proper understanding of the watershed response to different processes helps to proper watershed management. The present study would help a proper morphometric description of the area for tackling the water problems and related management.

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