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Remote Sensing And GIS Based Morphometric Calculation: A Case Study of Pahuj River Basin, Jhansi District, U.P., India

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Abstract

The morphometric analysis of drainage basin has become a study in understanding hydrological dynamics of the basin. The various parameters reflect the exact mathematics behind the water dynamics relating river and groundwater. The study area lies under one of the complex nature of rock-water relationship due to the erroneous behavior of hard rock reservoir. It is a part of Pahuj river basin located in the Jhansi district of Uttar Pradesh, India. It covers an area of 308.90 km^2. The drainage pattern of the watershed is delineated using LISS III-2014 on 1:50000 scale and Survey of India toposheets for a smooth blend of understanding the minute stream lines. The remote sensing and GIS have been proved to be efficient tools in drainage delineation and hence the morphometric parameters were computed using ArcGIS 10 software for a detailed study. The drainage pattern of the study area is dendritic and some part of the study area is trellis pattern with stream orders ranging from I to V orders. Drainage density ranges from <1 to >5 km/km^2 suggesting coarse to moderate drainage texture. The values of bifurcation ratio ranging from 2.00 to 4.71 indicate that the Pahuj watershed fall under normal basin category.

Keywords: *Remote Sensing, GIS, Morphometric, Arc GIS, Basin, Circulatory ratio*

1. Introduction

The Pahuj river, a tributary of Chambal river, basin lies under a geographic location between 78°18’10.12” to 78°33’13”E longitudes and 25°19’15.85” to 25°31’45.26”N latitudes. Lithology in the study area shows mostly hard rock terrain with some quaternary alluvial soil helping the vegetation of the area. The rock composition mostly consists of granitic gneisses, basic dykes and quartzites lying as part of Bundelkhand Granitic-Gnessic Complex. Typical tropical climate dominates the region having hotter summers to colder winters. The study area shows a general low relief but at places having steep slopes. Drainage pattern is parallel in nature aligned mostly in the NE-SW direction and also at places enriched with dendritic pattern and trellis pattern. The tributaries flowing themselves suggest being on hard rock terrain and are mostly structurally controlled. Monsoon months are the only time of groundwater recharge, high water in streams and humid condition unlike dry conditions throughout the year. The study area receives rainfall an average of about 880.0 mm annually having the mean annual temperature 38° C. The elevation varies between 214 m in the North-East to 375 m above mean sea level in the center of the watershed at ridge, above 300 m above mean sea level at South-West.

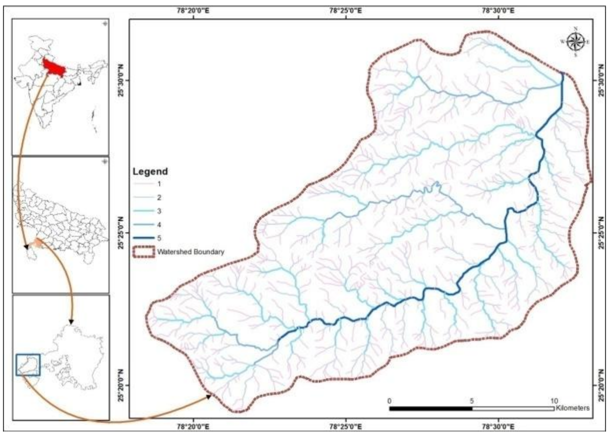

Fig. 1 Location Map of the Study Are

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2. Review of Literature

Water, one of the vital natural resources for agricultural, is becoming deficient because of over-exploitation, poor groundwater recharge, immoderate use etc. Therefore, the study of morphometric characteristics assumes greater significance in developing the surface and groundwater resources more particularly in Central India. *(Sahu, et.al, 2017)*

Development of a drainage system and the flowing pattern over space and time are influenced by several variables (*Horton 1945; Leopold and Maddock 1953; Abrahams 1984*).

"Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms" *(Agarwal 1998; Obi Reddy et al. 2002)*. The morphometric analysis is done successfully through measurement of linear, aerial, relief, gradient of channel network and contributing ground slope of the basin *(Nautiyal 1994; Nag and Chakraborty, 2003; Magesh et al. 2012).*

A widely acknowledged principle of morphometry is that drainage basin morphology reflects various geological and geomorphological processes over time, as indicated by various morphometric studies *(Horton 1945; Strahler 1952, 1964; Muller 1968; Shreve 1969; Evans 1972, 1984; Ohmori 1993; Cox 1994; Oguchi 1997; Hurtrez et al. 1999).* It is well established that the influence of drainage morphometry is very significant in understanding the landform processes, soil physical properties and erosional characteristics.

The Geomorphic characteristics of a drainage basin are important for hydrological investigations involving the assessment of groundwater potential, watershed management and, environmental assessment. (*Tiwari and Tripathi, 2018)*

Drainage provides a basic to understand initial gradient, variation in rock resistance, structural control, geological and geomorphologic history of the drainage basin or watershed.

Evaluation of morphometric parameters requires the analysis of various drainage parameters such as ordering of the various streams, measurement of basin area and perimeter, length of drainage channels, drainage density (Dd), bifurcation ratio (Rb), stream length ratio (RL), and relief ratio (Rh) *(Rai et. al, 2017)*. Therefore, the present study aims at the morphometric analysis on watershed using Remote Sensing and GIS.

3. Materials and Methods

The base map of the Pahuj watershed a part of Pahuj River basin was prepared based on Survey of India Topographic Maps on a 1:50,000 scale and also with IRS I C and ID (LISS-III), 2014 and SRTM (Shuttle Radar Topographic Mission, USGS) data. Global Mapper 15 was used for delineating the study area and exporting the information to DEM format. The SRTM DEM data was imported to ArcGIS 10, based on these data slope, aspect and contour map for the watershed was prepared. The drainage network of the watershed was prepared from Survey of India toposheets through ArcGIS 10 software. Based on the drainage order, the channels were classified according to drainage order following (*Strahler, 1964).* Watershed parameters, such as, area, perimeter, length, stream length, and stream order was also calculated. Later, these parameters were used to determine other influence factors, such as bifurcation ratio, Stream length ratio, stream frequency, drainage density, elongation ratio, circulatory ratio, form factor. Table 1 provides a list of the main parameters and, where appropriate, the formulae used to calculate them.

Table No. 1 Formulae adopted for Computation of Morphometric Parameters

S.N.	Morphometric Parameters	Formula	Reference
1	Stream order	Hierarchical rank	Strahler (1964)
2	Stream length (Lu)	Length of the stream	Horton (1945)
3	Mean stream length (Lsm)	Lsm =? Lu / Nu Where, Lsm = Mean stream length ? Lu = Total stream length of order 'u' Nu = Total no. of stream segments of order 'u'	Strahler (1964)
4	Stream length ratio (RL)	RL = Lu / Lu – 1 Where, RL = Stream length ratio Lu = The total stream length of the order 'u' Lu – 1 = The total stream length of its next lower order	Horton (1945)
5	Bifurcation ratio (Rb)	Rb = Nu / Nu + 1 Where, Rb = Bifurcation ratio Nu = Total no. of stream segments of order 'u' Nu + 1 = Number of segments of the next higher order	Schumn (1956)
6	Mean bifurcation ratio (Rbm)	Rbm = Average of bifurcation ratios of all orders	Strahler (1957)
7	Relief ratio (Rh)	Rh = H / Lb Where, Rh = Relief ratio H = Total relief (Relative relief) of the basin (km) Lb = Basin length	Schumm (1956)
8	Drainage density (D)	D = Lu / A Where, D = Drainage density Lu = Total stream length of all orders A = Area of the basin (km^2)	Horton (1932)

9	Stream frequency (Fs)	Fs = Nu / A Where, Fs = Stream frequency Nu = Total no. of streams of all orders A = Area of the basin (km^2)	Horton (1932)
10	Texture Ratio (Rt)	Rt = Nu / P Where, Rt = Texture Ratio Nu = Total no. of streams of all orders P = Perimeter (km)	Horton (1945)
11	Form factor (Rf)	Rf = A / Lb² Where, Rf = Form factor A = Area of the basin (km^2) Lb² = Square of basin length	Horton (1932)
12	Circularity ratio (Rc)	Rc = 4 * Pi * A / P² Where, Rc = Circularity ratio Pi = 'Pi' value i.e., 3.14 A = Area of the basin (km^2) P² = Square of the perimeter (km)	Miller (1953)
13	Elongation ratio (Re)	Re = 2(√A/Pi)/ Lb Where, Re = Elongation ratio, A=Area (km^2) Lb = Basin length	Schumn (1956)
14	Length of overland flow (Lg)	Lg = 1 / D * 2 Where, Lg = Length of overland flow D = Drainage density	Horton (1945)

4. Result and Discussion

According to *Clarke (1966)*, "Morphometry is the measurement and mathematical analysis of the configuration of the earth surface, shape and dimensions of its landforms". The morphometric analysis is carried out through measurement of linear, areal and relief aspects of the basin and slope contribution *(Nag and Chakraborty, 2003).*

The measurement of various morphometric parameters namely – stream order, stream length (Lu), mean stream length (Lsm), stream length ratio (RL), bifurcation ratio (Rb) mean bifurcation ratio (Rbm), relief ratio (Rh) drainage density (D), stream frequency (Fs) drainage fexture (Rt), form factor (Rf), circulatory ratio (Rc), elongation ratio (Re) length of overland flow (Lg) has been carried out and the data are presented in Table 3.

In the current study, the remote sensing data has been used for updation of drainages and the updated drainages have been used for morphometric analysis.

Table No. 2 Stream Parameter of Pahuj Watershed

S.N.	**1**	**2**	**3**	**4**	**5**
Stream Order	I	II	III	IV	V
Number of Stream	592	140	32	4	1
Length of Stream (Km.)	339.05	139.48	89.88	31.45	29.83

Table No.3 Calculation of different Morphometric Parameters of Pahuj Watershed

Watershed Name		**Pahuj Watershed**
Area (Sq. Km.)		308.90
Mean Stream Length in Km. (Lsm)	I	0.58
	II	0.99
	III	2.81
	IV	7.87
	V	29.83
Stream Length ratio (RL)	II/I	0.42
	III/II	0.65
	IV/III	0.35
	V/IV	0.95
Bifurcation Ratio (Rb)	I/II	4.23
	II/III	4.38
	III/IV	8
	IV/V	4
Mean Bifurcation Ratio (Rbm)		5.16
Perimeter (P) in Km.		785.53
Basin Length (Lb) in Km.		27.13
Total Reliefs (Meters)		156.5
Relief Ratio (Rh)		0.06
Elongation Ratio (Re)		0.74
Length of overland flow (Lg)		0.245
Drainage Density (D) (Km/Sq. Km.)		2.04
Stream Frequency (Fs)		2.49
Texture Ratio (Rt)		0.98
Form Factor (Rf)		0.42
Circulatory Ratio (Rc)		5.28

Stream Order

The designated stream order is the first step in the drainage basin analysis. In the present study, ranking of streams has been carried out based on the method proposed by Strahler (1964). The order-wise stream numbers, area and stream length of the Pahuj watershed is presented in table 2. In this watershed I to V^{th} order streams existed. It is noticed that the maximum frequency is in case of first order streams. It is also observed that there is a decrease in stream frequency as the stream order increases.

Stream Length

Stream length is measured from mouth of a river to drainage divide with the help of ArcGIS 10 software. This has been computed based on the law proposed by (*Horton, 1945)* for the study area. Generally, the total length of stream segments is maximum in first order streams and decreases as the stream order increases in the present case.

Mean Stream Length

"Mean stream length (Lsm) is a characteristic property related to the drainage network components and its associated basin surfaces" *(Strahler, 1964)*. This has been calculated by dividing the total stream length of order (u) by the number of streams of segments in the order. The mean stream length is presented in Table 3. It is seen that, Lsm values exhibit variation from 0.58 to 29.83.

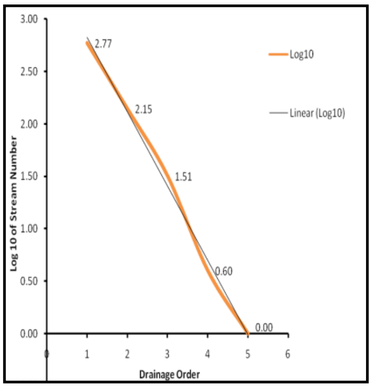

Fig.2

Stream Length Ratio

"Stream length ratio (RL) is the ratio of the mean length of the one order to the next lower order of the stream segments". The RL values are presented in Table 3. The stream length ratio between the streams of different orders of the study area shows a change in watershed. Stream length ratio of the study area between 0.42 to 0.95. This change might be attributed to variation in slope and topography, indicating the late youth stage of geomorphic development in the streams of the study area *(Singh and Singh, 1997 and Vittala et al., 2004*).

Bifurcation Ratio

According to *(Schumn, 1956*), "the term bifurcation ratio may be defined as the ratio of the number of the stream segments of given order to the number of segments of the next higher orders". Bifurcation ratio shows a small range of variation for different regions or for different environments except where the powerful geological control dominates *(Strahler, 1957).* The Rb values of study area (Table 3) indicate Rb values are not same from one order to next order. These differences are depending upon the geological and lithological development of the drainage basin *(Strahler, 1964).* In the study area, the higher values of Rb indicate a strong structural control in the drainage pattern whereas the lower values indicate that the watershed is less affected by structural disturbances *(Stahler, 1964; Nag, 1998; Vittala et al., 2004 and Chopra et al., 2005).*

The Rb value in the study area range from 4.23 to 8 indicating that watershed is falling under the normal basin category. *(Strahler, 1957)*

Relief Aspect

Relief is the elevation difference between the highest and lowest point on the valley floor of the region. The relief measurements like relief ratio, basin length and total relief have been carried out and the data are presented in Table 3.

Relief Ratio

"The maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line is termed as relief ratio" *(Schumn, 1956).* Relief ratio has direct relationship between the relief and channel gradient. The relief ratio normally increases with decreasing drainage area and size of the watersheds of a given drainage basin *(Gottaschalk, 1964).*

In the study area, the value of relief ratio is 5.77. It is observed that the Rh values increase with decreasing drainage area and size of a given drainage basin as proposed by (*Gottaschalk, 1964).*

Aerial Aspect

Aerial aspects include different morphometric parameters, like drainage density, texture ratio, stream frequency, form factor, circulatory ratio, elongation ratio and length of the overland flow. The values of these parameters are presented in Table 3 and discussed and interpreted.

Drainage Density

"Drainage density is defined as the total length of streams of all orders per drainage area. Density factor is related to climate, type of rocks, relief, infiltration capacity, vegetation cover, surface roughness and run-off intensity index. Of these, surface roughness has no significant correlation with drainage density. The drainage density indicates the closeness of spacing of channels" *(Horton, 1932).*

The drainage density in the study area shows 2.04 km.per km^2 suggesting low drainage densities. This low drainage density of the study area suggests that it has highly permeable sub-soil and coarse drainage texture.

Stream Frequency

"The total number of stream segments of all orders per unit area is known as stream frequency" *(Horton, 1932).* Hopefully, it is possible to have basins of same drainage density differing stream

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frequency and basins of the same stream frequency differing in drainage density.

The Fs value of the study area is presented in Table 3. Fs value of the study area is 2.49. It is also seen that the drainage density value of the study area exhibits +ve correlation with the stream frequency suggesting that there is an increase in stream population with respect to increasing drainage density.

Drainage Texture

"Drainage texture is the total number of stream segments of all orders per perimeter of that area" *(Horton, 1945)*. It is one of the important concepts of geomorphology which means that the relative spacing of drainage lines. Drainage lines are numerous over impermeable areas than permeable areas. According to Horton (1945), infiltration capacity as the single important factors which influences drainage texture and considered drainage texture which includes drainage density and stream frequency. The value of drainage texture ratio of the study area 0.98. According to Smith (1950), five different drainage textures have been classified based on the drainage density. The drainage density less than 2 indicates very coarse, between 2 and 4 is related to coarse, between 4 and 6 is moderate, between 6 and 8 is fine and greater than 8 is very fine drainage texture. The Pahuj watershed has low value of Rt indicating very coarse drainage texture.

Form Factor

"Form factor may be defined as the ratio of the area of the basin and square of basin length" *(Horton, 1932)*. The value of form factor would always be greater than 0.78 for a perfectly circular basin. Smaller the value of form factor, more elongated will be the basin. Rf values of the study area is presented in Table 2. It is noted that the Rf value of watershed is 0.42. The value of Rf (0.42) in Pahuj watershed indicate that Pahuj sub-circular and elongated.

Circulatory Ratio

The circulatory ratio is mainly concerned with the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin. It is the ratio of the area of the basins to the area of circle having the same circumference as the perimeter of the basin.

In the study area, the Rc value is 5.28 suggesting that Pahuj watershed is more or less circular in shape and is characterized by the high to moderate relief and the drainage system was structurally controlled.

Elongation Ratio

Elongation ratio (Re) describes the degree of stretching of a drainage basin with respect to its area. It is defined by the ratio of the diameter of a circle of the same area as the basin to the maximum length of the basin *(Schumm, 1956)*. The elongation ratio value of the study area is 0.74. The elongation ratio values generally exhibit variation from 0.6 to 1.0 over a wide variety of climatic and geologic types. In case of Pahuj watershed the elongation ratio is >0.6<1.0 indicating geologically controlled.

Length of overland Flow

"The length of overland flow (Lg) approximately equals to half of reciprocal of drainage density" *(Horton, 1945)*. It is the length of water over the ground before it gets concentrated into definite stream channels. This factor basically relates inversely to the average slope of the channel and is quite synonymous with the length of the sheet flow to the large degree. The Lg value of the study area is 0.98. The value of Lg is low in case of Pahuj watershed indicating high relief.

5. Conclusion

Remote sensing and GIS techniques have proved to be efficient tools in drainage delineation and their updation. These updated drainages have been used for the morphometric analysis. The morphometric analysis was carried out through measurement of linear, areal and relief aspects of basins. The morphometric analysis of the drainage networks of the study area show dendritic and some part of the study area shows trellis pattern. The variation in stream length ratio might be due to change in slope and topography. The bifurcation ratio in the watershed indicates normal basin category and the presence of high drainage density. The value of stream frequency indicates +ve correlation with increasing stream population with respect to increasing drainage density. The values of form factor and circulatory ratio suggest that Pahuj watershed is elongated. Elongation ratio indicates that the study area fully geologic controlled. The study is highly beneficial for watershed management as it gives the insight knowledge to understand the basin morphometry and helpful for further interdisciplinary studies.

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