Asian Resonance

Application of Remote Sensing and GIS in Morphometric Analysis: A Case of River Parbati Watershed, Himachal Pardesh (India)

Abstract

The present study is focused on the morphometric analysis of Parbati River Basin. The study has been done using remote sensing and GIS. Demarcation watershed and other parameters required for this study are extracted from Cartosat DEM. Geospatial technology has proved itself as an efficient tool in the analysis of morphometric parameters of a watershed. The parameters of the study for Parbati basin like linear and aerial aspects of the river basin were determined and computed. This river performs a 6th order drainage basin and drainage pattern mainly in subdendritic to sub-trellis type with coarse drainage texture. The basin has high bifurcation ratio which indicates its strong structural control on the drainage. It is also observed that the drainage density value is low which indicates the basin is highly resistant subsoil material. The circularity ratio value reveals that the basin is strongly elongated. This study would help the administration to utilize the watershed for sustainable development of the basin area.

Gursewak Singh Brar
Research Scholar
Department of Geography
Panjab University
Chandigarh

Keywords: Morphometric Analysis, remote sensing, GIS

Introduction

The drainage system and river pattern is very much affected by geomorphology, geology, structural components, soil, and vegetation of the area form where a river passes (Rekha et al. 2011). These hydrologic systems can be better understood by studying these parameters. A drainage basin which is considered as the basic units of water supply brings surface run-off to a well defined stream or river at a point. Its size varies from few hectares to thousands of km² (Chopra et al. 2005). Morphometric analysis plays a key role in understanding a particular drainage basin. This is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimensions of its landforms which provides quantitative description of the basin geometry to understand initial slope or inequalities in the recent diastrophism, rock hardness, structural controls, geomorphic and geological history of drainage basin (Strahler 1964; Clarke 1966).

Geographical Information System (GIS) and remote sensing techniques are widely used for the investigation of various morphometric and terrain parameters of the watersheds and drainage basins as they provide a digital environment and a powerful tool for handling and analysis of the geographical information for better understanding (Vijith 2006). Several scientists like Horton (1945) ; Smith (1950) ; Strahler (1957) ; Krishnamurthy and Srinivas (1995) ; Srivastava and Mitra (1995) ; Agarwal (1998) ; Biswas et al. (1999) ; Narendra and Nageswara Rao (2006), Brar (2014) etc. have conducted morphometric analysis using conventional as well as remote sensing and GIS methods. In the present study, morphometric analysis has been carried out in Parbati river watershed (Himachal Pardesh), which is a major tributary of River Beas.

2. Study Area

River Parbati is an important tributary of River Beas, which originates from Mantalai Glacier in Kullu district of Himachal Pardesh. It flows from north-northwest to west-southwest direction. After a journey of about 90 kilometer it joins River Beas at the place of Bhuntar. The river is fed by several Himalayan glaciers. River Parbati's watershed has an area of 1762.27 km² and its areal extent is 31°45'06"N to 32°13'26"N latitudes and 77°08'24"E to 77°51'08"E longitudes. The study area is characterized are generally composed of metamorphic rocks.

3. Materials and Methods

The delineation of River Parbati watershed and drainage network is done from Catrosat DEM by using ArcGIS 9.3 software. Morphometric analysis has been carried out for the following parameters: stream order(U), stream length(Lu), mean stream length (Lsm), stream length ratio (RL), bifurcation ratio (Rb), mean bifurcation ratio (Rbm), relief ratio (Rh), drainage density (Dd), stream frequency (Fs), drainage texture (Rt), form factor (Rf), circulatory Ratio (Rc), elongation ratio (Re) and length of overland flow(Lg). The methodology for the calculation of above mentioned parameters is given in Table 1.

4. Results and Discussion

The various morphometric parameters of the River Parbati watershed area are determined and are summarized in Tables 2 and 2(a).Stream Order (U)

First step to analyze drainage basin is designation of stream into various orders based on hierarchical ranking. In the present study, a method suggested by Strahler (1964) is adopted for stream ordering. The number of streams in each order and their length is given Table 2(a). The River Parbati watershed is designated as 6th order watershed having a total number of 620 streams of different orders (Map 2).

Fig 1: Location Map of River Parbati Watershed

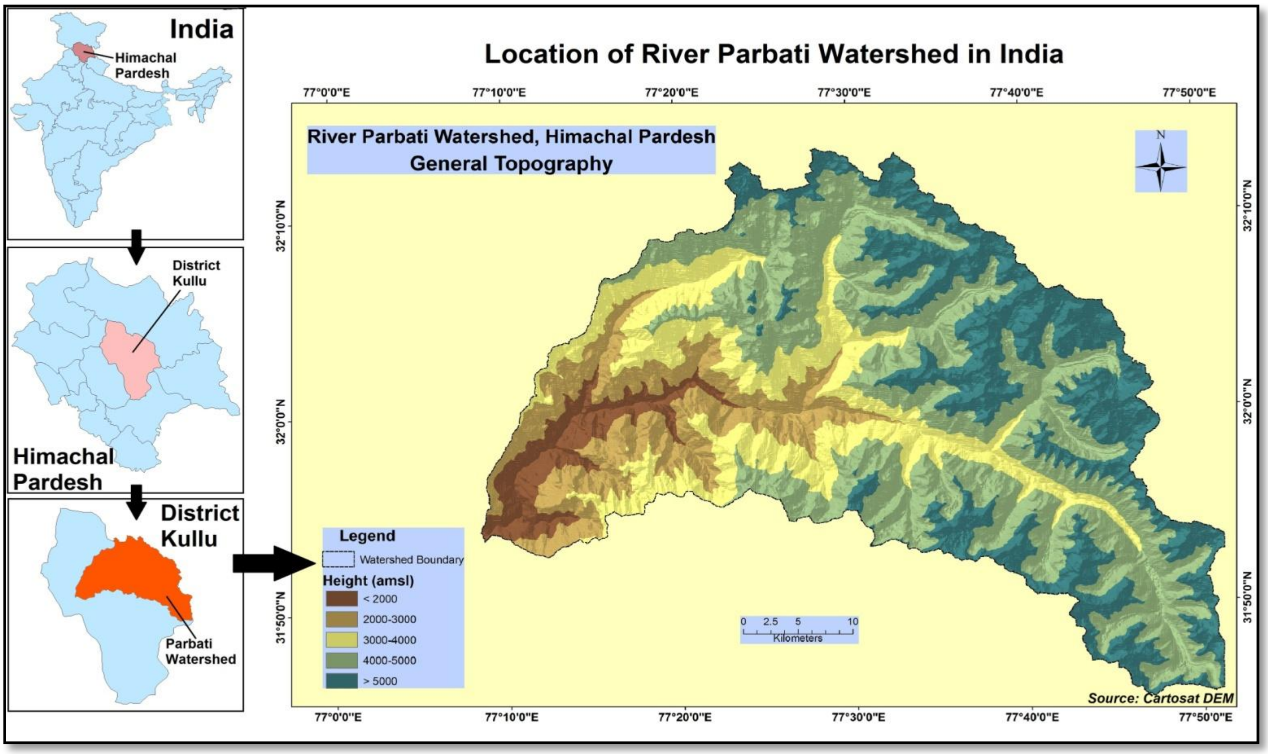


Table 1: Morphometric parameters with formula

Morphometric Parameters	Formula	Reference
Stream Order (U)	Hierarchical Rank	Strahler (1964)
Stream Length (Lu)	Length of Stream	Horton (1945)
Mean Stream Length (Lsm)	Lsm= Lu/Nu Where, Lsm = Mean Stream Length,,Lu = Total stream length of order 'u' and Nu= Total no. of stream segments of order 'u'	Strahler (1964)
Stream Length Ratio (RL)	RL= lu/Lu-1 Where, RL = Stream Length Ratio, Lu = The total stream length of order 'u' and Lu-1= The total stream length of its next lower order	Horton (1945)
Bifurcation Ratio (Rb)	Rb= Nu/Nu+1 Where, Rb = Bifucation Ratio, Nu = Total no. of stream segments of order 'u' and Nu+l= Number of segments of the next higher order	Schumm (1956)
Mean Bifurcation Ratio (Rbm)	Rbm= average bifurcation ration of all orders	Strahler (1957)

Relief Ratio (Rh)	Rh= H/Lb Where, Rh=Relief Ratio, H=Total relief (Relative relief) of the basin in Kilometer and Lb= Basin length	Schumm (1956)
Drainage Density (Dd)	Dd=Lu/A Where, Dd=Drainage Density, Lu=Total stream length of all orders and A= Area of the Basin (km²)	Horton (1932)
Stream Frequency (Fs)	Fs= Nu/A Where, Fs=Stream Frequency, Nu=Total no. of streams of all orders and A= Area of the Basin (km²)	Horton (1932)
Drainage Texture (Rt)	Rt= Nu/P Where, Rt = Drainage Texture, Nu=Total no. of streams of all orders and P=Perimeter (km)	Horton (1945)
Form Factor (Rf)	Rg= A/Lb² Where, Rf=Form Factor, A=Area of the Basin (km²) and Lb²=Square of Basin length	Horton (1932)
Circularity Ratio (Rc)	Rc= 4×π×A/P² Where, Rc=Circularity Ratio, π = 3.14, A=Area of the Basin (km²) and P = Perimeter (km)	Miller (1953)
Elongation Ratio (Re)	Re= 2(√A/ π)/Lb Where, Re= Elongation Ratio, π = 3.14 and Lb=Basin Length	Schumm (1956)
Length of Overland Flow (Lg)	Lg= ½*(1/D) Where, Lg=Length of overland flow and D=Drainage Density	Horton (1945)

Stream Length (Lu)

Total stream length in a particular order is represented by stream length (Lu). The numbers of streams of all six orders in the watershed are counted and their length is measured with the help of ArcGIS 9.3 and shown in table 2(a). In general, the length of streams decreases with increase in stream orders increase. In River Parbati watershed, the length of streams from 1st to 6th order decreases except 5th order which is against the general behavior and indicates that the terrain is characterized by high relief/moderately steep slopes, underlain by varying lithology and there is probability of upliftment across the basin.

Mean Stream Length (Lsm)

The mean stream length (Lsm) is calculated by dividing the total stream length of order 'u' and number of streams of segment of order 'u' (Table 1). It is a characteristic property related to the drainage network and its associated surfaces of the watershed. From the table 2(a), it can be noted that the mean stream length varies from 1.29 (KM) to 41.63 (KM). In River Parbati watershed, as the stream order increases mean stream length also increases. This might be due to changes in slope and topography of the watershed.

Stream Length Ratio (RL)

The stream length ratio (RL) is the ratio of the mean stream length (Lsm) of a given order to the mean stream length (Lsm) of next lower order. According to Horton's law of stream length (1945), the mean stream length segments of each of the successive orders a basin tends to approximate a direct geometric series with streams length increasing towards higher order of streams. The stream length ratio between successive streams orders depends on slope and topographic conditions and it has an important relationship with the surface flow discharge and erosional stage of the basin. In River Parbati watershed it varies from 0.401 to 1.567 (Table 2(a)).

Bifurcation Ratio (Rb)

The bifurcation ratio is the ratio of the number of stream segments of given order to the number of segments of next higher order (Schumn, 1956). Horton (1945) considered it as an index of relief and dissection. Bifurcation ratio shows only a small variation for different regions on different environment except where powerful geological control dominates (Strahler 1957). The value of bifurcation ratio for River Parbati watershed varies from 2 to 4.832 (Table 2(a)).

Table 2:Results of Morphometric Analysis

Parameter	Results
Basin Area (KM²)	1762.27
Perimeter (KM)	258.53
Basin Order	6
Basin Length (Lb)	93.24 KM
Basin Relief (M)	5494
Relief Ratio (Rh)	0.058
Mean Bifurcation Ration (Rbm)	3.266
Drainage Density (Dd)	0.67
Stream Frequency (Fs)	0.352
Drainage Texture (Rt)	2.4
Circularity Ratio (Rc)	0.33
Length of Overland Flow	0.745
Form Factor (Rf)	0.2
Elongation Ratio	0.51

Table 2(a): Results of Morphometric Analysis

Stream Order (U)	Stream Number (Nu)	Bifurcation Ratio (Rb)		Stream Length (Lu) (KM)	Mean Stream Length (Lsm)	Stream Length Ratio (RL)	
1	488	I/II	4.832	627.89	1.29	II/I	0.442
2	101	II/III	4.391	277.38	2.75	III/II	0.514
3	23	III/IV	4.6	142.56	6.2	IV/III	0.465
4	5	IV/V	2.5	66.24	13.25	V/IV	0.401
5	2	V/VI	2	26.56	13.28	VI/V	1.567
6	1			41.63	41.63		

Mean Bifurcation Ratio (Rbm)

Mean bifurcation ratio (Rbm) was suggested by Strahler in 1957. It is the average of bifurcation ratios of all orders used to investigate the influence of structural control in the development of drainage system. In this study area, the mean bifurcation ratio of3.266 indicates that there is strong structural control over the drainage development (Table 2).

Relief Ratio (Rh)

The difference in the elevation of the highest and lowest points in a watershed is its total relief, whereas the ratio of basin relief to basin length (horizontal distance along the longest dimension of the basin parallel to the principal drainage line) is Relief Ratio (Rh) (Schunm, 1956). It is used to measure the overall steepness of a river basin and is an indicator of intensity of erosion processes operating on the slopes of the basin. Normally, it has inverse correlation with drainage area and size of drainage basin. For the present study, it is 0.06 (Table 2).

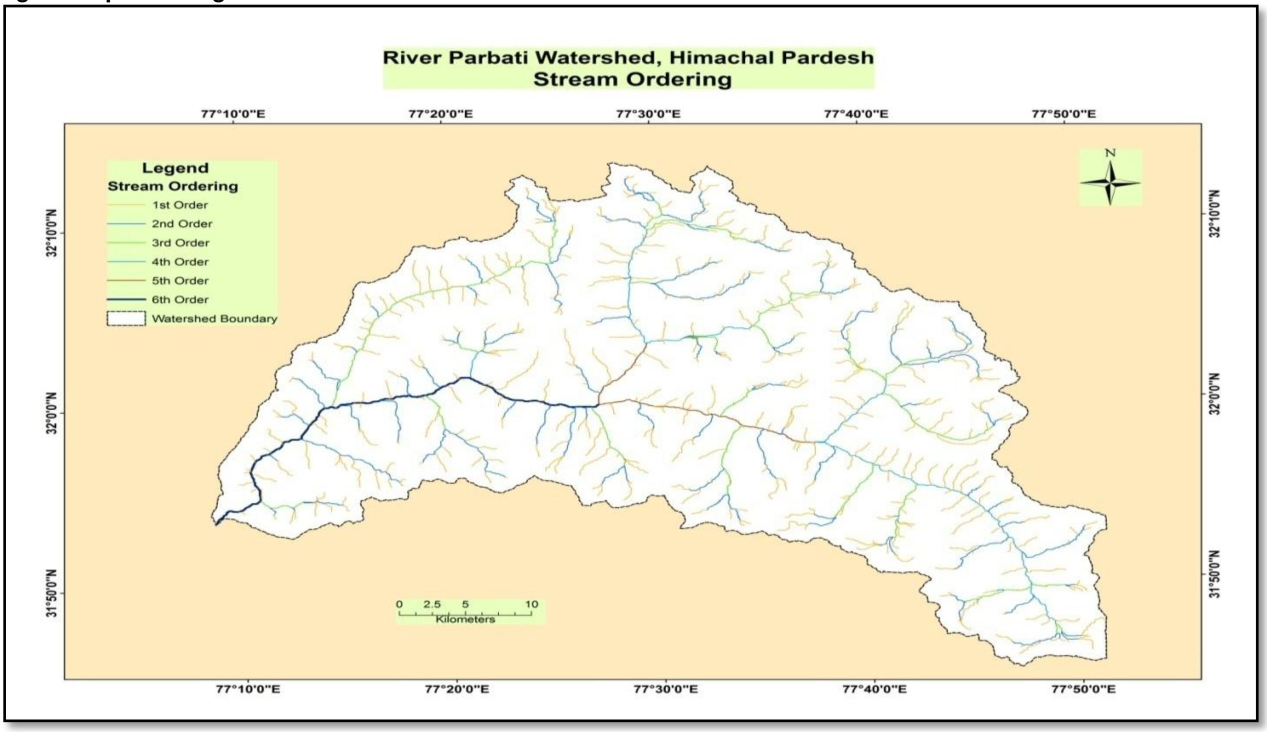
Drainage density (Dd)

According to the drainage density (Dd) is defined as the total length of streams per unit area divided by the area of drainage basin (Horton 1945). It is helpful in determining the permeability and porosity of the watershed. It is also a good indicator of landform elements in stream eroded topography. Low drainage density leads to coarse drainage texture and vice versa. Generally, low drainage density results in the area of highly resistant subsoil material and high drainage density is the resultant of weak subsurface material. In River Parbati watershed with drainage density value of 0.67, confirms the recognition the basin is highly resistant subsoil material and hilly relief.

Stream Frequency (Fs)

The stream frequency is the total number of stream segment of all order per unit area (Horton 1945). The stream frequency of study area is 0.352 per km².

Fig. 2: Map Showing Different Stream Orders in River Parbati Watershed



Drainage Texture (Rt)

Horton (1945) defined drainage texture as the total number of stream segments of all order in a river basin to the perimeter of the basin. It is important to understand geomorphology which means that how drainage lines are spaced in relation to each other. Drainage texture can be classified into 5 different textures i.e., very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (>8) (Smith 1950). In the present study the watershed has a drainage texture of 2.4.

Form Factor (Rf)

Form factor is the numerical index which is commonly used to represent different basin shapes (Horton 1932). Its value varies between 0.1-0.8. Smaller the value of form factor, more elongated will be the basin. A perfect circular basin has a form factor of 0.7854. The basins with high form factors have high peak flows of shorter duration, whereas, elongated watershed with low form factors have lower peak flow of longer duration. In River Parbati watershed, Rf value is 0.2 which indicates that it will be elongated in shape and suggesting flatter peak flow for longer duration.

Circularity Ratio (Rc)

Miller (1953) defined circularity ratio as the ratio of the area of the basin to the area of the circle having same circumference as the basin perimeter. Its value ranges between 0 (in line) to 1 (in a circle). Circularity ratio is dimensionless and expresses the degree of circularity of the basin (Miller 1953). The basins which have circularity ratios from 0.4 to 0.5 indicate strongly elongated and highly permeable homogenous geologic materials. The River Parbati watershed has a circularity ratio of 0.33 indicating that the area is highly elongated.

Elongation Ratio (Re)

Schumm (1956) defined elongation ratio (as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. The value of elongation ratio ranges from 0 (in highly elongated shape) to unity i.e. 1.0 (in the circular shape). Values close to 1.0 represent regions of very low relief, whereas values of 0.6 to 0.8 are usually associated with high relief and steep ground slope (Strahler 1964). The Re for the River Parbati watershed is 0.51 which indicates watershed to be more elongated with high relief and steep slope.

Length of Overland Flow (Lg)

Horton (1945) described length of overland flow (Lg) as the length of water over the ground before it gets concentrated into definite stream channels. It is expressed as equal to half of the reciprocal of Drainage Density. It is an important independent variable, which greatly affects the quantity of water required to exceed a certain threshold of erosion. This factor inversely related to the average slope of the channel and is quite similar with the length of sheet flow to a large degree. The study area has length of overland flow value 0.74 which indicates a well developed drainage network.

Conclusion

The morphometric analysis of River Parbati watershed using GIS and remote sensing retrieved that this tool is very helpful for the researchers to analysis the drainage basins easily and accurately in the short duration. The analysis of linear aspects of drainage basin result shows that the basin has a Sub-dendritic to sub-trellis pattern with 6^{th} order stream. High bifurcation ratio in the study area indicates a strong structural control on the drainage. The result of relief aspect shows the study area is characterized by high relief and high stream density. The results of aerial aspect show that the texture of drainage is coarse. The analysis of elongation ratio indicates the drainage basin is elongated in nature with high relief and steep slopes.

References

1. Agarwal, C. S. (Oct. 1998), Study of drainage pattern through aerial data in Naugarh area of Varanasi district, UP, Journal of the Indian Society of Remote Sensing, vol. 26, no. 4. pp. 169-175.
2. Biswas, S, Sudhakar, S. and Desai, V. R. (Nov. 1999), Prioritisation of subwatersheds based on morphometric analysis of drainage basin: A remote sensing and GIS approach, Journal of the Indian Society of Remote Sensing, vol. 27, no. 3, pp. 155-166.
3. Brar, G. S. (May 2014), Morphometric analysis of Siswan drainage basin, Punjab (India) using Geographical Information System, International Journal of IT, Engineering and Applied Sciences Research, vol. 3, no. 5, pp. 11-16.
4. Chopra, R., Dhiman, R. D. and Sharma, P. K. (Sept. 2005), Morphometric analysis of sub-watersheds in Gurdaspur District, Punjab using remote sensing and GIS techniques, Journal of the Indian Society of Remote Sensing, vol. 33, no. 4, pp. 531-539.
5. Clarke, J. I. (1966), Morphometry from maps, Essays in Geomorphology, G.H. Dury (Ed) American Elsevier Publ. Co., New York.
6. Horton, R. E. (1932). Drainage basin characteristics, Transactions American Geophysical Union, vol. 13, no. 1, pp. 350-361.
7. Horton, R. E. (March 1945), Erosional development of streams and their drainage basins: Hydrophysical approach to quantitative morphology, Geological Society of America Bulletin, vol. 56, no. 3, pp. 275-370.
8. Krishnamurthy, J. and Srinivas, G. (1995) Role of geological and geomorphological factors in groundwater exploration – a study through remote sensing techniques, International Journal of Remote Sensing, vol. 16, no. 14, pp. 2595–2618.
9. Miller, V. C. (1953), A Quantitative geomorphic study of drainage basin characteristics in the Clinch Mountain area, Virginia and Tennessee, Project NR 389-042 , Tech Report 3, Columbia University, Department of Geology, ONR, New York.

10. Narendra, K and Rao, K. N. (June 2006), Morphometry of the Meghadrigedda watershed, Visakhapatnam district, Andhra Pradesh using GIS and Resourcesat data, Journal of the Indian Society of Remote Sensing, vol. 34, no. 2, pp. 101-110.
11. Rekha, V. B., George, A. V. and Rita, M., (Sept. 2011) ,Morphometric analysis and micro-watershed prioritization of Peruvanthanam sub-watershed, the Manimala river basin, Kerala, South India, Environmental Research, Engineering and Management, vol. 3, no. 57, pp. 6-14.
12. Schumn, S. A. (May 1956), Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. Geol. Soc. Am. Bull., vol. 67, no. 5, pp. 597-646.
13. Smith, K. G. (Sept. 1950), Standards for grading textures of erosional topography, American Journal of Science, vol. 248, no.9, pp. 655-668.
14. Srivastava, V. K. and Mitra, D. (Dec. 1995), Study of drainage pattern of Raniganj Coalfield (Burdwan District) as observed on Landsat TM / IRS LISS II imagery, Journal of the Indian Society of Remote Sensing, vol. 23, pp. 225-235.
15. Strahler, A. N. (Dec. 1957), Quantitative analysis of watershed geomorphology, Transactions American Geophysical Union, vol 38, no. 6, pp. 913-920.
16. Strahler, A. N. (1964) Quantitative geomorphology of drainage basins and channel networks, Handbook of Applied Hydrology, McGraw Hill Book Company, New York.
17. Vijith, H. and Satheesh, R. (Jan. 2006), GIS based morphometric analysis of two major upland sub-watersheds of Meenachil river in Kerala, Journal of the Indian Society of Remote Sensing, vol. 34, no. 2, pp. 181-185.