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Analysis of GIS Based Morphometric Parameters and Hydrological Changes in Parbati River Basin, Himachal Pradesh, India

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Abstract

Morphometric analysis, including the aspects such as linear, aerial and relief aspects of the Parbati River basin has been done with the help of remote sensing and GIS techniques. Strahler's method of stream ordering is used for all stream related calculations. The river basin is designated as 6th order basin, and 1st order streams are mostly dominating the basin, and moderate drainage density indicates that weak subsurface material and belongs to medium texture. The study reveals that the basin has an oval to less elongated shape and associated with steep ground slopes. The ranges of Rb are high as mean Rb of the basin is 4.582, and it has been characterized by the influences of underlying structures and lithology. Relief ratio having a value of 0.073 indicates this basin is composed of resistant rocks, and the basin is under intense relief and steep slope. Climatic variability and anthropogenic causes enforce to a tendency of decrease in average annual and seasonal discharge in the Parbati River. These studies are essential for the proper management of the river basin.

Keywords: Morphometric analysis; GIS; SRTM data; Parbati river basin; Discharge

Introduction

The drainage basin is the fundamental unit in fluvial geomorphology within which the relationships between landforms and the processes that modify them have been studied. The study of the geometry of the basin and the way in which it changes in response to processes has become a major part of modern geomorphology. Morphometric analysis of a drainage basin is a quantitative description of a basin and an important aspect to know the character of the basin [1]. The term 'morphometry' signifies the meaning of 'measurement of form' derived from morpho (form) and metry measurement [2]. In geomorphology, the techniques are associated with the form measurement that includes a broad scope of measurement techniques having a large number of variables of the spatial pattern [2]. The morphometric analysis includes linear, relief, aerial and gradient of channel network and slope of the basin [3,4]. Several scholars have identified drainage basin and its relationship with climate, relief, structure of the basin [1,5-8]. Recently, with the advent of remote sensing and GIS techniques, more precise data generation for the morphometric analysis can be done [9-14]. The remote sensing technique is an authentic method for basin study as the satellite images provide the opportunities to get a synoptic view over a large area. Digital Elevation Model (DEM) in the field of GIS provides the three dimension evaluation of the earth surface. Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) and Shuttle Radar Topographic Mission (SRTM) provide the data of DEM and are very useful for hydrological analysis and extraction of stream network of a drainage basin [13]. The DEM is used assuming that the water will flow from higher to lower elevation using steepest descent, will produce a stream extraction model with a thematic layer of aspect, slope, relief, and drainage density, stream frequency [14]. GIS is used for the assessment of various basin parameters, is a reliable and authentic technique for the interpretation and analysis of spatial parameters of the drainage basin [12]. The Parbati river basin is the part of western Himalaya having different lithological structure and high altitudinal glacier at the source region. Recent glacial melting along with the anthropogenic activities caused some changes in the river hydrology and fluvial processes of the Parbati River [15,16]. The present study is an attempt to evaluate morphometric aspects of Parbati River basin and to find out the recent changes in the hydrology of the Parbati River.

Description of the Study Area

The Parbati River originates in the Kullu tehsil of Kullu District in Himachal Pradesh. It rises from Mantalai Glacier on the western slopes of the Greater Himalaya at an altitude of 5200 m above mean sea level and traverses in a northerly direction and flows down as a small stream in a narrow valley [17]. It turns into west after crossing 7 km from its origin and before joining the Beas River. The whole basin looks like an arc-shaped basin. The basin extends between 31°50' N to 32°05' N latitude and 77°05' E to 77°50' E longitude (Figure 1). It is one of the major tributaries of the Beas and meets with the Beas at Bhuntar at an elevation of 1096 meters above mean sea level and drains an area of 1938 km$^{2.}$ The average bed slope of Parbati River is 53 m/km, but it is fluctuating in various smaller stretches. The river, in general, is termed as a fast flowing and ferocious river. The river valley is located in a high mountain ranges, which rises to more than 1,000 m high on both the banks over most of its stretch (Sen and Prasad, 2002) (Figure 1). The Parbati River Basin is a hilly and mountainous tract with altitude ranging from 1096-6250mt above MSL. The basin represents an intricate mosaic of mountain ranges, spurs, hills and valleys. The basin consists of several gorges [18]. The Rocks types found in the basin are Phyllite, slate, quartzite, limestone, schist, and granites. The tourmaline occurs as intrusive, the probable source of high radioactivity in the area, where rocks and many hot springs are seen e.g. Manikaran [19]. The relief in the basin is formed due to the tectonic origin, and it is the predominance of folded structures, which appears as ridges or arch in the anticlines and valley and trough like on the syncline. In

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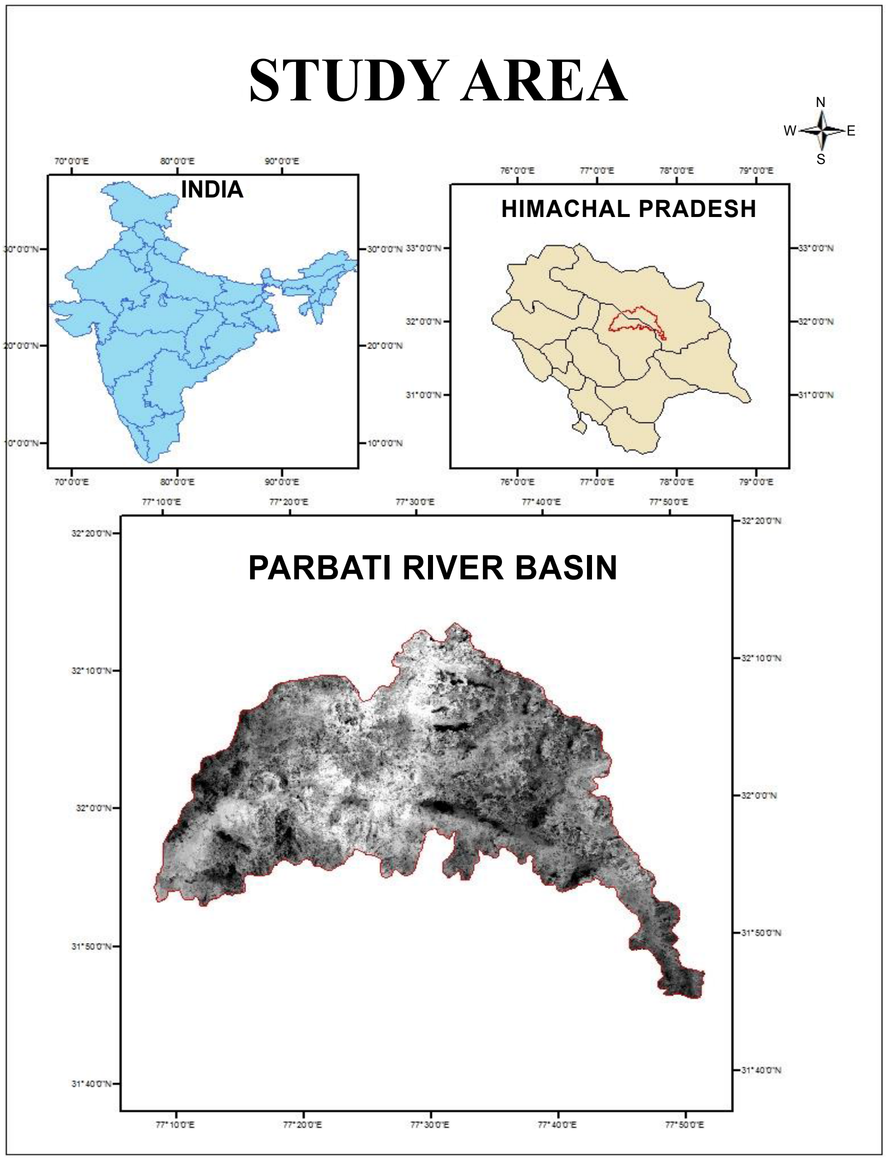

Figure 1: Local Map of the study area.

some places, the longitudinal structural valley is also seen. There are presences of some thrusts in the form of recumbent folds. Because of the lineaments, streams at numerous places in the basin flow straight and joins the main stream at a right angle with the main streams [20].

Methods and Materials for the Study

Keeping the view of the objectives, relevant data has been collected from various sources. Data are collected from the following sources: Survey of India (SOI) topographic map series of 1963 No. 52H/4, H/8, H/12, H/16 and 53E/1, E/5, E/9, E/13 on 1:50,000 scales were used as the base maps for delineation of the Parbati River Basin and its sub-basins. The basin has been extracted using SRTM images and by giving pour points, and it has been projected on WGS 1984 UTM zone 44. Landsat satellites imageries available at for the morphometric analysis are used. The slope and relief of the basin were examined using digital elevation model data (DEM) available at USGS Earth Explorer. Shuttle Radar Terrain Mapper (SRTM) data on 90 m resolution is used to delineate the river basin and construct the stream network. The law of Strahler's method of stream ordering has been adopted for ordering the streams [1]. The outcome of the stream order has been converted from raster to feature. A manual correction has been done by merging the stream of the same order and assigning these as same order streams. The stream order, stream length, mean stream length, stream length ratio, bifurcation ratios, mean bifurcation ratio, relief ratio, drainage density, stream frequency, form factor, circulatory ratio and elongation ratio were estimated using the mathematical formula given in Table1 with the SRTM DEM satellite images. ArcGIS and ERDAS IMAGINE software have used for the entire image processing and calculation of several parameters of morphometry study [21-25]. To show the changes in the hydrology of the Parvati River basin, the trend of water flow discharge has been analysed from 1965 to 2002. The fluctuations in the trend exert the peak flow of the river. The data has been collected from several thesises and dissertations [26] (Table 1).

Sl. No	Parameters	Formulae	References	Results
1	Stream order (u)	Hierarchical rank	Strahler [1]	6th order
2	Stream number	Based on stream order	Strahler [1]	2414
3	Stream length (Lu) (km)	Length of the stream	Horton (1945)	2033
4	Mean Stream length (Lsm)	$Lu = \frac{SL}{Nu}$	Strahler (1964)	0.842
5	Bifurcation ratio (Rb)	$Rb = \frac{Nu}{Nu+1}$	Schumm (1956)	Avg. 4.582
6	Length of overland flow (Lg)	$Lg = \frac{1}{D} X 2$	Horton (1945)	0.447
7	Drainage density (Dd)	$D = \Sigma Lu/Au$	Horton (1945)	1.049
8	Stream frequency (Fs)	$F = \Sigma Nu/Au$	Horton (1945)	1.246
9	Form factor (Ff)	$Ff = A/LP^2$	Horton (1945)	0.384
10	Circulatory ratio (Rc)	$Rc = 4\Pi A/P^2$	Strahler (1964)	0.500
11	Elongation ratio (Re)	$\mathrm{Re} = \frac{D}{Lb}$	Schumm (1956)	0.880
12	Leminscate method (K)	$K = \frac{L2}{4A}$	Chorley, et al. (1957)	0.650
13	Relief ratio	$Rh = \frac{H}{Lb}$	Schumm (1963)	0.073

Table 1: Linear, relief and aerial morphometric parameters.

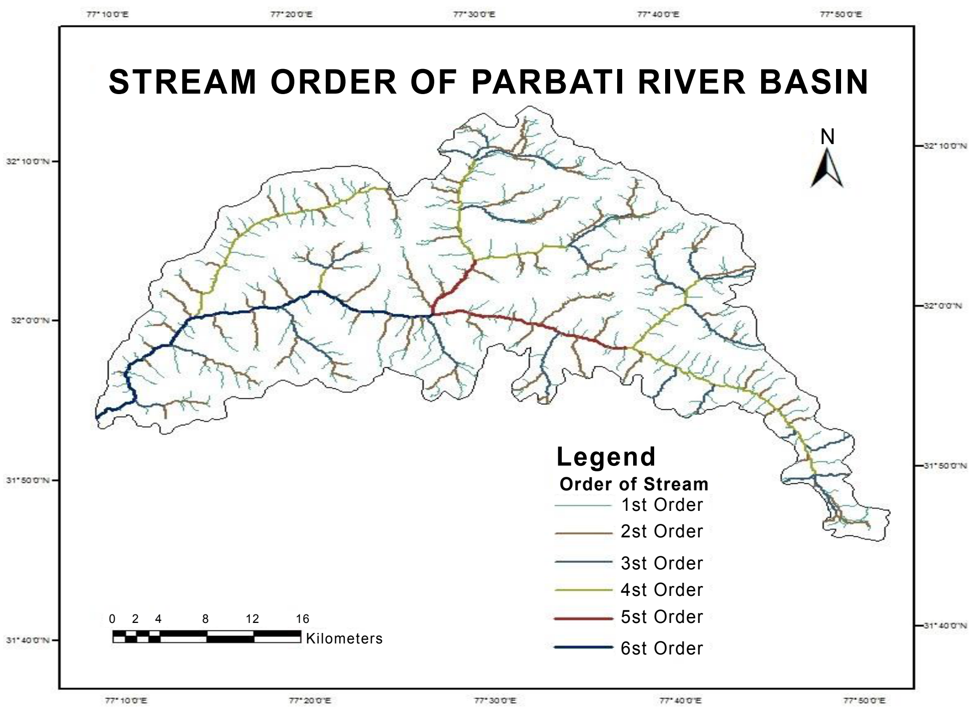

Figure 2: Hire archical stream orders of Parbati River basin.

Geomorphometric Parameters of the Parbati River Basin

Linear aspects of morphometry

Stream order (u): Stream order is defined as a measure of the position of a stream in the hierarchy of tributaries [27]. Gravelius made the first attempt in 1914 to order the stream and later by Horton [28] and Strahler [29], have put forward somewhat different stream ordering system. The streams having no tributaries are considered as first order streams. Then two first order streams join and form second order streams and so on. The Parbati River, which is a master stream of the study area, is the sixth order (Based on Strahler's method of stream order) (Figure 2). The variation in order and size of the tributary basin is mainly due to physiographic and structural conditions prevailing in this basin. The river basin develops over the soft shale, and slate rock and thereby the number and order of streams are high.

Stream number: The total stream segments in each order are known as stream number. R. E. Horton, the hydraulic engineer, is credited with formulating a law of stream number, states that the number of stream segments of each order from an inverse geometric sequence with the order number. The number of streams of different orders and the total has been counted with the help of ArcGIS software. A total number of streams in the basin are 2414. The underlying soft rocks favour a large number of streams. Numbers of streams are decreases with the increases in the order of the streams and thereby it can be said that the basin is developed over homogeneous rock materials. Similarly, in the Parbati basin, the first order of the streams is associated with the highest number of streams and vice-versa (Figure 3).

Stream lengths (Lu): The stream length has been generated based on the law proposed by Horton [5]. According to Horton, the average lengths of streams of each of the different orders in a river basin tend closely to approximate a linear geometric series in which the first term is the total length of streams of the first order. The total stream lengths of various orders have been measured with the help of calculate geometry of GIS tools. It is indicative of the chronological development of streams and derived from source to mouth of the streams [12]. The total length of the Parbati river is about 96 Kms, and the length of the total streams of the Parbati River basin is 2033 Kms.

Mean stream length (Lsm): For determining this morphometric property, the total length of stream measured using GIS tools and total stream length is divided by the total number of segments in that order. There is the relationship between mean stream length and basin order, i.e., mean stream length increases with successive increasing orders. It is related to the size of the drainage network (Strahler, 1964). Mean Stream Length of the Parbati River basin is 0.842 kms and is quite moderate.

Bifurcation ratio (Rb): The Bifurcation ratio may be defined as the ratio between the numbers of stream segments of any given order to the number the next higher order [17]. The bifurcation ratio ranges in between 3 to 5. The high value of the ratio indicates a lower degree of drainage integration and vice-versa. The irregularities of bifurcation ratio depend on the geological and the lithological development of the drainage basin. The lower value of the bifurcation ratio reveals that the basin has suffered less structural disturbances and the higher values of the bifurcation ratio indicate strong structural control on the drainage pattern [1]. The High bifurcation ratio shows significant variations in the number of stream segments of lower and higher order that represents the occurrence of relatively juvenile and mature topography [30]. Bifurcation ratio having >10 indicates the drainage basin developed over the easily erodible rocks [31]. The average value of bifurcation is 4.582 and values of the bifurcation ratio of different order ranges from 4 to 6.16 (Table 2), which is a higher value that indicates the basin has been characterised by the influences of underlying structures and lithology.

Length of overland flow (Lg): The length of overland flow is the length of water over the ground before it gets concentrated into definite stream channels. Normally, a higher value of Lg represents low relief and whereas a low value of Lg is an indicative of high relief. The length of the overland flow of Parbati River is 0.447 Km/Km^2. The value is usually low that indicates the basin is consists of high relief and slope, and thus rainwater enters the stream very quickly.

Aerial aspects of morphometry

Drainage density (Dd): Drainage density (Dd) is the ratio of the total length of the stream in a given drainage basin and the area of that drainage basin [1]. It was first introduced by Horton [28], and he mentioned it was an important indicator of the linear scale of the landform element in stream eroded topography. Horton [28] envisaged that the value of the drainage density ranges from 0.93 km/km^2 to 1.24 km/km^2 in the steep impervious area of the high precipitation region and zero for the permeable basin with high infiltration rate. Langbien considered that the drainage density is ranged from 0.55 to 2.09 for the humid region with the average drainage density of 1.03. The total length of the streams of the river basin is 2033 Kms. Low drainage density indicates permeable subsurface and coarse drainage [12]. Drainage density of the Parbati River Basin is 1.049km/ km^2, and it means weak subsurface material and belongs to medium texture.

Stream frequency (Fs): It is the ratio of a total number of channels cumulated for all orders within a given drainage basin and the area of that drainage basin. It was first introduced by Horton [28]. It is an index of various stages of landscape development and depends on the nature and amount of rainfall, the nature of rock and soil permeability of the region [12]. Stream frequency of the Parbati River basin is 1.840/ km^2, which indicates high relief and infiltration of the basin. Hence, both the drainage density and the stream frequency are the parameters for measuring the spacing of stream channel in a drainage basin [30].

Form factor (Ff): The Form factor of a catchment area is expressed as the ratio of the average width of the basin where the areal length of the distance along the longest basin dimension parallel to the main drainage line. It is the ratio of the basin area to the square root of the basin length [28]. The value of the form factor varies from 0 (highly elongated shape) to the unity, i.e., 1 (perfect circular shape). The value of form factor of the Parbati River basin is 0.384 which depicts that the basin form belongs to slightly elongated shape, and it is the indication of low peak flow of the basin.

Circulatory ratio (Rc): The Circulatory ratio is a dimensionless parameter which provides a quantitative index of the shape of the basin [30]. Miller [6] had defined circulatory ratio as the ratio of basin area to the area of the circle having the same parameter as the basin. A circular

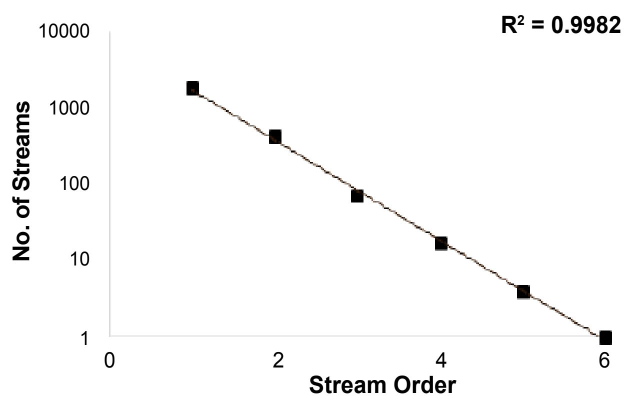

Figure 3: The Relationship between orders of streams against number of streams.

Order of Streams	I	II	III	IV	V	VI
Bifurcation Ratio	4.387	6.157	4.118	4.250	4.000	-

Table 2: Bifurcation ratio of the different orders of the streams.

basin has a maximum efficiency of the movement of runoff, whereas an elongated basin has the least frequency. This information is very significant in forecasting of drainage discharge, particularly in a time of the flood (Jha, 1996). The value of the circulatory ratio is 0.5 which explains moderate circular shape and low peak flow of discharge of the Parbati River basin.

Elongation ratio (Re): The elongation ratio reveals the shape or form of the drainage basin, which is the ratio of the diameter of the circle of the same area as the basin to the maximum basin length [32]. This ratio usually runs from 0.6 to 1.0 over a broad range of climatic and geological type). Values near 1.0 are a typical region of low relief while values from 0.6 to 0.8 are associated with strong relief and steep ground slope. The ratio is a meaningful index for classifying drainage basins into varying shapes: I) Circular (above 0.9), II) Oval (0.8-0.9), III) Less Elongated (0.7-0.8) and IV) Elongated (below 0.7). The value of elongation ratio of the Parbati River basin is 0.88. So, the basin has an oval shape and is associated with steep ground slopes and low peak flow.

Leminscate method (K): This method is given by Chorley, Malm and Pogorzelski. It is based on the comparison of the basin with the leminscate curve. The high value of K indicates elongated shape and on the contrary, a little value indicates the circular shape of the basin. The K value of Parbati river basin is 0.650 that depicts that the river is a slightly elongated to circular, and it indicates low peak flow of discharge of the basin.

Relief aspects of morphometry

Relief Ratio: The Relief ratio is the ratio between the total relief of a basin and the longest dimension of the basin parallel to the main drainage line [32]. According to Schumm, it is a dimensionless height-length ratio equal to the tangent of the angle formed by two planes intersecting at the mouth of the basin, one representing the horizontal, the other passing through the highest point of the basin. It denotes the overall steepness of a drainage basin and is an indicator of the intensity of degradational processes operating on slopes of that basin. The relief ratio of the river basin is 0.073 that indicates this basin is composed of resistant rocks, and the basin is under intense relief and steep slope.

Drainage patterns of the parbati river basin

In the Parbati river basin, Tree-like dendritic type of drainage pattern develops over the soft sedimentary rocks (Figure 4). It shows that this is an area of comparable lithology. Other types of drainage patterns are also significant in the basin. Marhigarh Nal, a tributary of Parbati River exerts the Herringbone type of drainage pattern where the tributaries tributes to the mainstream at almost a right angle. It reflects the controls of the underlying rock structure. In the Himachal Himalaya, several faults, lineaments are distinct. In some areas Parallel drainage pattern, where the control of the regional slope, parallel faults and lineaments predominate, is also discernible. In this drainage pattern, parents and tributaries flow in a parallel way. In some peak of the ridges, Centrifugal drainage pattern, where streams radiate in all directions from a common centre, is significant (Figure 4).

Long profile of the river: Long profile of a river is the plotting of height (H) against the distance downstream (L) [15]. It is generally concave to the sky, but the slope is decreasing rapidly at first and then gradually. The River originates at 4800 km above mean sea level. It runs over 90 kms. The profile of the river is more or less regular i.e. concave to the sky (Figure 5). The long profile of a river is dependent upon the lithology of the underlying structure, stream flow, discharge, the amount and texture of the channel load, flow resistance, flow velocity, width and depth of the channel, and regional slope [31]. The Parbati

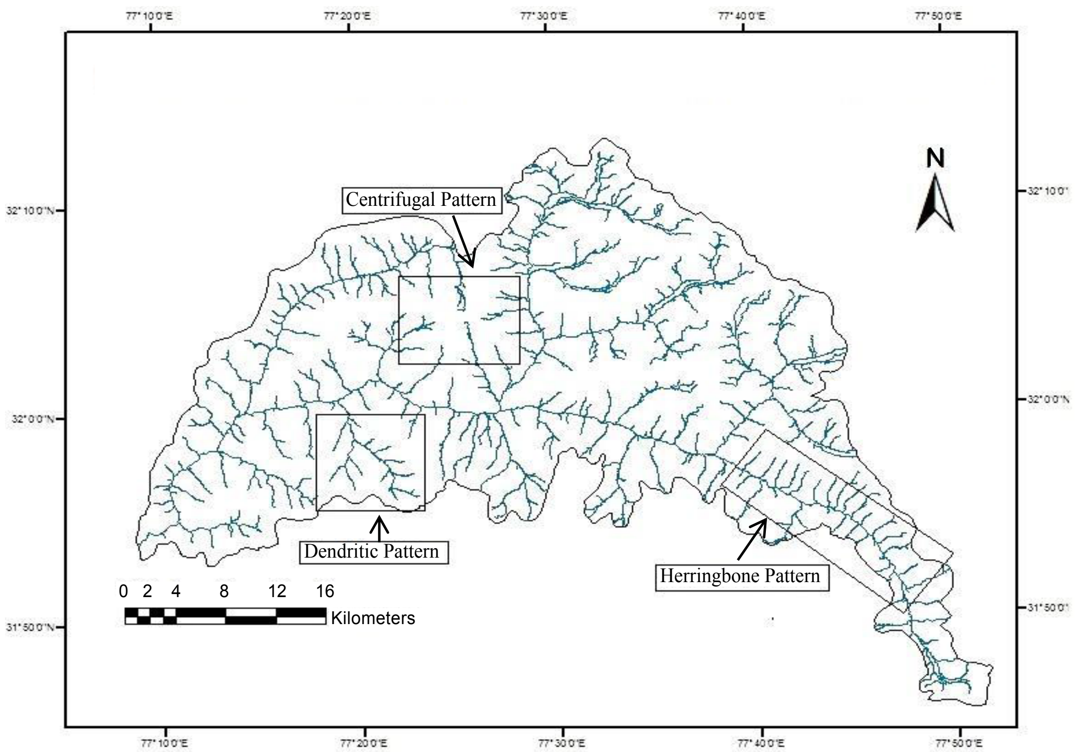

Figure 4: Drainage Patterns of the Parbati River Basin.

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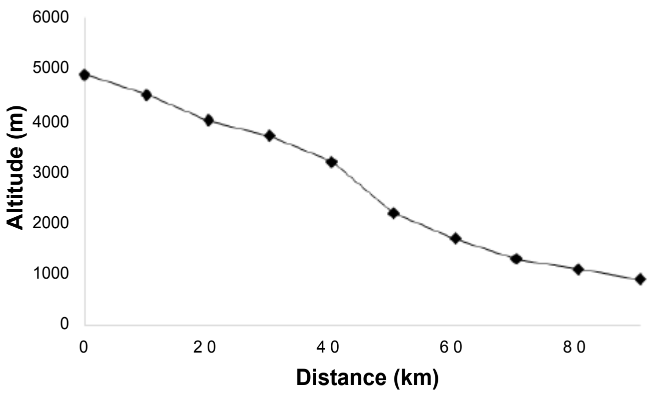

Figure 5: Long profile of the Parbati River.

River has a different channel slope and concavity. The regular concave profile is interrupted by the convex profile at about 40-60 kms from the origin. The convex slope is between 2500-4000 meters and concave in between 1200-2500 meters above mean sea level. The irregularities are due to the presence of the more resistance rock and change in slope from the tectonic activity and the glacier retreat (Figure 5).

Cross profiles of the river: The cross profile varies from the narrow, steep-sided trenches to gentle open form, ultimately depends on the resistance offered by the valley slopes and the erosive capacity of the water. Cross profile of the Parbati River in different regimes exerts the processes and dominant controlling factor. In Figure 6, four cross profiles represent valley of the rivers. These are from the source to mouth of the river. Most of the cross profiles are 'V' shaped in nature and it represents down cutting rather than lateral erosion. While, at the source of the river, the profiles (Figure 6A] are flatter than the other profiles (Figure 6A and 6B] that are generated in the lower course of the river. Near the source, the dominance of glacial processes and river have less stream power for down cutting, thus flat 'V' shaped profile is significant. On the contrary, at the downstream of the river, the fluvial processes form deeper channel valley. Most of the places there is steep valley along with the road on one side of the river (Figure 6).

Recent Hydrological Changes in Parbati River Basin

Of late, there are significant changes observed in the Parbati River Basin mainly due to climatic variability and anthropogenic causes. The climatic variability leads to increase in the temperature of the Himalayan region and thereby retreat of glaciers of the river basin is discernible. The Man Talai glacier, the source region of the Parbati River, has experienced with abrupt changes. The Parbati Project Stage-III is located in Chandigarh-Manali National Highway-NH-21 at a distance of 208 km from Shimla. Stage III dam site is located at a distance of 45 km from Bhuntar. The construction of power project changes the flow regime, the connectivity of the river. The establishment of human civilisation also alters the land use and land cover area of the river basin area. A slight deforestation in the basin area also increases the erosion capacity of the rivers. As a result, valley incision is predominantly increasing. Himachal Pradesh is the abode of tourism activity and this activity also harms not only in the Parbati River basin area but also in the other river basins of Himachal Pradesh. In 1963, the total glacier area was 46.8Km^2, but in 2006, it became only 31.0 Km^2. About 15.8 Km^2 (33.8%) glaciated area was reduced as an effect of climatic variability and human activities (Kumar, 2009).

Temporal changes in discharge of Parbati river

The changes in the water discharge of the Parbati River are significant. A tendency of decrease in average annual and seasonal discharge of the Parbati River has been observed (Figure 7). It is significant from the several studies that the decline of discharge in winter is observed. The flow characteristic is controlled by the glacier retreat

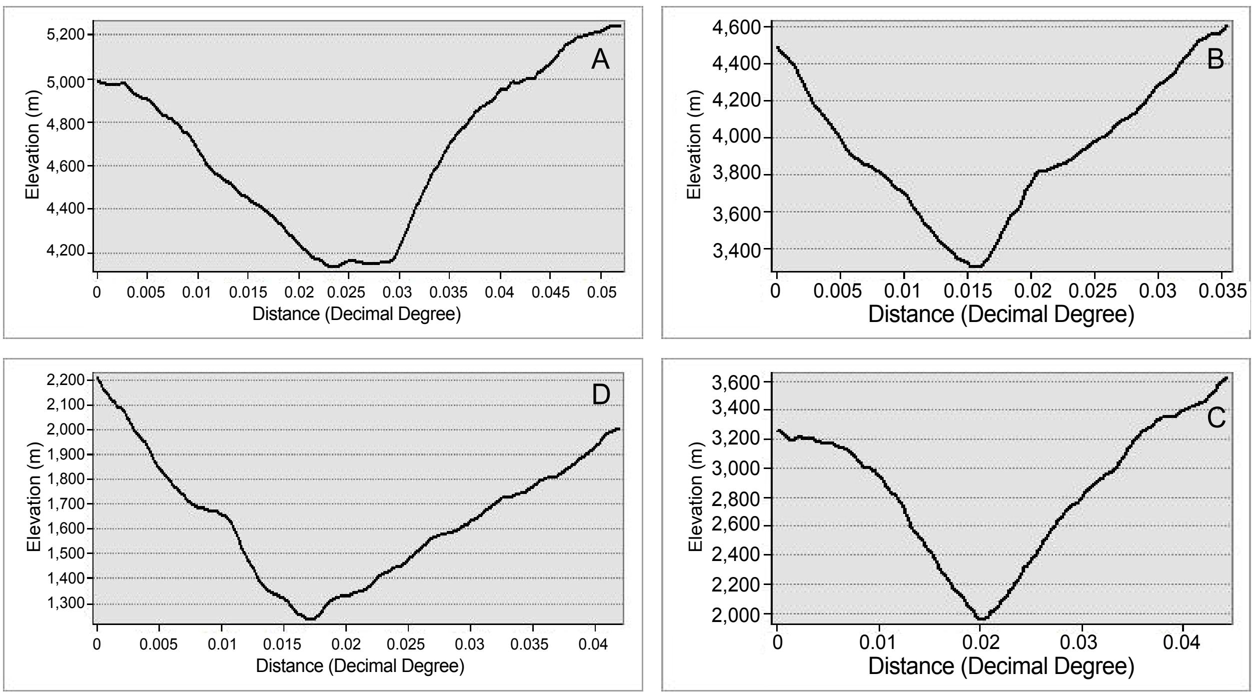

Figure 6: Cross profiles of the Parbati river. A,B,C and D represents cross section from 10km, 34km, 54km ad 78 km from the source respectively.

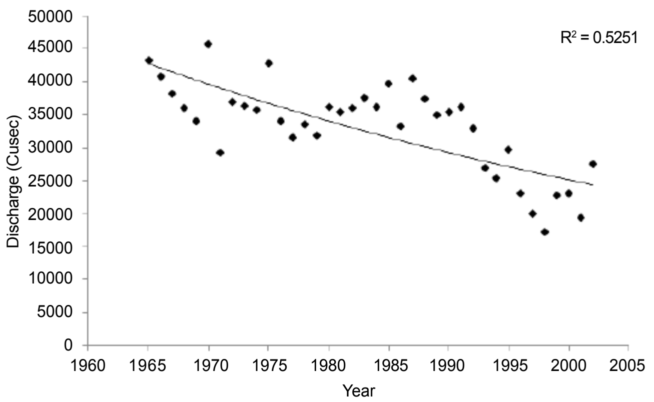

Figure 7: Trend of Decrease in flow discharge of Parbati river.

instead of the variability of rainfall. The gradual decrease of discharge is noticed due to mainly the decreasing tendency of glaciers and glacial retreat. The fluctuation in temperature is observed in the Parbati River Basin. From 1968-2005, the temperature is very slightly increasing . It may be one of the reasons for glacial retreat. A little rise in temperature can melt an abrupt amount of glaciers. But there is more or less same (near about 900 mm) of rainfall throughout the period of 1968-2005. From Figure 7, it is observed that in 1963, the flow discharge was 42000 cusec. There is a sudden decline in the discharge of water in 1972. In 1973, the highest amount of flow discharge was 46000 cusec over the studied period. After that, there was the gradual tendency of the decline in the discharge of water up to 1998 in between 40000-30000 cusec. But in 2001, the flow discharge surprisingly decreases up to 20000 cusec. At the end of 2005, the discharge of water was in between 30000-35000 cusec. From the above discussion, it can be mentioned that climatic variability can cause the changes in the discharge of the water of the Parbati River. Simultaneously, the irregularity of the Monsoon disrupts the average discharge of the river in a lesser extent (Figure 7). The present study on drainage basin has been done on the basis of geomorphological perspective. Study of the morphometry is concerned with the genesis, development and distribution of landforms. An important property of the drainage basin is its hierarchical in nature, each tributary in a drainage system has its basin area. In any drainage basin, there are several variables which always interacting with other variables and give birth to particular types of landforms. It is hardly possible to analyse all the parameter of a drainage basin with the help of morphometric analysis. Some parameter such as channel morphology, sediment analysis, palaeo flood analysis, flood and channel dynamics, analysis of channel-bed texture, meander dynamics, anthropogenic influences should be included along with the study of morphometric analysis. The morphometric analysis also helps to study about the relief, a slope that reflects the depositional characteristics that contribute to study the facies analysis. But it is essential for the fundamental study of further stages in the river basin study and fluvial geomorphology.

The study of morphometry of a river system includes the quantitative study of the various aspects of the Parbati River and its basin. The study reveals that the drainage basin is associated with the early stage of drainage development, and lower order of stream dominates the river basin. The elongated shape of the basin reveals low runoff and high infiltration capacity. The study area is associated with the active neo-tectonic activity, so the morphology of the river would be very much dynamic. This dynamicity is also observed in the most of the drainage basin of the Himalayan region. Recently, several anthropogenic activities and climatic variability caused the several hydrological changes in the Parbati River basin. Recent changes in discharge can affect the aggradational and degradational processes that also affect the facies development. Such changes can reflect in a catastrophic form that may be tough to compensate for natural as well as the human environment.

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