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Morphometric and Morphotectonic Analysis of Ferozpur Drainage Basin Left Bank Tributary of River Jhelum of Kashmir Valley, NW Himalayas, India

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Abstract

The Morphotectonic and morphometric analysis by the use of geomorphic indices and landforms helped us in deciphering the tectonic nature of the Ferozpur watershed. The present study has been carried out to study the tectonic geomorphology of the Ferozpur drainage basin, a left bank tributary of the River Jhelum, located in the Kashmir Himalayas. Various morphometric parameters like stream ordering, stream number, stream length, bifurcation ratio and Morphotectonic parameters like hypsometric integral, basin elongation ratio, drainage basin asymmetry, stream gradient index and river profiling (longitudinal) were calculated using Aster DEM, Toposheets, software's like Glober Mapper and Arc Gis 10.2. Overall assessment of the morphometric and morphotectonic analysis revealed that the tectonic uplift, lithology and climate forcing determine a significant position in the landscape evolution of the Ferozpur drainage basin plus the basin has experienced differential uplift and erosion rates from time to time. Thus, it is hoped that the result from this investigation will aid inference about the tectonic activity and provoke some thoughts about the futuristic ramifications of the geomorphic processes operating in the Ferozpur drainage basin.

Keywords: Morphotectonics; Morphometry; Drainage basin; Geomorphic indices; Toposheets; DEM

Introduction

Tectonic geomorphology describes the relationship between the tectonic processes and the surfacial processes resulting in the formation of geomorphic features [1]. The combination of these geomorphic features or landforms that constitute the landscape provide us best information regarding their shape and origin as a function of tectonic processes and also allows us to use geomorphology as a tool to evaluate the history, magnitude and rate of active tectonics. For such type of studies, Kashmir valley, the intermontane basin, located in the NW Himalayas between the Pir-Panjal range and the Greater Himalayan range, provides the great scoop. As the Kashmir valley possesses the diverse geography thus the study of the tectonically modified landforms is very much fruitful [2]. For quantitative measurements of such landforms or features, mathematical calculations of geomorphic indices are made with the help of topographical maps, digital elevation model, satellite images, aerial photographs and finally field validation. A lot of studies have been carried out in this field to understand the effect of tectonic and surficial processes on the evolution of the landforms [3-15].

Rivers, which are more significant landforms, are very sensitive to the tectonic movements and behaves as the fundamental unit of the fluvial landforms and thus provides the opportunity to understand the Quaternary tectonic activity in any area [16]. The quantitative analysis of drainage basins was first introduced by Horton [17] and the idea was later developed by Coates [18] and Strahler [19]. In fact they form the basic units of fluvial landscape and an immense amount of research has focused on their geometrics including the topology of the stream networks and their quantitative description. The geological setting and the lithological control of the area, framed by the main stream and their tributaries influence the drainage of the watershed. The geomorphic indices or landforms play a significant role in order to know the type of inducing processes especially in the case of young Orogens where the resulting sedimentation can cover young structures forming new landforms. The analysis of the drainage network and their pattern, obtained from topographical maps and aerial photographs can help us in knowing the position of active structures and rapid evaluation of large areas [20]. Thus with the help of the calculated morphometric data altogether with geomorphic data we can account the relative levels of active tectonics. Therefore, in this paper various morphotectonic parameters (linear and areal) have been calculated by using mathematical equations, in order to reveal the relationship between active tectonics and erosional processes which in turn proved very helpful to know the tectonic activity of the Ferozpur drainage basin.

Regional setting and geology of the area

Kashmir valley is an intermontane basin located on nearly horizontal Nappe sheet [21], surrounded by the Great Himalayan range towards northeast and the Pir Panjal range (Panjal Thrust) towards the southwest with vast morphological characteristics. Towards the southwest of the Pir Panjal Range, a complex pattern of faults are present like the MCT/Panjal, MBT/Murree, Riasi, and Kotli thrusts [22]. Further the valley preserves the complete stratigraphic record of rocks ranging from Archean to Recent (Figure 1 Modified after Middlemess 1911). The Ferozpur river (Figure 2) of Kashmir Valley lies towards the North Western side of district Baramulla with geographical coordinates of 34°3′17′ N and 74°25′53′ E. The lithology of the area comprises of Salkhala series which are found in the upper reaches in which dynamic high grade metamorphism is evident, consisting of slates, phyllite and schist with interbedded

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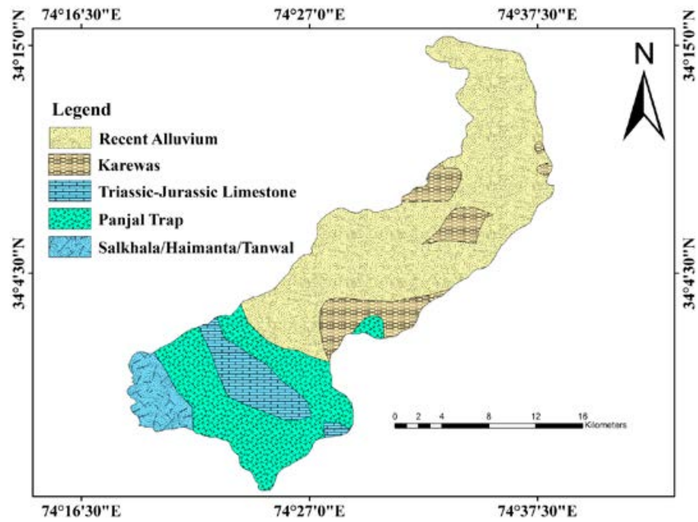

Figure 1: Lithological map of the study area modified after Middlemiss and HS Bion (1912-13).

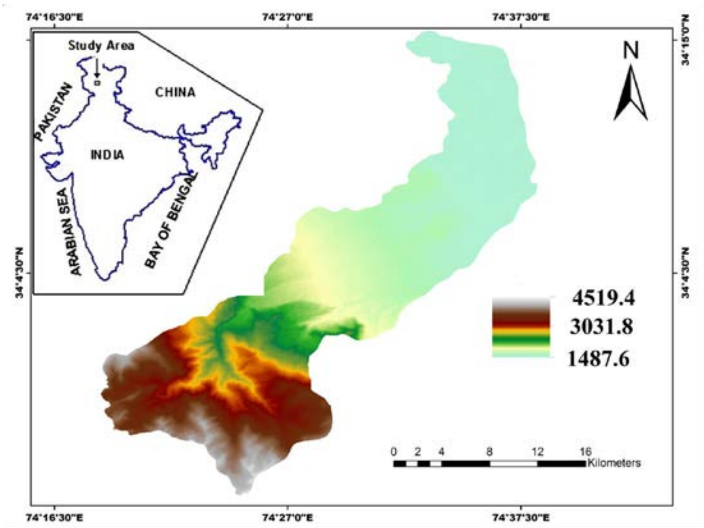

Figure 2: Showing the study area.

crystalline limestone and flaggy quartzite. Salkhala group are followed by Panjal Volcanics of Upper Carboniferous-Permian age in which the agglomeratic slate series is overlain, often intermixed with a thick succession of andesitic and basaltic traps. The Panjal Volcanics are followed by Triassic-Jurassic limestone. Lower part of the study area consists of Plio-Pleistocene deposits (Karewas) and recent alluvium whose colour varies from dark brown, reddish to flesh red.

Drainage characteristics of the study area

The length of the Ferozpur River is 51 kilometers formed by two important tributaries that originate from the northern slopes of snow fed Pir-Panjal range, through Jamianwali Gali (4084 m) that flows in NNE direction and second from the Apharwat range (4143 m) that flows in NE direction, joining together at a location namely Barbad Post. Before entering the relatively plain area, the trunk stream again gets divided into two branches, with one flowing towards NE and another towards SE, both retaining the original name. The Ferozpur river has a well-developed dendritic drainage pattern in the upper catchment with more or less parallel type of drainage pattern in the lower portion (Figure 3).

Materials and Methods

Toposheets in the digital format at a scale of 1:50,000 were used for the delineation of streams and river basin. These Toposheets were Georeferenced and onscreen digitization was done in Glober Mapper for the entire analysis of drainage Morphometry. The morphometric parameters like (Straight line length of mountain front (Ls), Length of mountain front at piedmont (Lmf), basin area, basin length, etc.) were calculated using mathematical equations for these geomorphic indices. The calculated values of these geomorphic indices were then employed in accessing the tectonics of the study area. Apart from above morphometric parameters various other parameters (linear and areal) were computed/determined using standard methodologies (Table 1). Digital elevation model at 30 m resolution was also used after processing to facilitate morphological characterization of the topography (Stream length gradient index (SL), Mountain front

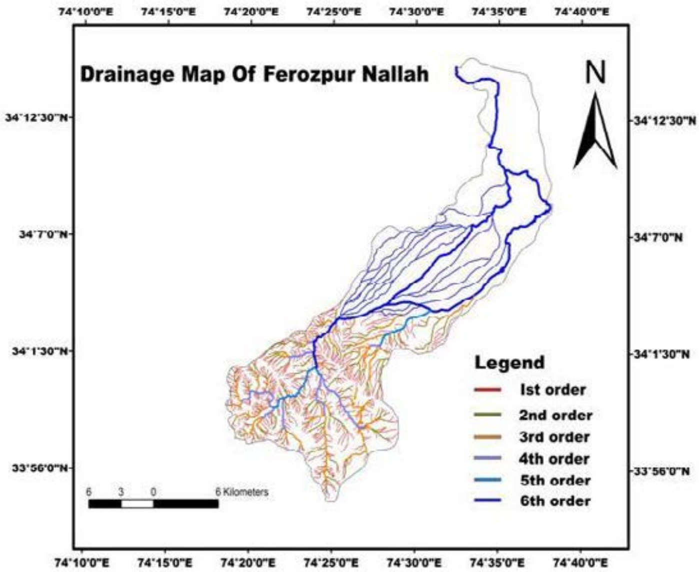

Figure 3: Drainage map of Ferozpur Drainage basin using Strahler's method.

S.No.	Morphometric parameters	Formula	References
1	Stream order (Su)	Hierarchial rank	Strahler [16]
2	Stream number (Nu)	No.of streams	Horton [7]
3	Stream length (Lu)	Length of streams	Horton [7]
4	Asymmetry factor (AF)	AF=100(Ar/At)	Hare and Gardner [28]
5	Transverse topographic symmetry factor(T)	T=Da/Dd	Cox [30]
6	Stream length gradient index (SL)	SL=(ΔH/ΔL)L	Hack [39]
7	Mountain-front sinuosity (Smf)	Smf=Lmf/Ls	Bull and McFadden [34]
8	Bifurcation ratio (Rb)	Rb=Nu/Nu+1	Schumm [10]
9	Drainage density (Dd)	Dd=Lu/A	Horton [18]
10	Elongation ratio (Re)	Re=d/Lb	Schumm [10]
11	Circulatory ratio (Rc)	$Rc=4\pi Au/Pr^2$	Miller [41]
12	Basin area (A)	A	Schumm [10]
13	Basin length (Lb)	Lb	Schumm [10]
14	Form Factor (Ff)	A/Lb^2	Horton [18]

Table 1: Showing various morphometric and morphotectonic parameters with their formulae or mathematical equations.

sinuosity (Smf), Asymmetry factor (AF), the Transverse topographic symmetry factor (T)) and landform features. Elevation map with a contour interval of 40 m was prepared to generate contour map. Geological information was obtained from the existing geological map of Kashmir (Middlemess 1912) which was first processed in Arc-Gis 10.2 and then different lithologies were digitized. The geological map was then used to delineate different types of rocks present in the area. The final layout of drainage as well as lithological map was done in Arc GIs 10.2. Finally different landforms present in the study area were analyzed and determined via field observations.

Results and Discussions

Morphometric parameters

Morphometry is simply the measurement of features present on the surface of earth formed due to endogenetic as well as exogenetic processes and their mathematical analysis [23]. The systematic geometrical description of a drainage basin and associated stream network is carried out by measuring its linear, areal and relief (gradient) parameters. Various morphometric parameters have been calculated using mathematical calculations or formulae from Table 1.

Stream order (Su): The designation of stream orders is the first step in drainage basin analysis and expresses the hierarchical relationship between segments. In the present study the number of stream ordering is carried out using the method given by Strahler. The stream ordering for the study area (Table 2) reflects that the maximum frequency is in the case of first order streams and goes on decreasing as the stream order increases.

Stream length (Lu): The total length of the streams of a particular order has been computed with the help of SOI topographical sheets. The total length of streams of Ferozpur basin is 650.842 km, while as the stream lengths of particular order are given in Table 2. Plot of logarithm of the stream length verses stream order (Figure 4) showed the linear pattern which indicates the homogeneous material subjected to weathering-erosion characteristics of the basin. Deviation from its general behavior indicates that the terrain is characterized by variation in lithology and topography.

Stream number (Nu): The order wise total number of stream segment is known as the stream number. The number of streams goes on decreasing as the stream order increases (Table 2). The plotting

Stream order(Su)	Stream length(Lu)	Stream number(Nu)	Log Lu	Log Nu	(A) (sq.kms)	(Lb) (kms)	(Re)	(Rc)	(Ff)
1st order	387.535	615	2.588	2.788	454.62	37.79	0.64	0.41	0.32
2nd order	106.635	133	2.02	2.12					
3rd order	75.585	39	1.878	1.59					
4th order	24.647	10	1.39	1					
5th order	13.175	3	1.119	0.47					
6th order	43.265	1	1.636	0					

Table 2: Showing the results of various morphometric parameters.

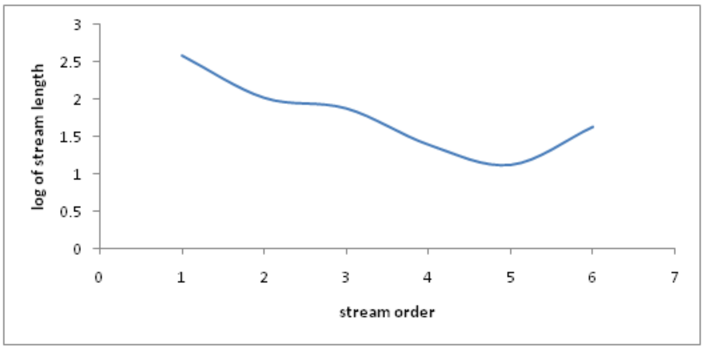

Figure 4: Relationship between stream order and log of stream length.

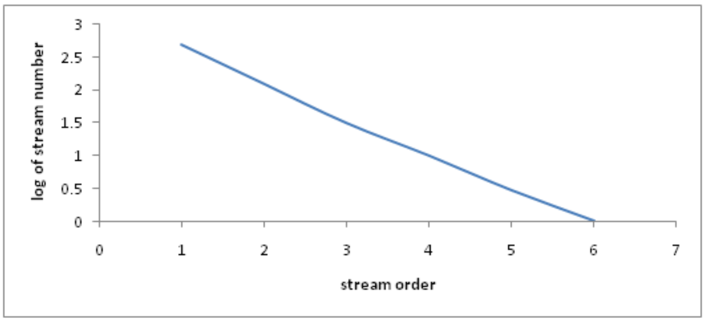

Figure 5: Relationship between stream order and log of stream number.

1st order/2nd order	2nd order/3rd order	3rd order/4th order	4th order/5th order	5th order/6th order	Mean bifurcation ratio
4.624	3.410	3.9	3.3	3	3.646

Table 3: Showing the Bifurcation ratio for all stream orders and whole drainage basin.

of logarithm of number of streams against stream order is given in (Figure 5), gives a straight line (Horton). This means that the number of streams usually decreases in geometric progression as the stream order increases.

Area (A), basin length (Lb) and form factor (Ff): Basin area is the direct outcome of the drainage development in a particular basin. In early stages basins are usually pear shaped and become elongated as the cycle advances [24]. The shape of the basin affects the stream discharge characteristics. The basin area is computed by using Glober mapper, which is 454.62 sq km (Table 2). The basin length is the maximum length or the longest dimension of the basin parallel to the principal drainage line Schumm. The length of the Ferozpur drainage basin is 37.79 km. Form factor is another important parameter defined as the ratio of basin area to square of the basin length. The value of form factor would always be less than 0.754 (for a perfectly circular watershed). Smaller the value of form factor, more elongated will be the watershed. The watershed with high form factors have high peak flows of shorter duration, whereas elongated watershed with low form factor of <0.54 indicates that they are elongated in shape and flow for longer duration likewise, the Ferozpur drainage basin whose form factor is 0.32.

Bifurcation ratio (Rb): Bifurcation ratio (Rb) is the ratio of the number of streams of any given order to that of the number of streams of next higher order. The basins with bifurcation ratio ranging between 3.0 to 5.0 reflect that geological structures do not influence the drainage pattern. The calculated values for all stream orders(1st to 6th Order) ranges between 3.0 to 4.624 with a mean value of 3.646 (Table 3), provide us vital information regarding that the geological structures present in the area have very less control over the whole drainage pattern.

Elongation ratio (Re): Schumm defined the elongation ratio as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. A circular basin appears more efficient than that of an elongated basin in case of discharge/run-off character of a basin [25]. This ratio ranges between 0.6 and 1.0 over a wide variety of climatic and geologic types. The varying slopes of watershed can be classified with the help of the index of elongation ratio, i.e. circular (0.9-

0.10), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (less than 0.5). The elongation ratio of Ferozpur river is 0.64 (Table 2), which represents that the watershed is more elongated in shape with slightly active tectonic inference, associated with strong relief and steep ground slopes.

Circularity ratio (Rc): Circularity ratio has been used as a quantitative method, defined as the ratio of watershed area to the area of a circle having the same perimeter as the watershed and it is pretentious by the lithological character of the watershed. The values of circularity index varies from zero (for a line) to unity i.e. one (for a circle). This ratio also indicates the stage of the basins (youth, mature and old) depending on its value (low, medium and high) [26]. The circularity ratio value of the watershed is 0.41 that indicates the watershed is elongated in shape with highly permeable homogenous geolgic materials.

Morphotectonic parameters

Asymmetry factor: The asymmetry factor was used to know the tectonic tilting of drainage basins at smaller as well as larger scales [27]. The asymmetry factor (AF) is the ratio of area of right side of the stream facing downstream to the total area of the drainage basin. The normal value 50 is for the streams that flow in stable part of earth and a deviation from this value suggests tilting. As in Ferozpur drainage basin, the trunk stream flows in the direction of northeast and the tilting is towards Southeast because the tributaries on the right side of the main stream are long occupying large area compared to tributaries on the left side with lesser area with (AF) of 57.59. (AF), one of the geomorphic index showing better results for drainage basins when underlain by same type of rock assuming that neither lithology nor climate of the area causes asymmetry [28].

Transverse topographic symmetry factor: This is one more quantitative index to assess basin asymmetry (T) and is calculated by measuring the deviation of the drainage basin midline from the midline of the active meander belt and the deviation of the basin midline from the basin divide using formulae (Table 1). Symmetrical basin has a value of (T) equal to 0 and if (T) increases, asymmetry increases with a value equal to 1. In this study we find a value of 0.40 that reflects the study area is asymmetrical. However, both asymmetry factor and transverse asymmetry factor does not show the direct indication of ground tilting, yet these are the methods showing possible tilt [29].

Stream length gradient index: The stream length gradient index (SL index) is one of the most important parameter in order to know whether the area is tectonically or lithologically controlled. This parameter is measured by using digital elevation map as well as contour map of the area and measuring the length of the river. By means of SL index we can quantify the characteristics of stream gradient behavior and its relationship with physiographical conditions, lithological control, topography, and associated drainage parameters [30]. The lithology of the river (Figure 4) from the source i.e. 0 to 2.3 km comprises of (Salkhala's), 2.3-6 km (Panjal Volcanics), 6-9 km (Limestone), 9-12.5 km (Panjal Volcanics) and the dominant one from 12.5 km to mouth is Alluvium. SL index values are very high where the river crosses hard rock's like Salkhala's, Panjal Volcanics. The index values are relatively low when the river passes through softer rocks (Limestone and Alluvium). However areas of higher SL index values on soft rock and lower values on hard rock depicts tectonic activity. Therefore in this study we find the higher values of SL index in case of Panjal Volcanics representing that the area is tectonically controlled.

Figure 6 shows the response of the SL index to different lithologies and longitudinal profile of Ferozpur river. Longitudinal river profiles are valuable in providing the information regarding geology, structures, and their position to recognize active tectonic deformations of an area [31]. The channel profile for ~51 km stretch of Ferozpur river was prepared from DEM at a spatial resolution of 30 m. Spatial variations in rock uplift along a river profile can lead to steeper, or flatter river's longitudinal profile. The steep sections of a river profile tend to erode faster than gentler reaches, which causes knick points to migrate upstream and in extreme cases can lead to river capturing. The response of channel gradient to upliftment is evident from various knick points (K1-K3) present along the river course. These knick points are very distinct and nearer to each other causing erosional changes in the drainage pattern, which suggests that the landform development is strongly under the control of tectonics and lithology of the area.

From the analysis of Drainage-Lithological map (Figure 7) the lithology in the majority of the streams is homogeneous with certain exceptions which suggest that the knick points have developed in response to recent tectonic activities. In the higher reaches of the Ferozpur Drainage basin, the river shows some sort of trellis drainage pattern formed due to the presence of fractures, joints followed by dendritic type of drainage pattern in the middle suggesting structural and lithological control respectively. The lower part with parallel drainage pattern is because of gentle, uniform slopes and less resistant bed rock like recent alluvium in the study area.

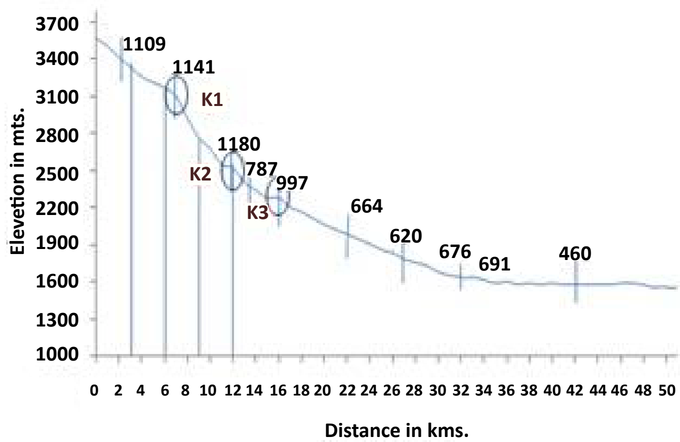

Figure 6: Showing stream gradient/longitudinal river profile with distribution of knick points.

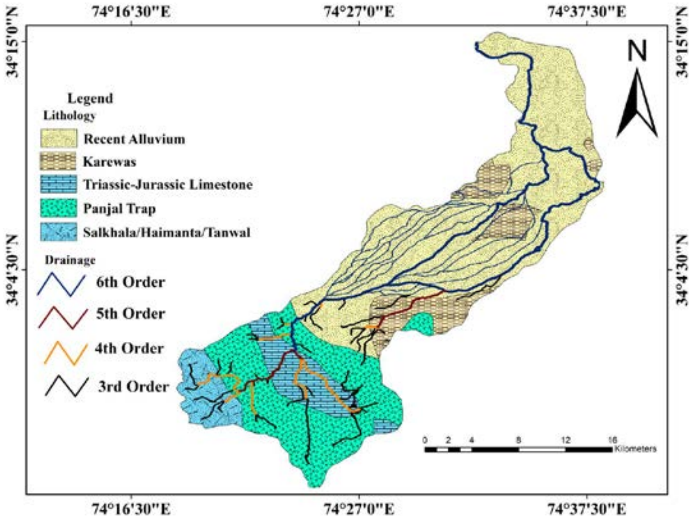

Figure 7: Lithological map overlain by Drainage map.

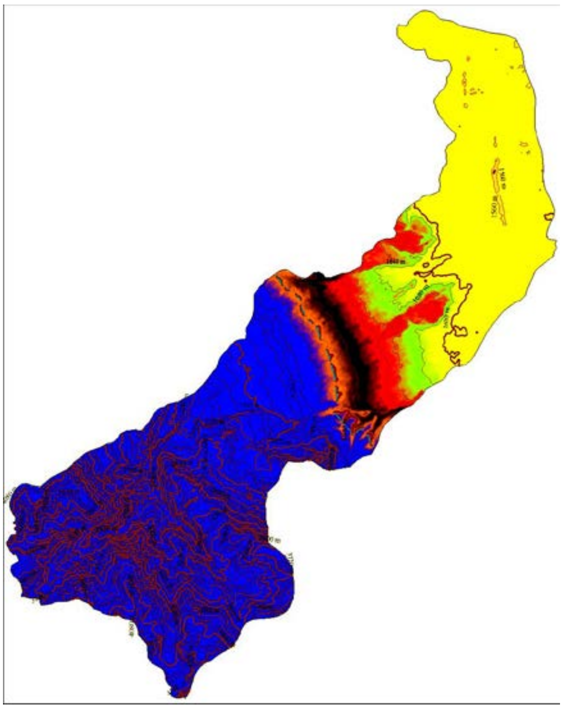

Figure 8: Mountain Front Sinuosity of twelve segments of a contour.

Mountain-front sinuosity (Smf): Mountain-front sinuosity depicts the relationship between erosional forces that form mountain fronts and the tectonic forces making them straight synchronized with active faults [32]. Mountain-front sinuosity (Smf) is the relationship between the length of the mountain front at piedmont (Lmf) and the straight-line length of the whole mountain front (Ls) [33].

Here mountain-front sinuosity was calculated using Glober Mapper and DEM to generate contour map (Figure 8). Most active mountain fronts are relatively straight having less Smf values from 1.0 to 1.6, whereas mountain fronts having Smf values greater than 1.6 are less active inferring us that the upliftment rate is very less with marked erosional processes. Mountain-front sinuosity was measured in twelve segments of a contour (Table 4) whose values range from 1.030 to 1.450. All these segments have values less than 1.6 indicating that the mountain fronts are straight and active, reflecting that the area is tectonically active.

Hypsometric integral (HI): The hypsometric integral (Hi) on regional patterns is used to quantify the degree of dissection of a drainage sub-watershed from that of the whole watershed. The values of which are the key elements to analyze and to distinguish whether the area is active or not. Hypsometric integral is easily obtained from topographic maps or by using Digital Elevation Models (DEM) and contour maps [34-40]. Higher values of hypsometric integral are associated where the topography is relatively high with respect to the mean, for e.g. uplifted surfaces carved by deeply incised streams. When the terrain is under the extreme exposure of erosional processes with uniform dissected drainage basins, the hypsometric integral has lower to intermediate value. The calculated hypsometric integral is 0.29, which is on the higher side indicating that the area is in youthful stage, high topography and incised streams thus suggesting that the area is tectonically controlled [41-43].

Field observations: An extensive fieldwork was carried out to analyze the different landforms present in the area. The features/landforms (Figure 9) suggest that the area has undergone recent tectonic activity.

Conclusion

This study helped us to know the influence of tectonic and erosional control in the development of landforms by studying the

Segment	Lmf (m)	Ls (m)	Smf (m)	Remark
1	751.39	669.39	1.222	Most active mountain fonts
2	225.2	216.62	1.039	
3	475.5	423.72	1.122	
4	563.68	547.13	1.03	
5	330.19	310.65	1.062	
6	917.92	747.15	1.228	
7	892.78	628.87	1.41	
8	1152	1009	1.141	
9	1116	765.91	1.45	
10	909.38	692.27	1.313	
11	667.76	566.51	1.178	
12	2079	1608	1.292	
Average	840.066	682.101	1.231	

Table 4: Showing mountain front sinuosity for twelve segments of a contour.

various parameters (linear and areal) of the Ferozpur drainage basin. The linear parameters including stream order (Su), stream number (Nu), stream length (Lu), bifurcation ratio (Rb) and basin length (Lb) etc. while as the areal parameters like Mountain front sinuosity (Smf), drainage basin asymmetry (AF), hypsometric integral (HI), river profile analysis and Stream length gradient index (SL) were calculated. The order wise stream number and length showed that the maximum frequency of first order streams decreases as the stream order increases. This is because of the presence of structures like fractures, joints, cracks etc. in the higher reaches of the study area. The results of bifurcation ratio showed that basin has experienced less structural complexity and differential uplift rates associated with tectonic uplift. It has been also noticed that this ratio shows a decreasing trend as the stream order increases. The lower values of Smf and development of triangular facets in the area provides the clear indication that the area is largely under tectonic control, rather than erosional one. The sinuosity index of Ferozpur river is 1.5 which clearly indicates a sinuous form of the river. The geological structures such as lithological contacts and linear structures also affect both the local shape of longitudinal profiles and the SL index. Lithologic discontinuities and tectonic uplift has resulted in the development of knick-points and an anomalously high SL index value. Asymmetry factor as well as Transverse topographic symmetry factor provides valuable information in rapid evaluations of drainage basins to determine the tectonic tilt. The values observed from asymmetry factor of the area were quite reflective to infer that the basin has experienced tilting. The calculated hypsometric integral value for the study area is 0.29, indicating that the area is in youthful stage, high topography and incised streams thus suggesting that the area is tectonically controlled. The morphometric analysis of these parameters and field study has demonstrated its usefulness in determining significant knowledge regarding the active tectonics of the area. Overall assessment of the morphometric and morphotectonic analysis revealed that the tectonic uplift, lithology and prevailing climate have

Figure 9: Field validation of different morphotectonic features as: (A) Non-paired terraces (B) river terrace (C) landslide (D) river braiding (E) Talus deposits (F) River meandering/point bar (G) point bars (H) Flood plain (I) confluence point.

played a significant position in the evolutionary history of the Ferozpur Drainage basin and the basin has experienced differential uplift and erosion rates from time to time.

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