Morphotectonic and Morphometric analysis of Vishav Basin left bank
Tributary of Jhelum River SW Kashmir Valley India

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Abstract. Morphotectonics interplays between the landscape development and the tectonics. Usually, the development of many geomorphic features has been related solely to exogenic and non-tectonic causes but many of them are developed mainly due to the prevailing tectonic forces in the area. In the present study the Vishav basin located in the NW-Himalayas has been selected for the morphotectonic study as Vishav is considered as one of the largest contributors to the Jhelum River. The different geomorphic indices were calculated using satellite data and toposheets. The calculated geomorphic indices were then used in accessing the tectonics of the study area. The parameters like mountain front sinuosity, hypsometry and the sinuosity index provide clues about the ample work of the tectonics in the area. The development of triangular facets in the area is also the indicator of the tectonic work in the area. Lithological variations and/or tectonic uplift have led to the development of knick-points and abruptly high SL index value. Morphotectonic analysis shows that the tectonic uplift, lithology and climate forcing played an interdependent role in the landscape evolution of the Vishav basin. Thus, the results of the present study will provide clues about the tectonic activity and may initiate some thoughts about the futuristic ramifications of the geomorphic activity operating in the Vishav drainage basin.

Keywords: Vishav basin, morphotectonics, knick point, morphometric analysis, satellite data.

Introduction

The tectonics provides information about the processes, structures and landforms associated with the earth’s crust and its deformation thereof (Keller and Pinter, 1996). The term geomorphology is the study of nature, origin and evolution of the landscape, focused on the processes that produce or modify landforms. So the core of tectonic geomorphology is to study the ample work of the tectonic processes that tend to generate topography and surface processes that tear off topography (Bloom, 2003). Tectonic processes encompass all types of deformation and isostatic processes like fluvial, glacial, eolian processes etc (Burbank and Anderson, 2012). Through the integrative approach of geomorphology, seismology, geochronology, structural geology and geodesy, the tectonic geomorphology has found ample influence in studying the present landscape in relation to the past dynamic processes. Due to the diverse geography of Kashmir valley tectonically modified landform study is very much beneficial (Dar et al., 2014). In present study the integrated observations from the remote sensing data and maps were made, which was then validated by the intensive field work to infer the tectonic nature of the study area.

Study area

The Vishav drainage basin covering an area of 1060.329 square kilometers is placed in the south-eastern part of Kashmir Valley (Fig 1), positioned between 33°39’N to 33°65’N latitude and 74°35’E to 75°11’E longitudes. The Vishav stream is the critical left bank tributary of the Jhelum stream having its source the basin is Kounsarnag located at an altitude of about 3,840 meters above MSL on the gentler northern side of the PirPanjal range of Kashmir Himalayas. In a Zig-zag pattern it first moves in a north direction, then take a southeasterly direction and finally flows gently in north-westerly direction till it empties in Jhelum at Niayun, Visually. The Vishav stream stems from a glacier fed stream near the foot of Kounsarnag called Teri, which then joins the blind stream supposed to originate from Kounsarnag 2 km downstream at Mahinag, drooping steeply north-northeast to reach the main strike Valley (Raza, 1978). The study area possesses an elongated shape with diverse topography. The soils of the Vishav basin pertain to the groups of brown forest and mountain soils, Karewa and alluvial soils. The valley possesses idiosyncratic climatic characteristics because of its high altitudnal location, being surrounded on all sides by high mountain ranges.
General geology of Vishav basin

Kashmir Valley posses a diverse geological record. Due to the rise of Pir-Panjal range the Karewas were deposited in the intermontane basin as fill deposits (Dar et al., 2013). Geologically the alluvium is dominant, which is followed by the Karewas and Jurassic and Triassic formations (fig. 2). The Triassic limestones rocks being bordered by Palaeozoics (Agglomeratic slates and Panjal traps) and Pleistocene and Recent sediments overlie the lateral one. The some of the Palaeozoics rocks are overlain by Triassic limestones occurring in the form of dissected ridges. The limestone is thinly bedded, with shale and sandstone horizons. The fluvio-glacial and fluvio-lacustrine deposits of Pleistocene regionally known as Karewas are composed of fine lacustrine sandstones beds of loess and conglomerates. Small valleys among limestone ridges and Karewas are full with Recent alluvial composed of fine muddy and silty sediments. Alluvium covers semi arid area within the plain trouncing the primary geological setup of the area. However, all along the streams the boulders and gravels are predominant. Triassic limestone is aquifer of the area that supplies water to most of the people for domestic and agriculture purposes. The basic Paleozoic rocks are impermeable. The Karewas overlying are not fruitful aquifer but perform as professional filters owing to their high porosity.
Drainage of the Vishav basin

The Vishav stream is one of the important left bank perennial tributaries of the Jhelum River. The drainage map (Fig. 3) of the study area is drawn from the topographic maps (1:50,000) by the process of digitization in Arc view GIS (3.2a) environment, depicts an elongate character. The Vishav drains the entire northern slope of the Pir Panjal between the Sundra top peak (local name of the peak) (3879m) in the east and the Bundil Pir pass (4264m) in the west. One of its head stream rises in the vicinity of Bundil Pir Pass. Another head stream and a major one rises in the Gulalmerj and Zajimarj area and washes the Pir Panjal slopes from Didan Gali (3810m) in the east to Brahma Sakal Peak (4706m) in the west. A third head stream of the Vishav originates from Konsar-Nag – a small lake in the Pir Panjal slopes at an altitude of above 3500m. The latter two streams also drain the Kongawatan area. After the union of three head streams, the Vishav flows in a sinuous course, followed by a very turbulent south easterly course and finally flow laminarly in north westerly direction up till it enters Jhelum at Niayun. The overall drainage pattern in this region is of dendritic to sub-dendritic type.

Data used and Methodology

Morphotectonic analysis of the area, conceded out with the help of geomorphic indices acts as a tool for the recognition of active tectonics. Landforms in the dynamic deformation areas are shaped by interaction of both endogenic and exogenic processes. As such river is one of the most important landforms that is very responsive to tectonic movements particularly uplift and tilting. Thus with the help of this study, one is able to attain valuable information about tectonic history of the area. The inputs employed to study the tectonic geomorphology of this region, are the drainage morphometry and calculation of morphometric indices. These geomorphic indices are calculated by using topographic maps, aerial photographs, satellite imageries (Aster DEM and Landsat ETM image-2008) in the Arc view 3.2a and Erdas-9.1 environment. After the completion of laboratory work the field work was carried out for the validation. The methodology adopted has been represented in flow chart (Fig. 4).
Morphometric Analysis

Morphometry is the qualitative and quantitative analysis of the configuration of earth’s surface, shape and dimensions of its landforms (Agarwal, 1998). The drainage basin and channel network analysis plays a significant role for understanding the geo-hydrological actions of drainage basin and express the climatic conditions, and finally we can get information about the tectonics. Surface stream networks have been used quantitatively to describe stream basins with the goal of understanding their processes and evolutionary history (Horton, 1945; Strahler, 1952). The drainage characteristics of Vishav basin have been examined to understand the tectonic geomorphology of the area with particular reference to stream order, stream number, stream length, bifurcation ratio, elongation ratio, circulatory ratio, asymmetrical factor, mountain front sinuosity, drainage density, stream gradient index and sinuosity index and hypsometric integral. The calculated morphometric parameters are described below (Table 1).

<table>
<thead>
<tr>
<th>Morphometric Parameter</th>
<th>Formula</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stream order</td>
<td>\text{Hierarchical rank}</td>
<td>Strahler(1964)</td>
</tr>
<tr>
<td>Stream number</td>
<td>\text{Nu}</td>
<td>Horton (1945)</td>
</tr>
<tr>
<td>Stream length</td>
<td>L_\mu</td>
<td>Schunn(1956)</td>
</tr>
<tr>
<td>Bifurcation ratio</td>
<td>\text{R_b=N_\mu/N_\mu+1}</td>
<td>Horton(1932)</td>
</tr>
<tr>
<td>Elongation ratio</td>
<td>\text{E_b=2(AB/3.14112)}</td>
<td>Schunn,(1956)</td>
</tr>
<tr>
<td>Drainage density</td>
<td>D_d=L_\mu/A</td>
<td>-</td>
</tr>
</tbody>
</table>

Results and Discussions

Stream ordering

Stream order designation is the primary step for the analysis of drainage basin by which we can quantify the position of a stream in the hierarchy of tributaries (Leopold et al., 1969). In the present study, the Strahler’s (1964) method was adopted to rank the streams. There are 2,643 streams, with 7th...
order being the highest order of streams, sprawled over an area of 1.043 square kilometers. The Vishav stream is the 7th order drainage basin. First order stream constitutes 75.86 (maximum portion) percent of the total number of streams of the catchment and the proportion contribution decreases with increase in stream order. Thus throughout the catchment we came to know that lower order streams have higher number of streams.

**Stream number**

Stream number which is the number of streams in a given order generally decreases as the order increases. The stream number shows the vice-versa relationship with the permeability and infiltration (Nageswara et al., 2010) As shown by the Table 2 the number of streams shows the general trend of decrease in number of streams with increase in order suggesting that the stream number in case of 1st Order is maximum.

**Stream length**

Stream length is indicative of the sequential development of stream segments counting breaks in tectonic disturbances. The stream lengths in the basin were calculated with the help of GIS softwares. We establish that the stream segment lengths decrease with increasing the stream order with the exception of 7th order stream that conforms to the Vishav drainage basin. The variations from general observations may be due to altitude effect, lithology, gradient and topography of the area (Singh, 1997; Vittala et al., 2004).

**Bifurcation ratio (Rb)**

Bifurcation ratio of a drainage network being defined as the ratio between the total numbers of stream segments of a given order to that of the next higher order (Schumm, 1956). The values of the bifurcation ratio (Table 3) clearly suggests that the average bifurcation ratio of the Vishav basin is 3.09. The highest Rb 4.26 is found between 2nd and 3rd orders indicating highest overland flow and discharge due to lithological and structural control with steep high slope. The fairly lower value of bifurcation ratio infers the difference in lithologies, higher permeability and lesser structural control in the area (Hajam et al., 2013).

**Drainage density**

The ratio of the total length of all streams in a given drainage basin to the drainage area of the same basin is defined as drainage density. This ratio gives an insight how densely a drainage basin is channelized. The area under consideration is having a drainage density of 2.03/km. This relatively low drainage density depicts that the region possesses permeable sub-soil, dense vegetation and medium relief.

**Morphotectonic analysis**

The quantitative measurement of landscape shape of a drainage watershed makes easy comparison of different landforms and evaluation of geomorphic indices/morphotectonic parameters that on other side may be useful for identifying a particular characteristic e.g; tectonic activity level of an area (Keller and Pinter, 1996). The utilization of geomorphic indices for morphotectonic analysis

### Table 2 Showing the order wise stream number and stream length.

<table>
<thead>
<tr>
<th>S.NO</th>
<th>Stream order</th>
<th>No of streams</th>
<th>Stream length(KM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1st order</td>
<td>2005</td>
<td>1301.16</td>
</tr>
<tr>
<td>2</td>
<td>2nd order</td>
<td>482</td>
<td>465.30</td>
</tr>
<tr>
<td>3</td>
<td>3rd order</td>
<td>113</td>
<td>204.15</td>
</tr>
<tr>
<td>4</td>
<td>4th order</td>
<td>28</td>
<td>98.83</td>
</tr>
<tr>
<td>5</td>
<td>5th order</td>
<td>11</td>
<td>64.64</td>
</tr>
<tr>
<td>6</td>
<td>6th order</td>
<td>3</td>
<td>32.75</td>
</tr>
<tr>
<td>7</td>
<td>7th order</td>
<td>1</td>
<td>38.52</td>
</tr>
<tr>
<td>Total</td>
<td>7 orders</td>
<td>2643</td>
<td>2205.35</td>
</tr>
</tbody>
</table>

### Table 3 Showing bifurcation ratio values.

<table>
<thead>
<tr>
<th>S.NO</th>
<th>Order number</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1st and 2nd</td>
<td>4.16</td>
</tr>
<tr>
<td>2</td>
<td>2nd and 3rd</td>
<td>4.26</td>
</tr>
<tr>
<td>3</td>
<td>3rd and 4th</td>
<td>4.03</td>
</tr>
<tr>
<td>4</td>
<td>4th and 5th</td>
<td>2.54</td>
</tr>
<tr>
<td>5</td>
<td>5th and 6th</td>
<td>3.66</td>
</tr>
<tr>
<td>6</td>
<td>6th and 7th</td>
<td>3.0</td>
</tr>
</tbody>
</table>
have been marked as a basic tool to recognize areas experiencing quick tectonic deformation (Bull and McFadden, 1977; Keller and Pinter 1996). The geomorphic indices which were used in the present study to understand the active tectonics of region are:

- Hypsometric Integral (HI)
- Mountain Front Sinuosity ($S_{mf}$)
- Basin Elongation Ratio (Eb)
- Basin Circulatory Ratio (Cr)
- Basin Asymmetry (Af)
- Sinuosity Index (Si)
- Transverse Topography
- River Profiling
- Stream Gradient Index (SL)

**Hypsometric Integral (HI)**

The quantitative evaluation of the degree of dissection of a drainage basin is given by hypsometric integral (HI) (Strahler, 1952). The calculation procedure used is $HI = (H_{mean} - H_{min}) / (H_{max} - H_{min})$ (Pike and Wilson, 1971). The hypsometric integral value premeditated for the Vishav basin is 0.41, 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.

**Mountain Front Sinuosity**

Mountain front sinuosity well-defined as; $S_{mf} = L_{mf} / L_s$, whose higher/lower value is associated with the rate of active tectonics and uplift i.e., low $S_{mf}$ related to active tectonics and uplift with mountain front relatively straight and higher $S_{mf}$ value if the rate of uplift is abridged or terminates with more irregular mountain front due to erosional processes. The calculated values of $S_{mf}$ for Vishav basin is given in Table 4.

The range of values is from 0.8 to 1.17 indicating that the area is tectonically controlled.

**Elongation ratio**

Schumm (1956) described ‘the ratio of diameter of a circle having the same area as the basin and the maximum basin length’ as Basin elongation ratio. Besides, structural control, in actively uplifting landscapes, youthful basins are commonly held to be relatively elongate with little of their area lowered to near base level (Molin et al., 2004). The estimated Basin Elongation Ratio of 0.15 of the Vishav basin portrays the basin as elongate suggesting that the area is tectonically active.

**Circulatory Ratio**

Ratio of the basin area ($A$) to the area of a circle ($Ac$) possessing the equal perimeter as the basin defined as circulatory ratio (Miller, 1953; Strahler, 1964) has been utilized as visualizing tool for the quantitative evaluation of the shape of the basin. The estimated value of 0.52 for the study area elucidates that drainage basin is almost elongated and categorized into medium relief.

**Basin Asymmetry (Af)**

The estimation of tectonic tilting of small scale drainage basin as well as large areas was done by utilization of asymmetry factor (Hare and Gardener, 1985). The calculated value of AF for the study area is 25.20, indicates that the Vishav stream has shifted downstream right side of the Vishav basin. The variation in the value from 50 shows the tilt perpendicular to the trunk stream (Keller and printer, 1996). In the present study the value of 25.20 is the clear indicator of the tectonically active nature of the watershed.

**Transverse topography**

Another way for determining tilt direction is transverse topography. This factor is calculated by the equation as $T=Da/DdT$ includes transverse topography symmetry factor, distance from the mid line of the basin is given by $Da$ to the mid line of active meander belt while the distance from midline of the basin to the drainage divide is given by $Dd$. Perfectly symmetric basins is given by the value of $T=0$, the asymmetry increases as the value
of T increases from 0 to 1. Assuming that the dip of bedrock has insignificant influence on the migration of stream channel. The transverse topography symmetry factor (T) for the Vishav basin has been calculated. The calculated values are 0.5, 0.40, 0.6, 0.3, 0.0, 0.7, 0.82, 0.9. As it is evident that values are almost approaching to 1.0 which shows the asymmetric nature of the basin. Thus the T value of the Vishav basin reflects the asymmetric approach of the watershed. This asymmetric nature of the watershed can be inferred as an inevitable work of the tectonics.

**Longitudinal River Profile**

A longitudinal river profile is a plot of a river or stream length with respect to river or stream elevation above mean sea level. It represents channel gradient of the river from its source to mouth. Longitudinal profile of Vishav basin is shown in Fig 5. The presence of the knick points in the area along the course of the river provides the clues of the tectonic disturbances in the area.

**Stream Gradient Index (SL)**

Stream gradient index reveals link among different parameters like stream power, rock resistance and tectonics (Hack, 1973). If change in stream slope is due to rock resistance or tectonic deformation SL is important parameter to estimate it in particular, if it has a vertical component (Keller and Pinter, 2002). The SL values are mostly high in areas where active tectonics has resulted in vertical deformation at the earth’s surface. Therefore, high SL infers that active tectonics is possibly shown by low to uniform resistant rocks (Keller,1986). The graphical representation of stream length gradient and knick point is shown in (Fig 6). The SL values for the Vishav Nalla increases from 218m over the mouth to 969 over the knick point (Aharbal fall).The SL values then again decreases and shows the normal gradient. The higher values of the knick point may be due to tectonic deformation as the basin in the stretch is composed of homogeneous lithology.

**Field observation**

The results shown in the present study were validated in the field and some of the photographs taken in the field are shown below, showing clear signs of tectonics in the study area.
Conclusion

The landforms analyses in the present study decipher the influence of tectonics in the development of Vishav basin and structures thereof. The most significant landform on the earth’s surface are rivers which are more vulnerable to tectonic movements and forms the fundamental units of fluvial landforms. In the present study various parameters (linear and areal) were studied. The different linear parameters include stream number (Nu), stream length (Lu), stream order (Su), bifurcation ratio (Rb) and basin length (Lb) etc. while the areal parameters calculated include mountain front sinuosity (Smf), hypsometric integral (HI), drainage basin asymmetry (AF), river profile analysis and stream length gradient index (SL). The field studies and morphometric analysis has revealed its importance in validating significant information about the tectonic processes operating in the study area. The calculation and analysis of different parameters provide a better understanding of the tectono-geomorphic character of the area and additionally, provide some insight into the evolution of landforms in the area.

The order wise stream number and length showed that the frequency increases is in the case of first order streams and decreases as the stream order increases. It is due to different geological structures in the rocks of the area. The bifurcation ratio shows that basin has experienced less structural complexity and uneven uplift rates, but as the stream order increases bifurcation ratio goes on decreasing.

The development of triangular facets and low Smf values in the area demonstrates the tectonic control over the basin rather than erosion. The sinuosity index of Vishav Nallah is 1.4 which clearly indicates a sinuous form of the river. The lithological boundaries and linear structures like faults affects the local shape of longitudinal profiles as well as the SL index. Lithological discontinuities and tectonic uplift has occasioned not only in the development of Knick-points and an anomalously high SL index value. Drainage basin asymmetry defined in terms of Asymmetry factor as well as Transverse Topographic Symmetry Factor provides valuable information in rapid evaluations of drainage basins to determine the tectonic tilt. The observed values of AF in the area show an extensive drainage basin asymmetry linked to tectonic tilting. Area elevation analysis or hypsometry is a dominant tool for discriminating tectonically active areas from inactive ones. The degree of dissection of a landscape is related to the hypsometric integral. Calculated hypsometric integral value for the study area is 0.41, which is on the higher side indicating that the area is in youthful stage. High topography and incised streams suggest ample work of tectonics in the area. Overall assessment of the morphometric and morphotectonic analysis revealed that the tectonic uplift, lithology and climatic forces played a major

Plate 1. Field evidences showing the different Morphotectonic features in Vishav basin.

(A) Triangular facets (B) Confluence point (C) River Meandering (D) Talus deposit (E) Gully erosion (F) Point bars (G) Knick point (H) River terrace (F) Deep incised valley.
role in the landscape development of the Vishav basin.

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