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# Longitudinal Profiles and Geomorphic Indices Analysis on Tectonic Evidence of Fluvial Form, Process and Landform Deformation of Doodhganga, SW Kashmir Valley, NW Himalayas

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**Abstract:** ***The drainage pattern and morphology of the doodhganga's piedmont zone are blatant signs of the active orogenic moments that was created by the most recent collision of the Indian and Eurasian plates. Since the Valley is surrounded by young, folded mountain ranges that are currently being uplifted, its geomorphic history is remarkably recent. The Valley has supported sub-aerial erosion and deposition at the same time; therefore the two processes are inextricably juxtaposed in the surface characteristics of the valley. Over the Pleistocene, there have been alternating periods of glacial and fluvial activity, complicating the already complex situation. The Doodhganga basin consists of zones of active tectonics drained by dhoohganga river and its tributaries. The present study is conducted for the different tributaries and sub-tributaries of Doodhganga which bear the imprint of active tectonics of the region, the most active thrust belt of Himalayas. Data and further fieldwork revealed that recent catastrophism had a continuous impact on the area. To assess the strength of the tectonic evidence, various tectonic indices were calculated. This includes the fractal dimension (FD), the hypsometric integral (HI), the basin asymmetry factor (AF), the basin shape index (Bs), the stream-length gradient (SL), the mountain front sinuosity (Smf), and the ratio of valley-floor width to valley height (Vf). The output of these indices is utilised to create a three-class active tectonics index that is displayed on a map. Then, the places with high tectonic index values are compared to the field evidence of the deformed landscape.***

**Keywords:** tectonic evidence; fluvial form; fluvial process; landform deformation

## 1. Introduction

From a geomorphological standpoint, the Kashmir valley in the Himalayas is unique because of the abundance of information about the topographical development of the region that is available. Since the Valley is surrounded by young, folded mountain ranges that are currently being uplifted, its geomorphic history is remarkably recent. The Valley has supported sub-aerial erosion and deposition at the same time, therefore the two processes are inextricably juxtaposed in the surface characteristics of the valley. The already complex situation has been made more complex by the alternation of glacial and fluviatile activity over the Pleistocene (Raza, 1978). The geography of the Valley is clearly affected by these operations. The Valley appears to be an enclosed valley because it is surrounded by a continuous series of mountains. It is separated from the frigid plateau-deserts of Ladakh and Baltistan to the northeast and northwest by the Great Himalaya and the North Kashmir Ranges, and it is separated from the Jammu area to the south and southwest by the Pir Panjal. The valley extends like a huge green bowl from the peak of the Pir Panjal, its lakes and flowing rivers being framed by the high, snow-capped peaks of the neighbouring mountains. The Kashmir Valley developed its current structure as a Graben between two Horst-type features, the Pir Panjal to the west and the Zanskar to the east, during the Pleistocene, during the Himalayan orogeny (Bhat 1982). The Panjal thrust caused the Pir Panjal mountain range to rise, forming the Kashmir valley (Burbank). It is essential to first comprehend the significance of the Kashmir valley in order to comprehend the geotectonics of the Kashmir Himalayas. The geology of the Kashmir region offers a temporal record of the Great Himalayan orogeny through sedimentation, tectonics, and volcanic activity. There are obvious folds, thrusts, nappes, igneous intrusions, and signs of dynamic structural deformation. Wadia (1931) highlighted three important tectonic or structural aspects in the Kashmir valley. Foreland zone: The Sub-Himalayan Ranges, which represent the northernmost limit of the Indian shield, were formed by the Tertiary deposits of Siwalik and Murees. This region is also known as the Shiwalik belt. A series of thrusts and the presence of sizable anticlines and synclines in the Siwalik rocks are typical structural features of the Himalayan region. The most noteworthy of them is the Main Boundary Thrust (MBT), which dips to the north. Due to the Murree push, the Siwalik group of rocks and the Muree formation are geographically separate. This area is covered in Tertiary sediments. The Foreland basin is composed of Siwalik molasses conglomerate deposits, red and purple shale, and greyish green sandstone. The Muree Thrust to the south and the Panjal Thrust to the north form a zone of rocks in the northern Foreland basin of the Himalaya. The Precambrian and a lone Eocene sliver make up the Autochthonous fold zone. The Sauni Volcanic Formation is a local suite of basalt and orthoquartzite association that stretches from Poonch to Dadu (Udhampur). It contrasts sharply with the Muree Formation to the south. Kashmir valley is commonly referred to as "The Nappe Zone of Kashmir" in geological literature due to its location wedged between the Panjal Thrust and the Great Himalayan range. The nappe zone in Kashmir is situated between the locally folded belt and the foreland basin portion, both of which have moved along a thrust. The Salkhala Formation, which is located south of the Kashmir valley, can be linked to the Kashmir Nappe Sequence. The Kashmir Nappe, which was deposited in a sizable lake around 4 million years ago, is referred to as karewas, which literally means "elevated tableland" (Burbank and Johnson, 1982; Agarwal et al. 1989) and since then, it has climbed to a height of 2493 metres above mean sea level. These Karewas rest on the natural rocks in several valley sites. The Karewas' home ranges over an area of about 2500 square km. Karewas unwind on the Kashmir basin's folded Paleozoic and Mesozoic rocks, which make up the valley floor. The Panjal push resulted in the formation of the Pir Panjal range, which is situated to the west of here. The Kashmir Valley is yet another illustration of an unbalanced tectonic basin, and is situated between the Pir Panjal and Great Himalayan mountain ranges. The Kashmir Valley is located in the far north of India. The valley's natural borders are provided by the Pir Panjal to the south and the Himalayas to the north. Because of the combined influence of the area's tectonic activity and climate, the geology of the Kashmir Valley is complex. This inquiry focuses on the geology of the Kashmir Valley. Precipitation peaks in March and April when westerly winds strike the Pir-Panjal Mountains' northern slope. Here, the average annual precipitation is 669 millimetres. The geology of the area runs from the Archean to the Recent, and the rocks of Pir-Panjal provide an illustration of this broad age range. The most prevalent rock types in the region include alluvium, karewa, and Panjal traps. Due to the fact that a large portion of it enters the Jhelum River, the area has very substantial drainage. A important tributary of the Jhelum River, the Dudhganga has its source near Tatakuti Mountain. The rocks in the study region span the eons, from the Archean to the modern era. Elevated portions in the research area may contain the Salkhala series, the oldest formation in the region, due to the presence of active high-grade metamorphism. The Salkhala group consists of interbedded slates, phyllite, and schist with crystalline limestone and flaky quartzite. The Muth quartzites and Panjal volcanics are the next most abundant rock types in the study region after the Salkhala group. Overlying the agglomeratic slate series in the Carboniferous age volcanic region of Panjal is a dense succession of andesitic and basaltic traps. After the panjal volcanics, you'll find limestone from the Triassic and Jurassic periods. The rocks are often compact and uniform but can also be diversified and pale blue or grey in color. As one moves further up the system, the beds thin and the outcrops become a consistently colored limestone, whereas in the lower part of the system, they are bedded with various interstratifications of black sandy and calcareous shales. The grains range from extremely fine to relatively coarse.

## 2. Study Area

The 660 km$^2$ Dudhganga watershed in Kashmir Valley is in northern India, between 330°42′ and 340°50′ North and 740°24′ and 740°54′ East (Fig. 1.1). From 1557 to 4663 metres above sea level, a wide diversity of elevations may be found in the area. The plains and slopes of this region, which is dominated by the soaring Pir-Panjal, are covered in flat-topped karewas. The Chenab valley and the Jammu region are divided from the Kashmir valley to the south and southwest by the Pir-Panjal mountain. A significant illustration of the terrain of the area is the Karewa formation. These lacustrine deposits, which originated during the Pleistocene era, include the clays, sands, and silts that make up this material. The three main soil types in the area are loamy soil, karewa soil, and underdeveloped mountain soil. 200 degrees Celsius on average are the yearly temperatures.

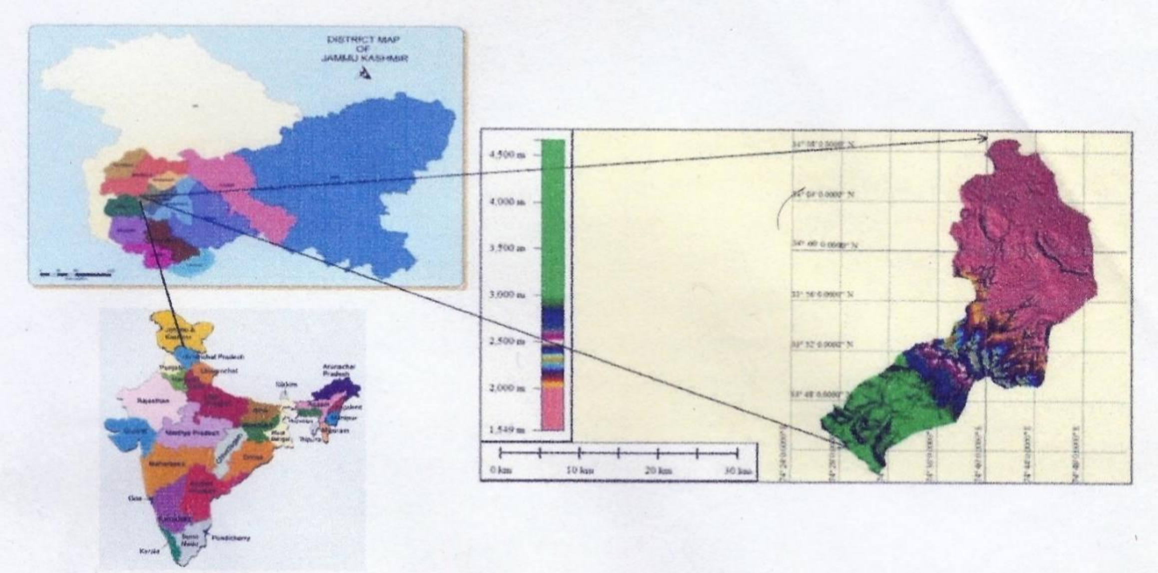

**Figure 1:** Location map of the study area

## 3. Data and Methods

### Stream-length gradient index (SLGI)

The sudden changes in the longitudinal profiles of the rivers provide compelling evidence of the structural and technological influence on the area that altered the channel dynamics. To compute these changes, Hack (1957) created the SLGI. Many scholars have used this SL index to understand how lithology and tectonics have affected the longitudinal profiles of the river (Lee & Tsai, 2009). The SL Index of a section of the river between two points can be calculated using the formula provided by Hack (1957), which is represented as follows:

$$\text{SL¼ð}h1\text{—}h2\text{Þ=½lnð}d2\text{Þ—lnð}d1\text{Þ];} \tag{1}$$

where SL is the stream gradient index, h1 and h2 are the heights of the first and second points, respectively, d1 and d2 are the distances between the first and second points, respectively, and ln is the natural log.

### Normalised stream-length gradient index (NSL)

For the examination of recent tectonic activity of the fluvial system, it is a very popular and practical method (Seeber & Gornitz, 1983). The claim can be expressed mathematically as:

$$\text{NSL ¼ SL=k;} \tag{2}$$

where k = Slope of the idealised Hack's graded profile and NSL = Normalised Gradient Index for the given portion of length, SL = Stream Gradient Index for the given part of length, respectively. Segments with NSL 2 are regarded as noticeably steeper, while segments with NSL 10 are known as extremely steep reaches. The NSL 2 data indicate a mild gradient.

### Analysis of hack profile

The SRTM 30 m DEM and the scanned Topographical sheets were used for the morphometric analysis. Using the editor tool in ArcGIS 10.2.2, the elevation of each contour crossing the six main tributaries of the River Tista—Neora, Gish, Chel, Lish, Mal, and Murti—as well as their sub-tributaries was discovered. The distance from the source was also determined to obtain the longitudinal profiles of the rivers. Concave rivers, which signify a downhill slope of the channel, are rivers that are in equilibrium. The river exhibits a convex long profile if it overflows through an area with significant tectonic activity. If the lengthy profiles for ideal rivers are drawn on a graph paper with a semi-logarithmic scale, they are seen as a straight line (Hack, 1973). The "Hack Profile" is another name for this profile (Hack, 1973).

$$H\text{¼}C\text{—}K\text{lnð}L\text{Þ:} \tag{3}$$

$$K\text{¼ }H_i\text{—}H_j\text{=ln}L_i\text{—In}L_j\text{:} \tag{4}$$

The SL Index, or average stream length gradient index, is K. Regression intercept C is. Since zero cannot be plotted on a logarithmic scale, the source of every river is assumed to be at a distance of 0.02 km.

### Long profile length and relief normalisation

The long river profiles reflect the changes in the basin's relief and size. Thus, the long profile length and relief are normalised to lessen the effects of the basin size and relief. To normalise the profiles, the elevations and distances were divided by the head (maximum basin relief) and the entire stream length, respectively (Lee & Tsai 2009). Breaks in the river profile are therefore a sign of a major structural influence on the river channel. Four basic mathematical operations form the foundation of the normalised long profile model;

The linear function

$$y\text{¼}ax\text{þ}b\text{:} \tag{5}$$

The exponential function

$$y\text{¼}ae^{bx}\text{:} \tag{6}$$

The logarithmic function

$$y\text{¼}a\ln x\text{þ}b\text{:} \tag{7}$$

The power regression model

$$y\text{¼}ax^{b}\text{:} \tag{8}$$

The best fit is determined by the R2 value. The curve that fits the data the best has the highest R2 value. According to earlier literature, the long profile exhibits a low degree of concavity and, as a result, a superior linear function fit when channel grain size exceeds the river's transit capacity (Lee & Tsai, 2009).According to Hack (1973), when erosion and resistance are balanced, the grain size of the channel sediment will decrease downstream, making the long profile more suitable for the logarithmic function. This is the river's "Graded Profile." The power function is increasingly suitable as the profile concavity increases. Therefore, the order of evolution should be linear, exponential, logarithmic, and power.

### Valley-floor width to height ratio (Vf)

The present scientific explanation was put forward by Bull (1977). It is expressed as;

$$\text{Vf¼2Vfw=½ðEld—EscÞþðErd—EscÞ];} \tag{9}$$

Where Vfw represents the width of the valley, Eld represents the altitude of the left bank, Erd represents the altitude of the right bank, and Esc represents the altitude of the channel. A valley with a high value of the valley-floor width to height ratio (Vf) was likely to be quite flat and wide floor nonetheless, the very narrow low value of "Vf" has elevating effects connected to active tectonics.

### Hypsometric curve and hypsometric integral (HI)

A typical technique used to explain the stage of land forms in a certain river basin or other types of land forms is the hypsometric curve and hypsometric integral. According to

Strahler (1952), hypsometric treatment primarily demonstrates the differences between erosional landforms and their stages of evolution. Percentage of relief and cumulative percentage of area are expressed in terms of the hypsometric integral, which has a variable 0–1 range (Pike & Wilson, 1971). When the hypsometric integral value is close to 0, the area is severely eroded, while the region close to 1 exhibits the opposite sort of character.

## 4. Results and Discussions

To the human eye, the tectonic deformations are invisible. For thousands of years, the earth's surface has been deformed by tectonic activity. Even though these deformations happen extremely slowly, rivers are very sensitive to them. Because rivers can adapt to deformations that occur over millennia to decades, river system analysis is a crucial tool for understanding tectonic geomorphology (Keller & Pinter, 1996, 2002). As a result, morphometric and morphotectonic parameters were used to examine the sensitivity of the Dhoodhganga River and its tributaries. This has made it easier to comprehend the latest tectonic developments in the area.

### Modelling long profiles

It is preferable to fit straightforward, logarithmic, linear, exponential, and power regression models to the elevation-distance data in order to comprehend the shapes of long profiles. In order to comprehend the link between form and process, a best fit model is used. When the river's grain size exceeds its transportation capacity, the long profile exhibits a low degree of concavity, tends towards a straight line, and fits the linear function better (Lee & Tsai, 2009).The lengthy profile is consistent with the exponential function once the channel's deposit and transport rates have reached dynamic equilibrium. Long profile fits more comfortably for a logarithmic function when the channel is sloped, or when the sediment grain size falls downstream. The lengthy profile fits the power function when the discharge and load suspension are both substantial. Therefore, according to Lee & Tsai (2009), the evolution sequence for the long profiles of the channels should be linear- exponential- logarithmic- power. The profiles that show a linear to exponential model have reduced concavity, which indicates that there have been recent tectonic events and changes in the river's path. The task of fitting the best fit model has been taken on for the Doodhganga River's tributaries and sub-tributaries. The exponential model is present in all the watersheds, including A1, D1B, D1C, D2A, and D2B (Figure 2; Table 1). However, there are no power regression models, which is an obvious sign of recent turbulence in the area.

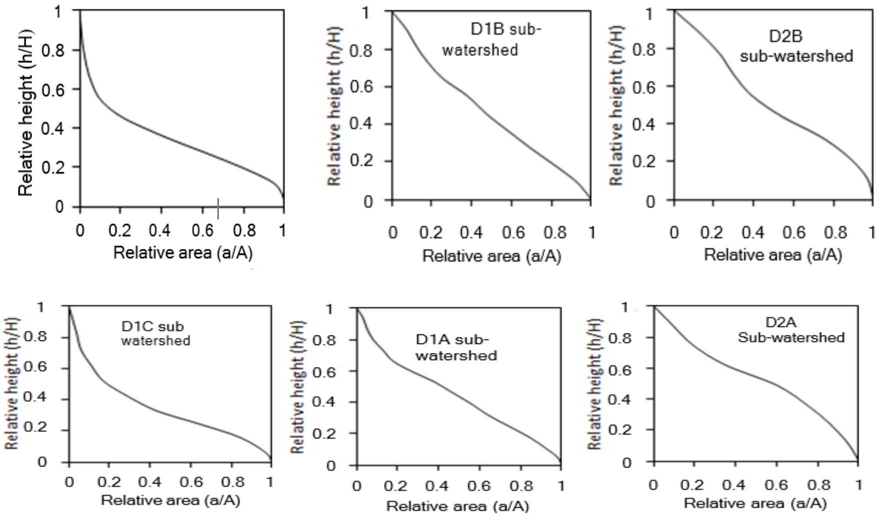

**Figure 2:** Normalised long profiles of watersheds of Doodhganga river i.e A1, D1B, D1C, D2A, and D2B. The profiles exhibit linear to exponential model implies less concavity in their profiles thus are evidences of disturbances in the course of the rivers and implications of recent tectonic movements.

### Segment-wise stream gradient index (SGL index)

The stream length gradient index (SL) serves as a valuable indicator for identifying recent tectonic activity by detecting high index values within the variations of a particular rock type. The tool exhibits a high degree of sensitivity towards variations in slope, enabling it to effectively evaluate the interrelationships among potential tectonic phenomena, rock resilience, and topographical features (Hack, 1973). The stream length gradient index is calculated for a particular reach of interest by multiplying the channel gradient (H/L) of the reach by the distance from the headwater division (L). In other words, the stream length gradient index (SL) is given by the equation SL = (H/L)/L. Elevated SL index values are indicative of the presence of hard rock formations at river crossings, suggesting a higher degree of tectonic activity. According to Hack (1973) and Keller and Pinter (2002), low values of the SL index indicate the presence of less durable and softer rock types, which in turn suggest a relatively low level of tectonic activity. The SL index is calculated for the Doodhganga watershed and its main tributaries along their respective stream channels. Within the realm of research, the SL index values are classified into six distinct categories, spanning a range of 15 meters to 727 meters, as depicted in Figure 3. The observed variability in SL index values within the drainage basin may be attributed to either lithological differences or tectonic activity.

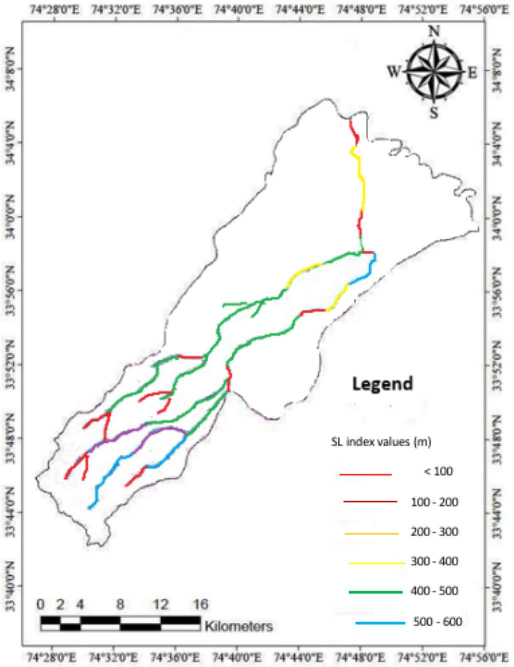

**Figure 3:** Stream length gradient index map of the Doodhganga watershed.

### Asymmetry Factor

The measurement of basin asymmetry is conducted through the utilization of the Asymmetry Factor (AF), which is a qualitative metric. The authors Keller and Pinter (2002) employ a morphometric variable known as AF to assess the presence of a regional tilt in a basin at the regional scale. The asymmetry factor, denoted as AF, is a metric used to quantify the ratio between the area of the right side of the drainage basin facing downstream of the trunk stream (Ar) and the overall area of the drainage basin (At). It is mathematically expressed as AF = (Ar/At) 100.

The creation of the drainage basin asymmetry factor (Hare and Gardener, 1985) was motivated by the need to detect tectonic tilting not only at the regional level but also at smaller scales within drainage basins. When the AF value exceeds 50, the primary channel of the drainage basin shifts towards the left (downstream) side. Conversely, when the value of AF is below 50, it indicates that the channel has shifted towards the downstream right portion of the drainage basin (Hare and Gardener, 1985). The inference of tilt block tectonics can be made based on the asymmetry observed in drainage basins (Gardener, 1987).The area factor (AF) for the Doodhganga basin was derived from a stream that was classified as the sixth order according to Strahler's (1957) stream ordering system. The basin has undergone a displacement towards the upper left direction relative to the channel, as visually depicted in Figure 5. The Doodhganga basin exhibits an AF value of 53% in this context. The presence of elongated tributaries on the right side of the basin, an increased number of tributaries joining the river, and a higher drainage density within the right division collectively indicate a tilting of the basin. The tilting of the basin is apparent based on several indicators. Firstly, longer tributaries are observed on the left side of the basin. Additionally, there is a higher number of tributaries joining the river on the left side. Furthermore, the left divide exhibits a higher drainage density, as evidenced by the calculated Af value of 21.62% for the Doodhganga basin (refer to Figure 4).

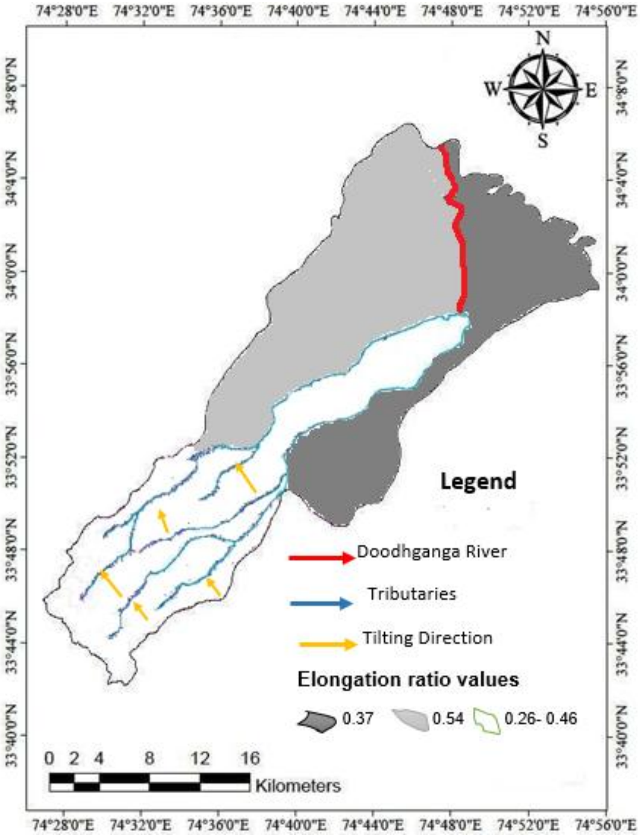

**Figure 4:** Elongation ratio map and tilting direction of the sub-watersheds.

**Table 1:** Computed elongation ratio of the sub-watersheds.

| Name of sub-watersheds | Area (A) sq.km | Basin length (Lb) km | Basin elongation ratio (Re) |
|---|---|---|---|
| WATERSHED A1 | 149 | 36.60 | 0.37 |
| D1B | 69 | 35.94 | 0.26 |
| D1C | 88 | 23.15 | 0.46 |
| D2A | 111 | 42.65 | 0.28 |
| D2B | 243 | 32.55 | 0.54 |
| Dudhganga Catchment | 660 | 62.56 | 0.46 |

### Valley Floor Width to Valley Height Ratio

The ratio of valley floor width to valley height (referred to as Vf) is a useful metric for assessing the extent of river down cutting and incision in uplifted regions, as suggested by Bull and McFadden (1977). The expression for the ratio of valley floor width to valley height ratio (Vf) can be represented as: Vf = 2 Vfw/ (Eld – Esc) + (Erd – Esc) In this context, Vfw represents the width of the valley floor, Esc denotes the elevation of the valley floor, and Eld and Erd refer to the elevations of the left and right valley divides, respectively. This index serves to distinguish between broad valleys characterized by relatively high values of Vf and V-shaped valleys characterized by relatively low values. According to Keller and Pinter (2002), there is an inverse relationship between high values of Vf and uplift rates, resulting in the formation of broad valley floors by streams. Conversely, low values of Vf indicate the presence of deep valleys where streams actively incise, typically associated with high uplift rates. In this study, the values of Vf were assessed at ten specific locations (1 to 10) along the Doodhganga river, as depicted in figure 5. The obtained values ranged from 0.07 to 0.32, as presented in Table 2. These values indicate the presence of deep, narrow, V-shaped valleys, suggesting an ongoing process of incision and gradual upliftment in the studied area.

**Table 2:** Estimated values Valley floor width to valley height ratio of the Doodhganga watershed.

| Segments number | Valley floor width to valley height ratio (Vf) |
|---|---|
| 1 | 0.07 |
| 2 | 0.08 |
| 3 | 0.10 |
| 4 | 0.11 |
| 5 | 0.13 |
| 6 | 0.16 |
| 7 | 0.19 |
| 8 | 0.22 |
| 9 | 0.27 |
| 10 | 0.32 |

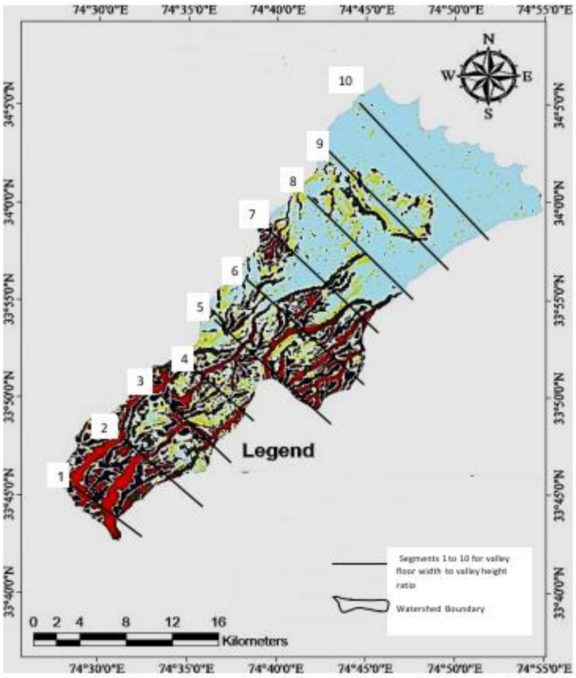

**Figure 5:** Valley floor width to valley height ratio of Doodhganga watershed

## 5. Conclusion

The active tectonics has an impact on the drainage system, pattern, and fluvial associate morphology of the piedmont zone of the NW Himalayas. Due to its convex semi-logarithmic profiles, the Doodhganga watershed and its nearby streams exhibit recent tectonic processes. Long profiles that show a linear to exponential model have less concavity in their profiles, which is a sign of recent tectonic movements and evidence of changes in river courses. In this study, several morphotectonic indices have been considered, namely the basin elongation ratio, asymmetry factor, transverse topographic symmetry factor, channel sinuosity, ratio of valley floor width to valley height, stream length gradient index, and mountain front sinuosity. Based on the elongation ratio, it can be inferred that the area exhibits tectonic activity. The majority of the sub-watersheds exhibit a slanted configuration, as indicated by the asymmetry factor values. Additionally, the total basin's asymmetry factor value suggests a tectonic tilt towards the west, which can be attributed to tectonic activity. The basin's asymmetry, which has been influenced by neotectonic activity, is evident through the estimated values of the transverse topographic symmetry factor. The sinuosity values of the Doodhganga River's channel serve as an indication of the river's meandering characteristics. The continuous erosion and gradual uplift of the valley have led to the formation of deep, narrow valleys with a high ratio of valley floor width to valley height, resulting in a V-shaped morphology. Thus the result clearly depicts that all the rivers are flowing in the zone of active tectonics and their form, process and landform deformation are affected by result of recent tectonic activities.

**Template 1**

**Template 2**

Template 3

Template 4

Photographs showing field evidences of Fluvial form, process and landform deformation of Eastern Himalayan Rivers which is strongly related with recent tectonics plates.

Template 1 River terraces at boniyar.
Template 2 Meandering of doodhganga
Template 3 Point bar deposits at branwar.Template4.Back tilitig of karewa at boniwar.

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