

# Morphotectonic analysis of Sheer Khadd River basin using geo-spatial tools

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**Abstract** In the present study, a quantitative morphotectonic analysis of Sheer Khadd River basin has been carried out based on geomorphic and morphometric indices such as hypsometric integral, drainage basin asymmetry, mountain front sinuosity, basin elongation ratio, valley floor width to valley height ratio, river sinuosity and stream length gradient index using ASTER digital elevation model (DEM) and Google Earth images to understand the morphotectonics of the basin. The results indicate that Sheer Khadd River basin is tilting towards east and is elongated in shape due to active faulting and folding activity in the terrain. A moderate hypsometric integral value indicates that the basin is still under mature stage of erosion and reflecting a complexity in topography. Fluctuations in stream length gradient index over fault zones indicate irregularities in the drainage course due to the presence of fluvial knick points. The results of morphotectonic and morphometric analysis using DEM data is useful tool for morphotectonic evaluation of any complex terrain.

**Keywords** Morphotectonics · Sheer Khadd River basin · Knick points · Geomorphic indices · GIS

## 1 Introduction

Morphotectonics deals with the landscape morphology that has developed as an outcome of past or present tectonic process and active structures can be evaluated by using morphotectonic indices [1]. The consequences of investigation of several morphometric indices can be collective in order to highlight the tectonic activity and to deliver a valuation of a relative degree of tectonic activity in any region [2]. Geomorphic indices are widely used for assessment of tectonism, includes precise assessment of geomorphic and structural features using digital elevation model (DEM) and satellite images in GIS environment. Tectonic activity plays significant role in the development of drainage basin morphology and its characteristics features. A detail analysis of a drainage basins with reference to tectonic processes can provides an important understanding of past and present deformational events of any tectonically active terrains [3]. It is well known that drainage channels and basins are very sensitive to any tectonic activity, therefore the drainage basin morphometry analysis is important for Neo-tectonism of any region and it's also provides information any deformations [4, 5]. The drainage channels are highly affected due to neo-tectonic activities and presence of active faults which can be change the characteristics of the river.

With the advent of high resolution remotely sensed data such as satellite image and aerial photos and good resolution DEM along with GIS and image processing tools provides the accurate measurements and analysis capability to evaluate and map the different terrain and developing the relationship to understand the tectonics of any area. The information about tectonic history of an area can be retrieved through study of topographic maps, satellite data and quantification of different morphotectonic indices [2].

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Many researchers have worked on Neotectonics of Himalayan regions and their significance has been discussed on morphotectonic, structural and drainage basin evaluation were discussed [3, 6–9].

A study reported on west Lidder basin, Kashmir Himalayas for identification of geomorphic signatures of active tectonics by generating important geomorphic indices such as hypsometric integral, basin elongation ratio, drainage basin asymmetry, Longitudinal River Profile, Transverse profile, stream gradient index (SL) from satellite data, DEM and field survey to understand the tectonics in the area and find that remote sensing technology along with field survey can be useful tool for indemnification of fault zones in Himalayan region [10]. An important work has been carried for morphotectonic and structural evolution of Giouchtas Mt., Central Crete, Greece based on interpretation and development of geomorphic indices viz. mountain front sinuosity index and valley floor/width ratio index from the remote sensing data and GIS techniques. They find that the Smf and Vf values are very useful for structural and tectonic evaluation of the basin [11].

Remote sensing, DEM and field data based study carried out for Mathemati basin of Kashmir to understand the tectonic activity based on geomorphic indices such as mountain front sinuosity, valley floor width to valley height ratio, hypsometric curve and integral, stream length gradient index, transverse topography symmetry, drainage basin asymmetry and basin elongation ratio. The study suggested that the basin is tectonically active and the results of present work can be useful for natural disaster mapping and management [6].

The basic objective of the present study is to understand the morphotectonics and morphopometric aspect of the basin using satellite data and DEM.

## 2 Geographical setup

Sheer Khadd River basin (Fig. 1) covers a total area of 107.07 km<sup>2</sup> under geographical coordinates of 76.26–76.36°E and 31.22–31.31°N. It is located on the eastern side of Govind Sagar and comes under the Survey of India Toposheet No. 53 A/11. The general elevation of Sheer Khadd River basin varies from 474 m lowest to highest 968 m and consists of Barsar Thrust fault and folds and makes the part tectonically active zone (Fig. 2). The general geological setup of the basin consists of sedimentary deposits such as boulder conglomerate and sandstone of lower Shiwaliks (Fig. 3). The basin receives the maximum rainfall during July to mid September, the temperature of the basin ranges from 35 to 40 °C during summers and winters are cold with fog over Govind Sagar.

## 3 Data used and methodology

Geocoded digital elevation model (GDEM) of ASTER of 30 m resolution was used for generation of topographical information and generation and calculation of geomorphic indices of the basin using image processing and Arc GIS Arc GIS-10.2 software. The Survey of India Toposheet 53 A/11 and published geological map of Geological Survey of India on 1:50,000 scales were used for the geological formation and structural setup of the basin along with published literature of the study area for reference. Geomorphic indices generated in the present work has been based on mathematical formulas suggested by different researchers [12, 13] through which evidences of recent and past deformations are identified. The important geomorphic indices such hypsometric integral, drainage basin asymmetry, mountain front sinuosity, basin elongation ratio, valley floor width to valley height ratio, river sinuosity and stream length gradient index and drainage map with stream order were generated from the ASTER 30-m spatial resolution DEM.

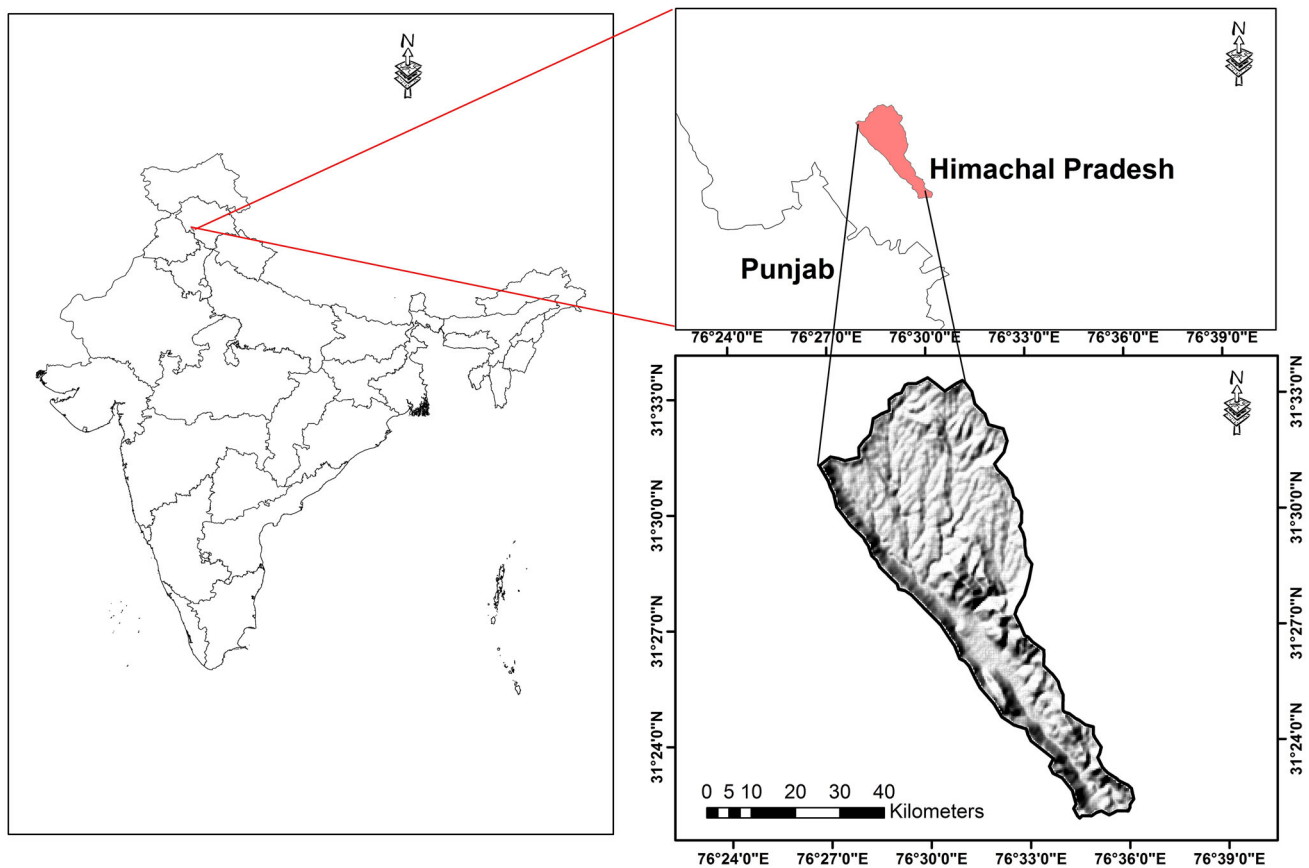
## 4 Result and discussion

Basin Morphometry is defined as the quantitative analysis of landscape and its important characteristics such as shape, size, elevation, and slope characteristics and the development of Landscape and morphological features of the drainage basins associated with combined effects of many erosional–denudational processes as well as the relative tectonic upliftment [4]. The Drainage map of the Sheer Khadd River basin has been generated from ASTER-DEM with 30-m spatial resolution in the GIS platform using Arc GIS-software. The Sheer Khadd River possesses first to fifth order basin and showing dendritic to sub dendritic type river basin and provides the important information for morphotectonic evaluation of the area (Fig. 4).

The geomorphic indices associated with drainage networks are the stream gradient index, the valley floor width to valley height ratio [2, 14, 15] and the mountain front sinuosity. In order to know the drainage characteristics and to have a set of systematic measures, various parameters have been measured and calculated for the area under study.

### 4.1 Drainage basin asymmetry (AF)

Basin asymmetry (AF) reflects the Neotectonism of the drainage basin by reflecting the direction of tilt and helps in



**Fig. 1** Location map of the Sheer Khadd River basin

evaluation the basin asymmetry and calculated by formula given below

$$AF = 100(A_r/A_t) \quad (1)$$

where AF = asymmetry factor,  $A_r$  = total area of right side of the trunk stream while facing down stream  $A_t$  = total area of drainage basin. If the AF is 50 or near it's represent no tilting and stable environment, however the value are less than and more than 50 indicates the basin is tectonically active [4]. The AF value of the basin was found to be 74.96, which indicates that the basin is tilting towards the Eastern side due to the presence of Barsar Thrust and tectonic upliftment is taking place in the basin (Fig. 5).

#### 4.2 Mountain front sinuosity (Smf)

Mountain front sinuosity (Smf) is known as one of the important factor to understand and to identify areas of tectonically active. Mountain front sinuosity is defined and calculated as equation given below

$$Smf = Lmf/Ls \quad (2)$$

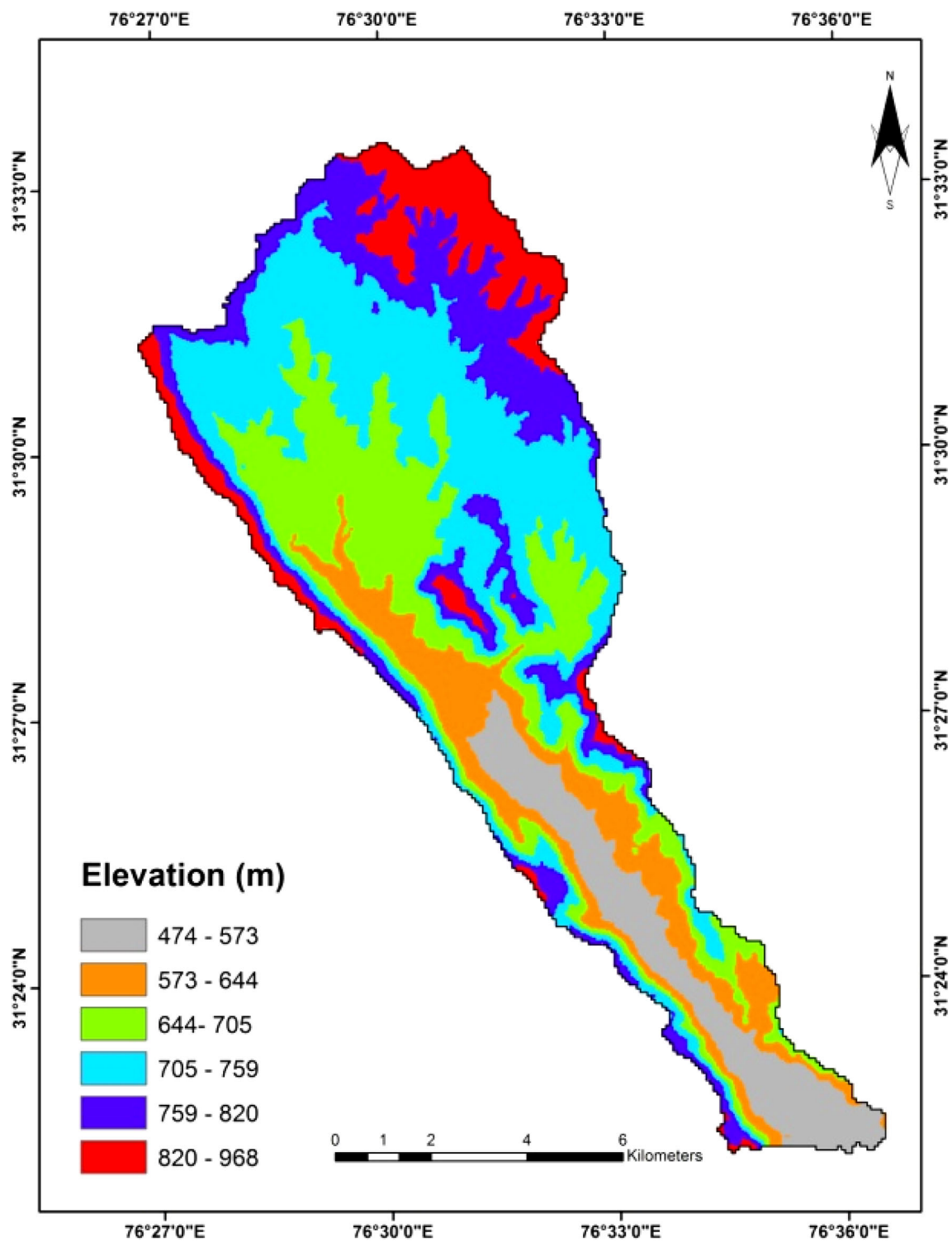
where Smf = mountain front sinuosity, Lmf = length of the mountain front along the foothills  $L_s$  = length of the

straight line of the front [2, 14]. Smf index indicates that the slope and drainage process shaping a mountain front which could be irregular and straight are symbolic of active tectonism. Therefore fronts which area straight due to tectonism is followed by erosion by the river and becomes more irregular with time. Bull and Mc Fadden [15] suggested that the standard mountain front sinuosity values varies between 1.0 and 1.6 for active terrains; for slightly active terrains, the values range between 1.4 and 3.0, and for inactive areas range between 1.8 and  $> 5$ . The value of Smf index of the study area ranges from 1 to 3 and Low Smf values are indicator of active tectonism, however in our study area Smf value varied between 0.89 over fault zones to 1.25 which indicates the drainage basin consist of more straight and tectonically active fronts as the value is closer to 1 (Table 1).

#### 4.3 Basin elongation ratio

According to Schumm [16] basin elongation ratio refers to the shape of the drainage basin which varies from circular to oval and is defined and calculated as

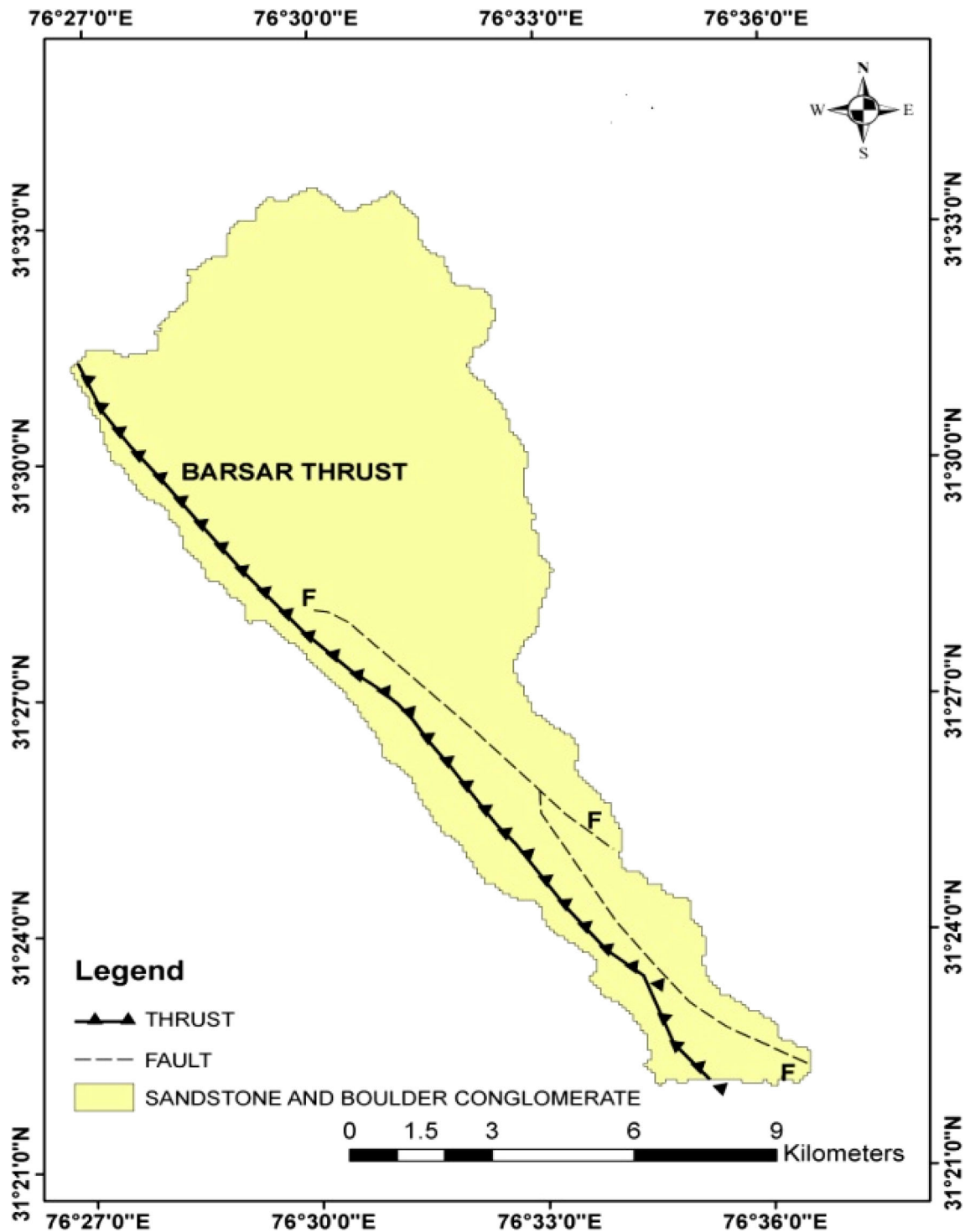
$$Re = \sqrt{(A_u/\pi)/L_b} \quad (3)$$



**Fig. 2** Elevation map of Sheer Khadd River basin

where  $A_u$  = area of the basin and  $L_b$  = basin length, the value of basin elongation ratio varies from 0 to 1 and the value  $> 0.9$  indicates circular shaped drainage basin, 0.7–0.9 indicates oval shaped basin, 0.5–0.7 indicates less

elongated and  $< 0.5$  value indicates highly elongated drainage basin [17, 18]. The basin elongation value less than 0.5 is a symbolic of active tectonical setup, 0.5–0.75 value represents slightly active tectonic setup where as

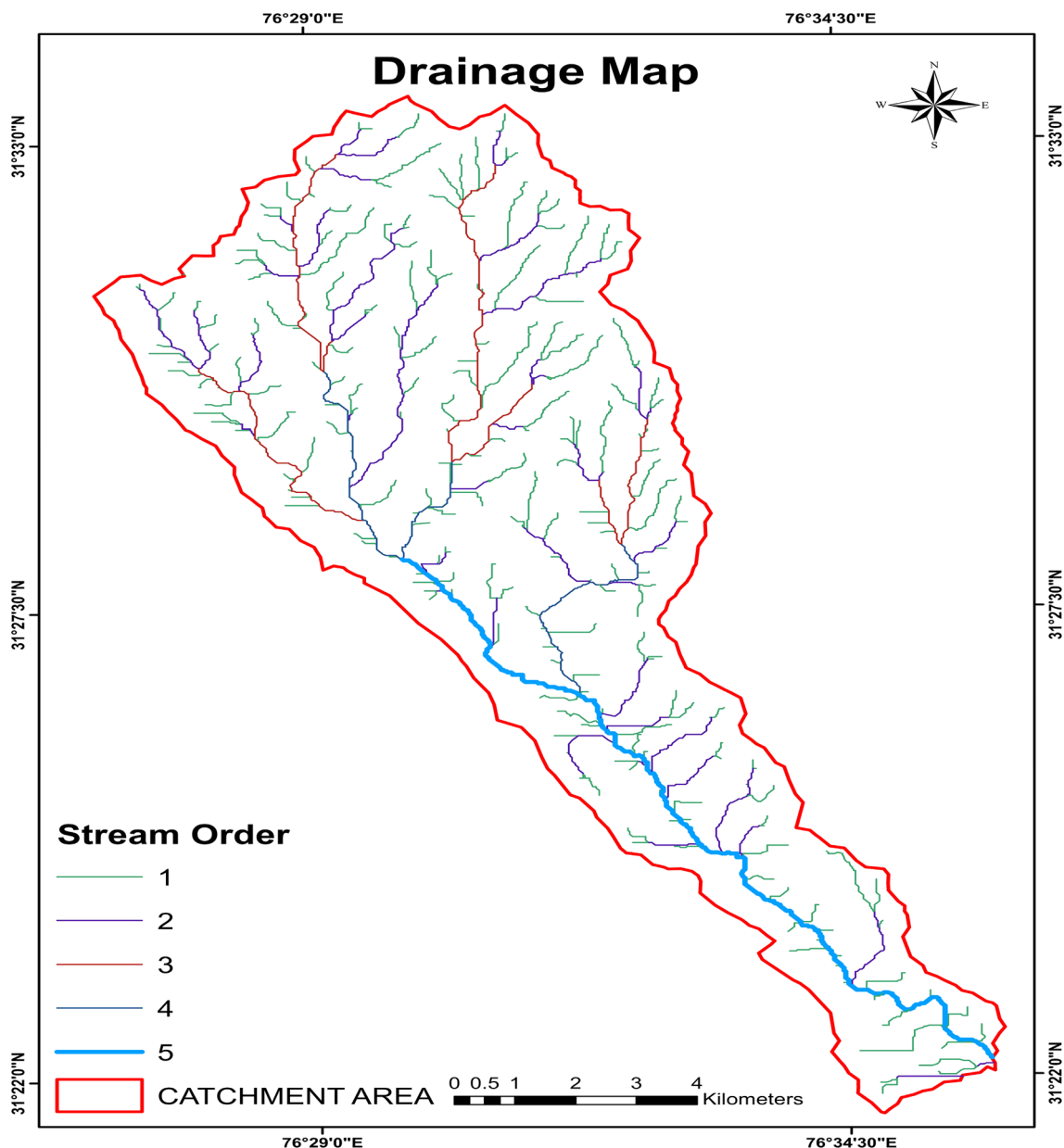


**Fig. 3** Geological map of Sheer Khadd River basin

value  $> 0.75$  indicates inactive setting. The value of basin elongation ratio observed for Sheer Khadd River basin is 0.10, which represents basin comes under tectonically active and elongated type of river basin.

#### 4.4 Hypsometric integral (HI)

Hypsometric curve is an important tectonic parameter for finding out the stage of the drainage basin under different tectonic setups which varies from youthful stage having deeply incised valleys to mature stage creating oxbow lakes



**Fig. 4** Drainage map with stream orders of Sheer Khadd River basin

and peneplain [19]. Hypsometric curve represents basin relative area below or above a given altitude and it is powerful tool to discriminate the area tectonically active and inactive [4]. The value and shape of the HI curve not only provide the information about erosional stage and environment of the basin, it's also useful for understanding tectonic, climate and lithological setup [6]. The hypsometric integral can be defined and calculated by the formula given below

$$H_i = (H_{\text{mean}} - H_{\text{min}}) / (H_{\text{max}} - H_{\text{min}}) \quad (4)$$

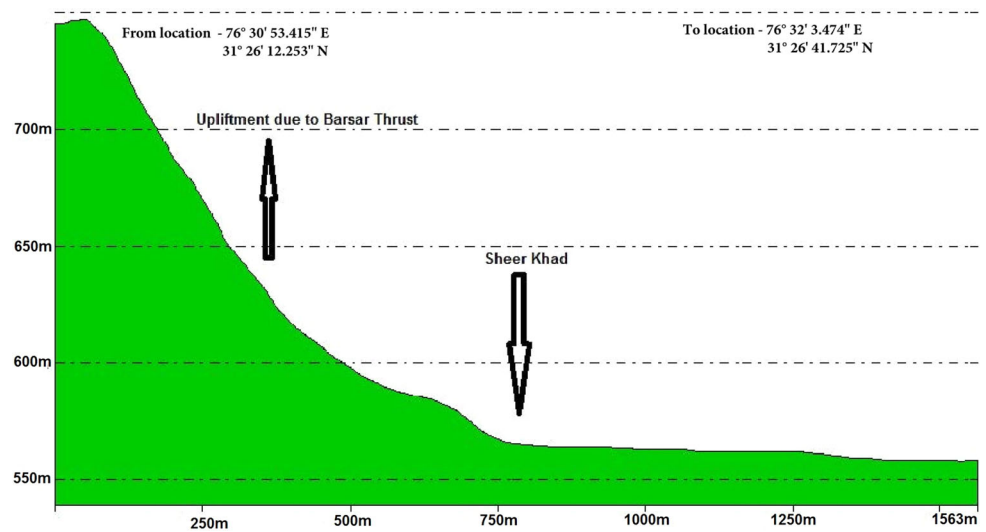
where  $H_i$  = Hypsometric integral,  $H_{\text{mean}}$  = Mean elevation  $H_{\text{min}}$  = Minimum elevation  $H_{\text{max}}$  = Maximum elevation. The general value of hypsometric integral ranges

between 0 and 1, where values close to 0.5 indicates maturity of the drainage basin, value less than 0.5 indicates old stage and more than 0.5 value indicates the younger stage of the drainage basin development. The HI value calculated for the basin is 0.47, which indicates the topography is maturity stage and suggested that the drainage basin is tectonically active and the river has not fully eroded category (Fig. 5).

#### 4.5 Longitudinal profile

The longitudinal profile of the river basin represents the elevation versus length plot of the stream from the source

**Fig. 5** Cross section of Sheer Khadd River representing slope facets and basin asymmetry

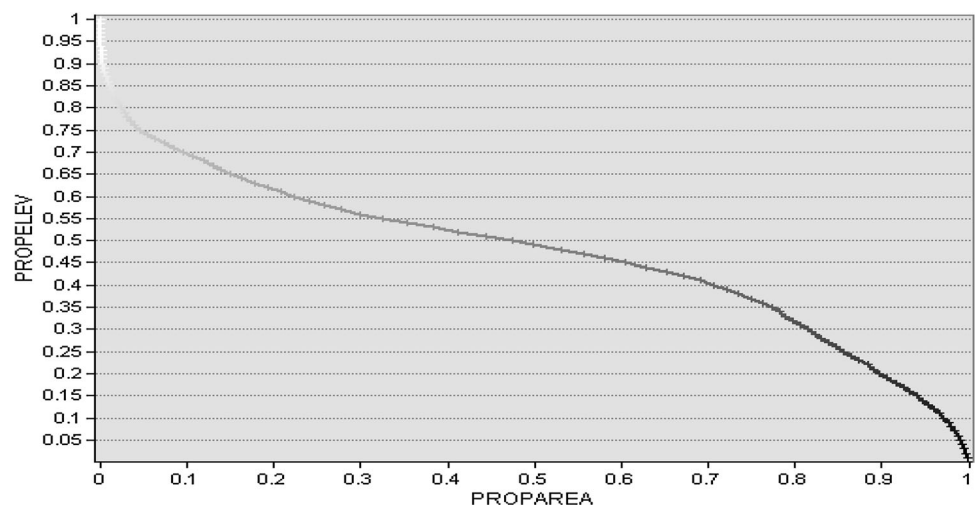


**Table 1** Mountain front sinuosity at random locations

Mountain	Lmf (km)	Ls (km)	Smf
1	1.89	2.11	0.89
2	3.16	2.51	1.25
3	17.9	17.7	1.01
4	3	2.84	1.05

to the mouth and condition the river profile is concave at the top due to the erosion and ultimately becomes convex near the mouth showing decrease in gradient monotonically but as the river comes in contact with an active fault zone they show knick zones with deformations in their course (Fig. 6). The River Sheer Khadd River basin represent concave value between 620 and 630 m elevations near the source followed by fluctuations in elevation due to active fault zones development taken place near knick

**Fig. 6** Hypsometric curve of Sheer Khadd River basin



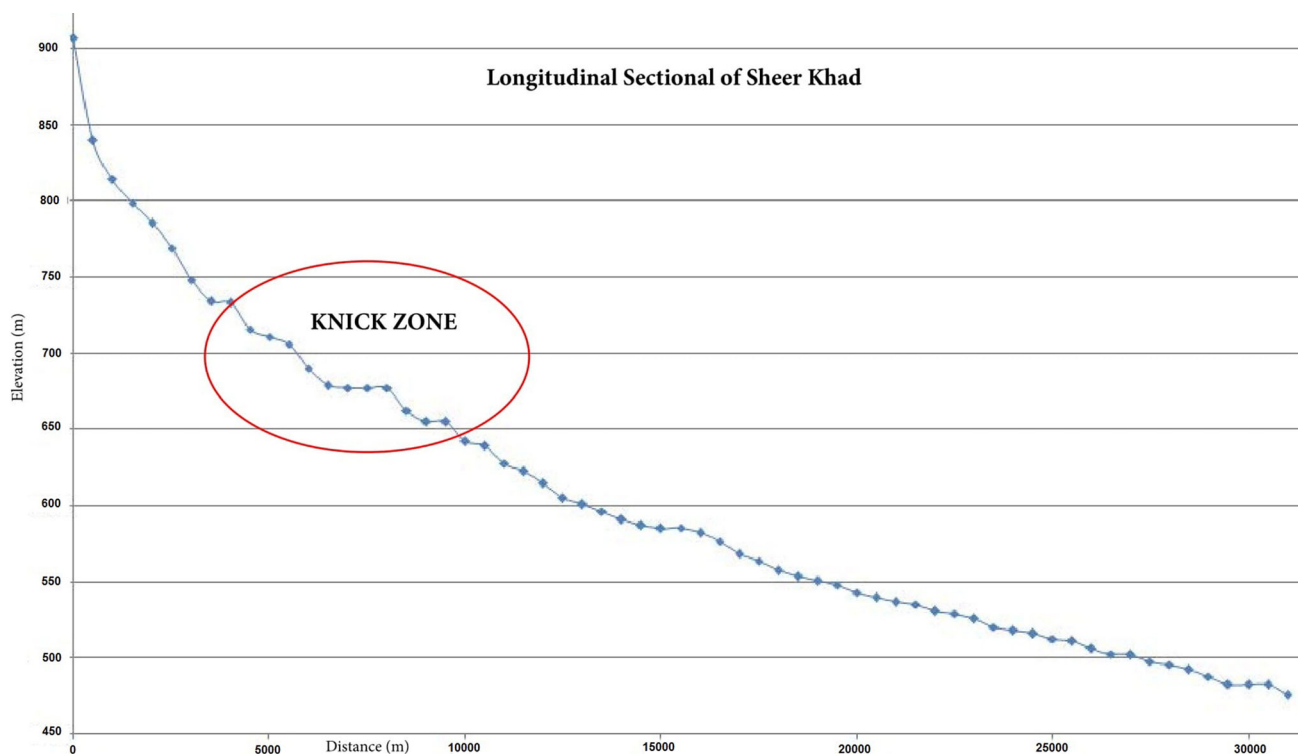
zones which suggests that the river course of Sheer Khadd is highly affected by tectonism (Fig. 7).

**4.6 Valley floor width to valley height ratio**

The valley floor width to valley height ratio (Vf) is another important and sensitive parameter to identify the tectonic uplift in the form of narrow or broad valley floors, thereby V- or U-shaped valley profiles. Valley floor ratio (Vf) index indicates the stage of fluvial cycle of drainage basin and also reflects the relative tectonic upliftment of the fronts of the mountain [20]. VF represented and calculated by the formula given below

$$Vf = 2Vw / [(Eld - Esc)] + [(Erd - Esc)] \tag{5}$$

where Vf is the valley floor width to height ratio, Vw = valley floor width, Eld = elevation of the left side of the valley, Erd = elevation on the right side of the valley Esc = valley floor elevation. The floor width of a valley to



**Fig. 7** Longitudinal profile of Sheer Khadd River basin

the height provides an index to understand, while stream is actively down cutting or eroding laterally into the adjacent hill slopes [7]. High values of the index suggests that the drainage basin is under late mature stage and showing lateral erosion with broad valleys without incision, where as lower Vf value indicates that there is an active down cutting by river with deep and V-shaped valleys in their youth to late youthful stage. In Sheer Khadd River basin, Vf value lies between 0.12 over active fault zones to 1.16 over stable zone which indicates that the drainage basin is tectonically active (Table 2).

#### 4.7 Stream length gradient index (SL)

The *stream length* (SL) index is a very valuable tool for the quantitative classification of stream gradient conditions and the assessment of relationship between imminent tectonic activity, rock resistance, topography, and stream length.

**Table 2** Ratio of valley floor width to valley height ratio

Channel length (m)	Straight length of valley (m)	River sinuosity
509.52	459.86	1.10
353.90	286.20	1.23
422.02	325.21	1.29
905.38	734.37	1.23

Stream length (SL) gradient index can be defined and calculated by formula given below

$$SL = (\Delta H / \Delta L) * L \quad (6)$$

where  $\Delta H$  = change in elevation,  $\Delta L$  = change in length of the stream.

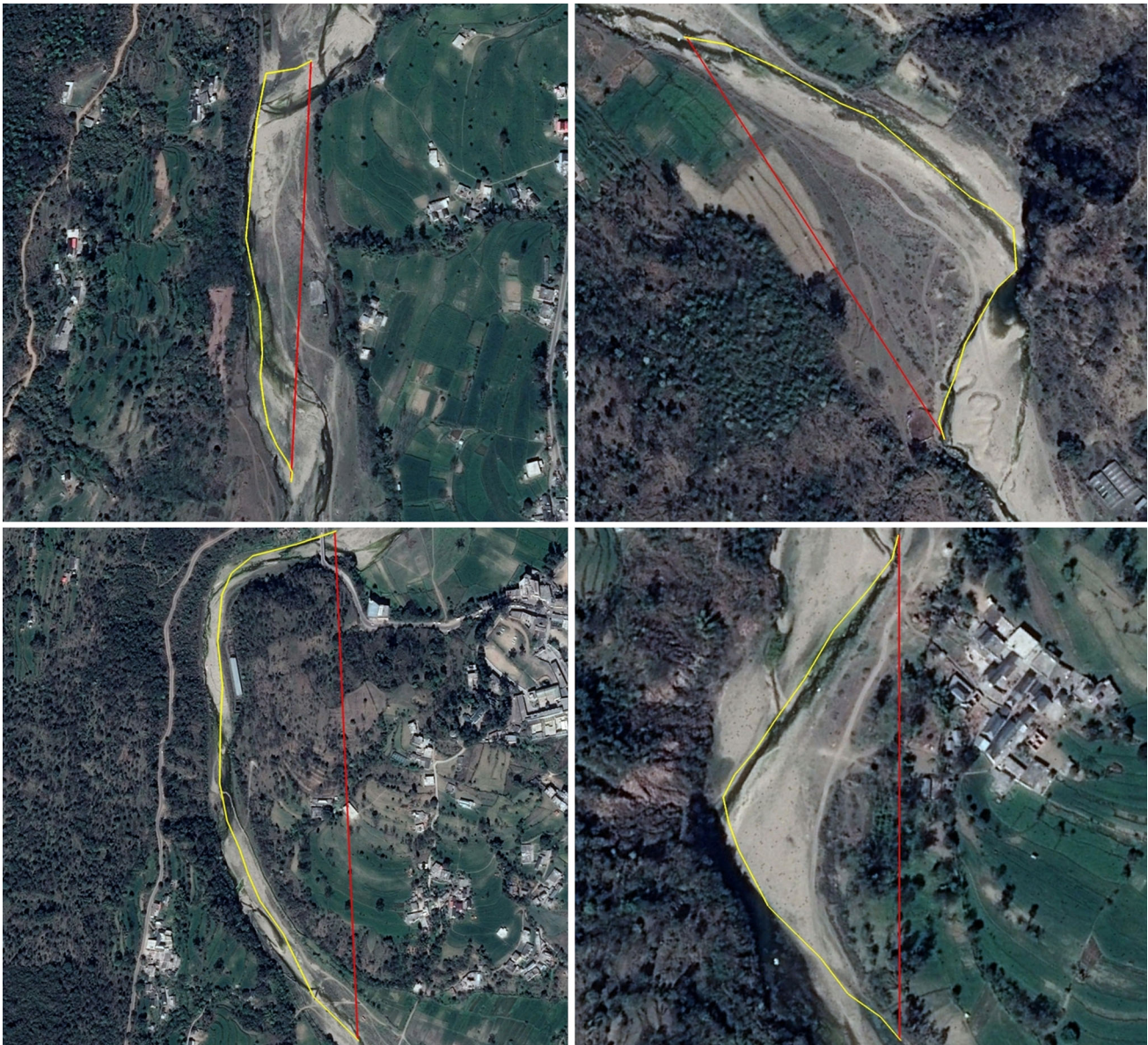
The SL index shows that ratio of drop in elevation to drop in stream length from source to mouth of the river. The index based on a threshold value is divided into many types such as < 500 (tectonically active), 300–500 (average tectonic activity) and < 300 (Little or no Tectonism). The SL were calculated for the main stream and vary between 11.65 and 1634 which suggest that the basin is under active deformations due to tectonism.

#### 4.8 River sinuosity

River in contact with active fault zone shows sudden slope changes with irregular pattern and changes in the curvature and river becomes identical followed by meandering of the river therefore; it is a useful tool for the assessment of tectonism in a drainage basin. The river which shows extreme meandering is very close to the equilibrium where as river showing straight profiles indicates Neo-Tectonism. River sinuosity can be defined and calculated by the formula given below

$$R = c/v \quad (7)$$





**Fig. 8** River sinuosity of different locations of Sheer Khadd River basin. (Color figure online)

where  $c$  = channel length  $v$  = straight length of the valley.

The study of basin for calculation of river sinuosity has been performed for 4 different locations of the basin using Google Earth imagery and the values range between 1.10 and 1.29. The values observed from the present study clearly suggest that the river falls under sinuous category and active tectonism (Fig. 8; Table 3).

## 5 Conclusion

The results observed from the assessment of morphotectonic analysis of the Sheer Khadd River basin reference to tectonic evaluation of the basin using satellite based DEM

**Table 3** River sinuosity values

Valley	Vfw (m)	Eld (m)	Erd (m)	Esc (m)	Value
1	35.60	507.52	517.63	482	1.16
2	5.52	660.08	661.60	618.36	0.12
3	53.36	615.07	641.05	501.68	0.42
4	11.12	663.13	602.28	579.46	0.20

and geomorphic indices provide the important tectonic information of the basin. Qualitative as well as quantitative analysis using several geomorphic indices to study the effect of Neotectonism on the river basin. The drainage basin asymmetry factor reflected a value of 74.96

indicating the Eastward tilt of the Drainage basin due to upliftment caused by nearby active fault zones. Due to the presence of thrusts and Faults, active fronts were reflected in the study area during the calculation of Sinuosity of mountain fronts and mountain front sinuosity value varied between 0.89 and 1.25 suggesting the mountain fronts are tectonically exposed. The Ratio of valley floor width to valley height reveals that the drainage basin widely consists of active incised v shaped valleys with relative upliftment. The basin is having hypsometric value of 0.47, which indicates that basin is in initial stage of maturity. The longitudinal profile of river indicates the presence of fluvial knick zones over the river course due to which high stream length gradient index values were noticed with sudden changes in slope values. The river sinuosity value indicates that the river falls under sinuous category. The overall geomorphic index analysis and results suggest that the Sheer Khadd River basin is under high tectonism, and showing active deformations at many places. The results observed from this study can be useful information for disaster assessment and management plan for seismological and geotechnical investigation.

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