

Active Tectonic Strike-Slip Fault Development near Goran, Samba and Kathua Districts, Jammu and Kashmir

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Abstract

Active tectonic morphometric studies of the sparsely investigated frontal Siwalik terrain around Goran in the Samba district bordering the Kathua district of J&K reveal the presence of NW-SE trending active sinistral strike-slip fault with oblique slip component which is parallel to the Surin-Masatgarh anticline. The Basantar River, the Tarnah stream, the Ujh River, the Sahaar stream and the Ravi River exhibit significant stream offsets where the fault crosses these channels. The values of the morphometric indices viz. stream sinuosity index (S), stream length gradient index (SL), valley floor width to valley height ratio (V_{d} , mountain front sinuosity index (S_{md}), hypsometric integral (Hi), basin asymmetry ratio (AF) and basin elongation ratio (Eb) calculated along the linear river offsets with respect to longitudinal River segments of the Rivers Basantar, Tarnah, Ujh, Sahaar and Ravi Rivers reveal that terrain is tectonically active and can be placed in tectonic active class I. The fault has an apparent offset of about 2000 m with it as it crosses the Basantar, the Tarnah, the Ujh, the Sahaar and the Ravi Rivers. The stream offsets upon field and laboratory investigations are developed due to an active sinistral strike slip fault which is being named as Goran fault. This fault has a surface expression of 100 km extending from the Basantar in the northwest up to the Beas River in the southwest whereas the remaining segment may exist as a hidden fault all along the Himalaya.

Keywords

Active Tectonics, Goran Fault, Stream Offsets, Himalaya

1. Introduction

The Himalayan frontal thrust marks the southern boundary of the deformation

front of the Himalayan orogenic belt [1]. The thrust faulting in the frontal Himalayan terrain is strongly influenced by the spatial and temporal patterns of active deformation recorded on the margin of the orogenic belts. The accumulated strain on account of the continuous northward migration of the Indian plate finds frequent release in the form of seismic events that display a conspicuous inter-relationship amongst the basal decollement surface, rate of thrusting and plate motion rates [2] [3] [4]. The data emerging from the spectacular surface rupturing earthquakes suggest that the current tectonic activity is primarily occurring in the frontal thrust terrain [5]. Active tectonic morphometric studies within the orogenic belts are of significant importance in the context of evaluating the models of deformation, thrust belt kinematics, as also the seismic hazard faced by the population habiting in close proximity to the active faults. [6] discussed the neotectonic activities that have occurred in the Himalayan terrain. [7] described the structure and shortening of the Kangra and Dehra Dun re-entrants of Sub-Himalaya. [8] has done reassessment of earthquake hazard based on a fault-bend fold model of the Himalayan plate. [9] has described the palaeo-seismicity and seismic hazard assessment in the Himalaya. [10] has identified and described the uplift and convergence along the Himalayan Frontal thrust of India. [11] has identified and described neo-tectonic activity near Nada village and Morni Hills in the Himalayan foothills. [12] described the earthquake recurrence and rupture dynamics of Himalayan Frontal Thrust. [13] discussed the convergence across the northwestern Himalava. [14] discussed reactivation of Himalayan frontal fault system and its implications. [15] described the shutter ridges and sag ponds along the Jainti Devi Fault near Chandigarh. [16] [17] described the neotectonic and seismo-tectonic characterization of the frontal Himalayan terrain. [18] documented recent fold growth and drainage development in the Janauri and Chandigarh anticlines of the Siwalik foothills. The neotectonic activity in the Markanda and Bata River Basins in Himachal Pradesh has been investigated by [19] and their study suggested upliftment and tilting of the Markanda and Bata River Basins due south. Seismites occurring in the frontal Himalayan terrain near Panchkula in Haryana were identified by [20]. [21] assessed the tectonic character of the terrain in the Frontal Siwalik hills near Trilokpur, northwestern Himalaya using remote sensing and tectonic morphometric approach. A comprehensive evaluation of the tectonic morphometric indices in terrain characterization has been attempted by [22]. Besides [23] [24] [25] [26] [27] have also worked on active tectonic aspects in the frontal Himalayan terrain of the northwestern Himalaya. The present study is aimed at identifying the active tectonic elements in the Kashmir Himalaya, especially in the region between the Basantar and the Ravi Rivers, as the Kashmir Himalaya has been considered to represent a seismic gap due to non-availability of historical earthquakes in this region [28] [29] except Kangra earthquake in 1905 and Uri-Muzzafrabad earthquake in 2005.

2. Geological Setup

The Middle Miocene to Middle Pleistocene (23.5 m.a. to 1.6 m.a.) Siwalik group

of rocks are quite well represented in the foothills of the Jammu and Kashmir Himalaya especially in the vicinity of Ravi River. The frontal Siwalik terrain between the Ravi and the Basantar River comprise the Upper Murree formation, the Lower Siwalik subgroup (Mansar Formation), the Middle Siwalik subgroup (Dewal and Mohargarh formations), and the Upper Siwalik subgroup (Uttarbahni and Dughor formations) as given (**Figure 1**) by [30] [31] (**Table 1**).



Figure 1. Geological map showing the location of the research area. Modified after GSI map Ref. No. 43P NW Himalaya [32].

Table 1. Lithostratigraphic classification of the area	modified after [30]	[31] [33].
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Sub Group	Formation (Equivalent Unit)	Lithology	Age
Post-Siwalik	Terrace (T6) Terrace (T5) Terrace(T4) (Loess)	T4, T5 and T6 represents Flood plain deposits composing gravel, sand, silt and clay beds.	Holocene
	Terrace (T3) Terrace (T2) Terrace (T1) (Lei-Conglomerate)	T1, T2 and T3 represents Secondary Boulder Conglomerate deposits having pale yellow to dark yellow silt matrix as flat-top surfaces.	Late Pleistocene
	Dughor (Boulder Conglomerate)	Conglomerate to intermittent layers of friable sandstone and rarely mudstone characterized by orange pigment in the matrix. Sandstones and conglomerates with interbeds of mudstones, laterally	Middle Pleistocene
Upper Siwalik	Nagrota (Pinjor)	grading into conglomerates.	Early Pleistocene
	Paramandal (Tatrot)	Mudstones and sandstones alternations with minor conglomerate beds, laterally changing to grey conglomerate, containing lenticular bands of sandstone.	Late Pliocene

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Middle Siwalik	Mohargarh (Dhokpathan)	Predominantly multistoried sandstones with minor mudstone partings. Massive, thickly bedded multistoried sandstones with subordinate	Middle Pliocene
	Dewal (Nagri)	mudstones.	Early Pliocene
Lower Siwalik	Ramnagar (Chinji)	Mudstones, siltstones and fine to coarse sandstone alternations.	Late Miocene
	Dodenal (Kamlial)	Very fine to medium sandstones, siltstones and mudstones.	Middle Miocene

The rocks of the Siwalik group in study area occur as an asymmetrical anticline referred to as the Surin-Masatgarh anticline. The rocks exhibit N50°W -S50°E trend with the dominant SW dip direction. The Surin-Masatgarh anticline marks the thrust front [34]. The folding of this anticline has been estimated on the basis of palaeomagnetic data and thermo chronometry. Detritial apatite studies by [35] suggests onset of folding before 2 m.a., while the palaeomagnetic data by [31] [36] suggests an age between 1.6 to 2.1 m.a.

3. Field Observations

The southern limb of the asymmetrical Surin-Masatgarh anticline between the Ravi River and the Basantar River is 60 km in length and 20 km wide at Basantar re-entrant and 10 to 12 km wide at Ravi re-entrant. The major geomorphic features identified on the satellite imagery include the Siwalik Hills, alluvial fans, piedmont fan deposits, alluvial plains and River terraces. Low, middle and high hills represent the Upper, Middle and Lower Siwaliks with in between intermontane basins (duns). The Siwalik Hills extend in a NW-SE direction in the form of a linear sinuous asymmetrical anticlinal ridge. The Lower Siwalik Mansar Formation (Lower Miocene to Middle Miocene) comprise well indurated fine to medium grained pale grey to dark grey coloured sandstones, siltstones and mudstones. The Middle Siwalik Dewal Formation (Early Pliocene) and Mohargarh Formation (Middle Pliocene) comprise massive, medium to poorly indurated, pale grey to light brown coloured sandstones, siltstones and mudstone. The upper Siwalik Parmandal formation (Late Pliocene) comprises light brown to dark grey sandstone and mudstone with minor intercalations of pebbly beds that grades into sandstone and conglomerate in Nagrota fm. The Nagrota formation (Early Pleistocene) is represented by light to dark grey to pale brown sandstone and mudstone in the lower part and coarser clastics in the upper part. The upper Siwalik Dughor formation (Middle Pleistocene) represent the Boulder Conglomerate unit and is represented by matrix supported polymictic friable conglomerate containing sandstone lenses and thin beds of friable sandstone and mudstone. Alluvial fans comprise a chaotic intermix of cobbles, pebbles, granules, sand, silt and clay particles which at places are intermixed with calcareous concretions. The piedmont plains are made up of poorly sorted debris, assorted sediments debouched by streams, draining the region. The terrain between the Ravi River and the Basantar River is being closely examined to identify active tectonic features in the terrain. Development of shutter ridges is observed along all the streams through which the linear tectonic element crosses on the basis of movement seen along this element, which is being named as Goran fault. The fault is active and trends northwest-southeastwards. This fault is a sinistral strike slip fault with considerable oblique slip component. The fault has a surface expression of about 100 km and a significant portion of it appears to be hidden.

Fault scarps are observed in the Ujh River near Jakhole village in the Kathua district of Jammu and Kashmir (Figure 2(a)). Triangular facets along the Goran fault are observed along the Ravi River near Basantpur-Jugial region (Figure 2(b)). Shutter ridges of 2000 m length are developed along all Rivers and major streams (Figure 2(c)). Development of sag pond is observed along the Ujh River (Figure 2(d)). Unpaired terraces have been identified in the vicinity of Ravi River near Basantpur-Jugial region (Figure 3). During field work in the Jugial





Figure 2. Field photographs of the structures observed in the Frontal Himalayan terrain, Kathua District, Jammu & Kashmir ((a) Fault Scarp; (b) Triangular Facets; (c) Shutter Ridge; (d) Sag Pond).



Figure 3. Google earth image showing unpaired terraces along the Ravi River.

region six terraces (T1, T2, T3, T4, T5 & T6) have been identified on the left bank of the Ravi River while only strath terraces (T1 & T2) have been identified on the right bank of the Ravi River. The terraces are made up of unconsolidated pebbles, sand, silt and clay. The younger terraces namely T5 and T6 are more fragile as compared to the older terraces.

4. Methodology

The active tectonic characterization of the terrain in the vicinity of Ravi River in the frontal Siwalik terrain is carried out in a multidisciplinary manner. The data obtained from comprehensive field surveys, satellite imageries and morphometric investigations is being analyzed to ascertain the tectonics of the area of investigation. The Google Earth images (Figure 4) and LISS-III imageries (Figure 5) are being analyzed for visual identification and interpretation of geologic and geomorphic features.



Figure 4. True Colour Google Earth Images showing the location along which River offsets (L1 to L5) and longitudinal profile segments (1 to 5) of different streams have been studied for computing morphometric parameters.



Figure 5. LISS III false colour composite image (Resourcesat: 1, 2010) [41] showing the location of the fault. GF-Goran Fault.

Active tectonic geomorphic indices viz. stream length gradient index by [37], stream sinuosity index [38], mountain front sinuosity index, ratio of valley floor to valley height [39] [40] hypsometric integral, asymmetry factor and basin elongation ratio have been computed for the affected portion of the terrain in the region. The features identified and interpreted on the imageries and the data generated through ArcGIS have been physically verified in the field through comprehensive field investigations. The Digital Elevation Model (DEM) of the selected terrain has been prepared and the LISS-III false colour composite imagery has been draped over it to understand the tectonic character of the region.

5. Morphometric Analysis

Morphotectonic analysis is widely used as a basic reconnaissance tool for geomorphic evaluation of active tectonics. The morphotectonic indices computed to substantiate the role of active tectonics in research area have been briefly discussed below. The channel morphology, the fluvial processes and the hydrological characteristics of a River are significantly influenced by the tectonic deformation processes. During the course of study significant water channels, namely the Ravi, the Ujh the Basantar with their tributaries namely the Sahaar stream and the Tarnah stream have been examined in detail to identify the signatures of presence of active tectonic control in the area of the investigation.

Morphometric analysis of the streams was carried out on the basis of lineament analysis and anomalous stream offsets. The vector layer for lineament was digitized. The linear element has resulted in stream offsets along all the streams that cross its surface trace. The stream offset (L1) for the Basantar River is 2000 m, stream offset (L2) for the Tarnah stream is 2000 m, stream offset (L3) for the Ujh River is 2000 m, stream offset (L4) for the Sahaar stream is 2000 m and stream offset (L5) for the Ravi River is 2000 m (**Figure 4**). The tectonic morphometric analysis for stream offsets L1 to L5 is being carried out and the tectonomorphometric indices namely stream length gradient index (*SL*), stream sinuosity index (*S*), mountain front sinuosity index (*S_{mt}*), basin asymmetry ratio (*AF*), basin elongation ratio (*Eb*), valley floor width to valley height ratio (*V_f*) and hypsometric integral (Hi) for all the River segments viz. Basantar (1), Tarnah (2), Ujh (3), Sahaar (4) and Ravi (5) have been computed.

5.1. Stream Sinuosity Index (S)

The Stream Sinuosity index helps in understanding the affect of tectonic character of the terrain on the River course. It is defined as the ratio of the channel length (*C*) to the valley length (*V*) *i.e.* S = C/V by [38] [42]. The *S* value more than 1.5 indicates the sinuous course. The *S* values for the Basantar River, the Tarnah stream, the Ujh River and the Sahaar stream and the Ravi River are 1.54, 1.714, 1.928 and 1.545 & 1.868 respectively. High *S* values indicate that the terrain is tectonically active.

5.2. Stream Length Gradient Index (SL)

The Stream Length Gradient Index (*SL*) is the rate of change of slope and provides a quantitative measure of tectonic activity or quiescence in a basin [43]. Mathematically, it is defined as, $SL = \Delta H \cdot L / \Delta L$, where ΔH is the change in elevation of the stream flow in the active segment and ΔL is the length of the active segment and *L* is the length of stream from its origin to the active segment. High *SL* values are indicative of high rates of tectonic uplift. *SL* values for the Basantar River, the Tarnah stream, the Ujh River, the Sahaar stream and the Ravi River (**Figure 6**) are 345, 144, 510, 221 and 183 respectively which are high and indicate tectonically active nature of the terrain.

5.3. Valley Floor Width to Valley Height Ratio (V_f)

The Valley Floor Width to Valley Height Ratio (V_t) was defined by [44] and later by [45] as $V_f = 2 V_{fw} / [(E_{ld} - E_{sc}/E_{rd} - E_{sc})]$, where V_{fw} is the width of the valley



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Figure 6. Longitudinal profile (——) and Stream Length gradient index (------) of River segments ((a) Basantar River, (b) Tarnah stream, (c) Ujh River, (d) Sahaar stream and (e) Ravi River). The peak SL index values are sensitive to the sudden change in elevation of the longitudinal profile which indicates the trace of active fault.

floor, E_{Id} is the maximum elevation to the left side of the defected segment, E_{rd} is the maximum elevation to the right side and E_{sc} is the elevation of valley floor at the deflected segment. This is a useful index that measures effectiveness of stream down cutting in response to the tectonic uplift [44]. When calculating V_f these parameters are measured at a set distance from the mountain front for every valley studied. It helps to discriminate between broad, flat floored canyons (with high values of V_f as > 1) with major lateral erosion in response to base level stability or tectonic quiescence, from the *V*-shaped valleys (with relatively low values of V_f as < 1) formed as a result of active down cutting in response to tectonic uplift. High values are reflective of low tectonic activity whereas low values are associated with tectonically active areas undergoing rapid uplift and valleys incision [45]. The V_f for the Basantar River is 0.359; for the Tarnah stream is 0.750; for the Ujh River is 0.941; for the Sahaar stream is 0.739 and for the Ravi River 0.121. Low V_f values varying from 0.121 to 0.941 indicate that the terrain is tectonically active.

5.4. Mountain Front Sinuosity Index (S_{mf})

Mountain Front Sinuosity Index is a reconnaissance tool to identify areas of tectonic activity. It is defined as the ratio of length of the mountain front (L_{ml}) along foot of the mountain at the pronounced break of slope to the straight line length (L_s) of the mountain front. *i.e.* $S_{mf} = L_{ml}/L_s$. The S_{mf} reflects the balance between erosion producing irregular/sinuous fronts and tectonic forces creating straight mountain fronts. Tectonically active mountain fronts have S_{mf} less than 1.4as given by [46]. Mountain front with lesser activity, but still reflecting active tectonics have S_{mf} value between 1.4 and 3, whereas S_{mf} values more than 3 reflects inactive mountain fronts [45]. The S_{mf} value for the hill ranges along the Basantar River is 1.58; along the Tarnah stream is 1.453; along the Ujh River is 1.216; along the Sahaar stream is 1.550 and hills bordering along the Ravi River is 1.6. The S_{mf} values along all localities are less than 1.6 that indicates the terrain is tectonically active.

5.5. Drainage Basin Asymmetry Factor (AF)

Drainage basin asymmetry analysis helps in finding out the neotectonic activity in an area. Drainage basin asymmetry has been used as a tool to identify quaternary tilting [47]. The Asymmetry Factor is a qualitative index that helps in evaluating basin asymmetry. It is defined as the AF = Ar/At, where Ar is the total area along the right side of the stream and At is the total area of the basin. In a stable environment AF is 50, whereas the value more or less suggests the tilt in the basin that represents neotectonic activity [43]. The values of AF for Basantar, Tarnah, Sahaar and Ravi Rivers are 34.3, 45.56, 44, and 22.34 respectively indicating the tilt towards right, whereas AF for Ujh River is 65.54 reflecting terrain tilting in left direction.

5.6. Hypsometric Integral (Hi)

The Hypsometric integral is defined as the distribution of different elevations across a landscape that can be evaluated over a small area to a large area extending from a single drainage basin to the entire surface of the earth. Mathematically it is defined as [(mean elevation-minimum elevation)/(maximum elevation-minimum elevation)]. Hypsometric analysis is a powerful tool for differentiating tectonically active from inactive regions. High Hi values are associated with higher rates of tectonic activity and linear range fronts [44] [48]. Hypsometric integral value for the Basantar River is 0.421, for the Tarnah stream is 0.395, for the Ujh River is 0.415, for the Sahaar stream is 0.400 and for the Ravi River is 0.421 indicating that the terrain is tectonically active.

5.7. Basin Elongation Ratio (Eb)

The Basin elongation ratio is one of the proxy indicators of neotectonic activity [44]. [49] defined the basin elongation ratio as the ratio of diameter of a circle having the same area (*A*) as the basin to the maximum length (*L*) of the basin. Mathematically, it is defined as $Eb = [(2A/\pi)/1/2]/L$. The *Eb* values below 0.50, in between 0.50 and 0.750 and more than 0.750 are characteristics of tectonically active, slightly active and inactive terrain settings respectively. The *Eb* value for the Basantar River is 0.460, for the Tarnah stream is 0.478, for the Ujh River is 0.354, for the Sahaar stream is 0.579 and for the Ravi River is 0.380. According to [50] the basin with *Eb* < 0.600 is tectonically active. The *Eb* value for each region

is low varying from 0.354 to 0.579 indicating tectonically active nature of the terrain.

5.8. Knick Points

All channels viz. the Basantar River, the Tarnah stream, the Ujh River, the Sahaar stream and the Ravi River have knick points along the River segments where the fault is crossing these channels (**Figure 7**). Along the knick points in the longitudinal River segment there is sudden change in the profile of the Rivers. This break in slope in a graded profile represents the trace of the active tectonic activity.



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Figure 7. Longitudinal profile of River segments showing knick points where the trace of active fault crosses the channels ((a) Basantar River, (b) Tarnah stream, (c) Ujh River, (d) Sahaar stream and (e) Ravi River)

6. Discussion

The Samba and the Kathua ditricts of Jammu and Kashmir are densely populated. Majority of the rural folk live in the non-masonary structures. Majority of such structures are built on the hill slopes and are vulnerable to seismic shaking. The Kangra earthquake (1905) and the Uri-Muzzfrabad earthquake (2005) caused considerable damage to life and property in this region. Identification of active faults is a significant parameter in assessing the seismotectonics of a region. It is in this context that the region between the Basantar and the Ravi Rivers is being closely examined to identify active faults on the basis of tectonic morphometric indices and field studies. The values of the various indices viz. stream sinuosity (S), stream length gradient index (*SL*), valley floor width to valley height ratio (V_d), mountain front sinuosity index (S_{md}), hypsometry index (Hi), drainage basin asymmetry factor (*AF*) and basin elongation ratio (*Eb*) reveal active tectonic character of the terrain.

7. Conclusion

The terrain between the Basantar River and the Ravi River has been closely examined. The tectonic morphometric indices along the Ravi River, the Sahaar stream, the Ujh River, the Tarnah stream and the Basantar River are indicative of active tectonic setup of the terrain. The field observations in conjunction with remote sensing investigations of the study area reveal the presence of an active sinistral strike slip fault which is named as Goran Fault. This fault has a surface expression of around 100 km and it is a significant seismo-tectonic element which needs to be taken into account considering the seismically active nature of the frontal Himalayan terrain of the Kashmir Himalaya. Future studies should consider a comprehensive subsurface investigation by appropriate geophysical techniques to identify and characterize the tectonic setup of the populated Himalayan foothills.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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