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Stream Length Gradient Index (SL Index) to Longitudinal Profile of Rispna River in the Front of Lesser Himalaya, India

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Abstract

Geologists and geomorphologists have employed various morphometric methods, techniques, and indices to study landform evolution, their origin, and spatial distribution. One of the widely used morphometric methods for the qualitative interpretation of slope–length gradient and drainage char-acteristics of rivers was proposed by Hack [1,2]. The present study applies the SL Index to analyse the morphotectonic framework of the Rispana River, located in the Dehradun district of the Garhwal Himalaya, India. The methodology is based on a high-resolution Digital Terrain Model (DTM) gen-erated from 1:50,000 scale Survey of India topographic sheets with 20 m contour intervals. On the basis of slope elements, the longitudinal profile of the river was divided into 14 segments. SL Index values were calculated for each segment and represented through tabular and graphical methods to identify spatial anomalies along the river course. The SL Index values range from 1 to 11.48. Out of the 14 segments, three exhibit first-order anomalies, seven show second-order anomalies, and the remaining four segments display no detectable anomalies. High SL values (11.00, 11.44, and 11.48) are associated with structurally resistant lithologies such as quartzite and dolomite, steep gradients due to tectonic uplift, and the presence of waterfalls and knickpoints. The SL Index shows an abrupt decline at segment 11 and subsequently fluctuates within moderate values (≈2–4), indicating gentler slopes and uniform sediment deposition in the downstream reaches within the Doon Valley. A dis-tinct contrast is observed between the two physiographic regions—the mountainous terrain and the Doon Valley Plain. The SL Index is consistently higher in the Lesser Himalayan zone and lower in the Doon Valley Plain. The application of the Hack Index proves to be highly effective for the geo-morphic analysis of Himalayan rivers, particularly in understanding the influence of lithology, tec-tonic control, and slope gradient.

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Introduction

Geologists and geographers have employed various morphometric methods, techniques, and indices to study landform evolution, their origin (genesis), spatial distribution, and to scien-tifically interpret the influence of structural, lithological, and tectonic controls in a given region. Morphometric methods refer to the quantitative analysis of landforms. This includes measuring aspects such as slope, elevation, drainage patterns, and basin shapes using tools like topographic maps, remote sensing data, and GIS (Geographic Information Systems).

The extensive application of statistical methods to analyze drainage basin characteristics gained momentum following the publication of Horton's seminal research in 1933. Since then, numerous geologists and geomorphologists have made significant contributions to var-ious aspects of relief and drainage basin morphometry. Notable among them are, among others [3-10]. Some of the morphometric methods are very useful and applied in geomor-phological studies using remote sensing and GIS techniques. One of the popular methods for the interpretation of slope length gradient of the river was initially proposed by Hack [1,2].

Recently, Montoeiro et al., applied the Hack Stream Length-Gradient (SL) Index to assess the geomorphic characteristics of the Tracunhaém River watershed, located in Pernambuco, Brazil [11]. In a similar context, Magar and Magar utilized the SL Index to analyze the lon-gitudinal profiles of rivers traversing the Satpura-Purna plain in Western Vidarbha, Maha-rashtra, India [12].

Several related geomorphic studies commonly carried out by various workers to describe SL index, tectonic deformation of an area, sinuosity index, valley floor width to height ration, basin asymmetry factor, stream lent gradient index Hack and hypsometric integral [9,13-18].

Hack's Law establishes an empirical relationship between the longitudinal slope of a river and the areal extent of its watershed, which can be indicative of geomorphic equilibrium. This relationship is quantitatively assessed using the Stream Length-Gradient Index (SL In-dex), a metric employed to analyze variations in stream gradients and identify potential zones of tectonic activity or disequilibrium within the fluvial system.

The Hack Stream Length (SL) index facilitates the identification of stream segments, sec-tions, or reaches that exhibit anomalous characteristics. Anomalies within river channels may arise due to various geomorphological and anthropogenic factors, including fluvial ero-sion, sediment deposition, tectonic deformation, and human-induced modifications. These influences can result in significant alterations to the channel's longitudinal profile, slope gradient, morphological structure, and hydraulic flow dynamics.

Based on the original methodology, the application of this geomorphic index facilitates the identification of anomalous segments within fluvial systems. These anomalies are character-ized by deviations in index values, which vary in response to the river incising through het-erogeneous lithological units and structural frameworks, each exhibiting distinct erosional resistances. In regions underlain by lithologically homogeneous substrates, detected anoma-lies are typically attributed to tectonic reactivation or neo-tectonic processes that postdate the establishment of the drainage network.

This approach has been widely employed to substantiate interpretations of differential ero-sion and to assess the influence of lithological heterogeneity and structural lineaments on drainage morphology. Furthermore, it has proven instrumental in delineating zones of active tectonic deformation within river channel systems [11,19].

In accordance with this framework, the present study focuses on the identification and spa-tial distribution of geomorphic anomalies within the Rispna River watershed at the fringe of Lesser Himalaya and Siwalik Ranges of Garhwal Himalaya.

Study Area

Rispna River is a tributary stream of the Song River, which in turn is a tributary of the Gan-ga River in the eastern Doon valley of Dehra Dun, Grhwal Himalaya, India (Fig. 1). It origi-nates from the Mussoorie hill of the Lesser Himalaya at an elevation of 2,296m and joins the Song River at a height of 575m near Mothorawala village. The river is confined between latitudes 30° 14' 20" to 30° 27' 40" N and longitudes 78° 01' 13" to 78° 6' 28" E, covering an area of about 57 square km. The river flows from north to south and has a relative height of 1,722m. Its average gradient is about 61m/km, varying from 177m/km in the hills to 20m/km in the Doon plain.

The area under investigation lies between the Lesser Himalayan Range in the north and the Siwalik Range in the south. The Lesser Himalayan slope abruptly descends towards the south within 12.54 km towards the mountain-Doon Junction. Thus, the whole Rispna River area is divided into two major geomorphic units, i.e., the Lesser Himalayan hilly zone (900m to 2296m) and the Doon fan deposit plain (575m to 900m). Morphometric characteristics of the Rispna River Basin are given in Table 1.

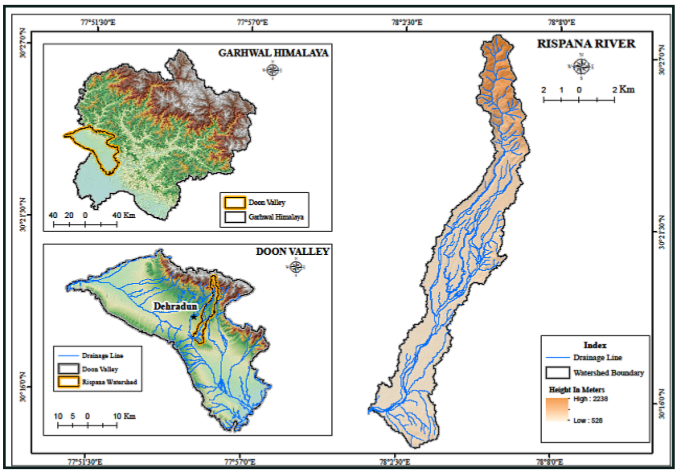

Figure 1: Geographical location of the Rispna River in Dehradun District, Garhwal Hima-laya

Table 1: Morphometric Characteristics of the Rispna River Basin

S.N.	Morph metric Properties	Rispna River
1	Source elevation (h1) in m	2296
2	Confluence elevation (h2) in m	575
3	Elevation difference ΔH in m	1721
4	Total stream length in km	30.54
5	Mountain zone length (source to mountain front) in km	11.54
6	Doon plain length (mountain front to confluence) in km	19.0
7	Percentage length (mountain zone)	37.79
8	Percentage length (Doon valley zone)	62.21
9	Total drainage basin area (Km2)	57.0
10	Basin area in mountain (Km2)	12.02
11	Basin area in Doon Valley (Km2)	44.98
12	Ratio of mountain basin area and piedmont basin area	0.27
13	Gradient in mountain zone	120m/km
14	Gradient in Doon valley zone	17m/km
15	Average gradient of the river	56.35m/km

Geology

The Main Boundary Thrust (MBT) represents a significant tectonic discontinuity delineat-ing the contact between the Lesser Himalayan sequence and the Doon Valley. It extends in a NW–SE orientation across the region. Distinct structural configurations, physiographic zones, and drainage patterns are prominently discernible in the Digital Terrain Model (DTM) of the study area (Fig. 2).

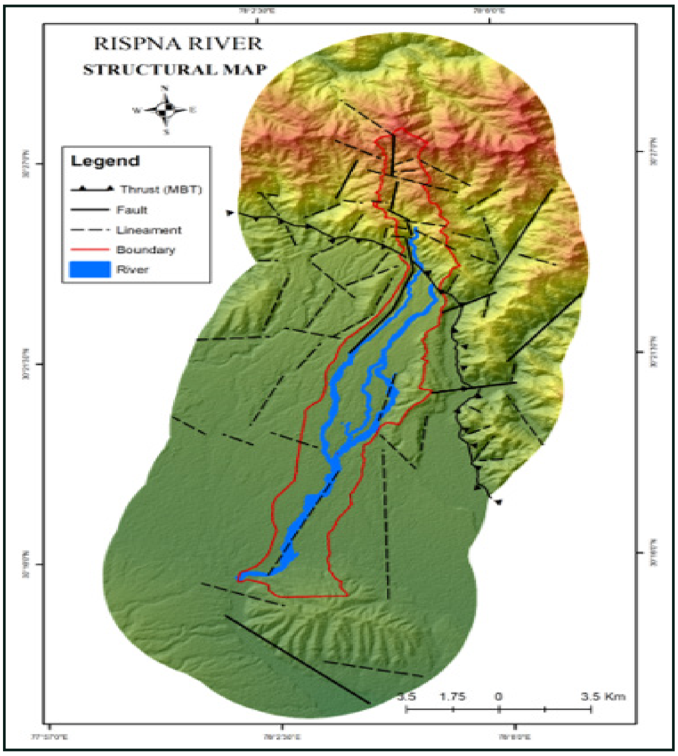

Figure 2: Digital terrain model showing the structural and topographic setting of the study area

North of MBT, the Lesser Himalayan unit is mainly composed of five lithological for-mations (Fig. 3): Tal quartzite, Tal slate/conglomerate, Krol limestone, Bilani rocks, Nag-that quartzite, and Chandpur phyllite. These formations primarily include argillite, phyllite, quartzite, carbonate, and slate [20,21].

Doon is a synclinal longitudinal valley situated between the Lesser Himalaya in the north and the Outer Himalaya (Siwalik) in the south. The geomorphic evolution of the Doon Val-ley involved multiple tectonic episodes, erosional and depositional phases, and continuous regulation by climatic changes [22]. Fan deposits in the Doon Valley are mainly composed of boulders, cobbles, pebbles, and gravels with a sandy and silty matrix Singh et al. (2001) described the detailed stratigraphic sequences of the sedimentary fill in the Dehra Dun fan [23]. Isolated hills, proximal fan, and distal fan plain are the three major sedimentary units in the Doon Valley. The study area experiences monsoon rainfall between the months of June and September. About 90% of the rainfall occurs in the summer season. There is a vast variation in the distribution of rainfall, with higher rainfall in the Mussoorie hills and lower rainfall in the south over the Doon plain.

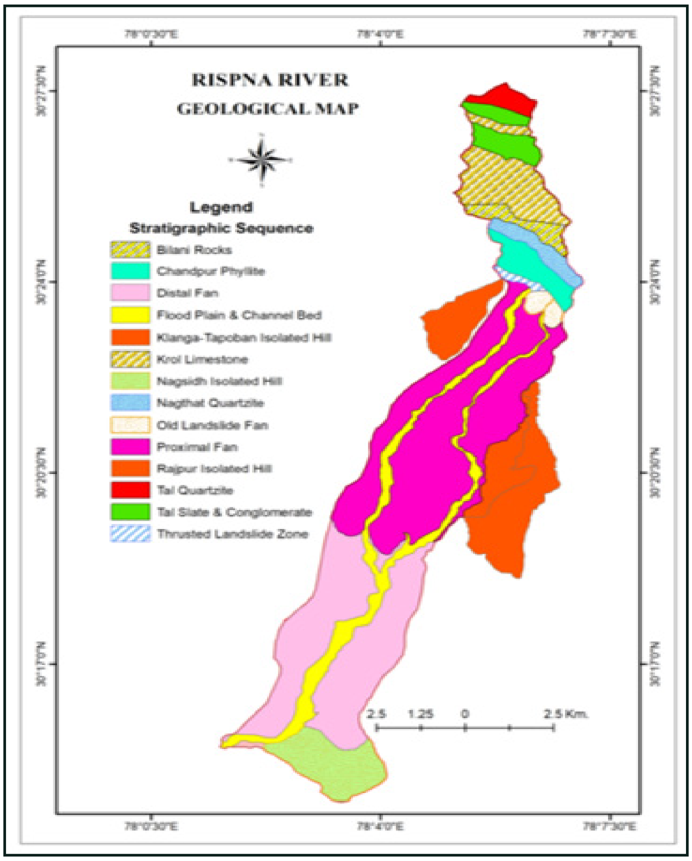

Figure 3: Geological setting and major lithological units of the study area

Methods of Study

In this study, the SL Index is used to analyse morphometric anomalies along the longitudinal profile of the Rispna River and to examine its correlation with controlling factors such as lithology and tectonics.
The method applicable for the following formula:
$SL = (\Delta H/\Delta L).L$
Where; $\Delta H = (h1 - h2)$ the difference between the highest and the lowest points of a channel segment and ΔL = Horizontal distance of the given segment of the channel
L= Total length of the channel from source to the far-

thest point of given channel segment.

This formula may be better understanding in the scheme below-

$SL_{segment} = (\Delta H/\Delta L).\ L$ ------------- (i)

$SL_{total} = (\Delta H/\Delta L).\ \text{in}\ L$ ------------ (ii)

Ratio Index = $SL_{segment} / SL_{total}$

This index can be used to identify areas of topographic breaks, Knick points, waterfall, me-ander and other features along a river. If the SL index obtained is less than 2, there are no anomalies in the channel profile or segments, the channel segment is not steep and longitu-dinal profile considered graded. When the index is equal to or exceeds 10, a first-order anomaly in stream segment is defined that is very steep. Additionally, when the index falls between 2 and 10, a second-order anomaly is identified the channel is moderately steep.

Results and Discussion

Longitudinal Profile and Geomorphic Control of the Rispna River

The longitudinal profile of the Rispna River was delineated and employed for the computa-tion of the Stream Length-Gradient (SL) index. This analysis was conducted using the Sur-vey of India topographic sheet 53J/3, at a 1:50,000 scale. Based on channel slope and topo-graphic parameters, the river profile was stratified into three geomorphologically distinct reaches: the upper hilly zone, the middle piedmont slope, and the lower Doon fan plain. Each reach was further subdivided into 14 segments, for which morphometric parameters were quantitatively assessed and tabulated in Table 2.

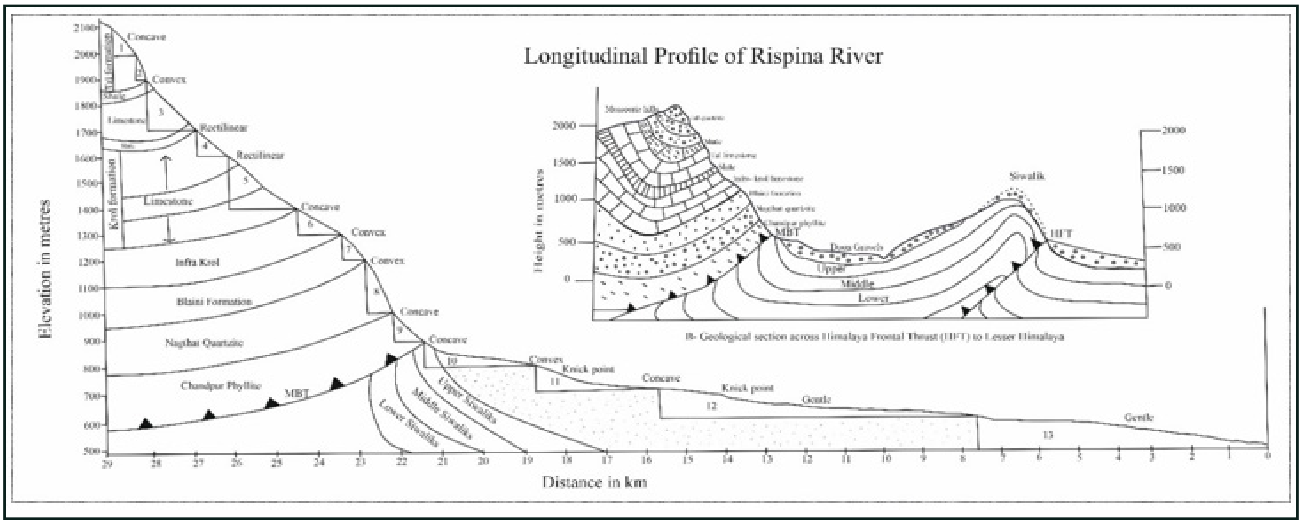

Figure 4: Longitudinal profile of the Rispina River illustrating variations in elevation, slope mor-phology (concave, convex, and rectilinear segments), knickpoints, and associated geological for-mations from the Lesser Himalaya to the Siwalik region across the Himalayan frontal zone.

To evaluate spatial variations in channel gradient, SL index values were computed and visu-alized through graphical representations (Fig. 5 and 6), enabling the identification of geo-morphic anomalies. Additionally, SL channel and SL total ratios were analyzed to determine whether the river segments exhibit graded or ungraded morphometric profiles.

Overall, reach-wise index values were calculated as 1.16 for the upper reach, 2.49 for the middle reach, and 1.26 for the lower reach. The middle reach exhibits a second-order anom-aly, whereas the upper and lower reaches show no anomalies. The average value of the SL index for all 14 segments is calculated as 4.53.

Although the upper reach yields an SL index of 1.16—typically representative of a graded, low-relief profile—field observations and slope characteristics reveal localized steep seg-ments, indicative of geomorphic anomalies. This discrepancy arises due to the equivalence of the horizontal channel length (ΔL) and the total channel length (L), which inherently con-strains the SL index to a value of one, potentially masking actual topographic variations.

Table 2: Channel segment wise slope features, SL Indexes and SL ratio index along the Longitudinal profile of the Rispna River

Elevation in m	Slope Feature	Lithology	Segment	SL Index		SL Index
				$SL_{channel}$	SL_{total}	$SL_{channel}/SL_{total}$
>2100	Ridge	Tal Quartzite	1	0.490	0.490	1.00
2000-2100	Convex	Tal Quartzite	2	0.200	0.143	1.399
1800-2000	Steep	Tal Quartzite	3	0.357	0.111	3.216
1600-1800	Concave	Tal Slate	4	0.167	0.091	1.835
1500-1600	Concave	Krol Limes.	5	0.125	0.033	3.789
1400-1500	State	Tal Slate	6	0.125	0.043	2.907
1200-1400	Concave	Infra Krol	7	0.091	0.017	5.353
1100-1200	Convex	Bliani Rocks	8	0.167	0.016	10.437
1000-1100	V Steep	Nagthat Qur.	9	0.333	0.029	11.483
900- 1000	Concave	Ch. Phyllite	10	0.143	0.013	11.000
----------------------------------- Main Boundary Thrust (MBT) --------------------------------						
800-900	Pediment Slope	Doon gravel fan	11	0.037	0.010	3.700
700-800	Concave slope	Proximal fan	12	0.032	0.007	4.571
600-700	Plain surface	Distal fan	13	0.012	0.005	2.400
<600	Lower plain	Distal fan	14	0.003	0.009	3.333

Table 3: Classification of SL Index with Associated Anomalies, Slope, and Channel Profile Characteristics

SL Index	Anomaly	No of Segment	Slope	Nature of profile
Less than 2	No anomalies	4	Gentle slope	Graded profile
2 - 10	2nd order anomalies	7	Moderately steep	Moderate gradient profile
Above 10	1st order anomalies	3	Very steep	Steep gradient profile

The results indicate that, out of a total of 14 segments, 3 segments exhibit first-order anoma-lies, while 7 segments exhibit second-order anomalies. The remaining 4 segments show no detectable anomalies.

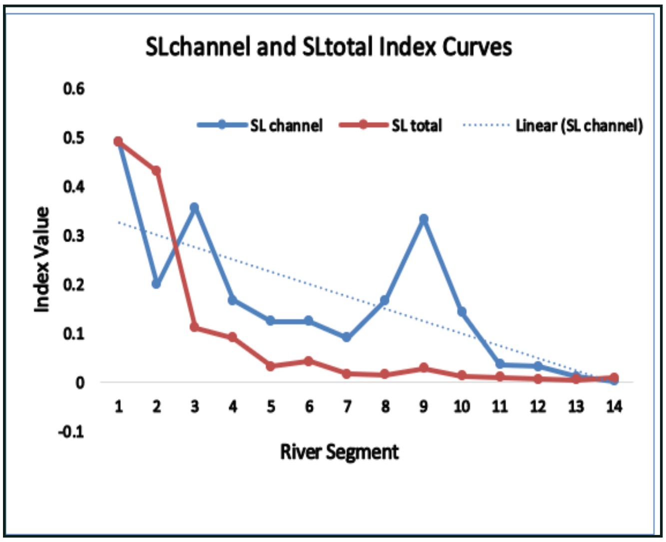

Figure 5: Graphical representation of SLchannel and SLtotal Index Curves

Figure 5 presents a comparative analysis of two indices along the river, which has been di-vided into 14 segments. The SL channel index (blue line) represents values calculated spe-cifically for the river channel, whereas the SL total index (orange line) incorporates broader geomorphic and tectonic influences beyond the channel itself. The dotted blue line is a line-ar trend line for the SL channel values.

Interpretation of SLchannel and SLtotal Index

Both SL channel and SL total indices exhibit an overall decreasing downstream trend, with higher values in the upstream segments (1–3) that progressively decline toward segment 14 (Fig. 5). This pattern indicates a reduction in river energy, channel slope, and geomorphic influence in the downstream direction. The SL channel (blue line) shows high initial values at segment 1 followed by fluctuations, with prominent local peaks around segments 3 and 9. These peaks suggest the presence of steeper gradients, knickpoints, waterfalls, or possible structural and lithological controls. Beyond segment 10, SL channel values decline sharply and approach zero, reflecting a low-energy downstream reach. The fitted trend line confirms an overall negative trend despite localized variability.

The SL total (orange line) displays very high values in segments 1–2, followed by a rapid decline by segments 3–4. From segment 5 onward, values remain consistently low and sta-ble, close to zero, indicating that broader basin-scale influences are dominant in the up-stream reaches but become negligible downstream.

The graph shows a river system that it has high energy and strong geomorphic influence up-stream, experiences localized disturbances or controls in the middle reaches and becomes progressively more stable and low-energy downstream.

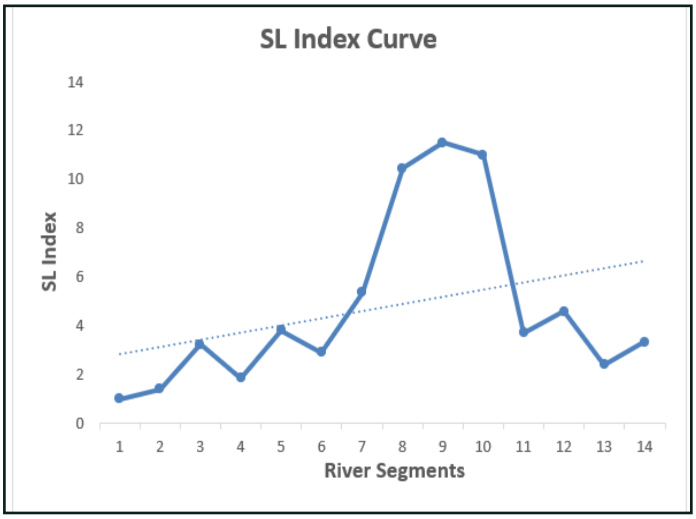

Figure 6: Graphical representation of the ratio between SL channel and SL total index curves

The graph (Fig. 6) titled "SL Index Curve" shows how the SL Index changes across differ-ent river segments. X-axis (River Segments): Numbered from 1 to 14, representing con-secutive sections of a river. Y-axis (SL Index): The Stream Length–Gradient (SL) Index, which is commonly used in geomorphology to indicate changes in river slope and possible tectonic or lithological controls.

Interpretation SL Index

The SL Index values are relatively low (around 1–6) with small fluctuations. This suggests a gentle and stable river gradient in the upstream sections. There is a sharp increase, with SL Index values rising rapidly and peaking around segments 8–10 (maximum ≈ 11–12). This indicates a zone of steep gradient or high energy, because of tectonic uplift, knickpoints, wa-ter fall and resistant rock layers (Fig.4a). The SL Index drops abruptly at segment 11 and then fluctuates at moderate values (≈ 2–4). This suggests a return to gentler slopes or more uniform geological conditions downstream. The dotted upward-sloping trend line represents the overall trend. It shows a general increase in SL Index downstream, despite local peaks and drops. This implies that, on average, the river gradient or erosional energy increases along the studied reach.

The river shows localized anomalies (especially around segments 8–10) rather than a smooth progression. These anomalies likely mark geomorphologically significant zones, such as tec-tonic activity, lithological changes, or major waterfalls and knickpoints. The graph high-lights how SL Index is useful for identifying non-uniform river behavior along its course.

Discussion

The longitudinal profile of the Rispna River demonstrates pronounced geomorphological variability and distinct changes in channel gradient as it transitions across the Lesser Hima-layan litho-tectonic zone, the piedmont tract, and the Doon gravel plain of the Doon Valley. Approximately 38% of the river's total length is confined to the rugged, tectonically active terrain of the Lesser Himalaya, while the remaining 62% traverses the intermontane Doon Valley.

Within the Lesser Himalayan domain, particularly across the Mussoorie Group of rocks, the river exhibits a markedly high channel gradient, averaging approximately 117 m/km. This reach is characterized by steep, structurally controlled slopes, deeply incised V-shaped val-leys, and a high-energy fluvial regime. Upon breaching the Main Boundary Thrust (MBT)—a major tectonic discontinuity separating the Lesser Himalaya from the Sub-Himalayan Zone—the river enters the tectonically uplifted piedmont zone and subsequently the Doon fan gravelly alluvial plain, where the gradient attenuates significantly to an average of 17 m/km.

The longitudinal profile analysis reveals high stream power and pronounced geomorphic ac-tivity in the upstream reaches, reflecting strong tectonic and lithological controls. The mid-dle segments exhibit localized perturbations, likely associated with structural discontinui-ties, knickpoints, or litho-structural variations. In contrast, the downstream reaches display comparatively stable channel conditions and reduced energy gradients, indicating a transi-tion towards a more mature fluvial regime.

An increase in channel steepness coupled with a decrease in horizontal length results in ele-vated SL index values, signifying anomalous channel behavior. Such anomalies are indica-tive of active tectonic deformation and differential lithological resistance.

A distinct geo-morphic contrast is evident between the two physiographic units—the Lesser Himalayan mountainous terrain and the Doon Valley Plain. Higher SL index values in the Lesser Hima-layan zone reflect active uplift and structural control, whereas lower values in the Doon Val-ley Plain suggest tectonic quiescence and depositional dominance.

The application of Hack's Stream Length–Gradient (SL) Index has proven to be an effective quantitative tool for detecting geomorphic anomalies and assessing tectonic influence in Himalayan river systems. Therefore, the SL index is a valuable parameter for addressing ge-omorphological problems across varying slope gradients, geological frameworks, and tec-tonic settings in the Himalayan region.

The upper (mountainous) reach of the Rispna River is geomorphologically dynamic, defined by high relief, entrenched channels, active headward erosion on shale and limestone (Fig. 7), and intense chemical weathering of limestone rocks. The fluvial system in this sector is competent, with turbulent flow regimes capable of transporting coarse bed load sediments. Several prominent waterfalls (5-8 m in height) and knickpoints—indicative of episodic base level changes and lithological or tectonic controls—punctuate the river's profile in this reach. Notable features include Mausi Fall, Jharipani Fall, and Shikhar Fall (Fig. 8, 9 and 10). As the river exits the mountain front and transitions into the piedmont fan zone, a marked reduction in stream power and transport capacity occurs, resulting in the formation of depositional features and accentuating existing knick points within the pediment fan sur-face.

The headwaters of the river are sustained by perennial discharge sourced from spring-fed systems, particularly in structurally fractured and weathered bedrock zones. However, down-stream of the mountain front, upon entering the semi-consolidated gravelly fan deposits of the Doon Valley, the river becomes ephemeral to intermittent due to high infiltration rates and anthropogenic water diversion for agricultural irrigation. Consequently, the Rispna Riv-er displays a seasonal hydrological regime across the Doon Valley, with peak discharge con-fined primarily to the monsoonal period (July to October), consistent with regional precipi-tation patterns.

The Rispna River traverses a north-south trending transverse fault, intersecting the MBT near Rajpur. This structural interaction has led to significant alluvial fan development and the presence of active landslide features along the mountain front, indicating recent and on-going tectonic activity. The noticeable deflection in the drainage pattern in the frontal part of the MBT provides further evidence of strong structural control on river morphology.

At the MBT crossing, the river exhibits a hogback feature, where the Rispna has captured the Nalapani Rao, suggesting an active and dynamic fluvial-structural interaction. As the Rispna River flows across the Doon Valley, from the mountain front to its confluence, it in-cises through various fan deposit zones, including isolated fans, proximal fans, and distal fan surfaces (Fig. 3), resulting in the formation of distinct river terraces [24].

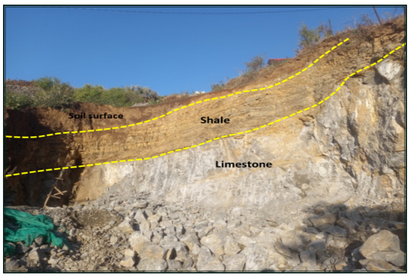

Figure 7: Lithological contact between Tal Limestone and Shale exposed in the uppermost segment of the Rispna River.

Between the altitudinal range of 1700 m to 2000 m, the river profile transitions to a slightly concave to rectilinear form (Fig.4). The average gradient in this zone is approximately 100 m/km. Segments 3, 4 and 5 falls within this altitudinal zone of 1700 – 1900m and are char-acterized by exposures of the Infra-Krol and Tal Slate Formations. The Infra-Krol Group is a thick sequence of carbonate rocks interbedded with shale, slate, and sandstone. Owing to the relatively high porosity of these lithologies, degradation processes dominate by chemical weathering, contributing to the concave nature of the river profile in this reach. The SL in-dex values for these segments range from 1.84 to 3.79, again reflecting second-order anoma-lies (Table 3 and Fig. 4). Key locations within this segment include Barloganj, Khetwal Vil-lage, and the St. George's College area. A prominent geomorphological feature in this sec-tion is the Mossy Waterfall (7m height), which represents a major knick point along the river channel.

Below Company Garden village, within the elevation range of 900 to 1400 meters, the Risp-na River flows through a narrow and deep faulted gorge characterized by multiple knick-points and waterfall. Among these features, several 1to 2-m high rapids are observed along the river channel. Based on the tabulated data and the associated graphs, it is possible to identify anomalous sections along the entire course of the Rispna River.

Segments 8, 9, and 10 exhibits the highest Stream Length-gradient (SL) index values—10.44, 11.48, and 11.00, respectively—indicating the presence of significant geomorphic anomalies. Notably, these high SL index values correspond with resistant litho logical units, including the Infra-Krol, Blaini Formation, Nagthat Quartzite, and the contact zone with Chandpur Phyllite (Fig. 4). The spatial distribution of SL index values, when overlaid on the lithological map of the study area clearly highlights these anomaly-prone zones. Evidence of high gradient and anomalous segment characteristics is observable in the waterfall diagram (Fig. 8-11).

The Blaini Formation comprises a sequence of rocks including diamictite units, siliciclastic sediments, argillite's, and pink microcrystalline dolomite [25]. This formation is structurally deformed by regional-scale folding and thrust faulting. It also includes lenticular diamictite bodies interbedded with shale, quartz arenite, and quartz wacke [26]. The Blaini Formation is overlain by black shales of the Infra Krol Formation. In segment 7, which lies within the Blaini Formation, the Stream Length-Gradient (SL) index was calculated to be 10.44, indi-cating the development of a convex longitudinal channel profile.

Figure 8: The figure shows a 7 m waterfall descend-

ing through a narrow rock gorge developed with-in the Blaini Rocks, composed of black shales of the Infra Krol Formation—a hard and resistant metamorphosed unit widely exposed in the Mussoorie hill belt (Segment 8). The waterfall is struc-turally controlled and geomorphologically significant.

Figure 9: The photograph shows an 8 m high, steep and narrow Jharipani cascade, where water falls almost vertically from a rocky cliff developed within Nagthat quartzite into a shallow pool below (Segment 9). The waterfall is surrounded by exposed rocky slopes and weathered cliff faces, indicat-ing active erosion in the Himalayan foothill terrain.

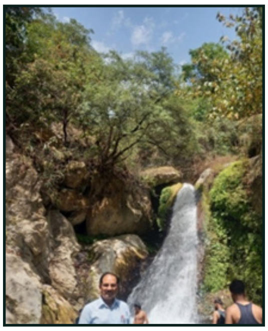

Figure 10: Shikhar Waterfall (approximately 6 m high) descends along a distinct lithological contact between quartzite and Chandpur phyllite, creating an excellent natural geological exposure. Shikhar Waterfall has strong potential as a geotourism destination because it combines scenic beauty with scientific importance.

Figure 11: Bedrock–boulder controlled rapid with plunge pool development in Segment 10 near Shekhar Fall, Rispna River

The Nagthat Formation is a Proterozoic sedimentary sequence in the Lesser Himalaya, con-sisting predominantly of quartzite, sandstone, conglomerate, and siltstone-shale alternations. The arenaceous facies of the Nagthat Formation display a range of primary sedimentary structures such as current bedding, ripple marks, and planar stratification, indicative of flu-vial to shallow marine depositional environments. Due to the mechanical strength of these lithologies and the influence of fault-controlled structural features, river channels in this segment exhibit steep gradients and entrenched courses. Consequently, a maximum Stream Length-Gradient (SL) index value of 11.48 has been calculated in this segment, indicating a high degree of channel profile anomaly and tectonic uplift.

The Chandpur Formation in the Lesser Himalaya, comprising primarily phyllites, is tectoni-cally juxtaposed against the Siwalik Group along the Main Boundary Thrust (MBT) (Fig. 4). In this region, Chandpur phyllites structurally override the younger Siwalik sediments [26]. The lithological composition includes orthoquartzite, sandstone, and slate. Along the MBT zone, phyllitic and slaty rocks exhibit intense cataclasis, mylonitization, and surface weath-ering. This structural disruption results in an abrupt transition in river longitudinal profiles, characterized by a pronounced concave-upward shape. The SL index for this segment is cal-culated to be 11, which corresponds to a first-order anomaly in the river channel, suggesting localized tectonic uplift or lithological control.

After crossing the Main Boundary Thrust (MBT), the river enters the piedmont zone, where its anomalous behaviour leads to a reduction in the Stream Length-Gradient Index (SL) val-ues, dropping from 11 to 3 and 4. All three segments within the Doon Valley exhibit SL val-ues greater than 2, indicating second-order anomalies. Among all segments along the longi-tudinal profile, only segment 14 has an SL value below 2, suggesting a graded profile with minimal or no tectonic or lithological disturbances.

From the Main Boundary Thrust (MBT) to the river mouth, the longitudinal river profile ex-hibits a graded nature, particularly within the lower reaches characterized by a very gentle slope across the piedmont zone and the Doon fan surface. In this segment, the river's longi-tudinal profile closely approximates a linear trend parallel to the horizontal axis, indicative of equilibrium conditions. The calculated Stream Length-Gradient (SL) index for this reach is approximately 1.25, which reflects a mature, graded profile devoid of significant geo-morphic or tectonic anomalies. Conversely, in the upper catchment—from the river's source to the MBT—the SL index increases markedly to approximately 3.56. This elevated value suggests an anomalous profile, likely influenced by active tectonic processes, lithologic var-iations, and may point to zones of heightened uplift, incision, and structural control.

Conclusion

The longitudinal profile analysis reveals high stream power and pronounced geomorphic ac-tivity in the upstream reaches, reflecting strong tectonic and lithological controls. The mid-dle segments exhibit localized perturbations, likely associated with structural discontinui-ties, knickpoints, or litho-structural variations. In contrast, the downstream reaches display comparatively stable channel conditions and reduced energy gradients, indicating a transi-tion towards a more mature fluvial regime.

An increase in channel steepness coupled with a decrease in horizontal length results in ele-vated SL index values, signifying anomalous channel behaviour. Such anomalies are indica-tive of active tectonic deformation and differential lithological resistance. A distinct geo-morphic contrast is evident between the two physiographic units—the Lesser Himalayan mountainous terrain and the Doon Valley Plain. Higher SL index values in the Lesser Hima-layan zone reflect active uplift and structural control, whereas lower values in the Doon Val-ley Plain suggest tectonic quiescence and depositional dominance.

The application of Hack's Stream Length–Gradient (SL) Index has proven to be an effective quantitative tool for detecting geomorphic anomalies and assessing tectonic influence in Himalayan river systems. Therefore, the SL index is a valuable parameter for addressing ge-omorphological problems across varying slope gradients, geological frameworks, and tec-tonic settings in the Himalayan region.

Geomorphic evidences of litho-stratigraphic control
Width and Height Ratio: The river valley floor width to valley height ratio is widely used to differentiate between broad-floored, mature, and tectonically active narrow V-shaped val-leys, which indicate relatively active rivers (Imsong 2019) [5,27]. The valley width to height ratio (Vf) is expressed as follows:
$Vf = 2\ Vfw\ [(Eld – Esc) + (Erd – Esc)]$,
Where Vf is the valley floor width to height ratio, Vfw is the width of the valley floor, Eld and Erd are elevation of the left valley divide and right valley divide and Esc is elevation of the valley floor.

For the present study, Rispna River Vf has been calculated at different places for analysis. It is found that the average Vf value of the Rispna River is lower. The low Vf value of the Rispna River indicates that it is tectonically active, following the path of a fault trending from north to south direction (Table 4).

Table 4: Geomorphic Evidence of Litho-Stratigraphic Control on the River

Parameter	Rispna River	Remark
Basin shape Index	12.22	Higher the index value shows tectonically active
Sinuosity index (SSI)	0.98	The SSI value 1 is indicates of straight faulted course.
Gradient Index (SL)	5.64	High & low values are used to ascertain tectonic stability and instability. High SL value showing the river traverses the fault line [28].
Elongation ratio ®	0.31	The lower the values of R, the more elongated shape of the basin.
Transverse topographic symmetry factor (T)	0.32	The low value of SSI to Rispna River corresponding to the transverse fault across MBT.

Basin Shape Index: Linear valleys are usually considered as geomorphic expressions of slip faults and thrusts. Fault and thrust zones are the weakest zones and erode easily. Streams are usually developed along these zones when structural blocks slip past each other (Burbank and Anderson 2001, Imsong 2019). The presence of a linear valley of the Rispna River from source to mouth can be interpreted as active tectonic activities along the transverse fault structure (Fig.2). The numerical value of the index (175) indicates that a simple deflection of the Rispna River along the fault creates a linear channel course. After the analysis of morpho-tectonics, it is considered that the linear valley of the Rispna River was created dur-ing the tectonic activities associated with the MBT, during which the development of paral-lel strike-slip splays in the south front Lesser Himalaya occurred (Imsong 2019).

Sinuosity Index (SSI): The sinuosity index (SSI) of a stream denotes the degree of deviation of its actual stream course (Singh and S 2010). It is used to differentiate between straight and sinuous or meandering river courses, which indicate tectonically active streams. The SSI value of 1.0 indicates a straight course, while index values between 1.0 and 1.5 indicate a sinuous course, and values above 1.5 represent a meandering course. The Rispna River from the MBT to the confluence of Nalapani Rao has an SSI of 0.98, indicating an approximately straight course indicating a sinuous nature of the course. The low values of SSI for the Risp-na River correspond to the transverse fault across the MBT.

Gradient Index: An average slope gradient of less than 1% is categorized as gentle, where-as values exceeding 4% are indicative of steep terrain. These gradient extremes are signifi-cant indicators of tectonic stability (low gradient) and instability (high gradient). Elevated Stream Length-Gradient (SL) index values suggest that the river is intersecting or aligned along fault zones. The calculated average slope gradient of the Rispna River exceeds 4%, implying that the river course is influenced by or traverses an underlying fault structure.

Elongation Ratio (R): The elongation ratio (R) is defined as the ratio of the diameter of a circle of the same area as the drainage basin to the maximum length of the basin [3]. The values of R vary from 0 to 1. Higher values of R (>0.7) indicate a more circular shape of the basin, while lower values (<0.5) indicate a more elongated and faulted shape. The elonga-tion ratio has been calculated for Rispna River. As the calculated value of elongation ratio is 0.31 Rispna rivers which is less than 0.7, thus the shape of h the river basin is more elongat-ed (<5). Low value of elongation ratio indicates that The Rispna River is flowing through N-S trending linear feature which is tectonically control.

Conclusion

The application of the Hack Index proves highly effective for the geomorphic analysis of Himalayan rivers, particularly in understanding the influence of lithology and tectonic con-trols. A clear contrast is observed between two physiographic regions—the mountainous ter-rain and the Doon Plain. The Stream Length-Gradient Index (SL) yields satisfactory results in distinguishing these zones.

The SL values also serve as reliable indicators of different stages of geomorphic evolution, consistent with the theories proposed by [29,30]. The geomorphology of Himalayan rivers and streams is significantly governed by lithological variations and tectonic activity, with notable anomalies present throughout their developmental stages [31-35].

In the present study of the Rispana River, the interaction between heterogeneous geological substrates and tectonic structures is clearly reflected in the drainage pattern. The analysis reveals that lithology significantly influences SL values across various river segments. Re-sistant lithologies such as Tal Quartzite, Nagthat Quartzite, Blaini Formation, and Chandpur Phyllite along the river course correspond to elevated SL values (greater than 10), indicating steep channel gradients and representing first order geomorphic anomalies. Conversely, as the river descends into the piedmont plain and across the Doon fan surface, the slope de-creases, resulting in lower SL values. These lower index values suggest a more mature geo-morphic stage with minimal or no anomalies.

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