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Application of Hack's Stream Gradient Index (SL Index) to Longitudinal Profiles of the Rivers Flowing Across Satpura-Purna Plain, Western Vidarbha, Maharashtra

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Abstract: *Longitudinal profile is an important morphometric property of the river, which indicates the ability of the river to adjust to topographic, tectonic, geologic and climatic conditions and these are not uniform throughout the course of the river. It provides a key element for understanding, explaining, quantifying and predicting the variations in river basin forms and processes. Main aim of this study is the application of Hack's Stream Gradient Index or SL Index to analyse the longitudinal profile of the rivers flowing across Satpura-Purna plain of western Vidarbha and to study the variation in SL values and its response to lithology and tectonics. The index is applied along the channels of nine rivers. The data used for the construction of longitudinal profiles and to compute SL index were obtained from Survey of India topographical maps of 1:50000 scale. The use of SL values permits comparison between different streams and also different reaches of the same river. All the rivers exhibit a concave profile. Analysis indicates that the longitudinal profiles are well controlled by tectonic activity along the Satpura piedmont zone and lithological differences with basalt forming the upper reaches and unconsolidated material of piedmont alluvial fans forming the lower reaches.*

Introduction

Longitudinal profiles are important elements in understanding the degree of adjustment of river systems to landform evolution and neotectonic activities of the region. A stream profile also adjusts to the geological structure and the climatic conditions which may not be uniform throughout the course of the river. The longitudinal profile is a curve obtained from the relationship between height and distance downstream of a channel, indicating the control of gradient on channel behaviour (Darton, 1950; Hack, 1957; Christofoletti, 1980, Martinez *et al.* 2011). Longitudinal profile parameters allows the morphometric characterisation of drainage network and provides the knowledge about geomorphological, hydrological and sedimentological factors that control the configuration and evolutionary history of a drainage basin. The stream gradient index proposed by Hack (1973) facilitates the identification of factors that control the drainage network such as occurrence of resistant rock, tectonic activity, changes in the local base level, tributary confluence, human interference etc. In this context, longitudinal profiles of rivers flowing across Satpura-Purna plain have been analysed by means of Hack's stream gradient index (SL Index) in order to determine the influence of lithology and tectonics. Hack (1973) attempted to determine whether a river is in morphological equilibrium on the basis of a relationship between channel slope and channel length which he referred to as Stream Length-Gradient Index (SL Index). The index is used to determine the effect of differential erosion, occurrence of lithological and structural control on the stream channel network. As regards the anomaly in SL index, Seeber and Gornitz (1983) computed the ratio of $SL_{channel}$ to SL_{total}. If the result obtained is less than 2, then there are no anomalies, while if the ratio obtained is inbetween 2 and 10, a 2nd order anomaly exists. When the result is equal to or exceeds 10, a 1st order anomaly is defined. This implies that where first order anomalies are found, stream channels are very steep. Second-order anomalies occur in sectors where stream channels are simply 'steep' and when the index ratio is less than 2, stream channel sectors are 'not steep' and the longitudinal profile is said to be graded.

Study area

The study area is a part of the Purna river basin — a major left bank tributary of the west flowing Tapi river. The area under investigation lies in the Tapi-Purna plain, between the Satpura range in the north and the west flowing Purna river in the south (Fig. 1). Elevation within the region ranges from 1016

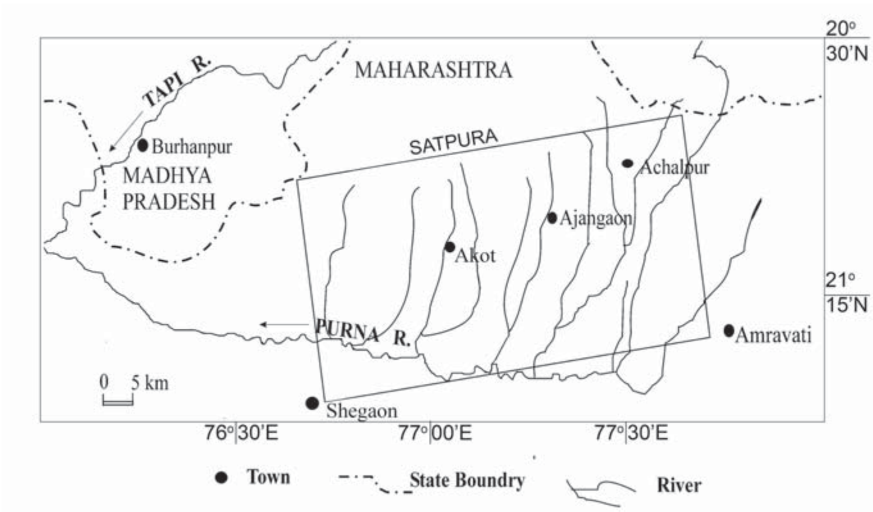

Figure 1. Location map of study area

m to 200 m. The Satpura range abruptly descends towards the south with a drop of 500–600 m within a distance of 4 to 5 km towards the mountain-piedmont junction (Dikshit, 1986). On the basis of relief and slope characteristics, the whole study area is divided into three geomorphic divisions (Fig. 2) — the high relief zone (1100m to 400m), the piedmont zone (400 m to 300 m) and the alluvial fan plain (300 m to 200 m).

The entire area is underlain by basalt rock of Cretaceous-Eocene age. The Purna valley is tectonically active (Balchandran, 1995). The unusually thick Quaternary deposits, in some part of Purna plain goes below the sea level (Tiwari, 1996). Occurrence of alluvial fans and the sharp descent of the fault scarps are also believed to be the evidence of tectonic activity in recent times (Balchandran, 1995; Tiwari, 1996; Tiwari *et al*. 1996). The study experiences tropical monsoon rainfall. About 90 percent of the rain arrives between June and September. Average annual rainfall of the region ranges from 700 mm to 1500 mm (Dikshit, 1986). There is a marked spatial variation in the distribution of annual rainfall over the region, with the higher values in the north near the Satpura mountains (Chikhalda: 1500 mm) and lower values are in the south over the plains (Anjangaon: 720.35 mm, Shegaon: 729.35 mm).

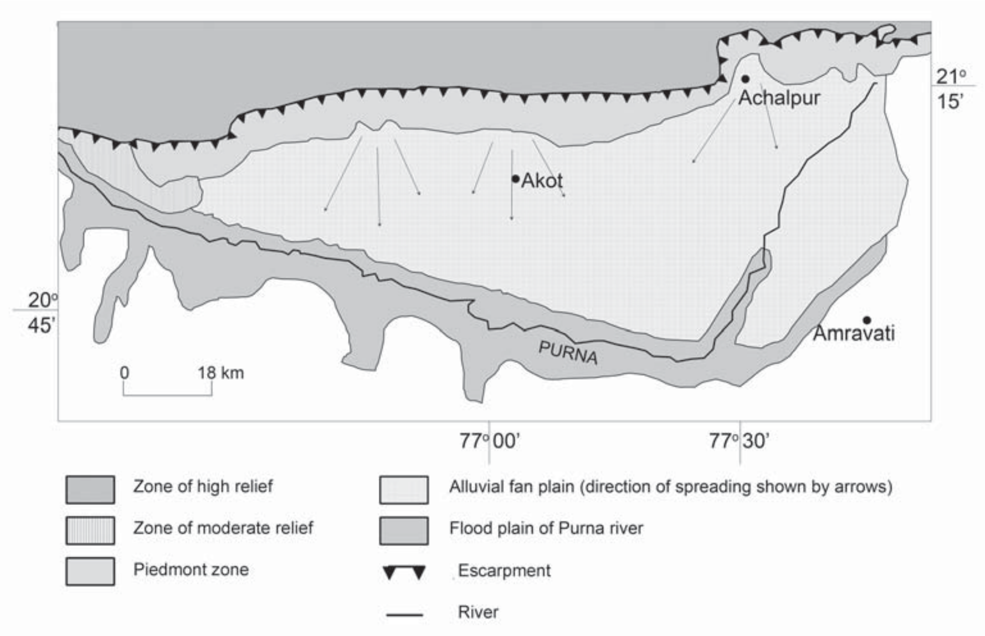

Figure 2. Geomorphological map of the Satpura-Purna piedmont plain (based on Magar *et al*. 2005)

Materials and methods

L Index allows the normalisation of the gradient values and the identification of anomalous points in each section of the river from headwaters to the mouth. The method consists of application of following equations:

$$SL_{channel} = (\Delta H/\Delta L).L \quad ... (1)$$

Where; $\Delta H = (h1 - h2)$ the difference between the highest and the lowest points of a channel reach

ΔL = Horizontal distance of the given reach of the channel

L = Total length of the channel from source to the farthest point of given channel reach

SL index for the total channel length can be obtained by considering the difference of altitude between the headwaters and mouth and the natural logarithm of the total length of the watercourse by using following formula.

$SL_{total} = \Delta H/\ln L$ ... (2)

The longitudinal profile data used in this study is obtained from Survey of India topographical maps at 1:50000 scale (55C/11, 55C/12, 55C/15, 55C/16, 55D/9, 55D/13, 55G/3, 4, 7, 8, 11, 12,15, 16, 55H/1, 5, 9, 13, 55K/2, 3, 4, 6). The longitudinal profiles of nine rivers were drawn and the changes in the channel gradient in the upper reaches, piedmont zone and the plains were calculated. The morphometric properties of each profile (Table 1) such as — elevation of the source region, elevation at the confluence, elevation difference between the source and the mouth, total length of stream, length of stream in the mountain zone and piedmont zone, percentage of length falling in each zone etc. were computed. For the obtaining the SL index, the SLchannel and SLtotal were calculated by equations 1 and 2 respectively. The method of Seeber and Gornitz (1983) to calculate the ratio of $SL_{channel}$ to SL_{total} was also used to identify whether these channel reaches are graded or ungraded.

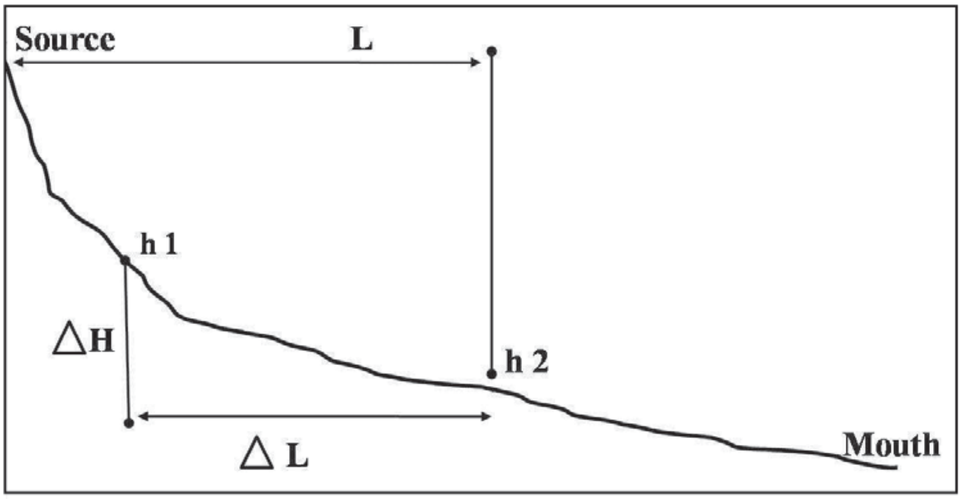

Figure 3. A schematic diagram showing the calculation of the SL index

Discussion and conclusion

All the rivers are ephemeral in nature, draining the Satpura mountain and Purna valley plain. The selected rivers are representing physiographic, lithologic, and tectonic compartments of the region. The length of rivers ranges from 25 km to 125 km, and are 3rd to 5th order tributaries in the hierarchic classification of Strahler (1952). Figure 4a and 4b allows comparison of different river profiles of varying length and gradient. The longitudinal profiles of the Mohidi, Pandarwadi, Jalgaon (J), Bembla (A), Lendi, Patharnala (Popatkhed), Shahnur, Chandrabhaga and Sapan rivers exhibit different characteristics.

Most of the rivers have headwater elevations between 1100 m and 500 m. These rivers flow over alluvial fan sediment for a

Table 1. Morphometric properties of streams draining Satpura-Purna plain

Name of the river	Source elevation (H) in m	Confluence elevation (h) in m	Elevation difference ΔH in m	Total stream length in km	Mountain zone length (source to mountain front) in km	Piedmont length (mountain front to confluence) in km	Percentage length (mountain zone)	Percentage length (piedmont zone)
	1	2	3	4	5	6	7	8
Mohidi	680	240	440	27.75	6.2	21.55	22.3	77.66
Pandarwadi	700	225	475	33.5	8.05	25.45	24	75.97
Jalgaon	700	230	470	31.75	5.55	26.2	17.5	82.52
Bembla	820	240	580	34.6	5.05	29.55	14.6	85.4
Lendi	700	240	460	43.8	8.65	35.15	19.7	80.25
Patharnala (Popatkhed)	920	260	660	53	21.6	31.6	40.8	59.62
Shahnur	1060	250	810	127.75	37.85	89.9	29.6	70.37
Chandrbhaga	1100	265	835	77.5	26.36	51.14	34	65.99
Sapan	1080	310	770	72	32	40	44.4	55.56

Table 1. (continued)

Total drainage basin area	Basin area in mountain	Basin area in piedmont	Ratio of mountain basin area and piedmont basin area	Gradient			
				overall	Mountain zone gradient	Piedmont zone gradient	Ratio
					> 400m	< 400m	
km^2	km^2	km^2		(m/m)			
9				10			
68	38	30	1:0.78	0.0158	0.0451	0.0074	1:0.16
60.25	37	23.25	1:0.62	0.0141	0.0372	0.0068	1:0.18
58.5	11	47.5	1:4.31	0.0148	0.0545	0.0064	1:0.11
51.7	25.2	26.5	1:1.05	0.0167	0.0831	0.0054	1:0.06
108	29	79	1:2.72	0.0105	0.0346	0.0045	1:0.13
92.5	57	35.5	1:0.62	0.0124	0.024	0.0044	1:0.18
181.2	141.2	40	1:0.28	0.0006	0.0017	0.0016	1:0.95
666.2	118.72	547.5	1:4.61	0.0107	0.0265	0.0026	1:4.61
317.72	117.72	200	1:1.69	0.0106	0.0212	0.0022	1:1.69

Table 2. Channel reachwise SL Index and total length SL Index with ratio

River	Zone	Channel reach	SL Index		$SL_{Channel}/SL_{total}$
			$SL_{Channel}$	SL_{total}	Ratio
Mohidi	Mountain	1	110	99.026	1.11
		2	109.23		1.1
		3	135.65		1.37
	Mountain piedmont junction	4	85.91		0.87
	Plain	5	93.4		0.94
Pandarwadi	Mountain	1	70	104.973	0.67
		2	101.67		0.97
	Mountain piedmont junction	3	155.02		1.48
	Plain	4	169.49		1.61
Jalgaon	Mountain	1	80	104.404	0.77
		2	157.14		1.15
	Mountain piedmont junction	3	158.33		1.52
	Plain	4	148.83		1.43
Bembla Adach	Mountain	1	120	127.779	0.94
		2	107.14		0.84
	Mountain piedmont junction	3	215.65		1.69
	Plain	4	71.51		0.56
		5	103.14		0.81
Lendi	Mountain	1	70	99.106	0.71
		2	70.48		0.71
	Mountain piedmont junction	3	121.9		1.23
	Plain	4	130.93		1.32
		5	73.93		0.75
Patharnala	Mountain	1	110	139.704	0.79
		2	116.6		0.83
		3	169.08		1.21
	Mountain piedmont junction	4	189.94		1.36
	plain	5	235.87		1.69
		6	154.91		1.11
		7	128.62		0.92
Shahnur	Mountain	1	199.03	258.62	1.25
		2	205.08		1.29
	Mountain piedmont junction	3	299.89		1.89
	Plain	4	209.03		1.32
		5	109.04		0.69
		6	96.38		0.61
Chandrabhaga	Mountain	1	160	173.371	0.92
		2	233.33		1.35
		3	200		1.15
		4	175		1.01
	Plain	5	112.79		0.65
Sapan	Mountain	1	240	158.425	1.51
	Mountain piedmont junction	2	648.39		1.47
	Plain	3	213.85		1.35

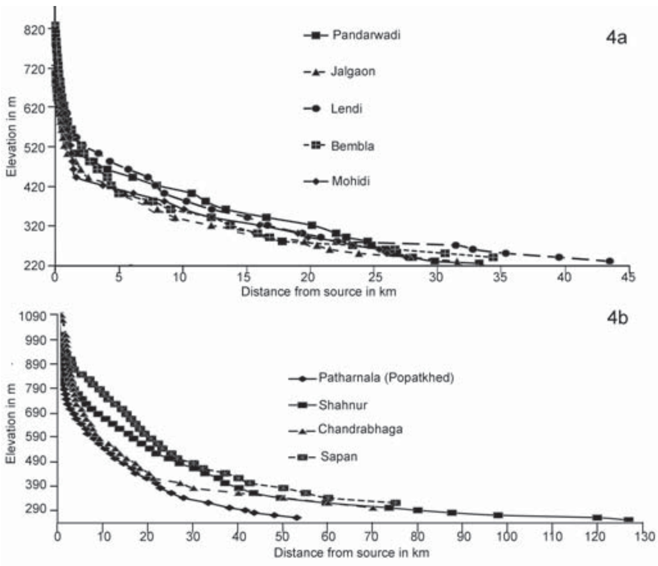

Figure 4a and 4b. Longitudinal profiles of piedmont rivers

significant distance. When traversing over alluvium, these rivers have extremely low channel gradients. Source areas of all the rivers are characterised by narrow and deeply incised valleys, steep gradient, turbulent flow, high erosion potential and high competence to transport the eroded sediments to the downstream reaches. After entering the plains all these rivers loose their velocity and competence due to sudden drop in gradient.

Out of the nine rivers studied, seven rivers have 60 to 80% length of channel within the piedmont zone whereas two rivers (Patharnala and Sapan) have about 50% length in mountainous zone as well as in piedmont zone. This can be attributed to the extended toe of the fan of these two streams spreading towards Purna river channel.

Rivers Jalgaon, Lendi, Chandrabhaga and Sapan have a large portion of their catchment area in piedmont zone than in the mountainous zone. Most of the major tributaries of these rivers originate over the piedmont plain and flow southward parallel to the master stream before joining it.

Determination of the knick point location along the river profile indicates that 6 out of 9 river profiles have their knick points near the mountain front.

Longitudinal profiles of rivers draining from Satpura mountains to the Purna plains are adjusted to two independent variables, viz. relief and litholgy. This adjustment takes the form of two segments of different concavity connected at the mountain front or mountain-piedmont junction. The rivers flowing over lithologically hard and resistant rock have greater SL values compared to SL values of piedmont or plain zone.

Longitudinal profiles of selected river have an overall concavity that reflects a progressive decrease in stream gradient. Upper reaches are more concave in nature and the lower reaches have a very gentle gradient. The concave nature of the river profile is associated with progressive increase in stream discharge in the downstream direction.

The SL Index values of all nine rivers

show that there is a large variation in the SL values in three zones (Table 2). SL values of all the rivers around mountain-piedmont junction are greater as compare to SL values of mountain and plain zone. This can be attributed to the abrupt change in litholgy and decrease in channel gradient.

Ratio of $SL_{channe}l$ to SL_{total} in most of the rivers is less than 02. Therefore all these rivers can be said to be graded.

In case of rivers Chandrabhaga and Sapan the SL Index significantly increase in mountain-piedmont junction. This can be attributed to the relatively larger catchment areas of the Chandrabhaga and Sapan rivers in the high rainfall mountainous zone.

Variation in Gradient Index reflects spatial variation in discharge, but more commonly it is the result of lithologic and or tectonic controls on channel gradient.

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n longitudinal profile: an elevation cross-section of the entire watershed from the source of flowing water to the mouth of the stream. n headwaters: the highest elevation where water collects to form a stream network. n base level: the lowest elevation that a stream can erode its channel.Â Longitudinal Profile and Watersheds. n A riverâ€™s gradient (slope) is steepest near the headwaters and gentlest near the mouth. n As rivers flow from their headwaters to their base level they carve valleys into the landscape by eroding, transporting, and depositing weathered rocks, soil, and sediment. Elevation (feet). 3,000. Rivers flowing over crystalline terrains erode with difficulty, whereas unconsolidated sedimentary rocks yield greater sediment loads to rivers. The enormous sediment loads in the Huang He is due to the presence of yellow loess derived from the deserts in Mongolia, whereas the Gangaâ€“Brahmaputra rivers carry huge sediment loads because they flow over the easily erodible carbonates and through the Himalayan terrains. Kattan et al.24 estimated that in the Senegal river, 20% of the total river transport is derived from channel erosion.Â Vorosmarty et al.31 estimate that 30% of the global sediment flux is trapped behind large reservoirs. Several large basins such as the Colorado and Nile show nearly complete trapping of sediments due to large reservoir construction and flow diversion. Stream gradient, a function of river gradient decreases with increasing drainage area and thus with length measurement, is computed as given in Eq. (3). The SL index river length (Hack, 1957; Larue, 2008b). However, our results show allows detection of the least knickpoint and very high or very low values poor correlation (r2 = 0.046) between total length and average gradi- that can reveal tectonic distortions if no correlation with lithologic ent (Fig. 6). Abnormal high gradients are shown by longer rivers such factors (Hack, 1973; Keller and Pinter, 1996; Larue, 2008a,b). as Karimpuzha, Kurumanpuzha, Kanjirapuzha, and Chaliyarpuzha and an unusual low gradient is exhibited by shorter rivers such as the Karakodupuzha and Cherupuzha. SL Â¼ Ã°Î”H=Î”LÃžL Ã°2Ãž 4.1.