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Litho-Structural Control on Upper Darakeshwar Basin, Purulia District, West Bengal

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Abstract: *Underlying structure, geology and lithology in a basin play an important role in controlling a fluvial system through the changes in adjacent landscape. Drainage basins are sensitive to change in tectonic deformation, physical properties of the underlying rocks and climatic effects. Thus, lithological deformations are well represented by the drainage basin of a region. The Darakeshwar, a monsoon-fed river system, flows through the Chhotanagpur plateau fringe region of southwestern Bengal over a tectonically stable region. The Chotanagpur gneissic complex is characterised by foliated, friable and ancient hard rock of Precambrian age with intense surface fractures, faults and lineaments exposed on the surface. In some parts of the basin Quaternary alluvium is deposited where flat wide valley and minor variation of channel gradient are evident. In some part of this ancient landscape presence of incised valley and tilted basin indicate lithological influence. In this context, the present study aims to analyse the surface deformation pattern with the help of linear and areal morphometric parameters. Litho-structural factors are also considered for assessing the influence of lithology and structure on the basin. DEM-based terrain analysis, sinuosity index, stream length-gradient index and lineament study have been carried out to study the litho-structural control on drainage basin form.*

Introduction

Among the various factors influencing the fluvial process and resultant landforms, underling structure and lithology are the most important. How the river adjusts to its underlying structure is thus a key factor for understanding channel behaviour. Such an understanding is essential for effective planning and management of the basin.

The present article on Upper Darakeshwar river Basin (UDB) aims to study the linear and areal aspects of the basin for assessing the influence of litho-structural factors on these morphometric properties.

Study area

Upper Darakeshwar Basin (UDB) is located in Purulia district of West Bengal. The

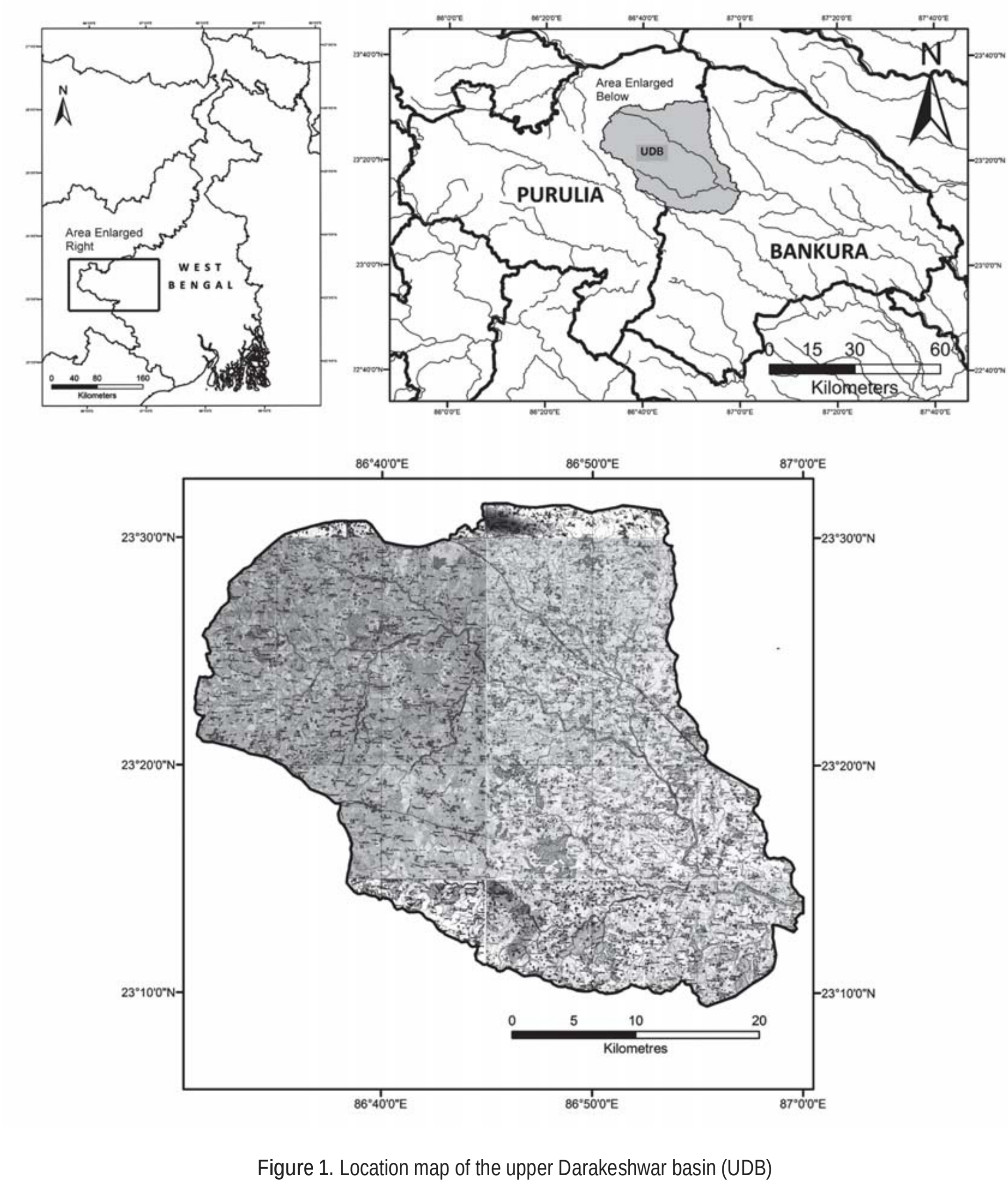

Figure 1. Location map of the upper Darakeshwar basin (UDB)

basin area is located within 23º08' N to 23°32' N and 86°30' E to 87° E covering an area of around 1,295.86 km^2 (Fig. 1). Darakeshwar river originates near Tilabani hills (446 m) around the badlands to the east of Bagalia in Purulia district. It is bounded by Damodar river in the north and Kansai river in the south. The area experiences subtropical climate with high evaporation rate and very low precipitation. Geologically, UDB is made

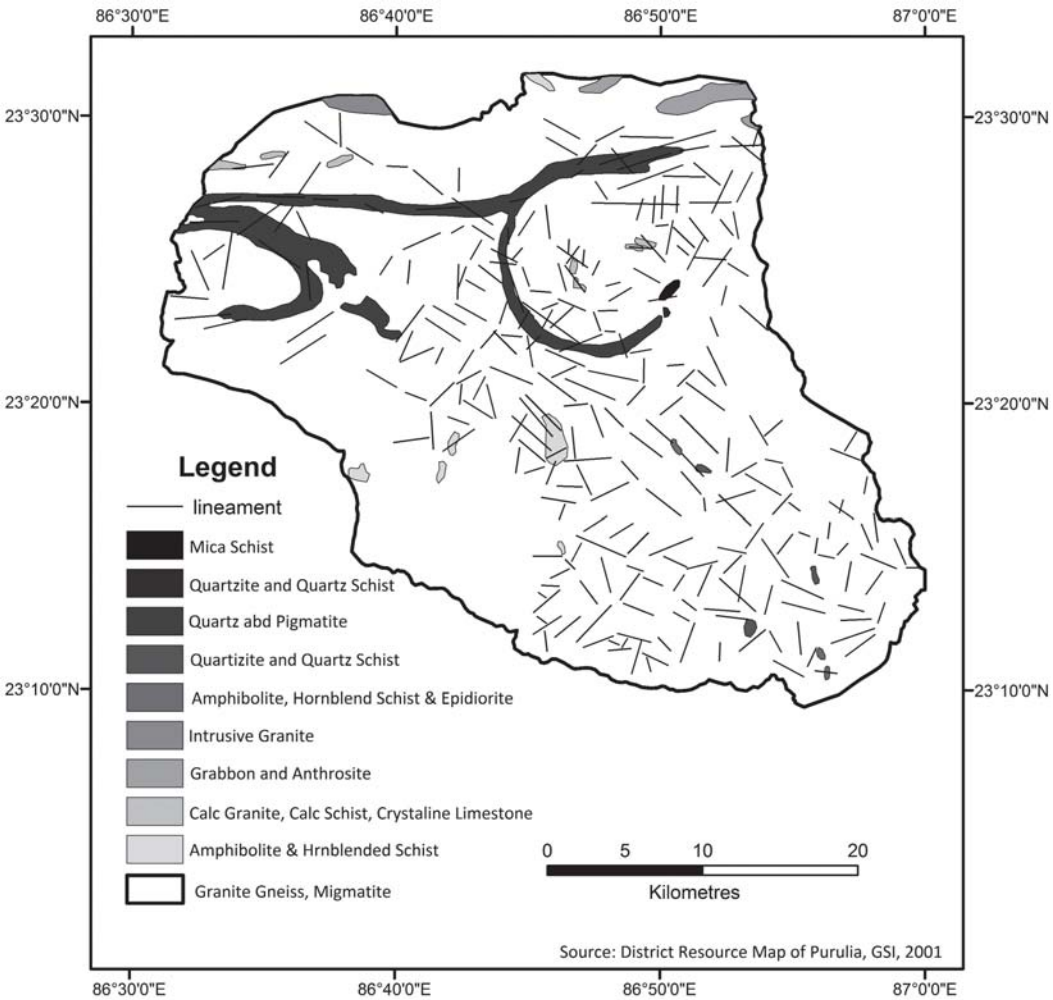

Figure 2. Geological map of the upper Darakeshwar basin

up of Precambrian rocks and recent alluvium. The rocks were formed during Proterozoic and Archean-Proterozoic age (Table 1). Granite, gneiss, migmatite, quartzite, quartz schist, calc granite, calc schist, crystalline limestone, mica schist, amphibolite and hornblende schist are the main rock types (Fig. 2). Among these, the rocks of Chhotanagpur gneissic complex are widespread, which are hard and massive in character. Consequently, the erosional capacity of the rivers flowing over these is very less. Some of the rocks are foliated, friable and soft, prone to weathering. Structurally, the region has a number of fractures, lineaments and faults, which act as planes of weakness wherever these are exposed on the surface (Fig. 2).

Objective and hypotheses

The basin under study is located in the fringe area of Chotanagpur plateau. The

Table 1. General geological and lithological characteristic of the study area (GSI, 2001)

Lithology	Geological Unit	Geological Time Scale		Nature and Characteristics of Rocks
		Era	Age (billion years)	
Intrusive granite	Kuilapia, Manbhum group	Proterozoic	0.57–2.5	Hard, massive rocks
Gabbro and anthracite	Plutonic complex			Hard, massive rocks
Granit, gneiss, migmatite	Chotanagpur gneissic complex	Archaean-Proterozoic	2.5–4.0	Hard, foliated, easily weathered rocks
Quartzite, quart schist				Hard layered rocks
Calc-granulite, calc-schist, and crystalline limestone				Hard, friable rocks
Mica schist				Soft, flaky rocks
Amphibolite and horn-blende schist				Hard rock with isolated softer patches

Source: Geological Survey of India, District Resource Map, 2001

Darakeshwar river flows through an area which is criss-crossed by lineaments, has prominent sheer zone, faults and foliations developed along the dip and strike of beds. Thus the surface is tectonically disturbed and structurally complex. Based on these observations, the objectives of the study is to analyse the role of structure and lithology in shaping the channel network. Considering all conditions we can assume the following hypothesis: 'Darakeshwar is a structurally controlled river'.

The hypothesis may be or may not be applicable for this region and need complete evaluation.

Materials and Methods

The various data sources used in the present study are mentioned in Table 2. The software used for image processing include Erdas Imagine version 9.1 and Geomatica version 9.1. The maps of UDB are prepared with the help of Mapinfo Professional version 7.0 and ArcGIS version 9.3. The methods for analysis of various morphological aspects sinuosity index (SI), topographical cross section, slope map, lineament map, stream ordering, bifurcation ratio and strem length-gradient (SL) index have been used.

Result and analysis

Sinuosity Index

Sinuosity index is an important parameter for understanding the effect of lithological control on drainage development. Lithology influences resistance to flow and can be regarded as an alternative to slope adjustment when valley slope is treated as constant at the short and medium time scales (Knighton, 1984). 'Mueller's sinuosity indices (Mueller,

Table 2. Maps and satellite images used in this study

Maps / Images	Year
District Planning Maps of Purulia and Bankura	2001
District Resource Map (Purulia and Bankura) of (National Atlas and Thematic Mapping Organisation (NATMO)	2001
Survey of India (SoI) topographical sheet no.: 73I, 73 I/10, 73 I/11, 73 I/12, 73I/14, 73I/15, 73I/16	1969-74
IRS LISS III (4 bands)	2001
SRTM data (30 m.)	2006

1968) have been used in the present study and described below:

$$SI = CI / VI$$

Where, CI refers to Channel Index and VI refers to Valley Index.

We have considered Morisawa's classification of channel patterns (Table 3) to draw the actual hydrogeomorphic significances of sinuosity index (Morisawa, 1985; Goudie, 2004).

Table 3. Sinuosity index of Upper Darakeshwar river

Topographical sheet no.73I and 73I/10, 11, 12, 14, 15, 16 (1974)	Length in km			Indices used				
River	Channel length	Valley length	Air length	Channel Index (CI)	Valley Index (VI)	Standard Sinuosity Index (SI)	Hydraulic Sinuosity Index (%)	Topographic Sinuosity Index (%)
Upper Darakeshwar river	72.64	71.62	95.1	0.7639	0.753	1.0145	-4.62	104.62

The standard sinuosity Index (SSI) of main river of upper Darakeshwar basin is 1.0145 (Table 3) which means that it is a straight river. The value is close to 1.05, so it is nearly sinuous but not actually so. In the rolling plains of plateau fringe straight planimetric river form is not common.

The hydraulic sinuosity index (HIS) and standard sinuosity index (TSI) give a more meaningful result. HSI indicates the influence of hydraulic slope and TSI indicates the influence of topographic slope on the channel. Here HSI shows the value -4.62 which means almost negligible influence of hydraulic slope, but TSI is 104.62 which mean that Darakeshwar is a strongly topographical slope-guided river. Both the slope and topography are moulded by the regional lithological composition.

Topographical cross-sections

Topographical profile or cross-section gives us a clear idea about the entire terrain of the basin. It provides the idea that how much the rivers are adjusted with its topography. Here six cross sections have been drawn based on SRTM 30 m data (Fig. 3 and 4) covering the entire basin.

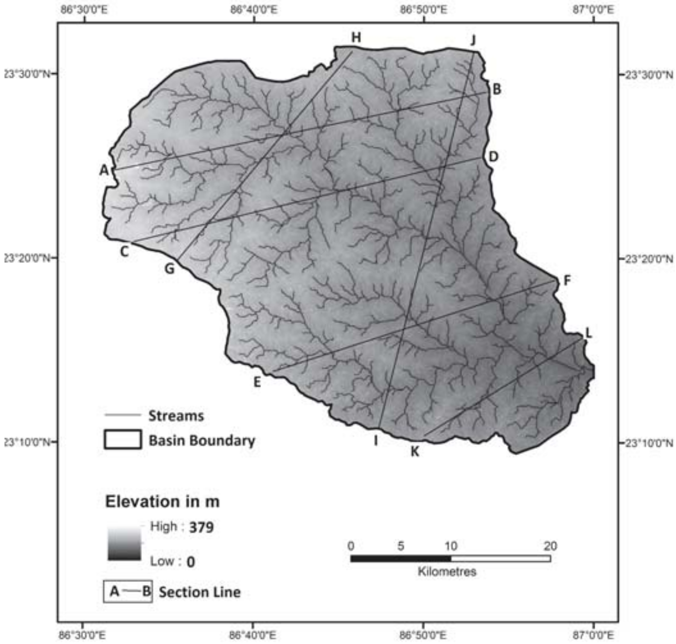

Figure 3. Elevation map of upper Darakeshwar basin with locations of topographical cross sections. *source:* SRTM data of 2000

All the profiles show higher elevation towards southwest direction. Another cross section is drawn from southwest (Kansai river) to northeast (Damodar river) direction to see the regional slope direction in a large scale (Fig. 5). The entire region is topographically tilted towards northeast direction as Damodar flows through a major fault line. Another major fault line is located in the southwest of Kansai River. The entire Darakeshwar basin has a number of lineaments bearing signatures of past tectonic deformation during the evolution of Chhotanagpur plateau.

Analysis of DEM and slope map

The elevation of the basin ranges between 350 m to 100 m. The entire basin has undulating topography. Northwestern and northcentral portions show highest elevation, whereas southeastern corner shows lowest elevation. Due to resistant rocks the rivers are unable to erode much and the entire bed is full of massive boulders of granite, quartzite and mica schist which are evident from the bed configuration (Fig. 6).

The slope map of UDB is prepared in ArcGIS 9.3 based on SRTM 30 m. data (2006). The map shows very little variation of slope, which remains within 2° (Fig. 7), reflecting minimum slope and almost flat terrain. The western and northcentral portions show maximum slope angle of 3º30′ to 4º 0′, where the region has highlands within rolling plains towards the direction of confluence of the river with Damodar.

Study of lineament map

The lineaments are extracted from satellite images and geological maps of the study area. To understand the lithological control on drainage development the study of lineament

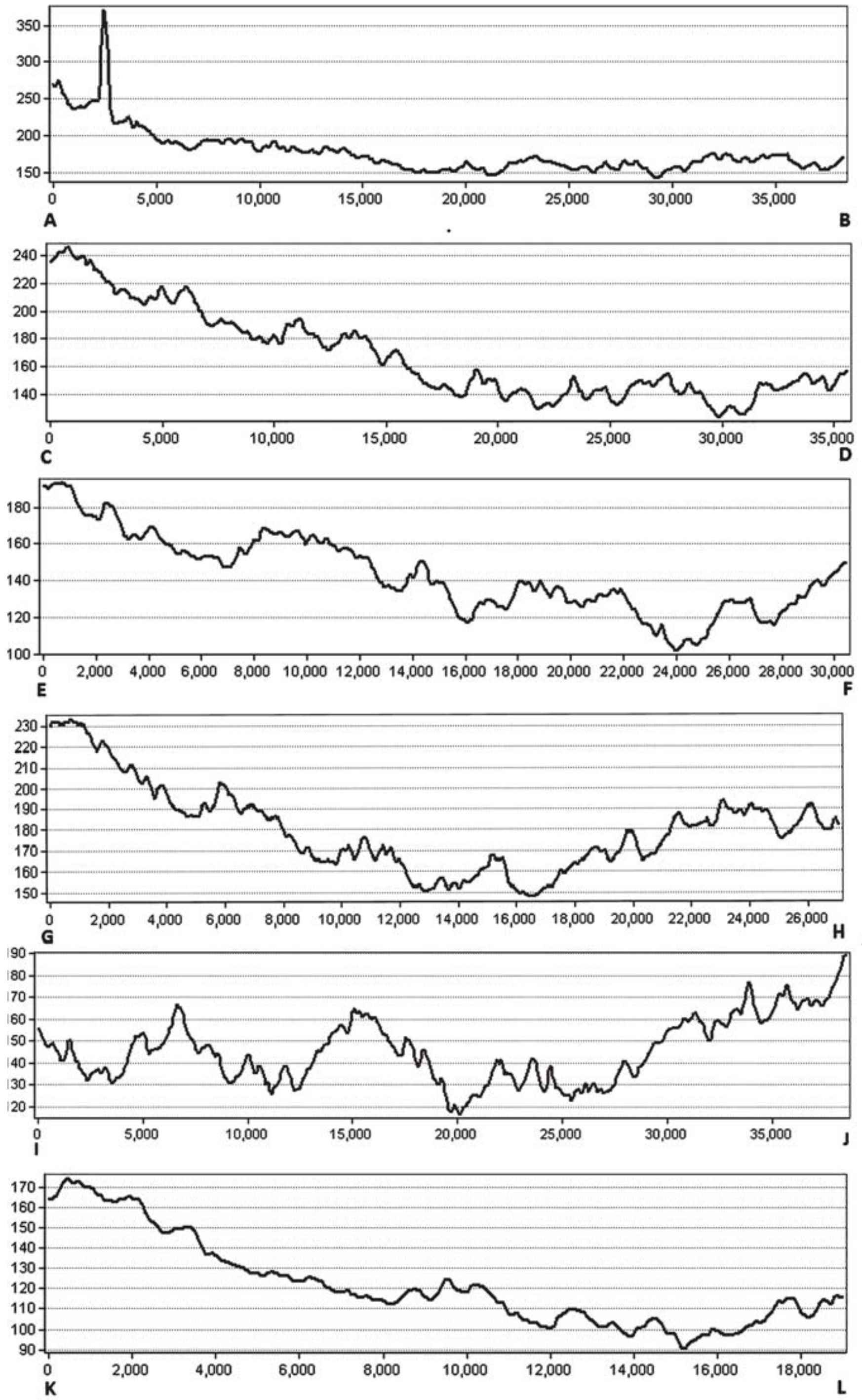

Figure 4. Topographical sections, upper Darakeshwar basin. See Fig. 3 for location of profiles. Units are in metre.
source: SRTM data of 2000

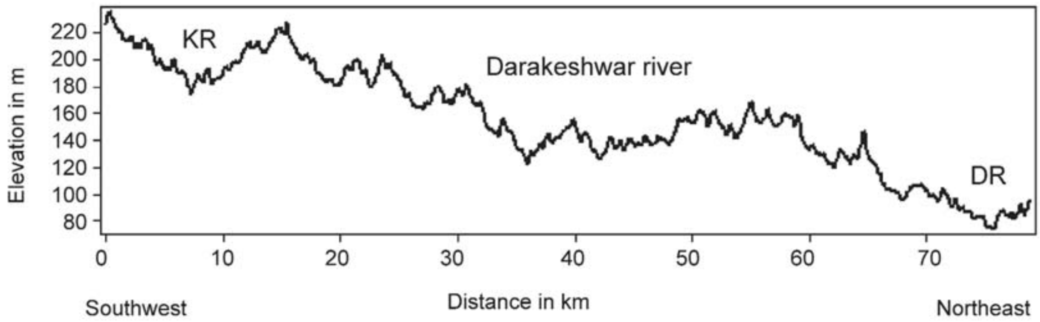

Figure 5. General topographical profiles across the upper Darakeshwar basin. KR and DR stand for Kansai river and Damodar river respectively. Units are in metres. *source:* SRTM data of 2000

map is crucial. To have a clear understanding of this, the drainage map is superimposed on the lineament map (Fig. 8). Major rivers of the basin are flowing almost along the lineaments, which essentially act as planes of weakness. The concentration of lineaments on the surface varies from one portion of the basin to another. The portions on the map indicated by circles show relatively higher concentration of drainage network and the same region also shows higher concentration of lineaments. Majority of the streams flow along the lineament tracts.

So, from this analysis it is clear that Darakeshwar river is controlled by underlying lithological character and structural geology. Being a structure-controlled river, the flow path of Darakeswar should not migrate as frequently as the alluvial rivers. To analyse this we have used chronological data. Here the positions of the river from topographical map of 1969–74 are super imposed on the satellite image of 2001. Though the time span is not significant in this case, but the result shows that Darakeshwar river is flowing through the same path which it maintained earlier and this is also evident from field observations in some portion of the UDB.

Stream ordering and bifurcation ratio

Stream ordering is referred to as significant criteria to understand the

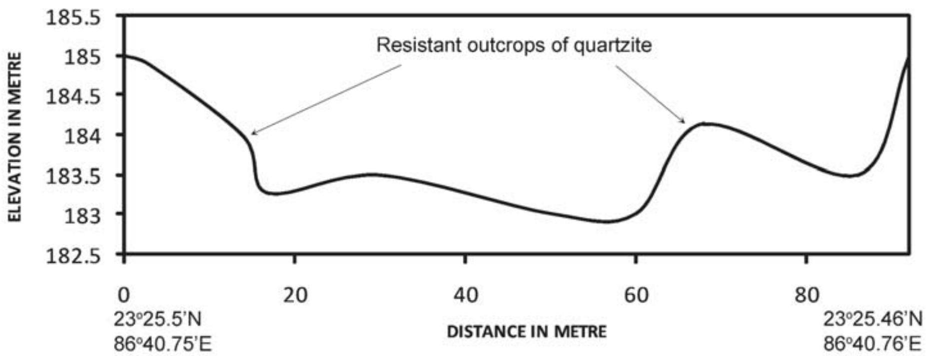

Figure 6. Cross profile of the upper Darakeshwar

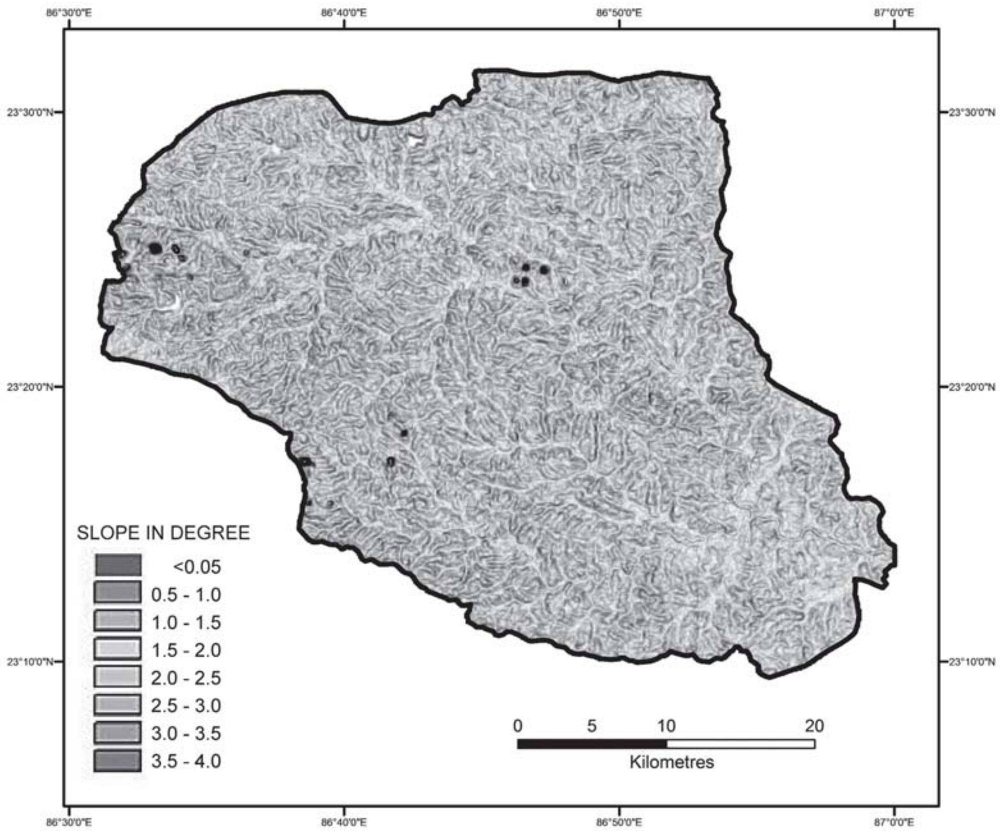

Figure 7. Slope map of the upper Darakeshwar basin

hierarchical position of a stream within a drainage basin. It is a good index to interpret the maturity of a drainage basin which is influenced by lithology. Higher order stream indicates high maturity of the drainage.

Among different methods Strahler's (1957) method is simple and easy for application (Fig. 9). According to this method, Darakeshwar is a fifth order basin. So it is a relatively mature river basin. The trunk stream of the basin is originating near Tilabani hills, but notably it is joint by a northeastern tributary which is also a fifth order stream, highlighted by the circle on the map (Fig. 9). This may have happened as the northeastern portion has dense drainage network due to abrupt change of elevation and presence of high lineament density.

Bifurcation ratio (Rb) is related to the branching pattern of the drainage network. It is defined as ratio of the number of streams of a given order to the number of streams of the next higher order. It is expressed as:

$$Rb = Nu / Nu+1$$

Where Nu refers to the number of streams of a given order and Nu+1 stands for number of streams of next higher order (Table 4).

The relation between stream number and stream order shows strong positive relation (R2= 0.999) (Fig. 10). With the decreasing stream number, stream order increases. So, stream order is dependent on stream number

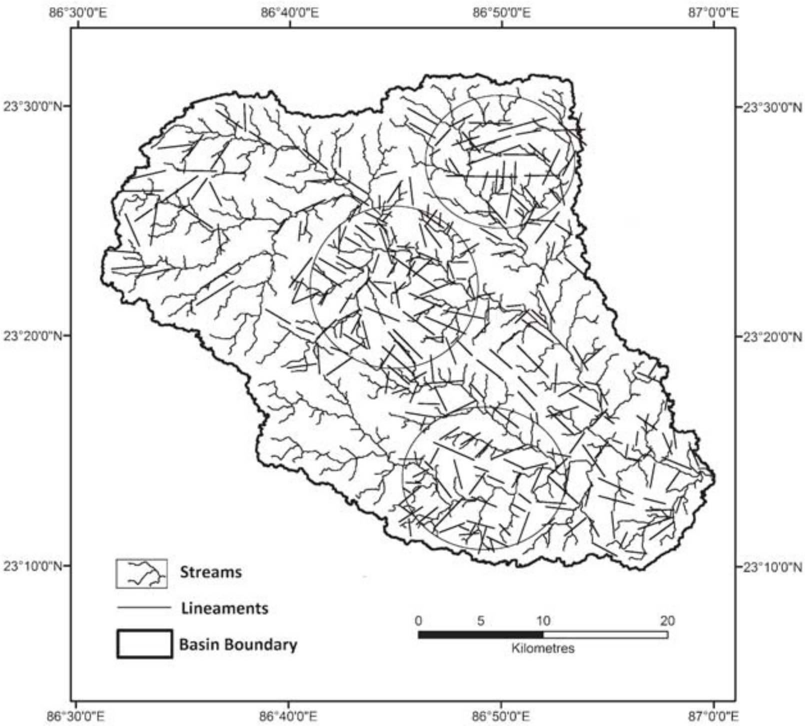

Figure 8. Superimposition of drainage and lineament map, upper Darakeshwar basin

that is why other than the main river, its tributary first appear as a fifth order stream.

Stream Length-Gradient Index (SL)

Hack's long profile and SL Index is considered an excellent measure to infer stream power and rock erodibility (Hack, 1973) because it is sensitive to minute changes or perturbations in the channel slope (Burbank and Anderson, 2001).

$$SL = (\Delta H/\Delta L)\ L$$

where, $\Delta H/\Delta L$ is the local channel gradient and L is the length of the channel from the midpoint of a segment in which SL is calculated to the highest point in the channel.

The long profile of trunk stream shows an interesting pattern, where observed profile and estimated profile do not start from the same point, which is generally uncommon. The upper and lower portion shows the dominance of erosional activity, (Fig. 11) whereas the middle portion shows depositional activity. So the river is not fully adjusted to its topography and continuous re-adjustment is going on. The observed profile in the middle portion of the curve i.e. one to ten kilometres from the source is seated above the calculated profile and the SL values are high in this portion. After that there is a continuous decrease of SL values from 958.87 to 23.90.

The river is flowing through very hard massive Precambrian rocks of Chotanagpur gneissic complex. The convex shape of the profile indicates that lithology and tectonics controls the profile of the river. The average

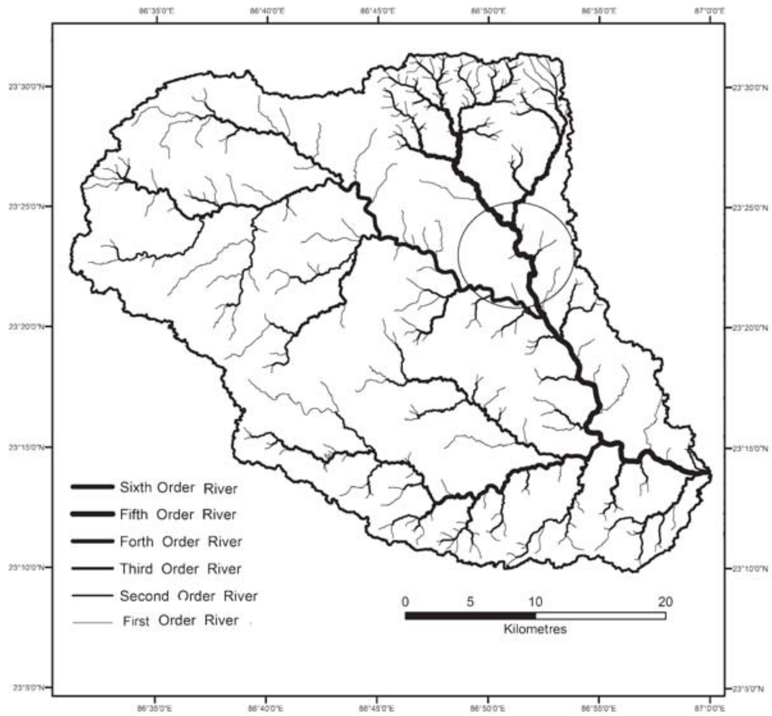

Figure 9. Drainage map of upper Darakeshwar basin

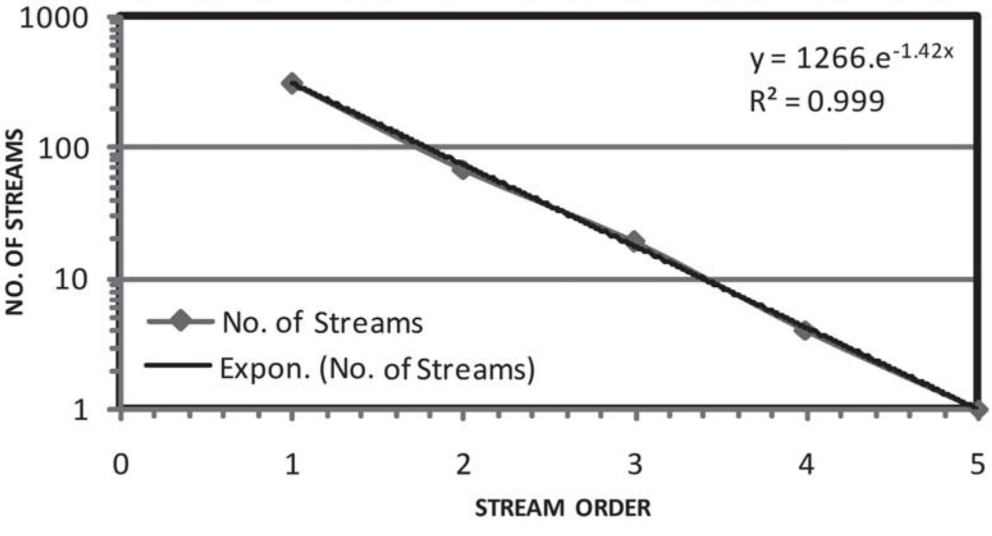

Figure 10. Relation between streamer number and order

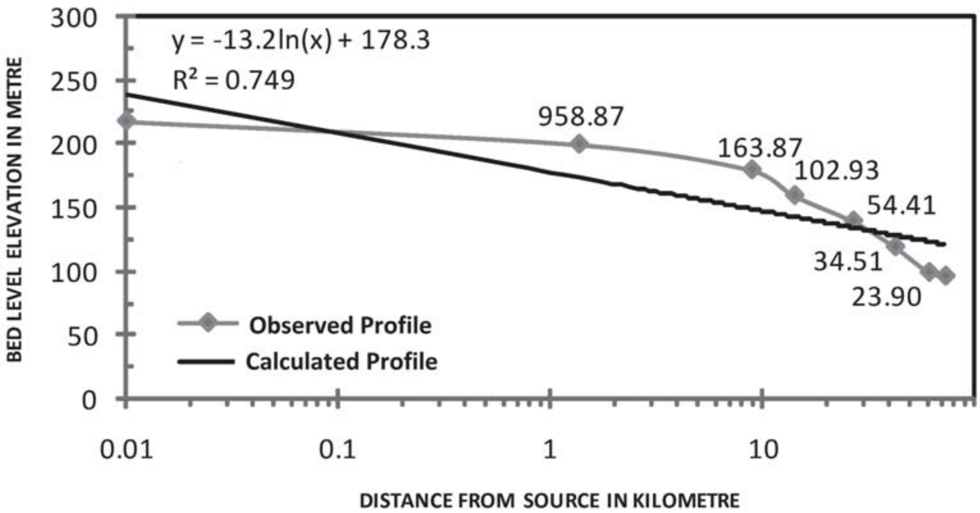

Figure 11. Long profile of the upper Darakeshwar (J.T. Hack method)

Table 4. Calculation of bifurcation ratio

Stream Order	No. of Streams	Bifurcation Ratio (Rb)	Average Bifurcation Ratio (Rb)
1	308		
2	68	4.53	
3	19	3.58	4.215
4	4	4.75	
5	1	4	

SL value is 191.64 which are relatively high indicating that the drainage network of UDB is controlled by underlying geology.

Conclusions

The following may highlighted to summarise the findings based on the aforesaid discussions which satisfy the initial hypothesis.

- The HSI shows the value of –4.62 which indicate almost negligible influence of hydraulic slope, but a relatively high TSI of 104.62 suggests that Darakeshwar river is strongly guided by topographical slope. The slope and topography is in turn controlled by lithology and underlying rock character.
- The superimposition of the drainage map of UDB on the lineament map shows that majority of the rivers of this basin are closely following the lineament tracts and a dense drainage network has developed where lineament density is high. Hence, it may be stated that Darakeshwar and its tributaries are strongly guided by the structure.
- Darakeshwar flows through almost the same path which is evident from negligible migration of rivers. The region where Darakeshwar basin is situated did not face any recent tectonic actives, thus its path remains remarkably stable. This is usually the characteristics of a structurally control river.
- The convex profile and a relatively high average SL value of the trunk stream also supports that Darakeshwar is controlled by the underlying lithology.

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