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Geomorphological Evolution of the Rushikulya Basin,Odisha

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Abstract: *Geomorphic evolution of a river basin is the result of a complex interplay between the bedrock composition, geological structure, fluvial processes and the land cover. For the study of the evolution of the basin various morphometric parameters like drainage frequency, density, texture, length of overland flow, basin elongation and slope have been analysed. For determining the stage of basin evolution, the hypsometric curve, longitudinal profile and cross profile were analysed. The basin is composed of granite and gneiss mostly in the south and southwest and in some parts of the west and north. Khondalite and charnockite rocks are found extensively in the north, northeast and east of the basin. Other less significant rocks are calcareous granulites, crystalline schists, laterites and alluvium. A major fault passes through the basin along the main streams. Fractures and lineaments are found criss-crossed all over the basin. The longitudinal profile of the main stream as well the tributary streams shows high rate of denudation leaving less than 25% area with steep gradient. The cross profiles show that the slope of the basin is from south to north and west to east. Drainage density, frequency, texture and length of overland flow show lower values for major part of the basin and higher value for limited areas. The river does not have a delta at its mouth as the amount of sediment in the basin is low and the slope is relatively high. The mouth is extended as a narrow channel as it enters the coast, roughly aligned with the direction of the northward drift of the coastal current.*

Introduction

The drainage basin is the surface upstream and uphill of a channel that contributes water and sediment to that channel .A drainage basin is an open system, in to which and from which energy and matter flows and its boundaries are normally well defined. Drainage basins are the fundamental unit of geomorphic analysis as a large part of terrestrial landscape is drained by rivers (Chorley, 1969). Rains falling over the basin infiltrate or flow overland under the influence of gravity until it collects in surface rills, gullies. The network of branching stream channels includes only about 1 to 5 percent of the total basin area but its role in eroding and transporting sediment is critical to the basins' behaviour and evolution. In mountains and in terrains with fine textured badlands, drainage basins are well defined by sharp ridges around their perimeters. In regions of low relief drainage basin divides are much less distinct. Drainage basins with low relief in tropical regions are marked by seasonally waterlogged and predominantly grass covered shallow linear depressions without a marked stream channel. Horton demonstrated hydrological measurements to quantify the description and theories of developing drainage basins and river networks. The quantitative relationship between geomorphic processes and landform evolution is known as morphometry — the measurement and mathematical analysis of various landform parameters.

Study area

The Rushikulya basin is a 6th order river basin of 8402 km^2 area located on the eastern coast of India in southern Odisha adjacent to the southern margin of the Chilika lake. The basin is flanked by the Eastern Ghats in a semi-circular manner on the northeast, north, west and south. Towards the east the basin opens in to the Bay of Bengal. The basin is located between 19° 3′17″ N to 20° 17′17″ N and 84° E to 85° 17′17″ E. The basin spreads over the administrative districts of Ganjam, Gajapati, Khurda, Nayagarh and Phulbani (Fig. 1 and 2)

Database and methodology

Geomorphic evolution of the basin has been studied using Survey of India topographical sheets (73D/8, D/12, D/16; 74A/1, A/2, A/5 to A/16) of scale 1:50,000. Geological information about rock composition, distribution and stratigraphic sequences were used to assess the evolution of various types of landforms. Morphometric parameters like stream order (Strahler's method), bifurcation ratio, stream frequency, drainage density, drainage texture, length of overland flow and slope (Wentworth's method) were taken into consideration along with longitudinal and cross profiles of the main river to study stream development and evolution of associated landforms.

Geological formation and structure

The basin is mainly comprised of metamorphics belonging to the Eastern Ghat group of rocks of Archaean era (Dikshit, 1981). The rock types in this group include khondalite, charnockite, granite, gneiss, quartzite etc. In some areas these country rocks are intruded by gabbro, norite, diorite, syenite and anorthosite (Table-1). These intrusions are manifested as massive denudational hills and ridges.

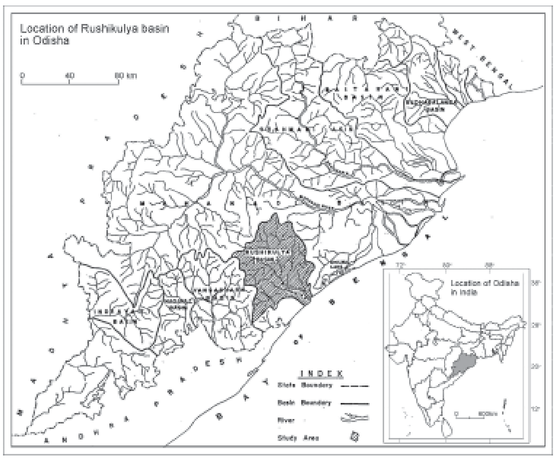

Figure 1. Location of Rushikulya basin.

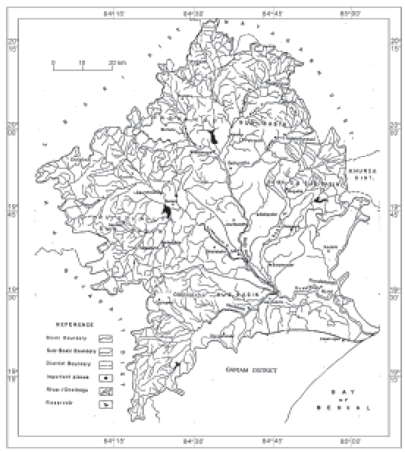

Figure 2. Drainage map of Rushikulya basin.

Laterites, at some places occur as capping over older formations. Formation of laterite is common here, representing the residual product of weathering during the recent period. Recent alluvium occurs only along the river valleys and flood plains. The basin is criss-crossed by numerous faults, joints, fractures and lineaments (District Forest Working Plan, 1990; Fig. 3). The rocks of Eastern Ghat super group exhibit complex structural and tectonic history. In general the rocks of this group have foliations, dipping

Table 1. Stratigraphic Sequence of the Rushikulya Basin (Mohanty, B.K. and Devdas, V. Geological mapping of Quaternary formations in Rushikulya river basin in parts of Ganjam District, Orissa, Records Geological Survey of India, 122(3), pp.5-6.)

Geological Age	Formation	Outcrops
Recent to sub-recent	Alluvial, laterite and laterite gravels	Sand, clay, silt of various grades
	Unconformity	
	younger intrusions	Gabbro, Norite, Diorite Syenite, Anorthosite Granite
	Granite suite	Prophyroblastic, Biotite Bearing and Granetiferous Granite gneiss, Pegmatite and Quartz veins
Archaean (Eastern Ghat)	Charnockite suite	Acid,Intermediate,Basic/ Ultrabasic Charnockite
	Khondalite suite	Quartz,Garnet,Sillimanite Gneiss and Schist,Garneti Ferrous quartzites
Base unknown		

from NNE to SSW at angles varying from 4° to 70°. Two sets of joints are quite prominent, one set with strike aligned in N-W direction and the second set of strike aligned E-W, both dipping vertical to sub-vertical. The major shear zone represents deep seated fracture in the crust. The general trend of the shear zone is NNW to NW and NNE to NE. Three main shear zones occur in the basin — (i) Taptapani to Chandragiri about 25 km long and 1.5 km wide, (ii) Monora to Bedakona in a northeasterly direction and

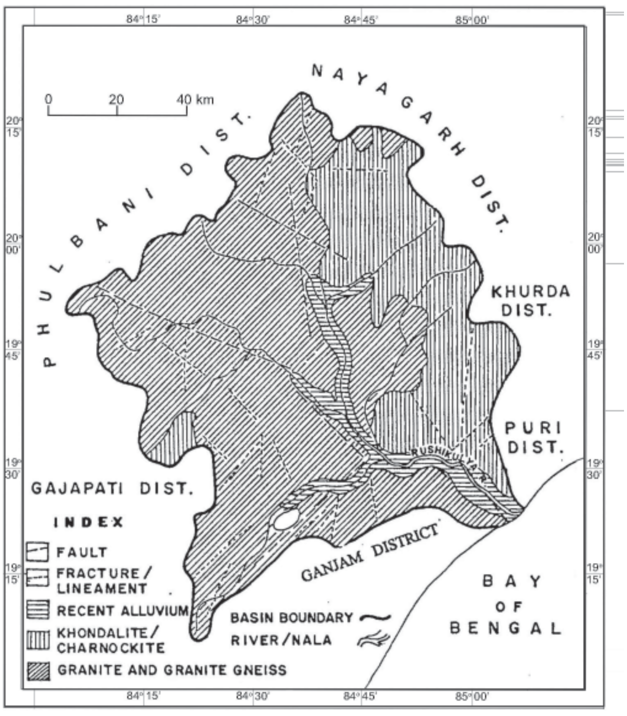

Figure 3. Geological map of Rushikulya basin.

(iii) Mahulapada to Gurabhalsa. The whole sequence was folded and refolded several times and subjected to several deformations (Orissa Lift Irrigation Corporation Ltd., 1990). The primary structure appears to be asymmetrical antiform or anticlinorium with the axis steeply plunging in a NNW-SSE direction. The outcrop is represented by the band of Khondalite rocks. The information available on geology of the basin is scanty, as no systematic geological survey has been taken up in this basin perhaps due to the absence of mineral resources.

The central and southern part of the basin is dominated by plutonic rocks, mainly granite and gneiss. This part of the basin was never been folded, disturbed or submerged beneath the ocean. Some of the plutonic rocks are amongst the earliest formations. The schists are possibly older than the first sedimentary rocks of the Archaean group. Structurally the area is complex .The geometrical pattern of surface expression of folds appears to represent the superimposition of two generations of fold axis almost at right angles to each other. The present immature physiography of the rugged hilly tracts with sporadically scattered flat low-lying areas suggests poly cyclic erosion accompanied by neotectonics uplift (Vaidyanathan, 1964). The southern part of the basin is devoid of any minerals of economic importance.

Relief and slope

The basin shows high relief in the west and south than north and east. From the sea level the basin relief increases gradually till the middle part of the basin and suddenly rises to an elevation of 1290 m at Daringibadi, the source region of the Rushikulya river. There are isolated peaks distributed in the middle part of the basin (Fig. 4) showing high rate of denudation. The factors like tectonic character, hardness of rocks, density of fractures, joints, faults and lineaments, presence of vegetative cover, rainfall intensity and runoff rate all influence denudation rate landform evolution.

More than 60% of the basin area shows low relief with less than 8° slope. The slope analysis of the basin has been done using the method of Wentworth, (1930), to understand the varied nature of the topography due to differential rate of denudation. The average

Figure 4. Important peaks in Rushikulya basin

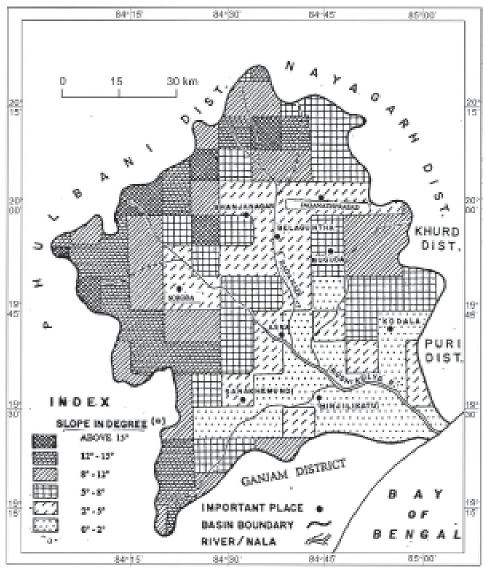

Figure 5. Slope variation in Rushikulya basin

slope of the basin varies from 0° to 19°. About 17.5% of the basin area is below 2° slope. Gentle slopes of 2°–5° mostly occupy the pediments and low foothills, which accounts for 22.04% area. Moderate to moderately steep slope (5°–12°) occupies 41% of the area and steep to very steep slope (more than 12°) accounts for only 19% of the area (Table2, Fig. 5).

Area-height relationship

The relationship between area and altitude is of fundamental geomorphological significance. The hypsometric curve shows the area of land between two adjacent contours depending on the selected contour interval. As seen in the curve, 25% of the area lies above 260 m, 50 % of the area lies above 100 m and 75% of the area lies above 40 m. The area-height bar graph also indicates the same trend where nearly 50% of the area is below 100 m elevation (Fig. 6). This is an indication that the basin experienced high degree of planation, mainly by fluvial action and also by tropical weathering processes (Strahler, A.N., 1952; Sinha Ray, S., 2002).

Analysis of profiles of Rushikulya basin

Longitudinal Profile

The longitudinal profile of a river may offer valuable evidence of its geomorphological history, particularly in a polycyclic drainage basin, with marked breaks of slope between different graded reaches (Monkhouse and Wilkinson, 1989; Nellton, 1955). Three longitudinal profiles were drawn for the basin — one along the main river Rushikulya and the other two along the two main tributaries viz. Bada nadi and Ghodahada nadi. The Rushikulya river has an average gradient of

Table 2. Slope variations in the Rushikulya basin

Nature of Slope	Slope in degrees	Area in km^2	% of area to total basin area
Level ground	0°–2°	1470.93	17.51
Gentle	2°–5°	1851.63	22.04
Moderate	5°–8°	1809.32	21.53
Moderately steep	8°–12°	1640.23	19.52
Steep	12°–15°	1238.32	14.73
Very Steep	15°<	392.41	04.67
Total		8402.84	100.00

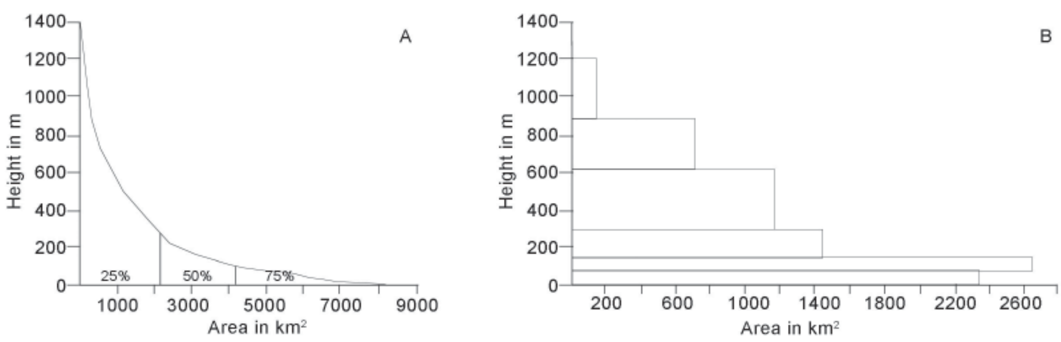

Figure 6. A) Hypsometric curve and B) area-height bar diagram showing area-altitude relationship in Rushikulya basin

1:114, but critical observation of the long profile indicates variations at number of reaches along the course of the river. The four distinct reaches for the Rushikulya river can be marked — Stage I) from the source to Daringibadi plateau for a distance of 4 km the mean gradient is 1:11; Stage II) from Daringbadi plateau the river flows for a distance of 11 km up to a height of 800 m with a gradient of 1:50; Stage III) in this stretch the river descends from 800 m to 250 m within a distance of 16 km with gradient of 1:30. This reach is steeper than Stage II. Stage IV extends over a total length of 123 km with gradient of 1:417 (Fig. 7).

Ghodahada river has an average gradient of 1:91 with two distinct segments of varying slope — Segment I extends for 18 km from the source up to a height of 200 m, having a gradient of 1:28 with very steep slope. The Segment II extends for a distance of 58 km from 200 m up to the rivers confluence with the Rushikulya river at an elevation of 40 m. The gradient in this segment is 1:357.

Bada Nadi has an average gradient of 1:196. The longitudinal profile of this river also reveals two segments. Segment I extends for 200 km from the source up to a height of 200 m with gradient of 1:40 — it is the steeper part of the channel. Segment II descends to an elevation of 50 m, where it meets with the Rushikulya river with an average gradient of 1:526.

Cross profile

Profiles have been drawn across the basin to show the configuration of the landforms from west to east. It clearly shows the hills, valleys, plateaus, erosional and depositional landforms. For analysis cross profiles from south to north along the parallels have been drawn. The profile shows continuous rise and fall indicates different rate of development of fluvial erosional land forms. The southern part of the basin shows higher degree of denudation resulting in the formation of extensive plain (Summerfield and Hulion, 1994). In the northern part of the basin the denudational process is slow exhibiting extensive high lands. Towards the central part of the basin a number of isolated hills with extensive flood plain shows evidences of fluvial planation (Fig. 8).

Morphometric properties

The order of the Rushikulya basin has been determined with the application of Strahler's method of stream ordering. The bifurcation ratio ranges from 3.7 to 4, but it is exceptionally high in the 5th and the 6th order. The mean bifurcation ratio is 3.8 which is indicative of a dendritic drainage pattern and nearly homogenous condition in the development of the stream network (Abraham, 1984). But regional variations in the topography and morphological conditions are revealed in the varied bifurcation ratios

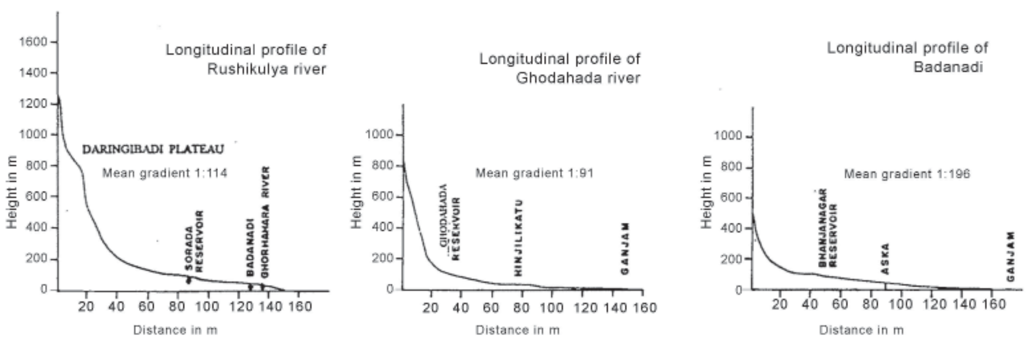

Figure 7. Long profiles of Rushikulya and its tributaries – Ghodahada and Badanadi

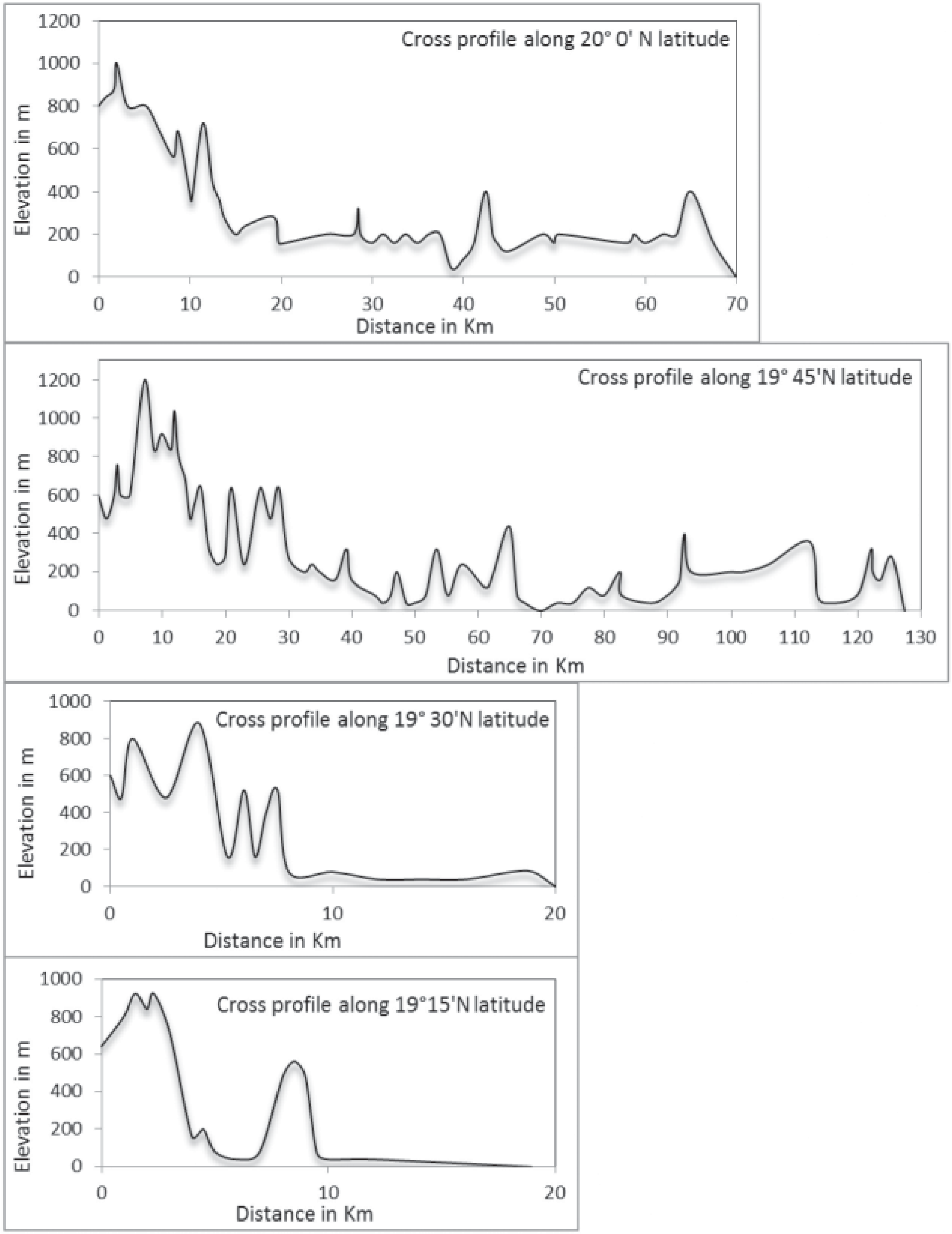

Figure 8. Cross profiles of Rushikulya basin drawn along selected latitudes

between different orders. In general, stream number and stream length conforms to the laws of morphometric properties of drainage basins, whereas mean stream area and mean stream slope do not reveal the conformity. This indicates the differential influence of topography and geology on the development of streams and their network (Table 3, Fig. 9).

Length of overland flow

The rain water flows for some distance as surface runoff before it is channelised as a stream. Since this length of overland flow is about half the distance between two streams, it is taken roughly equal to half the reciprocal of drainage density (Horton, 1945). For this basin the overland flow length is about 0.24 km^{-2}. In the overland flow map of the basin it can be seen that, its value is more where the surface is composed of rocks of less resistance, while the value is less when the surface rock is hard and resistant. In the Rushikulya basin its value is 1 at the catchment area and varies between 1 and 2 at the central part of the basin (Fig. 9).

Basin elongation

Basin elongation is the ratio of the diameter of a circle with same area as the basin to basin length (Schumm, 1956). The value of basin elongation is nearly 1 for basins which are nearly circular and has very low relief. The basin elongation ratio of Rushikulya basin is 0.8336. This confirms to the observation that greater part of the basin has low relief and the basin shape is nearly circular.

Stream Frequency

Stream frequency is the number of stream segments km^{-2}. It is obtained by dividing the total number of stream segments by the total drainage area.

In Rushikulya basin stream frequency is 0.11. In the basin it varies from less than 0.05 km^{-2} to 0.15 km^{-2}. Stream frequency is observed to be more when the overland flow gets plenty of time to cover a considerable distance, thereby developing small stream channels. The process of physical as well of chemical erosion takes place to curve out a permanent depression on the surface. The stream frequency decreases with decreasing hardness of the surface rock and retardation of overland flow (King, 1964). Surface water either seeps down rapidly or due to existence of loose bed rock most of the surface runoff is diverted underground. Slope of the land also plays a leading role in determining the stream frequency — steeper slopes have less frequency than gentler slopes.

In the basin maximum stream frequency is found in the catchment area of the Bada Nadi due to the presence of granite, gneiss and charnockite group of rocks in association with gentle slope. But in the catchment area of the Rushikulya river around Daringibadi plateau and downstream for some distance the stream frequency is less than 1 due to steeper slope

Table 3. Morphometric properties of the Rushikulya basin

Stream order	Number of streams	Bifurcation ratio	Mean stream length in km	Length Ratio	Mean stream area in km^2.	Mean stream slope in degree
1st	643		3.00		5.24	7.97
		3.70		2.40		
2nd	173		4.50		34.54	0.57
		4.10		2.40		
3rd	42		7.50		33.54	1.15
		3.00		1.00		
4th	14		22.00		631.25	0.11
		2.30		3.00		
5th	6		45.00		2391.00	0.11
		6.00		0.90		
6th	1		60.00		8402.33	0.06

and the presence of faults which reduces the overland flow. Similar situation prevails at the middle portion of the basin extending in semi-circular pattern from east to south of the basin. Another area with low values of stream frequency is just at the lower eastern part of the basin around the mouth of the river. The middle and lower part of the basin has low drainage frequency because of loose alluvial soil. Stream frequency within the value of 1

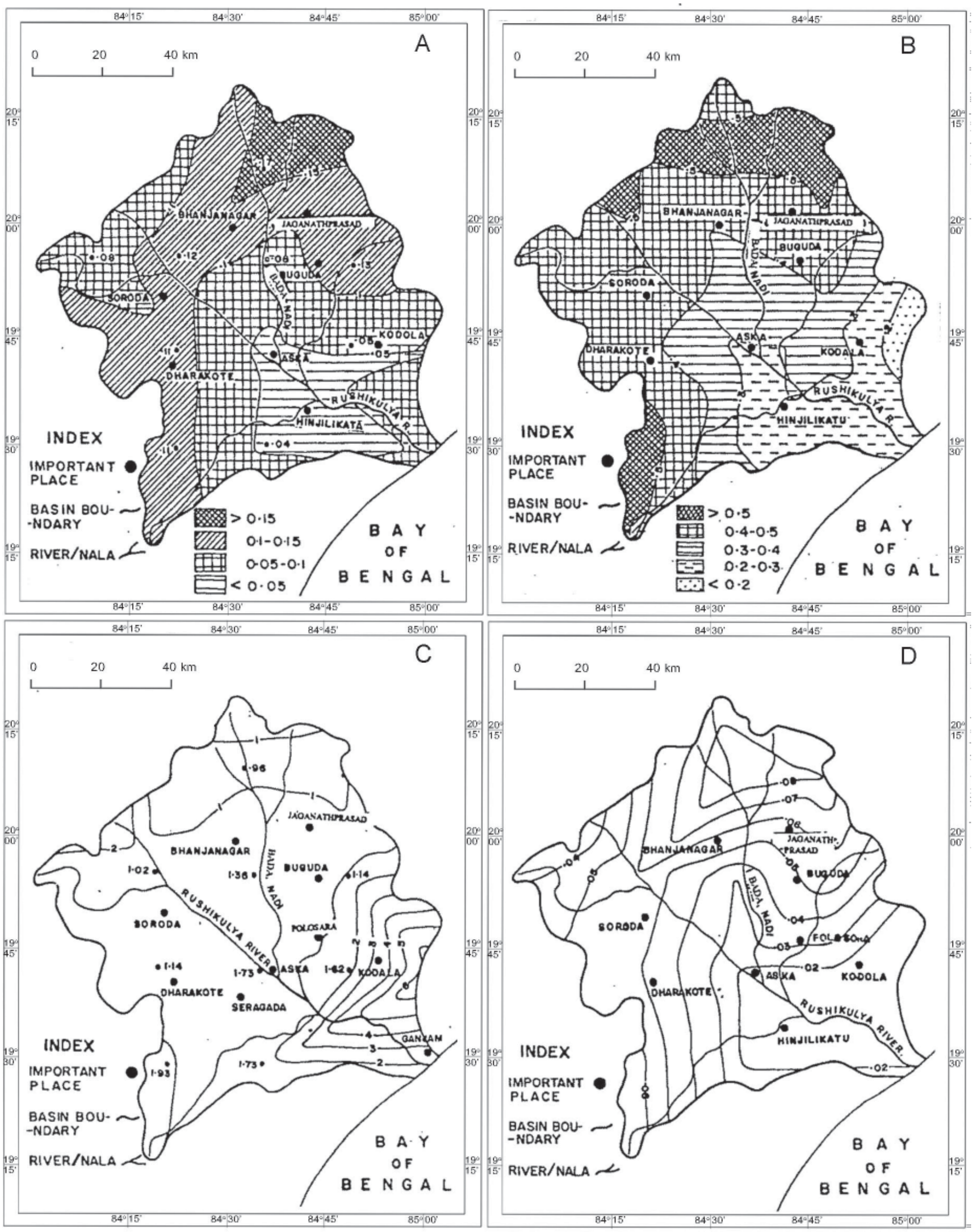

Figure 9. Morphometric properties of Rushikulya basin — A) Drainage frequency, B) Drainage density, C) Length of overland flow, D) Drainage texture

to 15 is found just downstream of the highest frequency of the basin in the northeast and medium frequency in the northwest. Lowest stream frequency of less than 0.05 is found at the lower part of the basin where seepage is more due to proximity to the coast (Fig.9 and Fig. 10).

Drainage density and texture

Drainage density is defined as the length of stream per km^{-2} area. The average drainage density of Rushikulya basin is 0.43 km km^{-2} and it is influenced by the nature of the bed rock, slope of the land, vegetation cover and the amount of rainfall received by the area. Drainage density is normally high near the catchment area which gradually decreases towards the coast. At the upper catchment the drainage density is 0.5 km km^{-2}. The value gradually decreases along the slope to less than 0.2 km km^{-2} near the mouth of the stream. The drainage density of an area reflects the texture of the drainage, which in its turn is dependent on the lithology, structure and hydrology of the area. The average drainage density of the basin being much less than 3 km km^{-2}.is categorised as coarse textured (Fig. 9).

Conclusion

The Rushikulya basin located within the Eastern Ghats has its catchment area within 40 km from the coast. This 6th order river basin is composed mainly of metamorphic rocks belonging to the Eastern Ghat group of rocks of Archaean age. Laterites and alluvial deposits of recent origin are found along the foothills and river valleys. The entire basin shows evidences of polycyclic evolution with differential rates of weathering. The eastern part of the basin is represented by denudational hills and alluvial flood plains. The basin topography slopes from the catchment to the middle part of the basin

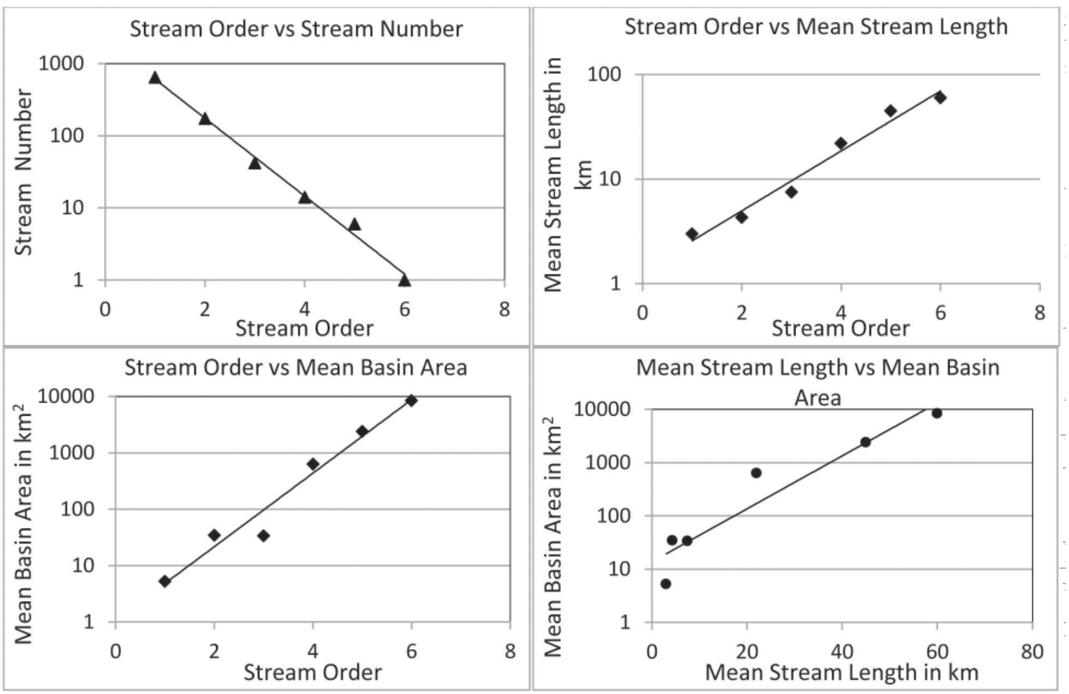

Figure 10. Relation between different morphometric parameters of Rushikulya basin.

and continues to the coast. Except for a few sinuous bends the river does not exhibit a meandering course, indicating a moderate gradient which allows quick discharge of flood water to the sea sometimes resulting in flash floods inundating the low lying areas. Sediment transport by the river is very low; hence there is no delta formation at its mouth. Isolated hills in the middle portion of the basin as indicated by the cross profiles show slow but steady rate of weathering leading to receding of the mountain front and rising of the flood plain level.

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