MORPHOMETRIC ANALYSIS OF THE POLYGENETIC DRAINAGE BASIN: A STUDY IN SALI RIVER, BANKURA DISTRICT, WEST BENGAL

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Abstract

In the present study, an attempt has been made to apply the various morphometric techniques to Sali river basin in Bankura district, West Bengal, which is developed over polygenetic surface. The morphometric characteristics of the basin contain important information regarding its formation and development, as all hydrologic and geomorphic processes occur within the basin area. The quantitative analysis of morphometric techniques of the said basin is very significant in understanding the landform processes, estimation of run-off, flood discharge, ground water recharge, soil and water conservation and sustainable environmental management. For detailed study, different statistical techniques and Geographical Information System (GIS) has been applied to evaluate the linear, areal and relief aspects of the said basin. Different thematic maps i.e. drainage density, drainage frequency, stream ordering and other maps have been prepared by using GIS software.

Keywords: Morphometric techniques, Polygenetic surface, Sustainable environmental management, Geographical Information System (GIS).

Introduction

The Morphometric Analysis of The Drainage Basin Plays A Vital Role In Understanding The Geo-Hydrological Behavior of drainage basin. Quantitative analysis in the field of geomorphology marked its era with the analysis of drainage basin. The drainage basin is considered as more logical geomorphic units, so the quantitative assessment of drainage networks of a basin can provide useful clues to understanding the basin geometry. According to Gardiner (1982, p.131), the morphometry is potentially a most important approach to geomorphology, since it affords quantitative information on large scale fluvial landforms, which make up the vast majority of the earth configuration. Morphometry is the measurement and mathematical analysis of configuration of the earth's surface, shape and dimensions of its landforms (Clark, 1966, p. 235). Systematic description of the geometry of a drainage basin and its stream channel system requires measurement of linear aspects, areal aspects and relief properties of the drainage basin. Morphometric analysis of a watershed provides a quantitative description of the drainage system,

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which is an important aspect of the characterization of watersheds (Strahler, 1964). GIS techniques are presently used for assessing various terrain and morphometric parameters of the Sali river basin or watershed, as they provide a flexible environment and a powerful tool for the manipulation and analysis of spatial information.

Geo-Identity of the Study Area

The study area is located in the north and north-eastern parts of Bankura district, West Bengal, India. Sali is an important right bank tributary of Damodar River that drains the northern part of Bankura district in the Indian state of West Bengal. The Sali River basin with an elongated shape is located in between 23^0 $07^/$ to 23^0 26 $^/$N latitude and 87^0 $3^/$ to 87^0 $38^/$ E longitude and its total geographical area is about 727.13 Km^2. It covers the interfluve area between Damodar River in north and Dwarakeswar River in the south. The Sali River originates from north-western part of the study area (Belbuni and Rajamela village, Gangajalghati block) in pedimental landforms. The Sali River flows towards north-western to south-eastern direction and meets with river Damodar near Somsar village in Indus block of north-eastern parts of Bankura district. The total length of Sali River is 80.75 km.

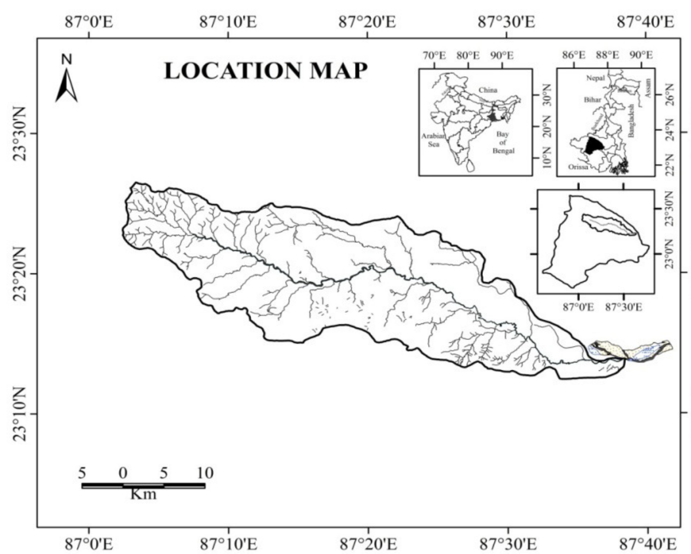


Figure 1: Location map of the Sali river basin.

The basin is characterized by sub-tropical wet and dry type climate of mean monthly temperature is ranging between 20^0C to 40^0 C and annual rainfall varies from 1100 mm to 1400 mm. The average number of rainy days in a year is 69; about 78 percent of the rainfall comes from south –

west monsoon (four monsoon months June to September) wind. North-western and southern part of the Sali basin is covered with Protected Forest (P.F), mainly dry deciduous forest (Sal, Eucalyptus, Akashmani, Sonajuri, Mahua, Palsh and open scrubs,etc) .North-eastern and eastern part is mainly characterized by fertile agricultural land. Lateritic soil, yellowish brown red soil, yellowish alluvial soils are the dominant soils in the study area.

Data Source and Objectives

In the present study, the following data have been identified which is very much relevant in the present work.

Table 1: Source of data for morphometric analysis.

Data	Source	Year
Topographic maps (Sheet Number 73M /3,7,8,11,12; scale 1:50,000) Toposheet No.73M on 1:250,000 scale	Survey of India	1976 & 2004
IRS P 6 LISS III in 4 bands (Green: 0.52 - 0.59µm, Red: 0.62 - 0.68µm, NIR: 0.77 - 0.86µm and SWIR: 1.55 - 1.70µm)	National Remote Sensing Agency (NRSA), India	24 Jan, 2011
Geological map of Bankura	Geological Survey of India	2001
Field data	Ground truth collected during the study	2013-2014

Morphometric analysis has been done based on Topographical map and satellite imagery. The geological map of the study area under reference has been consulted to find out the relationship of structure, lithology and tectonics with the various fluvio-geomorphic attributes of the basin and finally different morphometric parameters have been generated through GIS software.

The main objectives of the study area are as follows:

- To analyze the linear, areal and relief morphometric characteristics of the Sali river basin.
- To show relationship between different morphometric attributes with various geomorphological processes operating in the basin.
- To identify the stage of the cycle of erosion in the Sali river basin and its tributary basins.

Geology and Hydrological Condition

The Sali river basin is not developed over homogenous structure but developed over polygenetic surface. The upper part of the Sali basin is predominantly a pre- cambrian gneissic terrain, characterized by the Archean-Proterozoic associations whereas middle part of the basin formed by lalgarh formation (laterite -yellowish brown sandy silt (latosol),dark brown hard crust (duricrust)) and lower (eastern) parts of the basin are formed by Tertiary and Quaternary deposits(sandy alluvial soil). Chotanagpur Granite- Gneiss Complex (CGC) consists of Achaean Gneiss, Schist, Amphibolite, Hornblend, Dolerite, Porphyritic Granite, Pyroxinite Granite, Phyllite & Mica–Schist of different ages with enclaves of meta sedimentaries. In the upper catchment presence of crystalline rock and in the middle catchment lateritic mass due to their compactness and low permeability do not serve as good aquifer for large ground water storage. But in this area fault, joint and fracture identified as lineament act as conduits for ground water recharge. Lower and middle parts mainly characterized by older and younger alluvium conducive for ground water storage.

Morphometric Analysis

Table 2: Morphometric analysis of the Sali river basin

Morphometric Parameter	**Formula / Definition**	**Reference**	**Result**
LINEAR ASPECT			
Stream Order (Su)	Hierarchical Rank	Strahler (1964)	5^{th}
Stream Number (Nu)	Nu = N1+N2+…Nn	Horton (1945)	311
Stream Length (Lu)	Length of the all stream	Strahler (1964)	540.37 km
Mean stream length (Lsm)	Lsm=Lu/Nu; Where, Lu=Mean stream length of a given order (km), Nu=Number of stream segment.	Horton (1945)	1.01-33.88
Stream length ratio (RL)	RL= Lu / Lu-1 Where, Lu= Total stream length of order (u), Lu-1=The total stream length of its next lower order.	Horton (1945)	0.54-6.36
Bifurcation Ratio (Rb)	Rb = Nu / Nu+1 Where, Nu=Number of stream segments present in the given order,Nu+1= Number of segments of the next higher order	Strahler (1964) Schumm (1956)	2.00 – 7.50
Weighted Mean Bifurcation Ratio(Rb_w)	$Rb_w = Rb1 \times n_1 + Rb_2 \times n_2 + \ldots / n_1 + n_2 + \ldots$	Horton (1945)	3.88
AREAL ASPECT			
Drainage density (Dd)	Dd=L/A Where, L=Total length of stream, A= Area of basin.	Horton(1945)	0.74 Km/Km^2
Drainage Frequency (Df)	Df = ∑ N / A , ∑ N= Total no. of stream segment, A= Basin Area	Horton(1945)	$0.43/km^2$
Drainage Texture (Dt)	Dt = Nu /P Where, Nu = No. of streams in a given order and P = Perimeter (Km)	Horton(1945)	1.93/km

Infiltration Number (Dn)	Dn=Dd*Df	Faniran (1968)	0.32
Drainage Intensity (Di)	Di= Df/Dd	Faniran (1968)	0.58
Length of Overland Flow (Lg)	Lg =A/2*Lu or, Lg=1/2D Km Where, D=Drainage density (Km/Km2)	Horton (1945)	0.67 km.
Constant of Channel Maintenance (C)	C = 1 / Dd, where Dd =drainage density	Schumm (1956)	1.35 Km^2/ Km
Elongation ratio (Re)	Re=√(Au/π)/ Lb Where, A=Area, Lb=length	Schumn (1956)	0.47
Form Factor (Rf)	Rf = A/Lb^2 Where, A = Area of the basin and Lb = (Maximum) basin length	Horton (1945)	0.17
Circulatory ratio (Rc)	Rc = 4πA/ P^2 where, A = Basin area (Km2) and P= Perimeter of the basin (Km)	Strahler(1964), Miller(1953)	0.35
RELIEF ASPECT			
Basin Relief (H)	H= E – e Where, E = Maximum elevation of the basin (m) and e = Minimum elevation (m)	Schumn (1956)	117 m.
Relief Ratio (Rh)	Rh =H / Lb Where, H=Basin relief, Lb=Basin length	Schumn (1956)	1.81
Ruggedness Number (Rn)	Rn = Dd * (H /1000) Where, H= Basin relief, Dd=Drainage density	Schumn(1956)	0.087
Hypsometric Integrals (Hi)	Hi=h/H & a/A	Strahler (1952)	48.21%
Erosional Integrals (Ei) %	Ei=h/H & a/A	Strahler (1952)	51.79 %

Source: Calculated from Topographical map and satellite imagery.

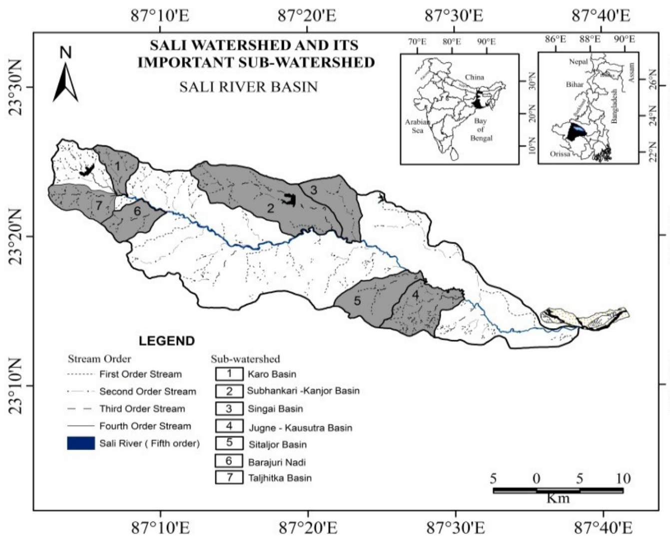
Linear Properties of the Drainage Basin

Stream Order (Su)

The first step in basin morphometry is the stream ordering. The concept of stream order was first introduced by Horton (1945) and later modified by Strahler (1957 and 1964), Bowden and Wallis (1964), Scheidegger (1965), Woldenberg (1966) and Shreve (1967). In this paper the stream ordering has been done by Strahler (1964) method. In the study reveals that the Sali basin is 5^{th} (V) order drainage basin. It has also noticed that there is a decrease in stream frequency as the stream order increases (Table 3). The variation in stream order in the said basin is due to physiographic and geological condition of the basin.

Stream Number (Nu)

The total number of order wise stream segments is known as stream number. In this study, the channel segments of different drainage basins are ranked according to Strahler's stream ordering system. Horton (1945) states that the numbers of stream segments of each order form an inverse geometric sequence with order number (Figure 2b).



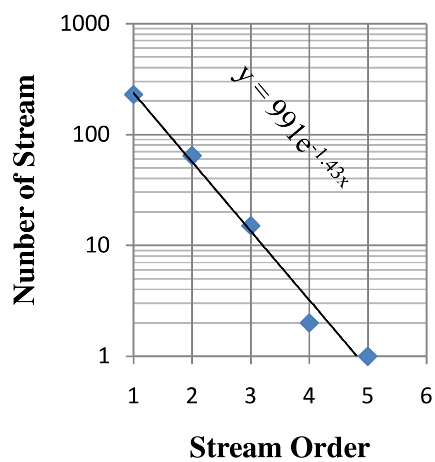


Figure 2a: Sali watershed and its tributary basin.

Figure 2b: Relationship between stream ordering and number of stream.

Table 3: Linear properties of the Sali river basin

Stream Order	Stream Number	Stream length (km)	Bifurcation Ratio	Weighted Mean Bifurcation Ratio	Mean Stream Length	Stream Length Ratio
I	229	229.18		3.88	1.01	
			3.58			2.25
II	64	145.20			2.27	
			4.27			2.35
III	15	79.89			5.33	
			7.50			6.36
IV	2	67.75			33.88	
			2.00			0.54
V	1	18.36			18.36	

Source: Calculated from Topographical map and satellite imagery.

Stream Length (Lu)

The total stream length is maximum for first order and decreases as the stream order increases. Some discrepancy is also noted in both right and left bank tributaries (like Singai nadi) where second order stream length is greater than first order stream due to variation in geological structure and slope of the concerning order. The plotting of logarithm of stream length against stream order shows the linear pattern which indicates the basin is subject to weathering-erosion characteristics (Figure 3b).

Mean Stream Length (Lsm)

Mean stream length is a dimensionless property revealing the characteristic size of components of a drainage network and its contributing basin shape (Strahler 1964, p.4-45). Mean stream length is the ratio between the total stream length and the number of streams of a given order. The mean stream length of fifth order tributary (Sali River) is 18.36 (Table 4).The mean stream length of the Sali river basin follows Horton's law of stream length. The lower value of mean stream length indicates higher number of stream segment in that order or vice versa.

Stream Length Ratio (RL)

The stream length ratio is the ratio between the mean stream length of one order to that of the next lower order of stream segment. Stream length states that mean stream length of each successive orders of a basin tends to approximate a direct geometric series with stream length increasing towards higher order of streams (R.E. Horton, 1945).Table 3 indicates that the stream length ratio is increasing with the increasing orders in most of the drainage basins, but there are discrepancy is noted in different drainage basins due to variation in lithology and slope(Karo Nadi in between II and III order , Kausutra Nala-Jugne Nadi in between III and IV order). The increasing length ratio indicates mature stage of geomorphic development of the basin. So Sitaljor Nadi (23.27), Subhankari-Kanjor Nadi (9.73), Barajuri nadi (8.52), Taljhitka Nadi (6.46), Singai Nadi (6.31) are in early mature stage and other basins show the late mature stage of geomorphic development.

Bifurcation Ratio (Rb)

The ratio between the total numbers of streams of one order to that of the next higher order in a drainage basin is known as bifurcation ratio. High values of the Rb indicate strong structural control on drainage pattern and low value indicates that the basin has suffered less structural disturbance and drainage pattern has not been distorted (Nag.S.K, 1998). The bifurcation ratio is considered as an indicator of the shape of the basin. An elongated basin is likely to have a high bifurcation ratio, while a circular basin is likely to have a low bifurcation ratio. The Rb value of the study area ranges from 7.50 (III- IV order) to 2.00 (IV- V order).The large variation in stream frequency between successively higher order stream result in higher values of bifurcation ratio (Table 3).

Weighted Mean Bifurcation Ratio (Rbw)

The weighted mean bifurcation ratio is an index of the more representative bifurcation ratio for each successive pair of orders, which is obtained by multiplying the bifurcation ratio for each successive pair of stream orders by the total number of streams involved in the ratio and then dividing the sum of these values by the sum of the total number of stream segments involved in each pair (Strahler, 1953). The value of the weighted mean bifurcation ratio of the study area is 3.88 (Table 3).

Table 4: Linear properties of the Sali River and selected tributary basins.

Name of the Basin	Area (km2)	Order	Total length (km)	Mean Stream Length (km)					Rb	Dd	Df	Dn	Er	Cr	Rf
				I	II	III	IV	V							
Sali River	727.1	5th	540.37	229.18	145.20	79.89	67.75	18.36	3.88	0.74	0.43	0.32	0.47	0.35	0.17
Kausutra Nala-Jugne Nadi	36.68	4th	54.33	28.74	12.09	9.84	3.65		4.25	1.48	1.5	2.22	0.65	0.46	0.34
Subhankari-Kanjor Nadi	78.52	3rd	57.8	26.02	10.8	20.99			4.35	0.73	0.36	0.26	0.56	0.43	0.25
Sitaljor Nadi	36.07	3rd	18.27	9.6	0.69	7.98			3.13	0.51	0.28	0.14	0.61	0.51	0.29
Barajuri Nadi	21.00	3 rd	13.23	5.45	2.03	5.75			2.75	0.63	0.57	0.36	0.85	0.65	0.57
Karo Nadi	16.22	3 rd	19.51	8.88	6.82	3.81			3.79	1.2	1.00	1.18	0.67	0.54	0.36
Taljhitka Nadi	23.9	3 rd	27.67	12.64	7.24	7.8			3.68	1.16	1.05	1.22	0.71	0.66	0.4
Singai Nadi	29	2nd	12.63	4.07	8.56				3	0.44	0.14	0.06	0.68	0.5	0.36

Source: Calculated from Topographical map and satellite imagery.

Areal Properties of the Drainage Basin

Drainage Density (Dd)

Drainage density is the ratio between the total lengths of stream in a drainage basin to the area of that drainage basin. Drainage density is an important indicator of the linear scale of landform element in stream eroded topography. Low drainage density generally results in the area of highly resistant or permeable subsoil material and high drainage density is the resultant of weak or impermeable subsurface material (S.K.Nag, 1998).The drainage density value in the study area is 0.74 Km/ Sq.Km indicating moderately low drainage density (Figure 3a) .

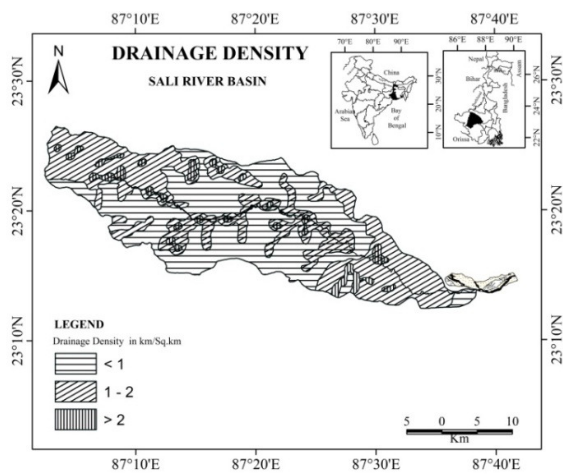


Figure 3a: Drainage density in the Sali river basin

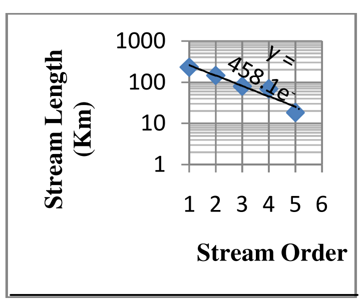


Figure 3b: Relationship between stream ordering and stream length

Drainage Frequency (Df)

Drainage frequency is defined as the number of stream segments per unit area of a drainage basin (Horton, 1945). In the present study area, the value of drainage frequency is 0.43/ Sq.Km. It exhibits positive correlation with drainage density in the basin indicating an increase in stream segments with respect to increase in drainage density.

Drainage Texture (Dt)

Drainage texture is one of the important concept of geomorphology which means that the relative spacing of drainage lines (Pareta.K, 2011). The drainage texture is defined as the ratio between total number of stream segments of all orders per perimeter of that area. Smith (1950) has classified drainage texture into five classes i.e, very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (>8).In the present study area, the drainage texture of the basin is 1.93 and categorized as very coarse drainage texture.

Infiltration Number (Dn)

The infiltration number of a basin is defined as the product of drainage density and stream frequency which gives an idea about the infiltration characteristics of that basin. The higher the infiltration number, the lower will be the infiltration and the higher run-off. The infiltration number in the study area is 0.32 (Table 2).

Length of Overland Flow (Lg)

The Length of Overland Flow (Lg) is the length of water over the ground surface before it gets concentrated into the definite stream channel (Horton, 1945). The length of overland flow is approximately equal to the half of the reciprocal of drainage density. In the present study, the length of overland flow of the Sali river basin is 0.67 Km, (Table 2), which indicating moderate surface runoff of that area.

Constant channel maintenance (C)

Schumm (1956) used the inverse of drainage density or the constant of channel maintenance as a property of landforms. The constant indicates the number of Km^2 of basin surface required to develop and sustain a channel 1 Km long. The constant of channel maintenance indicates the relative size of landform units in a drainage basin and has a specific genetic connotation (Strahler, 1957). Channel maintenance constant of the watershed is 1.35 Km^2/Km (Table 2). It means that on an average 1.35 sq.km surface is needed in basin for creation of one linear km of the stream channel.

Elongation Ratio (Re)

The elongation ratio is a representation of the shape or form of a drainage basin. It is the ratio between the diameter of a circle with the same area as basin and maximum basin length (Schumm, 1956, p.612). Elongation ratio can be grouped into three class namely Circular (>0.9), Oval (0.9-0.8), and Less elongated (<0.7). In the present study area, the elongation ratio of the Sali river basin is 0.47 which indicating moderately low relief of the terrain and elongated shape of the drainage basin.

Form Factor (Rf)

The ratio of basin area (Au) to the square of basin length is called form factor (Horton, 1932). This factor indicates the flow intensity of a basin of a defined area. The form factor value of the basin is 0.17 which indicates lower value of form factor and thus represents elongated in shape. The elongated basin with low form factor indicates that the basin will have lower peak flows for longer duration.

Basin Circularity Ratio (Rc)

Circularity ratio is also dimensionless index to indicate the outline form of drainage basins (Strahler, 1964, p.451and Miller, 1953, p. 8).It is the ratio between the basin area and the area of a circle having the same perimeter of the basin. This ratio is influenced by the length and frequency of streams, geological structures, land use/ land cover, climate and slope of the basin. The circularity ratio of the study area is 0.35 which indicating that the basin is elongated in shape and highly permeability of the subsoil condition.

Relief Aspect of the Drainage Basin

Relief Ratio

Difference in elevation between highest point of the basin and lowest point of the valley floor of that basin is known as the total relief of that drainage basin. The relief ratio is the ratio between the total relief of a basin and the longest dimension of the basin parallel to the principal drainage line (Schumm, 1956, p.119). It gives an idea of the overall steepness of a drainage basin and indicates the intensity of degradational processes operating on slopes of that particular basin. There is a direct relationship between relief ratio and channel gradient, i.e, lower the relief ratio, lower the mean channel gradient of the main valley and vice versa. The relief ratio of the Sali river basin is 1.81 indicating moderately low relief and moderate slope.

Table 5: Different morphometric parameters in Sali River and its tributaries

Basin Geometry	**Result**
Basin Order	5th
Basin Area (A) in Sq Km	727.13
Basin Length (Lb) in Km	64.51
Mean Basin Width (Wb) in Km	11.27
Basin Perimeter (P) in Km	161.06
Relative Perimeter (Rp) Rp= A/P	4.51
Main Channel Length (Cl) in Km	80.75
Total Basin Relief (H) in m	117
Drainage Pattern	Dendritic

Source: Calculated from Topographical map and satellite imagery.

Ruggedness Number

It is defined as the product of relative relief and drainage density. It is a combined expression of relief, texture and slope steepness of a drainage basin. The value of ruggedness number in present basin is 0.087 (Table.2).The low ruggedness value of the basin implies that area is less prone to soil erosion and have intrinsic structural complexity in association with relief and drainage density (Pareta.K, 2011).

Hypsometric Analysis (Hs)

In the present study area percentage hypsometric curve method has been used and calculated the hypsometric integral (Hi), erosion integrals (Ei), which provided the accurate knowledge of the stage of geomorphic development. The hypsometric integral of the Sali river basin is 48.21% and the erosion integral of the watershed is 52.79% (Table 2), which indicates the middle mature stage of the basin development.

Texture Ratio (Rt)

The texture ratio is expressed as the ratio between the first order streams and perimeter of the basin (Rt = Nl / P) and it depends on the underlying lithology, infiltration capacity and physiographic condition of the terrain. In the said basin, the texture ratio of the basin is 1.42 and categorized as low in nature.

Conclusion

The morphometric properties of the Sali basin clearly reflect the polygenetic character of the basin, because morphometric parameters of the Sali basin and selected seven drainage basins are different in different lithological condition. The overall morphometric analysis shows that the basin has medium relief and elongated in shape. The dendritic pattern of drainage indicates that there is less structural control in drainage network and the development of stream segments more or less affected by rainfall. The coarse drainage texture and moderately low stream density of the basin revels that the nature of subsurface strata is permeable. Rc, Rf and Re show that elongated shape of the basin has low discharge of runoff and moderately low relief of the terrain. The study also reveals that the basin is passing through middle to late mature stage of the geomorphic development.

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