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Geomorphometric Analysis of Chamoli and Karnaprayag District, Uttrakhand in Respect to Hazard Zonation of The Area

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Abstract

Chamoli and Karnaprayag district of Uttrakhand comprises of fragile lithological formations and lies in highly vulnerable zone in terms of natural disasters. It's latitude and longitude ranges between 29°50'N to 30°40'N and 78°40'E to 79°50'E. The area is highly prone to frequent hazards like landslide, earthquake, cloud burst and flash floods. Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) has been used for preparing Digital Elevation Model (DEM), slope, aspect and various other maps which have been used for evaluation of linear and areal parameters. The studies have been carried out on 64 selected 4th order river basins in Chamoli and Karnaprayag district using ARC GIS. There are various parameters like stream order, stream number, Bifurcation ratio, Drainage density, Form Factor, Elongation ratio etc. had been analyzed on the river basins. The lower values of Bifurcation ratio in basins represent geological heterogeneity, high permeability and less structural control. The value of Drainage Density varies between 1.3-2.2 Km^{-1} which implies development of coarse grained texture. The complex relationship between the values of Elongation ratio, Circularity ratio and Form factor in some basins represents that these passing through structural thrust. The anomalous values of linear and areal parameters suggest that basins of the study area are geologically, structurally and lithologically controlled. The occurrences of landslide, earthquake has reliable relation with computed parameters. Since the outcome of the study will act as precursors for natural disasters.

Keywords: Geomorphometric; Aster; GDEM; GIS

Introduction

Himalaya are one of the youngest and active tectonic belt on earth which consequently affect geology, hydrology, geomorphology and environment of the river basins. GIS technologies are broadly used in morphometric analysis to determine tectonically active regions [1-3]. The basic fundamental unit of morphometric analysis is ground water. Its occurrence is a result of interaction of various parameters like climate, geomorphology and structural parameters [4]. Morphometric analysis is a quantitative description and mathematical analysis in configuration of earth's surface, shape and various other dimensions [5,6]. Role of rock types and geological structure in development of stream network can be implicit with morphometric analysis [7]. In the field of basin Morphometric analysis forerunner work has been carried out by Horton [8] and Strahler [9]. Quantitative measurements of Morphometry used as a reconnaissance tools to make interpretations about specific characteristic of an area. Geomorphology and hydrology of the river basin is intrinsically related to morphometric parameters as change in dependent morphometric parameters will consequently affect behaviour of river [10]. Morphometric characteristics at watershed scale contains relevant information as all the hydrological and geomorphological activities occurs within watershed. In the present analysis an attempt has been made to decipher the different stages of geomorphic development with the support of morphometric parameters like streams order, streams number, streams length, mean streams length, bifurcation ratios, elongation factor, circularity index, drainage density, stream frequency, length of overland flow, constant channel maintenance, infiltration number, hypsometric curve and various other parameters. The delineation of 64 basins of Alaknanda River along Chamoli and Karnaprayag has been done using Horton [8] method modified by Strahler [9]. The basin analyzed in this study will help in identifying landslide susceptible areas which may need proper mitigation and management measures for safe development planning.

Study Area

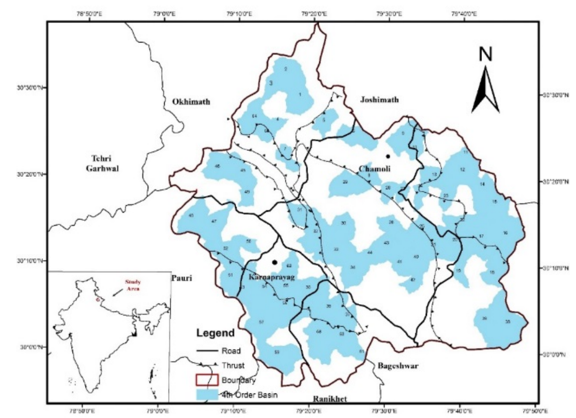

Figure 1: Study area Map.

The Alaknanda River, which originate from Satopanth glacier in Garhwal Himalaya, passes through Chamoli and Karnaprayag sub district of the study area. The area is located between the latitude 29°50'N to 30°40'N and Longitude 78°40'E to 79°50'E which covers an area of 3362 Sq.Km and Perimeter of 312 Km. The location map of the

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study area is shown in Figure 1. The main rock type are schist phyllites and quartzite's. The average annual rainfall is around 1230 mm and the maximum and minimum temperature of study area varies between 31°C to -2.9°C. Total of 64 sub watershed basin of the river Alaknanda in Chamoli and Karnaprayag district have been studied.

Geology and Geomorphology

Geologically the area belongs lesser Himalayan sequences, ranging from green schist to lower amphibolites facies. The main rock types are schist's, phyllite and quartzites. The major geological groups and formation of Chamoli and Karnaprayag district are represented in the Figure 2. Munsiari formations and Baijnath klipee lies under the active tectonic zone and this particular geological formation in high hazard zone as per morphometric analysis. Geomorphologically Chamoli district comprises of narrow valleys, cliffs and deep gorges having very high gradient. Alaknanda river basins in the area comprises of distinctive litho stratigraphy, active tectonics and structural complexities. Cliffs are more prone towards subsidence and dislocation of rock masses. Chamoli district had been classified into phreatic zone due to irregularly distributed heavy rainfall [11].

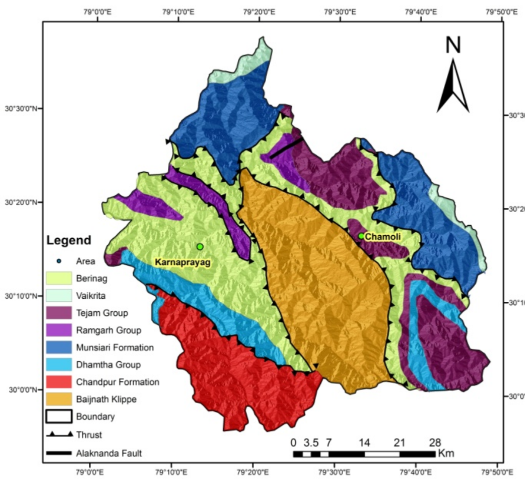

Figure 2: Geological Map of the Study Area.

Methodology

Survey of India (SOI) toposheet number 53 O, M and N in the scale of 1: 50000 along with that satellite Images and ASTER GDEM data were used to create base maps which have been used to create base map. 64 drainage basins were identified and delineated. Linear and Areal parameters of Morphometric analysis is described Table 1. The elevation data was collected from ASTER GDEM stands for Advanced Space borne Thermal Emission and Reflection Radiometer, Global Digital Elevation Model. It has resolution of 30 m and an accuracy of 10 m. DEM is providing data in 1° × 1° in Geotiff format with Geographic coordinate system. The stream ordering was done using Strahler [9] method on base maps and well as on ASTER GDEM. Various maps like slope map, relief map, aspect map, shaded relief maps, classified elevation maps and other geomorphological maps were prepared in consideration with Landslide Hazard Aspects.

Result and Discussion

Morphological studies play a key role in identifying the behavior of the river, aggradations or degradation, shifting of river course. These studies will help in predisaster planning for various hazard like landslide, earth quakes etc. Morphometric analysis carried out for 64 Fourth-order drainage sub-basins of Alaknanda River in Chamoli and Karnaprayag region and describe feature and it's characteristic. Also, an attempt has been made to find out the stages of geomorphic development with the help of the Morphometric parameter given in Table 1. Their affects are correlated on lithological, structural and various other tectonic parameters.

Linear parameters

There are various parameters which comes under linear aspects of a drainage basin such as stream order, stream number, stream length, mean stream length, stream length ratio, bifurcation ratio, mean bifurcation ratio and basin length.The size of rivers and basins varies greatly with the order of the basin. Ordering of streams is the first stage of basin analysis.

Parameters		Symbol	Formula	Reference
Linear Parameters	Stream Order	U	Stream order only increases when streams of the same order intersect. Therefore, the intersection of first order link and second order link will remain a second order link ,rather than create a third order link	[9]
	Stream Number	Nu	Total number of streams (Nu) of a given order (U) within basin.	[9]
	Total Stream Length	Lu	The summation of the length of all streams within each basin boundary	[8]
	Mean stream Length	Lū	Lū=Lu/Nu Lu=Total stream length of order 'u' Nu=Total no. of stream segments of order 'u'	[15]
	Bifurcation Ratio	Rb	Rb=Nu/Nu+1 Nu=Total no. of stream segments of order 'u' Nu+l=Number of segments of the next higher order	[16]

	Mean Bifurcation ratio	Rbm	Rbm=Average of bifurcation ratios of all orders	[9]
	Basin Length	Lb	The maximum Length of the Basin	-
Areal Parameters	Drainage area	Au	Area bounded by drainage basin boundary	-
	Drainage Density	D	D=ΣLu/ Au Lu=Total stream length of all orders Au=Area of the Basin (km^2)	[17]
	Stream Frequency	F_s	Fs=ΣNu/Au Nu=Total no. of streams of all orders Au=Area of the Basin (km^2)	[8]
	Drainage Texture ratio	R_T	Rt=ΣNu/P Nu=Total no. of streams of all orders P=Perimeter (km)	[8]
	Elongation Ratio	Re	Re=2{√(Au/π)}/Lb Au=Area of the Basin (km^2) π (Pi)=3.14; Lb=Basin length	[16]
	Circularity Ratio	Rc	$Rc=(4\pi Au)/P^2$ π (Pi)=3.14 Au=Area of the Basin(km^2), P=Perimeter (km)	[20]
	Form Factor	R_f	$Rf=Au/Lb^2$ Au=Area of the Basin (km^2) Lb^2=Square of Basin length	[17]
	Infiltration number	If	If=D.Fs D=Drainage density, Fs=Stream Frequency	[21]
	Length of overland flow	L_g	Lg=Au/2.ΣLu, Au=Drainage Area; Lu=Total stream length	[8]
	Constant Channel of Maintenance	C	C=I/D D=Drainage density	[16]

Table 1: Morphometric parameters.

Stream order (U): The streams of Chamoli and Karnaprayag area have been ranked according to the method described by Strahler [9] which was slightly modified from Horton [8]. According to this method streams order increases only when streams of same order intersect. Confluence of two first order streams will results in second order stream whereas convergence of two second order streams will results in third order streams and so on. The high values of streams order represent high drainage development and predominant dendritic pattern represents lithological homogeneity [12]. Highest numbers of streams are in first order and it continuously reduces as stream order increases [13]. The trunk stream/main River will be assigned as stream of highest order. In our study area Alaknanda River is identified as the stream segment of highest Order. Higher number of streams in first and second order in study area indicates that it's more prone towards erosional processes.

Stream number (NU): Stream order is inversely proportional to stream number as stream order increases number of streams segments of higher order will decrease [14]. The highest number of stream segments of whole basin is observed are 10742 in first order while 84 in 7^{th} order stream segments. The Streams number of each basin is described in Table 1. Stream power has much correlation with Stream number as amount of discharge will increase in stream number of particular order. Analysis of Stream order against stream segments increases with decreasing stream order. Figure 3 indicates that number of stream segments increases with decreasing stream order.

Stream length (LU): It's the most important fluvial parameter of the basin as it reveals Surface runoff behaviour. Lu of various segments is calculated with the help of ARC GIS. It's measured from the farthest drainage divide to the mouth of the river based on the law proposed by Horton [8]. The cumulative length is highest in first order streams and it's continuously decreases when stream order increases. Smaller length streams are indicative of high slopes in respect to longer length streams that have much flatter gradient. Graphical Plot between basin area and

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total stream length (Lu) had shown conformable relationship in Figure 4.

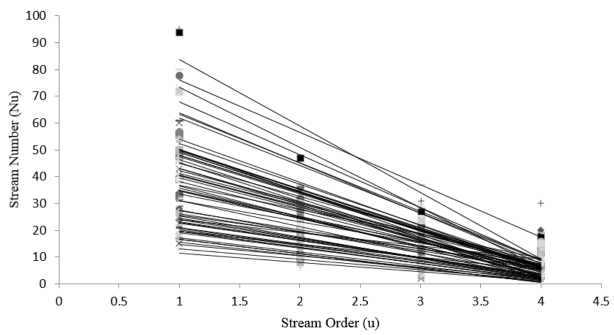

Figure 3: The number of stream segments and their stream order.

Mean stream length (LSM): Mean Stream length is a characteristics property has a direct influence on drainage network components and connected basin surfaces [15]. It's a dimensionless property which has been calculated by total length of stream order (U) by the Stream segment of that particular order. Mean stream length increases with increase in stream order. Anomalous trend in the values of mean stream length representing structural complexities, variable lithology in the basin. These basins are passing through thrusts and faults.

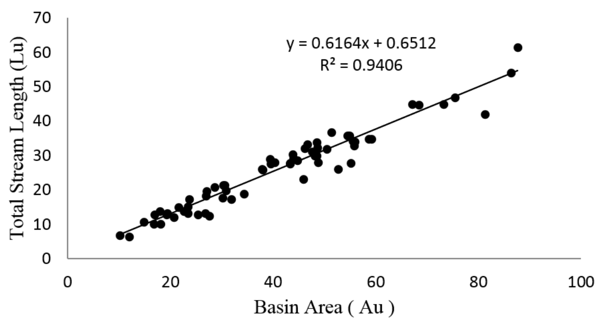

Figure 4: A Graphical Plot between basin area and total stream length.

Bifurcation ratio (RB): Bifurcation ratio describes the branching pattern of a drainage network and it's the ratio of total number of stream segments of order (U) to the segments of the next high order [16]. Lower values of Rb have lesser structural disturbances in respect to basins which had higher value of Bifurcation ratio is generally found in highly dissected drainage basins [8]. Bifurcation ratio characteristically ranges between 3.0 and 5.0 for basins in which geological structure don't have much influence [8,15]. It's noticed more than half of the watersheds in study area have higher value of bifurcation ratio for the first and second order streams. Higher value of bifurcation ratios for the first and second order streams indicate more chances of erosion in the upper reaches of a mountainous watershed. The graph between mean bifurcation ratio and Basin index is represented in Figure 5. The value of Mean bifurcation ratio in all the watershed ranges between 1.64 to 5.37 and the average of all watersheds is 2.09. The lower values of Bifurcation ratio represent geological heterogeneity, higher permeability and less structural control.

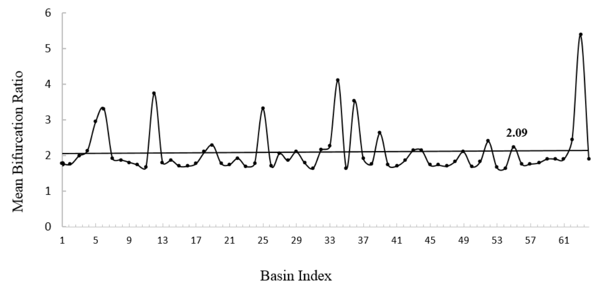

Figure 5: A graph between mean bifurcation ratio and basin index.

Areal parameters

The areal aspects are a two-dimensional property of the basin. There are various areal parameters of the study area like drainage area, drainage density, stream frequency, drainage texture ratio, elongation ratio, circularity ratio, form factor, infiltration number, length of overland flow and constant of channel maintenance is calculated to determine the hydrological parameters.

Drainage area (AU) and perimeter (P): The area drained by streams or system of streams such that all streams flow originating in the area is discharged through a single outlet is termed as drainage area [12]. Perimeter is the length of the boundary of the basin which can be calculated from topographical maps and ARC GIS 9.3. It's an important parameter in hydrology because it directly affects the size of storm hydrograph and magnitude of peak and mean runoff. The calculation of all the basins had been done using Arc GIs 9.3 and using topographical maps. The total drainage area of basin is 3362 Sq Km. The perimeter of the basin area is 312 km. The Figure representing relationship between basin area and basin length. Basin area and Basin length both are relative to each other and shows positive correlation as shown in Figure 6.

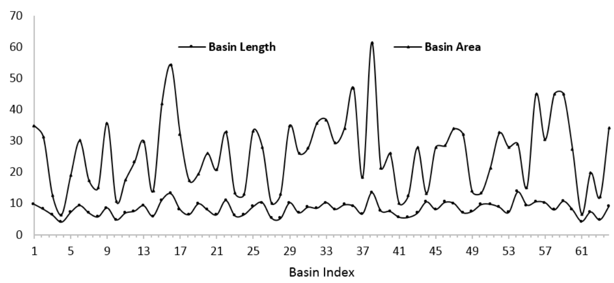

Figure 6: A graph between basin area and basin length.

Drainage frequency or stream frequency: It's defined as the ratio of total number of stream length of all order in a basin to area of the basin [17]. For the present study area it varies from 2.5 to 4.5. and it's also representing positive correlation with respect to drainage density. Drainages of streams which have higher frequency are more prone towards flash floods and higher runoff.

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Drainage texture (Rt): The total number of stream segments of all order in a basin to the ratio of perimeter of the basin. It's classified into 5 different textures i.e., Very coarse (<2), Coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (>8). In 64 basins of the study area drainage texture varies between coarse texture to very fine textures. Basin Index representing higher drainage texture are prone towards erosion.

Drainage density (Dd): Drainage density is a tool to characterize the degree of drainage development within the basin. It's defined as the total length of all the streams and river in a drainage basin to the ratio of total area of the basin [17]. Low drainage density tends to occur in regions of highly resistant and permeable subsoil materials with dense vegetation and low relief whereas high drainage density is dominant in regions of feeble, impermeable subsurface material which is sparsely vegetated and has high relief [15]. Smith [18] had classified drainage density into three classes i.e. low (D<1.5 Km^{-1}) Medium (1.5-2.5 Km^{-1}) and High (>2.5Km^{-1}). In study area value of Drainage Density varies between 1.3-2.2 Km^{-1}. Drainage Density Map of Chamoli District is represented in Figure 7. A plot between drainage density and basin Index is shown in Figure 8. According to Smith Classification most of the basin lies in low and medium classes. It results in development of coarse drainage texture in the area.

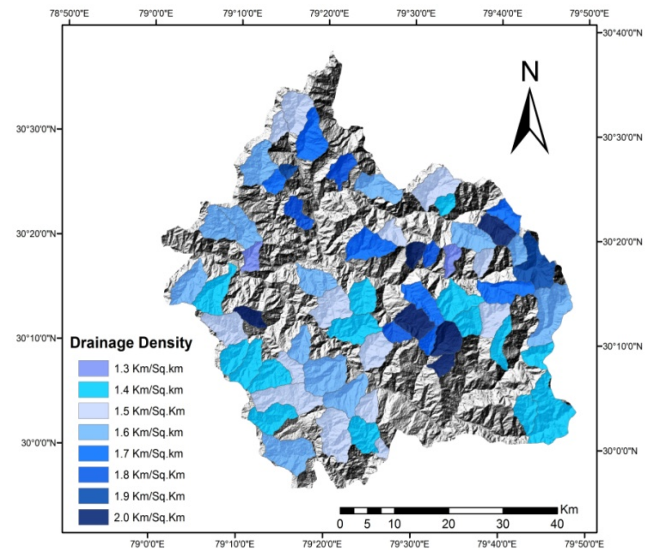

Figure 7: Drainage density map of Chamoli district.

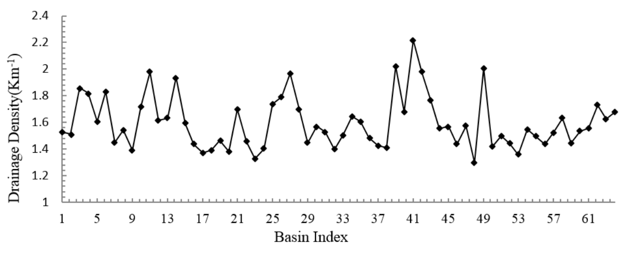

Figure 8: A plot between drainage density and basin Index.

Infiltration number: Infiltration number is defined as the product of drainage density and drainage frequency. According to Strahler [15] if the amount of Infiltration is less than Infiltration number will be higher whereas higher amount of Infiltration will result in low infiltration number. The values of Infiltration number in the study area ranges between 8.42 and 3.19. Basin Index 4 have highest Infiltration number from all the basins as it passes through MCT II and have less Infiltration capacity and it represents rigid Topography. Basin 49 has the lowest value of Infiltration number as it's representing higher permeable strata in that particular basin.

Length of overland flow: Length of the overland flow is stated as the distance of flow of the precipitated water, over the land surface to reach the stream. It's described as the Length of overland flow (Lg) as the length of water over the ground before it gets concentrated in to definite stream channels. It's the ratio of drainage area to the half of the Total Length of the Streams [17]. On an average length of overland flow in our study area is 0.33. The Length of overland flow in our study area varies between 1.30 to 0.23. The basins which have higher length of overland flow having basin index 9 is 1.30 while basins which have lower overland flow is 0.23.

Constant of channel maintenance (C): The reciprocal of drainage density is termed as constant of channel maintenance [16]. The value of constant of channel maintenance varies between 0.77 to 0.45. Basin representing highest value of constant of channel maintenance lies near MCT II. It's has direct influence on the lithology, permeability and infiltration capacity of surface material.

Form factor (Rf): Form factor is defined as the ratio of the Basin area to the square of Basin length [17]. It's a dimensionless unit and values of form factor varies between 0.1-0.8. If the value of form factor is higher than its representing circular shape of the basin while lower values indicate elongated shape of the basin and it's structurally controlled [19]. The values of form factor of all the basin or watersheds varies between 0.1-0.7. Basins of the study area are indicating elongated shape of the basin while some of the basins are representing circular shape of the basin.

Elongation ratio (Re): It's defined as the ratio between the diameter of a circle with the same area that of the basin to the maximum length of the basin [16]. The value of Re varies from 0 (in highly elongated shape) to 1.0 (circular shape). Values close to 1.0 are typical of regions of very low relief, whereas that of 0.6 to 0.8 are usually associated with high relief and steep ground slope [15]. The value of elongation ratio in all the 64 basins varies from 0.4 to 1.0. Higher numbers of basins are more prone to elongated shape while many of the basins range from oval to circular in shape.

Circularity ratio (Rc): Circularity ratio is the ratio of the area of the basin to the area of the circle having same circumference as the basin perimeter [20,21]. Circularity ratio of all the basins ranges between 0.37 to 0.79. Naturally most of the basins have a tendency to become elongated to reach mature stage. Higher values of Rc represents circular basins and vice versa.

Relation between elongation ratio, circularity ratio and form factor: There is mutual relationship between the values of Elongation ratio, Circularity ratio and Form factor. According to analysis graph Elongation ratio>Circularity Ratio>Form Factor. These three aerial parameters are conformable and appropriate for defining shape of the basin. In some of the basins parameters are not following ideal pattern. Basin 43, 45, 48, 53, 56, 58 represented in the box showing complex pattern from which it can be interpreted that its showing Structural

Control on the basins. All these basins are passing through structural thrust and have major control of lithology. All these three parameters are correlated in the Figure 9.

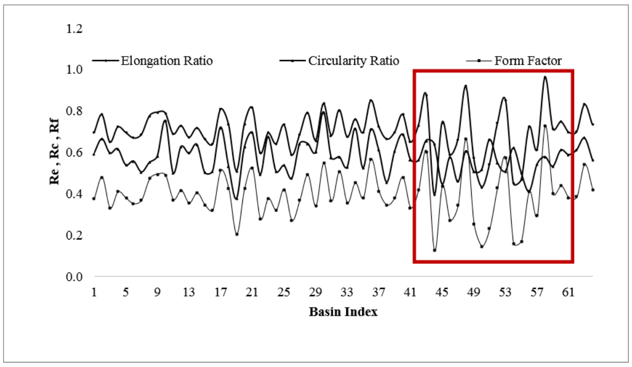

Figure 9: Basin 43, 45, 48, 53, 56, 58 represented in the box showing complex pattern.

Conclusion

The morphometric studies carried out reveal that Chamoli district is prone towards frequent occurrences of landslide, earthquakes and various other tectonic activities. The analysis of Linear and Areal Morphometric parameters has also indicated towards the influence of tectonic activities. Active tectonic basins, out of 64 delineated fourth order river basins lie in the Zone comprises of MCT–II and MCT–III. The Linear and Areal Morphometric parameters of these basins are showing anomalous behaviour. Higher number of streams in first and second order stream represents that these are more influence towards erosional process. Lower values of Bifurcation ratio represent geological heterogeneity and structural complexities. Basin belongs to Munsiari formations have higher values of Bifurcation ratio. Basin Index belongs to thrusts zones shows complex relationship between elongation ratio, circularity ratio and Form factor. These basins are structurally controlled and it can be interpreted by the occurrence of Various Landslide like Maithana, Nandprayag and other major landslide in that particular regions.

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