

RESEARCH ARTICLE

GEOMORPHOLOGY OF THE BHOGAVATI RIVER BASIN, KOLHAPUR DISTRICT, MAHARASHTRA, INDIA

P.A Pisal¹, S.B Hivarekar¹, R.A Patil¹ and H.D Bhosale²

1. Department of Civil Engineering, Annasaheb Dange College of Engineering & Technology, Ashta, Sangli, MH, India.

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2. Department of Civil Engineering, D. Y. Patil College of Engineering & Technology, Kolhapur, MH, India.

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Abstract

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Watershed development and management plans are very important for surface and groundwater conservation. To prepare a watershed development plan, it becomes important to know the topography, lithology, erosional status and drainage pattern of the area. In the present investigation various morphometric parameters of the Bhogavati river basin are outlined. The Bhogavati river basin is 5th order and shows dendritic to sub-dendritic type drainage pattern. The elongation and circulatory ratio reveals that the Bhogavati river basin is highly elongated and flood flows are easier to manage than that of circulatory basins. The bifurcation ratio reveals that the basin is not having any structural control. The highest number (69) and longest length (99.8 km) of lineament is oriented in NWW-SEE sector while lowest number (32) in NE-SW sector and shortest length (32.6 km) of lineament oriented in NNE-SSW sector. The hypsometric curves suggest that basin is in late youth to early mature stage of the fluvial geomorphic cycle.

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Introduction:-

The fluvial geomorphology is related to the study of various landforms with their origin and distribution. Geomorphology plays an important role in the planning of rural and urban settlement. Without a scientific analysis of landforms, appropriate planning of human settlement is not possible. The geomorphology of any river basin is mainly controlled by morphometric parameters. The population growth has been creating maximum stress on agriculture sector for increasing the food grain production, which resulting in deforestation and demand for more water.

The infiltration capacity of water is related to the different morphometric parameters of that basin. Therefore it is necessary to use advanced techniques for harvesting and conservation of available water resources. The geomorphological characteristics of various basins have been studied by various scientists using conventional methods (1-3). The morphometric parameters have been used in various studies of geomorphology and surface water hydrology, such as flood characteristics, sediment yield and evolution of basin morphology. The basin management studies have a special importance in the field of research, due to the increasing demand of water. Pawar and Raskar (4), has carried out morphometric analysis of Panchaganga river basin of Kolhapur district. Yadav and Sawant (5), has estimated morphometric parameter of Sheri Nala basin, Sangli district. Jangle and Patil (6), has done morphometrical parameter estimation of Nalganga river, Buldhana, Maharashtra. Nageswara (7) has carried out

Corresponding Author:- P.A Pisal

Address:- Department of Civil Engineering, Annasaheb Dange College of Engineering & Technology, Ashta, Sangli, MH, India.

morphometric analysis of Gostani river basin in Andhra Pradesh. Babar and Shah (8) have successfully carried out Geological and geomorphological characteristics on groundwater occurrence in Deccan basalt hard rock area of Tawarja river sub-basin Latur, Maharashtra. Golekar (9), has been studied morphometric and hydrogeological characters of Anjani and Jhiri river basin Maharashtra. Khadri (10) has proved that the geomorphic and morphotectonic evolution of landscape in the Vidarbha river basin has been controlled by various parameters viz., hydrogeomorphological, lithological, structural, climatic and environmental factors. The landforms have been resulted from various geomorphic processes like erosion, deposition, faulting, upliftment, tilting and pediplanation. Geomorphological study will help to understand the hydrological characters and their results will helpful for comprehensive water resource management and planning. In the present study an attempt have been made by authors to study geomorphological set up of the area, which is useful for management of water resources and landuse planning.

Study Area:

The Bhogavati river basin bounded between latitude $16^{0}19'45''$ N to $16^{0}44'30''$ N and longitude $73^{0}50'15''$ E to $74^{0}11'50''$ E in Survey of India Toposheet numbers 47 H/15, 47 L/2 and 47 L/3 and having area of about 440.5 km² (Figure 1).



Figure 1:- Location Map of Study Area.



Figure 2:- Drainage Map of the Study Area.

The Bhogavati river is one of the major tributary of the Panchaganga river and Panchaganga river is a tributary of river Krishna. The study area is covered by Deccan volcanic basalt of Upper Cretaceous to Lower Eocene age. The study area comprises black and red soil, which is highly fertile and important for agricultural purpose. The climate of the area comes across as an amusing blend of the coastal and inland climate of Maharashtra. The temperature ranges between 10° C and 40° C. The average annual rainfall in the area is 4,800 mm. The Bhogavati river basin is 5th order and shows well developed dendritic to sub-dendritic type drainage pattern. (Figure 2).

Methodology:-

The Survey of India toposheet numbers 47 L/2, 47 L/3 and 47 H/15 on the scale of 1:50,000 were used for study of different morphometric parameters of the basin. Stream ordering method as suggested by the Strahler (3) has been employed. All the morphometric parameters were grouped into three categories linear, areal and relief aspects of the basin. The different morphometric parameters have been calculated by using standard formulae. Rosette diagram is prepared from the lineament map (Figure 6).

Results and Discussions:-

The drainage characteristics of Bhogavati river basin have been examined with reference to linear, aerial and relief aspects.

Linear Morphometric Aspects

Stream Order (u):

Stream order of drainage basin is the successive assimilation of the streams within a drainage basin. The ordering of the basin have been carried out by the method suggested by Strahler (3). The Bhogavati river basin is 5th order basin (Table 1).

Stream Number (Nu):

The total number of stream segments present in each order is the stream number (Nu). Nu is number of streams of order u. Individual counting of the streams in the river basin reveals the total number of the streams. Bhogavati river basin has 1506 streams, of which 77.5% are the first order streams having 1167 segments. The second order stream segments are 270 (17.9%), third order stream segments are 57 (3.8%), fourth order stream segments are 11 (0.73%)

and fifth order stream segment is 1 (0.07%) (Table 1). The study reveals that the development of first order streams is maximum in the southern half part and minimum in the northern alluvial plains. The total number of stream segments is found to decrease as the stream order increases in the basin. The logarithm of stream length of each stream order as a function of order is plotted and yields a straight line which indicates that the study area has no structural disturbance (Figure 3).



Figure 3:- Regression of logarithm of Number of streams Vs. Stream Order.

Bifurcation Ratio (Rb):

It is the ratio of number of streams of any given order to the number of streams in the next lower order1.

The significance of this ratio is that as the ratio is reduced so the risk of flooding within the basin increases. it also indicates the flood risk for parts of the basin. In the Bhogavati river basin bifurcation ratio ranges from 4.32 to 11. The mean bifurcation ratio for Bhogavati river basin is 6.31. The mean bifurcation ratio of the basin reveals that there appears to be no strong geological control in the development of the drainage, homogeneous nature of lithology and drainage network of study area is in well developed stage (Table 1).

Weighted Mean Bifurcation Ratio (Rbwm):

To arrive at a more representative bifurcation number Strahler11 used a weighted mean bifurcation ratio obtained by multiplying the bifurcation ratio for each successive pair of orders by the total numbers of streams involved in the ratio and taking the mean of the sum of these values. The values of the weighted mean bifurcation ratio of Bhogavati river basin is 4.46, which reveals that study area composed of homogeneous subsurface material with little structural control (Table 1).

Stream Length (Lu):

The study of the stream length with respect to the stream order is of significant importance. The total length of individual stream segments of each order is the stream length of that order. Stream length measures the average (or mean) length of a stream in each orders, and is calculated by dividing the total length of all streams in a particular order by the number of streams in that order. The stream length in each order increases exponentially with increasing stream order. Stream length for the basin of the given order is inversely proportional to the stream order. Stream length of the basin indicates surface runoff characteristics. Streams of relatively smaller lengths are characteristics of area with greater slopes. The mean length of channel (Lu) of order (U) is the ratio of the total

length to the number of streams of a given order. Mean length of channel segments of a given order is greater than that of the next lower order but less than that of the next higher order. The logarithm of stream length of each order as a function of order is plotted (Fig. 3) and relation between stream order (u) and mean stream length, yields a set of points lying generally along a straight line that indicates no strong structural control in the area (Fig. 4).



Figure 4:- Relation between Stream Order (u) and Stream Length (Lu).

Stream Length Ratio (Rl):

The ratio in between the average lengths of successive orders is stream length ratio1. In the southern half part of basin large number of small streams are developed where the formations at upstream side and are less permeable. The values of stream length ratio vary from 1.5 to 9.6 which indicate difference in slope and topographic conditions in the area and late youth to early mature stage of river development (Table 1).

Rho Coefficient (ρ) :

The Rho coefficient is an important parameter relating drainage density to physiographic development of a basin which facilitate evaluation of storage capacity of drainage network and hence, a determinant of ultimate degree of drainage development in a given basin (11). The climatic, geologic, biologic, geomorphologic, and anthropogenic factors determine the changes in this parameter. Rho values of the Bhogavati basin is 0.52. This is suggesting higher surface water storage during floods and attenuation of effects of erosion during elevated discharge.

Aerial Aspects of Drainage Basin:

Basin Area (A)

Basin area is the direct outcome of the drainage development in a particular basin. The area of Bhogavati river basin is about 440.5 sq. km. which indicates that rain water will reach the main channel more rapidly, where the water has much further to travel.

Drainage Density (Dd) :

Drainage density is defined as a ratio of total length of all streams to the total area of the basin (12).

Drainage density of the any basin reveals the terrain configuration that is properties of rock of the area. On the basis of the drainage density, a drainage basin can be classified into five different textures viz; very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (>8)13. The drainage density (Dd) of the Bhogavati river basin is 2,20, which is classified as coarse drainage density (Table 2). In the study area southern half part of basin shows high drainage density which indicates region having non-resistant or impermeable subsurface material with mountainous relief and having maximum runoff, whereas northern half part of basin shows low drainage density which indicates region having basin rock or highly permeable subsurface material with low relief and minimum surface runoff.

Stream Frequency (Fs):

The stream frequency of the basin is the ratio of total number of stream segments of all orders to the basin area(13). Stream frequency is a good indicator of drainage pattern. The stream frequency value of the Bhogavati river basin is 3.42 which is moderate and indicates moderate runoff in the basin (Table 2).

Constant of Channel Maintenance (C):

The Constant of Channel Maintenance is the inverse of the drainage density (14). Therefore higher the drainage density lowers the constant of channel maintenance and vice versa. In the southern half part of the basin the value of Constant of channel maintenance is very low which indicate that rocks are relatively impermeable or terrain is very steep. But in the northern half part of the basin the value of constant of channel maintenance is relatively high which indicate the presence of little more permeable overlying material than southern part of the basin. The average constant of channel maintenance of Bhogavati river basin is 0.42 which indicates maximum area of the basin is covered by permeable subsurface material (Table 2).

Basin Perimeter (P):

Perimeter is the outer boundary of the basin which enclosed its area. Basin perimeter separates each basin from other basin. It is good indicator to study size and shape of the basin. The perimeter of Bhogavati river basin is 153 km.

Texture Ratio (Rt):

It is the ratio of total stream numbers to the total perimeter of the basin (15) Texture ratio is an important factor in the drainage morphometric analysis which is depending upon the subsurface lithology, infiltration capacity and relief aspect of the terrain7. Smith [2] has classified drainage density into five groups viz; very coarse (< 2), Coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (>8). The texture ratio of the Bhogavati river basin is 7.62, which indicate fine texture and area under high relief and steep slopes (Table 2).

Elongation Ratio (Re):

Elongation ratio is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length (14). It is the very significant index in the analysis of basin shape which gives an idea about hydrological characters of a drainage basin. The value of elongation ratio (Re) generally varies from 0.6 to 1.0 and associated with a wide variety of climate and geology. Values close to 1.0 are typical of regions of very low relief, whereas that of 0.6 to 0.8 are associated with high relief and steep ground slope (15). These values can be grouped into three categories, viz; circular (>0.9), oval (0.9 to 0.8) and elongated (< 0.7). The lower value of the elongation ratio indicates that particular watershed is more elongated than others16. The Elongation ratio of the Bhogavati river basin is 0.27 which indicate basin is highly elongated (Table 2).

Circulatory Ratio (Rc):

Circulatory ratio is the ratio of basin area to the area of circle having the same perimeter as the basin (17). It is influenced more by the length, frequency and gradient of streams of various orders than slope conditions and drainage pattern of the basins (3). Circulatory ratio of Bhogavati river basin is 0.24, which is below 0.5 and shows strongly elongated basin with semi-permeable homogeneous lithology (Table 2).

Form Factor Ratio (Rf):

Form Factor Ratio is the dimensionless ratio of the basin area to the square of basin length (12). Form factor has a direct relation to the stream flow and shape of the watershed. Low form factor ratio values indicate that the drainage basin is elongated in nature and higher values indicate that the drainage basin has developed and rectangular to circular shape (13). The Form Factor Ratio value of the Bhogavati river basin is 0.057 which is very nearer to zero, indicate the shape of basin is highly elongated. In such elongated basin with low form factor will have a flatter peak

flow of longer duration. Flood flows in elongated basins are easier to manage than that of the circular basins (18) (Table 2).

Length Area Relation (Lar):

Hack (19) suggests that for a large number of basins, the stream length and basin area are related by a simple power function as follows:

Lar = 1.4 * A0.6.

It is found that, Length Area Relation of Bhogavati river basin is 54.01 (Table 2). It indicates that as compare to total area, the length of Bhogavati river is too large which results in elongated basin.

Lemniscate's (k):

Chorely20, express the Lemniscate's value to determine the slope of the basin. By the formula k = Lb2 / 4 * A.

Where, Lb is the basin length (Km) and

A is the area of the basin (km2).

The Lemniscate (k) value for the Bhogavati river basin is 17.3 (Table 2), which shows that the basin occupies the maximum area in its regions of inception with large number of streams of smaller order.

Texture Ratio (Rt):

According to Schumm (21), texture ratio is an important factor in the drainage morphometric analysis which is depending on the underlying lithology, infiltration capacity and relief aspect of the terrain. The texture ratio is expressed as the ratio between the first order streams and perimeter of the basin (Rt = Nl / P). In the present study, the texture ratio of the basin is 7.62 and categorized as moderate in nature (Table 2).

Drainage Texture (Dt):

Drainage texture is one of the important concept of geomorphology which means that the relative spacing of drainage lines. Drainage texture is relies on the underlying lithology, infiltration capacity and relief aspect of the terrain. Dt is total number of stream segments of all orders per perimeter of that area1. Smith2, has classified drainage texture into five different textures viz; very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (>8). The drainage texture of the Bhogavti river basin is 9.84, indicates that very fine drainage texture (Table 2).

Compactness Coefficient (Cc) :

According to Gravelius (22), compactness coefficient of a basin is the ratio of perimeter of basin to circumference of circular area, which equals the area of the basin. The Cc is independent of size of basin and dependent only on the slope. The compactness coefficient of Bhogavati river basin is 2.13, indicates that the basin is highly elongated in shape (Table 2).

Fitness Ratio (Rf) :

As per Melton (23), the ratio of main channel length to the length of the basin perimeter is fitness ratio, which is a measure of topographic fitness. The fitness ratio for Bhogavati river basin is 0.35, which reveals that the Bhogavati river basin shows elongated shape (Table 2).

Wandering Ratio (Rw):

According to Smart and Surkan24, wandering ratio is defined as the ratio of the main stream length to the valley length. Valley length is the straight line distance between outlet of the basin and the farthest point on the ridge. The wandering ratio of the Bhogavati river basin is 1.24, suggest that main stream length is greater than valley length of the Bhogavati river basin (Table 2).

Basin Eccentricity (τ):

Black (25) has given the expression for basin eccentricity, which is: $\tau = [(Lcm2 - Wcm2)] 0.5 / Wcm$ Where: $\tau = Basin eccentricity, a dimensionless factor,$ Lcm = Straight length from the basin mouth to the centre of mass of the basin, andWcm = Width of the basin at the centre of mass and perpendicular to Lcm.

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The basin eccentricity, value is 0.81 indicates that length of the Bhogavati river basin is greater than its width (Table 2).

Centre of Gravity of the Basin (Gc):

It is the length of the channel measured from the outlet of the basin to a point on the stream nearest to the center of the basin. The centre of the Bhogavati river basin has been determined using following steps:

i) A card board piece was cut in the shape of Bhogavati river basin.

ii) The centre of gravity was located on the basin shape card board piece using point balance standard procedure

iii) The card board piece marked with centre of gravity was superimposed over the basin plan

iv) By pressing a sharp edge pin over the centre of gravity of the card board piece it was marked on the basin. The centre of gravity of the basin is computed by using India-WRIS WebGIS portal (Version 4.0) software, which is a point showing the latitude $16^{0}26$ ' N and longitudes $74^{0}59$ 'E (Table 2).

Drainage Intensity (Di):

Faniran (26) defines the drainage intensity, as the ratio of the stream frequency to the drainage density. The drainage intensity value for the basin is 1.55, which is low value (Table 2). This low value of drainage intensity implies that drainage density and stream frequency have little effect on the extent to which the surface has been lowered by agents of denudation. With the low value of drainage intensity, surface runoff is quickly removed from the basin, making it not susceptible to flooding, strong gully erosion and landslides.

Infiltration Number (If):

The infiltration number of a basin is defined as the product of drainage density and stream frequency and given an idea about the infiltration characteristics of the basin. The infiltration number of Bhogavati river basin is 7.52. In Bhogavati river basin area the value of infiltration number is higher in southern half part which reveals that the lower infiltration and the higher runoff and vice versa (Table 2).

Length of Overland Flow (Lg) :

It is the length of water over the ground before it gets concentrated into definite stream channels. This factor relates inversely to the average slope of the channel and is quite synonymous with the length of sheet flow to a large degree (27). It approximately equals to half of reciprocal of drainage density1. The value of Lg of Bhogavati river basin is 0.23 (Table 2) which indicates high relief and quick runoff.

Relief Aspects of Drainage Basin

Basin Relief (H):

The difference between the vertical distance of point of maximum elevation and minimum elevation is the relief of basin. Basin relief is important tool which helps to study basin slope, runoff and sediment transport in the area. The basin relief of Bhogavati river is 1562 meters, which reveals that Bhogavati river basin having moderate relief with moderate rate of runoff and sediment transport (Table 3).

Relief Ratio (Rh) :

When basin relief (H) is divided by maximum basin length (Lb) gives the relief ratio (28). The relief ratio of Bhogavati river basin is 17.85, which indicates that the basin has strong relief and steep slope (Table 3). The higher stream frequency values show that the permeability of rocks is less at upstream to the middle portion of the basin. Here the infiltration is mainly through fractures and joints, which are the extension of the surface joints. But the permeability of rocks are weathered.

Ruggedness Number (Rn):

Ruggedness number is the product relief of basin (H) and drainage density (Dd). The ruggedness number of Bhogavati river basin is 3436.4 which indicate both relief and drainage density are high (Table 3). Such higher values are expected in a mountainous region of tropical and sub-tropical climate with higher rainfall14.

Lineament Analysis of the Study area:

Lineaments have been defined as extended mappable linear or curvilinear features of a surface whose path align in straight or nearly straight relationships that may be indication of folds, fractures, or faults in the subsurface area. These features are studied at various scales, from local to regional, and can be utilized in structural disturbance study

of the area and also in groundwater exploration studies. The azimuth of all of the lineaments indicated on the lineament map were measured and arranged in related ten degree bearing groups (Fig. 5 and 6) (Table 4).

For a better understanding of the sector distribution of lineament numbers and lengths from the population of lineament data is prepared (Table 5). Six sectors were considered, each of 300 span, viz; NNE-SEW, NE-SW, NEE-SWW, NWW-SEE, NW- SE and NNW-SSE sectors. In the study area, the NWW-SEE sector has the highest numbers (69), longest length of lineaments (99.8 km). While the NE-SW sector has the lowest numbers (32) and NNE-SSW sector has shortest lengths (32.6 km) of lineaments. Other sectoral data fall in between these two extremes. On the other hand average unit length of lineaments is highest for the NE-SW sector and lowest for the NNE-SSW sector. The other sectors fall between the two extremes (Fig. 6) (Table 5). Thus the lineament analysis of area matches closely with the spatial trends of the lineaments caused due to the Patan and Koyna faults (29).



Figure 5:- Lineament map of study area.



Figure 6:- Rosette diagram of lineaments of study area.

Dissection Index (DI:

Dissection index is the ratio between relative relief and to the absolute relief, which is an important morphometric indicator of the nature and magnitude of dissection of terrain. Dissection index is also used for the determination of the stages of cycle of erosion as old, mature and young stages. The study of dissection index reveals that the rate of dissection is high in plateau area, moderate in plain area but low in hilly area due to lack of sufficient streams, comparatively hard rock and vertical cliff shape hills. Therefore, the overall study suggest that the Bhogavati river basin (DI = 0.26) passes through the early mature stage (DI = 0.20-0.33) of development (Table 6).

Hypsometric Analysis (Hs):

In order to evaluate the amount of dissection brought about by the fluvial processes, the area altitude analysis i.e. hypsometric analysis has been carried out by following the method suggested by Strahler (16). The curve for the basin has been prepared and presented in figure-7 It is the study of the distribution of the horizontal cross-sectional area of the landmass with respect to elevation. This is represented graphically with respect to elevation, by plotting cross sectional area of the basin under investigation to the respective elevation. This plot results in the form of a smooth curve (Fig. 7). The percentage hypsometric method has been used to estimate the amount of dissection that the individual drainage basin has undergone (30). In the hypsometric analysis two ratios are involved, viz;

a) Ratio of the area between a contour and the upper perimeter to total drainage basin area and

b) Ratio of the highest contour above the base to the total height of the basin.

It is seen that the average value of hypsometric integral is equal to 0.5 which indicates that the Bhogavati river basin is in a late youth to early mature stage of development.



Figure 7:- Hypsometric curves of the study area.

Drainage Morphometry and Its Influence on Geomorphology

The underlying geology, exogenic and endogenic activities, drainage morphometry and considerable changes in climate influence the genesis and morphology of landforms. Structural hill, pediment, and valleys formed by the influence of permeable geology are moderate to nearly level plains, with medium to low drainage density (<2.0), low cumulative length of 4th and 5th order streams. On the other hand landforms like the hill top plains/dissected plateau landforms are associated with high drainage density, bifurcation ratio and high cumulative length of first, second and third order streams. Denudational processes are actively involved in landscape reduction processes. About 75% and 25% part of the Bhogavati river basin is covered by erosional and depositional landforms respectively (Fig. 8).



Figure 8:- Geomorphological landform map of the study area.

Conclusion:-

The morphometric study of Bhogavati river indicates that the basin is fifth order basin and is passing through an early mature stage to old stage of the fluvial geomorphic cycle. The basin shows dendritic to sub-dendritic type drainage pattern. Mean length of channel segments of a given order is greater than that of the next lower order but less than that of the next higher order. The logarithm of stream length of each order as a function of order is plotted and relation between stream order and mean stream length yields a set of points lying generally along a straight line that indicates no strong structural control in the area. The average bifurcation ratio of the basin reveals that there appears to be no strong geological control in the development of the drainage, homogeneous nature of lithology and drainage network in study area is well developed stage. The southern half part of the basin is under high relief which shows steep slopes with high drainage density, high stream frequency, and low constant of channel maintanence and less permeable subsurface lithology. The northern half part of the basin is under low relief as compare to the southern part which shows gentle slopes with low drainage density, low stream frequency, high constant of channel maintenance and highly permeable subsurface lithology. The elongation ratio, circulatory ratio and form factor reveals that the Bhogavati river basin is highly elongated and flood flows are easier to manage than that of circulatory basins. The study also reveals that the texture of Bhogavati river basin is very fine and basin is highly elongated. The drainage basin size analysis reveals that the flooding is lesser. From the lineament analysis it is clear that, in the study area, the NWW-SEE sector has the highest number (69), longest length (99.8 km) of lineaments. While the NE-SW sector has the lowest number (32) and NNE-SSW sector has shortest lengths (32.6 km) of lineaments. Thus the lineament analysis of area matches closely with the spatial trends of the lineaments caused due to the Patan and Koyna faults.

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Stream	Stream	Stream	Mean	Stream	Log	Log	Bifurcation	No. of	Product	Weighted
Order	Number	Length	Stream	Length	Nu	Lu	Ratio	Streams	of	Mean
(u)	(Nu)	in km	Lengths	Ratio	6	7	8	used in	Column	Bifurcation
1	2	(Lu)	4	(R <i>l</i>)				the	8&9	Ratio
		3		5				Ratio	10	11
								9		
Ι	1167	606	0.52	-	3.0	2.7	-	-	-	4.46
II	270	212	0.78	1.5	2.4	2.3	4.32	1437	6207.8	
III	57	73	1.28	1.64	1.7	1.8	4.73	327	1546.7	
IV	11	43	3.90	3.05	1.0	1.6	5.18	68	352.24	
V	01	37.5	37.5	9.61	0	1.0	11	12	132	
Total	1506	971.5						1844	8238.7	
Mean				3.95			6.30			

Table 1:- Linear aspects of the drainage network of the study area.

Morphometric Parameters	Symbol / Formula /Method	Calculated Value
Area (sq. km)	А	440.5
Perimeter (km)	Р	153
Drainage Density	Dd = Lu/A	2.20
Stream Frequency	Fs = Nu/A	3.42
Texture Ratio	$Rt = N_1/P$	7.62
Basin Length (km)	Lb	87.5
Elongation Ratio	$2\sqrt{A/\pi}$	0.27
	$Re = \frac{1}{Lb}$	
Circulatory Ratio	$Rc = 4\pi A/P^2$	0.24
Form Factor Ratio	$Rf = A/Lb^2$	0.057
Constant of Channel Maintenance	C = 1/Dd	0.42
. Length Area Relation (Lar)	$Lar = 1.4 * A^{0.6}$	54.01
Lemniscate's (k)	$\mathbf{k} = \mathbf{L}\mathbf{b}^2 / 4 * \mathbf{A}$	17.3
Drainage Texture (Dt)	$Dt = \Sigma Nu / P$	9.84
Compactness Coefficient (Cc)	Cc = P/circumference of circular area, which	2.13
	equals the area of the basin	
Fitness Ratio (Rf)	Rf =Main channel length / P	0.35
Wandering Ratio (Rw)	$\mathbf{R}\mathbf{w} = \mathbf{M}\mathbf{a}\mathbf{i}\mathbf{n}$ stream length / the valley length	1.24
Basin Eccentricity (τ)	$\tau = [(\text{Lcm2} - \text{Wcm2})]0.5 / \text{Wcm}$	0.81
Centre of Gravity of the Basin	India-WRIS WebGIS portal (Version 4.0)	latitude 16 ⁰ 26' N, and
(Gc)		longitude 74 ⁰ 59'E
Drainage Intensity (Di)	Di = Fs/Dd	1.55
Infiltration Number (If)	If = Dd $*$ Fs	7.52

Table 2:- Aerial Aspects of the drainage network of the study area.

Where, Lu = Total Stream length of all orders.

Nu = Total number of streams of all orders

N1 = Total number of 1st order streams.

Lcm = Straight length from the basin mouth to the centre of mass of the basin,

Wcm = Width of the basin at the centre of mass and perpendicular to Lcm.

 $\Pi = 3.14$

Table 3:- Relief aspects of drainage network of study area.

Morphometric Parameters	Symbol / Formula	Calculated Value
Maximum elevation in the area (mts.)		3327
Minimum elevation in the area (mts.)		1765
Basin Relief (mts.)	H = Max. Elevation – Min. Elevation	1562
Relief Ratio (Rh)	$Rh = \frac{H}{Lb}$	17.85
Ruggedness Number (Rn)	Rn = H X Dd	3436.46

Table 4:- Data for lineaments observed on the topographic maps.

	NNE-SSW [0-30 ⁰ & 180 ⁰ -210 ⁰]	$\frac{\text{NE-SW}}{[30^{\circ}-60^{\circ}\&}$ $210^{\circ}-240^{\circ}]$	NEE- SWW [60 ⁰ -90 ⁰ & 240 ⁰ -270 ⁰]	NWW-SEE [90 ⁰ -120 ⁰ & 270 ⁰ -300 ⁰]	NW-SE [120 ⁰ -150 ⁰ & 300 ⁰ -330 ⁰]	NNW-SSE [150 ⁰ -180 ⁰ & 330 ⁰ -360 ⁰]
Number of Lineaments (a)	49	32	39	69	46	62
% of total Lineaments	16.5	10.8	13.1	23.2	15.5	20.9
Length of Lineaments (b)	32.6	47.8	55.4	99.8	67.4	79.6

in km						
% of total length	8.5	12.5	14.5	26.1	17.6	20.8
Avg. length of lineaments	0.67	1.49	1.42	1.45	1.46	1.28
(b/a) km						

Table 5: Sectorial distribution of lineament numbers and lengths.

	N	N %	L	L %	
0-10	NNE - SSW	27	9.24	40	9.55
10-20		09	3.08	11	2.62
20-30		13	4.45	17.6	4.20
30-40	NE - SW	10	3.42	14.8	3.53
40-50		12	4.10	17.8	4.25
50-60		10	3.42	15.2	3.63
60-70	NEE - SWW	04	1.36	5.4	1.29
70-80		08	2.73	11.6	2.77
80-90		27	9.24	38.4	9.17
90-100	SEE - NWW	30	10.27	45.8	10.94
100-110		19	6.50	24.6	5.87
110-120		20	6.84	29.4	7.02
120-130	SE - NW	19	6.50	26.4	6.30
130-140		15	5.13	21.2	5.06
140-150		12	4.10	19.8	4.73
150-160	SSE - NNW	27	9.24	35.4	8.45
160-170		23	7.87	25.6	6.11
170-180		12	4.10	18.6	4.44

Table 6:- Calculation for Relative Hypsometric Curve.

Absolute	Relative	Dissection	Relative	Area	Cumulative	Relative	Hypsometric
Relief	Relief	Index (DI)	Height	(Km^2)	Area	Area (a/A)	Integrals
(Mts)	(Mts)		(h/H)				
3250	1250	0.3846	1.00	1.76	1.76	0.003	0.5
3000	1000	0.3333	0.80	33.46	35.22	0.060	
2750	750	0.2727	0.60	56.79	92.01	0.158	
2500	500	0.2	0.40	99.07	191.08	0.328	
2250	250	0.1111	0.20	154.57	345.65	0.595	
2000	0	0	0.00	235.17	580.82	1.000	
Average		0.26	0.60	96.80	207.75	0.35	