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Morphometric Analysis of Kasura Watershed Using RS and GIS Techniques

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Abstract: Remote Sensing and Geographic Information System are recognized as crucial instruments for conducting geographical and geospatial research. RS and GIS technology was employed to assess the morphological Characteristics of the Kasura River Watershed situated within the Parbhani and Jalna Districts of Maharashtra, India. The entire drainage area of the Kasura River basin measures 490.13 square kilometers (km^2). Various morphometric characteristic were calculated and examined, encompassing linear features such as stream number, stream order, mean stream length, stream length, and stream length ratio, areal attributes including elongation ratio, circularity ratio, form factor, constant of channel maintenance, drainage density and drainage texture and relief characteristics such as relief, relief ratio, maximum relief, ruggedness number, relative relief, and length of overland flow. These findings underscore the significance of employing morphometric analysis in watershed assessment, offering a quantitative method for characterizing the surface attributes of a drainage pattern and yielding valuable insights into the topography and runoff dynamics of the region.

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INTRODUCTION

Remote Sensing is the process of acquiring information about an object, region, or phenomenon without the need for direct physical interaction. In contrast, a Geographical Information System primarily revolves around handling geographic data, which is analyzed, manipulated, and efficiently organized using computers to address real-world issues (*Patra, 2015*). The utilization of Remote Sensing techniques proves to be a convenient approach for conducting morphometric analysis. Satellite images offer a comprehensive overview of vast areas, making them highly valuable for examining the morphometry of drainage basins (*Rai et al., 2014*). Understanding the morphometric characteristics of the basin is crucial for gaining insights into a range of hydrological behaviors and processes. (*Sarma et al., 2013*). Different hydrological phenomena are linked to the physiographic attributes of a drainage basin, including factors like its size, shape, drainage area slope, drainage density, as well as the dimensions and lengths of its contributing elements. (*Pande and Moharir, 2015*). A comprehensive morphometric analysis of a basin proves invaluable for comprehending how the morphological aspects of drainage systems impact landforms and their distinguishing features. (*Sreedevi, 2009*). The application of morphometric and hypsometric analyses is a common approach for evaluating the drainage attributes of river basins. (*Umrikar, 2016*). The rapidly advancing field of Spatial Information Technology, along with Remote Sensing, Geographic Information Systems, and GPS, proves to be potent instruments for addressing a multitude of challenges in land and water resources planning and management. These modern techniques surpass conventional data processing methods in their effectiveness. (*Rai et al., 2014*). In the last twenty years, there has been a

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growing trend in obtaining this information from digital renditions of topography, commonly referred to as Digital Elevation Models (DEMs). In recent times, the automated calculation of drainage basin parameters has demonstrated efficiency, time-saving benefits, and represents an ideal utilization of GIS technology. (*Sarma et al., 2013*). In this current research, the aim was to analyze the morphometric features of the watersheds in the Maharashtra districts of Parbhani and Jalna using RS and GIS techniques.

MATERIALS AND METHODS

Study area

As shown in Figure 1, The study focuses on the Kasura River in Parbhani and Jalna districts, covering coordinates 76007′E to 76030′E longitude and 19021′N to 19030′N latitude, spanning 490.13 sq km. Emerging near Dudhana, it's part of the Purna River sub-basin with an 860 mm annual rainfall, the region mainly comprises black cotton soil, clay-like and deep black, originating from iron, lime, and magnesium-rich "Deccan trap" rock (basalt). Temperatures range from 32.50°C to 41.50°C. Monsoons (June-September) bring heavy rainfall.

Watershed delination

The process of watershed delineation holds significant importance within the realm of watershed management. (*Singh, 2000*). The ArcGIS 10.8 software facilitates watershed delineation through the utilization of Carto-DEM data. The resulting shapefile from the delineation process within the study area is subsequently employed to crop satellite images for subsequent analysis.

Morphological characteristics

The hydrologic analysis is greatly influenced by the physical attributes of the watershed, impacting the runoff traits. Morphological features including drainage density, channel length, stream order, channel slope, watershed dimensions, topography, soil attributes, geology, vegetation, climate and land use collectively contribute to comprehending the physical mechanisms operating within the watershed. (*Singh, 2000*).

The methodical description of the geometry of a watershed is called morphological characterisation. The following measurements were necessary due to the its stream channel system and drainage basin's geometry. (*Singh, 2000*):

A. Linear aspect of the drainage network
B. Areal aspect of the drainage basin
C. Relief aspect of the channel network as well as contributing ground slopes

The morphometric characteristics of the watershed, along with the corresponding symbols and utilized formulas, are presented in Table 1.

RESULTS AND DISCUSSION

The morphometric characteristics of the Kasura river basin have undergone examination, with detailed outcomes outlined in Tables 2, 3, and 4. The values from the sub-basins were obtained using the calculate geometry tool within ArcGIS 10.8. The total drainage area of the Kasura River basin is 490.13 km^2. The classification (Figure 4) has been used to rank the streams within the Kasura River Basin, which are then discussed in detail below. (Strahler's, 1964)

A. Linear aspects of the drainage network: -

1. Stream order (u)

The research area's drainage network has been determined to have a drainage network up to a 5th - order basin by using this ordering procedure through GIS.

2. Stream number (Nu)

According to the data in Table no 2, there are 436, 91, 15, 2, and 1 stream of the first, second, third, fourth, and fifth orders in the watershed, respectively. The overall number of streams was shown to gradually decrease as the stream order increased. The drainage map for the catchment area around the Kasura River is shown in Figure 3.

3. Bifurcation ratio (Rb)

According to the data in Table 2, The mean bifurcation ratio (Rb) for the watershed was determined to be 5.09. The watershed's mean Rb value indicates that geological formations do not interfere with the drainage pattern. The fact that Rb for the watershed was 5.09 indicates that geologic formations don't have a significant impact on the drainage pattern (*Chow, 1964*).

4. Mean stream length (Lu)

According to the data in Table 2, it can be noticed that as the stream order increases, the average length of streams tends to decrease. This phenomenon could be attributed to various factors such as geomorphological, lithological, and structural influences, which may exhibit notable differences. (*Strahler, 1964*).

5. Stream length ratio (RL)

According to the data in Table 2, it can be noted that the average stream length of ratio for catchment was determined to be 0.4425. This ratio holds significance in its association with the discharge of surface water and the erosion level within the basin. It is influenced by the configuration of the watershed and the presence of shorter streams. Consequently, these watersheds are more susceptible to erosion. (*Sreedevi et al., 2009*)

B. Areal aspects of the drainage network

1. Form factor (Rf)

According to the data in Table 3, it was noted that the form factor for watersheds equaled 0.212. This ratio serves as an indicator of the shape of the watersheds. In all cases, this value suggests that the watersheds exhibit an elongated to sub-circular configuration. An elongated basin implies a flatter peak in flow. The form factor index shows an opposite relationship with the square of the axial length while displaying a direct connection with peak discharge (Horton's, 1945). Thus, it mitigates the impact of peak floods, it is imperative to establish soil conservation structures.

2. Circulatory ratio (Rc)

According to the data in Table 3, it was observed that the circulatory ratio for watersheds were 0.1679 respectively. These watersheds suggest that the basin has an elevated shape, has small runoff flow, and has highly permeable subsoil characteristics. The dimensionless circulatory ratio (Rc) represents the ratio of the basin's area to the area of a circle with an equivalent perimeter to that of the basin. It is noted that circulatory ratios typically fall within the range of 0.4 to 0.5, signifying the presence of strongly elongated and permeable homogeneous geological materials. The circulatory ratio (Rc) primarily relates to factors such as the slope geological formations, LULC, relief, climate and the frequency of streams and length of the basin. (*Miller, 1953*).

3. Elongation ratio (Re)

According to the data in Table 3, it can be observed that the elongation ratio for watershed values of the kasura river is 1.264, This suggests that the most significant part of the basin exhibits the highest relief. The Re is a crucial index used in the analysis of catchment shape. It represents the relationship between the diameter of a circle having an equivalent area to the drainage basin and the longest length of the river basin. This ratio provides valuable insights into the hydrological parameter of a drainage basin. This suggests that these areas are vulnerable to significant erosion and sedimentation loads. Additionally, it points to the presence of pronounced steep ground and relief slopes. (*Rai et al., 2014*).

4. Drainage Density (Dd)

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According to the data in Table 3, it can be observed that the drainage density for watershed were 1.38 km^{-1}, respectively. This parameter reflects the proximity of channel spacing within the entire basin, including its stream channels. In this particular watershed, the drainage density suggests the presence of less porous sub-surface materials, robust vegetation cover as well as significant relief. (*Manjare et al., 2014*).

5. Constant of channel maintenance (C)

According to the data in Table 3, it can be observed that the constant of channel maintenance for watersheds were 0.724, indicating that these watersheds exhibited higher values for this parameter, suggesting a lower drainage density. (*Schumn, 1956*).

6. Drainage texture (T)

According to the data in Table 3, it can be observed that drainage texture for watershed were 2.87 km^{-1} respectively. This characteristic represents the relative spacing of the drainage network. A drainage texture measuring less than 2 indicates an extremely coarse network, whereas values ranging between 2 as well as 4 signify a coarse network. If the value falls between 4 and 6, it indicates a moderate drainage network, whereas values between 6 and 8 suggest a fine drainage network. Anything above 8 signifies a very fine drainage texture. (*Smith, 1950*). Therefore, these watersheds have coarse drainage texture.

C. Relief aspects of the drainage network

1. Relief (H)

According to the data in Table 4, it is observed that the relief within the watersheds measures 0.04 km. Understanding the denudational characteristics of the basin heavily relies on the relief of the area (Sreedevi et al., 2009).

2. Maximum relief

According to the data in Table 4, it can be observed that the maximum relief for these catchments were 0.12 km, respectively.

3. Relief ratio (Rn)

According to the data in Table 4, it can be observed that relief ratio for these catchments were 0.4 km respectively. In hilly regions, high relief ratios are indicative of steep slopes and elevated terrain, whereas low values are associated with valley regions. (*Sreedevi et al., 2009*).

4. Relative relief (Rhp)

According to the data in Table 4, it can be observed that the relative relief for catchment were 0.21 %. Relative relief, often referred to as the "amplitude of available relief" or "local relief," is a morphometric parameter that quantifies the variation in elevation within a defined area. To calculate relative relief, you can find it by the ratio of the difference in elevation between the highest and lowest points in a basin (H) to the perimeter of that basin (P). In mathematical terms, this can be expressed as:

$$\text{Relative relief} = H/P.$$

The values obtained for relative relief are classified into three groups based on the data: (i) low relative relief, ranging from 0 meters to 100 meters, (ii) moderate relative relief, falling between 100 meters and 300 meters, and (iii) high relative relief, which is any value exceeding 300 meters. (*Melton, 1958*)

5. Ruggedness number (RN)

According to the data in Table 4, The catchment's ruggedness number was determined to be 0.552, indicating significant values for both variables, with a steep and extensive slope (Strahler 1956).

Table 1. Morphometric parameters .

Sr No	Symbol	Morphometric Parameters	Formulae	Particulars	Reference
A.		**Linear aspect of drainage network**			
1	u	Stream order	Hierarchical Rank	u = stream of order	Strahler, 1964

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2	Nu	Stream number	-	Nu = Number of streams order u	Strahler, 1964
3	Rb	Bifurcation Ratio	$R_b = \frac{Nu}{Nu+1}$	NRb = bifurcation ratio u = number of streams of order u N_{u+1} = number of streams of order u+1	Schumm, 1956
4	$\bar{L}_u$	Mean Stream length	$\bar{L}_u = \frac{\sum_{i=1}^{n} Lu}{Nu}$	$\bar{L}_u$= mean length of the channel order u Lu = total length of a stream segments order u	Hortan, 1945
5	R_L	Stream length ratio	$R_L = \frac{\bar{L}u}{\bar{L}u-1}$	$\bar{L}_{u-1}$= mean length of the stream next lower order	Hortan, 1945
B.	**Areal aspect of drainage basin**				
1	Rf	Farm Factor	$R_f = \frac{Au}{(Lb)^2}$	Au = basin of area L_b = basin of length	Hortan, 1945
2	Rc	Circulatory ratio	$R_C = \frac{Au}{Ac}$	AC = area of circle	Miller, 1953
3	Re	Elongation ratio	$R_e = \frac{Dc}{Lbm}$	Dc = Circle diameter Lbm = length of maximum basin	Schumm, 1956
4	Dd	Drainage density	$D_d = \frac{L}{A}$	L = Total length of the all-stream segments A = area of watershed	Hortan, 1945
5	C	Constant of channel Maintenance	$C = \frac{1}{Dd}$	Dd = drainage density	Hortan, 1945
6	T	Drainage Texture	$T = \frac{N}{P}$	N = Total number of the streams P = Perimeter of basin	Hortan, 1945
		C. Relief aspect of channel network			
1	H	Relief	-	H= Basin of Relief	Schumn, 1956
2	H_{max}	Maximum relief	H_{max}= Different Bet^n Highest and Lowest Point	H_{max} = Maximum Relief	Schumn, 1956
3	R_n	Relief ratio	$R_n = \frac{H}{L_h}$	H = basin relief L_h = horizontal distance	Schumn,1956
4	R_{hp}	Relative relief	$Rh_P = \frac{H}{p} \times 100$	H = relief basin P = basin perimeter	Schumn,1956
5	RN	Ruggedness number	RN = H × Dd	H= basin relief Dd = Drainage density of basin	Strahler, 1964
6	L_g	Length of the overland flow	$L_g = \frac{1}{2Dd}$	Dd = Drainage density	Hortan, 1945

Table 2. Linear aspects of drainage network.

Morphological Parameters	**Kasura River Watershed**
Area (km²)	490.13
Perimeter (km)	190.41
Length of Basin (km)	47.98
Stream Order	
Ist Order	436
IInd Order	91
IIIrd Order	15
IVth Order	2
Vth Order	1
Total	**545**
Bifurcation Ratio	
R_{b1}	4.79
R_{b2}	6.06
R_{b3}	7.5
R_{b4}	2
Average	**5.09**
Stream Length (km)	
L_{u1}	378.00
L_{u2}	159.00
L_{u3}	80.00
L_{u4}	49.00
L_{u5}	12.00
Total	**678.00**
Mean Stream Length (km)	
$\overline{Lu_1}$	0.87
$\overline{Lu_2}$	1.75
$\overline{Lu_3}$	5.33
$\overline{Lu_4}$	24.5
$\overline{Lu_5}$	12
Total	**44.45**
Stream Length Ratio	
R_{L1}	0.42
R_{L2}	0.5
R_{L3}	0.61
R_{L4}	0.24
Average	**0.4425**

Table 3. Areal aspects of drainage network.

Areal Aspects	**Kasura River Watershed**
Basin Area (km²)	**490.13**
Form Factor	**0.212**
Circulatory Ratio	**0.1679**
Elongation Ratio	**1.264**
Drainage Density (km^{-1})	**1.38**

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Constant of Channel Maintenance ($km^2\ km^{-1}$)	0.724
Drainage Texture (km^{-1})	2.87

Table 4. Relief aspects of drainage network.

Relief Aspects	Kasura River Watershed
Relief (km)	0.4
Maximum Relief (km)	0.12
Relief Ratio	0.4
Relative Relief (%)	0.21
Ruggedness number	0.552
Length of overland flow (km)	0.36

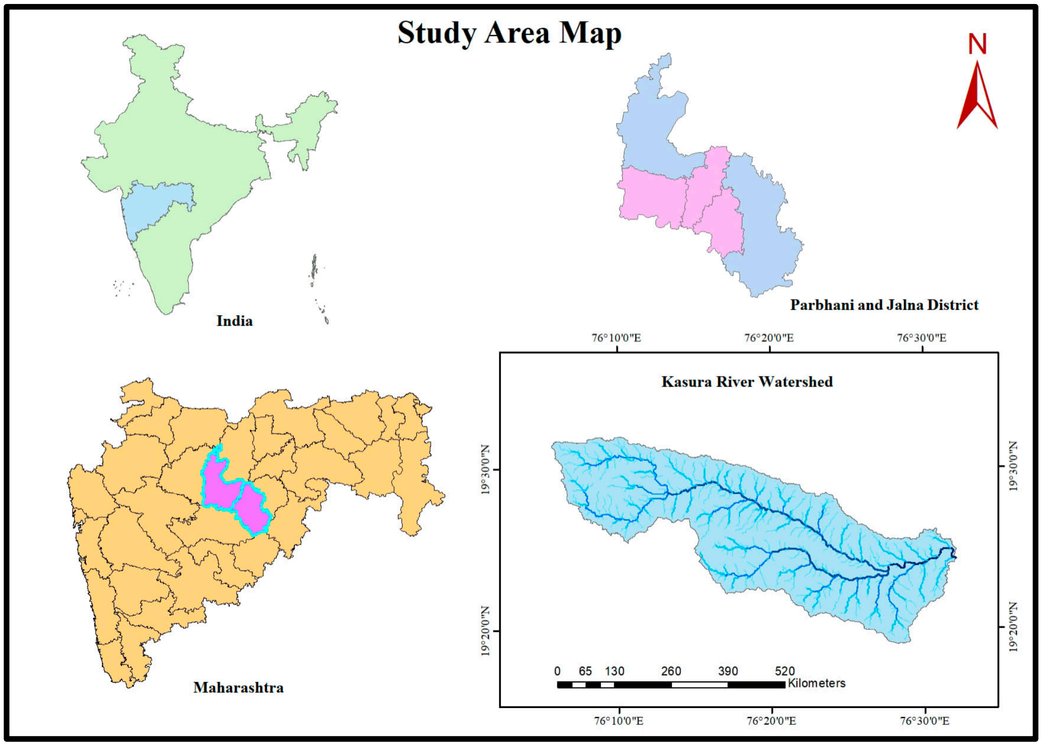

Figure 1. Location of the study area map.

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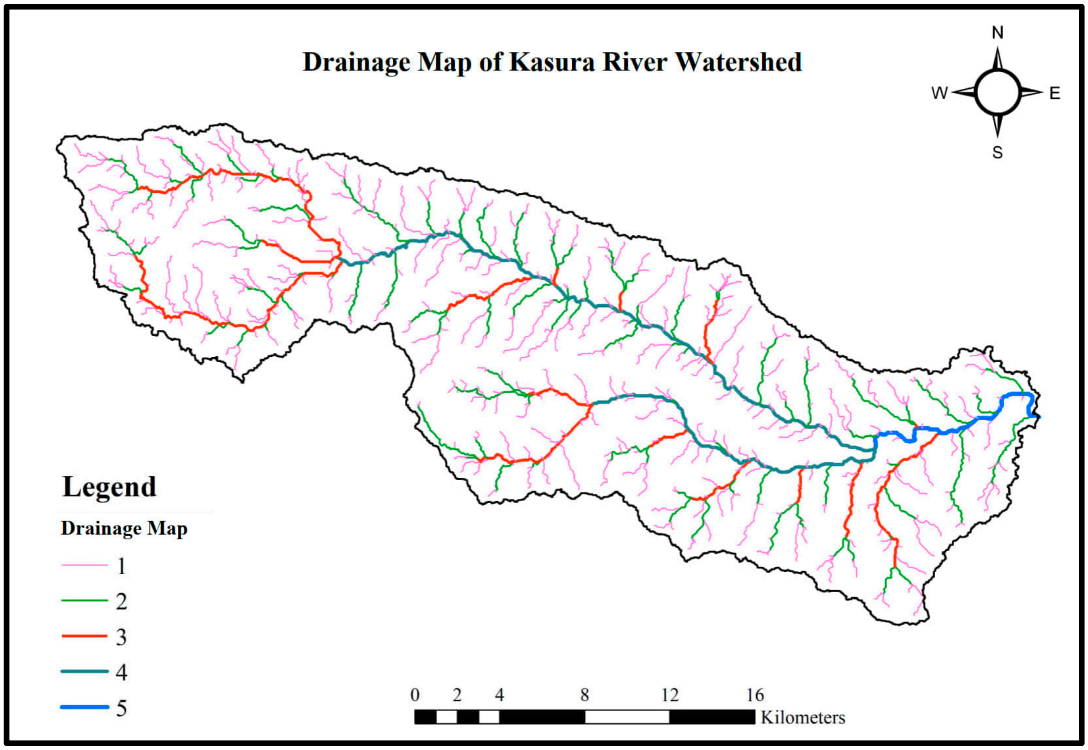

Figure 2. Drainage Map of Kasura Watershed.

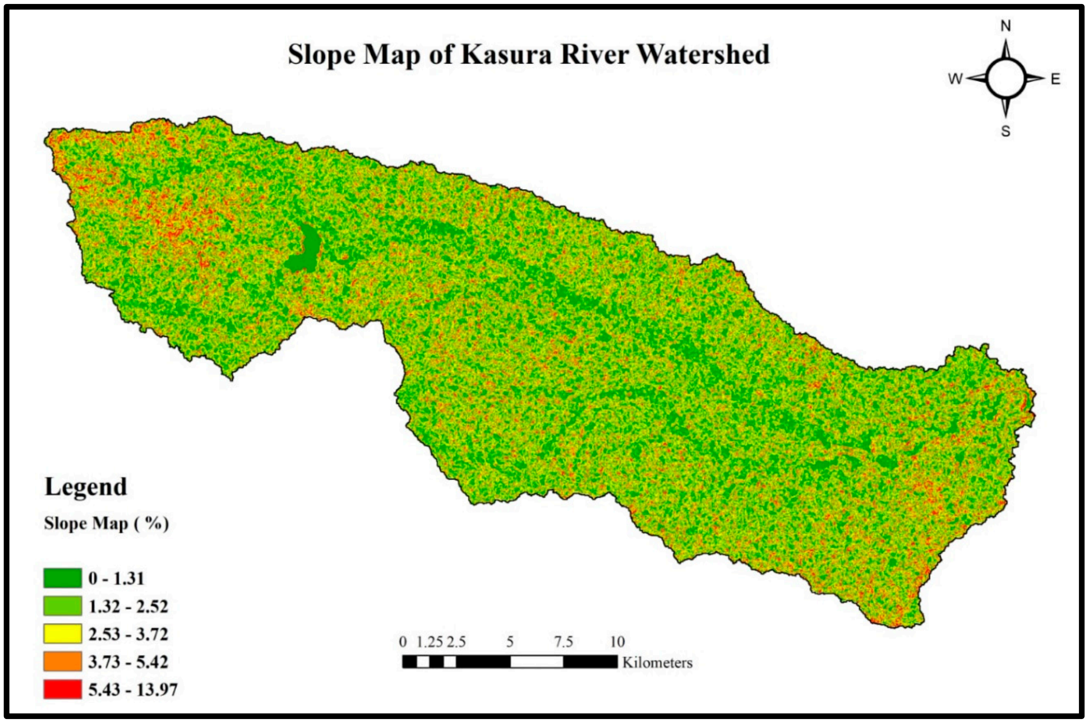

Figure 3. Slope Map of Kasura River Watershed.

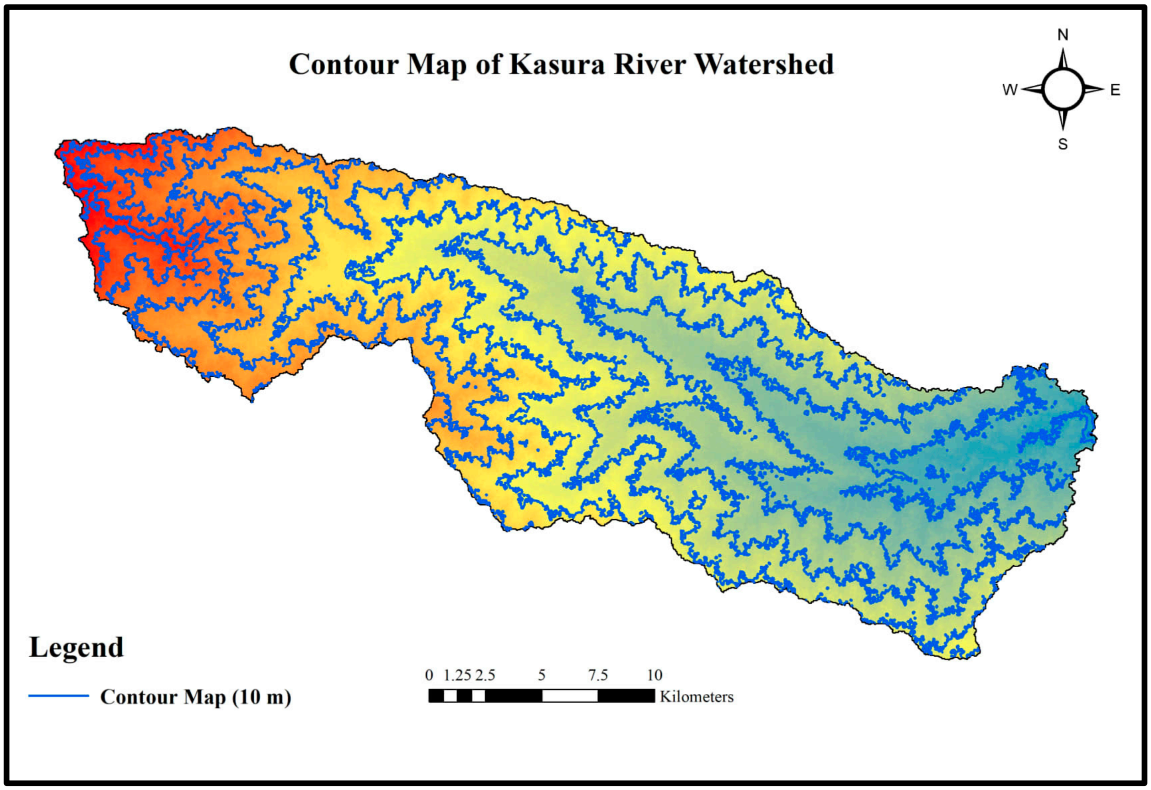

Figure 4. Contour Map of Kasura River Watershed.

6. Length of overland flow (Lg)

According to the data in Table 4, it can be observed that the overland flow length for the catchment was observed to be 0.36 km. The important morphometric factors that influence the topographic as well as hydrological development of the drainage network is the length of the overland flow (Kumar, 2013) and a highest value for this characteristic indicate highest surface runoff (Manjare et al., 2014).

CONCLUSION

In Conclusion, utilizing morphometric analysis for a catchment represents a quantitative approach for delineating the surface features of a drainage system, offering valuable insights into the topography and runoff patterns of the area. A greater bifurcation ratio signifies an elongated shape for the watershed, while a lower ratio suggests a more circular shape. In the varying stream lengths in the studied region result from diverse topography and slope discrepancies. The form factor for all catchment consistently suggests they exhibit shapes ranging from elongated too nearly circular. The circulatory ratio of 0.1679 signifies the inclination of small drainage basins within uniform geological materials to maintain geometric similarities. A high elongation ratio value suggests robust infiltration capabilities and minimal runoff conditions, while low elongation ratios indicate vulnerability to substantial erosion and sedimentation. When drainage density values are low, it suggests lower permeability, moderate to steep slopes, and increased surface runoff. Watersheds with a size of 0.04 km generally exhibited varying relief characteristics. Elevated relief ratios denoted hilly terrain with steep slopes, while lower values suggested valley regions. Furthermore, high length of the overland flows a value indicated significant surface runoff, while low value corresponded to the low surface runoff.

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