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MORPHOMETRIC ANALYSIS FOR SOIL EROSION PREVENTION PRIORITIZATION IN KUSHAVATI RIVER BASIN, GOA : A GEO-INFORMATIC APPROACH

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ABSTACT:

The present study focuses on the morphometric analysis of the Kushavati River basin in Goa for the purpose of prioritizing subwatersheds for development. Utilizing Survey of India (SOI) Topographical maps (1: 50000) and Cartosat DEM (30m resolution), various morphometric parameters were analyzed, including drainage density, bifurcation ratio, stream frequency, drainage texture, compactness constant, elongation ratio, circularity ratio, and form factor. These parameters, collectively known as erosion risk assessment parameters, were employed to assess the erodibility of the basin. The study also involved GIS software for tasks such as drainage map creation, digitization of the basin and streams, and sub-basin demarcation.

1. Introduction

Rivers play a pivotal role in shaping the landscape and ecosystems, influencing the socio-economic well-being of regions they traverse. The Kushavati River basin in Goa is no exception, with its significance extending beyond its natural beauty to encompass agriculture, water supply, and environmental sustainability. In the context of burgeoning developmental needs, understanding the morphometric characteristics of this river basin becomes imperative.

The present study embarks on a comprehensive morphometric analysis of the Kushavati River basin, utilizing advanced geospatial tools and data sources. Morphometric parameters, ranging from linear features like drainage density and stream frequency to aerial aspects such as basin shape and compactness, are scrutinized. These parameters collectively provide insights into the erosion risk associated with different sub-basins within the Kushavati River basin.

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2. Aims and Objectives:

The primary aim of this study is to prioritize subwatersheds within the Kushavati River basin through morphometric analysis. By assessing erosion risk using parameters derived from Survey of India (SOI) Topographical maps and Cartosat DEM, the study seeks to contribute valuable information for effective watershed development and management. The objectives of the research is to morphometric analysis, parameter evaluation, sub-basin evaluation and priority classification in the kushavati river basin.

3. Study Area

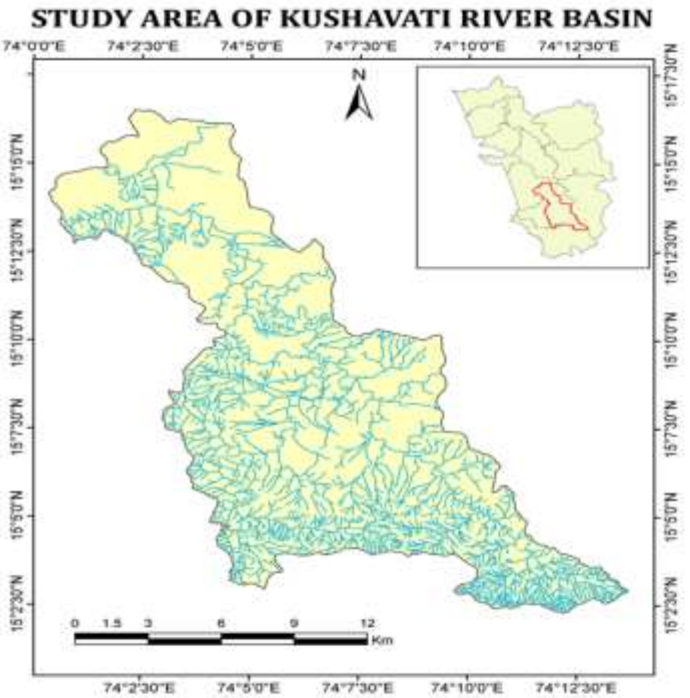

Fig. 1: Location Map of Study Area

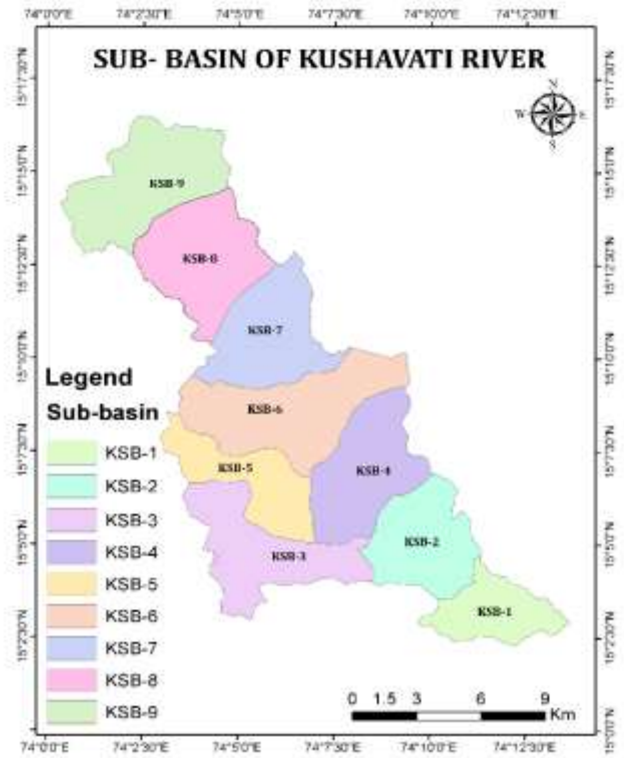

Fig. 2: Kushavati River sub-basin

4. Data and Methodology

The present study is based on morphometric analysis of Kushavati river basin in order to prioritize the basin for the developmental purposes. To assess morphometric condition survey of India (SOI) Topographical maps (1: 50000) and cartosat DEM (30m resolution) are used. Maps as drainage map, digitization of the basin and streams, sub- basin demarcation are done using GIS software.

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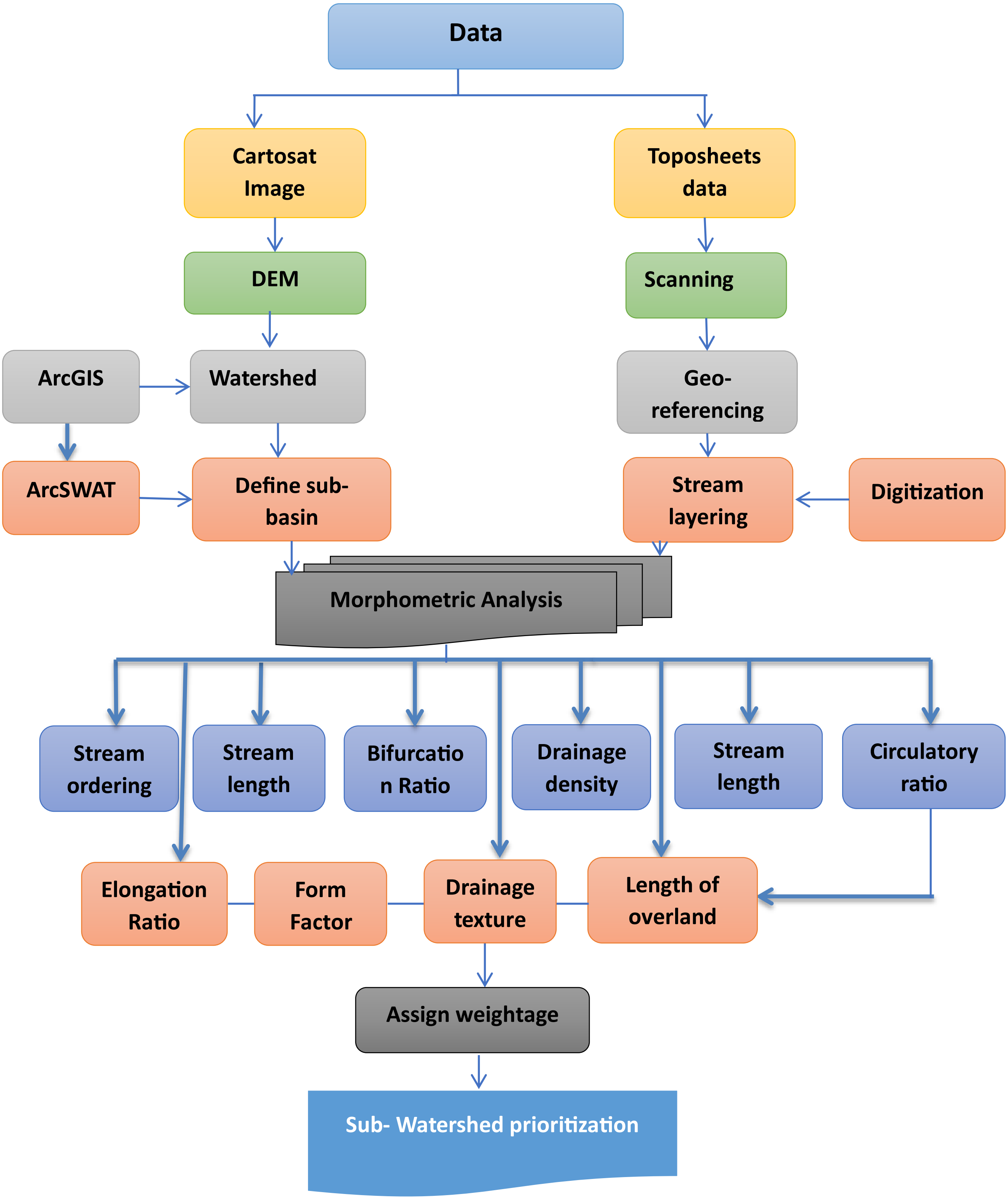

Fig. 2: Research Methodology Chart

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5. Result and Discussion

Table 1: Morphometric analysis Formula chart

Sl.no	**Morphometric parameter**	**Formula**	**Reference**
A	**Linear aspect**		
1.	Stream Order	Hierarchical Rank	Strahler (1952)
2.	Stream Numbers (Nu)	Nu =N1+N2+.......Nn	Horton (1945)
3.	Stream Length (Lu)	Lu =L1+L2+........Ln Lu = Total stream length of order 'u'	Strahler (1964)
5.	Bifurcation Ratio (Rb)	Rb = Nu/Nu+1 Where, Nu = Total no. of stream segments of order 'u', Nu+1 = No. of segments of the next higher order	Schumm (1956)
B	**Aerial aspect**		
1.	Stream frequency (Fs)	Fs = Nu/A Where, Nu = Total no. of stream of all orders, A = area of the basin	Horton (1932)
2.	Drainage Density (Dd)	Dd = Lu/A Where, Lu= Total stream length of all orders, A= area of the basin	Horton (1945)
3.	Drainage texture (T)	T = Nu/P Where, Nu = Total no. of stream of all orders, P = basin perimeter	Horton (1945)

4.	Form Factor (Rf)	$Ff = A/Lb^2$ Where, A= area of the basin, Lb = basin length	Horton (1932)
5.	Elongation ratio (Re)	$Re = (4* A/ \pi)^{0.5}/Lb$ Where, π= 3.14 , A= area of the basin, Lb = basin length	Miller (1953)
6.	Circulatory Ratio (Rc)	$Rc = 4* \pi* A/P^2$ Where, π= 3.14 , A= area of the basin, P = basin perimeter	Miller (1953)
7.	Compactness Constant (Cc)	$Cc = 0.2821\ P/A^{0.5}$ Where, A= area of the basin, P = basin perimeter	Horton (1945)

5.1 Parameters of Morphometric Analysis

A. Linear aspect

Linear aspects of the river channel system includes Stream order (U), Stream numbers (Nu), Stream length (Lu), Stream length ratio (RL), Bifurcation Ratio (Rb), and Length of overland flow (Lof).

1. Stream Order (U)

Stream ordering is the most important aspect of the river basin. The Stream ordering is defined as the measure of stream branching in watershed. The streams are ordered according to the stream segment. It is the first parameter of drainage basin analysis. The concept of stream ordering has initially placed by Horton (1945), and later Strahler (1952) had made some modifications. Stream ordering is the measure of stream branching in the watershed. In the study area the basin has 6 stream ordering. The channel in the lower order joins the channel in the higher order. The first order tributaries join to form the second order tributary. In the Kushavati river basin 6th order is the highest stream order which indicates the larger amount of water flow. The sub-basins of Kushavati River including KSB-6, KSB-7, KSB-8 and KSB-9 have the 6th stream ordering.

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2. Stream Number (NU)

The total number of stream segments in the basin is stream numbering. The total streams of Kushavati river basin is 1697 streams. The 1st order has more number of streams as compared to the other orders. The 1st order streams consist of 1212 streams, 2nd order consist of 392 streams, 3rd order consist of 65streams, 4th order consist of 23 streams, 5th order consist of 3streams and 6th order consist of 2 major streams. The sub-basin of Kushavati River basin is also divided with the number of streams. The maximum numbers of streams of Kushavati river basin are found in the sub-basin of KSB-3 fallowed by KSB-1. The less number of streams are found in the sub-basin of KSB-9 which consists of 89 streams of all the orders.

Table 2: Stream Order and total stream segments of Kushavati River Basin

Stream order	Total stream segment (Nu)
1	1212
2	392
3	65
4	23
5	3
6	2
Total	**1697**

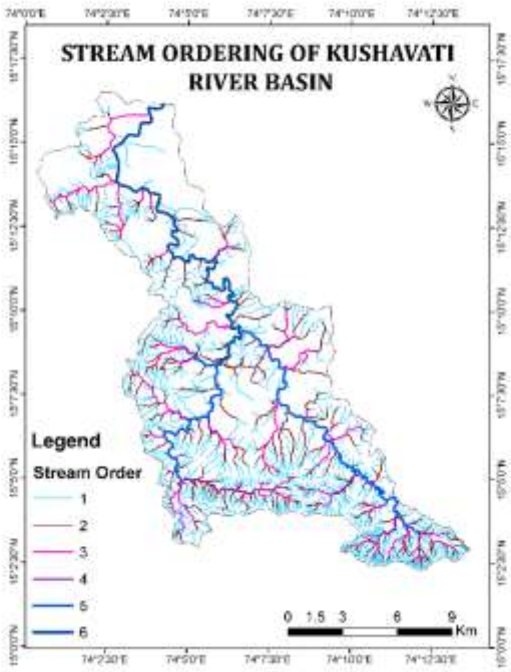

Fig.3: Stream Ordering of Kushavati River Basin

Table 3: Total Stream Numbers of Kushavati River Basin

Sub-basin	Stream Number of different orders						Total
	1	**2**	**3**	**4**	**5**	**6**	
KSB-1	233	59	13	4	1	-	310
KSB-2	168	51	8	5	1	-	233
KSB-3	249	102	12	3	1	-	367

KSB-4	77	32	5	-	1	-	115
KSB-5	80	33	5	3	1	-	122
KSB-6	149	41	9	4	3	2	208
KSB-7	108	31	5	4	-	1	149
KSB-8	80	27	7	-	-	1	115
KSB-9	69	17	2	-	-	1	89

(Source: Data Analysed by researcher)

3. Stream length (Lu)

The total length of streams of different order is stream length. The stream length of different orders is calculated using the formula of Horton, given in 1945. The Kushavati River basin has six stream orders denoted by different stream length. The total stream length of the basin is 764.04 Km. The stream length of different sub basins with their stream orders has been derived. The result indicates that as the stream order increases the length of the streams decreases. The reasons for this are slope, lithology, altitude etc. The sub-basins as KSB-1, KSB-3, and KSB-6 have more length of the streams KSB-8 and KSB-9. Lesser order streams with fewer lengths are often found in the hilly regions. The streams which have higher order are found in the plain surface. The highest length of the streams are found in the sub-basin of KSB-3 having the stream length of 135.73 Km. this is followed by the sub-basins of KSB-6 and KSB-1 having the total stream length of 107.73 and 103.65 Km. The lowest stream length is found in the sub-basins of KSB-9 fallowed by KSB-8 having the stream length of 54.56 and 62.64 Km.

Table 4: Order-wise Stream length of Kushavati River

Stream order	Stream length (km)	Stream order	Stream length (km)
1	440.37	4	23.60
2	160.12	5	33.37
3	76.50	6	30.08

Table 5: Order-wise stream length of Kushavati sub- Basin

Sub-basin	Order wise Stream length (km)						Total
	1	**2**	**3**	**4**	**5**	**6**	
KSB-1	65.68	18.90	10.05	5.64	3.38	-	103.65

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KSB-2	62.42	15.18	9.47	2.96	7.11	-	97.16
KSB-3	83.82	27.56	11.80	6.90	5.65	-	135.73
KSB-4	32.80	23.72	8.71	-	6.46	-	71.69
KSB-5	34.14	13.75	5.52	3.25	3.47	-	60.13
KSB-6	60.09	26.33	7.10	3.39	7.28	3.54	107.73
KSB-7	36.12	13.58	8.29	1.43	-	11.15	70.57
KSB-8	35.96	12.04	6.04	-	-	8.60	62.64
KSB-9	29.28	9.02	9.49	-	-	6.77	54.56

4. Bifurcation Ratio (Rb)

Bifurcation ratio is the ratio of number of segment of a given order to the number of segments of the higher order. Higher the elevation more is the bifurcation ratio and vice versa. The reason for this is because there is more number of streams in the 1st order formed at the higher elevation which will merge with the other streams to form the next higher order. The highest bifurcation ratio is for KSB-9 which is followed by KSB-8. This is because these basins are at the higher elevations then the other sub-basins. There is more number of 1st order streams flowing in this sub-basin. KSB-5 and KSB-6 has a lower bifurcation ratio. This is because this region has a gentle slope and there are less number of 1st order streams in the sub-basin.

Table 6: Bifurcation Ratio of Kushavati sub-Basins

Sub-basin	**Bifurcation Ratio**						**Mean**
	1	**2**	**3**	**4**	**5**	**6**	
KSB-1	3.9	4.5	3.2	4	1	-	3.3
KSB-2	3.3	6.4	1.6	5	1	-	3.4
KSB-3	2.4	8.5	4	3	1	-	3.8
KSB-4	2.4	6.4	5	-	1	-	3.7
KSB-5	2.4	6.6	1.6	3	1	-	2.9
KSB-6	3.6	4.5	2.2	1.3	1.5	-	2.6
KSB-7	3.5	6.2	1.2	4	-	1	3.2
KSB-8	2.9	3.8	7	-	-	1	3.67
KSB-9	4.0	8.5	2	-	-	1	3.9

B. Areal aspect

1. Stream frequency (Fs)

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Stream frequency is the total number of stream segment of all order per unit area. The maximum stream frequency indicates the large number of stream availability. The stream frequency of sub-basins of Kushavati River has been calculated using the formula of Horton given in the year 1932. KSB-1 has the highest stream frequency which is followed by KSB-3. The lowest stream frequency is found in the sub –basin KSB-9 followed by KSB-8 and KSB-4.

Table 7: Stream frequency of Kushavati River Basin

Sub-basin	Stream frequency (Fs)	Sub-basin	Stream frequency (Fs)
KSB-1	20.72	KSB-6	6.23
KSB-2	10.50	KSB-7	5.92
KSB-3	14.01	KSB-8	4.13
KSB-4	4.43	KSB-9	2.95
KSB-5	6.55		

(Source: Data Analysed by researcher)

2. Basin length (Lb)

Basin length is the maximum length between drainage basin mouth and reach. The total basin length of Kushavati river basin is 32.09 Km. The basin length of the sub-basin is helps us to know the longest and the Shortest basin. The longest basin length is found for the sub-basin KSB-6. This sub-basin has the length of 10.93 Km. This is followed by KSB-3 and KSB-5 which is having the basin length of 9.74 and 9.40 Km. The shortest Sub-basin found in the whole basin is KSB-2 having the length of 6.20 Km. this is followed by the sub-basin KSB-1, KSB-7, and KSB-8 having the length of 7.02, 7.67, and 7.73 Km.

Table8: Sub-basin length of Kushavati River Basin

Sub-basin	Basin length(Km)	Sub-basin	Basin length(Km)
KSB-1	7.02	KSB-6	10.93
KSB-2	6.20	KSB-7	7.67
KSB-3	9.74	KSB-8	7.73
KSB-4	8.84	KSB-9	8.86
KSB-5	9.40		

(Source: Data Analysed by researcher)

3. Basin Area

The basin area of Kushavati river basin is 224.079 sq.km. The basin area of the sub-basins is being calculated. KSB-6 has more basin area followed by KSB-9 having the area of 33.35 and 30.15. These basins are larger than the other sub-basins found in Kushavati River basin. This indicates that this basin has larger water holding capacity than the other basins as it is covering the larger area of the basin. KSB-1 has a smaller coverage area of 14.96 sq.km which is followed by KSB-5 covering the area of 18.62 sq.km

4. Basin Perimeter

Basin perimeter is the outer boundary of the watershed that encloses its area.KSB-6 has a higher basin perimeter which is followed by KSB-9 having the perimeter of 30.52 Km and 26.44 Km. The lowest basin perimeter is found for sub-basin KSB-1.

Table 9: Area and Perimeter of Kushavati sub- Basin

Sub-basin	Area (sq.km)	Perimeter (km)
KSB-1	14.96	19.92
KSB-2	22.17	21.07
KSB-3	26.18	32.37
KSB-4	25.95	23.27
KSB-5	18.62	24.98
KSB-6	33.35	30.52
KSB-7	25.14	24.73
KSB-8	27.78	22.92
KSB-9	30.15	26.44

5. Drainage density

Drainage density is the total stream length per unit area. A high drainage density specifies weak basin and impermeable subsurface material with sparse vegetation and high relief. Whereas low drainage density manifests weak coarse drainage texture, high potential runoff and potential erosion of basin area. Drainage density is the measure of the texture of the network, and indicates the balance between the erosive power of overland flow and resistance of surface soils and rocks. The drainage density in the Kushavati sub-basins varies from 1.81 to 6.93. KSB-1 has a higher drainage density which is followed by KSB-3. This value indicates that the basin has week impermeable surface material, less vegetation, and high relief. The lower drainage density is found in the sub-basin KSB-9.The value indicates that

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this basin has highly resistant, impermeable subsoil material with dense vegetation cover and low relief. (Kulkarni, July 2015)

6. Drainage Texture

Drainage texture is the total number of stream segments of all orders to the perimeter of the area. Drainage texture depends on the underlying lithology, climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and stage of development infiltration capacity and relief aspect of the terrain. The drainage texture is classified as very coarser (<2), coarser (2 to 4), moderate (4 to 6), fine (6 to 8), very fine (>8) material. The drainage texture for Kushavati River basin varies from 3.36 to 15.56. KSB-1, KSB-2 and KSB-3 have very fine texture. The sub-basin KSB-6 and KSB-7 has fine texture which indicates that the percolating capacity of water is low due to smaller particle size. KSB-9 has the coarser texture having the infiltration capacity as compared to the other sub-basins. The other sub-basins have the moderate texture.

Table 10: Drainage Density and Drainage Texture of Kushavati Sub- Basin

Sub-basin	Drainage density (Dd)	Drainage texture (T)
KSB-1	6.93	15.56
KSB-2	4.38	11.05
KSB-3	5.18	11.33
KSB-4	2.76	4.94
KSB-5	3.22	4.88
KSB-6	3.23	6.81
KSB-7	2.80	6.02
KSB-8	2.25	5.01
KSB-9	1.81	3.36

7. Form factor

Form factor is the ratio of basin area to the square of the basin length. The value of the form factor is equal to or less than 0.754(perfectly circular). Smaller is the form value lore elongated is the basin and higher is the form value less elongated is the basin. The form factor in kushavati River basin varies from 0.21 to 0.57. This indicates that KSB-2 is less elongated as compared to the other sub-basins Whereas, KSB-5 and KSB-6 is more elongated.

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8. Elongation ratio

Elongation ratio is the ratio of the diameter of the circle of an area to maximum basin length. The value 1.0 shows the circular shape of a drainage basin. Elongation ratio analyze the shape of river basin and is depends on various climatic and geological factors. The elongation ratio is classified as circular (>0.9), oval (0.9 to 0.8) and less elongated (<0.7). The analysis revails that the most basin is less elongated as the values varies from 0.51 to 0.85. KSB-2 is oval in shape having the value of 0.85. (Kulkarni, July 2015).

9. circulatory ratio

Circularity ratio is the ratio of an area of basin to an area of circle having same circumference as the perimeter of basin. It is vital ratio that reveals dendritic stage of drainage due to variation in the slope and relief pattern of the basin. This ratio is prominently relevance to the length and frequency of streams, geological structures, land use/ land cover, climate, relief, and slope of the basin. Low, medium and high value of circularity ratio exhibits the young, mature and old stages of the life cycle of tributary drainage basin. The basin circulatory ratio varies from 0.31 to 0.66 which represent that the sub- basin is elongated. The highest value is found for the sub-basin KSB-8 which indicates that this sub- basin has steep slope and high relief.

Table 3.11: Form Factor, Elongation Ratio & Circulatory Ratio of Kushavati Sub- Basin

Sub-basin	Form factor (Ff)	Elongation ratio (Re)	Circulatory ratio (Rc)
KSB-1	0.30	0.62	0.47
KSB-2	0.57	0.85	0.62
KSB-3	0.27	0.59	0.31
KSB-4	0.33	0.65	0.60
KSB-5	0.21	0.51	0.37
KSB-6	0.28	0.60	0.44
KSB-7	0.42	0.73	0.51
KSB-8	0.46	0.76	0.66
KSB-9	0.38	0.69	0.54

10. Compactness constant (Cc)

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Compactness constant is expressed as the basin perimeter divided by the circumference of a circle to the same area of the basin. The compactness constant of Kushvati River basin varies from 9.49% to 13.85%. KSB-3 has the highest the highest Compactness constant value indicating that this basin is more compact and KSB- 8 has the lowest Compactness constant value indicating that this basin is less compact.

Table 12: Compactness coefficient of Kushavati Sub- Basin

Sub-basin	Compactness coefficient	Compactness (in %)
KSB-1	1.45	11.30
KSB-2	1.26	9.80
KSB-3	1.78	13.85
KSB-4	1.28	9.96
KSB-5	1.63	12.68
KSB-6	1.49	11.60
KSB-7	1.39	10.81
KSB-8	1.22	9.50
KSB-9	1.35	10.50
Total	**12.85**	**100**

C. Relief aspect

1. Basin Relief

Basin relief is the elevation difference between the highest and the lowest point of the valley floor. The highest relief value is 755 of KSB-1 and the lowest relief value is 21 in KSB-2.

Table 13: Basin Relief of Kushavati Sub- Basin

Sub-basin	Highest relief (m)	Lowest relief (m)	Basin relief (m)
KSB-1	755	22	733
KSB-2	451	21	430
KSB-3	560	32	528
KSB-4	417	48	369
KSB-5	387	53	334
KSB-6	329	61	268
KSB-7	265	84	181
KSB-8	262	90	172
KSB-9	258	101	157

(Source: Data Analysed by researcher)

5.2 Prioritization of Kushavati River Basin

The morphometric parameters like drainage density, bifurcation ratio, stream frequency, drainage texture, compactness constant, elongation ratio, circularity ratio, form factor which are also known as erosion risk assessment parameters are used for watershed prioritization. The highest value in the parameters is given 1st rank which is followed by the other parameters. The parameters such as drainage density, stream frequency, bifurcation ratio, drainage texture, have a direct relationship with erodibility while as parameters such as elongation ratio, circularity ratio, form factor, basin shape and compactness coefficient have an inverse relationship with erodibility. The linear and the areal parameters are summed up to get the compound parameter in order to prioritize the watershed basin. The priority classes have been decided based on the priority classes. Kushavati river basin is classified into three priority classes which include High, Moderate and Low priority. KSB-5, KSB-6 and KSB-9 are having low priority. This indicates that these sub-basins should get the highest priority for watershed development and management. Highest priority specifies the greater degree of erosion in the sub-basin and applying soil conservation measures is very important in these sub-basins. The sub basins KSB-4, KSB-7 and KSB-8 has to be given moderate priority and the sub-basins KSB-1, KSB-2 and KSB-3 are categorized as low priority regions where in there is less erodibility.

Table 14: Final Prioritization chart of Kushavati River Basin

Sub-basin	Rb	Cc	Dd	T	Fs	Rc	Ff	Re	Compound parameter	Final priority
KSB-1	6	4	1	1	1	6	6	6	3.87	6
KSB-2	5	8	3	3	3	2	1	1	3.25	7
KSB-3	2	1	2	2	2	9	8	8	4.25	5
KSB-4	3	7	7	7	7	3	5	5	5.5	3
KSB-5	8	2	5	8	4	8	9	9	6.62	1
KSB-6	9	3	4	4	5	7	7	7	5.75	2
KSB-7	7	5	6	5	6	5	3	3	5	4
KSB-8	4	9	8	6	8	1	2	2	5	4
KSB-9	1	6	9	9	9	4	4	4	5.75	2

(Source: Data Analysed by researcher)

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Fig.4: Sub-watershed Prioritization of Kushavati River Basin

6. Major Findings

The morphometric analysis of the Kushavati River basin has yielded significant insights into the geomorphological characteristics and erosion susceptibility of its sub-basins. The following are the major findings derived from the study:

- **Erosion Risk Assessment**: Morphometric parameters such as drainage density, bifurcation ratio, stream frequency, and drainage texture were crucial in assessing erosion risk. Parameters like elongation ratio, circularity ratio, form factor, basin shape, and compactness coefficient provided additional context, forming a comprehensive erosion risk assessment framework.
- **Sub-Basin Prioritization:** The linear and areal morphometric parameters were integrated to create a compound parameter for prioritizing sub-basins. Three distinct priority classes were established: High, Moderate, and Low, based on the degree of erosion risk within each sub-basin.
- **Priority Classification:**

  i) High-Priority Sub-basins (e.g., KSB-5, KSB-6, KSB-9): These sub-basins exhibited the highest erosion risk, signaling an urgent need for intervention. They demand immediate attention for implementing soil conservation measures and sustainable land management practices.

ii) Moderate Priority Sub-basins (e.g., KSB-4, KSB-7, KSB-8): Sub-basins in this category demonstrated a moderate level of erosion risk. Targeted interventions are required, though the urgency is comparatively lower than in high-priority areas.

iii) Low Priority Sub-basins (e.g., KSB-1, KSB-2, KSB-3): These sub-basins showed lower erodibility, suggesting a lower risk of erosion. Planning for erosion prevention and sustainable land management practices is recommended.

- **GIS as a tool for watershed Analysis:** The utilization of GIS for drainage mapping, digitization, and sub-basin demarcation proved instrumental in conducting a detailed morphometric analysis. GIS facilitates a spatial understanding of the basin, aiding in decision-making processes for sustainable watershed development.

6. Conclusion

The major findings underscore the importance of a nuanced and context-specific approach to watershed development. By identifying and prioritizing sub-basins based on erosion risk, the study provides a foundation for effective planning and resource allocation. The implications extend beyond environmental conservation, emphasizing the need for community involvement, adaptive management, and the integration of advanced geospatial tools in future watershed management initiatives in the Kushavati River basin.

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