ISSN – 2277-7911
Impact Factor – 5.958
YOUNG RESEARCHER
A Multidisciplinary Peer-Reviewed Refereed Research Journal
Jan-Feb-Mar 2025
Vol. 14 No. 1

GIS-Based Morphometric Analysis of the Upper Kundalika Watershed, Maharashtra.

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DOI - 10.5281/zenodo.15876720

Abstract:

Upper Kundalika watershed is a minor catchment zone on the Konkan region, covering 371.75 sq. km of hard massive basalt rocks from Sahyadri hill range. The sixth-order stream has a circular basin. Drainage development in Upper Kundalika River basin created a 43.68-km basin. Circular drainage basins impact catchment stream discharge. The basin has 1690 streams. Although Upper Kundalika River has a tiny catchment in Konkan, it supplies water to 108 settlements and an industrial sector developed there. Circularity ratio is larger than elongation ratio, indicating water from all catchments. The river is perennial; however, flash floods occur in the wet season. Dams or power projects near Roha tehsil retain remaining water. The morphometric analysis of the Upper Kundalika River Basin provides vital insights into the hydrological behavior, drainage characteristics, and terrain evolution of the region. Located in the Western Ghats of Maharashtra, this basin exhibits a dendritic drainage pattern and varied topographical features influenced by monsoonal precipitation and geological structure. This study employs remote sensing and GIS techniques to evaluate key linear, areal, and relief parameters such as stream order, bifurcation ratio, drainage density, form factor, and hypsometric integral. The results suggest that the basin is moderately dissected with a youthful geomorphic stage, indicative of active fluvial processes and high runoff potential. Such morphometric insights are essential for sustainable watershed management, soil conservation, and planning of water resource development in the Upper Kundalika basin.

Keywords: Upper Kundalika, Linear Aspects, Stream Number (Nu), Stream Order, Bifurcation ratio (Rb), Stream Length, Stream length Ratio (RL), Length of Overland Flow (Lg), Areal Aspects, Drainage Density (Dd), Stream Frequency (Fs), Texture Ratio (T), Elongation ratio (Re), Circularity Ratio:(Rc), Compactness Coefficient (Cc), Form factor ratio (Rf), Relief Aspects, Basin Relief (Relative Relief), Relief Ratio, Basin slope (Sb)

Introduction:

Hydrological research of a river watershed involves knowledge of the drainage basin's morphometry and hypsometry, which reveal its lithological and mechanical control, relative runoff and recharge, erosional aspect, and stage of development. To understand watershed hydrodynamics, landform development, morphometric processes, and characteristics must be studied. These parameters, along with total precipitation, evapotranspiration, and soil and vegetation absorption, determine land water recharge. Morphometric analysis is covered here.

Morphometry means "the measurement of forms and landform." Morphometric analysis examines landform geometry. Horton (1945) was the first to emphasize that geomorphological investigations require quantitative analysis rather than quantitative description to provide hydrologists with mathematical data. Schumm, 1956; Stahler, 1957; and Melton, 1958, extended on Horton's (1945) work. A complete morphometric investigation requires planimetric measurements of the drainage basin's linear and aerial characteristics. Relief of the channel network and vertical inequalities of the land slope form the drainage basin.

Methodology:

1. Digitization of Layer:

The toposheet displays geographic data as signs and symbols with properties. The GIS program evaluates this data and studies the area using several levels. Arc GIS 9.3 was used to digitize all rivers and spot heights in Kundalika Basin.

2. Topology of the data

Once the data has been digitized, error rectification is required before the analyst may use it. Topology is required for error correction. The digitized layer's topology was created using the same software.

3. Ordering of Stream:

Each and every tributary and main stream must be ranked in order for the morphometric analysis of the river in the basin area. Between the headwaters of a stream and a location some distance downstream, channel segments were arranged sequentially. The tributaries in the headwaters of the stream are given the value 1, and numerical ordering starts there. An order of two was assigned to a stream segment that was created by combining two segments of the first order. A 3rd order stream was created from two 2nd order streams, and so on.

4. Formation of Drainage Map:

Drainage map of all the sub watershed is made according to orders by using Arc GIS Software 10.2. Using 1:50000 scale SOI topographical maps, the Kundalika watershed and an associated drainage network (Fig. 2) were identified and digitally captured using Arc GIS 10.2. Actually, Kundalika has a basin area of 371.75Sq. Km, making it a sizable watershed. Calculating the watershed's overall morphometry is essential. Calculation of the morphometric parameters the following parameters are evaluated through morphometric analysis: the bifurcation ratio (Rb), the relief ratio (Rh), the ruggedness number (Rn), the relief ratio (Rh), the drainage density (Dd), the stream frequency (Fs), the texture ratio (T), the form factor (Rf), the length of overland flow (Lof), and the constant channel maintenance (C) (aerial parameters).

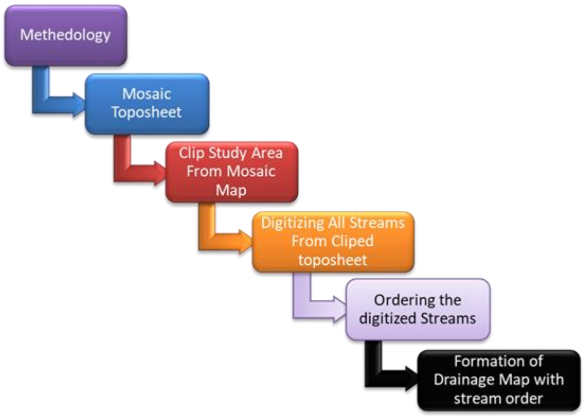

Figure 1: Flow Chart of Methodology

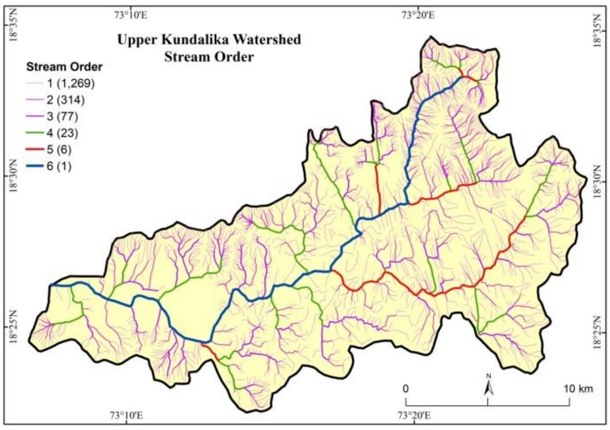

Figure1: Drainage Map of Upper Kundalika River Basin

Table 1. Formulae for computation of morphometric parameters

Morphometric Parameters	Formula	Reference
Stream Order (U)	Hierarchical order	Strahler (1964)
Stream Length (Lu)	Length of the stream	Horton (1945)
Mean Stream Length (Lsm)	Lsm = Lu/Nu Where, Lu = Stream length of order 'U' Nu=Total number of stream segments of order 'U'	Horton (1945)
Stream Length Ratio (RL)	RL = Lu/Lu-1 Where, Lu = Total stream length of order 'U' Lu-1 = The total stream length of its next lower order	Horton (1945)
Bifurcation Ratio (Rb)	Rb = Nu/Nu+1 Where, Nu = Total number of stream segment of order 'U'; Nu+1 = Number of segments of next higher order	Schumn (1956)
Drainage Density (Dd)	Dd = L/A Where, L = Total length of streams of all orders A = Area of the basin (km2)	Horton (1945)
Stream Frequency (Fs)	Fs = N/A Where, N = Total number of stream A = Areas of the basin (km2)	Horton (1945)
Drainage Texture (Rt)	Rt = Nu/P Where, Nu = Total number of streams of all orders P = Perimeter of the basin (km)	Horton (1945)
Circulatory Ratio (Rc)	Rc = 4πA/Lp2 Where, A=Area of the basin Lp=Perimeter of the basin	Miller (1953)
Elongation Ratio (Re)	Re= (2 × (A / π)0.5) / Lb Where, A=Area of watershed, π=3.14, Lb=Basin length	Horton (1945)
Compactness Coefficients (Cc)	Cc = 0.2821 P/A0.5 A = areas of basin (km2), P = basin perimeter (km)	Schumn (1956)
Basin Relief (Bh)	Vertical distance between the lowest and highest points of watershed	Schumn (1956)
Relief Ratio (Rh)	Lg = 1/Dd*2 Where, Dd = Drainage density	Horton (1945)
Chanel Sinuosity	Channel sinuosity = OL / EL Where, OL = observed path of a stream; EL = expected straight path of a stream	Schumm (1963)

Morphometric Analysis:

1. Linear Aspects:

The channel patterns of the drainage network, which are used to study the topological characteristics of the stream segments in terms of open links, are strongly related to the linear aspects of the basins. The drainage network, which comprises of all stream segments of a particular river, is simplified to the level of graphs, where the intersections of streams function as points and streams. When two points are connected, they become links, and the stream is made up of all these linkages.

Table 1: Drainage Basin and Network Morphometry

Sr. No.	Parameters	Calculated Value
Linear Aspect		
1.	Stream order	6
2.	Total Stream Length	1150.228086
3.	Length of main stream	43. 69 km.
4.	Stream Length Ratio	3.284471363
5.	Bifurcation Ratio	4.260096554
6.	Length of Over land flow (Lg)	0.646386628

A) Stream Number (Nu):

The total number of streams, organised by segment, is the "stream number". Horton 1945. The GIS program shows that the number of channels lowers as the number of projected stream orders grows. Route and addition basin parameters directly affect stream frequency. Increased streams indicate lower permeability and infiltration.

B) Stream Order:

Stream ordering is a drainage basin's stream hierarchy. The river basin has many stream segments in different locations. Every stream affects rivers. The basin analysis' initial stage determines stream orders. In this study, Strahler's stream ordering approach ordered the drainage basin's channel segment. Small fingertip tributaries are Strahler's (1964) order 1. Two first-order channels converge to make a channel segment of order 2, two second-order channels merge to form a channel segment of order 3, and so on for the fourth and following orders. The stem stream, the highest-order stream component, discharges water and sediment. Table 1.1 shows the stream ordering mechanism and the number of streams per order segment (Nu) (U). Higher stream orders indicate higher river discharge, whereas lower orders indicate lower discharge. The upper Kundalika River Basin research region has sixth-order streams.

C) Bifurcation ratio (Rb):

A drainage network's branching structure and bifurcation ratio are linked. Schumn (1956) defines the bifurcation ratio as the ratio of streams in one order to those in the next higher order. In basins whose geologic formations do not change drainage, Strahler (1964) found a bifurcation ratio between 3.0 and 5.0. According to Strahler (1957), the bifurcation ratio has a small variance that varies with the environment. Early hydrograph peaks may be vulnerable to flash flooding during storms in places with these stream patterns due to the high bifurcation ratio. A much smaller bifurcation ratio indicates increased permeability, less structural control, and geological heterogeneity throughout the area. The calculated bifurcation ratio for the Upper Kundalika River basin is 4.260096554, indicating that flash floods occur in the monsoon season and dry season except around the dam.

D) Stream Length:

Stream length shows the historical history of its portions, including tectonic interruptions. Stream length is perhaps the basin's most important hydrological top feature because it signifies surface runoff. Larger gradients and finer textures identify smaller streams. Lower flow rates are associated with longer stream beds. Total stream segments are usually higher in first-order streams and decrease with stream acquisition. The number of streams in a basin and their patterns from mouth to drainage and breakdowns are commonly described using ArcGIS 9.3 software.

E) Stream length Ratio (RL):

The length ratio (RL) is the ratio of the order's mean stream segment length to the order below. A substantial association exists between stream length ratio and basin surface flow, discharge, and erosion stage. The mean River Upper Kundalika stream length ratio is 3.284471363. It shows the river's early geomorphic evolution. Actually, it illustrates the river's origin and tremendous erosion.

F) Length of Overland Flow (Lg):

Overland flow length is a major independent variable affecting drainage basin physiography and hydrology (Horton R.E. 1932). Soil infiltration and percolation affect overland flow over time and space (Kanth T.A. 2012). The watershed is in a stage of development. Overland flow length for upper Kundalika is 0.6463. It demonstrates the river's youth.

2. Areal Aspects:

In quantitative geomorphology, basin area (A) and perimeter (P) are crucial. The basin area affects storm hydrograph size, peak, and mean runoff measurements. Maximum flood discharge per unit area is inversely related to size (Smart S. and Surkan, 1967). Aerial drainage basin parameters were calculated, including basin area (A), drainage density (Dd), stream frequency (Fs), texture ratio (Rt), elongation ratio (Re), circularity ratio (Rc), and form factor ratio.

Table 2: Drainage Basin and Network Morphometry

Sr. No.	Parameters	Calculated Value
Aerial Aspect		
1	Basin Area (km2)	371.746027
2	Basin Length (km)	35.536041
3	Basin Perimeter (km)	121.094694
4	Form Factor	0.294379966
5	Circularity Ratio	0.318699029
6	compactness coefficient	1.7717
7	Elongation Ratio	0.017232578
8	Drainage Density (km/km2)	3.094123413
9	Stream Frequency (streams/km2)	4.54611449

A) Drainage Density (Dd):

Drainage density affects water travel time (Schumn, 1956). Dd helps quantify terrain subdivision and drainage (Chorley et al. 1957). High drainage density denotes a highly dissected drainage basin with a rapid hydrologic response to rainfall events (Melton, 1957). This is in contrast to low drainage density. Techniques for regulating surface runoff affect Dd and the drainage basin's water and sediment discharge (Chorley, 1969). Ozdemir et al. (2009) say Dd changes with climate and vegetation. Dd is usually inversely related to soil hydraulic conductivity. Montgomery and Dietrich (1992) held the belief that steep slopes exhibited an inverse correlation. As soil transmissivity and rock infiltration decrease, Dd rises. Horton (1945) defined

Dd as the sum of channel lengths (Lu) divided by catchment area (A). Kundalika has a 3.094123413 km/km^2 drainage density. It indicates weak or impermeable subsurface material, scarce vegetation, hilly topography, and fine drainage. Industrialisation makes vegetation scarce and settlements rise.

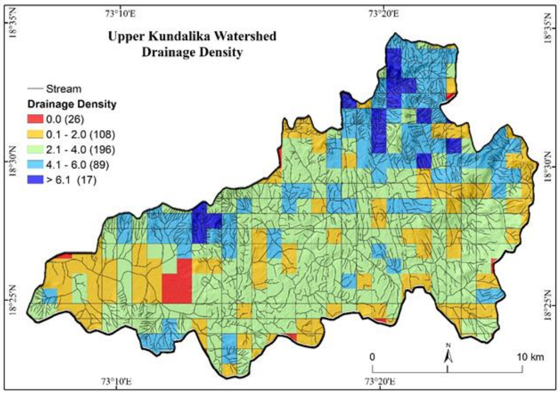

Figure 3: Drainage Density of Upper Kundalika Watershed

B) Stream Frequency (Fs):

Stream or channel frequency (Fs) is the number of stream segments for all orders in a unit region (Horton, 1932). The drainage network texture and basin lithology determine the outcome. It marks the progression of landscape development. Permeability of underground materials, rainfall, vegetation, relief, and rock structure affect stream frequency. Drainage density and stream frequency are linked. Runoff is slower in basins with low to moderate drainage density and stream frequency, which makes flooding unusual (Carlston, 1963). This river basin has 4.54611449 streams/km^2. A higher drainage density indicates healthy vegetation, medium relief at the river's origin, strong infiltration capacity, and later peak flows resulting from a low runoff rate.

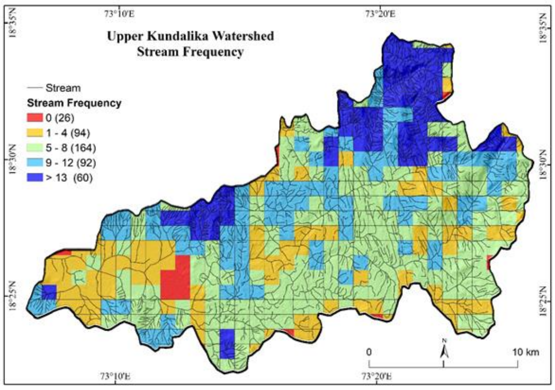

Figure 4: Stream frequency of Upper Kundalika River Basin

C) Texture Ratio (T):

As a result, density is low and continual channel maintenance is high (Kale and Gupta, 2010). According to Smith (1950), drainage textures can be classified into five different categories based on drainage density. Less than 2 drainage density indicates very coarse, between 2 and 4 indicates coarse, between 4 and 6 shows moderate, between 6 and 8 indicates fine, and greater than 8 suggests very fine drainage density. The basin of the upper Kundalika River

D) Elongation ratio (Re):

Schumm (1956) defines elongation ratio (Re) as a circle's diameter divided by its longest basin length. The elongation ratio (Re) helps basin form analysis reveal a drainage basin's hydrological structure. Similar to form factor, basin shape affects hydrological system response. Strahler 1964 and Sarma 2013. Upper Kundalika River Basin elongation ratio: 0.017232578. The basin form is less elongated.

E) Circularity Ratio:(Rc)

The circularity ratio (Rc) quantifies basin form (Christopher et al. 2010). It's affected by basin lithology. Distance, frequency (Fs), and gradient of streams of different orders affect the ratio more than the basin's drainage pattern and slope. When the circularity ratio is close to 1, the basin can infiltrate uniformly but takes a long time to reach the excess water at the exit, depending on local geology, slope, and land cover. Length, frequency (Fs), and gradient of distinct orders affect the ratio more than the slope and drainage pattern. The upper Kundalika river basin's circularity is 0.318699029. It means the upper Kundalika's watershed is circular.

F) Compactness Coefficient (Cc):

The compactness coefficient compares a hydrologic basin to a circular basin of the same area. Due to its fastest drainage pattern, a circular basin is the most dangerous. Concentration before basin peak flow. Upper Kundalika's compactness coefficient of 1.7717 indicates moderate risk. It's riskier at the source than the outlet.

G) Form factor ratio (Rf):

Basic ratios of area, perimeter, and length can establish a basin's shape (Thornbury, 1969). Miller and colleagues (1953) defined a dimensionless circularity ratio (Rc) as the ratio of the basin's surface area to a circle with the same perimeter. He said the basin has a circularity ratio between 0.4 and 0.5, indicating extremely permeable homogenous geologic materials.

3. Relief Aspects:

The study of three-dimensional properties involving area, volume, and height of vertical dimension of landforms is closely related to the relief aspects of drainage basins to examine various geohydrological characteristics. Analysis is done on some significant alleviation parameters associated with the investigation.

Table 3: Drainage Basin and Network Morphometry Relief Aspect

Sr. No.	Parameters	Calculated Value
Relief Aspect		
1	Basin Relief	1036
2	Relief Ratio	0.90069
3	Basin Slope	11.5372 degree

A) Basin Relief: (Relative Relief):

The maximum vertical distance between a basin's lowest and highest points is known as relief. Understanding the denudational characteristics of the basin depends on the relief of the basin.1036 m. is relative relief of the selected basin. It is indicated that most of the area of the watershed is hilly region which is found at origin part of the river Kundalika.

B) Relief Ratio:

Schumm observed that the amount of loose silt per unit area is closely connected with relief ratios, highlighting the possibility of a close relationship between relief ratio and hydrologic parameters of a basin. The Relief ration which is calculated for the selected river basin is 0.9007. it is indicated that higher relief in origin region and decreases with higher order of steams and mouth of stream.

C) Basin slope (Sb):

According to the Slope map this area is falls under the western *ghat* region it means there have undulating types of slopes from origin to mouth of the river

Kundalika. The Slope map shows undulating slopes from the origin to the mouth of the Kundalika River in the western ghat region. Average regional slope is 11.73 degrees. The river's beginning has a higher slope. More than 30 to 75 degrees slope in that location. This area has mostly hilltops. The middle of the basin has a 9- to 30-degree slope, with part level and some hilly. The outlet zone of the river basin at Roha and Industrial has a slope of less than 10 degrees. This area shows the plains where agriculture and industry flourish.

The aspect map (Figure 5) displays the slope across the entire upper Kundalika Basin river relief. The Upper Kundalika River flows west-east in Konkan. The northern Kundalika River origin is north to northeast, while the southern origin is north to northwest. Most rivers in this region spring from hills, including Kundalika. The middle part of the Kundalika River in the selected region is moderately sloped and mostly east-west, with some northeast-southwest and southeast-northwest tributaries meeting the main channel. East-west direction is apparent in the region's mouth. This plain is depicted by green and green shades on the upper Kundalika River aspect map (Fig. 5).

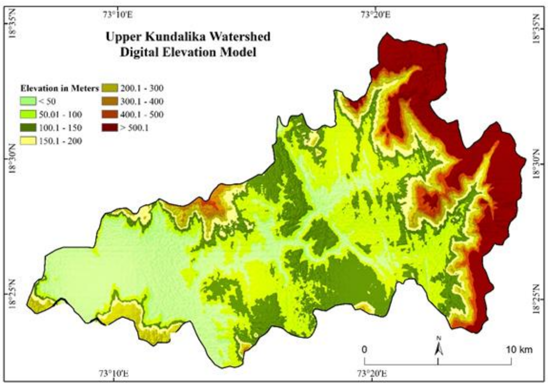

Figure 2: DEM of Upper Kundalika River Basin

An aspect map (Figure 1.5) illustrates the slope direction across the entire relief of the upper Kundalika Basin river. The Upper Kundalika River takes the path from the west to the east direction in the Konkan region. At the origin, the southern part of the Kundalika River has a direction from north to northwest, and the northern origin part of the River Kundalika has a direction from north to northeast. In this region most of the rivers originate from hilly regions, with the main channel of the river Kundalika. The middle part of the Kundalika River in the selected region is moderate in slope, and mostly the direction of this region is from east to west, with some areas found from northeast to southwest and some found in a southeast to northwest direction where the tributaries meet the main channel of the Kundalika River. And the clear direction from east to west is found in the mouth of the region. This plain area is shown by green and green shades in the aspect map of the upper Kundalika River (Fig. 5).

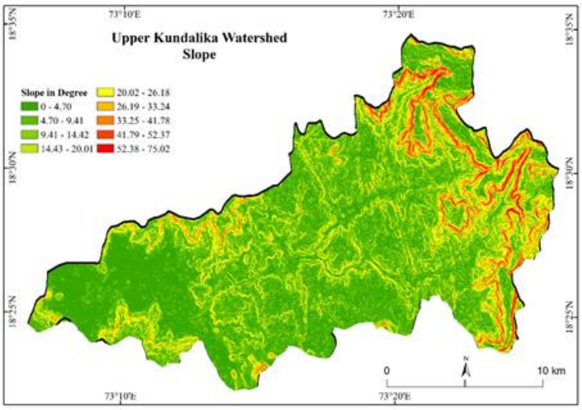

Figure 3: Slope Map of Upper Kundalika River Basin

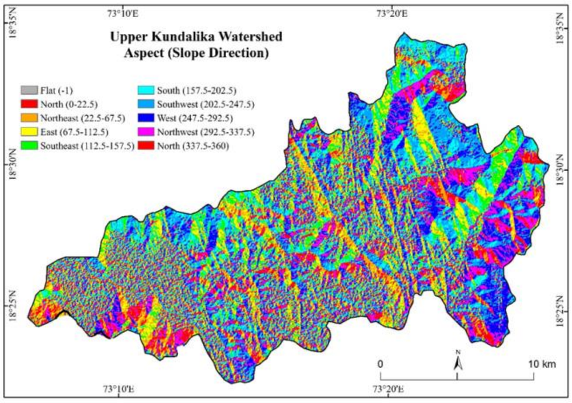

Figure 4: Aspect Map of Upper Kundalika River Basin

Conclusion:

The Upper Kundalika watershed is a very minor catchment zone in the Konkan region. It encompasses an area of 371.75 square kilometres and is covered with hard, massive basalt rocks that originate from the Sahyadri hill range. This stream is of the sixth order and has a basin that is round in shape. The expansion of drainage in the Upper Kundalika River basin caused the basin to grow to a total length of 43.68 kilometres, which is the direct result of irrigation. The drainage basin is circular in shape, which has an effect on the growth of stream discharge in the catchment region. In total, there are 1690 streams that are contained inside the basin. The Upper Kundalika River has a relatively modest catchment in Konkan, but it is an important catchment because it provides water to 108 settlements and an industrial zone that is located in that region. It is a permanent river; however, the largest flash floods are experienced during the rainy season. The circularity ratio is larger than the elongation ratio, which indicates that water is getting from all of the catchment areas of the river. Water that is not used is stored in dams or power projects that are located close to the Roha tehsil.

This river basin has a stream frequency of 4.55 streams per square kilometre. It is higher, which suggests that there is good vegetation, medium relief (in the area where the river originates), strong infiltration capacity, and later peak discharges as a result of a low runoff rate. The term "drainage density" measures the texture of the drainage system within a given area. It has a drainage density of 3.094 km/km^2, which indicates that it has a coarse drainage texture. This result is attributable to the very resistant subsoil material and the low relief. The Upper Kundalika basin features a compactness coefficient of 1.7717, which indicates that it is a basin with a moderate level of danger. However, the danger is significantly higher at the point of origin and significantly lower at the point of sale. 1036 meters is the relative elevation of the basin that was chosen. There is evidence to suggest that the majority of the watershed is comprised of mountainous terrain, which may be found in the valley where the Kundalika River begins its journey. 0.9007 is the relief ratio that has been determined to be appropriate for the river basin that has been chosen. The relief is greater in the region of origin and decreases with the order of streams and the stream's mouth. Because the overall slope of the region ranges from 2 to 76 degrees and the average slope is 11.73 degrees, it can be deduced that the surface of the territory is exceptionally undulating.

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