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Geospatial analysis of morphometric parameters in the Kal River Basin, Western Konkan: Implications for hydrological characteristics

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Abstract
Remote sensing and Geographic Information Systems (GIS) are vital tools for gathering and analyzing extensive geographical data. Globally available digital elevation models (DEMs), like those from satellite launches, help characterize watersheds of any size by computing morphometric parameters crucial for effective watershed management. The present study investigated the application of remote sensing and GIS (Geographic Information System) in computing morphometric parameters for the Kal River basin in the Raigad district, Maharashtra, India. The AW3D30 Digital Elevation Model (DEM) obtained from satellite data was utilized to delineate the Kal River basin in ArcGIS 10.8.1 software. The study computed 28 morphometric parameters to analyze various aspects of the basin. The total drainage area of the Kal River basin was determined to be 457.82 km², signifying the extent of the basin. It was classified as a 5th order basin based on the Strahler stream order classification. In linear aspects, the mean bifurcation ratio (2.17), stream length ratio (0.7 to 1.1) etc were calculated. These values suggest that the basin is less structurally disturbed and in the initial stage of geomorphic development. In areal aspects, drainage density (0.877 Km^{-1}), stream frequency (1.11 $Streams/Km^2$) etc indicate that the basin has highly permeable subsurface strata with a coarser texture, resulting in less runoff potential and longer flow paths. In areal aspects, Form factor (0.25), Elongation ratio (0.56) indicate an elongated basin shape with less likelihood of attaining a flatter peak in flood hydrograph. In relief aspects, relief ratio (0.02), relative relief (1.06 m/km), ruggedness number (1.01), time of concentration (14 hr 54 min) provide information about the basin's relief characteristics. A statistical study indicates a strong correlation between stream order and both stream number and stream length. The shape of the hypsometric curve reflects the erosive phases within the Kal River basin. The Kal river basin exhibited complex physiographic and geological characteristics, contributed by presence of the Sahyadri ranges, mafic dyke's swarms and Tapi fault. This study's findings suggest the necessity of implementing measures to conserve water and soil resources for the watershed's sustainable long-term development.

Keywords: AW3D30 DEM, digital elevation model, morphometric parameters, remote sensing and GIS technology and watershed

1. Introduction
A river basin is a geographical area of land where all the surface water from rainfall, snowmelt, and rivers converges to a single point, typically a larger river or a body of water, like a lake or an ocean (Sangma and Guru 2020) [29]. River basins are vital in collecting and transporting water, shaping landscapes, and supporting ecosystems. Analyzing their characteristics involves morphometric parameters like basin size, drainage patterns, and relief aspects. Traditional field surveys are time-consuming for large-scale analysis, making remote sensing (RS) and Geographic Information Systems (GIS) a preferred choice. RS provides crucial data like Digital Elevation Models (DEMs), aiding in hydrological studies, erosion analysis, and watershed planning. GIS efficiently manages and analyzes diverse watershed data, integrating factors like soil, vegetation, and land use. Its ability to overlay datasets supports informed decision-making for sustainable development, making GIS indispensable in hydrology, environmental science, and resource management. Watersheds are ever-changing systems, showing variations in runoff, discharge, sediment load, and other characteristics over time and space. These alterations in input and output affect the overall dynamics of the basin. (Parvez and Inayathulla, 2019) [25]. Absolutely, understanding a watershed's characteristics involves a multifaceted analysis that encompasses various linear, aerial, and relief aspects (Sutradhar H. 2020) [38]. Each category of variables provides unique insights into the landscape and hydrology of the watershed.

Linear variables such as stream length, number of streams, bifurcation ratio, mean stream length ratio, etc offer quantitative measures related to the flow and distribution of water within the watershed. Relief variables like watershed relief, relief ratio, relief relative, ruggedness number, maximum elevation, and minimum elevation depict the topographical features, elevation differences, and ruggedness of the terrain. Aerial variables including circulatory ratio, frequency of streams, stream length ratio, stream density, drainage texture, drainage intensity, form factor, elongation ratio, provide insights into the shape, size, and spatial distribution of the watershed. The hypsometric curve is a valuable tool that illustrates the relationship between elevation and the percentage of the watershed's area above certain elevations. It helps in understanding the slope distribution and erosion patterns within the basin. Moreover, it aids in identifying erosional phases, which are vital for planning catchment treatment, basin management, and the strategic placement of infrastructure for rainwater collection. (Jothimani *et al*., 2020) [15]. By comprehensively analyzing these variables and utilizing tools like hypsometric curves, hydrologists, geologists, and environmental planners can gain a holistic understanding of the watershed. This knowledge is crucial for effective watershed management, conservation efforts, and sustainable development practices. The acquisition of watershed's morphometric parameters by traditional survey method is not easy due to numerous problems like huge area of land, irregular topographic features, time and cost factor (Meshram *et al*. 2020) [20]. The question arises which technique will be suitable to acquire this huge data while conserving time and cost factor. Over the past two decades, the largely deriving technique of Remote Sensing and GIS to acquire remotely sensed data like terrain elevation data by Digital Elevation Model, and land cover data by Landsat satellites etc., The GIS proved to be a feasible application in the evaluation of the hydrological response behavior of any drainage basin (Rai *et al*. 2017) [27]. GIS-based drainage morphometric analysis is computationally faster and more efficient when analyzing basin characteristics and watershed prioritization studies (Yadav *et al*. 2014) [43]. By understanding the morphometric and hydraulic characteristics of Kal river basin, it becomes possible to identify vulnerable areas and implement targeted measures to minimize soil and nutrient losses. This knowledge will aid land use planners in designing appropriate land management practices, such as the implementation of erosion control measures, afforestation programs, or the establishment of buffer zones along water bodies. The goal of the present study is to determine morphometric parameters for the Kal River basin in India, including linear, relief, and areal aspects. The study also seeks to determine the hypsometric analysis of the basin.

2. Materials and Methods

2.1 Study area

The study area Kal river basin located in the Raigad district of Maharashtra state in India (Fig. 1). It is one of the major tributary of Savitri River basin in Konkan coast of M.S. contributing an area of 457.82 km^2. The geographical coordinates of the Kal River lie between approximately 18° 05' and 18° 25' North latitude and 73° 10' and 73° 13' East longitude. This region experiences a subtropical climate characterized by alternating dry and wet periods. Categorized as the 2nd VRN (Very High Rainfall Zone) by the Agriculture Department of the Government of Maharashtra (2005), it witnesses an average annual rainfall of 3590 mm, indicating substantial precipitation spread across the year. Temperature fluctuations are notable, ranging from 12 °C to 39 °C. The lower limit suggests cooler conditions, while the upper range signifies hotter periods experienced within the region.

2.2 Data used and Methods.

The integrated remoted sensing and GIS approach used to analyze the morphometric parameters of the basin. The study area delineated or drainage network extraction using Alos World 3D (AW3D30) 30 m resolution-based DEM in ArcGIS 10.8.1 software by procedure shown in (Fig. 2). The processing of the DEM and SOI toposheet was done using ArcGIS 10.8.1 software, and the watershed is classified based on morphometric analysis. The analysis of morphometric properties has led to the classification of these traits into three aspects: linear, relief, and areal. Numerous empirical methods are available to evaluate these three aspects. RS and GIS techniques are used to analyses the hypsometric analysis for the Kal river basin region. The hypsometric curve for the catchment was plotted out by using these numbers, with the help of attribute feature classes.

2.3 Hypsometric Analysis of basin or Area -Elevation Analysis

It is the relationship between the horizontal cross-sectional area of drainage basin and the elevation i.e., a curve is drawn by plotting the relative height (h_w/H_w) and relative area(a_t/A_t), the obtained curve is called a "hypsometric curve or hypsometric index". It is a dimensionless curve. It described the elevation distribution across an area of the land surface (Pike and Wilson 1971) [26].

Where
h_w = The height of a given contour in watershed, m
H_w = Relief of a given basin or watershed, m
a_t = Total cross- sectional area of contour, m^2
A_t = Total area of given basin, m^2

It is important indicator to assess and compare the geomorphic evolution of various landforms.

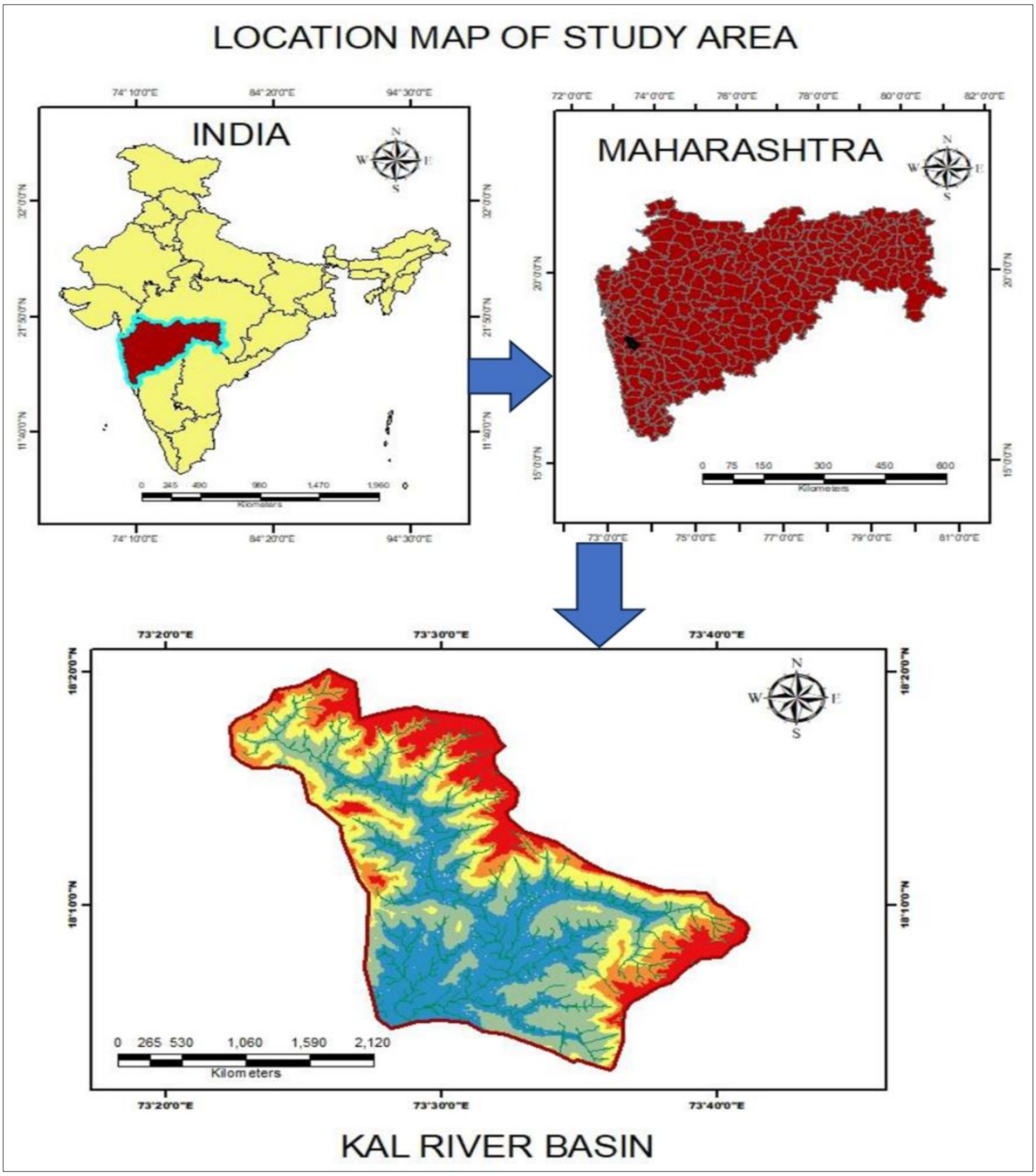

Fig 1: Study area map Kal river basin.

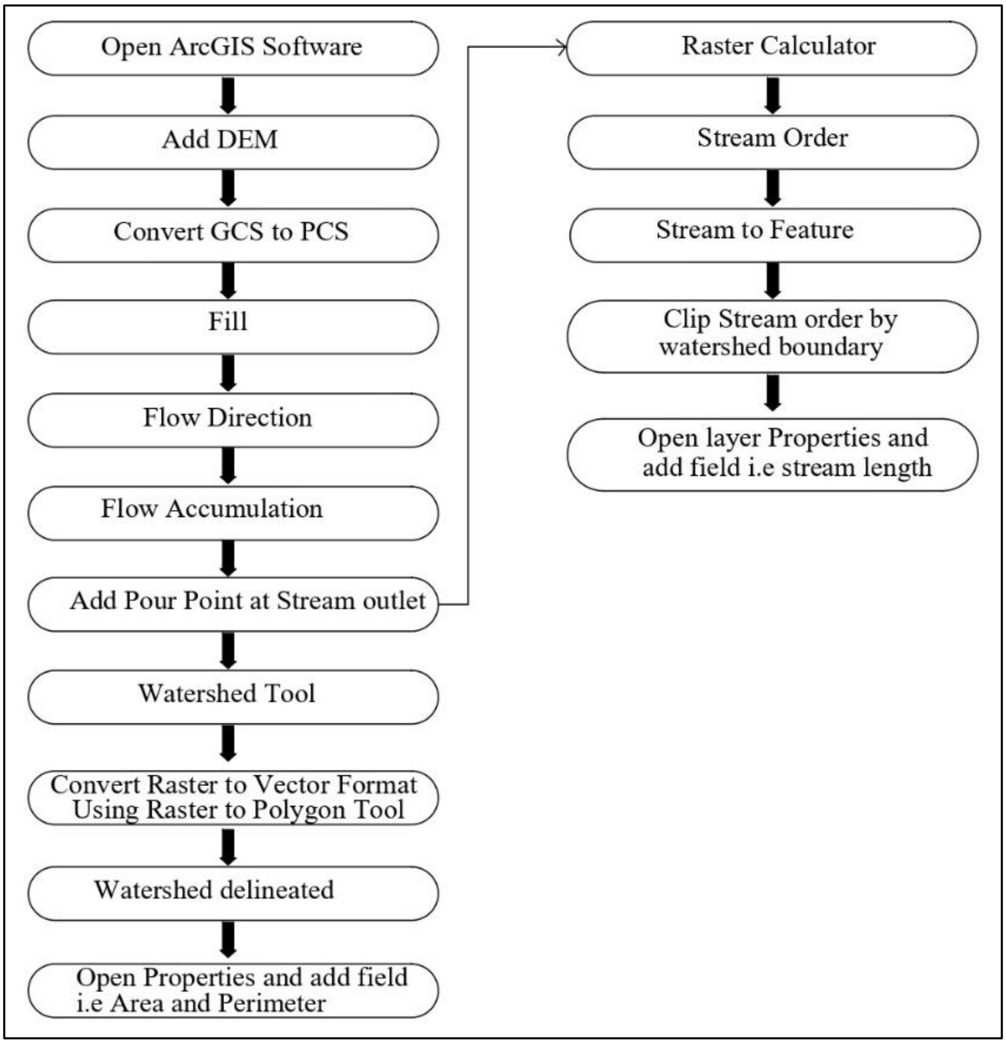

Fig 2: Watershed delineation and stream network extraction process using ArcGIS 10.8.1.

Table 1: Formulas for estimation of Morphometric parameters:

No.	Parameter	Symbol	Formula	Units	References
Basic morphometric parameters					
1	Watershed area	A	Arc GIS Software	km^2	
2	Perimeter	P	Arc GIS Software	km	
4	Max. Elevation	H_{max}	Arc GIS Software	M	
5	Min. Elevation	H_{min}	Arc GIS Software	M	
6.	Length	L_b	$Lb = 1.312 \times A^{0.568}$	km	Nookaratnam (2005) [22]
Linear aspects parameters					
7.	Stream order	μ	Hierarchical rank	Dimensionless	Strahler (1957, 1964) [35, 36]
8.	Number of streams	N_μ	Total number of stream segments of the order "μ"	Dimensionless	Strahler (1957) [35]
9.	Stream length	L_u	$L_u = L_{u1} + L_{u2} + \ldots + L_{un}$	M	Horton (1945) [13]
10.	Stream length ratio	R_l	$R_l = L_\mu / L_{(\mu-1)}$	Dimensionless	Horton (1945) [13]
11.	Bifurcation ratio	R_b	$R_b = N_u / N_{(u+1)}$	Dimensionless	Schumm (1956) [30]
12.	Mean bifurcation ratio	R_{bm}	R_{bm}= average of al l orders	Dimensionless	Strahler (1957) [35]
Areal aspects parameters					
13.	Drainage density	D_d	$D_d = L_\mu / A$	km/km^2	Horton (1945) [13]
14.	Stream frequency	F_s	$F_s = N_\mu / A$	Km^{-2}	Horton (1945) [13]
15.	Drainage Intensity	D_i	$Di = F_s / D_d$	Km^{-1}	Faniran (1968) [9]
16.	Drainage texture	T	$T = Nu / P$	Km^{-1}	Horton (1945) [13] Smith (1950)
17.	Length of overland flow	L_g	$L_g = 1/D_d \times 2$	Km	Horton (1945) [13]
18.	Form factor	F_f	$F_f = A / L_b^2$	Dimensionless	Horton (1945) [13]
19.	Elongation ratio	R_e	$R_e = D/L = 1.128\sqrt{A}/L$	Dimensionless	Schumm (1956) [30]
20.	Circulatory ratio	R_c	$R_c = 4\pi A / P^2$	Dimensionless	Strahler (1957) [35]
Relief aspects parameters					
21.	Relief	R	$R = H_{max} - H_{min}$	M	Hadley & Schumm (1961) [11]
22.	Relative relief	R_{hp}	$R_{hp} = R \times 100/P$	Dimensionless	Melton (1957) [19]
23.	Relief ratio	R_r	$R_r = R / L_b$	Dimensionless	Schumm (1956) [30]
24.	Ruggedness number	R_n	$R_n = R \times D_d$	Dimensionless	Strahler (1957) [35]
25.	Constant of channel maintenance	C	$1/D_d$	km^2/km	Schumm (1956) [30]
26.	Basin Infiltration Number	I_F	$If = D_d \times F_s$	km^{-3}	Pareta & Pareta, (2011) [24], Faniran (1968) [9]
28.	Dissection index	DI	$DI = R_{hp} / H_{max}$	Dimensionless	Nir (1957) [21]

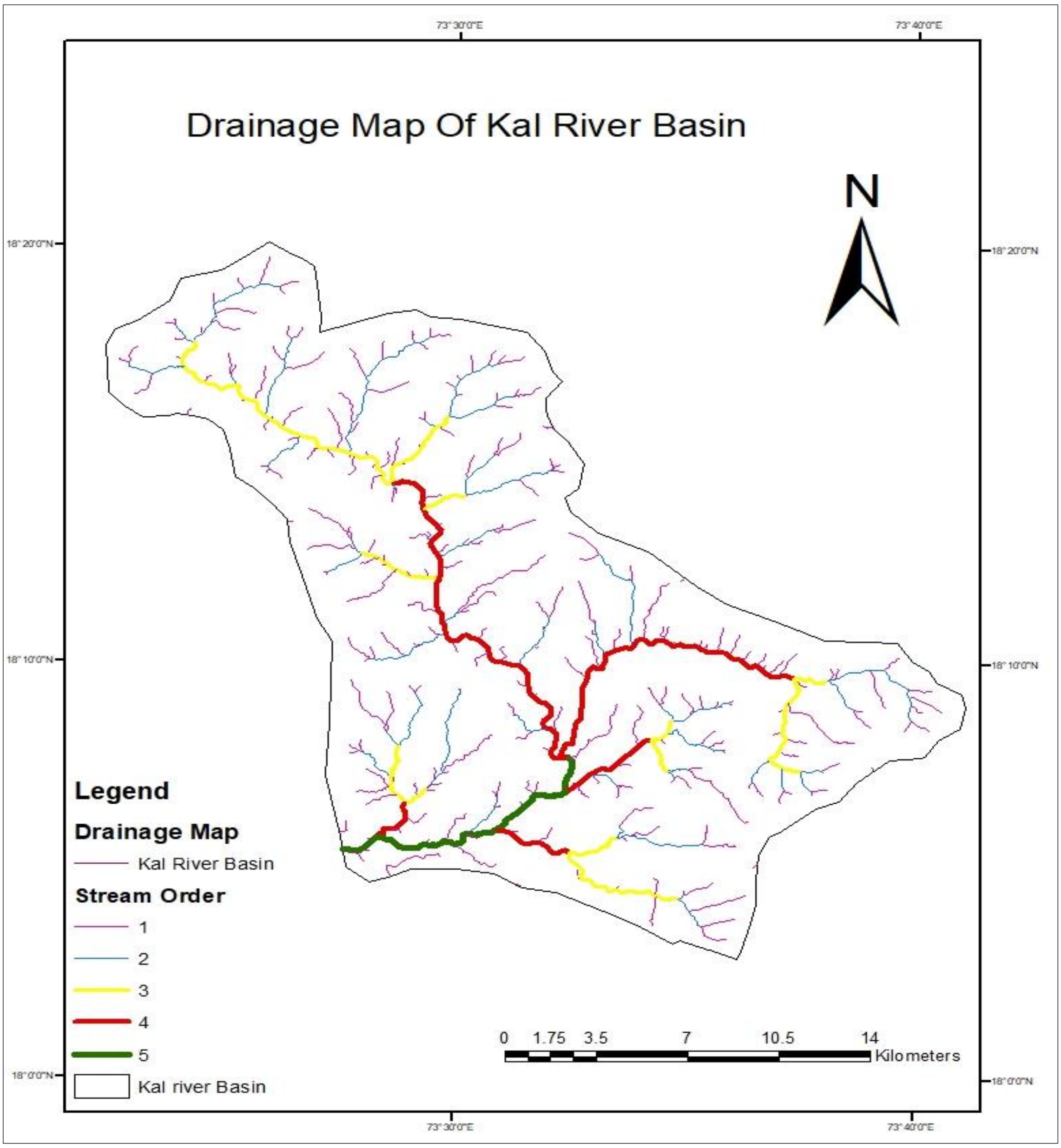

Fig 3: Drainage Density/stream order map of Kal river basin.

3. Result and Discussion

The geomorphological characteristics, geological circumstances, and behavior of river basins over different hydrological cycles are all better understood when combined with the quantitative description of the geometrical conditions provided by the morphometric properties of the Kal River basin. The following is a discussion of the outcomes of different parameters.

3.1 Basic Morphometric Parameters

In this paper, the values of fundamental morphometric parameters such as area (A), perimeter (P), length (L), and elevation (H) pertaining to the studied basins have been collected and are tabulated in Table 4.

3.2 Linear aspects: Linear parameters of the basin are closely related to the stream network where the topological features of the stream segments are analyzed. It included stream orders, stream number (N_u), stream length (L_u), stream length ratio (R_L), and bifurcation ratio (R_b), (Table No.4). These parameters were calculated using the stream network extracted from Digital Elevation Model (DEM) data using ArcGIS software.

3.2.1 Stream Order (u): Stream ordering, pioneered by Horton 1945 [13] and refined by Strahler 1952 [34], organizes streams by tributaries and junctions. It starts with 1st order streams branching from ridgelines, progressing to higher orders as tributaries merge. The highest order stream signifies the main discharge channel. Determining stream orders aids in understanding flow patterns, identifying erosion-prone areas, and characterizing the watershed's stream network. In the present study, the highest stream order was obtained as 5th from the AW3D30 DEM dataset, which indicated the presence of a large, well-developed stream network with multiple tributaries and were connected drainage network. According to Wandre and Rank (2013) [42], a greater stream order means reduced permeability and infiltration. On the other hand, increased permeability and infiltration are indicated by lower stream order. The stream order map of Kal river basin is shown in Fig 3.

3.2.2 Stream Number (N_u): Stream segments form a tree-like structure, with the number decreasing as the order increases, as described by Horton (1945) [13]. In the current investigation identified an inverse geometric sequence that displayed a linear relationship and shows homogeneous lithology (Fig: 4). The log of the stream numbers of each individual order is plotted against the stream order. The order-wise different stream number was obtained was 262 for the Ist order, 112 of IInd order, 66 of IIIrd order, 56 of IVth order and 16 of Vth order. Results reveal that the number of streams decreases as stream order increases which reflect the quantity of surface runoff stream flow capacity due to structural and geomorphological features of the basin. This information can provide valuable insights into the hydrology and geomorphology of the basin, benefiting flood control, water management, and land use planning.

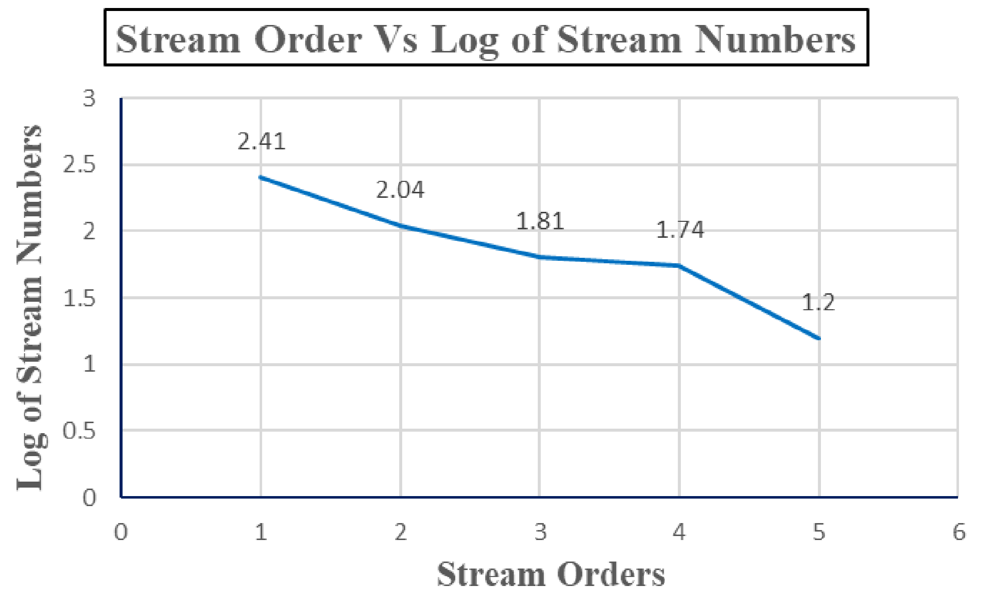

Fig 4: Stream order Vs log of Stream numbers.

3.2.3 Stream Length (L_u): Stream length decreases as order increases, transitioning from steep, hard strata in lower orders to flatter terrain with finer texture. This pattern, noted by Horton and Strahler, aligns with findings showing higher stream lengths in mountainous areas compared to plateaus in river basins (Vittala *et al*. 2004, Sreedevi *et al*. 2005) [40, 33]. In the present study, the total stream length was observed to be 401.8 km with order-wise stream lengths being 206.096 km of Ist order, 96.458 km of IInd order, 44.547 km of IIIrd order, 42.712 km of IVth order and 11.99 km of Vth order (Table 2). The highest stream length was obtained from Ist order streams which reveal that the maximum study area comes under a hydrologically high rainfall zone with uneven topography (Sharma, 2014) [31]. The results also show that stream length decreases as stream order increases.

Table 2: Stream order-wise stream number and stream length.

Stream Order	Stream Number	Stream Length
I	262	206.096
II	112	96.458
III	66	44.547
IV	56	42.712
V	16	11.99
Total	512	401.80
Mean		80.3606

3.2.4 Bifurcation Ratio (R_b): It is the ratio between total numbers of streams in one order (N_u) to the number of next higher order (N_{u+1}) (Schumm 1956) [30]. It can measure surface water potential and hydrographs of a watershed (Jain *et al*. 2020). It varies between 1 to10, normally in range of 3 to 5 (Strahler 1964). The mean bifurcation ratio obtained was 2.17 varying in range of 2.33 of I/II order, 1.69 of II/III order, 1.17 of III/IV order and 3.5 of IV/V order (Table 3). The R_b between 2nd and 5th order streams may be considerably higher than the R_b in other sequence due to active ravines and gullies (Verstappen 1983) [39]. Variations in basin geometry and lithology lead to changing R_b values across stream orders. Lower R_{bm} signifies a less disturbed basin, maintaining an undistorted drainage network and lower flood potential (Suji *et al*. 2015) [37]. It suggests delayed hydrograph peaks and minimal structural impact on drainage development in the basin.

3.2.5 Stream Length Ratio (R_L): It is the ratio between total stream length of one order to the total stream length of its previous order. It shows relationship between basin surface water flow and discharge as well as stage of erosion. The mean stream length ratio was found to be 0.766 with order wise variation of 0.786 of II/I, 0.861 of III/II, 0.674 of IV/III and 0.762 of V/ IV, which shows an inverse proportion between stream lengths and stream order (Table 3). The stream length ratio from DEM suggests an area in its early geomorphic stages with a high potential for future changes and non-uniform hydrological behavior.

Table 3: Stream order-wise bifurcation ratio and stream length ratio.

Stream Order	Bifurcation Ratio	Stream Length Ratio
I-II	2.33	0.786
II-III	1.69	0.861
III-IV	1.17	0.674
IV-V	3.5	0.762
MEAN	2.17	0.766

3.3 Areal Aspects of Drainage Network

Areal aspects of drainage network give the description of arrangement of areal element like Drainage density (D_d), Drainage Intensity, Drainage texture, Stream frequency (F_s), Length of overland flow. All the afore said parameters were computed and the results have been presented in Table 4.

3.3.1 Drainage density (D_d)

It is ratio of the total stream length to the area of the basin (Horton 1932) [12]. Drainage density has an inverse relationship with infiltration capacity, permeability and vegetative cover (Horton 1945) [13]. Strahler (1957) [35] categorized Dd in different ranges like coarse (< 5 km^{-1}), medium (5.00 to 13.7 km^{-1}, fine (13.7 to 155.3 km^{-1}), and ultra-fine (> 155 km^{-1}). The lower Dd means permeable subsoil or highly resistant, dense vegetative cover, low relief and runoff, whereas higher Dd value have a more streams number that results in rapid stream response (Chorley 1969). In present study, the value of drainage density was 0.877 km/km^2 (as observed using AW3D30 DEM), which indicates coarse drainage density, infiltration characteristics, highly permeable resistant subsurface strata that tend to lower runoff and with denser vegetation. These features suggest that basin is highly suitable for groundwater recharge.

3.2.2 Drainage texture (T)

Drainage texture is the ratio between total stream number of all orders and perimeter of that area (Horton 1945) [13]. It is critical factor which affects infiltration capacity (Horton 1945) [13], however Smith (1950) suggested that drainage texture depends on various physical factors like rainfall, type of soil, vegetative cover and relief. They categorized drainage texture values in the five groups, very fine (> 8), fine (6–8), moderate (4–6), coarse (2–4), and very coarse (< 2). The drainage texture value for the study area was found to be 4.70 km^{-1}, indicating a moderate drainage texture. This implies that the watershed has larger basin lag periods compared to fine-textured basins.

3.3.3 Stream frequency (F_s)

It is the ratio between total number of streams of all orders and unit area of the watershed. It gives drainage basin response to runoff processes. It has inverse relationship with mean annual rainfall and Infiltration, whereas it is directly related to runoff and degree of dissection (Pankaj and Kumar 2009) [23]. The results showed that the value of S_f was 1.11 streams per square kilometer, indicating a relatively low density of streams in the watershed. This is likely due to a large area of the plateau having a low slope and poor drainage network, which leads to more infiltration and less runoff.

3.3.4 Drainage intensity (D_i)

It is the ratio of stream frequency to the drainage density of basin. (Faniran 1968) [30]. The lower value of stream frequency (F_s) and drainage density (D_d) shows ultimately lower values of drainage intensity (D_i). The drainage intensity of the study area was 1.274 Km^{-1}, which is relatively low value. This indicates that surface runoff is not removed quickly, and that the watershed has a good capability of absorbing water into the soil, which helps in groundwater recharge. The low drainage density also suggests a reduction in flood risk since the water has more time to infiltrate into the soil rather than flowing over the surface.

3.3.5 Length of overland flow (L_g)

It is equal to half of the drainage density (D_d) which describes the length of surface runoff flow over ground before it becomes accumulated in definite streamline channel. Chandrashekar *et al*. 2015 [6] and Bharadwaj *et al*. 2014 [3] suggested the different ranges of L_g with certain indications, such as, value <0.2 km indicates short flow length due to a steep slope and low infiltration causes more runoff from the catchment; If the L_g value between 0.2 to 0.3 km, indicates moderate condition; If the L_g value >0.3 km, indicates longer flow path due to low slope and high infiltration causes low runoff from the catchment. In the present study, the value of L_g was obtained to be 0.438 km, indicating a relatively longer flow path due to more infiltration and the relatively permeable nature of the river basin. This suggests that the catchment has a low response to runoff, which could be beneficial in reducing the risk of floods. (Kudnar and Rajasekhar, 2020) [17].

3.3.6 Form factor (F_f)

It is defined as the ratio of the area of the watershed to the square of its basin length. The form factor affects stream flow because it depends on the basin shape. A lower value of form factor indicates an elongated shape of the basin, whereas a higher value indicates a circular shape of the basin, which is responsible for maximum peak flow with a short time period (Horton 1932) [12]. In the present study, the value of the form factor was observed to be 0.252, which indicates an elongated shape of the basin. This suggests that the basin has elongated shape which results in a longer time of concentration, which can cause a delay in the peak flow and an increase in the time to peak.

3.3.7 Elongation ratio (R_e)

Elongation ratio is defined as the ratio of diameter of circle of same area as the watershed to the basin length. The R_e always vary in range of 0 for highly elongated shape to 1 for circular shape of basin (Strahler 1964). These values categorized in different groups as 0.9 to 1 for circular, 0.8 to 0.9 for oval, 0.7 to 0.8 for less elongated, 0.5 to 0.6 for elongated and <0.5 for more elongated (Biswas *et al*. 1999) [5]. A value of 1 indicates a perfect circle, while a value closer to 0 indicates a highly elongated shape. In the present study area, an elongation ratio of 0.566 falls within the category of elongated basins.

3.3.8 Circulatory ratio (R_c)

It is the ratio of the area of basin to the area of the circle having the same circumference as the basin perimeter. The value of the R_c always varies between 0 (in line) to 1 (in a circle) (Chougale and Jagdish 2017) [8]. The value of R_c of the study area was 0.48. R_c depends on various factors like stream length and its frequency, relief, geology and climate. The results indicated that the basin is elongated shape having pervious strata, low relief and younger stage of basin.

3.4 Relief Aspects of Drainage Basin

This refers to the analysis of basin relief (R), Relative Relief (Rhp), Relief ratio (R_r), Infiltration Number (I_F), Channel of Constant Maintenance (C), Ruggedness number (R_n). The character relates to the distribution of slope of the basin that further depends on the contour distribution within it. All the values of relief aspects are tabulated in Table 4.

3.4.1 Basin relief (R)

The difference in elevation between the highest and lowest points in a basin determines its topographic features, such as slope, drainage patterns, and erosion potential. In the present study, the maximum relief of the basin was 1157 m (using AW3D30 DEM), indicating a significant variation in elevation within the basin. Basins with higher relief tend to be more sensitive to gravity-driven flows and infiltration rates, which can affect the distribution of runoff and recharge. The study area appears to be predominantly flat, with only a small percentage of the basin falling within the 6–11-degree slope range.

3.4.2 Relief ratio (R_r)
It is defined as the ratio between the total relief (H) and the maximum basin length parallel to the main drainage line (L). A lower value of R_r indicates the presence of rolling and gentle slopes in the basin, which tends to have the least intensity of erosion susceptibility. The value of Rr changes inversely with basin area and size (Adhikary and Dash 2018) [1]. It gives idea about overall slope steepness, erosion susceptibility on watershed slopes (Schumn 1956) [30]. In this study, the value of R_r obtained was 0.027, which suggests the presence of rolling and gentle slopes in the basin and hence a low susceptibility to erosion (Kasi *et al*., 2020) [16].

3.4.3 Relative relief (R_{hp})
Relative relief (R_{hp}) is a measure of the basin's steepness and susceptibility to erosion. It is calculated as the ratio of basin relief to the perimeter of the basin. In this study, the value of relative relief was obtained to be 1.06 m/km. A low R_{hp} value suggests gentle topography with low erosion susceptibility.

3.4.4 Ruggedness number (R_n)
The ruggedness number is a measure of surface roughness and structural complexity of a basin, (Strahler 1957) [35] and it is calculated by multiplying the basin relief (R) and the drainage density (Dd). Based on the classification suggested by Yahya *et al*. (2015) [44], R_n < 0.1 shows smooth morphology; 0.1 to 0.4 shows slight morphology, 0.4 to 0.7 shows moderate morphology, 0.7 to 1.0 shows sharp morphology, >1.0 shows extreme morphology. The value of the ruggedness number for the study area is 1.01, which falls into the extreme morphology category. This means that the study area has extremely rugged terrain, with high relief and drainage density (Alam *et al*., 2021) [2].

3.4.5 Constant of channel maintenance (C)
It is the inverse of drainage density (D_d), which measures the unit channel length of drainage basin area. Kumar *et al*., 2010 suggested the value of C <1 shows the drainage basin network facing structural disturbance, less pervious strata, steep to more steep slopes and maximum surface runoff, whereas the high value shows basin under less structural disturbances and low runoff value. In the present study, this value was 1.13 km^2/km, the value indicates that the drainage basin network is under less structural disturbance and has a low runoff. A higher value of C also suggests that the basin is in a mature or old stage of evolution, indicating that it has reached a state of equilibrium between erosion and deposition over time.

3.4.6 Infiltration number (I_F)
It is obtained by the multiplication of drainage density (D_d) and stream frequency (S_f). It has inverse relationship with infiltration rate and surface runoff (Faniran 1968) [9]. The value of infiltration number was 0.98 km^{-3}, the low value of I_F in the present study suggests that the basin has more permeable soil and a high infiltration rate, which can be beneficial for groundwater recharge and mitigating the risk of flooding (Bhat and Ahmed, 2014) [4].

3.4.7 Dissection index (D_I)
It is the ratio between relative relief (R_r) to the maximum elevation (H). It measures degree of erosion undergone in basin. The value of D_I varies between 0 to 1, in which ‘0’ indicates vertical dissection is absent with stage of maximum denudation and ‘1’ indicates vertical basin area with stage of minimum denudation. The higher Di is generally observed at mountainous basin compared to plainplateau of river basin (Waikar and Nilawar 2014) [41]. The D_I value for the Kal River basin was 0.99, indicating vertically dissected characteristics and depicting the maximum denudation stage of geomorphic development.

3.4.8 Time of concentration (T_c)
Time of concentration is defined as the time period required for a drop of water to travel from the most hydrologically remote point on the ridgeline in the watershed to the collection point or outlet. Tc value indicates the length of time required for water to travel through the watershed. It depends on various factors like topographic features, soil type, vegetation, presence of soil and water conservation structures, etc. In the present study, the value of T_c was obtained to be 14 hours 54 minutes, indicating that water requires more time to travel due to the large area and various topographic features.

3.4.9 Hypsometric analysis: Hypsometric curves are graphical representations of the distribution of land elevation within a given area, showing the percentage of land at different elevations. Hypsometric curves represented using relative surface area and heights. A convex ascending hypsometric curve indicates a juvenile basin, a mature basin has S-shaped hypsometric curve, and old or eroded basin has concave hypsometric curve. The hypsometric curves for the Kal River basin have a mix of convex and concave and S shapes (Fig 4), which could be attributed to soil erosion caused by washout of the soil mass, and stream cutting (Salunke and Wayal, 2023) [28].

Table 4: Drainage basin morphometric parameters generated by AW3D30 DEM.

Sr. No.	Parameter	Symbol	Units	Results
Basic morphometric parameters				
1	Watershed area	A	km^2	457.837
2	Perimeter	P	Km	108.78
4	Max. Elevation	H_{max}	m	1159
5	Min. Elevation	H_{min}	m	2
Linear aspects parameters length				
6.	Stream order	μ	Dimensionless	1 to 5
7.	Number of streams	N_μ	Dimensionless	512
8.	Stream length	L_u	Km	401.803
9.	Length	Lb	Km	42.58
11.	Stream length ratio	R_l	Dimensionless	0.7 to 1.1
12.	Bifurcation ratio	R_b	Dimensionless	1.1 to 3.5
13.	Mean bifurcation ratio	R_{bm}	Dimensionless	2.10
Areal aspects parameters				
14.	Drainage density	D_d	km/km^2	0.877
15.	Stream frequency	F_s	Km^{-2}	1.11
16.	Drainage Intensity	D_i	Km^{-1}	1.274
17	Drainage texture	T	Km^{-1}	4.70
18.	Length of overland flow	L_g	Km	0.438
19.	Form factor	F_f	Dimensionless	0.252
20.	Elongation ratio	R_e	Dimensionless	0.566
21.	Circulatory ratio	R_c	Dimensionless	0.485
Relief aspects parameters				
22.	Relief	R	m	1157
23.	Relative relief	R_{hp}	Dimensionless	1.06
24.	Relief ratio	R_r	Dimensionless	0.027
25.	Ruggedness number	R_n	Dimensionless	1.01
26.	Time of concentrations	T_c	Hrs.	14.54
27.	Constant of channel Maintenance	C	km^2/km	1.13
28	Basin Infiltration Number	I_F	km^{-3}	0.98
29.	Dissection index	DI	Dimensionless	0.99

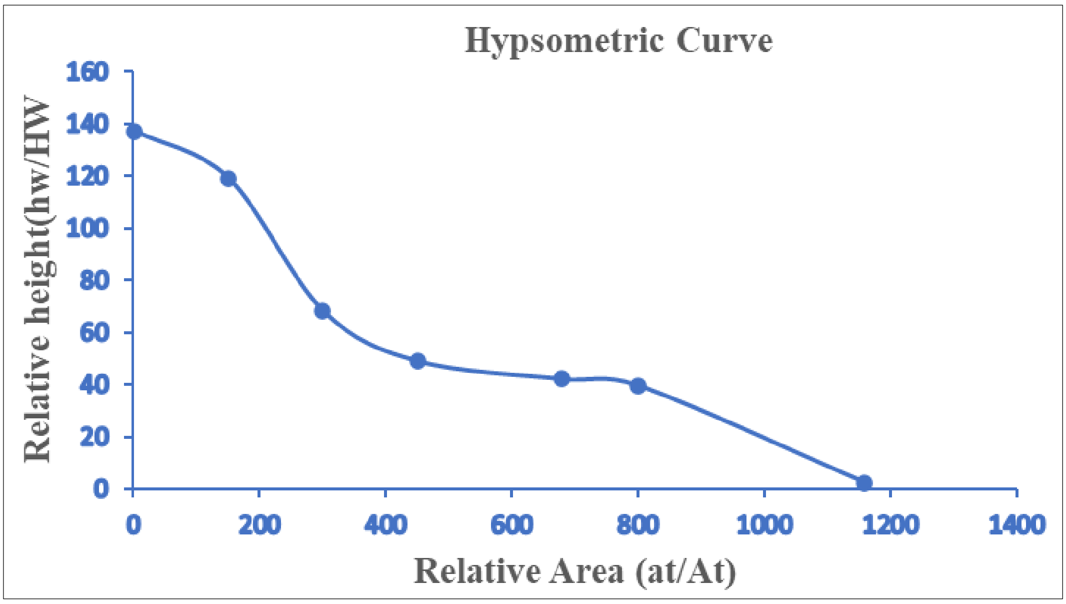

Fig 4: Hypsometric analysis of Kal river basin.

4. Conclusion

GIS and Remote Sensing techniques were used to conduct the morphometric study of the Kal river basin. In this study, twenty-eight morphometric parameters were computed and scientifically analyzed. Topography, slope, lithology, surface runoff, infiltration capacity, and hydrological characteristics are all comprehended with the morphometric parameter. The Kal river basin exhibited complex physiographic and geological characteristics, contributed by presence of the Sahyadri ranges, mafic dyke's swarms and Tapi fault. The Kal river is part of west flowing river system flow in dendritic drainage pattern in an elongated basin, the morphometric and hypsometric studies point mature stage of landform development with low relief, low structural control, sparse vegetation and low infiltration rate. This study's findings suggest the necessity of implementing measures to conserve water and soil resources for the watershed's sustainable long-term development.

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