

Remote Sensing and GIS-based Morphometric analysis of Bembla sub-basin in Maharashtra

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Abstract: The present study aims to demonstrate the use of remote sensing and GIS based tools and techniques in analysing and maintaining water resources. Morphometric analysis involves evaluation of the linear and spatial aspects like drainage area and relief of a basin to better understand the properties and geomorphological controls of the basin. The Bembla river is a VIIIth order stream and a tributary of Wardha River. The Bembla sub-basin covers an area of 3040 km². Morphometry of the Bembla sub-basin indicates that the drainage basin is slightly elongated. The Bembla sub-basin is of low relief and has a coarse drainage. The basin overlies relatively impermeable stratum with low peak floods and high storage capacity. The study was undertaken using a SRTM data coupled with ArcGIS tools to process the data which enables the calculation of terrain parameters like slope, relief, ruggedness and establishes their relationship with the drainage network.

Keywords: Morphometric Analysis, Bembla Sub-basin, Aerial aspects, Relief Aspects

1. Introduction

Morphometric analysis characterizes landforms quantitatively. It provides invaluable insights into the geometry, behaviour, and evolution of river basins. Morphometric analysis involves quantifying various geometric and topological properties of landforms, including rivers and their corresponding basins. This process entails collecting data through various means, such as topographic maps, remote sensing and geographic information systems (GIS), and field surveys. The collected data is then processed and analyzed using a range of morphometric parameters, which can be broadly categorized into linear, and spatial parameters which includes aerial and relief parameters. Linear parameters encompass attributes like stream length, Bifurcation ratio, and Rho Coefficient, while areal parameters include basin area, shape factors, drainage texture. Relief parameters relate to aspects such as relief, relief ratio, and ruggedness number.

Morphometric analysis provides crucial insights into the hydrological and hydraulic behaviour of river basins. By quantifying attributes like stream order, bifurcation ratio, and drainage density, researchers can grasp the basin's efficiency in capturing and transporting water. Understanding stream network organization aids in predicting water flow patterns and identifying potential flood-prone areas. Hydraulic characteristics, such as channel slope, cross-sectional area, and flow velocity, help in estimating sediment transport capacity, which is essential for managing erosion and sedimentation in rivers. Morphometric analysis allows researchers to infer the geological and tectonic history of river basins. The shape and dimensions of river basins can indicate the influence of tectonic forces, uplift, and erosion rates over geological timescales.

2. Study Area

The study area, Bembla sub-basin is in Yavatmal and Amravati, Washim district of Maharashtra (figure 1). The coordinates enclosing the research area are latitude 20°45' 20°33' N and longitude 77° 27' 78° 16' 08" E. The area is covered by SOI toposheet no 55H/10, 55H/14 55L/2, 55L/6. Bembla River is a perennial tributary of Wardha River in the Godavari River basin. Of the nine tributaries of Godavari River, Wardha River is the fifth longest. It rises in the Amravati district and extends from Khatnapur, Washim in west to Savangi (Rout), Yavatmal in east, draining in Wardha River at Sangameshwar Ghat, Sawangi (Rout), Babhulgaon Tehsil, Yavatmal. The geographical area of the Bembla sub-basin is about 3040 sq. km.

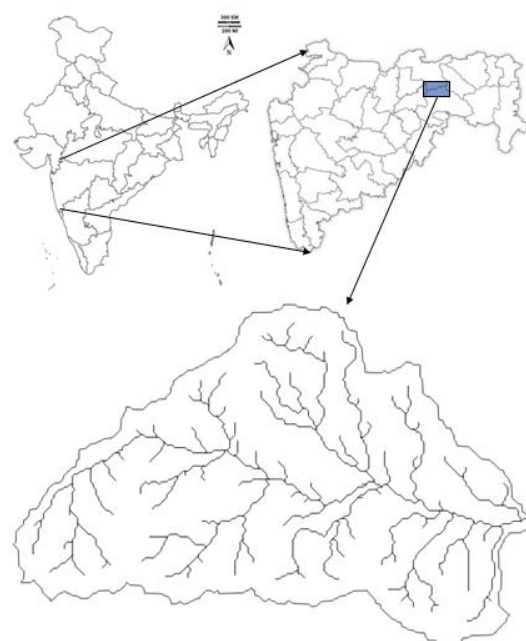


Figure 1. Location of the Study area Bembla Sub-basin

3. Methodology

Survey of India toposheets no 55H10, 55H14, 55L2, 55L6 of 1:50000 scale were used for the present study. SRTM- DEM at 30m spatial resolution for the drainage basin was obtained from the BHUVAN portal. Delineation of drainage basin was done using tools from ArcGIS desktop software (figure 2). Certainly, morphometric analysis involves the study of various quantitative parameters that can be broadly categorized into three types: linear parameters, aerial parameters, and relief parameters. These parameters help in understanding the spatial organization of stream channels, basin and other geomorphological characteristics

4. Results

4.1. Linear Parameters

Linear parameters focus on measurements related to the length, perimeters, flow paths, and branching pattern of the drainage network within the basin. They provide insights into the spatial arrangement and complexity of the drainage system.

Stream Order (Nu)

Stream order of a drainage basin is a quantitative classification system that assigns numerical value to

every segment of river network based on its position. It was introduced by (Strahler 1964). Higher order streams have more extensive drainage and are formed by convergence of multiple lower-order streams. The Bembla River is a VIIth order stream. All the stream orders are presented in (Table 1).

Stream length (LU)

Stream length is the combined length of all the stream segments which includes main channel and its tributaries within a drainage basin measured from outlet of main channel to the farthest point upstream. It was introduced by (Horton, 1945). Stream length of a drainage basin explains the overall complexity and extent of drainage basin. The total stream length for all the orders are presented in (Table 1). The total stream length of stream order I is 5434km, stream order II is 317 km, stream order III is 122.19 km stream order IV is 46.80km, stream order V is 1.3143, stream order VI is 3.09km and stream order VII is 1.0718km.

Mean Stream length (LSM)

It is calculated when the total length of all stream segments is divided by number of segments in the network. It was introduced by (Strahler, 1964). The mean stream length of the Bembla sub-basin ranges from 1.1052km to 0.1095km. This high irregularity indicates morphological control on the basin.

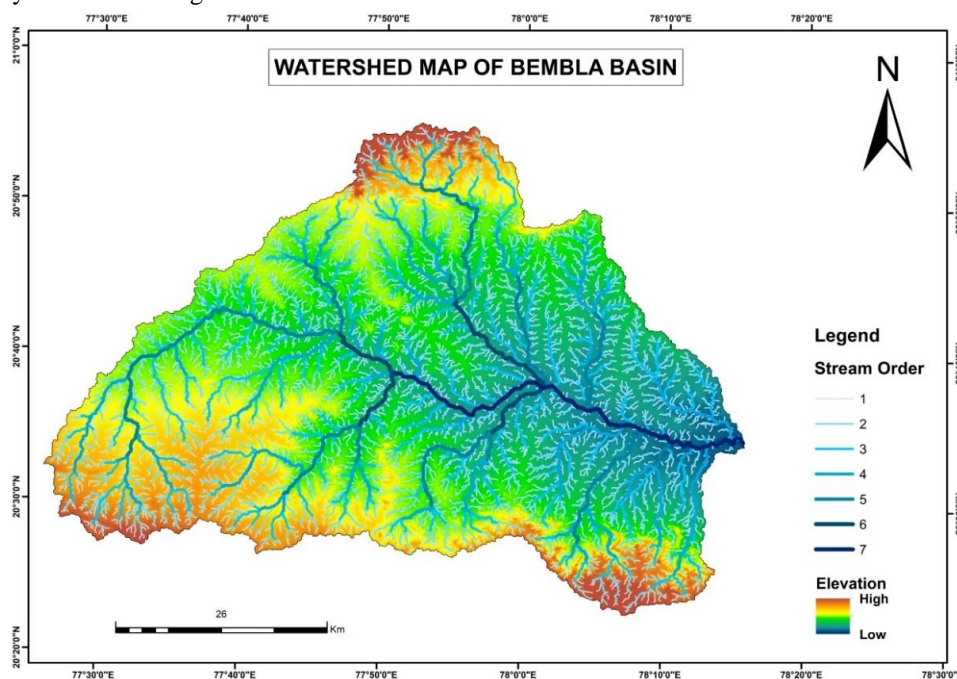


Figure 2. Watershed Map of BEMBLA basin

Table 1. Linear Parameters of Bembla Sub-basin

Sr.No.	Stream Order	No. of Streams	Stream length (km)	Mean stream length (km)	Bifurcation ratio	Stream length ratio	Rho Coefficient
1	I	4917	5434.07	1.11			
2	II	1046	317.74	0.30	I/II = 4.70	17.10	3.63
3	III	211	122.19	0.58	II/III= 4.95	2.60	1.90
4	IV	48	46.80	0.96	III/IV=4.39	2.61	1.68
5	V	12	1.31	0.11	IV/V= 4	35.60	8.9

6	VI	6	3.09	0.51	V/VI= 2	0.425	0.21
7	VII	1	1.07	1.07	VI/VII=6	2.88	0.48
Total		6241	5926	4.66			
Mean				0.6657	4.34		

Table 2. Areal parameters of Bembla Sub-basin

Sr.No.	Aerial Parameters	Formula	Results	References
1	Basin Area (A)	S	3040 km ²	
2	Basin length	Lb	86 km	
3	Drainage Density (Dd)	Dd = Lu/A	1.95 km/km ²	Horton (1932)
4	Stream Frequency (Fs)	Fs = Nu/A	2.05 /km ²	Horton (1932)
5	Elongation Ratio (Re)	Re = 2√(A/π) / Lb	0.72	Schumm (1956)
6	Circulatory Ratio (Rc)	Rc = 4πA/P ²	0.51	Miller (1953)
7	Form factor (Rf)	Rf = A/Lb ²	0.41	Horton (1932)
8	Length of overland flow (Lof)	Lof = 1/(2*Dd)	0.256	Horton (1945)
9	Compactness Coefficient (Cc)	Cc = P/(2√Aπ)	1.4	Gravelius (1914)
10	Constant of channel maintenance	C= A/Lu	0.51	Schumm(1954)
11	Compactness Index	Lb/√A	1.56	Horton (1932)

Table 3. Relied parameters of Bembla Sub-basin

Sr.No.	Relief parameters	Results	Reference
1	Basin Relief	261	Schumm (1956)
2	Relief ratio	0.0030	Schumm (1956)
3	Ruggedness Number	0.13	Strahler (1964)

Stream Length Ratio (RL)

It is the ratio of total stream length of one order to the stream length of next lower order of stream segment. It was introduced by (Horton 1945). The high variability in the range of stream length ratio from lower order to higher order indicates that the stage of geomorphic development of drainage area is of late youth stage. The stream length ratios of Bembla sub-basin are presented in (Table 1).

Bifurcation Ratio (RB)

It is the ratio of number of the streams of a specific stream order to the number of streams of the next higher stream order. Bifurcation ratios indicate branching pattern and higher values suggest a well branched network (Schumm 1956). The bifurcation ratios of the streams in Bembla sub-basin are presented in (Table 1). The mean bifurcation ratio is 4.34. The bifurcation ratio (R_B) between 3-5 indicates that the basin lies over a relatively homogenous rock type.

Rho Coefficient (ρ)

The ratio of stream length ratio to Bifurcation ratio is called the Rho Coefficient. Rho Coefficient quantifies the relationship between the density of stream networks and the geomorphic evolution of the drainage basin (Horton 1945). The high value of Rho coefficient (ρ>0.60) indicates high storage potential of the basin. It also indicates that basin has a tendency to reduce erosion effects. The rho coefficients are presented in (Table 1).

4.2 Aerial parameters

Aerial parameters focus on measurements related to the area and shape of the drainage basin, providing insights into its spatial extent and geometry (Table 2).

Basin Area (A)

The total area of the basin delineated by the drainage divide or watershed boundary of river basin. It fundamentally measures the basin size and water storage potential. The basin area of the Bembla sub-basin is 3040 km².

Drainage Density (Dd)

Drainage density is calculated by dividing the total length of all streams in a drainage basin by basin area. According to Ramaiah et al. (2012), a high drainage density indicates a well-developed and efficient network. It is usually characteristic of impermeable subsurface and sparse vegetation susceptible to flooding, while low density indicates a dispersed network with highly permeable subsurface, high density vegetation and a mountainous terrain. The drainage density of the Bembla sub-basin is 1.95 km/km² indicating coarse texture and low relief which means a homogenous and permeable geological material underlies the study area.

Stream Frequency (Fs)

Stream frequency is the ratio of number of all the stream segments in a drainage basin to the total basin area. The lower values of F_s indicate poor drainage network. The stream frequency (F_s) of Bembla sub-basin is 2.05 streams/km which indicates that the Bembla sub-basin has a low gradient.

Elongation ratio (Re)

It is the ratio of diameter of a circle with the same area as the drainage basin to maximum length of the drainage basin. It is an indicator of how much main channel length deviates from maximum basin length. The elongation ratio of the Bembla sub-basin is 0.72 which indicates that basin is slightly elongated and has gradual ground slope. High number of lower order streams is also an indicator of elongated basins.

Circulatory ratio (Rc)

It is the ratio of the area of the basin to the area of the circle with same perimeter as the basin perimeter. It indicates geomorphological stage of a watershed. The circulatory ratio (R_c) of the Bembla Sub-basin is 0.5108 indicating youth to intermediate stage and highly permeable homogenous geological setting

Form factor (Rf)

It is the ratio of basin area to the square of the basin length. A high value indicates high peak in short interval of time, flatter basin and comparatively less efficient drainage network. The form factor of the Bembla sub-basin is 0.41, a characteristic of a slightly elongated basin. Floods can be easily managed in elongated basin (Strahler, 1964).

Length of overland flow (Lof)

It is the length of the longest path taken by water over ground before getting concentrated into stream channels. Low value indicates gradual slope, and short surface runoff. It is useful for estimating time of concentration and potential flood travel distances. The intermediate value of 0.256 of length of overland flow of the Bembla sub-basin denotes medium infiltration rates.

Compactness Coefficient (Cc)

It is the ratio of perimeter of a basin to the circumference of a circle with area equivalent to the basin (Gravelius, 1914). Higher values indicate compact circular basins. The compactness coefficient of Bembla sub-basin is 1.4. Low values of Compactness Coefficient (>2) is indicative of low risk of erosion.

Constant of Channel Maintenance (C)

It is the ratio of basin area to the combined length of all the stream segments in the drainage basin (Schumm 1954). It provides an estimate of drainage area required to maintain unit length of channel. The constant of channel maintenance of Bembla sub-basin is 0.51 which indicates intermediate permeability and relief.

Compactness Index

It is the ratio of length of drainage basin boundary to circumference of circle having same area as the basin. The shape index of the basin is 1.56 which reveals that the Bembla sub-basin is a tectonically controlled elongated basin of younger age.

4.3 Relief Parameters

Relief parameters focus on measurements related to elevation, slope, and relief within the drainage basin (Table 3).

Basin Relief (H)

Basin Relief is the vertical distance between highest and lowest point of the basin. It evaluates the potential energy of the drainage system. The basin relief of the Bembla sub-basin is 261m.

Relief Ratio (Rr)

It is the ratio of basin relief to the basin length. It is indicative of steepness of basin's topography. The relief ratio of Bembla sub-basin is 0.0030 indicating a flat topography basement rock.

Ruggedness Number (Rn)

It is calculated by multiplying basin relief with the drainage density. The ruggedness number of Bembla sub-basin is 0.13 which is a low value indicating that the soil in the study area is less likely to erode and has low slope (Strahler 1957).

3. Conclusion

On the basis of drainage orders, Bembla River is a VIIth order stream. The basin shows dendritic drainage indicating homogenous surface. The number of streams is found to be decreasing with increasing stream order. The stream length ratio shows variability indicating difference in slope and topography a characteristic of intermediate to youth stage of geomorphic development. The Rho Coefficient of the basin is high which indicates low risk of flooding and high storage during heavy rainfall. The elongation ratio and circulatory ratio of the Bembla sub basin show variability indicating that basin is only slightly elongated. The ruggedness number is very low indicating that the soil in the area is less likely to undergo erosion. The drainage density and other linear parameters like bifurcation ratio indicates that the drainage is coarse. The results from the above study can be used to explore ways in which water can be stored and located.

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