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Quantitative Morphometric Analysis Of The Wang River Basin Using A Gis Approach

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Abstract: An attempt has been made in this paper to analyze the various morphometric parameters of the Wang River basin in Satara district of Maharashtra which is a tributary of the Koyna River. Linear, areal and relief parameters of the basin were derived from the SRTM DEM data and ArcGIS software was used for analysis. The result reveals that the catchment of Wang River can be described as a 6^{th} order basin with total area of 375.03 km^2. The drainage pattern is mostly dendritic with some parts showing parallel arrangement. The higher bifurcation ratio in the western side of the basin shows some control of geologic structures on the drainage. The textural analysis shows that the drainage density and stream frequency go on increasing from west to east which indicates decrease in permeability of the subsurface rock. The relief parameters suggest that the basin is characterized by steep slopes on the ridge faces which is a typical feature of the Western Ghats.These findings have implications for watershed planning and management in the region.

Index Terms–Morphometric analysis, Wang River basin, GIS, Strahler Method.

Introduction

A watershed is an important feature when it comes to the study of any river basin. It is an area characterized by catchment of all the streams flowing and contributing to one common outlet. It is defined by various morphological aspectssuch as linear, areal and relief factors. Quantitative description of these factors aids in the understanding of the influence of drainage morphometry on landforms and their characteristics (Reddy, 2004). Morphometric studies have been studied using conventional methods (Horton,1945; Strahler, 1952,1957,1964). In this work, Strahler's method was used to determine the order of streams.

Morphometric analysis is a straightforward approach for describing hydro-geological behavior, landform processes, soil physical properties, and erosion characteristics. It provides comprehensive insight into the hydrologic behavior of watersheds (Strahler 1964). Understanding morphometry necessitates evaluating various factors such as size, shape, slope, basin area, bifurcation ratio, drainage density, and stream frequency, which can be instrumental in correlating critical hydrological phenomena. Understanding drainage morphometry is also a pre-requisite for runoff modeling, geotechnical investigation, identification of water recharge sites and groundwater prospect mapping (Sreedevi, 2005; Fenta, 2015; Roy and Sahu, 2016).

Collection of this data and analyzing it manually by conventional methods has always been very tedious and time-consuming work historically. But with the technological advent of geographical information system (GIS) in the past decade, computational tools have helped in minimizing human effort and error. Remotely sensed data like Digital Elevation Models (DEM) with spatial resolution 2mand ArcGIS 10.8 tools were used to determine the morphometric parameters in this study and understand their influence on the landform characteristics and hydrology of the basin. Geo-coded resource database generated on drainage, landforms and soil parameters in the core of GIS provides an excellent means of storing, retrieving and analyzing data at river basin level to find out their association (Reddy, 2004).

In this paper, some of the morphometric parameters of the Wang River basin in Satara district of Maharashtra have been studied to understand the effect of these parameters on the topography and geomorphology in the area using the GIS software.

Study Area

The Wang River basin scales in both the adjacent talukas namely, Patan and Karad in Satara district of Maharashtra. The average annual rainfall in this region can reach up to 1500mm which gradually decreases from west to east. The district experiences a typical tropical wet and dry climate with mean temperature around 23.5°C. The latitudinal extent of the Wang River basin is 17° 17' 41" N to 17° 07' 52" N and its longitudinal extent is 73° 47' 53" E to 74° 06' 50" E. Wang River is a tributary of Krishna River. It receives major discharge from Marathwadi dam located upstream and towards south-west on the slopes of Western Ghats. Wang River originates from the eastern slopes of the Sahyadris and flows towards east direction to confluence with Koyna River(which is another main tributary of the Krishna River)near Padalikese village situated approximately 9 kms west from the city center of Karad.

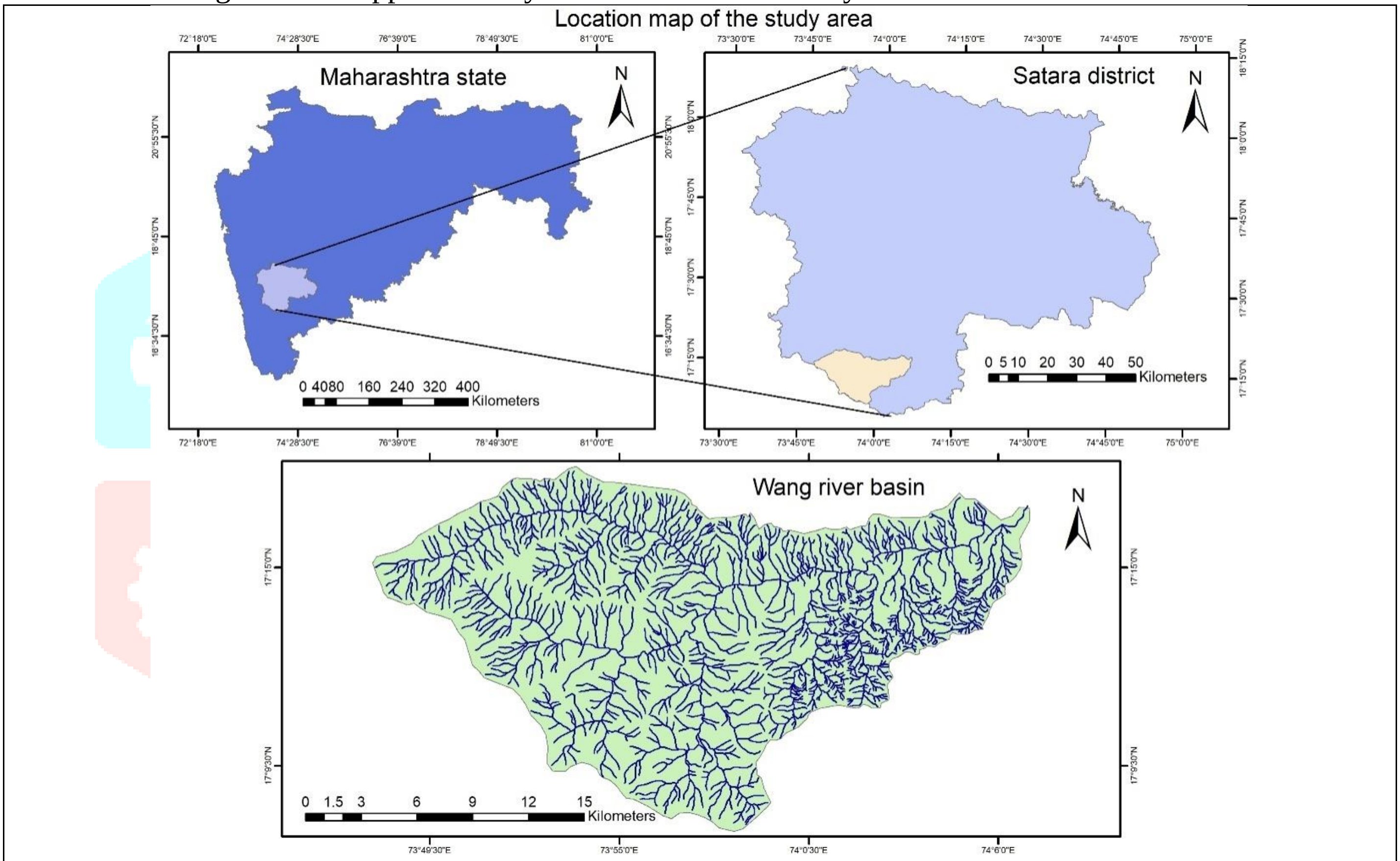

Fig 1: Location map of Wang River basin in Satara district

Materials and methodology

GIS based morphometric analysis of the Wang River basin was done using SRTM-DEM data with a spatial resolution of 2m and ArcGIS 10.8.Using ArcGIS, the basin was delineated into 43 sub-watersheds based in third order stream delineation for detailed analysis. Linear, areal and relief factor associated morphometric parameters namelystream order, stream number, stream length, bifurcation ratio, basin area, drainage density, stream frequency, basin slope and basin aspect analysis were calculated using formulae suggested by Horton (1945), Miller (1953), Schumn (1956), Strahler (1964). The slope and the aspect parameters were determined using the ArcGIS tools. The formulae to compute these parameters are provided in Table 1 below.

Table 1: Formulae for computation of various morphometric parameters

Sr. no.	Morphometric parameters	Formula	References
Linear Aspects			
1	Stream order (U)	Hierarchical rank	Strahler, 1964
2	Stream number (N_u)	The total order wise stream segments are known as stream number	Horton, 1945
3	Stream length (L_u)	Length of the Stream in km	Horton, 1945
4	Bifurcation ratio (R_b)	Rb = Nu / Nu + 1 Where, Nu=Number of stream segments present in the given order Nu+1= Number of segments of the next higher order	Schumn,1956
Areal Aspects			
5	Basin area (A) in km^2	Area from which water drains to a common stream and boundary determined by opposite ridges	ArcGIS tool
6	Drainage density (D_d)	Dd = Lu/A Where, Dd = Drainage Density (1/km); Lu = Total stream length of all orders; A = Basin Area (km2)	Horton, 1945
7	Stream frequency (F_s)	Fs = Nu/A Where, Fs = Stream Frequency; Nu = Total no. of streams of all orders and; A = Area of the basin (km2)	Horton, 1945
Relief Aspects			
8	Basin slope	-	ArcGIS tool
9	Basin aspect	-	ArcGIS tool

Morphometric analysis

The present study employs an integrated approach using remote sensing and Geographic Information System (GIS) techniques to perform a comprehensive morphometric analysis of the Wang River Basin, located in the Satara district of Maharashtra. Morphometric analysis serves as a fundamental tool in hydrological and geomorphological investigations, as it enables the quantitative assessment of drainage basin characteristics that influence surface runoff, erosion, sediment transport, and overall watershed behavior. By analyzing various morphometric parameters—such as stream order, drainage density, bifurcation ratio, elongation ratio, and relief ratio—this study aims to establish the hydrological and geomorphic significance of the Wang River Basin and its sub-watersheds.

Understanding the geometry of the basin and stream network is critical in relating watershed form to the transmission of water and sediment. The size of a drainage basin directly impacts the total volume of water yield, while its shape, length, slope, and elevation differences significantly influence the velocity, timing, and magnitude of water discharge. In this context, the Wang River Basin was discretized into forty-three third-order sub-watersheds to facilitate a more detailed and localized analysis. Spatial data were extracted from high-resolution satellite imagery and topographic maps, and processed through advanced GIS software to derive parameters such as area, stream length, drainage pattern, and relief characteristics.

The resulting morphometric values were systematically analyzed and interpreted to understand the spatial variability in hydrological behavior across the basin. This analysis not only provides valuable insight into the watershed's structural and functional dynamics but also serves as a vital input for effective watershed management, flood risk assessment, soil conservation strategies, and sustainable land-use planning. The integration of remote sensing and GIS has proven to be an efficient and powerful approach for deriving precise, scalable, and actionable insights in morphometric studies.

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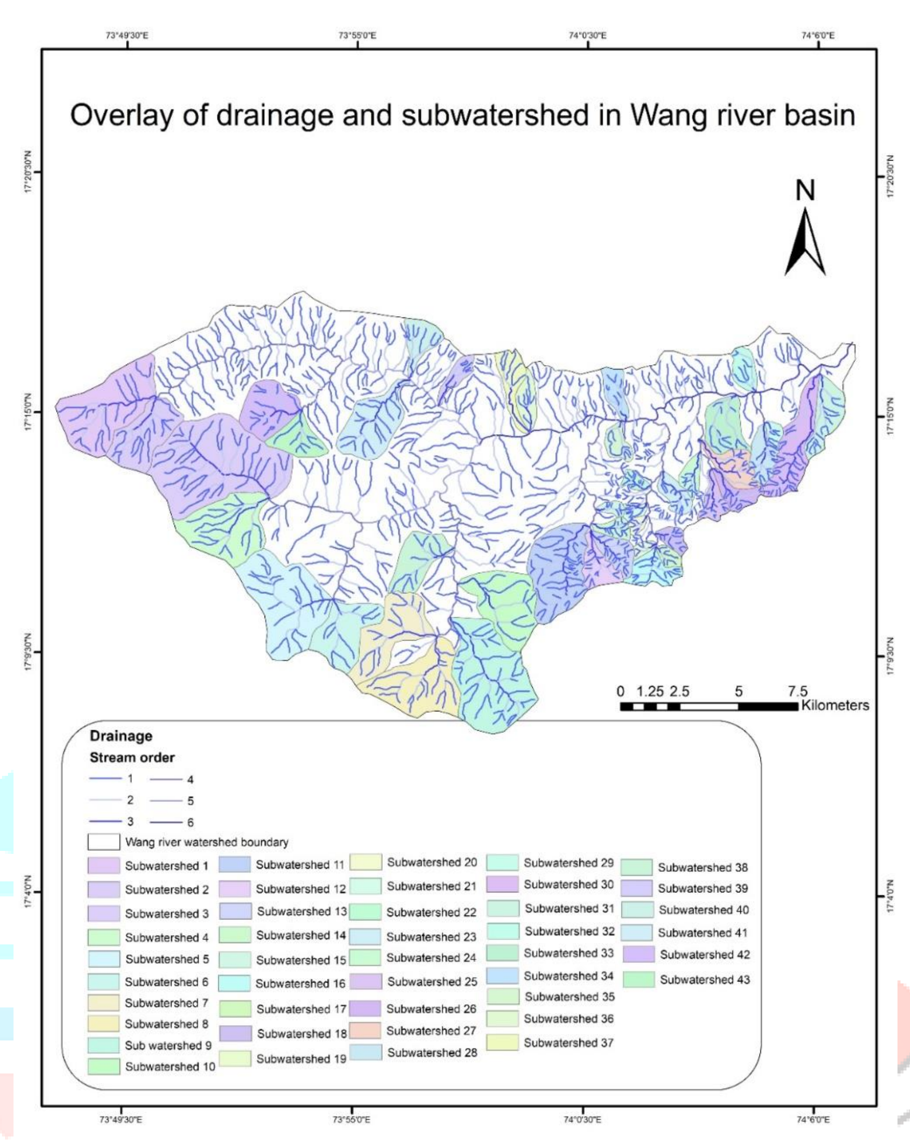

Fig 2: Drainage network and sub-watersheds of Wang River basin

Results and Discussion

Linear Aspects

Stream Order (U)

Stream order refers to the hierarchical arrangement of streams in a drainage basin, with higher-order streams formed by the confluence of lower-order streams. The variation in order and size of the tributary basins is largely due to physiographic and structural conditions of the region (Shreedevi, 2012). Based on (Strahler, 1964) method of stream ordering, this analysis has designated Wang basinas a 6th order drainage basin. The total number of streams in the basin are 607, out of which 460 are first order, 120 are second order, 19 are third order, 6 are fourth order and one each of fifth and sixth order streams. Further, 43 sub-watersheds were delineated based on third order streams in GIS.Streams were observed to be more in number and compacted in the sub-watersheds towards the north-western, western and south-eastern part of the basin indicating a topography which is still undergoing active erosion while other sub-watershedsshow a comparatively mature topography.

Stream Number (N_u)

Stream number is the total number of streams of a particular order in a given basin and is calculated by using GIS tool and method defined by Horton (1945). It has an inverse relation with the order of the streams, that is, number of streams goes on reducing as the order of stream increases. It is a crucial parameter in morphometric analysis because it directly relates to the basin's drainage network and provides insights into its evolution, morphology, and hydro-geomorphic characteristics. The number of streams at each order helps understand the overall structure and density of the drainage network.The analysis showed that there are 607 streams present in the basin.

Stream Length (L_u)

Stream length is one of the most significant hydrological features of the basin as it reveals surface runoff characteristics (Waikar, 2014). Length of the stream also gives an insight into the hydrological characteristics of the underlying bedrock. Streamswith relatively short lengths are representative of areas with steep slopes whereas longer lengths of stream are generally indicative of lower gradients (Pande, 2015). Total length of all the streams in the entire Wang basin is 558.97 km.

Bifurcation Ratio (R_b)

The term bifurcation ratiois a dimensionless property which is used to express the ratio of number of streams of a particular order to the number of streams of higher order. (Schumm 1956). By computing bifurcation ratio, geological and structural control of the drainage basin can be easily understood. Interpretation of the birfurcation ratio is given in Table 3 below. The values for the $R_b$in the basin vary from 3.1 to 6.3.The mean bifurcation ratio (Rb_m) may be defined as the average of bifurcation ratios of all the orders and it is 3.38 in case of Wang River basin.In the given basin, second and fourth order streams show higher values suggesting geological structure control to some extent. In few of the sub-watershed clusters such as 1 to 9, 20 to 24 and 39 to 43, a high value of bifurcation ratio is observed owing to a structural presence in the region.

Table 2: Linear aspects of the entire Wang basin

Basin	Stream order	No. of streams	Length of streams (km)	Bifurcation ratio
Wang River	1	460	353.10	3.83
	2	120	121.93	6.31
	3	19	35.37	3.16
	4	6	19.75	6
	5	1	8.96	1
	6	1	19.83	-
	Total	**607**	**558.97**	

Table 3: Interpretation of bifurcation ratio

Bifurcation Ratio	Interpretation
<=2	Flat terrain
2-5	Mountainous terrain
>=5	Structurally controlled terrain

Areal Aspects

Basin Area (A)

The area of the river basin is another important parameter like the length of the stream drainage. The total catchment area of Wang basin was computed to be 375.03 km^2 by using GIS technology. Basin area is hydrologically important because it directly affects themagnitudes of peak and mean runoff. (Shreedevi, 2012).

Drainage Density (D_d)

Drainage density is the ratio of total channel segment length cumulated for all order within a basin to the basin area, which is expressed in terms of Km/Km^2(Horton, 1945). It is generally inversely related to hydraulic conductivity of the underlying soil. The drainage density indicates the closeness of spacing of channels, thus providing a quantitative measure of the average length of stream channel for the whole basin. (Waikar,2014). Drainage density is related to various features of landscape dissection such as valley density, channel head source area, relief, climate and vegetation. (Rai, 2014). It is commonly observed that low drainage density occurs in a highly permeable bedrock under dense vegetation and has a low relief while high drainage density is seen where the rock is relatively impermeable with sparse vegetation and high relief. The $D_d$of the entire Wang basin is calculated to 1.49 indicating low to moderate drainage densities which in turn suggests that most of the area has relatively permeable sub-surface with moderate relief. When sub-watersheds were analyzed, the clusters towards north-west, west and south-west (i.e. 1-4, 38-43) showed lower drainage density implying permeable subsurface. The drainage density increases while moving in the eastward direction in the basin.

Stream Frequency (F_s)

The stream frequency is expressed as the total number of stream segments of all the orders per unit area. It has a direct correlation with drainage density in the watershed. Streamfrequencymainlydependsonthelithologyof thebasinandreflects thetextureof thedrainagenetwork (Rai, 2014). The $F_s$of the Wang basin is 1.62 indicating low to moderate stream frequency which suggests that the basin is well drained. Similar sub-watershed clusters (i.e. 1-4, 38-43) predominantly showed poor stream frequency inferring good permeability of the subsurface material while the others showed very high values likely to have tendency of more surface runoff. The spacing between the streams is determined by the frequency which can be seen as scarce in the western part of the Wang basin and it increases towards the eastern side.

Table 4: Areal aspects of entire Wang basin

Basin	Stream order	No. of streams	Length of streams (km)	Area of basin (km^2)	Drainage density	Stream frequency
Wang River	1	460	353.10	375.03	1.49	1.62
	2	120	121.93			
	3	19	35.37			
	4	6	19.75			
	5	1	8.96			
	6	1	19.83			
	Total	**607**	**558.97**			

Relief Aspects

Basin Slope

The slope is an important geomorphic aspect which indicates the degree of inclination of a basin concerning the horizontal surface (Das, 2018). The formation of the slope is influenced by climatomorphogenic processes operating in the region, where rocks exhibit differing degrees of resistance to erosion and weathering. An understanding of slope distribution is essential as a slope map provides data for planning, settlement, mechanization of agriculture, deforestation, planning of engineering structures, morpho-conservation practices, etc. (Sreedevi et al. 2005, 2009). The slope map for Wang basin was prepared from SRTM dataset into slope and aspect grids using ArcGIS. The slope of Wang basin was computed to be from 0° to 50°. Five slope classes were defined in the basin as shown in Figure 2. Flat (0°-5°) and gently undulating (5°-15°) areas cover maximum area of the basin i.e. 34% and 33% respectively. Similarly, low slopes (15°-30°)and sub-vertical cliffs (30°- >45°)constitute of 15% and 6% respectively of the total basin area. It can also be observed that the change in slope gradients is gentler in the western and south-western region of the basin as compared to the slopes on the eastern side. The slopes are higher on all the ridge faces that can attribute to high erosive vulnerability and the topography gradually flattens towards the confluence with the main river.

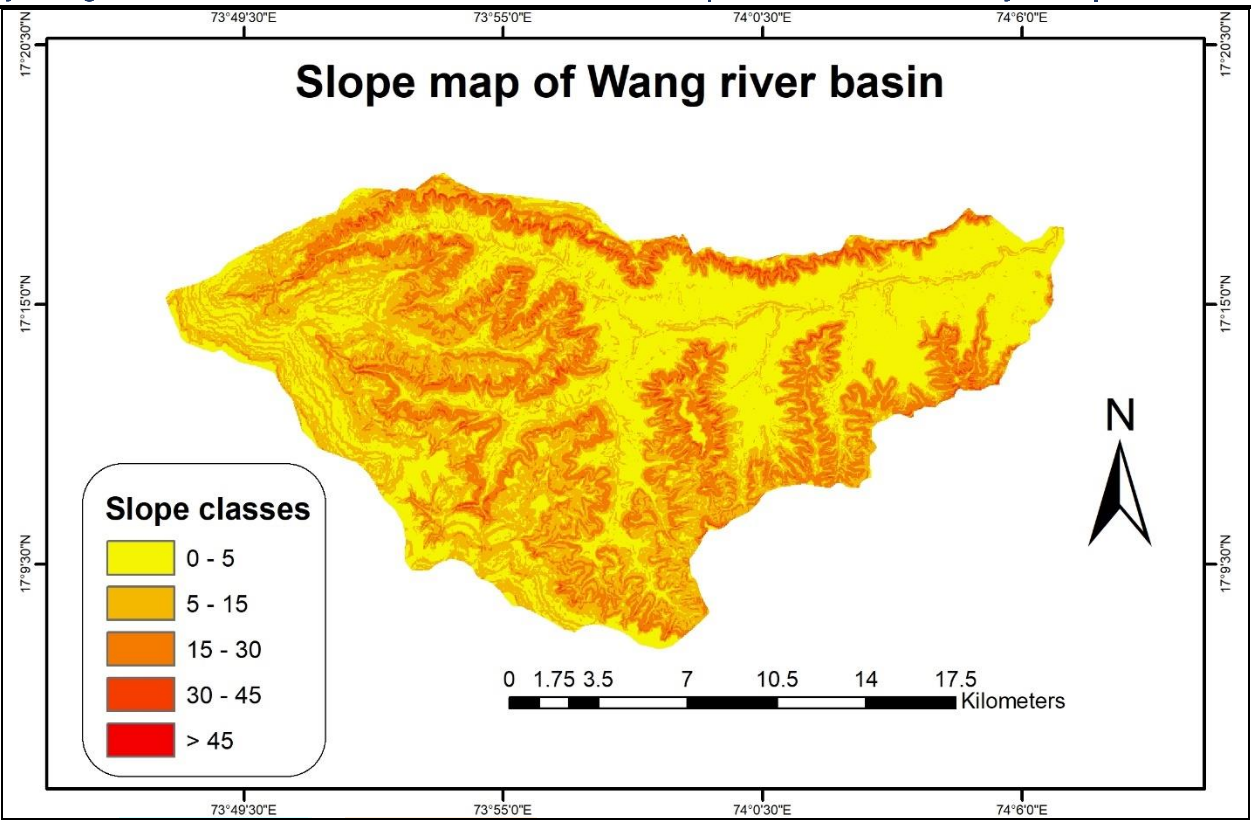

Fig 2: Slope map of Wang River basin

Basin Aspect

Aspect, in geomorphological and hydrological studies, refers to the compass direction that a slope or surface faces. It plays a crucial role in shaping the microclimatic conditions of a region by determining the amount and duration of solar radiation received on a given slope. This, in turn, significantly influences surface temperature, soil moisture content, rates of evapotranspiration, vegetation density, and local water balance. Understanding aspect is essential for interpreting landscape processes, especially in regions with pronounced topographic variation, such as mountainous or hilly terrains.Sunlight exposure varies with slope orientation, thereby creating distinct microenvironments across different aspects. Slopes facing east generally receive sunlight during the cooler parts of the day, which limits evaporation and results in higher soil moisture retention. These conditions are conducive to denser vegetation cover and improved groundwater recharge potential. In contrast, slopes facing west are typically exposed to direct solar radiation during the hottest period of the day, resulting in higher soil temperatures, increased evaporation, and reduced moisture availability. Consequently, these west-facing slopes often support sparse vegetation, exhibit lower infiltration rates, and are more prone to surface runoff, soil erosion, and reduced recharge capacity.Additionally, aspect influences plant growth dynamics, as it affects not only soil moisture availability but also plant transpiration rates. The variability in vegetation density and soil properties across different slope aspects plays a crucial role in determining land stability, erosion susceptibility, and local hydrological behavior.From a hydrological perspective, aspect analysis is also instrumental in delineating watershed boundaries and understanding the direction of surface water flow. Since water flows perpendicular to contour lines and downslope from ridgelines, the orientation of slopes informs the connectivity between various parts of the drainage network. This is particularly useful for modeling runoff paths, identifying recharge zones, and developing effective watershed management strategies.

In the present study, visual interpretation of aspect data (refer to Figure 3) reveals that the majority of the slopes within the Wang River Basin are oriented towards the south and west. This implies a predominance of slope faces that are subject to higher solar radiation and, consequently, lower soil moisture levels. These conditions suggest an increased potential for surface runoff and reduced vegetative cover on many of these slopes, highlighting areas that may require special attention in terms of water conservation, afforestation, or erosion control interventions.

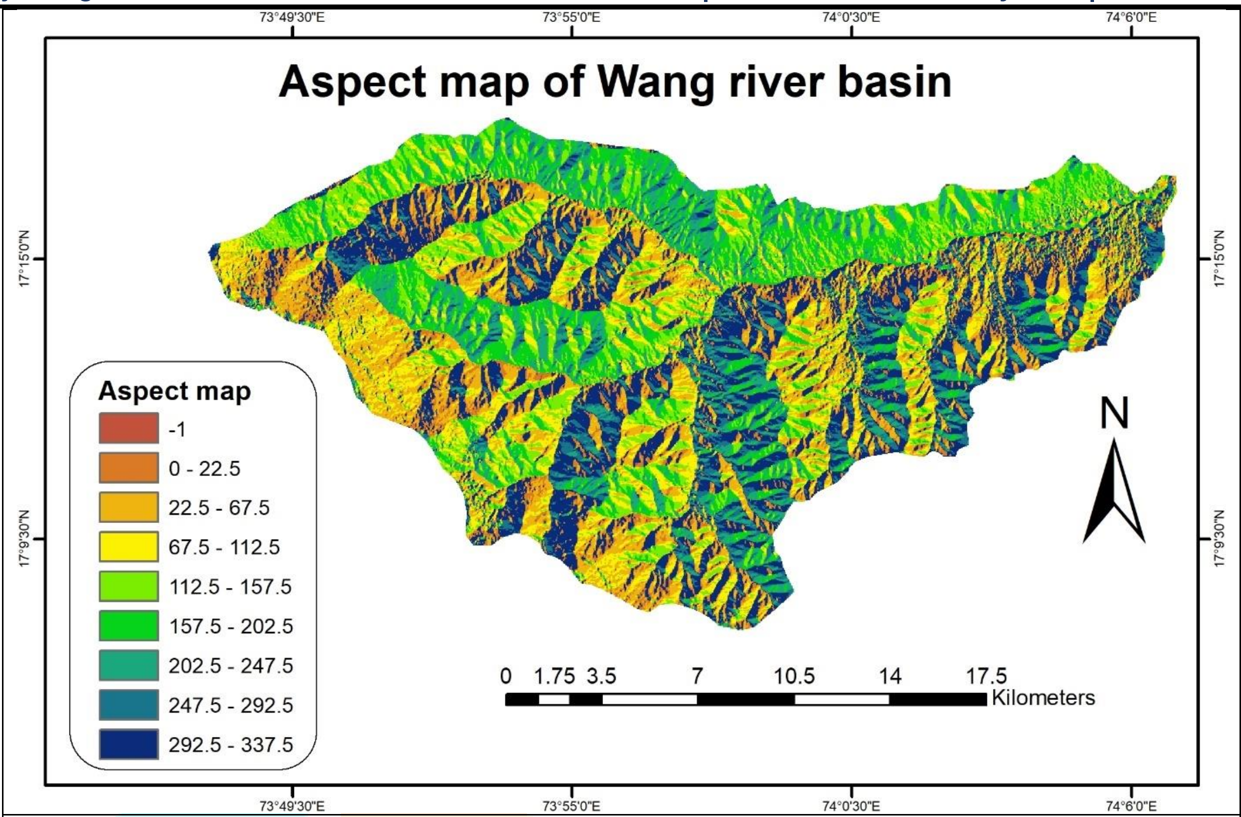

Fig 3: Aspect map of Wang River basin

Conclusion

This study demonstrates that the application of remotely sensed data and GIS in drainage morphometry and their influence on hydrological characteristics at a basin level is more appropriate than the previous conventional methods. GIS aids in delineating various important factors such as basin dimensions, sub-watersheds and drainage network with efficiency. In this paper, Wang River basin in Satara district of Maharashtra is studied using several morphometric parameters derived from remote sensing and GIS datasets.The drainage pattern that is observed is mainly dendritic, sub-dendriticto parallel dominantly from the river's confluence with Koyna in the east to its upper mountainous reaches towards west respectively indicating an incremental structural control along the way. From the results, it can be commented that the western region of the basin consisting of sub-watershed clusters (1-4, 38-43) show lesser number of streams with longer lengths and are sparsely distributed. This indicates moderate permeability of the subsurface material with good infiltration capacity. While the sub-watersheds in eastern region of the basin show increasing number of streams with shorter lengths which are tightly spaced meaning reduction in permeability and chances of very high runoff during peak rainfall. First order streams accounted for about 75% of the total number of streams, such a high proportion can indicate some sort of structural control in the basin predominantly in the form of fractures or lineaments. The underlying rock is same throughout the Wang basin (i.e. basalt) but with this variation in the morphometric parameters, it indicates the varying degree of weathering and fracturing which is the inherent property of this rock. Drainage density increases strikingly from west to east indicating decreasing permeability and thus change in rock type and its resistance to erosion i.e. probably lateritic nature in the west to more of a basaltic naturein the east. In the sub-watersheds of the western part, it is also observed that there is some structural control of the terrain on the drainage. Hence, it could be mentioned that these structures may be aiding in the good permeability of the bedrock. The study shows that systematic analysis of morphometric parameters through integrated remotely sensed data and GIS can be used effectively in land resources evaluation, understanding the spatial distribution of soil characteristics and status of land erosion for judicious resources planning and watershed management at river basin level. The results of this study can inform watershed conservation strategies, recharge zone planning, and flood risk mitigation in the Wang River basin and similar terrains.

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