Research Article
Open Access
CrossMark

Prioritization of sub-watersheds based on quantitative morphometric analysis of the Narmada River, India, using SRTM-DEM and GIS techniques

Abstract

Investigating the contribution of basin to the cycle of hydrological and the area's size, shape, and creation through quantitative analysis of these characteristics of the local scenery. Additionally, estimates of the denudation rate and hypsometric analysis were made in order to comprehend the sub-basin's quantitative geomorphological properties. The link between the morphometric parameters shows that the local geological and geomorphological features significantly influence the drainage system. On a less elevated surface with a moderate slope, stream geometry displays a pattern as semi-dendritic in greater stream order flow. On mountainous terrain surfaces, main-order streams display a dendritic drainage pattern combined with a coarse texture of drainage. The center zone of the Narmada River basin's sub-watersheds area (9461 km^2) underwent morphometric investigation utilizing geographical information systems (GIS) with remote sensing methods. It highlights the usefulness of using Shuttle Radar Topographic Mission – Digital Elevation Model (SRTM-DEM) and satellite images to enhance basin management to evaluate and comprehend many geo-hydrological aspects, like topographic & drainage analyses. ArcGIS hydrological modeling has been used to identify and study basins utilizing SRTM-DEM having 10 m resolution. For the micro-level research of its physiographic characteristics and flow structural control along with runoff, using morphometric parameters like relief, aerial, and linear is also beneficial. This may assist in predicting floods, their extent, and their severity.

Keywords: morphometric analysis, characterization, prioritization, sub-watershed, SRTM-DEM, GIS, Narmada River

Volume 7 Issue 1 - 2024

Digvesh Kumar Patel,[1] Shankar Karuppannan,[2,3] Abhinav Sao,[4] Tarun Kumar Thakur[1]

[1]Department of Environmental Science, Indira Gandhi National Tribal University (IGNTU), India
[2]Department of Applied Geology, School of Applied Natural Science, Adama Science and Technology University, Ethiopia
[3]Department of Research Analytics, Saveetha Institute of Medical and Technical Sciences (SIMATS), Saveetha University, India
[4]Department of Genetics and Plant Breeding, Indira Gandhi Krishi Vishwavidyalaya, India

Correspondence: Tarun Kumar Thakur, Department of Environmental Science, Indira Gandhi National Tribal University (IGNTU), Amarkantak (MP), India 484887, Tel 09425015752, Email tarun.thakur@igntu.ac.in

Received: February 29, 2024 | **Published:** June 06, 2024

Introduction

This is critical given that cities worldwide are becoming more populous, the global population is growing, and water demand is increasing. The hydrological nature of the basin's drainage and the mineral makeup of the exposed rocks are well-explained by the quantitative morphometric method used to evaluate the drainage basin's features. The measuring and quantitative research of dimensions, shapes, and earth surface configurations and landforms is known as morphology, according to Clarke.[1] Recently the field of geomorphology has focused heavily on the quantitative physiographic approaches development to explain the formation and functioning of surface drainage networks.[2–4] As per Clarke[1] morphometric is the measurement and computer modelling of the surface topography of the earth. The objective underlying morphometric investigations was to quantify numerous stream features in order to determine comprehensive stream parameters.[5,6] Later, other geologists improved and developed Horton's laws. The physiographic features of drainage basins may be related to a number of significant hydrologic phenomena, including shape, size, drainage density, slope, and the number and stream length.[7] When planning and expanding, it's important to consider the watershed's size, profile, physiography, land use and cover, hydrogeological context, etc. In comparison to traditional ground surveys, it is now possible to increase approval of resources from better basin areas in a much shorter time frame and a more inclusive manner with the aid of Remote Sensing (RS) & Geographical Information Systems (GIS).[8–10]

GIS approaches have previously been utilized for evaluating different topography & morphometric aspects of the drainage basin & watersheds because they offer a versatile environment along with a potential tool for altering & analyzing spatial information. Identification as well as information extraction in the future for improved comprehension.[11] Morphometric properties refer to the quantitative measurements of the physical features of a river basin or sub-basin. These properties can include the basin's size, shape, relief, drainage network, and other related features. "Traditional approaches" refer to the methods used to measure and analyze these properties, which can include field surveys, map interpretation, and analysis of satellite imagery.[12–16]

Numerous scholars have examined the morphometric characteristics utilizing RS & GIS methods to investigate the physiographic settings of river basins.[17–21] Thus, a river basin's morphometric analysis offers a first-hand understanding of the geomorphology and watershed characteristics. Recently, numerous scholars have used GIS methods to generate drainage morphometric analysis.[22–25] The primary causes of landslides, according to DSCWM[26] include toe-cutting on steep slopes, inadequate water management after significant precipitation, and fissures forming in the rocks on steep slopes after earthquakes. On the other hand, stress concentration and redistribution take place. The stress balance is significantly impacted by the toe-cutting of the slope, which results in the body of natural slope.[27,28] Where rivers flow at the base of mountains, Toe-cut slopes typically fail to slide on hill slopes or in areas where it is always raining.[29] Heavy rains increase the water content of slope and saturate the mass of earth, which decreases the cohesiveness of the slope materials and wears down and mobilizes rock or loose soil.[30,31] Landslides frequently result in river damming in narrow and deep river basins in mountainous terrain.[32] Depending on the size, material, stream power, upstream catchment area, and valley breadth, landslide dams can last from a few hours to several years.[33,34] People and their way of life downstream may be seriously jeopardized in the case of a sudden dam breakdown. In the state, unstable steep slopes, flimsy rock formations, and heavy rainfall are some environmental factors that cause slope failure. Road construction and widening, settlement growth, development, and deforestation are examples of anthropogenic activities. Stream length, number, segment, order, and their various ratios are among the 20 different aspects of rivers and river basins that Estela studied and interpreted, and they now play a crucial role in morphometric investigations. So that proper identification of landforms can be used clearly, the data generated through such measurements are illustrated using a variety of cartographic approaches, including maps, statistical graphs, diagrams, and sketch diagrams. Conversely, the association among stream number & stream order exhibits the least departure from a straight line in the figure and a lower logarithm value, representing the presence of regional uplift males within the research area.[35–37] Topographical data and satellite imagery maps are used to evaluate the morphometric features such stream order, drainage pattern, density, bifurcation ratio, and other linear and area-based measurements.[38] Understanding watershed features was the goal of the present research, which concentrated on the River Narmada's sub-basins. Three distinct morphometric studies were conducted in light of this. In this research, the topography, slope, and drainage lines were plotted on topographical maps (scale 1: 50,000) using GIS. India's need for geospatial data has been satisfied for the last 20 years by online national and international spatial data providers. The drainage basin morphometric features, like the stream slope and network, the pattern of drainage, and the drainage position, must be quantified. Digital topography maps (DEM), reliable satellite photography, and digital topography maps may all provide these specifics.[39–42] In the present study, we have thoroughly analyzed the morphometric parameters to depict the tectonic activity in upper catchment of the Narmada River in central India. The current research uses geospatial tools as the most conventional and integrated approach to quantify the morphometric indices.

Materials and methods

Study area

The present research area is situated in 5 districts of Madhya Pradesh (Anuppur, Dindori, Mandla, Seoni, and Jabalpur), Central India and it is depicted in Figure 1. The research area lies between the 22^0 00'N to $23^0$00'N and 80^0 00'E to 82^0 00' E, which covers the watershed area with a mean altitude of 1048 m from the Digital elevation model. The max temp is in May, while the min is in December. The southwestern monsoons bring rainfall from the month of June - September, and mean annual precipitation is more than 1600 mm. The area's mean 12-month temp ranging from 16.1°C in the winter - 31°C in the summer, while the mean relative humidity ranges from 50 to 85%. Figure 1 shows a systematic approach for the current monitoring and morphometric analysis. The longer summer months of April - June, the rainy season of July- October, and the shorter winter months of November to February are all results of the sub-humid tropical monsoon climate. With lows below 6°C, the two months of April and May were the hottest and coldest. 16.2°C to 40.12°C was the temperature range for the yearly average. Precipitation amounts of between 1360 and 1610 mm per year have been noted. Give the approach technique for the present monitoring and evaluation analysis. The multiple steps of the analysis work performed during the current investigation are illustrated in a self-explanatory flow chart in Figure 2.

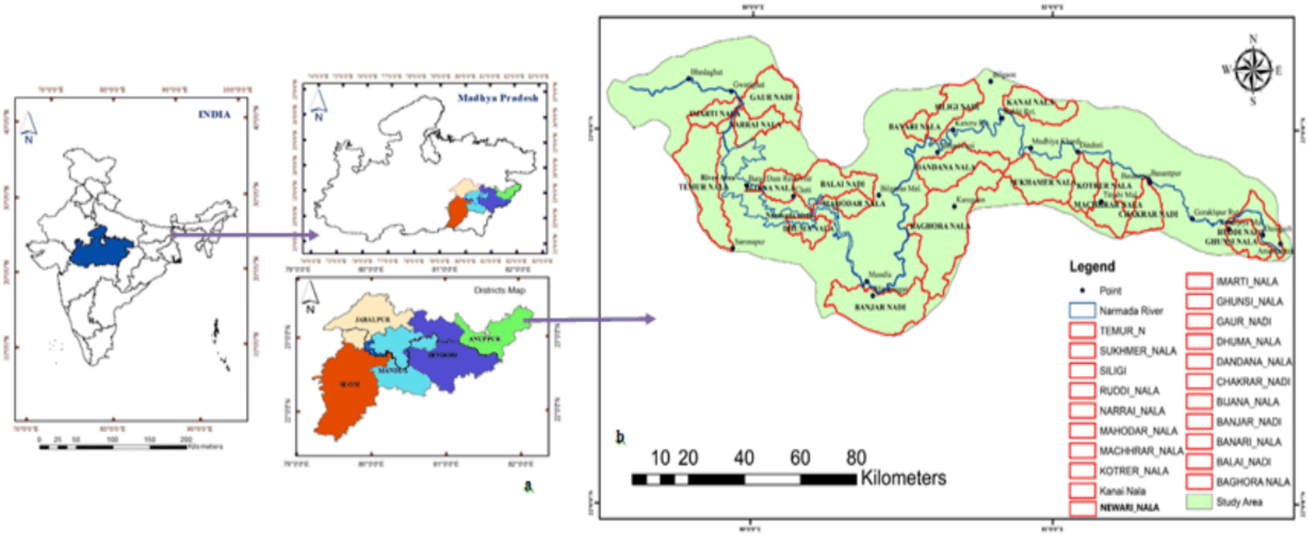

Figure 1 Layout Map and sub basin of the Narmada River Area (a & b).

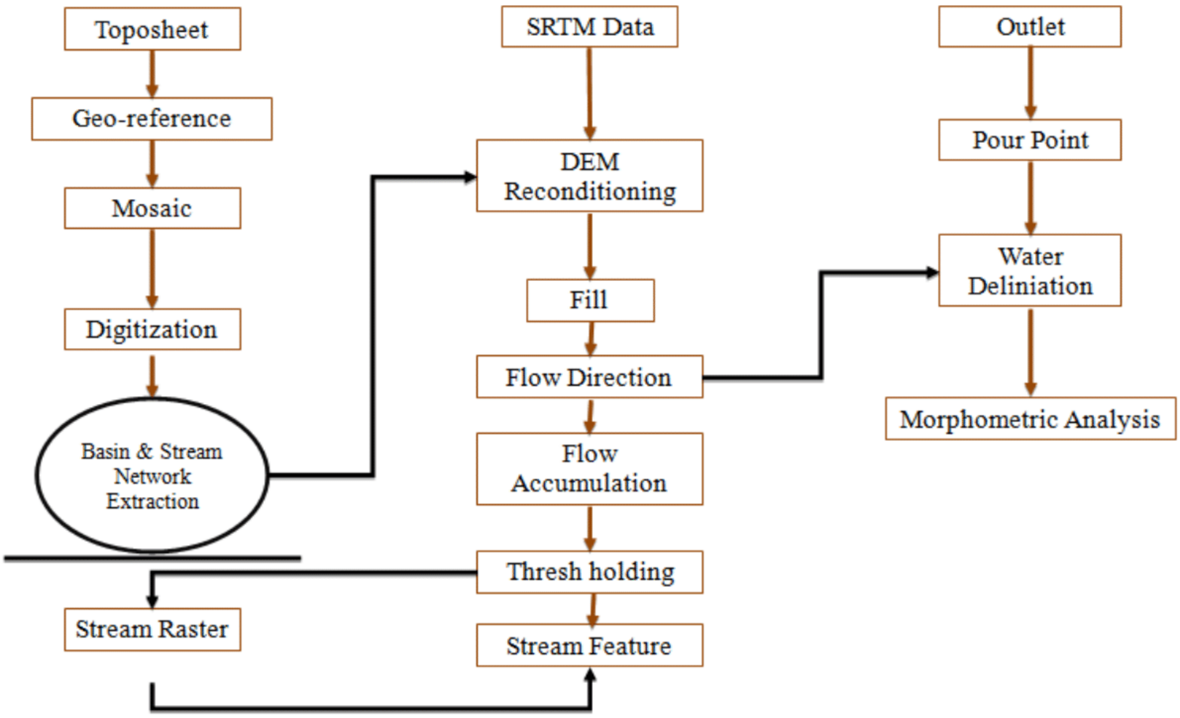

Figure 2 Steps of data processing.

Preparation of geo database for thematic layer

The current study used multispectral satellite data, SRTM (Shuttle Radar Topographic Mission), DEM (Digital Elevation Model), and SOI topographical sheets to create a database and extract numerous drainage parameters. Horton's law states that a stream that is unbranched is called a 1st -order stream and a stream that is formed while two 1st-order streams combines is called a 2nd-order stream. A 3rd order is created while two 2nd-order streams combine, and so on. Each order's number of streams is tallied and noted. Digital line coverage of the drainage map and basin boundaries serves as each stream order's identification number. The digitized map is modified and saved as Arc view GIS software line coverage. In comparison to previous manual delineation methods, the automated delineation of drainage networks and streams ordered from SRTM-DEM is more practical, time-saving, and accurate. The study's methodology involves extracting the river basin along with the drainage network. From the http://earthexplorer.usgs.gov website, SRTM-DEM pictures were first obtained, and after they were, they were successfully mosaicked. The Narmada river basin region was retrieved using the Arc hydro tool in ARC GIS 10.4 software after the river basin boundary had been delineated utilizing a mosaicked picture. The mapping of the research area's drainage system utilizing the Survey of India's 1:50,000 scale topographic sheets came next (Figure 3).

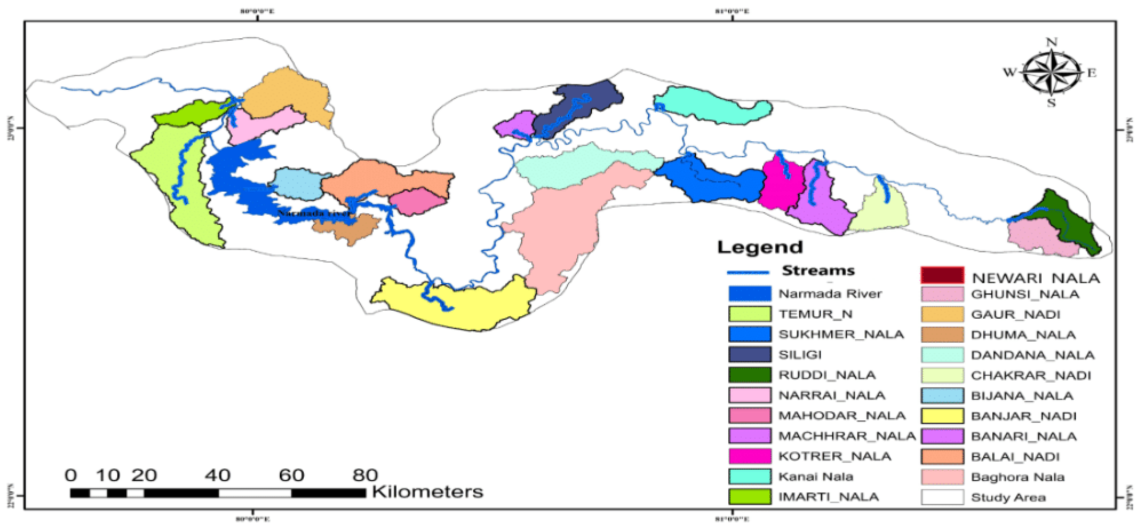

Figure 3 Drainage networks of sub-watersheds up to their higher stream orders.

Citation: Patel DK, Karuppannan S, Sao A, et al. Prioritization of sub-watersheds based on quantitative morphometric analysis of the Narmada River, India, using SRTM-DEM and GIS techniques. *Biodiversity Int J.* 2024;7(1):22‒33. DOI: 10.15406/bij.2024.07.00208

Analysis of the watershed morphometric

The drainage systems have been delineated using a 1:50,000 scale survey of India toposheets-64-A-13/13/19, 64-F-1/5/9/13 64-B-1/2/5/6/9/10, 55-M-16/13, and satellite images. The image processing program ERDAS Imagine (2014) was utilized to georeferenced satellite imagery and toposheets, which were then used in the current investigation. Measurements of the basin's linear, relief, and aerial features and slope contribution have been utilized for the morphometric evaluation. Table 1 displays data from the measurement of numerous morphometric parameters. Arc GIS (V 10.4), a GIS program, was utilized for output production, calculation, and digitization. In the current study, three morphometric measurements were performed using predetermined mathematical equations: i) linear ii) areal and iii) relief (Table 1). Measurements were made of linear structures like the main length of the channel, the extended sub-basin length, the bifurcation ratio, the overland flow length, the stream length ratio, and the stream mean length to assess the sub-basin linear morphometric features.

Table 1 The equations of mathematics are used to assess the morphometric parameters quantitatively

	Morphometric parameters	Formula	Reference
A. Linear			
	Stream order	Hierarchical rank	Strahler (1964)
	Stream no.	Total no. of streams in each order in a basin	
	Stream length (Lu)	Length of the stream	Horton (1945)
	Mean stream length	(Lsm) Lsm=Lu/Nu. Where, Lsm=mean stream length; Lu=total stream length of a given order; and Nu=total no. of stream segments of a given order	Strahler (1964)
	Stream length ratio (RL)	RL=Lu/Lu−1. Where, RL=stream length ratio; Lu=total stream length of a given order; and Lu−1=total stream length of its next lower order	Horton (1945)
	Bifurcation ratio (Rb)	Rb=Nu/Nu+1. Where, Rb=bifurcation ratio; Nu=total no. of stream segments of a given order; and Nu+1=no. of segments of the next higher order	Schumn (1956)
B. Areal			
	Drainage density (D)	D=Lu/A. Where, D=drainage density; Lu=total stream length of all orders; and A=area of the Basin (km2)	Horton (1932)
	Drainage frequency/stream frequency (Fs)	Fs=Nu/A. Where, Fs=drainage frequency; Nu=total no. of streams of all orders; and A=area of the basin (km2)	Horton (1932)
	Drainage texture ratio (Rt)	Rt=Nu/P. Where, Rt=drainage texture ratio; Nu=total no. of streams of all orders; and P=perimeter of the basin (km)	Horton (1945)
	Circulatory ratio (Rc)	Rc=4×Pi×A/P2. Where, Rc=circularity ratio. Pi='Pi' value, i.e. 3.14; A=area of the basin (km2); and P2=square of the perimeter (km)	Miller (1953)
	Form factor (Rf)	Rf=A/Lb2. Where, Rf=form factor; A=area of the basin (km2); and Lb2=square of basin length (km)	Horton (1932)
	Elongation ratio (Re)	Re=2×Sqrt (A/Pi)/Lb. Where, Re=elongation ratio; A=area of the basin (km2); Pi='Pi' value, i.e. 3.14; and Lb=basin length	Schumn (1956)
C. Relief			
	Relative relief or total relief	Maximum elevation minus minimum elevation of the basin	
	Relief ratio (Rh)	Rh=H/Lb. Where, Rh=relief ratio; H=total relief (relative relief) of the basin in kilometers; and Lb=basin length	Schumm (1956)
	Ruggedness no. (Rn)	Rn=Dd×Tr/1000. Where, Rn=ruggedness no.; Dd=drainage density; and Tr=total relief (km)	Strahler (1964)

Extraction of drainage network

Using conventional techniques like topographic maps or field observations, drainage networks throughout the catchment could be identified (Ruddi Nala 127.2 km^2, Gunshi Nala145.88 km^2, Chakrar Nadi 125.38 km^2, Machhrar Nala 165.09 km^2, Kotrer Nala 123.64 km^2, Sukhmer Nala 200.27 km^2, Kanai Nala 167.07 km^2, Siligi Nadi 161.91 km^2, Banari Nala 51.33 km^2, Dandana Nala 226.15 km^2, Baghora Nala 521.12 km^2, Banjar Nadi 356.41 km^2, Mahodar Nala 67.04 km^2, Balai Nadi 219.36 km^2, Dhuma Nala 85.69 km^2, Bijana Nala 92.41 km^2, Temur Nala 361.64 km^2, Narrai Nala 107.89 km^2, Imarti Nala 85.51 km^2, Newari Nadi 198.58 km^2, Gaur Nadi 212.03 km^2) (Figure 4). Due to their extensiveness over a wide area, the traditional approach's primary flaw is the time-consuming effort required to investigate all stream networks through field observations.[43–45] The stream segment size & shape can occasionally depend on the cartographer's subjective opinion, especially in remote areas.[46,47] In recent years, using GIS software based on the (multi-direction technique) paradigm has made it fairly simple to automatically extract drainage networks from DEM data sources. Reducing pixel-based defects such as peaks and sinks and eliminating discontinuities in the drainage network increased the accuracy of the DEM. The stream ordering approach[48] was used to retrieve the stream segments through whole DEM. Using a methodical GIS procedures series, such as pixel filling, flow direction, and flow accumulation calculation, a DEM is utilized to map a reasonably high-accuracy drainage network. The area of contribution through which water flows into an output grid cell is subsequently computed.[49,50] In this study, a 0.5 threshold value has been utilized to extract the drainage network through a DEM grid, and a topographical map from the Survey of India was used to confirm the drainage pattern's correctness.

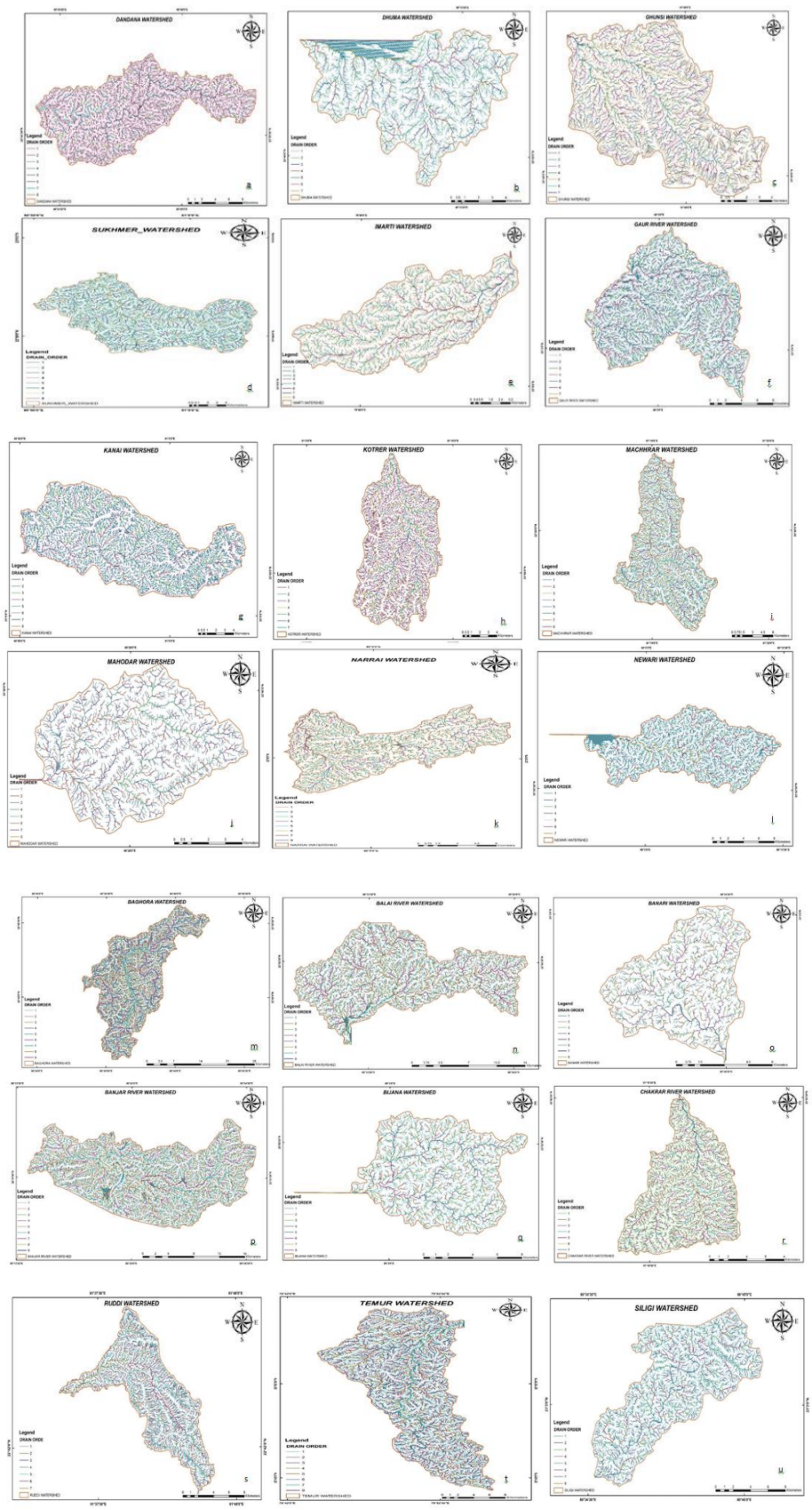

Figure 4 Drainage networks of the sub-watersheds (a to u).

Citation: Patel DK, Karuppannan S, Sao A, et al. Prioritization of sub-watersheds based on quantitative morphometric analysis of the Narmada River, India, using SRTM-DEM and GIS techniques. *Biodiversity Int J.* 2024;7(1):22–33. DOI: 10.15406/bij.2024.07.00208

Slope estimation

A vector slope has both a length and direction. The approach that produces slope and aspect values through a normal vector is standard for calculating slope. Aspect and slope are based on the nature of digital terrain in two different ways- utilized model (DTM). DTM slope and aspect in raster are calculated using a database and three-by-three windows. A center cell tilted plane that is the best fit for the where Z is the height at the position of the equation $Z = a + bm + cn$ interest. A, B, and C were constants in the window center. The slope & aspect of the center cell could be determined utilizing the below calculations.

$$S = b^2 + c^2$$

$$A = Tan^{-1}(c/b)$$

S is for slope, and A is for aspect.

The formula establishes the aspect and slope of each triangle that is produced by the TIN (Triangulated Irregular Network) model.

Terrain condition

Every bedrock and landform type has its unique form of topographic, involving a typical shape and size. A clear topographic change may be observed when two different landforms come together in nature. The terrain in the area can be characterized as vast, ominous, broken-up steep hillsides, gully slopes, etc. The research region's terrain status was observed during the examination.

Result and discussion

The results of the current work, which focuses on satellite remote sensing for morphometric analysis, are explored in more detail below. A watershed is a basic hydrological and geomorphological unit of a river system that can be used to accurately define topographic shapes as data could be organized, collected, and evaluated. Unlike conventional drainage basin morphology, this study area's topography and topographic structure are different in the hydrological process due to the short length of the drainage network on the sloping topographic surface. The main hydrological elements that regulate hydrodynamic activities in that region, like intensity of flow, surface runoff, and surface runoff at the outflow, are the flow segments and their shape. Utilizing an RS and GIS, a quantitative examination of this sub-morphology basin has been carried out in terms of linear, acreage, and topographic elements to assess the drainage characteristics.

Linear features

For the linear feature, which contains stream length (Lu), stream order, stream number (Nu), stream length ratio (RL), mean stream length, mean bifurcation ratio, and the bifurcation ratio, the outcomes were depicted in Table 2. Twenty-one sub-watersheds contained streams up to highest rating after all streams were ranked using[48] hierarchical ranking system. Streams up to 9th order and then sub-watershed arranged (Table 2). Several stream segments of each order "form an inverse geometric sequence with the order number," by[4] law. The biggest percentage of 1st -order streams among all sub-watersheds may be found in four major water shades Baghora, Temur, Bajar, and Balai Nadi, which is a sign of soft lithology and less-permeable formation.

This analysis used[4] legislative proposal for the 21 sub-watersheds in the research region. GIS software aids in determining the stream's length through the river mouth to the drainage split. The greatest length of streams during current inquiry is presented in Table 2 for the 21 sub-watersheds and declines as the stream order rises. This might be caused by streams coming from great elevations, lithological variety, a change in type of rock, relative slopes of steep, and possible uplift across the basin.[51,52]

Their mean stream length[48] characterizes the network of drainage components and the accompanying surfaces of the basin. This may be determined by dividing the order's total stream length by number of segments in specified sequence as streams. The 21 sub-watersheds average stream length from Table 2. Lsm's value ranges from 0.16 to 190.38km. It has been found that Lsm of any certain order is higher in comparison to the lesser orders & less than except for the Seven, eight, and Ninth-order streams in Baghora, Temur, Bajar, and Balai Nadi, which are higher in comparison to that of their next greater order up to 9th order stream Values in the sub-watershed are lower than lower-order values. Variations in terrain and slope may bring this on.

The mean stream length ratio of the given order to following stream segments in lower order can be used to define this. It significantly impacts surface discharge and flow.[4] Table 2 provides the sub-watershed stream length ratio values, as per the.[51,53,54] Variance in RL in the Baghora, Temur, Bajar, and Balai Nadi sub-watershed may be caused by variations in slope & topography, reflecting the geomorphic development late youth stage in the study area's streams.

Several stream segments in a specific order divided by the number of segments in the next greater orders is the bifurcation ratio, as per.[55] With the exception of areas where the strong geological influence predominates, it displayed a narrow variety of variance for various regions or various environments.[10] According to the Rb values in the research region (Table 2), the Baghora and Temur sub-watersheds Rb values uniformly drop from 1st order to the next. However, the Rb values in the other four sub-watersheds vary from order to order. These variations rely on the drainage basin's lithological and geological evolution.[48] According to Strahler,[10] the values of Rb in the research region varied from 4.00 to 7.50, indicating that all sub-watersheds fit into the typical basin group. The sub-watershed is not as much impacted by structural instabilities when Rb is at its lowest value, implying great structural control over the pattern of drainage.[48,52,53] The bifurcation ratio values found during the research the Western Ghats show that the formations geologically have no bearing on the networks of drainage.[56]

Aerial aspect

Various morphometric metrics are included, like drainage texture, drainage density, and drainage frequency, Form factor, Circulatory ratio, elongation ratio, and (Rt), as well as overland flow length (Lg). As per[57] frequency of drainage is the sum of all stream segments for all orders within a given region. Fs values for the research area's sub-watersheds display a positive association. The values of drainage density (Table 2), indicate a relation to a rise in stream population Drainage Density (Table 2). The essential concept in geomorphology is the drainage lines' relative spacing. There are more drainage lines over the impermeable ground than over permeable land. It is over-all number of stream segments for all orders within a given border, according to Horton[4] Five different textures were identified by[58] on the basis of drainage density: very coarse (2), coarse (2–4), moderate (4–6), fine (6–8) and very fine (>8). Table 2 shows that the sub-watersheds drainage density values ranged from 7.02 to 9.02, suggesting a drainage texture that is very coarse - coarse.

As per[58] the contour of a drainage basin can be quantitatively expressed using the form factor. It is basin's area ratio to the total number of square measures. The form factor in area under consideration ranged from 0.07 (in the Kotrer sub-watershed) to 0.25 (in the Dhuma sub-watershed) over the course of the inquiry (Table 2). This suggests that the Chandni sub-watershed is in circular, in contrast to the other sub-watersheds, which are generally rectangular in shape.

As per the[55] the value of Re represents the ratio of drainage basin maximum length to diameter of circle which is similar in size to the drainage basin. As per[54] a circular basin is superior to an extended basin in terms of its ability to effectively discharge runoff. According to[48] values between 0.6 and 0.8 are frequently discovered in regions that have a large amount of relief and a steep slope of ground, whereas values close to the value 1.0 suggest regions that have an exceedingly low amount of relief. The elongation ratio values typically fall somewhere in the range of 0.6 and 1.0 across a broad range of climatic & geology types. It is possible to create Re values in the following categories: (a) circular with a diameter greater than 0.9, (b) oval with a diameter between 0.9 and 0.8, and (c) less elongated (0.7). The elongation ratio was found to be at its maximum in Baghora sub-watershed, indicating that the topography in the Banari sub-watershed was the most mountainous and had the steepest slopes. This denotes a flat, low-relief landscape with a gradual slope. In addition to this, it shows that Baghora Sub watershed is in circular, while the other sub-watersheds are not stretched in any way.

Drainage density is a hydrograph measurement for a drainage basin shape and a crucial statistic for identifying subterranean water potential regions. It is explained as the total stream length ratio to a basin overall area.[59]

Permeability has an opposite relationship with drainage density. Rainfall penetration decreases when rock becomes less porous; surface runoff becomes more concentrated. This is where a sophisticated and excellent drainage system gets its start. Because the connection to surface permeability and runoff, drainage density was regarded as one of the indicators of groundwater occurrence in the current study since it might indirectly suggest a region's potential for groundwater.[60] The drainage density map in (Figure 5) revealed that the drainage density is low on gentle slopes and comparatively high on hills and steep slopes, leading to higher infiltration. The research area is also home to around four perennial streams in addition to several seasonal streams (Table 2). The research region's drainage density values (km^2) were divided into five categories. The areas fall under the nil-very low category. Very low-low (7.08-7.18), encompassing area, low moderate (7.18-7.23), accounting for the area, moderate-high (7.45-7.75), accounting for the area, and high-very high (9.02), accounting for the entire research area. Permeability has an opposite relationship with drainage density.

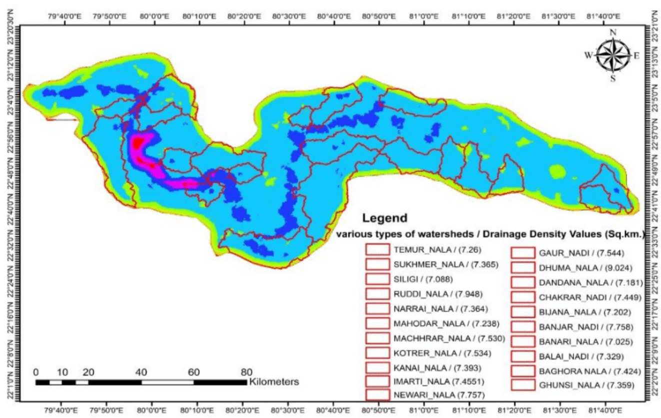

Figure 5 Drainage density map of the study area.

Relief aspects

Results on the relief ratio, including total relief, and roughness number are depicted in Table 2. The elevation variation among the high & low places on a sub-watershed valley floor is recognized as that sub-watershed complete alleviation.[55] Asserted that the Rh of greatest relief, the longest dimension of the basin's horizontal distance that lies parallel to the main line of drainage, is known as He added that there is an immediate benefit as alleviation ratio. Channel gradient and connection between reliefs. The relief ratio gauges a structure's general steepness. A drainage basin and a measure of the degree of working on the slope of basin is the erosion process. That is assuming a connection between hydrological characteristics and a drainage basin's relief ratio. According to[61] a sub-watershed area of drainage and size reduces as the Rh typically rises.

As per data narrated in the Table 2, lists the range of Rh, which ranged from 17.67 (Temur sub-watershed) to 71.65 (Chahrar sub-watershed). According to the findings of the observations, a high Rh value indicates a steep slope and a significant amount of relief, but a low Rh value might suggest the basement rocks existence that is visible in the form of little mounds & ridges on a terrain with a more gradual slope (GSI 1981).

Watershed delineation according to[53] watershed is a naturally occurring hydrological thing by the surface runoff flows to designated channel, drain, & river stream at specific location. In accordance with the rules, the average watershed area is 50% of less than $500km^2$. Additionally, watersheds are divided into Mini-watersheds (10–30 km^2) and sub-watersheds (30–50 km^2), according to IMSD and micro-watersheds (between 5 and 10 km^2) Technical Guidelines.[62] As a result, the complete watershed was then divided into sub-watersheds, each measuring 127.2 to 521.125 km^2 in size (Figure 6 and Table 2).

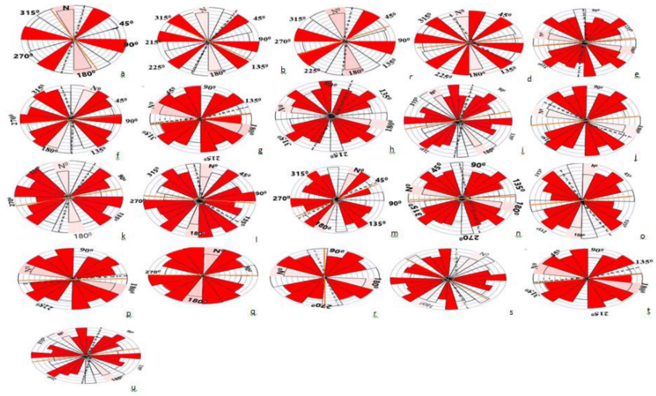

Figure 6 Rose diagrams show the geometry of the streams all direction and length (a-u).

Analysis of drainage network

Traditional approaches like topographic maps, satellite imaging, and observations of field were utilized in order to locate the sub-watershed drainage networks. The aforementioned methods were utilized in the current research to locate the drainage networks that are associated with the sub-watersheds. Figure 5a–u shows the sub-watershed drainage networks up to their upper stream orders. The size, form, and stream segments distribution within the network of drainage all have the potential to have an effect on the morphologic properties of drainage basin.[63] The connections between these elements, land cover, and land use regulate the surface runoff and water discharge in the mid-region with a mild sloping surface and a plain surface in southern part. On the other hand, the rates of the key factors that affect groundwater entering the subsurface include the geological makeup and drainage system of the area. Drainage analysis aids in defining the assessment of the association among the tectonic structures and the drainage network's geometry. In the current study, we are looking into the Narmada River basin's whole drainage system. The evaluation of the interaction between them is defined by the fact that the main river stems that historically ran from EW to NW drain the upper portion of sub-basin I. In middle of the sub-basin, the main stems deviate from the original course (EW-NW) and are redirected perpendicularly. But sub-basin II likewise has a pattern of dendritic-type drainage and flows in direction of EW-NW, showing a rising gradients trend from the SW to the NW Rivers. Though, the major river in the sub-basin first flowed in an NE–SW direction before abruptly changing to direction of NW–SE. Higher order streams, on the other hand, depict the NW-SE direction, while lower order streams (1–4) indicate the E-W and NWSE directions. The drainage network in the sub-basin has a rectangular pattern of drainage. In addition to NE-SW & NW-SE trends for the high-order streams, the rose diagram for low-order streams also displays EW & NW-SE trends. Additionally, this basin's main drainage pattern is consistent throughout. The network of drainage in the sub-basin has a NE-SW drainage trend. The scenery has changed as a result. Understanding the connection between tectonics and channel orientation is simplified by the relationship that exists between lineament and the direction in which drainage occurs. Research on stream channels & lineaments has revealed that there are some preference orientations, that are most likely tectonically governed. The direction of the lineament was measured for each individual sub-basin. The Narmada River's first-order to fifth-order streams all drain into higher-order streams in all of the sub-basins, with the majority of water moving in the north-south and east-west directions, respectively. Eighth- and ninth-order streams in the Narmada River drainage basin have dominant domains that run EW to NW and NW-SE, respectively. A lineament trend analysis shows that the rose diagram peak locations are in the EW to NW (Figure 5 a - u) direction.

Terrain status

In 21th sub-watersheds, the elevation ranged from 327 to 1200 m, as shown in Figure 7 and listed in Table 3. The Gaur, Narrai, and Imarati sub-watershed had the lowest elevation, and the Ruddi, Machhrar, Ghunshi, Kanai, Kotrer and Sukhmer sub-watersheds had the highest elevation.[64] Investigated the Narmada river basin terrain status in the upper catchment area and noted mid and high lands, which typically come from the linear ridge, stony slope (scarp face), hillcrest, hilly terrain, and side slope and occupy low-order streams up to various order. The slope range in the research region ranged from 49.6 to 1200%. The sub-watershed had the lowest slope, while the Gunjari sub-watershed had the highest slope. According to[56] analysis of the Ghats' slope state, the local lithology and erosion cycle regulate slope variance.

The slope plays essential part in influencing the morphometric features of watershed. This refers to topographical features and the angle at which they incline in comparison to a level, flat surface. Using the Arc-GIS 10.4 surface analyzer tool, the research region was created using the incline of the STER DEM data (10 m). The estimated slope gradient for this sub-basin is to the regional distribution of various slope gradients, Classes are shown in Table 4. Despite the ridged surface, the slope is reported to be facing south and downward. The structural hills in the areas have different slope orientations. For all sub-watersheds in the current research, the slope is estimated in percent, displayed in Figure 8 a - u and listed in Table 4.

Table 3 Terrain status in Sub watershed of the Narmada River

S.No.	Sub-watershed	Elevation in meters
1	Gaur Nadi	367 – 592
2	Dhuma Nala	410 – 629
3	Siligi Nala	499 – 878
4	Ruddi Nala	751 – 1144
5	Narrai Nala	370 – 575
6	Newari Nala	412 – 672
7	Machhrar Nala	671 – 1008
8	Kanai Nala	599 – 1010
9	Ghunsi Nala	747 – 1124
10	Imarti Nala	366 – 559
11	Temur Nala	369 – 617
12	Sukhmer Nala	624 – 967
13	Dandana Nala	476 – 892
14	Chakrar Nadi	696 – 1023
15	Banjar Nadi	432 – 817
16	Balai Nadi	409 - 694
17	Bijana Nala	413 – 596
18	Banari Nala	500 - 776
19	Baghora	432 – 889
20	Kotrer Nala	657 – 966
21	Mahodar Nala	414 – 690

Table 4 Percent status of slope in the Sub watershed of the Narmada River

S.No.	Sub-watershed	Slope in percent (%)
1	Gaur Nadi	0 - 72
2	Dhuma Nala	0 – 68
3	Siligi Nala	0 – 149
4	Ruddi Nala	0 – 89
5	Narrai Nala	0 – 69.5
6	Newari Nala	0 – 84.3
7	Machhrar Nala	0 – 96.69
8	Kanai Nala	0 - 72.3
9	Ghunsi Nala	0 – 103
10	Imarti Nala	0 – 49.6
11	Temur Nala	0 – 743
12	Sukhmer Nala	0 – 75.88
13	Dandana	0 – 224
14	Chakrar Nadi	0 – 186
15	Banjar Nadi	0 – 1200
16	Balai Nadi	0 – 93.21
17	Bijana Nala	0 – 147
18	Banari Nala	0.- 125.3
19	Baghora	0 – 127
20	Kotrer Nala	0 – 63.3
21	Mahodar Nala	0 – 124

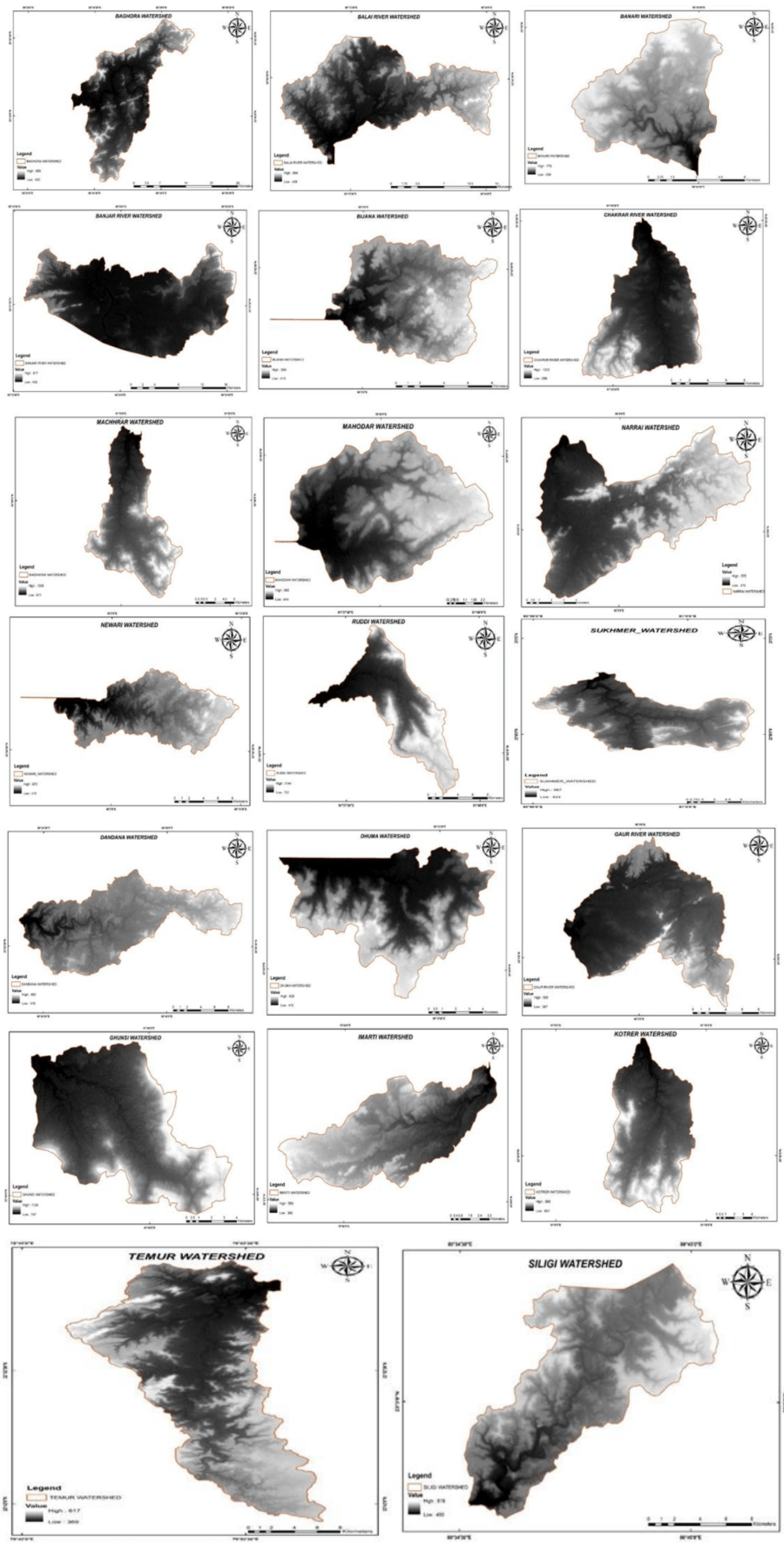

Figure 7 DEM map of the various watersheds.

Citation: Patel DK, Karuppannan S, Sao A, et al. Prioritization of sub-watersheds based on quantitative morphometric analysis of the Narmada River, India, using SRTM-DEM and GIS techniques. *Biodiversity Int J.* 2024;7(1):22‒33. DOI: 10.15406/bij.2024.07.00208

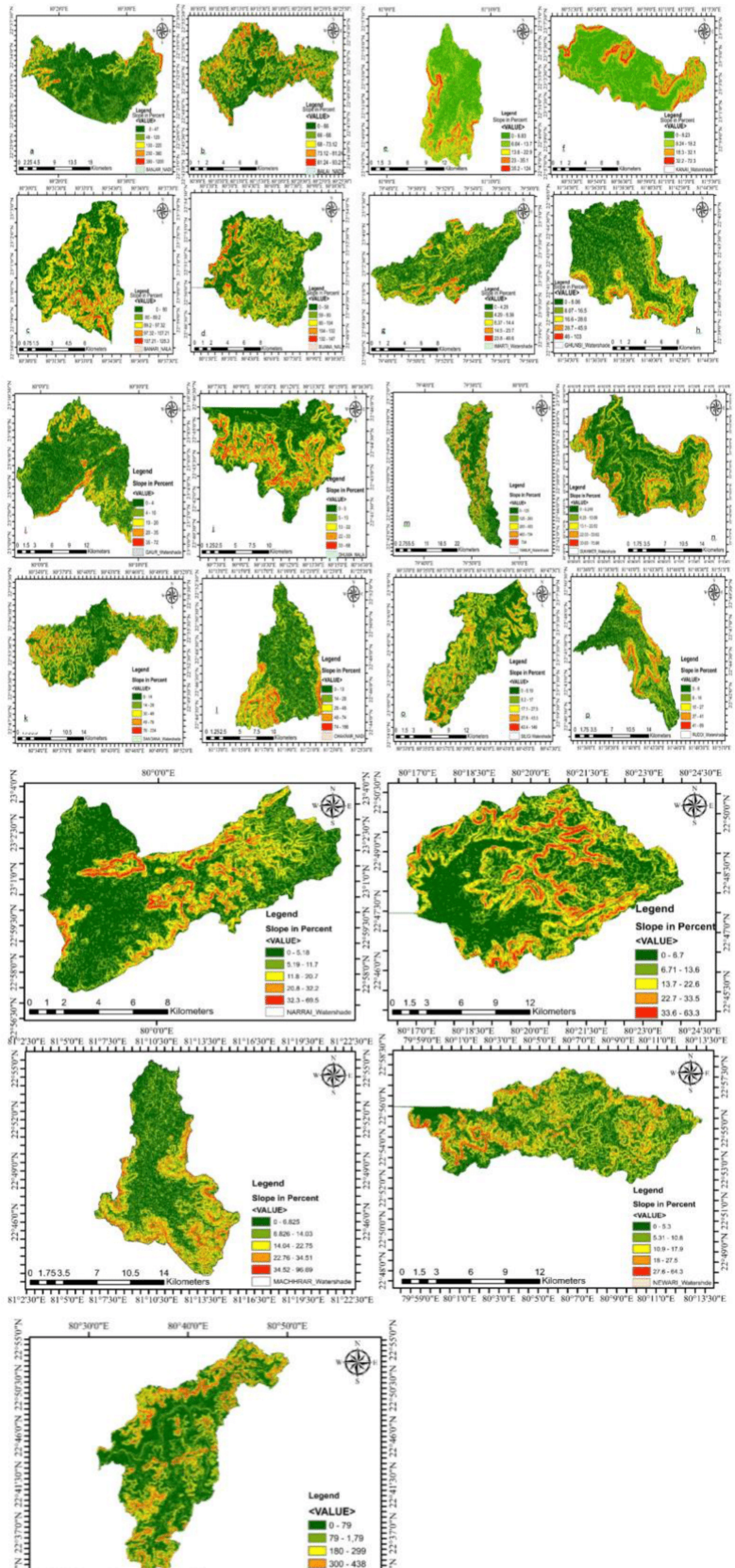

Figure 8 Slope map of the sub watershed in Narmada River (a to u).

Citation: Patel DK, Karuppannan S, Sao A, et al. Prioritization of sub-watersheds based on quantitative morphometric analysis of the Narmada River, India, using SRTM-DEM and GIS techniques. *Biodiversity Int J.* 2024;7(1):22‒33. DOI: 10.15406/bij.2024.07.00208

Conclusion

Quantitative analysis of morphological parameters helps assess river basins, prioritize watersheds for conservation of water & land, and manage natural resources at the micro-level. The Morphological evaluation performed in the Narmada River catchment indicates that basin has low topography and is oval. The drainage network of basin is presented as mainly dendritic kind, showing uniformity in the texture along with the lack of structural control. Soaking and grouting the terrain revealed parallelism and model in some parts of the basin. The graph representative's linear model indicates the study area's erosive weathering characteristics. Morphology parameters calculated utilizing a GIS helped us understand many topographical parameters like the bedrock nature, permeability, flow, etc. The middle zone of the Narmada basin's sub-watersheds has undergone effective morphometric investigation utilizing a RS & GIS approach. The sub-watersheds were observed. Demonstrate the stream length ratio & dendritic drainage pattern changes that may affect topography and slope. The bifurcation's values might vary. The ratio between the sub-watersheds is responsible for the variation in geometric & topography growth. The river frequencies for sub-watersheds of the research area show an association having values of drainage density favorable to stream population growth in relation to rising drainage density. The sub-watershed drainage patterns show very course-to-course texture. The Baghora Nala sub-watershed is circular, as seen by the elongation ratio, whereas the remaining values suggest an elongated pattern. Sub-watershed relief features show a mild to moderate slope, encouraging high infiltration & minimal runoff.

Acknowledgments

None.

Funding

None.

Conflicts of interest

The authors declare that there are no conflicts of interest.

References

1. Clarke JI. Morphometry from maps. Essays in geomorphology. Elsevier Publ. Co., New York. 1966;8(1):235–274.
2. Abrahams A. Channel networks a geomorphological perspective. *Water Res Res*. 1984;20(2):161–188.
3. Leopold LB, Maddock T. The hydraulic geometry of stream channels and some physiographic implications. Professional paper. 1953;252:1–57.
4. Horton R. Erosional development of streams and their drainage basins; hydro physical approach to quantitative morphology. *Geo Soc Am Bull*. 1945;56(3):275–370.
5. Horton RE. Approach toward a physical interpretation of infiltration capacity. *Soil Sci Soc Am J*. 1940;5:339–417.
6. Strahler AN. Equilibrium theory of erosional slopes approached by frequency distribution analysis. *Am J Sci*. 1950;248(10):673–696.
7. Rastogi RA, Sharma TC. Quantitative analysis of drainage basin characteristics. *J Soil Water Conserv India*. 1976;26:18–25.
8. Kumar A, Jayappa KS, Deepika B. Prioritization of sub–basins based on geomorphology and morphometric analysis using remote sensing and geographic information system (GIS) techniques. *Geocarto Int*. 2011;26(7):1–24.
9. Chow VT, Maidment DR, Mays LW. *Hand book of applied hydrology: a compendium of water resource technology*. Mc Graw–Hill Book. Co. New York. 1964.
10. Strahler AN. Quantitative analysis of watershed geometry. *Trans Am Geophys Union*. 1957;38(6):913–920.
11. Vijith. GIS based morphometric analysis of two major upland sub–watersheds of Meenachil River in Kerala. *J India Soc Remote Sensing*. 2006;34(2):181–185.
12. Swamy SL, Darro HR, Mishra AL, et al. Carbon stock dynamics in a disturbed tropical forest ecosystem of Central India: strategies for achieving carbon neutrality. *Ecol Indicat*. 2023;154.
13. Thakur TK, Dutta J, Bijalwan A, et al. Evaluation of decadal land degradation dynamics in old coal–mines of Central India. *Land Degrad Develop*. 2022.
14. Thakur TK, Kripogu KK, Thakur A, et al. Disentangling forest dynamics for litter biomass production in biosphere reserve of Central India. *Front Env Sci*. 2022;10:940614.
15. Thakur TK, Dutta J, Upadhyay P, et al. Assessment of land degradation and restoration in coal mines of central India: a time series analysis. *Ecol Eng*. 2022;175:106493.
16. Srivastava A, Garg RD, Arrawatia, ML. Morphometric analysis of a watershed in northern India using remote sensing and GIS techniques. *Environ Monitor Assess*. 2008;136(1–3):469–480.
17. Barya M, Kumar A, Thakur T. Utilization of constructed wetland for the removal of heavy metal through fly ash bricks manufactured using harvested plant biomass. *Ecohydrology*. 2022;15(5):e2424.
18. Rawat S, Khanduri VP, et al. Variation in carbon stock and soil properties in different Quercus leuco trichophora forests of Garhwal Himalaya. *Catena*. 2022;213(1):106210.
19. Thakur TK. Diversity, composition and structure of under storey vegetation in the tropical forest of Achanakmaar biosphere reserve, India. *Environ Sustain*. 2018;1(2):279–293.
20. Moniruzzaman M, Hassan QK, Hossain MA, et al. Assessment of water quality parameters using water quality index in the Buriganga River, Bangladesh: a study based on principal component analysis. *Environ Earth Sci*. 2018;77(1):12.
21. Sreedevi PD, Sudheer KP, Chaubey I, et al. Watershed–scale hydrologic and water quality models: a review. *J Am Water Res Assoc*. 2013;49(2):451–476.
22. Rai PK, Chandel RS, Mishra VN, et al. Hydrological inferences through morphometric analysis of lower Kosi river basin of India for water resource management based on remote sensing data. *Appl Water Sci*. 2018;8(1):1–16.
23. Hajam RA, Hamid A, Bhat S. Application of morphometric analysis for geo–hydrological studies using geo–spatial technology –a case study of vishav drainage basin. *Hydrol Current Res*. 2013;4(3):157.
24. Magesh NS, Chandrasekar N, Soundranayagam JP. Morphometric evaluation of Papanasam and Manimuthar watersheds, parts of Western Ghats, Tirunelveli district, Tamil Nadu, India: a GIS approach. *Environ Earth Sci*. 2011;64(2):373–381.
25. Pareta K, Pareta U. Quantitative morphometric analysis of a watershed of Yamuna basin, India using ASTER (DEM) data and GIS. *Int J Geomat Geosci*. 2011;2(1):248–269.
26. DSCWM Guideline on landslide treatment and mitigation. Department of soil conservation and watershed management. 2016.
27. Zhuang JQ, Peng JB. A coupled slope cutting- a prolonged rainfall–induced loess landslide: a 17 October 2011 case study. *Bull Eng Geol Environ*. 2014;73:997–1011.

28. Zhang S, Pei X, Wang S, et al. Centrifuge model testing of loess landslides induced by excavation in northwest China. *Int J Geo Mech*. 2020;20(4):1–18.
29. Xu X, Xing Y, Guo Z, et al. Stability analysis of rainfall–triggered toe–cut slopes and effectiveness evaluation of pile–anchor structures. *J Earth Sci*. 2021;32(5):1104–1112.
30. Dutta J, Zaman S, Thakur TK, et al. Assessment of the bioaccumulation pattern of Pb, Cd, Cr and Hg in edible fishes of East Kolkata wetlands, India. *Saudi J Biol Sci*. 2022;29(2):758–756.
31. Kim, SW, Chun KW, Kim M, et al. Effect of antecedent rainfall conditions and their variations on shallow landslide–triggering rainfall thresholds in South Korea. *Landslides*. 2021;18(7):569–582.
32. Delaney KB, Evans SG. Rockslide dams in the northwest Himalayas (Pakistan, India) and the adjacent Pamir mountains (Afghanistan, Tajikistan), central Asia. *Lecture Note Earth Sci*. 2011;133:205–242.
33. Costa JE, Schuster RL. The formation and failure of natural dams. *Geol Soc Am Bull*. 1988;100(7):10541068.
34. Chen Y, Zhou C, Zheng H. A numerical solution to seepage problems with complex drainage systems. *Comp Geotech*. 2008;35(3):383–393.
35. Javed A, Khanday M, Ahmad R. Prioritization of sub–watersheds based on morphometric and land use analysis in Guna district (m.p.): a remote sensing and GIS based approach. *J Indian Soc Remote Sens*. 2009;37:261–274.
36. Pankaj A, Kumar P. GIS based morphometric analysis of five major sub–watershed of Song River, Dehradun district, Uttarakhand with special reference to landslide incidences. *J India Soc Remote Sens*. 2009;37:157–166.
37. Sreedevi PD, Owais S, Khan HH, et al. Morphometric analysis of a watershed of South India using SRTM data and GIS. *J Geol Soc India*. 2009;73(4):543–552.
38. Mesa LM. Morphometric analysis of a subtropical Andean basin (Tucumán, Argentina). *Environ Geol*. 2006;50(8):1235–1242.
39. Thakur T, Swamy SL, Thakur A, et al. Land cover changes and carbon dynamics in Central India's dry tropical forests: a 25–year assessment and nature–based eco–restoration approaches. *J Environ Manag*. 2024;351:119809.
40. Thakur TK, Patel DK, Dutta J, et al. Assessment of decadal land use dynamics of upper catchment area of Narmada River, the lifeline of Central India. *J King Saud Univ Sci*. 2021;33:101322.
41. Martz L, Garbecht J. Numerical definition of drainage network and sub catchment areas from digital elevation models. *Comp Geosci*. 1992;18:747–761.
42. Moore ID, Grayson RB, Ladson AR. Digital terrain modelling: a review of hydrological, geomorphological, and biological applications. *Hydrol Process*. 1991;5:3–30.
43. Bhagwat TN, Shetty A, Hegde VS. Spatial variation in drainage characteristics and geomorphic instantaneous unit hydrograph (GIUH); implications for watershed management–a case study of the Varada River basin, Northern Karnataka. *Catena*. 2011;87(1):52–59.
44. Ozdemir H, Bird D. Evaluation of morphometric parameters of drainage networks derived from topographic maps and DEM in point of floods. *Environ Geol*. 2009;56:1405–1415.
45. Rinaldo A, Rodriguez–Iturbe I, Rigon R. Channel networks. Jeanloz R, Albee AL, Burke KC (eds). Annual review of earth and planetary sciences. *Annual Rev*. 1998;26:289–327.
46. Tarboton DG, Bras RL, Rodriguez-Iturbe I. On the extraction of channel networks from digital elevation data. *Hydrol Process*. 1991;5(1):81–100.
47. Maidment DR. *Arc Hydro: GIS for water resources*. ESRI Press, Redlands. 2002:220–225.
48. Strahler AN. *Quantitative geomorphology of drainage basins and channel networks*. In: V.T. Chow (Ed.), Handbook of Applied Hydrology. McGraw-Hill, New York. 1964:4.39–4.76.
49. Tarboton DG, Baker ME. *Towards an algebra for terrain-based flow analysis.* In representing, modeling and visualizing the natural environment: innovations in GIS 13, Edited by N. J. Mount, G. L. Harvey, P. Aplin and G. Priestnall, CRC Press, Florida. 2008.
50. Wilson PJ, Gallant JC. *Digital terrain analysis*. In: Wilson P.J. and Gallant J.C., Eds., Terrain Analysis: Principles and Applications, John Wiley and Sons, New York. 2000:1–27.
51. Rudraiah M, Govindaiah S, Vittala SS. Morphometry using remote sensing and GIS techniques in the sub-basins of Kagna River basin, Gulburga district, Karnataka, India. *J Ind Soc Rem Sen*. 2008;36:351–360.
52. Chopra R, Dhiman RD, Sharma PK. Morphometric analysis of sub-watersheds in Gurdaspur District, Punjab using remote sensing and GIS techniques. *J Ind Soc Rem Sen*. 2005;33:531–539.
53. Vittala S, Govindaiah S, Honne GH. Morphometric analysis of sub-watersheds in the Pavagada area of Tumkur district, South India using remote sensing and GIS techniques. *J Ind Soc Rem Sen*. 2004;32(4):351–362.
54. Singh S, Singh MC. Morphometric analysis of Kanhar River basin. *Nat Geosci J Indian*. 1997;43(1):31–43.
55. Schumm SA. Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. *Geo Soc Am Bull*. 1956;67(5):597–646.
56. Magesh NS, Chandrasekhar N. GIS model-based morphometric evaluation of Tamiraparani subbasin, Tirunelveli district, Tamil Nadu, India. *Arab J Geosci*. 2014;7:131–141.
57. Horton RE. Drainage basin characteristics. *Eco Trans Am Geophys Union*. 1932;13(1):350–361.
58. Smith KG. Standards for Grading Textures of Erosional Topography. *Am J Science*. 1950;248(9):655–668.
59. Anbarasu S, Brindha K, Elango L. Multi-influencing factor method for delineation of groundwater potential zones using remote sensing and GIS techniques in the western part of Perambalur district, southern India. *Earth Sci Inform*. 2020;13:317–332.
60. Altaf S, Meraj G, Romshoo SA. Morphometry and land cover based multi-criteria analysis for assessing the soil erosion susceptibility of the western Himalayan watershed. *Environ Monit Assess*. 2014;186(12):8391–8412.
61. Gottschalk LC. *Reservoir sedimentation*. In: Chow, VT, Ed, Handbook of Applied Hydrology. 1964; McGraw Hill Book Company, New York.
62. NRSA. *Integrated Mission for Sustainable Development (IMSD)*- Technical guidelines. National Remote Sensing Agency, Hyderabad 1995.
63. Obi-Reddy GP, Maji AK, Gajbhiye KS. Drainage morphometry and its influence on landform characteristics in a basaltic terrain, Central India—a remote sensing and GIS approach. *Int J Appl Earth Obs Geoinfo*. 2004;6(1):1–16.
64. Joji VS, Nair SK. Terrain characteristics and longitudinal, land use and land cover profiles behaviour- a case study from Vamanapuram river basin, southern Kerala, India. *Arab J Geosci*. 2014;7:1351–1361.

Citation: Patel DK, Karuppannan S, Sao A, et al. Prioritization of sub-watersheds based on quantitative morphometric analysis of the Narmada River, India, using SRTM-DEM and GIS techniques. *Biodiversity Int J*. 2024;7(1):22–33. DOI: 10.15406/bij.2024.07.00208