



Morphometric Characterization and Hydrological Dynamics of the Dzuza, Dhansiri and Khova Watersheds in Nagaland, India: Implications for Sustainable Management

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ABSTRACT

Background: Morphometry is the quantitative assessment and mathematical analysis of landforms, essential for understanding watershed dynamics. The Dzuza, Dhansiri and Khova river basins in Nagaland, India, were analysed to comprehend their shape, drainage network and ecological importance. These watersheds are crucial for the sustainable management of water and land resources, particularly considering Nagaland's diverse topography and hydrological circumstances.

Methods: A field-laboratory study was performed utilising GIS and remote sensing technologies. Digital Elevation Model (DEM) data were acquired and analysed utilising ArcGIS 10.5 software to identify watersheds and calculate morphometric characteristics including drainage density, stream frequency, relief and slope. The data were examined to clarify the linear, relief and aerial characteristics of the three basins.

Result: Dzuza Basin, a sixth-order system with 2815 m elevation and 6.44 ruggedness, is prone to erosion. Dhansiri, a seventh-order basin with a 4116.50-km stream network, has a complex drainage pattern, while the smaller Khova Basin also has distinct hydrological characteristics. High drainage densities (2.29-2.43 km/km²) suggest runoff potential, but north/northeast-facing slopes usually retain rainfall. Sustainable management requires customised watershed methods for erosion mitigation in Dzuza, water retention in Dhansiri and integrated soil-water conservation in Khova.

Key words: ArcGIS, DEM, Drainage network, Morphometry, Sustainable.

INTRODUCTION

Watersheds are defined as geographical regions that gather and channel water to a shared outlet, such as a river or lake. They serve a pivotal function in environmental planning and management. By comprehending their hydrological dynamics across time and various places, we may formulate efficient policies for natural resource conservation. Participatory watershed development has emerged as a compelling strategy for rural development in recent decades (Gor *et al.*, 2022). Every watershed necessitates a localized study to guide suitable management strategies. Clarke (1996) asserted that morphometry is an essential instrument for delineating watershed drainage and comprehending hydrological processes *via* quantitative assessments. The advancement of Geographic Information Systems (GIS) and Remote Sensing (RS) technologies has transformed watershed studies, enabling more precise evaluations of morphometric attributes (Kumar *et al.*, 2020). These tools enable researchers to replicate topographical diversity, drainage patterns and water flow with enhanced accuracy (Gaur *et al.*, 2019). This study seeks to address this gap by performing a comprehensive morphometric analysis of the three watersheds (Dzuza, Dhansiri and Khova) utilizing GIS and RS. This investigation will assess the impact of regional topography on hydrological dynamics and offer insights for future watershed planning and management. The literature

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review emphasizes significant research that has influenced our comprehension of morphometry and watershed dynamics. Horton (1945) and Strahler (1964) established the foundational principles for morphometric research by delineating critical parameters, including stream order and bifurcation ratio. The incorporation of GIS and RS in watershed studies has facilitated more precise and comprehensive analysis (Aher *et al.*, 2010; Grohmann, 2004; Sreedevi *et al.*, 2009; Kusre, 2016 and Singh, 1994). Numerous studies have been conducted in India by

authors such as Aparna *et al.* (2015); Javed *et al.* (2009); and Magesh *et al.* (2012) these studies present information regarding the various hydrological and topographical conditions of India. Very recently, the typical features of Northeast India were studied by Kusre, (2016) and Kichu *et al.* (2022). Such studies have characterized the region as one whose rugged topography offers the challenge of establishing monitoring stations and acquiring hydrological data while the case of the state of Nagaland is much less represented. Categorizing the works thematically will provide us with a deeper knowledge of the evolution of watershed research and the usefulness of applying the methodologies to the specific characteristics of the Dzuza, Dhansiri and Khova watersheds. In this research work, the technologies of RS and GIS are implemented to calculate morphometric properties like drainage density, slope and relief. These technologies provide the complex Digital Elevation Models (DEMs) that are needed to have a proper knowledge of the hydrological and topographical behavior of the watersheds. It is imperative to employ them to build personalized management strategies to preserve the diversity of species, to stop erosion and to enhance the quality of the watersheds.

MATERIALS AND METHODS

Study area

This study was conducted at the Department of Agricultural Engineering and Technology, School of Engineering and Technology, Nagaland University, with research carried out in the year 2024. The study area is located in Nagaland,

India, at coordinates 26.1584°N, 94.5624°E, with an area of 16,579 km². Fig 1 shows the study area of the research region. Nagaland is primarily agricultural, with the majority of cultivation occurring on mountainous terrain and dependent on rain-fed irrigation systems. The region receives an average annual precipitation of about 2,500 mm, with peak rainfall in June and July and minimal rainfall in December and January (Kichu *et al.*, 2022). The varied precipitation patterns and the region's undulating topography profoundly influence hydrological dynamics, rendering proper watershed management essential. The Kohima and Dimapur districts within the Dzuza River drainage basin have an area of approximately 349.647 km². Water from the watershed is essential for supplying potable and irrigation water to the nearby towns that rely on it for domestic and agricultural usage. Conversely, some areas of the Dhansiri River basin were positioned by the Peren and Dimapur districts as part of further complicating the hydrological framework of this entire region. It can be considered a vital hydrological resource that impacts the ecological well-being of the region and contributes to the water supply. The Khova basin has an area of approximately 110.45 km². It falls under the watershed of Dhansiri. In all these regards, a deeper understanding of the entire watersheds' dynamics is needed, mainly due to the special topography and hydrology of Nagaland, more precisely in the Dzuza, Dhansiri and Khova basins.

Sources and processing of data

Digital Elevation Model (DEM) data were obtained from the United States Geological Survey (USGS) website <https://>

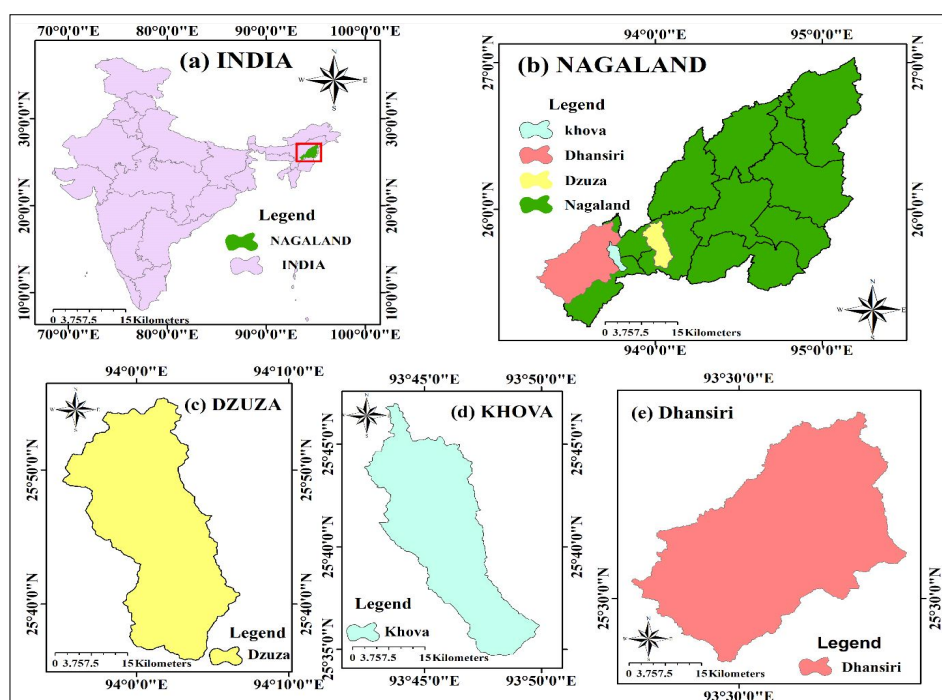


Fig 1: (a) Location of Nagaland of in India map (b) Dzuza, Dhansiri and khova watershed boundaries in Nagaland map (c) Dzuza basin, (d) Khova bain, (e) Dhansiri basiin.

earthexplorer.usgs.gov/ with a spatial resolution of 30 meters. ArcGIS 10.5 software was employed to delineate the watersheds and compute morphometric characteristics. DEM of the study areas are presented in Fig 2. The DEM obtained from the Shuttle Radar Topographic Mission (SRTM) was employed for simulations. Table 1 shows the formulas employed for morphometric analysis. Following the technique established by Torre Franca *et al.* 2024, the analysis encompassed comprehensive procedures for quantifying linear, relief and aerial characteristics of the watersheds. The DEM was utilized to identify watersheds, calculate flow accumulation and create stream networks and connections depending on elevation.

RESULTS AND DISCUSSION

Aspect and slope of the basin

The slope analysis of the Dzuza, Khova and Dhansiri Basins reveals unique topographical features in each location. In the Dzuza Basin, slope values vary from 0 to

247% [Fig 3 (a)], with mild slopes (0-15%) predominating in the northern and center regions, signifying elevated erosion potential and swift surface runoff in these places. Aspect analysis of the three basins yields information about their directional slope attributes. The Dzuza Basin features predominantly north and northeast-facing hills as shown in Fig 3 (b), which facilitate moisture retention and promote thicker vegetation owing to moderate solar exposure. Southeast and southwest-facing inclines receive increased sunshine, resulting in elevated evaporation and arid conditions. There are also flat regions with no distinct characteristics (-1°), indicating level terrain with negligible runoff effects. Fig 4 (b) shows the Khova Basin's aspect map, the basin predominantly features north and northeast-facing slopes, which facilitate vegetation development and moisture retention. Southeast and west-facing slopes are dispersed throughout, presumably receiving greater solar exposure and heightened evaporation. Flat zones are also observed, contributing to places with diminished runoff impact. The Dhansiri Basin exhibits a comparable pattern

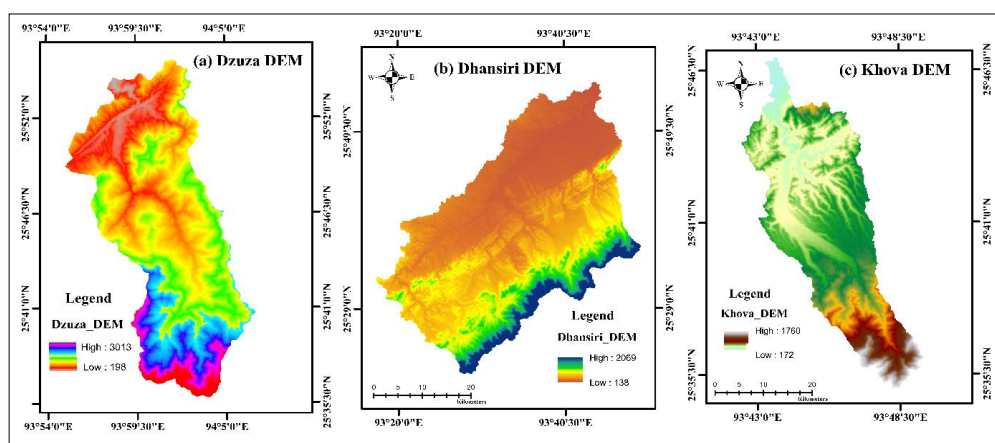


Fig 2: (a) DEM of Dzuza basin (b) DEM of Dhansiri basin (c) DEM of Khova basin.

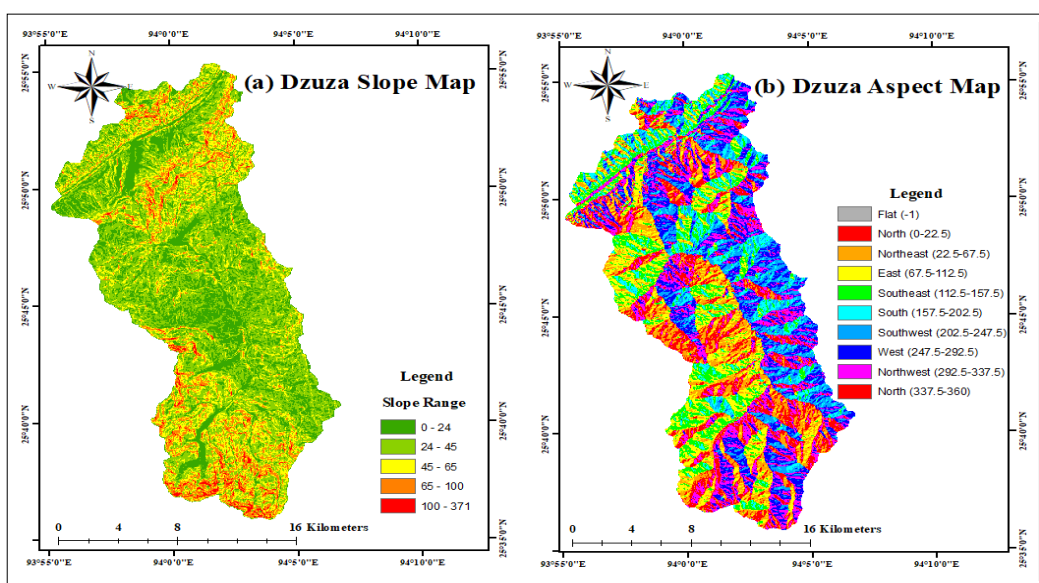


Fig 3: (a) Slope map of Dzuza basin (b) aspect map of Dzuza basin.

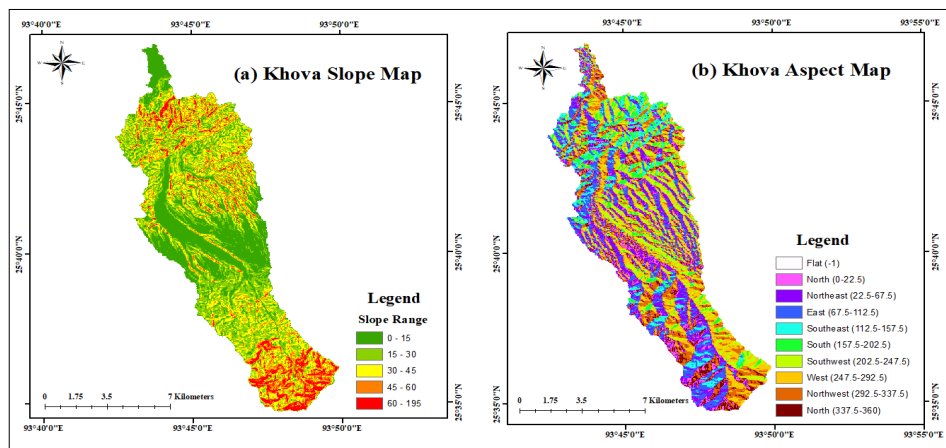
Table 1: Methods of calculation of different Morphometric parameters.

Morphometric parameters	Methods	References
Linear aspects		
Stream order (U)	Hierarchical order	Strahler (1964)
Stream length (Lu)	Length of the stream	Horton (1945)
Mean stream length (Lsm)	$Lsm = Lu/Nu$, Where Lu = Stream length of order. "U" Nu = Total number of stream segments of order "U".	Horton (1945)
Stream length ratio (RI)	$RI = Lu/Lu-1$ Where Lu = Total Stream length of order "U". Lu-1 = Stream length of next lower order.	Horton (1945)
Bifurcation ratio (Rb)	$Rb = Nu/Nu + 1$ Where Nu = Total Number of stream segments of order. UNu + 1 = Number of stream segments of next higher order.	Schumm (1956)
Relief aspects		
Basin relief (Bh)	Basin relief is the vertical distance between the lowest and highest points of the watershed.	Schumm (1956)
Relief ratio (Rh)	$Rh = Bh/Lb$ Where Bh = Basin relief. Lb = Basin length.	Schumm (1956)
Ruggedness number (Rn)	$Rn = Bh \times Dd$. Where Bh = Basin relief. Dd = Drainage density.	Schumm (1956)
Height of basin mouth (z), m	GIS analysis/DEM	
Maximum height of the basin (Z), m	GIS analysis/DEM	
Total basin relief (H), m	$H = Z - z$	Strahler (1952)
Relative relief ratio (Rhp)	$Rhp = H \times 100/P$	Melton (1957)
Gradient ratio (Rg)	$Rg = (Z - z)/Lb$	Sreedevi <i>et al.</i> (2005)
Melton ruggedness number (MRn)	$MRn = H/A0.5$	Melton (1957)
Aerial aspects		
Drainage density (Dd)	$Dd = L/A$, Where L = Total length of streams. A = Area of watershed.	Horton (1945)
Stream frequency (Fs)	$Fs = N/A$ Where N = Total number of streams. A = Area of watershed.	Horton (1945)
Drainage texture (T)	$T = Fs \times Dd$ Where Fs = Stream frequency. Dd = Drainage density.	Horton (1945)
Form factor (Rf)	$Rf = A/(Lb)^2$ Where A = Area of watershed. Lb = Basin Length	Horton (1945)

Table 1: Continue...

Table 1: Continue...

Circularity ratio (R_c)	$R_c = 4\pi A/P^2$, Where A = Area of watershed. P = Perimeter of watershed; $\pi = 3.14$.	Miller (1953)
Elongation ratio (R_e)	$R_e = 2\sqrt{A/\pi}/L_b$ Where A = Area of watershed. L_b = Basin Length. $\pi = 3.14$	Schumm (1956)
Length of overland flow (L_{of})	$L_{of} = 1/2D_d$. Where D_d = Drainage density.	Horton (1945)
Constant channel maintenance (C)	$C = 1/D_d$ Where D_d = Drainage density.	Horton (1945)
Infiltration number (I_f)	$I_f = F_s \times D_d$	Faniran (1968)
Basin area (A), km ²	GIS software analysis	Schumm (1956)
Basin perimeter (P), km	GIS software analysis	Schumm (1956)
Fitness ratio (R_f)	$R_f = C/I/P$	Melton (1957)

**Fig 4:** (a) Slope map of Khova basin (b) aspect map of Khova basin.

(Fig 5b), characterized by predominantly north and northeast-facing slopes, signifying regions with extended moisture retention. South and southwest-facing slopes exist but are more restricted, indicating areas with greater solar exposure and enhanced evaporation. Level regions are also dispersed throughout the basin. The Dzuza, Khova and Dhansiri Basins exhibit distinct topographical variations, with the Dhansiri Basin presenting the steepest gradients and the biggest potential for erosion threats. All three basins predominantly exhibit north and northeast orientations, which enhance moisture retention and vegetation proliferation, significantly influencing the hydrological and ecological dynamics within these areas.

Linear aspects

The linear characteristics of the Dzuza, Khova and Dhansiri basins were evaluated using stream order, stream length,

mean stream length, stream length ratio and bifurcation ratio. Fig 6 indicates that the Dzuza basin is categorized as a 6th-order stream system, predominantly comprising first-order streams, accompanied by 248 second-order streams and 53 third-order streams. Table 3 is a comparative overview of the morphometric properties, hydrological behavior, and management implications of the Dzuza, Dhansiri, and Khova Basins. From Table 2, we can see that the Dhansiri basin exhibits a more elaborate drainage network with a stream order of 7, signifying more complex hydrological circumstances. The Khova basin contains 309 first-order streams, indicating a lower stream order and a less complex drainage system. The Dzuza basin has a total stream length of 799.58 km, the Dhansiri basin has a considerably bigger stream length of 4116.50 km and the Khova basin has a total stream length of 266.22 km. These changes signify disparities in the hydrological capacity of

each basin. Mean stream lengths yield more insights: 0.67 km for Khova, 0.64 km for Dhansiri and 0.58 km for Dzuza. This indicates that the Dzuza basin can have a higher potential for erosion and runoff due to the shorter mean stream lengths that lead to increased surface runoff and

less infiltration possibilities (Horton, 1945). The stream length ratio is highly informative about drainage effectiveness. The mean bifurcation ratios of the Dzuza, Dhansiri and Khova basins were 4.31, 4.19 and 4.19 respectively these are normal signs of fairly regular

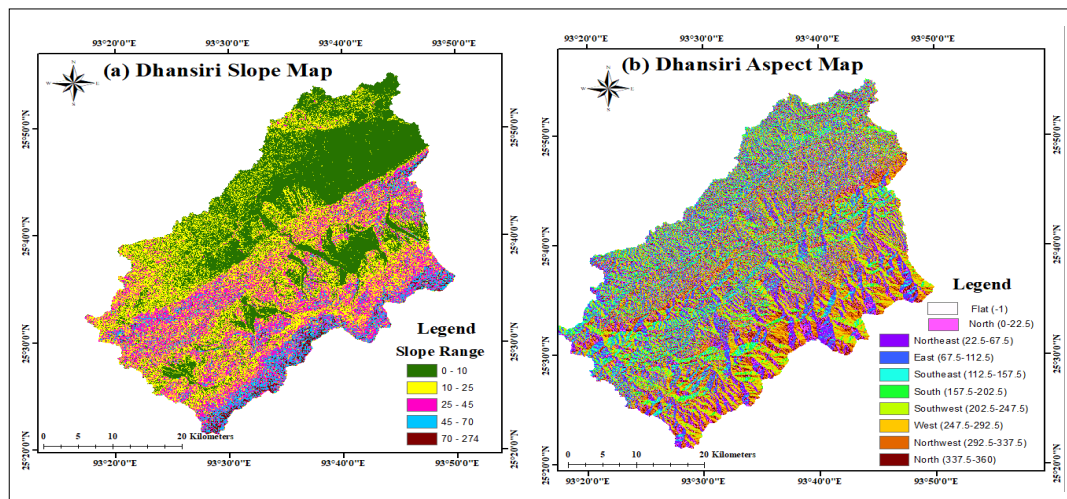


Fig 5: (a) Slope map of Dhansiri basin (b) aspect map of Dhansiri basin.

Table 2: Results of the morphometric parameters of the study areas.

Morphometric parameters	Dzuza	Dhansiri	Khova
Linear aspects			
Stream order (U)	1-6	1-7	1-5
Stream length (Lu), km	799.58	4116.50	266.22
Mean stream length (Lsm)	0.58	0.64	0.67
Stream length ratio (RI)	2.18	1.99	2.12
Bifurcation ratio (Rb)	4.31	4.19	4.19
Relief aspects			
Basin relief (Bh), m	2815.0	1931	1600
Relief ratio (Rh)	0.079	0.028	0.067
Ruggedness number (Rn)	6.44	4.69	3.86
Height of basin mouth (z), m	198.0	138	167
Maximum height of the basin (Z), m	3013	2069	1767
Total basin relief (H), m	2815	1931	1600
Relative relief ratio (Rhp)	2.57	0.76	2.29
Gradient ratio (Rg)	0.079	0.028	0.067
Melton ruggedness number (MRn)	150.54	46.89	152.24
Aerial aspects			
Drainage density (Dd)	2.29	2.43	2.41
Stream frequency (Fs)	3.94	3.79	3.59
Drainage texture (T)	12.57	25.39	5.67
Form factor (Rf)	0.34	0.36	0.19
Circularity ratio (Rc)	0.6	0.33	0.28
Elongation ratio (Re)	0.59	0.67	0.49
Length of pverland flow (Lof)	0.219	0.21	0.21
Constant channel maintenance (C)	0.44	0.41	0.41
Infiltration number (If)	9.01	9.22	8.66
Basin area (A), km ²	349.65	1696.01	110.45
Basin perimeter (P), km	109.6	253.83	69.97
Fitness ratio (Rf)	0.43	0.44	0.43

drainage systems with little structural disruption. The minor differences can be due to the variability of geological or hydrological conditions. Bifurcation ratios tend to indicate the intensity of the effect of the underlying geology; lower ratios are a sign of greater conditions of regularity, while increased ratios can signal tectonic activity or altered drainage systems (Strahler, 1964).

Relief aspects

The relief analysis of the Dzuza, Dhansiri and Khova basins indicates that Dzuza is the highest relief basin (2815 m), the highest number of ruggedness (6.44), the highest relief

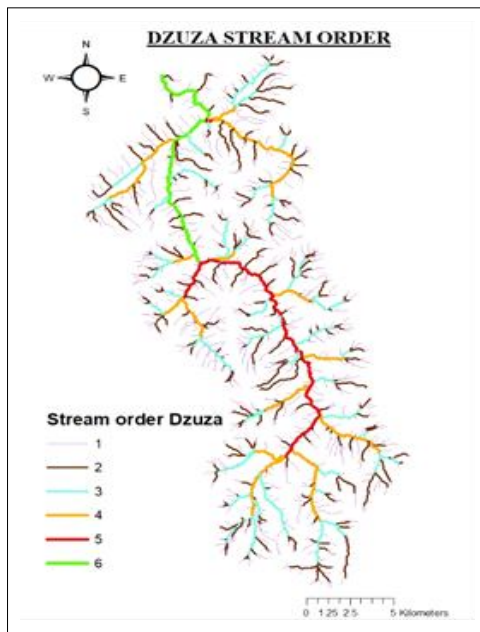


Fig 6: Stream order map of the Dzuza basin.

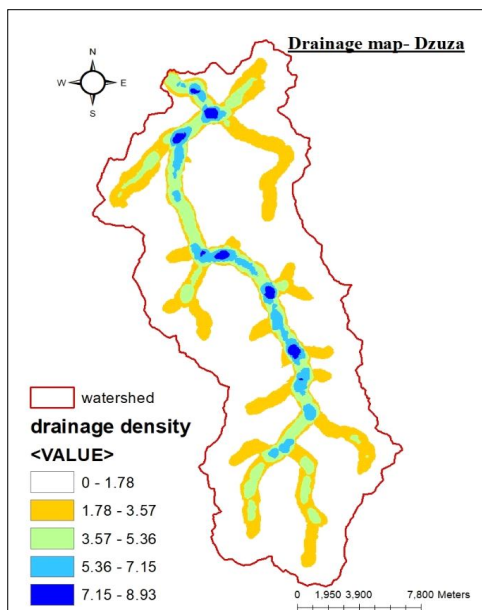


Fig 7: Drainage density map of Dzuza basin.

Table 3: Comparative summary of morphometric characteristics, hydrological behavior and management implications for the Dzuza, Dhansiri, and Khova Basins.

Morphometric parameter	Dzuza basin	Dhansiri basin	Khova basin	Implications for management	References
Slope	Steep slopes	Moderate to steep slopes	Moderate slopes	Steep slopes require erosion control measures like terracing and vegetation.	(Strahler, 1964)
Drainage Density	High	Moderate	Low	High density suggests fast runoff, requiring water retention infrastructure.	(Horton, 1945)
Stream Frequency	High	Moderate	Low	High frequency may indicate higher erosion potential.	(Grohmann, 2004)
Circularity Ratio	Low	Moderate	Moderate	Low ratios may indicate elongated basins prone to prolonged runoff.	(Mesa, 2006)
Form Factor	Elongated	Slightly elongated	Slightly circular	Elongated basins need flood management measures like levees and buffer zones.	(Miller, 1953)
Relief Ratio	High	Moderate	Low	High relief suggests rapid runoff and higher soil erosion risk.	(Rao et al., 2011)

ratio (0.079), the highest slopes and the highest erosion potential. Dhansiri with the lower measurements (1931 m relief, 4.69 ruggedness, 0.028 relief ratio) represents less terrain with greater stability. Khova with intermediate measurements (1600 m relief, 3.86 ruggedness, 0.067 relief ratio) represents a stable intermediate terrain. Accordingly, erosion control is the priority in Dzuza, measures of water retention are the priority in Dhansiri, while a combination of soil conservation measures with measures of water conservation is the priority in the case of Khova to manage the watershed successfully.

Aerial aspects

The Dzuza, Dhansiri and Khova basins' drainage density, stream frequency, form factor and circularity ratio indicate hydrological behavior and management requirements. Dzuza, Dhansiri and Khova have dense drainage patterns with drainage density estimates of 2.29, 2.43 and 2.41 km/km² respectively that indicate less infiltration and greater potential for runoff. Dzuza's steep terrain and problematic terrain can enhance the potential for runoff, evidenced by its stream frequency measures of 3.94, 3.79 and 3.59 (Strahler, 1964). Dzuza-type elongated basins have the following form factors of 0.34, 0.36 and 0.19 that lead to less peak discharge and greater flood duration (Rao *et al.*, 2011). Dzuza with a circularity ratio of 0.6, Dhansiri with a value of 0.33 and the value of 0.28 of the Khova indicate that the circular Dzuza basin is highly vulnerable to flash floods while the elongated Dhansiri and the elongated Khova basins can manage the runoff (Fig 7). The Dzuza basin drainage density is shown to have a spatial distribution that determines erosion-prone areas and areas of high-runoff to implement soil conservation measures like terracing or vegetative barriers to managing the soil conservation and the runoff. Dzuza requires well-engineered drainage systems to curtail flash floods and erosion while Dhansiri and the elongated Khova can improve with soil conservation and retention of water (Kichu, *et al.*, 2022).

CONCLUSION

The morphometric analysis of the Dzuza, Dhansiri and Khova basins of Nagaland is imperative to provide necessary information regarding their hydrology and topography with a need to implement watershed management techniques that are tailor-made to their needs. The dynamic interaction between hydrological processes and the topographical properties was made possible by the use of GIS and remote sensing methodologies. Steep slopes with inadequate drainage conditions of the Dzuza Basin call for erosion management through the practice of terracing, vegetation cover and afforestation to preserve soil and diversity. Reservoirs, farming ponds and riparian buffer areas are necessary to retain water and manage floods within the Dhansiri Basin. Equal conservation measures like vegetative covers and gully plugs are necessary due to the medium slopes of the Khova Basin. Climate resilience

measures like rainwater harvesting and floodplain zoning are necessary to overcome the impact of the change in rain patterns and increase drainage density across all basins. Circular basins call for increased drainage systems to prevent flash flood. The present research investigates the gap in watershed management of the basins of Northeast India with a detailed approach that integrates research with conservation efforts. Active surveillance with adaptive management will support the protection of the unique biotic and hydrological properties of the basins to the next generation of humans.

Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided but do not accept any liability for any direct or indirect losses resulting from using this content.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the study's design, data collection, analysis, decision to publish, or manuscript preparation.

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