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URBAN WATERSHED MANAGEMENT IN THE DOON VALLEY: A GEOSPATIAL ASSESSMENT OF HIMALAYAN WATERSHEDS

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ABSTRACT

Understanding the watershed's topography and Land Use Land Cover (LULC) is essential for developing a watershed management policy. In this research, Digital Elevation Model (DEM) data, Survey of India (SOI) Toposheet, and multispectral satellite imagery were used to analyse Himalayan rivers (Bindal and Rispana) watersheds hydrology and topography along with LULC. The morphometric analysis approach was employed for hydrological and topographical characterization, and the supervised classification method was applied to LULC classification. This study concludes that both watersheds have low to moderate relief and dendritic drainage patterns with elongated shapes. Also, compared to the Bindal watershed, whose relief ratio value is 26.59 and has a compactness coefficient value (1.92), the Rispana watershed has a higher relief ratio (69.84) and a higher compactness coefficient value (2.42), respectively, making it more susceptible to erosion and landslides. Further, based on the LULC classification, the Built-up class is the second dominant class in both watersheds, after the Forest class, with 40.36 % in the Bindal watershed and 26.83 % in the Rispana watershed. This increases biotic pressure may cause urban flooding, health risks, biodiversity loss, and ecosystem imbalance in both river systems. These findings address critical gaps in understanding urban watershed dynamics and offer valuable insights for sustainable resource management and policy formulation.

Keywords: Morphometric Analysis; Hydrology; Topography; LULC; Drainage Density

INTRODUCTION

Growing urbanization and climate change have worsened problems like freshwater scarcity, water stress, and ongoing pollution (Jury & Vaux, 2007; du Plessis, 2019; Grill *et al*., 2019). Rapid changes in socioeconomic and demographic patterns, along with changes in climate within nations, have had a substantial impact on riverine ecosystems, causing land cover to shift, river beds to diminish, and river morphology and topography to change (Hazarika *et al*., 2015; Russell *et al*., 2017; Kayitesi *et al*., 2022; Mani *et al*., 2023).

India is a country covered by six distinct regions of Water Resource Regions (WRR) (AISLUS, 1990). It's Himalayan rivers have greatly aided in the advancement and expansion of civilization (Singh *et al*., 2017). These rivers play a significant part in urbanization and industrialization, as evidenced by the fact that the human population is more dependent on them in many areas, including water supply, ecological services, and agricultural use (Misra, 2010). Sustainable water resource management and river preservation initiatives are crucial to maintaining the health of rivers and a steady supply of fresh water (Kumar *et al*., 2005; Afroz *et al*., 2014).

In identifying the characteristics of a watershed, the potential for groundwater, and the river's flow, morphometric analysis is required (Yadav *et al*., 2014, Choudhari *et al*., 2018; Rai *et al*., 2018). Morphometric analysis is beneficial in understanding channel geometry, patterns, bifurcation ratio, surface runoff, water discharge, compactness ratio, movement, gradient, stream orders, frequency, and length of basin (Kumar *et al*., 2012; Mani *et al*., 2022). It can also help investigate soil erosion control upstream and channel siltation problems downstream (Bewket & Teferi, 2009; Castelli *et al*., 2017). Moreover, morphometric research is among the best techniques for studying several aspects of hydrological morphology (Mahala, 2020; Shekar & Mathew, 2024).

Remote sensing and GIS are the most suitable methods for morphometric analysis, watershed delineation, and monitoring to safeguard river functionality and ecology (Patel *et al*., 2013). When paired with remote sensing data, multispectral satellite imagery from different GIS-based platforms significantly impacts natural resource management (Singh *et al*., 2012). Scholars have used GIS and remote sensing technologies to study watersheds in various terrains (Javed *et al*., 2009). Singh *et al.* (2014) found that compared to older conventional methods, the accuracy of remote sensing DEM data used for the hydrological analysis of watersheds is much greater. Bajirao *et al*. (2019) examined how GIS and remote sensing technologies may be used to analyze the hydrology and morphometry of a watershed in order to identify and address a variety of concerns at the watershed scale, such as deforestation, urbanization, drought, flood proneness. The areal, linear, and relief aspects of a watershed can be clarified through GIS and remote sensing-based morphometric analysis, which helps understand the region's hydrology, according to Mani *et al.* (2022). In their study, Garg & Anand (2022) talked about how city expansion impacts the hydrological regime of the Rispana River. Their study's findings indicated that the area may experience urban flooding as a result of urbanization and the expansion of the city.

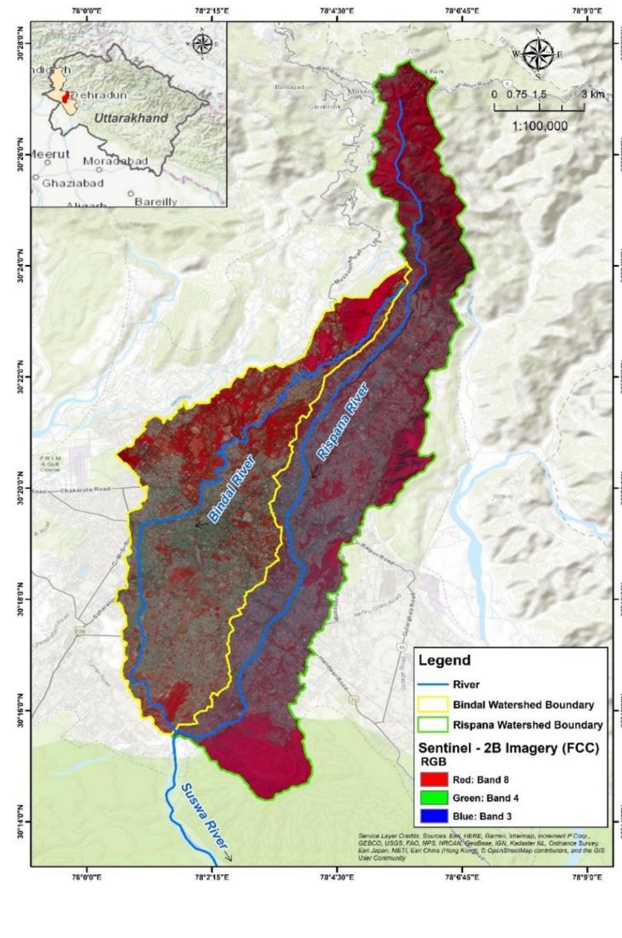
Uttarakhand was admitted to the Republic of India as a state in 2000, with Dehradun as its capital. Therefore, after 2000, there is a maximum amount of land encroachment into cities for development purposes such as housing, infrastructure, and utilities. Dehradun's population is rapidly growing, contributing to its increasing urbanization in the Indian Himalayan Region (IHR). The growing housing needs resulted in an increase in the invasion of agricultural land and forest areas for the construction of infrastructure (Agarwal *et al*., 2018). Bindal and Rispana rivers flow through the Doon Valley's Central Business District (CBD). While flowing through the region, both these rivers receive municipal sewage waste and industrial effluent. The watersheds of Bindal River and Rispana River are under stress due to improper drainage, urban flooding, urbanization, and industrialization (Garg & Anand, 2022). It could threaten the biodiversity and health of the rivers in both river systems. The study hypothesizes that the Geospatial analysis of morphometry and LULC changes can effectively identify critical areas for sustainable watershed management and ecological preservation. Therefore, the objective of this study is to analyze the morphometric characteristics, topography, and LULC dynamics of the Bindal and Rispana watersheds using geospatial techniques to enhance understanding of their hydrology and vulnerability. These scientific databases may be beneficial resources for future hydrological studies. The results of this study will also aid policymakers and decision-makers in better understanding the earth's resources.

MATERIAL AND METHOD

Study Area

The Bindal and Rispana rivers flow entirely within the Doon Valley and are the most polluted rivers (Mani *et al.*, 2023). Both rivers originate from the Lesser Himalaya. Bindal River is approximately 23 km long, while Rispana River is around 27 km long. Near Mothrowala, they eventually combine to form the 21 km-long Suswa River, which further merges with the Song River and the Ganga River (Mani *et al*., 2022). The Bindal watershed covers an area of 44.40 km^2, which has elevations ranging from 575 m to 1039 m a.s.l. and The Rispana watershed covers an area of 58.09 km^2, which has elevations ranging from 573 m to 2276 m a.s.l. Rajpur, Jakhan, Paltan Bazar, Dalanwala, Kargi, Race Course, Ajabpur Kalan, and Mothrowala are important localities of Dehradun city within both watersheds. The geographic boundaries of the study area's latitude and longitude are 30°14'N to 30°28'N and 78°01'E to 78°07'E, respectively. Alluvium and Middle Shiwalik are the geological formations of the study area (Rupke & Sharma, 1974; Mani *et al*., 2024). The Central Doon Valley region experiences an annual average rainfall of 2000mm yearly (Mani *et al*., 2022). In addition, the region's average annual temperature varies from 1°C to 44°C. Below is a map of the study area, Figure 1.

Fig. 1: The Study Area Map of Bindal and Rispana Watersheds



Data and Methods

In this study, a spatial database is developed, and several hydrological analyses are evaluated through the combined use of Digital Elevation Model (DEM) data, multispectral satellite imagery, and Survey of India (SOI) Toposheet. The topographical layers and the boundaries of the Bindal and Rispana watersheds were delineated using the Shuttle Radar Topography Mission (SRTM) data in association with the SOI Toposheet in ArcGIS desktop software version 10.6. The morphometric analysis method was used to understand the watershed's linear, areal, and relief aspects.

The Land Use Land Cover (LULC) layer was prepared using Sentinel-2B satellite imagery for 2022. ERDAS Imagine software 2016 was used to execute a conventional supervised classification technique. The overall accuracy and Kappa coefficient were calculated using the 60 training samples in the Bindal River and 75 in the Rispana River from the six LULC classes (built-up, agricultural land, forest, wasteland, dry riverbed, and waterbodies). User's accuracy, producer's accuracy, overall accuracy (OA), and kappa coefficient (k) are mentioned in Eq.1, Eq.2, Eq.3, and Eq.4 (Islami *et al*., 2022). For enhancing watershed practices, LULC is essential to accomplishing sustainable development goals (Turner *et al*., 2003). Table 1, Table 2, Table 3 and Figure 2 below provide the data source information, morphometric analysis formulas, Kappa coefficient rating criteria and methodology flowchart, respectively.

$$\textit{User's Accuracy} = \frac{\textit{Number of Correctly Classified Pixels in each Category}}{\textit{Total Number of Reference Pixels in that Category (The Row Total)}}$$

$$\textit{Producer's Accuracy} = \frac{\textit{Number of Correctly Classified Pixels in each Category}}{\textit{Total Number of Reference Pixels in that Category (The Column Total)}}$$

$$\textit{Overall Accuracy (OA)} = \frac{\textit{Total Number of Correctly Classified Pixels (Diagonal)}}{\textit{Total Number of Reference Pixels}}$$

$$\textit{Kappa Coefficient (k)} = \frac{(TS \times TCS) - \sum(\textit{Column Total} \times \textit{Row Total})}{(TS)^2 - \sum(\textit{Column Total} \times \textit{Row Total})} \times 100$$

Table 1: Data source information

S. No.	Data Type	Data Source
1	Shuttle Radar Topography Mission (SRTM) DEM data at 30m spatial resolution	United State Geological Survey (USGS) Earth Explorer https://earthexplorer.usgs.gov/
2	Sentinel – 2B imagery at 10m spatial resolution (2022)	Copernicus Data Space Ecosystem https://dataspace.copernicus.eu/
3	Toposheet No.: 53J3 at 1: 50,000 scale.	Survey of India, Govt. of India.

Table 2: Morphometric analysis formulas

S. No.	Parameter	Formula	Reference
1	Stream order (w)	*Hierarchical rank*	(Strahler, 1964)
2	Stream length (L_u)	*Length of the stream*	(Horton, 1945)
3	Stream number (Nu)	*Number of streams*	(Horton, 1945)
4	Mean stream length (L_{sm})	$L_{sm} = L_u/N_u$	(Strahler, 1964)
5	Stream length ratio (R_L)	$R_L = L_u / (L_u — 1)$	(Horton, 1945)
6	Bifurcation ration (R_b)	$(R_b) = Nu/Nu + 1$	(Schumm,1956)
7	Mean bifurcation ratio (R_{bm})	R_{bm} = *average of bifurcation ratios of all order*	(Strahler, 1957)
8	Area (A)	*Watershed Area*	(Horton, 1945)
9	Perimeter (P)	*Watershed Perimeter*	(Horton, 1945)
10	Drainage density (D_d)	$D_d = L_u/A$	(Horton, 1945)
11	Drainage Texture (T_d)	$T_d= N_u/P$	(Horton, 1945)
12	Stream frequency (F_s)	$F_s = N_u/A$	(Horton, 1945)
13	Elongation ratio (R_e)	$Re=2\sqrt{(A/\pi)}/L_b$	(Schumm, 1956)
14	Circularity ratio (R_c)	$R_c = 4 \pi A/P^2$	(Miller, 1953)
15	Form factor (F_f)	$F_f = A/L^2$	(Horton, 1945)
16	Basin Relief (R)	$R = (H) — (h)$	(Strahler, 1952)
17	Relief Ratio (Rr)	$R_r = R/L$	(Schumm, 1956)
18	Compactness Coefficient (Cc)	$Cc = 0.2821*P/ (A)0.5$	(Horton, 1945)

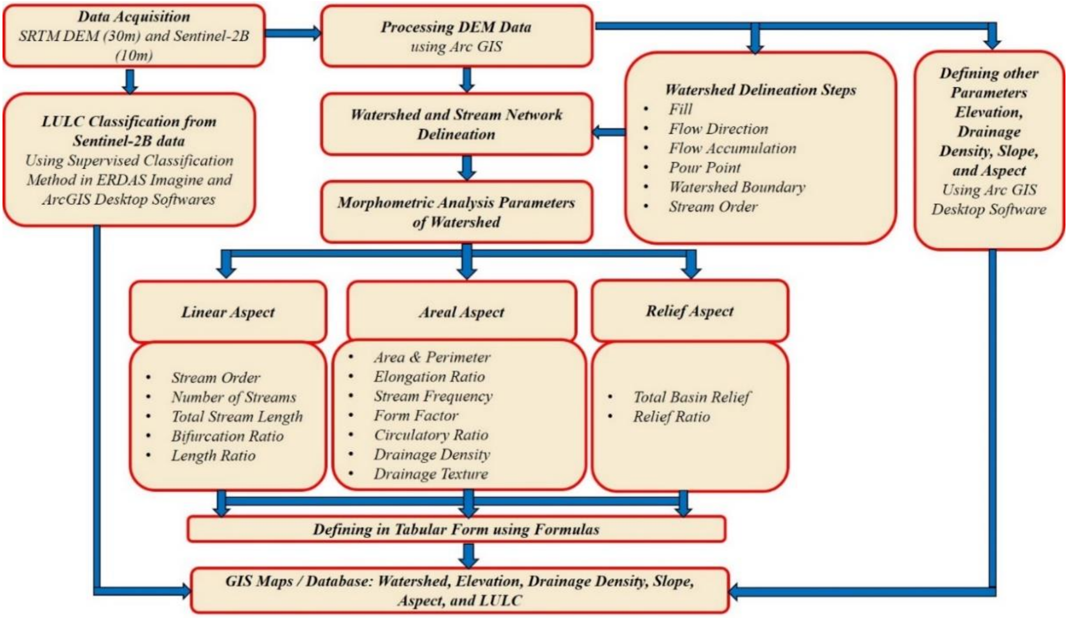
Nu: Number of Streams, Lb: Basin Length, H: Maximum height of Basin, h: Minimum height of Basin

The morphometric analysis of the Bindal and Rispana watersheds was conducted using a systematic methodology grounded in established hydrological principles and geospatial techniques (Table 2). Data acquisition involved Digital Elevation Models (DEMs), multispectral satellite imagery, and Survey of India (SOI) toposheets, which were preprocessed for georeferencing, projection setting, and watershed boundary delineation using GIS tools. Drainage networks were extracted and classified hierarchically to determine the stream order (w) as per Strahler's (1964) method. Parameters such as stream length (Lu), stream number (Nu), mean stream length (Lsm), and stream length ratio (RL) were calculated following Horton's (1945) and Strahler's (1964) formulations. Bifurcation ratio (Rb) and mean bifurcation ratio (Rbm) were derived based on the relationship between stream numbers in successive orders, as per Schumm (1956) and Strahler (1957). Areal parameters like watershed area (A) and perimeter (P) were measured, enabling the computation of drainage density (Dd), stream frequency (Fs), and drainage texture (Td) using Horton's (1945) formulas. Relief aspects, including basin relief (R) and relief ratio (Rr), were determined from the elevation difference and basin length (Schumm, 1956; Strahler, 1952). Basin shape descriptors like elongation ratio (Re), circularity ratio (Rc), form factor (Ff), and compactness coefficient (Cc) were calculated to evaluate watershed geometry using methods from Schumm (1956), Miller (1953), and Horton (1945). All calculations were integrated into GIS-based spatial analyses to generate thematic maps for drainage patterns, LULC, and morphometric parameters, providing a comprehensive visualization of the watershed dynamics. This approach facilitates a detailed understanding of hydrological behavior, highlighting urbanization impacts and aiding in sustainable watershed management.

Table 3: Kappa Coefficient rating criteria

S.No.	Kappa Coefficient	Strength of agreement
1	<0	Poor
2	0.00 – 20.00	Slight
3	20.01 – 40.00	Fair
4	40.01 – 60.00	Moderate
5	60.01 – 80.00	Substantial
6	80.01 – 100	Almost perfect

Fig. 2: Flowchart of the Methodology



Results and Discussion

Morphometric Analysis

The morphometric analysis method can comprehend the watershed's linear, areal, and relief aspects, which helps understand its hydrological characteristics (Sukristiyanti *et al*., 2018; Mani & Kumar, 2020).

Linear Aspect

The linear aspect is one-dimensional for watershed studies. It includes the bifurcation ratio, length ratio, stream order, stream length, and stream numbers. The drainage network of both watersheds follows Horton's first law, which states that as stream order increases, the number of streams within a watershed decreases (Fig. 3a & 3b). The Bindal Watershed has a stream order of 1 to 4, and the Rispana Watershed has a stream order of 1 to 5 (Fig. 4). The mean bifurcation ratio values of the Bindal and Rispana watersheds are 5.22 and 4.03, respectively (Table 4). When a surface is flat and undulating, the bifurcation ratio is 2, but in hilly or valley drainage basins, it might be 4 or 5 (Bogale, 2021). The study watersheds are highly susceptible to flooding due to the high bifurcation ratio. The bifurcation ratio justifies the various drainage patterns in the watershed (Asfaw & Workineh, 2019; Mani *et al*., 2023). The drainage pattern for the Bindal and Rispana watersheds is dendritic.

Fig. 3: Graphical Representation of Number of Streams (Nu) and Stream Order (w) for the (a) Bindal and (b) Rispana Drainage Systems

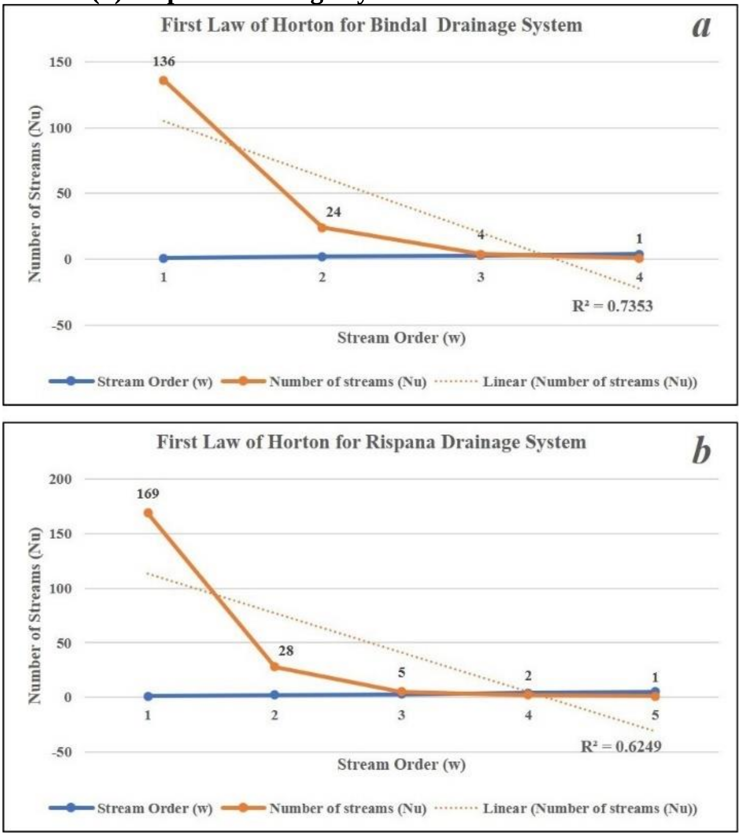


Table 4: Linear Aspects Table

Watershed	Stream Order (w)	No. of streams (Nu)	Bifurcation ratio (RbF)	Mean bifurcation ratio (Rbm)	Total length of streams (km)	Mean length of streams (km)	Length ratio (RL)
Bindal	1	136			56.39		
	2	24	5.67		42.53		0.75
	3	4	6.00	5.22	19.71	0.77	0.46
	4	1	4.00		8.31		0.42
	Total	**165**		**Total**	**126.94**		
Rispana	1	169			77.42		
	2	28	6.04		36.66		0.47
	3	5	5.60	4.03	15.37	0.75	0.42
	4	2	2.50		15.91		1.04
	5	1	2.00		8.45		0.53
	Total	**205**		**Total**	**153.81**		

Areal Aspect

The areal aspect of the Bindal and Rispana watersheds are evaluated using a two-dimensional areal aspect. These include the area, perimeter, circularity ratio, density, drainage texture, compactness coefficient, form factor, elongation ratio, and frequency of streams within the watersheds. The Bindal Watershed area and perimeter are 44.4 km^2 and 45.26 km, respectively, while the Rispana Watershed area and perimeter are 58.09 km^2 and 65.42 km, respectively (Table 5). Schumm (1956) classified the elongation ratio into four groups: elongated (<0.7), less elongated (0.8 - 0.7), oval (0.9 - 0.8), and circular (> 0.9). Both watersheds have an elongated shape, with values of 0.43 and 0.34, respectively. The study watersheds are not circular but elongated in shape, as indicated by the circularity ratio values 0.27 and 0.17. The form factor affects the intensity of the watershed's flow. The form factor values are 0.09 for Bindal Watershed and 0.15 for Rispana Watershed, which is extremely low. Lower elongation ratio, form factor, and circulation ratio values indicate less permeability, less infiltration, and more runoff potential; higher values, on the other hand, indicate more permeability, more infiltration, and less runoff potential. (Farhan & Anaba, 2016; Ali *et al*., 2017; Singh *et al.*, 2020). According to Horton (1945), there is a correlation between stream frequency and drainage density. The stream frequency values are 3.72 and 3.53 for the Bindal and Rispana watersheds, respectively. The Mean drainage density values for both watersheds are 2.86 km/km^2 and 2.65 km/km^2. Since the alluvium formation is present in the area, the drainage texture values for both watersheds are 10.62 and 9.34, respectively, indicating a fine drainage texture (Smith, 1950; Rupke & Sharma, 1974). The compactness coefficient determines the overall compactness of the watersheds. The compactness coefficient values for the Bindal and Rispana Watersheds are 1.92 and 2.42, respectively. Higher values of the compactness coefficient indicate a greater risk of erosion and landslides (Farhan *et al*., 2016). Based on a compactness coefficient comparison between the Bindal and Rispana watersheds, the Rispana Watershed is more susceptible to erosion and landslides.

Table 5: Areal Aspects Table

Watershed	**Area (km^2)**	**Perimeter (km)**	**Length (km)**	**Form factor (Ff)**	**Elongation ratio (Re)**	**Circularity ratio (Rc)**	**Drainage density (Km/km^2)**	**Stream Frequency (Fs)**	**Drainage Texture (Td)**	**Compactness Coefficient (Cc)**
Bindal	44.4	45.26	17.45	0.15	0.43	0.27	2.86	3.72	10.62	1.92
Rispana	58.09	65.42	25.1	0.09	0.34	0.17	2.65	3.53	9.34	2.42

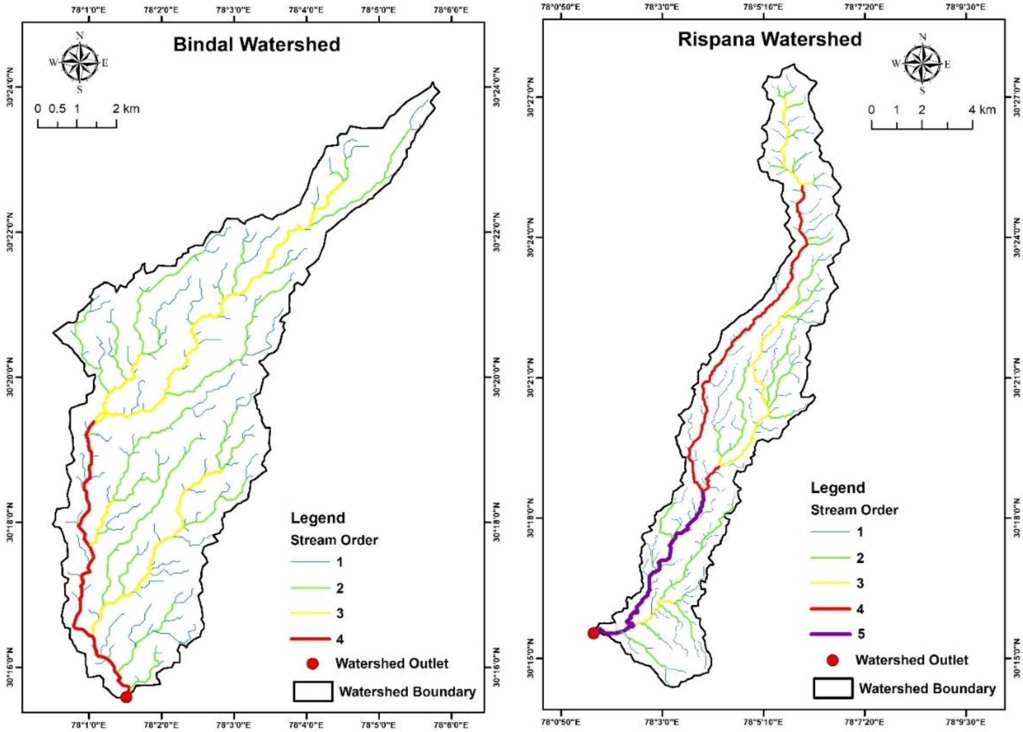
Relief Aspect

The three-dimensional aspect is a relief. The basin relief values of 464 m and 1753 m for the Bindal and Rispana watersheds, respectively, indicate a considerable elevation difference (Table 6). Bindal Watershed and Rispana Watershed have relief ratio values of 26.59 and 69.84, respectively. According to Shit *et al*. (2016), a high relief ratio value indicates that the watershed has a steep slope and is therefore vulnerable to landslides. For this study, the Rispana Watershed is susceptible to landslides and erosion.

Table 6: Relief Aspects Table

Watershed	Height of basin mouth (z) m	Maximum height of the basin (Z) m	Total basin relief (R) m	Relief ratio (Rr)
Bindal	575	1039	464	26.59
Rispana	523	2276	1753	69.84

Fig. 4: Watershed Map of Bindal and Rispana Watersheds

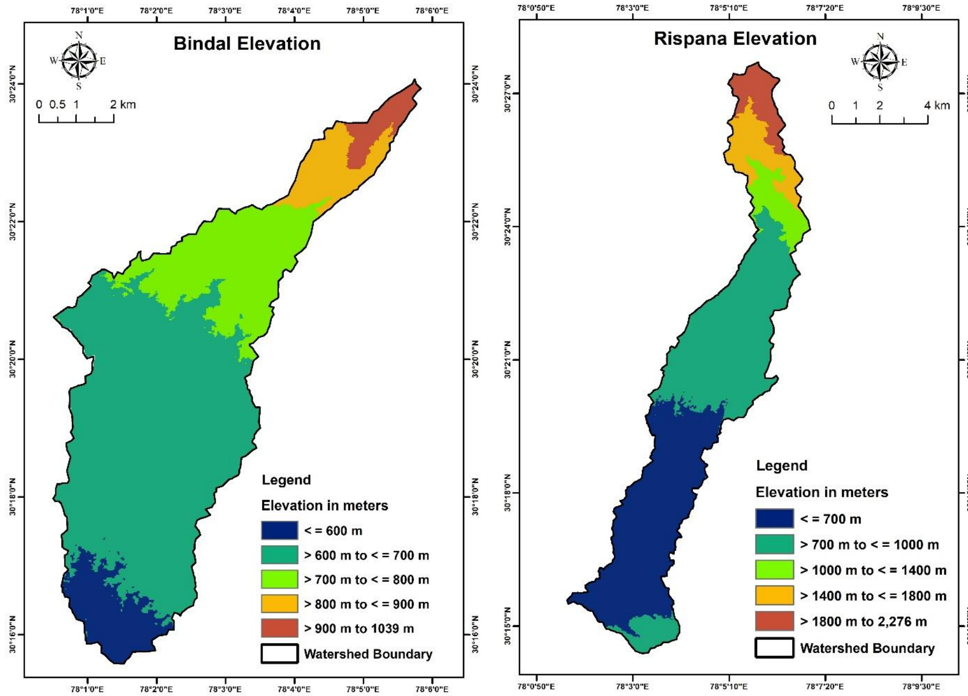


Topographical Factors

Elevation

Elevation is a topographical factor that is crucial for understanding the watershed. It is a crucial component of watershed study and is necessary to understand how environmental shifts will impact hydrology processes and manage water resources. There are five classifications for the Elevation of Bindal and Rispana watersheds (Fig. 5). For Bindal watershed, Class 1: (<= 600 m), Class 2: (> 600 m to < = 700 m), Class 3: (> 700 m to < = 800 m), Class 4: (> 800 m to < = 900 m), and Class 5: (> 900 m to 1039 m). For Rispana Watershed, Class 1: (<= 700 m), Class 2: (> 700 m to < = 1000 m), Class 3: (> 1000 m to < = 1400 m), Class 4: (> 1400 m to < = 1800 m), and Class 5: (> 1800 m to 2276 m). Both rivers flow through the valley region of Dehradun city because most of the watershed area is at a lesser elevation than 1000 meters. Analyzing elevation data is essential for describing an area's topography and understanding how it impacts water availability, flow, and storage (Singh *et al*., 2014). As the elevation increases, the probability of landslide occurrence increases (Addis, 2024). On Comparing the Bindal and Rispana watersheds based on elevation, the Rispana Watershed is at more risk of erosion and landslides.

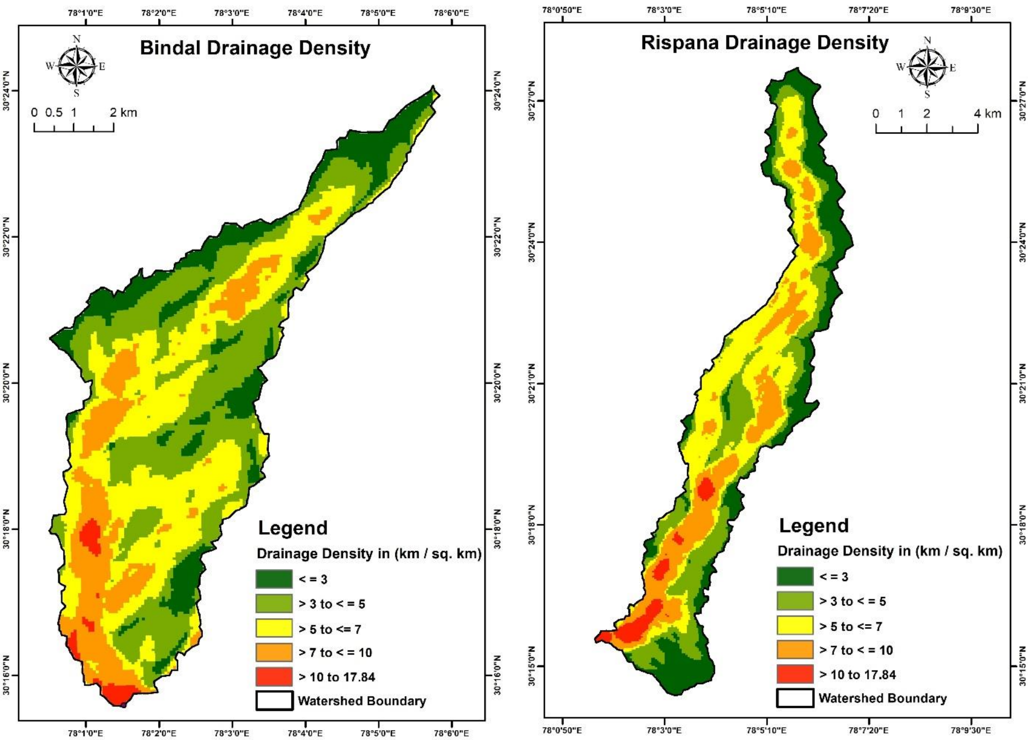
Fig. 5: Elevation Map of Bindal and Rispana Watersheds



Drainage Density

The drainage density is a crucial feature in watershed research that describes the drainage pattern and drainage flow of drainage systems in a specific region. A simple method to calculate it is to divide the total area of a watershed by the length of its river channels. Based on the data presented in (Fig. 6), the Bindal and Rispana watershed's drainage density in km/km^2 is classed into five classes: very low (<= 3), low (> 3 to < = 5), medium (> 5 to < = 7), high (> 7 to < = 10), and very high (> 10 to < = 17.84). Because of the valley region, most of the watershed's areas have low to medium drainage density, which denotes a steep slope, less infiltration, and increased potential for runoff (Das *et al*., 2021). At the riverscape of both rivers, there is a higher drainage density, which denotes a gentle slope, more infiltration, and decreased runoff potential due to alluvium formation (Mani *et al*., 2024). The spatial distribution of the drainage system affects hydrological practices and is essential for evaluating and managing water resources (Mani *et al*., 2023; Shekar & Mathew, 2024). Especially in watershed management, drainage density is an essential parameter for hydrology researchers and managers of water resources (Mani & Kumar, 2020).

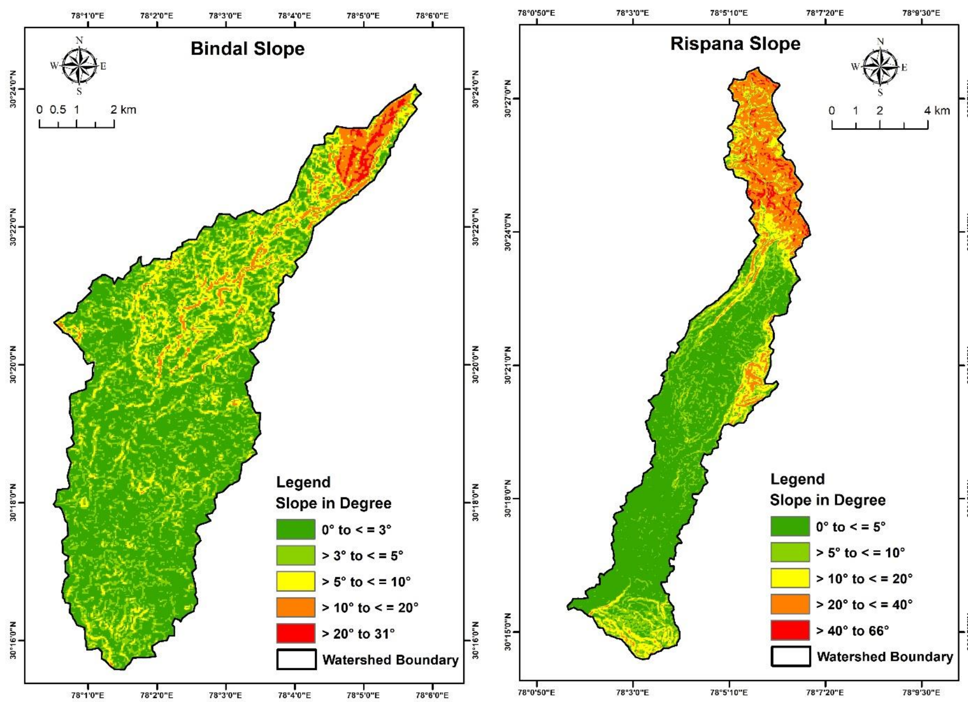
Fig. 6: Drainage Density Map of Bindal and Rispana Watersheds



Slope

Slope is another key element in understanding topography. To understand how water moves across the surface of the Earth, one must understand slope, a fundamental concept in hydrology. Usually, it refers to how sloping or hilly the terrain is. As per the data presented in (Fig. 7), the Bindal and Rispana watersheds are classified into five slope classes. For Bindal Watershed, very gentle (< = 3°), gentle (> 3° to < = 5°), moderate (> 5° to < = 10°), steep (> 10° to < = 20°), and very steep (> 20° to 31°). For Rispana Watershed, very gentle (< = 5°), gentle (> 5° to < = 10°), moderate (> 10° to < = 20°), steep (> 20° to < = 40°), and very steep (> 40° to 66°). The slopes of the Bindal and Rispana watersheds are, respectively, gentle to moderate and gentle to steep. According to Singh *et al*. (2014), a steep slope raises the possibility of landslides and soil erosion by indicating that the watershed has greater runoff and less infiltration.

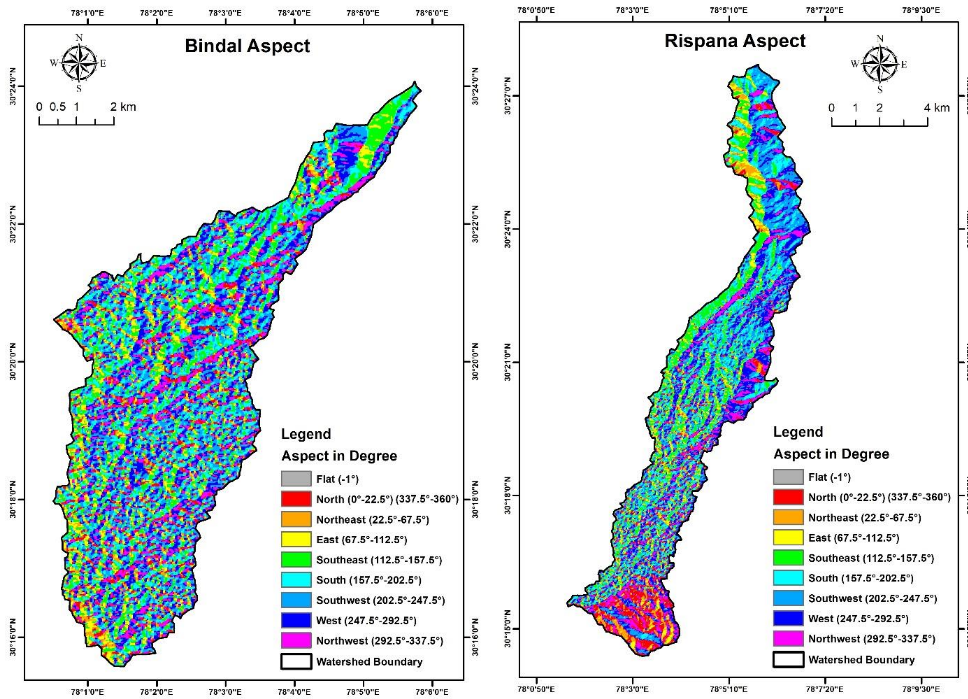
Fig. 7: Slope Map of Bindal and Rispana Watersheds



Aspect

The aspect shows the direction of the slope (Mani *et al*., 2022; Mani *et al*., 2024). It indicates which vegetation kinds are most common in the region. Aspect additionally enhances erosion modelling. According to (Fig. 8), the aspect value is north at 0° and 22.5°, northeast at 22.5° and 67.5°, and so forth. The Bindal and Rispana watersheds are facing the southward slope. Wastelands can be found in many places on the northward slope. According to slope and aspect, both watersheds are in a valley area suitable for agricultural practices and forest techniques. However, since 2000, the growing urbanization in the area increased the encroachment of agricultural land and forest area (Agarwal *et al*., 2018).

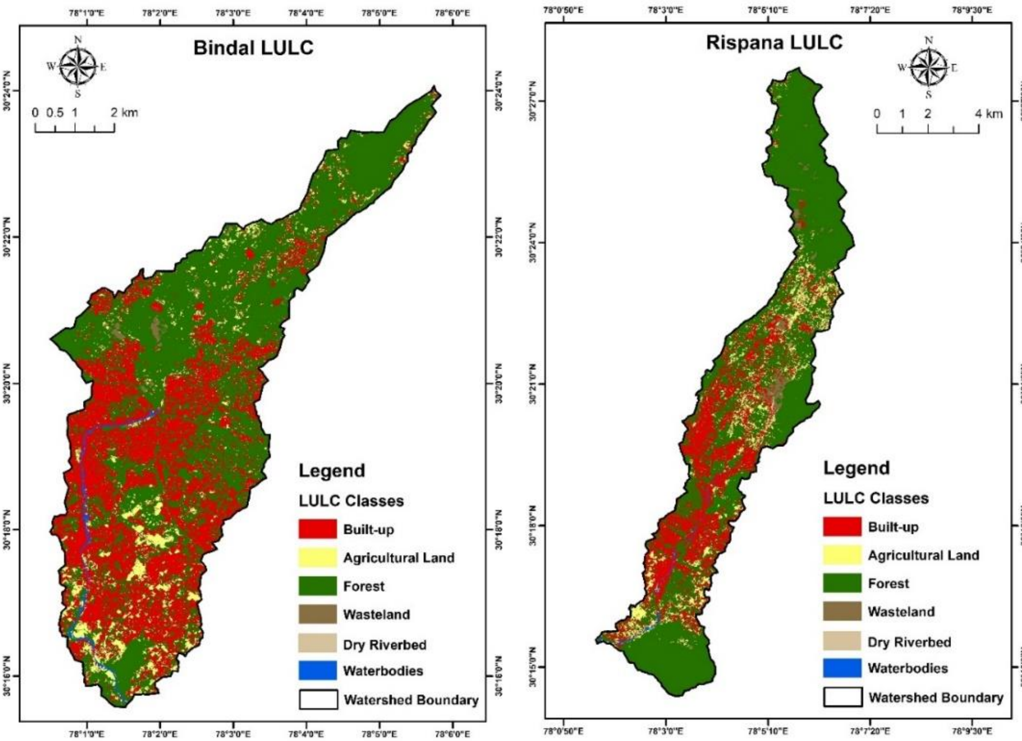
Fig. 8: Aspect Map of Bindal and Rispana Watersheds



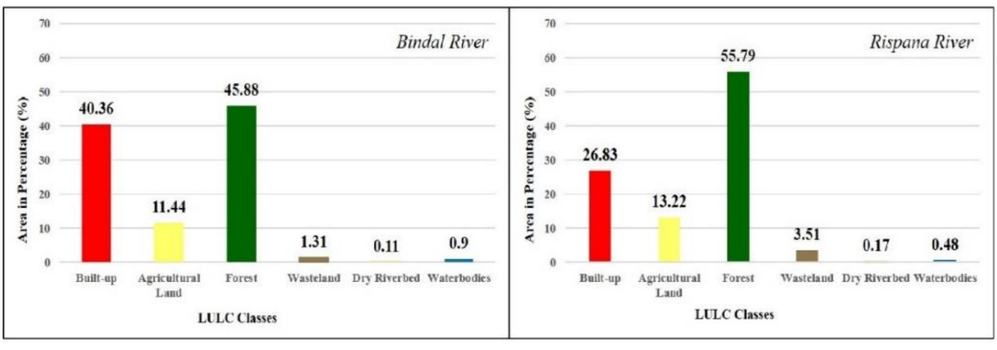
Land Use Land Cover Analysis (LULC)

Another critical factor for evaluating the watershed of any region across both spatial and temporal dimensions is the LULC classification (Ansari & Golabi, 2019). It describes how anthropogenic activities, particularly urbanization and agriculture, utilize land resources and deteriorate biodiversity and ecology (Fang *et al*., 2022; Mohammed *et al*., 2024). This study identified the six LULC classes: Built-up, Agricultural Land, Forest, Wasteland, Dry Riverbed, and Waterbodies (Fig. 9a). The LULC classification achieved an overall accuracy of 0.87 and a kappa coefficient of 82.58 % for Bindal River and an overall accuracy of 0.85 and a kappa coefficient of 80.54 % for Rispana River (Tables 7 and 8). The most dominant class in the Bindal and Rispana watersheds, with 45.88 % and 55.79 % of the total area, respectively, is forest (Fig. 9b). The more significant amount of forest cover in the area contributes to Dehradun's beautiful weather and pleasant climate; however, over the past twenty years, urbanization and industrialization in the area have caused the climate to rapidly change and increase Land Surface Temperature (LST) while decreasing green cover (Mani *et al*., 2021). In Bindal Watershed (40.36 %) and Rispana Watershed (26.83 %), built-up areas are the second most dominating type. This reveals that the significant anthropogenic stress on the Bindal and Rispana watersheds will immediately impact the river's biodiversity and health (Rana *et al*., 2017; Rauthan *et al*. ,2023). In Addition, urban flooding in both river systems could be caused by increased biotic pressure (Garg & Anand, 2022). Agricultural Land, Wasteland, Waterbodies, and Dry Riverbeds are the other LULC classes in both watersheds. LULC analysis is necessary for identifying potential pollution sources, landslides and erosion-prone locations, and watershed regions at land degradation risk (Romshoo *et al*., 2021; Mandal *et al*., 2024; Mani *et al*., 2024). Identifying areas in which urbanization, agriculture, or human activity have a significant influence becomes more accessible by the LULC classification (Liu *et al*., 2022). With this comprehensive understanding, it is simpler to develop targeted interventions and management plans that reduce adverse effects on water resources (Munthali *et al*., 2020; Kudnar *et al.*, 2022). This information is essential for creating strategies and guidelines for watershed management because of the intricate relationship between the area's hydrology, topography, and land use patterns.

Fig. 6: (a) LULC Maps of Bindal and Rispana Watersheds using Sentinel-2B Satellite Imagery for the Year 2022 and (b) Graphical Representation of LULC Area Statistics



(a) LULC Map of Bindal and Rispana Watersheds



(b) Graphical Representation of LULC Area Statistics

Table 7: Accuracy assessment table for Bindal River

		Reference data							
	LULC Class	Built-up	Agricultural Land	Forest	Wasteland	Dry Riverbed	Waterbodies	Total (User)	User Accuracy
Classified data	Built-up	**14**	0	0	1	0	0	15	0.93
	Agricultural land	0	**9**	2	0	0	0	11	0.82
	Forest	0	2	**18**	0	0	0	20	0.90
	Wasteland	3	0	0	**5**	0	0	8	0.63
	Dry Riverbed	0	0	0	0	**2**	0	2	1.00
	Waterbodies	0	0	0	0	0	**4**	4	1.00
	Total (Producer)	17	11	20	6	2	4	**60**	
	Producer Accuracy	0.82	0.82	0.90	0.83	1.00	1.00		
	Overall Accuracy (OA) = 0.87								
	Kappa Coefficient (κ) = 82.58%								

Table 8: Accuracy assessment table for Rispana River

		Reference data							
Classified data	LULC Class	Built-up	Agricultural Land	Forest	Wasteland	Dry Riverbed	Waterbodies	Total (User)	User Accuracy
	Built-up	**16**	0	0	2	0	0	18	0.89
	Agricultural land	0	**9**	2	0	0	0	11	0.82
	Forest	0	2	**26**	0	0	0	28	0.93
	Wasteland	4	0	0	**6**	0	0	10	0.60
	Dry Riverbed	0	0	0	1	**2**	0	3	0.67
	Waterbodies	0	0	0	0	0	**5**	5	1.00
	Total (Producer)	20	11	28	9	2	5	**75**	
	Producer Accuracy	0.80	0.82	0.93	0.67	1.00	1.00		
	Overall Accuracy (OA) = 0.85								
	Kappa Coefficient (κ) = 80.54%								

DISCUSSION

The use of geospatial datasets such as DEM, multispectral satellite imagery, and SOI Toposheet for morphometric analysis proves to be an effective approach in watershed management (Singh *et al*., 2014). DEM provides essential information on elevation, slope, and aspect, which are key in understanding hydrological dynamics and landform characteristics (Das *et al*., 2021). Multispectral satellite imagery offers valuable data for LULC classification, allowing for a comprehensive analysis of anthropogenic impacts, such as deforestation, urbanization, and urban flooding (Demissie, 2022). The combination of these datasets offers a holistic view of watershed characteristics, enabling accurate identification of areas vulnerable to erosion and landslides, while also highlighting the impact of anthropogenic activities on hydrological processes (Agaton *et al*., 2016). The morphometric analysis method, in particular, was crucial for identifying the drainage patterns and assessing the linear, areal, and relief aspects which are critical indicators of watershed stability (Rai *et al*., 2018). However, integrating more dynamic datasets like rainfall and land cover change over time could enhance future studies.

The study’s findings reveal significant differences between the Bindal and Rispana watersheds in terms of geomorphological features and vulnerability to environmental risks. The higher relief ratio and compactness coefficient values of the Rispana watershed suggest a higher susceptibility to erosion and landslides, which may exacerbate flooding and soil degradation in the urbanized region (Mandal *et al*., 2024). The dominance of the Built-up class as the second most prevalent LULC type across both watersheds highlights the increasing anthropogenic pressures that may worsen watershed degradation (Garg & Anand, 2022). The study emphasizes the need for effective urban watershed management policies that consider both natural topography and human activities to mitigate potential risks such as floods, river health and soil erosion (Rauthan *et al*., 2023).

The findings have global relevance, particularly in rapidly urbanizing regions where natural ecosystems are increasingly being modified (Welde & Gebremariam, 2017). Understanding the interaction between watershed topography, hydrology, and urbanization is crucial for developing sustainable management strategies (Sewnet, 2015). These results contribute to the growing field of Landscape Ecology, offering empirical evidence that links geomorphic characteristics to biological processes and landscape resilience (Negesse, 2024). The study underscores the importance of incorporating both natural and anthropogenic factors in watershed management, a concept that is increasingly vital in urban regions worldwide (Zheng *et al*., 2020; Leta *et al*., 2021). Landscape planners and policymakers can leverage these insights to design adaptive strategies for managing urbanized river systems, promoting long-term sustainability, and enhancing resilience to environmental hazards across diverse geographical contexts.

CONCLUSION

Urban watershed management policies depend mainly on understanding watershed hydrology, topography, LULC, and drainage as shown in the comprehensive evaluation of the Himalayan River's watersheds. The Bindal and Rispana watersheds were carefully investigated using geospatial datasets such as DEM, multispectral satellite imagery, and SOI Toposheet. By applying the morphometric analysis method, the study's findings revealed that both watersheds have dendritic drainage patterns and low to moderate relief with elongated shapes. Comparing the relief ratio and compactness coefficient values of the Bindal and Rispana watersheds, the findings indicated that the Rispana watershed is more vulnerable to erosion and landslides due to its higher relief ratio and greater compactness coefficient values. Additionally, the Built-up class ranks as the second most dominant class in both watersheds, after the Forest class, which raises concerns about increased biotic pressure and the potential risk for urban floods in the river systems. The findings emphasize combining topographical, hydrological, and LULC data into urban watershed management strategies to reduce environmental risks and guarantee sustainable resource management. These results have global relevance as they illustrate the interaction between geomorphic characteristics and anthropogenic influences in shaping watershed vulnerability in rapidly urbanizing regions. It also offers empirical evidence about the impact of watershed topography and urbanisation on biological processes, hydrological connectivity, and landscape resilience within the domain of Landscape Ecology. These insights are essential for landscape planners and policymakers seeking to manage risks and improve sustainability in urbanised river systems worldwide.

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CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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