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Evaluating Urban Topography and Land Use Changes for the Urban River Management Using Geospatial Techniques †

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Abstract: This study focused the urban river management using geospatial techniques of the Dehradun Municipal Corporation (DMC) and its associated watersheds of Bindal River and Rispana River. The Shutter Radar Topography Mission (SRTM) Digital Elevation Model (DEM) data with a spatial resolution of 30 m has been used for the delineation of watershed boundary, drainage network, and identifying topographic features. Additionally, Sentinel-2 data with a spatial resolution of 10 m has been utilized to analyse change in land use in 2017 and 2022. The drainage pattern in Bindal and Rispana watersheds were dendritic in shape with moderate relief. The study found, a significant decline in Agricultural Land from 17.94% in 2017 to 14.66% in 2022. This decline was accompanied by increase in Built-up area from 32.53% to 35.44%. The increased biotic pressure poses a critical threat to river health and biodiversity. The study highlights the urgent need of comprehensive river management strategies to efficiently monitor the biotic pressure due to transformation of land use. This research will be beneficial to diverse stakeholders, including decision-makers and urban planners engaged in sustainable management of water resources and urban development.

Keywords: Remote Sensing; Geographic Information System (GIS); Digital Elevation Model (DEM); land use changes; watershed; urban river management

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1. Introduction

The world is towards the freshwater crisis which affects the river system and its surrounding environment [1]. Urbanization, climate change, over-exploitation of natural resources, and increasing population pose a threat to the ecosystem services and biodiversity of the freshwaters [2,3]. With increasing land development and human activities in nearby and distant watersheds, the supplies of drinking water for cities are at stress due to potential contamination. India's 35% urban population generates almost 65% of the country's wastewater [4]. Urban river management in India is crucial for controlling the effects of growing anthropogenic pressure on the river system [5]. Urban river management refers to the comprehensive planning, development, and sustainable utilization of river resources within urban areas. The maintenance and restoration of these resources are essential elements of effective urban river management. This may include maintaining water quality, managing river flow, taking steps to prevent flooding, reviving riverfront areas for recreation and biodiversity, and making sure adequate sanitation and wastewater treatment. The role of Digital Elevation Model (DEM) and multispectral sensor based geospatial techniques is significant for urban river management studies. Earlier geospatial techniques are tedious, expensive, and error-prone than the latest geospatial techniques. Spatial and temporal analysis of an area will provide us with a comprehensive view of the topography and change in the land use pattern of an area [6]. In the study, we will evaluate the land use changes and topographical factors of the Dehradun Municipal Corporation (DMC) and its associated watersheds. This study's main concern is the impact of humans on the nearby river systems. Urban planners and water resource managers who are involved in urban river management and sustainable development will benefit from the findings of this study.

2. Methods

2.1. Study Area

The Dehradun Municipal Corporation (DMC) is the lifeline of the Doon Valley in Uttarakhand, India. It is the Central Business District (CBD) of the Dehradun City. After originating from the Lesser Himalayas, the Bindal River having a total length of ~23 km, and the Rispana River having a total length of ~27 km flows through the DMC before merging to form the Suswa River near Mothrowala, which then flows to Song River and eventually joins the Ganga River [7]. The study area coordinates falls between Latitude (from 30°13′45″ N to 30°27′30″ N) and Longitude (from 77°55′00″ E to 78°08′45″ E). For the total study area, the watershed areas of the Bindal and Rispana Rivers viz. 44.40 km^2 and 58.09 km^2 are combined with the DMC area of 183.70 km^2 [8], then excluding the watershed area which falls inside the DMC area. Finally, the study covers a total area of 204.23 km^2 and has elevations that range from 549 m to 2278 m. The region receives ~2000 mm of average annual rainfall each year. The winters are extremely cold with a temperature of 2 °C and the summers are mostly hot with a temperature of 43 °C. The map of the study area is represented in Figure 1 below.

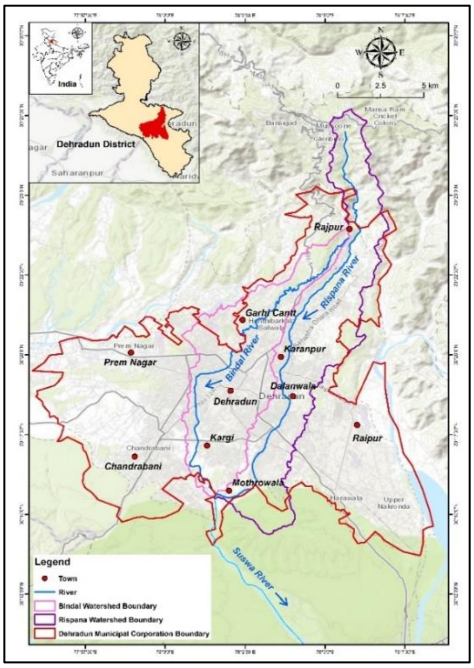


Figure 1. Study Area Map.

2.2. Materials and Methods

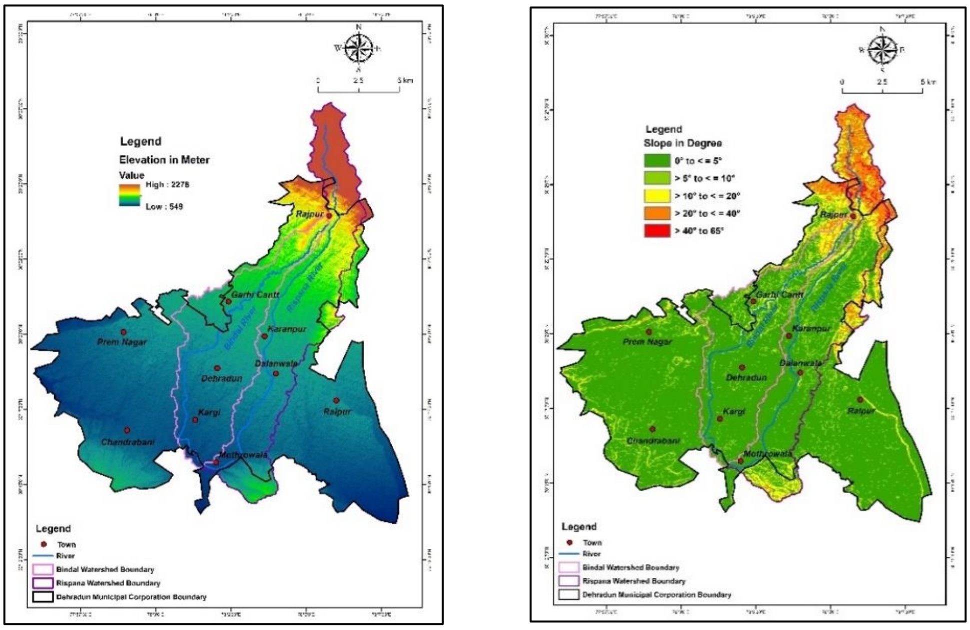
The Integrated use of Digital Elevation Model (DEM) data and satellite based multispectral sensor data has been used to understand the study area. The Shutter Radar Topography Mission (SRTM) DEM data at 30 m resolution for the year 2014 has been used for topographical evaluation [9]. This data further processed in ArcGIS desktop software using Spatial Analysis Tools for the delineation of watershed boundaries and drainage networks. The Sentinel 2 multispectral sensor data at 10 m resolution for the years 2017 and 2022 has been used for land use changes [10]. The land use changes has been performed through the supervised classification method in ERDAS Imagine software. The supervised classification method involves selecting specific representative samples for each land use class, referred to as training samples, and the accuracy of the classification largely relies on the quality of these training samples [11]. These samples are employed by the image classification algorithms to recognize land use classes across the entire image. In this study, we applied the widely used Maximum Likelihood Classifier (MXL) as our supervised classification algorithm. Further, the statistical process is done in ArcGIS desktop software. Additionally, elevation, slope, drainage network, and land use changes maps of the study area have been prepared.

3. Results and Discussion

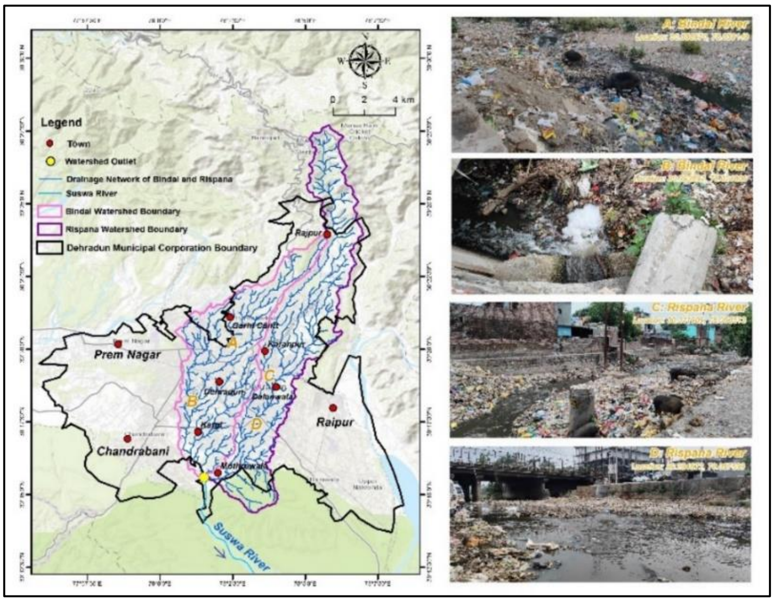
Topographical factors such as elevation, slope, and drainage network along with land use change are essential for the urban river management studies. The following factors have been explained below.

3.1. Elevation

The Elevation of DMC and its associated watershed ranges from 549 m to 2278 m (Figure 2a). The higher the elevation, the greater the slope [12]. The DMC area is having low to moderate elevation range.



(**a**) (**b**)



(**c**)

Figure 2. (**a**) Elevation Map; (**b**) Slope Map; (**c**) Drainage Network Map.

3.2. Slope

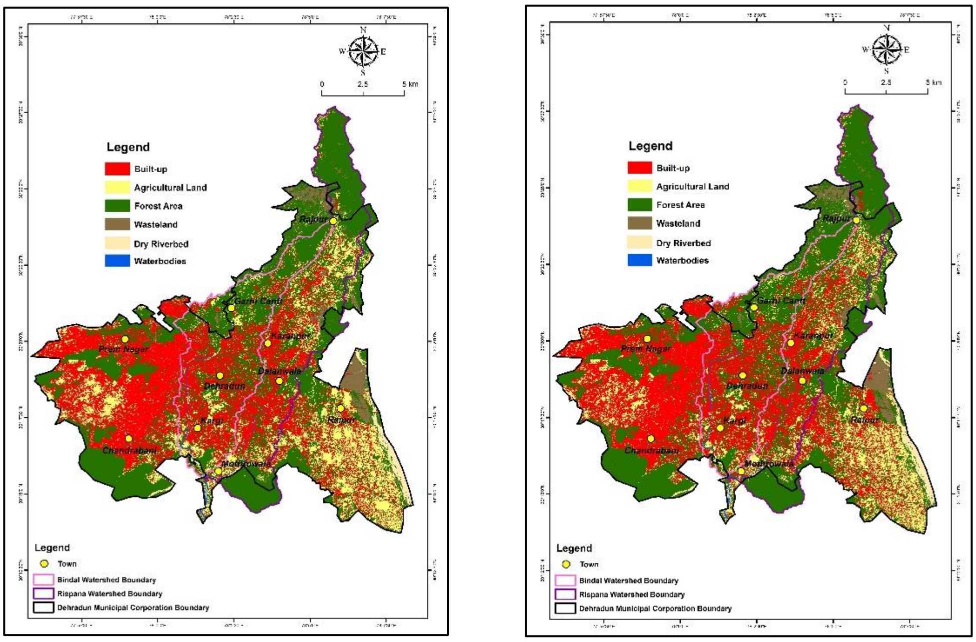
The area's steepness is indicated by the slope. According to Figure 2b, the slope has been classified into five classes: very gentle (0° to <=5°), gentle (>5° to =10°), moderate (>10° to =20°), steep (>20° to =40°), and very Ssteep (>40° to 65°). The majority of the area has relatively gentle to medium slopes. A gentle and moderate slope has high groundwater infiltration and less runoff, whereas a steep slope has low groundwater infiltration and less runoff [13]. Additionally, steep slope regions are vulnerable to soil erosion.

3.3. Drainage Network

A drainage network is comprised of all the paths of streams that flow toward a reference point. It is constrained by a topographically defined drainage divide. Rainfall falling on the far side of the drainage divide runs down-slope into an adjoining drainage network. The drainage pattern is dendritic in shape. All the drainage inside the Bindal River and Rispana River watersheds drain through the DMC area in a south direction towards an outlet in Mothrowala (Figure 2c). Both rivers bring municipal households' sewage waste and industrial effluent into the Suswa River, which joins the Song River near Jhabrawala and ultimately merges with the Ganga River near Tehari Farm, Raiwala, Uttarakhand, India. The drainage network's role is crucial for understanding the anthropogenic threats near urban rivers.

3.4. Land Use Changes

Multidisciplinary research on land use changes includes economics, geography, urban planning, and environmental studies [14,15]. It plays a crucial role in informing policies and practices that can help balance human development with the preservation of natural resources and ecosystems [16]. The supervised classification approach in the ERDAS Imagine software was used in this study to create land use changes for the years 2017 and 2022. Statistical analysis has been also performed using ArcGIS desktop software. The dominating classes in the area are Dense Vegetation and Built-up (Figure 3a,b). According to the analysis of land use changes, from 2017 to 2022, there would be a 2.91% increase in Built-up area and a 3.28% decrease in Agricultural Land area (Table 1). The change in Agricultural Land area to Built-up area depends on the increasing population growth, expansion of smart cities, and rapid socio-economic growth [17]. Also, increasing tourist pressure and Dehradun climate are other significant factors for the rise in Built-up area [18]. River health and biodiversity are under serious threat by the rising Built-up area and other anthropogenic factors [19].



(**a**) (**b**)

Figure 3. (**a**) Land Use Map 2017; (**b**) Land Use Map 2022.

Table 1. Land Use changes analysis.

S. No	**Land Use Classes**	**2017 Area in km²**	**2022 Area in km²**	**2017 Area in %**	**2022 Area in %**	**Area Change in km²**	**Area Change in %**
1	Built-up	66.43	72.37	32.53	35.44	5.94	2.91
2	Agricultural Land	36.64	29.95	17.94	14.66	−6.69	−3.28
3	Barren Land	10.58	10.98	5.18	5.38	0.4	0.2
4	Dense Vegetation	86.59	86.88	42.4	42.54	0.29	0.14
5	Dry Riverbed	3.23	3.15	1.58	1.54	−0.08	−0.04
6	Waterbodies	0.76	0.9	0.37	0.44	0.14	0.07
	Total Area	**204.23**	**204.23**	**100**	**100**		

4. Conclusions

This study investigates the possible impacts of topographical factors and land use changes on urban river management using DEM and multispectral sensor based geospatial techniques. Comprehensive evaluation and interpretation implied that from 2017 to 2022, there is a change in the land use, the Agricultural Land area is decreasing and Built-up area is increasing. The dendritic pattern of the watershed's drainage system makes it easier to understand various topographical factors, including runoff and infiltration rate. The findings of this study demonstrate the increasing biotic pressure on urban rivers driven by municipal households' sewage waste and industrial effluent which flows from small river systems to large river systems. In order to effectively monitor the biotic pressure caused by land use changes, this study emphasizes the urgent necessity for proper urban river management planning. This study will be useful to the urban planners and policymakers who are involved in urban development and water resource management. Also, in the near future, topography, and land use changes-based studies will be significant for valuable and systematic urban river management.

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