



Integration of GIS and Geomorphic Data to Assess the Impact of Landscape Features on River Water Quality

Damanjeet Aulakh ^{1*} , Dr. Shashikant Patil ² , M. Sunil Kumar ³ , Uma Bhardwaj ⁴ 

^{1*} Assistant Professor, Chitkara University Institute of Engineering and Technology, Centre for Research Impact and Outcome, Chitkara University Institute of Engineering and Technology, Chitkara University, Rajpura, 140401, Punjab, India. E-mail: damanjeet.aulakh.orp@chitkara.edu.in

² Professor, Department of uGDX, ATLAS SkillTech University, Mumbai, Maharashtra, India. E-mail: shashikant.patil@atlasuniversity.edu.in

³ Assistant Professor, Department of Mechanical Engineering, Faculty of Engineering and Technology, JAIN (Deemed-to-be University), Bangalore, Karnataka, India. E-mail: sunilkumar.m@jainuniversity.ac.in

⁴ Professor, Department of Biotechnology & Microbiology, Noida International University, Greater Noida, Uttar Pradesh, India. E-mail: vc@niu.edu.in

Abstract

Assessing the impact of landscape features on river water quality is essential for effective water organization. Geographic Information Systems (GIS) serve as valuable tools for integrating spatial data, while geomorphic characteristics offer critical insights into the hydrological processes that impact water quality. Traditional research has typically lacked a full grasp of the direct impact of certain land cover features on water quality in rivers, sometimes overlooking the complicated connections between geomorphological elements and water characteristics. As a result, this research intends to combine GIS and geomorphic data to assess the impact of landscape characteristics on river water quality. Water samples were obtained from numerous river locations, with essential characteristics, such as pH, dissolved oxygen (DO), turbidity, and temperature, to perform a thorough assessment of water quality. Geomorphic factors such as slope, elevation, and landscape pattern were also included in a GIS to spatially examine their connection to water quality indicators. The research used a comparison of water quality indicators from Low Geomorphic Relief Areas (LGRA) and High Geomorphic Relief Areas (HGRA) to investigate spatially changing correlations across areas. The findings show that water quality varies significantly between LGRA and HGRA, with landscape characteristics, such as elevation and landscape pattern, having a considerable influence on water quality indicators. This technique illustrates the efficiency of combining GIS and geomorphic data in managing and protecting river ecosystems.

Keywords:

Geographic information systems (GIS), Geomorphic data, River water quality, Low geomorphic relief areas (LGRA), High geomorphic relief areas (HGRA).

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Introduction

River water quality is vital to the health of aquatic ecosystems, biodiversity, and the provision of key resources for human and agricultural use (Vinusha et al., 2024). River water quality is measured by a variety of elements, including chemical, physical, and biological processes that are frequently dictated by their surroundings (Mei et al., 2025). The combination of Geographic Information Systems (GIS) and geomorphic data has emerged as an effective method for comprehending the complicated interaction between landscape characteristics and water quality (Lakhia et al., 2024). It enables a spatially explicit investigation of how topographical, and hydrological, topographies influence water quality across different river systems (Gu et al., 2025). Rivers are nature's most important gift, accounting for around 0.0002% of total water on Earth. Since the beginning of time, it has sustained humans and other living things and it assists as the primary source of life. Human activities and natural processes interact within landscapes, resulting in complicated water quality patterns throughout river networks (Wibowo et al., 2024). Agricultural runoff, urban growth, deforestation, and soil erosion are major causes of water contamination (Fattahi et al., 2014). These operations contribute a variety of contaminants to river systems, including fertilizers, sediments, and heavy metals, creating severe environmental issues (Wei et al., 2025). GIS provides a supplementary strategy by combining extensive information on land cover, hydrology, and water quality, allowing researchers to examine spatial trends and identify probable contamination sources more efficiently. River plan change is the movement of water and sediments along a river's groups and beds, affecting available resources (Tahir et al., 2025). Various ecosystems inside a river channel shape its course throughout time and space (Pešević et al., 2019). River plan evolution refers to the effect of natural and human factors on erosion and deposition in catchments, including river flow, flood, surface, sedimentation, agriculture, industrialization, grazing, and deforestation. River discharge and sediment load fluctuations cause long-term effects, rather than instantaneous responses (Al-Assadi & Al Kaabi, 2024). Water quality is a global concern due to anthropogenic, climate change, and natural factors like erosion, surface runoff, sedimentation, wastewater, land recovery, environmental change, and air pollution (Asadipooya & Nezhad, 2019). Water quality relates to water's biological, physical, and chemical properties, as well as its expected use and restrictions. Surface waters are polluted by typical processes such as precipitation, disintegration, weathering, sedimentation, subsidence, and human activity, including industrial, urban, horticultural, and agricultural activities (Xu et al., 2024). Urbanization is one of the most major land-use shifts that has impacted river water quality. As cities grow, impermeable surfaces like highways, buildings, and parking lots replace natural vegetation, reducing the land's ability to absorb water. The resulting increase in surface runoff transports contaminants like oil, heavy metals, and garbage into rivers, degrading water quality. Furthermore, development often results in increased trash discharge, both from industrial and domestic sources, directly contaminating river water with hazardous chemicals, pathogens, and organic matter. Furthermore, metropolitan areas commonly suffer warmer temperatures due to the urban heat land effect, which accelerates evaporation and impacts the temperature of neighboring water bodies, thereby hurting aquatic life. The primary goal is to combine GIS and geomorphic data to determine how landscape characteristics influence river water quality, as well as to identify major environmental elements that influence water conditions and ecosystem health (Friday & Godfrey, 2023).

Chatrabhuj et al., (2024) explained the effort in incorporating remote sensing, GIS, and Artificial Intelligence (AI) technology for improved river system organization aimed at better conservation of water resources, agricultural productivity, and ecological health. The application of satellite images from the Landsat and Sentinel series, along with AI-based GIS methods for river condition assessment, classifying land use, flood forecasting, and water quality monitoring. Their outcomes indicated that automatic processing of huge amounts of data, together with trend forecasting and greater analytical capabilities, led to far Superior River monitoring and management. Research evaluation procedures are resolved further through continued inquiry and collaboration. Mishra et al., (2024) described the perceptions of local community members were combined to understand river water quality and delivered an in-depth reflection on its role in the ecosystem and public health. GIS was used to map water quality in seven crucial places, combined with Participatory Rural Appraisal (PRA) and rigorous water quality monitoring, to collect both community insights and scientific data. The data was confined to seven places along the river and did not completely reflect regional water quality trends. Diaz et al., (2021) developed a spatial model of nutrient water levels at the local scale that applied to a variety of geophysical and land-use circumstances. GIS, and Remote Sensing are used to forecast nitrogen and phosphorus concentrations. The findings indicated major eutrophication hazards and model viability, while model applicability in varied contexts was a drawback. Das, (2025) evaluated the drinking water quality of surface water in the Mahanadi River Basin (MRB). 47.37% of locations had good water quality; the main pollutants were agricultural runoff and unlawful garbage dumping. It was confined to 19 specific locales and does not completely represent regional pollution variations. Sodhi et al., (2024) showed how to monitor surface water dynamics and water quality measurements to assess the health of the Gobind Sagar Reservoir for long-term development. A semi-analytical inversion technique utilizing data from satellites was used to examine surface water dynamics and quality parameters. The reservoir contained constant water with minimal alteration, but water quality fluctuations were caused by climatic variables such as rainfall and runoff. It were constrained by the availability of satellite data for detailed seasonal comparisons. Angalaparameswari et al., (2024) examined the coastal landforms changed in Joao Pessoa, Brazil, between 2000 and 2011, with an emphasis on the influence of human activity and climate conditions. The coastal landform evolution, and spatial data from multiple sources were analyzed utilizing change detection techniques and methods. The investigation discovered erosion and accretion along different areas of the shoreline. The limitations included data resolution and the exclusion of other environmental effects. Santos et al., (2024) developed a framework to assess and isolate river water pollution in the Paraopeba River basin influenced by agriculture, industrial, urban activities, and tailings dam collapse. Metal contamination and nutrient pollution were identified, with varying impacts on river tributaries and the main river. The research focused on a specific watershed, and the findings do not apply universally. Cong, (2024) investigated the use of GIS for the automatic monitoring of ecological water pollution. It outlines data collection, spatial distribution analysis, pollution diffusion simulation, and monitoring system design. Results demonstrated GIS's effectiveness in pollution monitoring, but limitations include data accuracy issues and real-time monitoring challenges. Mukhtar et al., (2024) described the quantified flood risk in the Hunza-Nagar Valley utilizing a GIS-based Multi-Criteria Decision Analysis (MCDA) method and large amounts of climatic data. The flood danger mapping took nine parameters into account, with rainfall, distance to the river, elevation, and slope having the greatest weights. The model's accuracy was shown using ROC-AUC analysis. The limitations include potential data error, the omission of some dynamic flood elements, and the dependence on static data for forecasting.

- The research integrates GIS and geomorphic data to evaluate river water quality. It describes the impact of landscape factors (elevation, landscape pattern, and slope) on water quality.
- Water quality differs significantly between low and high geomorphic relief areas. It creates a comprehensive framework for river ecological management.

- This approach demonstrates the effectiveness of integrating GIS and geomorphic data to manage and protect river ecosystems.

Materials and Methods

The primary goal is to combine GIS and geomorphic data to determine how landscape characteristics influence river water quality, as well as to identify major environmental elements that influence water conditions and ecosystem health. The pH, DO, turbidity, and temperature are utilized to conduct a comprehensive assessment of water quality. The geomorphic features such as slope, elevation, and land scape pattern were integrated into a GIS to spatially analyze their relationship with the water quality parameters. Water quality varies significantly between LGRA and HGRA, with landscape features such as slope, elevation and landscape pattern influencing water quality indicators.

Data Collection

Water samples were taken from numerous river locations to analyze critical water quality indicators such as pH, DO, turbidity, and temperature, allowing for a thorough assessment of the river's state. Geomorphic factors, including slope, elevation, and landscape pattern, were included in a GIS to spatially examine their link to water quality indicators. High-resolution topography and landscape pattern data were utilized to categorize landscape elements throughout the research region. The river's economic growth is impacted by its natural surroundings. The highest effects include a backward economy, a delicate natural atmosphere, and low forest cover. The middle reaches supply water to both internationally recognized brands alongside stringent purity standards and lower reaches have an outstanding biological environment and a well-developed tourism industry.

Water Quality Evaluation

The water quality indicators used in the investigation included 4 physical elements: pH, DO, turbidity, and temperature, to conduct a comprehensive assessment of water quality. The Pollution Load Index (PLI) used in the research not only highlights the most important pollution problems but also considers other elements that contribute to excellent water quality, reducing the subjective effect of arbitrary weight allocations during the computation procedure. The calculation formula is followings; where j_k represents the single pollution index, T_y and T_{io} denote the metal concentrations using Equation (1). CF Contamination factor; n number of metals; C metal: metal concentration in polluted sediments using Equation (2).

$$j_k = \frac{T_y}{T_{io}} \quad (1)$$

$$PLI = \sqrt[n]{(CF1 \times CF2 \times CF3 \times \dots \times CFn)} \quad (2)$$

Three categories are used to assess geomorphic features such as slope, elevation and land cover across different sites. LGRA, which includes 6 sites and HGRA, which also includes 6 sites.

Geomorphic Features

The slope is separated into five sections, with slope demarcation marks of 0° and 45° , along with the geographical peculiarities of the river. Soil and land classification based on slope range is essential in deciding the use of land, especially in the case of environmental impacts like water quality. Type A - Flat land (0-5 degrees) is nearly flat land that should be used for urban development, agriculture and infrastructure. Very minimal slope makes this contour non-influential to water drainage or soil erosion. Type B - Gently sloped

land (6-15 degrees) with a gentle slope needed consideration in agriculture. Water runoff starts showing some influence on construction or farming with little consideration for erosion control. Type C - Land with Moderate Slope (16-30 degrees) are slopes inclined somewhat more than Type B, therefore having a larger risk of erosion. Type D - Steep slope lands (31-45 degrees) are steep enough such that serious erosion and water flow problems come into play and become a barrier to any activities in construction or agriculture. These lands are typically left undeveloped and mainly utilized for recreation or conservation purposes. Type E - Lands with very steep slopes (>45 degrees) are steep areas, consisting of very steep lands, where steep runoff and considerable erosion risks inconceivable development for agriculture. Generally, these spaces are set aside for natural features or tourism. Thus, the slope classification provides insight into the potential environmental impacts in addition to water quality and is a useful management tool. Figure 1 shows the grading standard of slope.

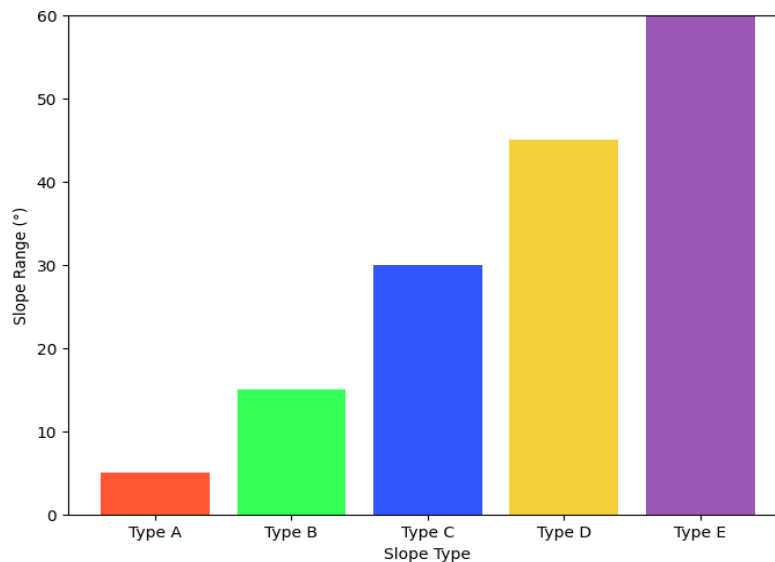


Figure 1. Grading standard of slope

Landscape Pattern

ArcGIS, a comprehensive GIS, offers a range of tools for landscape analysis and spatial pattern metrics, especially through its Spatial Analyst extension. ArcGIS is used to determine the landscape index for each type level, as well as the landscape characteristics that have a significant impact on river water quality. The selected landscape indexes include Land Cover Diversity, Vegetation Fragmentation Index (VFI), Wetland Area (WA), Impervious Surface Area (ISA), Mean Patch Size (MPS), and Forest Cover (FC). Table 1 depicts the landscape patterns.

Table 1. Landscape pattern patterns

Index	Description	Equation
Land Cover Diversity (LCD)	Measures the diversity of land cover types using the Shannon Diversity Index. A higher value indicates a more diverse landscape.	$LCD = -\sum p_i \ln p_i$
Vegetation Fragmentation Index (VFI)	Calculates the ratio of total edge length (E) to total area (A). A higher value indicates greater fragmentation of vegetation.	$VFI = \frac{E}{A}$
Wetland Area (WA)	Computes the total area A_i of all wetland patches, representing wetland coverage. A larger value suggests greater wetland presence.	$WA = \sum A_i$

Impervious Surface Area (ISA)	Measures the total area B_i covered by impervious surfaces (e.g., roads, buildings). A higher value indicates increased urbanization.	$ISA = \sum B_i$
Mean Patch Size (MPS)	Calculates the mean area of patches, where A_i is the area of patch i and N is the total number of patches. The result is inversely proportional to landscape fragmentation larger MPS values indicate less fragmented landscapes.	$MPS = \frac{\sum A_i}{N}$
Forest Cover (FC)	Computes the percentage of land covered by forests, where $\sum \frac{A_i}{N}$ the forested area is and FC is the total land area. A higher value suggests better forest coverage.	$FC = \frac{\sum A_i}{N} \times 100$

Elevation

Elevation significantly influences river water quality by affecting hydrological processes, erosion, and pollutant transport. Digital Elevation Model (DEM) analysis extracts elevation and identifies high-erosion zones and runoff pathways. LGRA and HGRA water quality factors topographic natural procedures using Equation (3).

$$Sn = \max(L) - \min(L) \quad (3)$$

Where Sn is the relief of the topographic; $\max(L)$ and $\min(L)$ are the low and high altitudes in the area, respectively. Relief largeness is greatly controlled by spatial scale; hence wise to take variations of scale into account in its computation. The moving window technique is first used on DEM data to calculate environments across a wide variety of window sizes. Relief amplitude is the difference between the highest point of the max pixel and the lowest point-min pixel within a window. Average relief amplitude varied with window size, following a logarithmic pattern that fit quite well. Precisely identify the transition point; within the optimal statistical range, a mean turning-point analysis is performed. The geographic detector method was subsequently applied in quantifying the equity among manipulating factors and watershed water quality, analyzing both separate impacts and interaction. In diverse avenues of research, this method has been broadly employed to detect spatial differentiation and reveal causal relationships in geographic phenomena. By comparing the spatial coherence between water quality and geographic layers, potential influencing factors were identified. Each geographic factor is stratified into layers, with a different stratum, representing unique attribute values.

LGRA river refers to a river flowing through a landscape with very little elevation change, meaning the land is mostly flat with minimal hills or slopes, resulting in a gentle gradient and a slow-moving river with a wide, meandering channel, often found in large floodplains; essentially, a river in a low-relief area with minimal topographic variation. Due to the flat terrain, the river has a very low gradient, leading to slow water flow. The slow flow often results in a highly meandering channel pattern with numerous bends and oxbow lakes. HGRA about a river refers to a section of the river's landscape with a significant difference in elevation between the highest and lowest points, typically found in mountainous regions where the river cuts through steep slopes and valleys, resulting in a rapidly changing topography with high gradients and strong erosive forces along the river channel. Steep slope areas are characterized by steep hillsides and valleys, leading to a pronounced vertical drop in elevation along the river course. The high gradient causes fast-moving water, which can significantly erode the riverbed and banks, creating features like rapids, waterfalls, and deep gorges.

Experimental Result

This section evaluates the water quality, landscape pattern, slope patterns and elevation in the area. The water quality indicators identified, along with the testing results for the physical and chemical parameters at both

stages of the river LGRA and HGRA, include the mean and standard deviation for each water quality indicator. Table 2 displays the water quality characteristics.

Table 2. Water quality characteristics

Parameter	Area Type	Mean	SD	Min	Max
pH	LGRA	7.2	0.5	6.5	8.1
	HGRA	6.8	0.6	6.2	7.8
Dissolved Oxygen (DO) (mg/L)	LGRA	8.5	1.2	6.9	10.4
	HGRA	7.3	1.1	5.8	9.0
Turbidity (NTU)	LGRA	15.3	4.7	8.9	22.5
	HGRA	22.1	5.2	13.4	29.7
Temperature (°C)	LGRA	23.5	2.1	20.0	26.4
	HGRA	21.8	2.4	18.5	25.0

Higher pH values experienced in LGRA are associated with HGRA, representing slightly alkaline conditions in low-relief areas. DO levels were higher in LGRA, suggesting better oxygenation due to more stable water flow and vegetation cover. Turbidity: Higher turbidity in HGRA reflects increased sediment runoff from steep slopes during rainfall. Temperature: LGRA showed slightly higher temperatures, lower elevation, and reduced shading compared to HGRA. The table displays that LGRA has a higher pH (7.2), DO (8.5 mg/L), and lower turbidity (15.3) compared to HGRA. Figures 2 (a) and (b) show the correlation exploration among landscape composition and water quality index LGRA and HGRA.

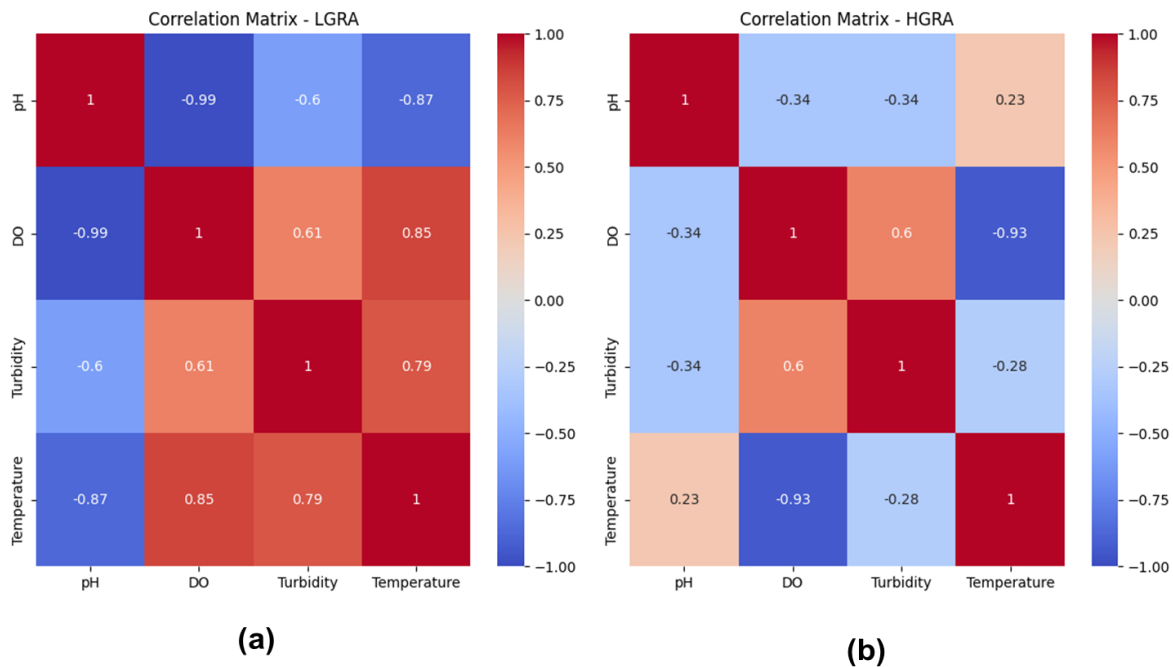


Figure 2. Result of the correlation matrix

The correlation matrices for LGRA and HGRA reveal the relationships between various water quality parameters. In LGRA, the pH and DO values show a moderate positive correlation, indicating that higher pH levels tend to coincide with higher DO. Turbidity and temperature show less correlation with other variables. In HGRA, the correlations are slightly stronger, with turbidity and temperature showing a notable positive relationship, suggesting that steeper areas have higher sediment levels, affecting temperature.

Landscape Pattern and Slope Patterns in Topographic Relief Areas

Landscape pattern refers to the material items observed on the Earth's surface, such as flora, water, and urban areas, whereas slope patterns describe the steepness of the terrain. These variables influence erosion and runoff in topographic relief areas, leading to an impact on water quality. Steep slopes and certain land uses can lead to increased sedimentation and pollution transfer, reducing water quality. Six landscape pattern indexes, namely LCD, VFI, WA, ISA, MPS and FC slope class were obtained based on Flat Land, Low Slope Land, Moderate Slope Land, Steep Slope Land and Very Steep Slope Land. Table 3 depicts the landscape in LGRA and HGRA.

Table 3. Landscape in LGRA and HGRA

Slope Class	Region	Land Cover Diversity (LCD)	Vegetation Fragmentation Index (VFI)	Wetland Area (WA) (%)	Impervious Surface Area (ISA) (%)	Mean Patch Size (MPS) (ha)	Forest Cover (FC) (%)
Flat Land (0–5°)	LGRA	0.65	0.48	12.5	18.3	3.2	25.4
	HGRA	0.58	0.52	10.8	22.1	2.9	30.2
Low Slope Land (6–15°)	LGRA	0.72	0.44	15.3	20.7	4.0	35.6
	HGRA	0.66	0.49	13.2	25.5	3.5	32.0
Moderate Slope Land (16–30°)	LGRA	0.81	0.38	18.6	15.2	5.1	40.7
	HGRA	0.75	0.45	16.8	19.6	4.5	42.3
Steep Slope Land (31–45°)	LGRA	0.85	0.32	20.9	10.5	6.2	50.8
	HGRA	0.78	0.40	19.1	14.2	5.8	47.9
Very Steep Slope Land (>45°)	LGRA	0.92	0.28	25.4	8.3	7.5	60.1
	HGRA	0.88	0.35	22.7	11.1	6.9	55.4

The table compares land characteristics across different slope classes, Flat to Very Steep for LGRA and HGRA regions. LCD increases with an increase in slope from 0.65 Flat LGRA to 0.92 Very Steep LGRA. WA is increasing from 12.5% Flat LGRA to about 25.4% Very Steep LGRA. ISA gradually decreased from 18.3% in Flat LGRA to 8.3% in Very Steep LLRA. FC quickly from 25.4% in Flat LGRA to about 60.1% in Very Steep LGRA. MPS steadily progressed from 3.2 in Flat LGRA to 7.5 in Very Steep LGRA, which signifies superior patches of land over the steeper slopes. As the slope increases, the VFI diminishes, showing that fragmentation was low on steeper slopes.

Elevation

Elevation refers to the height of a location above a reference point, usually sea level. It is a critical factor influencing various environmental processes, such as climate, vegetation, and hydrology. In geomorphology, elevation helps to determine landscape features like slopes and valleys, impacting water flow, drainage patterns, and ecosystems. Higher elevations often experience cooler temperatures and greater precipitation. Table 4 displays the geomorphic relief zones by elevation, which are LGRA and HGRA.

Table 4. Result of elevation

Geomorphic Relief Areas	Sites	Mean	SD
LGRA	1	320	45
	2	310	50
	3	305	48
	4	315	42
	5	316	45
	6	325	47
HGRA	7	300	55
	8	310	43
	9	280	49
	10	290	40
	11	305	46
	12	307	48

The table compares measurements across different sites within two geomorphic relief areas: LGRA and HGRA. LGRA mean values range from 305 to 325, with SDs ranging from 42 to 50, showing considerable data variance. In comparison, HGRA has mean values between 280 and 310, with SD ranging from 40 to 55, indicating significantly larger variability, most significantly at Site 7, where the SD is 55. Overall, the mean values in LGRA tend to be slightly higher than those in HGRA, whereas the SD in HGRA represents more variability in the observations between sites.

Discussion

This research goal is to integrate GIS and geomorphic data to evaluate the influence of landscape features on river water quality. The elevation data determine significant variances between the LGRA and HGRA sub-basins, which influence landscape and water quality features. Higher LGRA values correspond with better DO and mostly higher pH values, indicating more stable hydrological conditions. In contrast, HGRA, with a lower elevation, has more turbidity because of steeper slopes and increased sediment flow after falls. These elevation differences help to create diverse water quality patterns, demonstrating how topography influences water flow, sediment transport, and ecosystem health. LGRA has greater pH (7.2), DO (8.5), and lower turbidity (15.3) than HGRA. In comparison, HGRA has mean values between 280 and 310, with SD ranging from 40 to 55, indicating significantly larger variability, most significantly at Site 7, where the SD is 55. In HGRA, the correlations are slightly stronger, with turbidity and temperature showing a notable positive relationship, suggesting that steeper areas have higher sediment levels, affecting temperature.

Conclusion

This research has shown that landscape factors, including elevation and landscape pattern, have a substantial impact on river water quality, underlining the significance of combining GIS and geomorphic data for successful watershed organization. The results that have been derived from the research create application possibilities between geomorphological and water quality attributes, which become the platform for the organization of river ecosystems. In HGRA, the relationships are most profound; turbidity and temperature showed a significant positive correlation, implying that steeper slopes experienced higher levels of sediment, hence influencing temperature. The amount of forest cover is the biggest increase, conventionally up from 25.4% in Flat LGRA to 60.1% in Very Steep LGRA, thus showing a very sharp increase in the forest cover with an increase in slope. Future models will be expanded to include more environmental factors and to test their applicability in other river systems to illuminate further understanding of the landscape-water quality relationships.

Author Contributions

All Authors contributed equally.

Conflict of Interest

The authors declared that no conflict of interest.

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