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Automated Drainage Characterization of Shaliganga Watershed

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ABSTRACT- Shaliganga watershed, situated in Budgam district of Jammu and Kashmir, holds critical importance for the socio-economic and environmental well-being of the region. This paper presents a comprehensive geospatial analysis of morphometric parameters of the watershed. The current study used the ASTER Digital Elevation Model (DEM) in conjunction with hydrologic analytic capabilities in ArcGIS Spatial Analyst to automatically delineate and characterize the drainage of the Shaliganga watershed for a thorough examination of its linear, areal and relief parameters. Additionally, Strahler's classification was applied for the ordering of streams. The morphometric analysis revealed that Shaliganga watershed exhibits a dendritic to sub-dendritic drainage pattern, indicative of a relatively homogeneous lithology and moderate structural control. The calculated morphometric parameters included stream order value of 4. The circularity ratio (Rc) was measured at 0.2, significantly lower than the standard range of 0.4 to 0.5, while the elongation ratio (Re) was found to be 0.35, categorizing the watershed as "elongated." These values suggest that the watershed has a stable structure but requires management to address soil erosion and degradation, especially in the Karewas and Kandi zones.

KEYWORDS: Shaliganga, Watershed, Morphometric analysis, Remote Sensing, GIS, DEM, Linear aspects, Areal aspects, Relief aspects.

I. INTRODUCTION

A watershed is a geo-hydrological unit that channels water through a system of streams to a common outlet. Food and agriculture Organization (FAO) [3], defines it as the geographical area drained by a watercourse. Essentially, a watershed refers to an area of land that directs runoff to a specific drainage point along a waterway [2]. All land belongs to some watershed, and it encompasses both the land and water area that contributes runoff to the main flow channel [16]. A watershed serves not only as a hydrological unit but also as a socio-ecological system that plays a vital role in securing food, social stability, and economic well-being, especially for rural populations [27]. Watersheds are divided by natural boundaries called water divides or ridge lines, meaning each watershed functions as an independent drainage unit [12]. Each watershed is unique, much like a fingerprint, and no two are exactly alike. Watersheds can range in size from a few square kilometers to thousands of square kilometers, and each river has its own watershed [16].

Morphometric analysis, which involves the quantitative measurement and mathematical study of landforms, plays a crucial role in understanding the geohydrological characteristics of a drainage basin, particularly in relation to terrain features and flow patterns. This analysis is essential for evaluating lake basins, prioritizing watersheds, and managing soil, water, and natural resources at a micro- level [1].

Through morphometric analysis, one can gain a comprehensive view of terrain features, such as hydrological and lithological information, slope variations, relief, groundwater recharge, soil properties, flood peaks, rock resistance, permeability, and runoff intensity. This information is valuable for geological, hydrological, groundwater assessments, civil engineering, and environmental studies [4]. The quantitative analysis of morphometric parameters is found to be of immense utility in river basin evaluation, watershed prioritization for soil and water conservation and natural resources management at watershed level. Quantitative description of the drainage system which is an important aspect of the characterization of watersheds [26].The influence of drainage morphometry is very significant in understanding the landform processes, soil physical properties and erosional characteristics. Drainage characteristics of many river basins and sub basins in different parts of the globe have been studied using conventional methods [6][23][24][9].

Morphometry also provides insight into the topographical expression of land, including aspects such as area, slope, shape, and length, all of which influence the flow patterns of streams through their impact on concentration time. These landscape parameters significantly affect stream flow [13], which can be expressed as a function of the geomorphology of a watershed. Morphometric analysis is useful for understanding the processes within a drainage basin and for comparing its characteristics. It provides insight into the historical development of the basin, making it a valuable tool for managing natural resources, such as land and water, as well as for mitigating the effects of natural disasters to achieve sustainable development. This analysis aids in the hydrological identification of a watershed and helps predict its behavior when combined with geomorphological and geological data [14].

Traditionally, morphometric analysis was conducted using contour lines from topographic maps, but modern Geographic Information System (GIS) techniques have significantly enhanced the ability to assess terrain and morphometric parameters. These techniques provide a flexible, reliable, and cost-effective approach to processing spatial data, making watershed management more efficient. By analyzing drainage patterns, soil properties, and geomorphological features, morphometric studies contribute to the sustainable management of land and water resources, enabling effective planning to mitigate natural disasters and promote resource conservation.

II. STUDY AREA

Shaliganga River watershed (Figure 1), covers an area of approximately 162 square kilometers. It is geographically positioned between latitudes 33° 44' to 34° 40' N and longitudes 74° 28' to 74° 45' E. It is the sub catchment of Dudhganga catchment of Kashmir valley. The region is characterized by a complex interplay of topographical features, ranging from the towering peaks of the Pir Panjal Mountain ranges to the gentle slopes and flat-topped plains of the Karewa formations [8]. Shaliganga river originates from the glaciers below the Ashdhar Gali (Ashtar) near the Tatakuti peak, located in the Pir Panjal Range.

The physiography of the Shaliganga watershed is marked by significant altitudinal variations, ranging from 1,567 meters to 4,663 meters above mean sea level. The higher elevations are dominated by rugged mountainous terrain, steep slopes, and alpine ecosystems. In contrast, the lower elevations of the watershed are characterized by the Karewa formations.

These are unique lacustrine deposits of the Pleistocene age, consisting of clays, sands, and silts. Shaliganga watershed experiences a temperate climate, typical of the Kashmir Valley, with distinct seasonal variations. The mean annual temperature is around 20°C, [7] with significant fluctuations between the summer and winter seasons. The drainage system of the Shaliganga watershed is highly dependent on snowmelt from the upper elevations, particularly during the spring and early summer seasons. The region receives an average annual precipitation of about 669 mm [7]. The maximum rainfall occurs between March and April, driven by westerly winds that bring moisture from the Mediterranean region. These winds strike the northern face of the Pir Panjal mountains, leading to orographic precipitation in the form of rainfall and snow. The soils within Shaliganga watershed are diverse, reflecting the varied topography, climate, and vegetation cover of the region. The soils in the area are generally of three types, viz., loamy soil, karewas soil and poorly developed mountain soil [17] as classified by the Indian Council of Agricultural Research (ICAR).

The Shaliganga River watershed is an integral component of the ecological and socio-economic fabric of the Khansahib area of Budgam district. Its unique geographical setting, diverse physiography, and varied climatic conditions make it a critical area for understanding the interactions between natural and human systems. The watershed's strategic role in supporting agriculture, tourism, and hydropower highlights its importance in sustaining and enhancing the region's development. Sustainable management of the Shaliganga watershed is essential for preserving its ecological integrity and ensuring the continued well-being of the communities that depend on it.

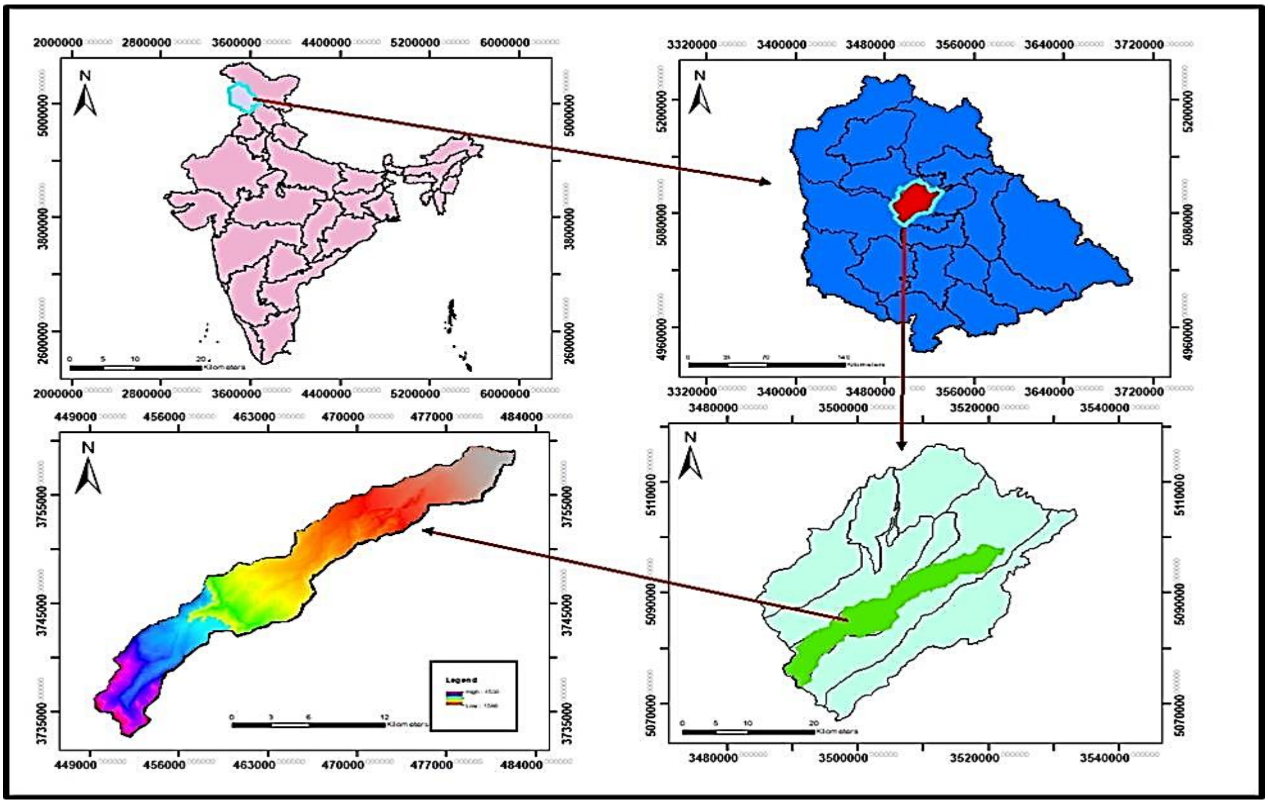

Figure 1: Study area map of Shaliganga watershed

III. METHODOLOGY

The methodology for this study consists of two main components: Watershed delineation using ArcGIS tools and Morphometric analysis based on Strahler's stream classification system. The detailed workflow is as follows:

A. *Watershed delineation using dem*

Watershed delineation was conducted using the ArcMap toolset in ArcGIS. The process is divided into the following steps:

DEM acquisition and preprocessing- The SRTM 30 m DEM tiles were downloaded from the USGS Earth Explorer platform. The tiles were mosaicked and reprojected from GCS WGS 1984 to an appropriate Projected Coordinate System for the study area.

Steps for delineation:

- Fill Sinks: Sinks (areas with artificially low values in the DEM) can interfere with accurate flow direction calculations. The Fill tool in ArcGIS was used to eliminate these depressions, producing a filled DEM that represents a continuous surface.
- Calculate flow direction: Using the filled DEM as input, the Flow Direction tool was applied to compute the flow direction for each cell. The D8 Flow Model was employed, assuming water flows from each cell to one of its eight neighboring cells depending on the steepest gradient.
- Calculate flow accumulation: The flow direction raster was used to estimate the number of upslope cells contributing flow to each point in the watershed using the Flow Accumulation tool. This helped identify areas where water converges.
- Define stream network: Based on the flow accumulation data, stream networks were defined by specifying a threshold value for the contributing area. The critical support area (threshold) was determined through trial and error, validated by comparing extracted channels with known streams from topographic maps.
- Stream segmentation: Once the stream network was derived, each stream section was assigned a unique identifier based on its flow direction, which is crucial for subsequent morphometric analysis.

B. *Morphometric analysis*

Morphometric analysis was conducted using Strahler's stream ordering system, a widely used technique for stream network classification. The smallest unbranched tributaries are assigned an order of 1 (first-order streams). When two first- order streams merge, they form a second-order stream, and so on. Stream order increases only when two streams of the same order meet, providing a hierarchical framework for the entire stream network.

Calculation of Morphometric Parameters: Using Strahler's classification, various morphometric parameters were derived to quantify the watershed's hydrological characteristics. These include(see the below table 1):

Table 1: Morphometric Parameters.

S.No	Parameter	Symbol/Formula	Reference
1	Stream order	Hierarchical rank	[24]
2	Stream length (Lu)	Length of the stream	[6]
3	Mean stream length (Lsm)	Lsm = Lu / Nu where Lu = Total stream length of order 'u' Nu = Total number of stream segments of order 'u'	[24]
4	Stream length ratio (Rl)	Rl = Lu / Lu1 where Lu = Total stream length of order 'u' Lu1= The total stream length of its next lower order	[6]
5	Bifurcation ratio (Rb)	Rb = Nu / Nu + 1 where Nu = Total no. of stream segments of order 'u' Nu + 1 = Number of segments of the next higher order	[19]
6	Mean bifurcation ratio (Rbm)	Rbm = Average of bifurcation ratios of all orders	[23]
7	Drainage density (Dd)	Dd = Lu /A where Dd = drainage density Lu = total stream length of all orders A = area of the basin(km²)	[6]
8	Stream frequency (Fs)	Fs = Nu/A where Fs = stream frequency Nu = total number of streams of streams of all orders A = area of the basin, km²	[6]
9	Drainage texture (T)	T= Nu/P where Nu = total no. of streams of all orders P = basin perimeter, km	[6]
10	Circulatory ratio (Rc)	Rc = 4 * π * A/P² where Rc = circularity ratioπ = π value i.e., 3.141 A = area of the basin, km² P² = square of the perimeter, km	[15]
11	Form factor (Ff)	Ff = A/Lb² where, Ff = form factor A = area of the basin, km² Lb = basin lengt	[19]
12	Elongation ratio (Re)	Re = 2√A /π / Lb where Re = elongation ratio A = area of the basin, km² π = π value i.e., 3.141 Lb = basin length	[19]

IV. RESULTS AND DISCUSSION

The quantitative morphometric parameters offer insights into the hydrological characteristics of a watershed. The morphometric analysis of the watershed includes calculating the linear attributes of the stream networks, the aerial aspects of the drainage basin, and the relief aspects of the channel network.

A. Linear aspects of watersheds

Stream order (Nu):
Each channel segment in a stream system has a definite position in a hierarchal order of magnitude.
Following Strahler's stream ordering system, all "fingertip" channels of the headstream have been recognized as first order streams. The merge of the two first order streams give rise to a second order segment; the union of second order streams creates a segment of the third order. The network thus goes on integrating itself up to the highest order. The trunk stream through which all discharge of water and sediment passes is therefore the stream segment of highest order. Table 2, show the number of stream segments with their lengths in each order. The study area is a 4th order drainage basin. The total numbers of 70 streams were identified of which 55 are 1st order streams, 12 are 2nd order, 2 are 3rd order and one 4th order stream. (See the below Figure 2).

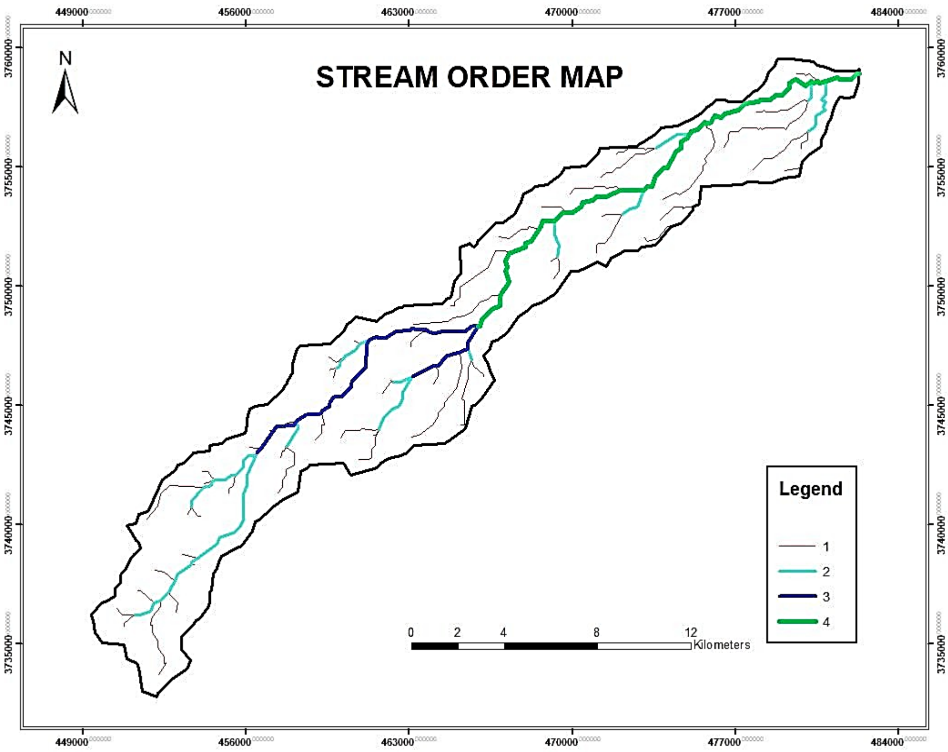

Figure 2: Stream order map of Shaliganga watershed.

Table 2: Number of streams in Shaliganga watershed.

Stream Order u	Number Of Streams Nu	Total Length of Streams Lu	Mean Stream Length (km)
1	55	80.9839	1.47
2	12	29.4095	2.45
3	2	16.4346	8.21
4	1	22.8011	22.80
Total	**70**	**149.62**	

Stream length (Lu): Stream length is a crucial hydrological attribute of a basin as it provides insight into surface runoff characteristics. Shorter stream lengths typically indicate areas with steeper slopes and finer textures, while longer stream lengths are associated with flatter gradients. Generally, the total length of stream segments is highest for first-order streams and decreases progressively with increasing stream order.
In the study area, as shown in Table 2, the order-wise mean stream lengths are 1.47 km for first-order streams, 2.45 km for second-order, 8.21 km for third-order and 22.80 km for fourth- order. The length of different stream segments can be calculated for each order, and the total and mean lengths can be determined accordingly. The mean stream length for a given order is obtained by dividing the total length by the number of stream segments of the same order. The mean stream length of a channel is a dimensional property that reveals the characteristic size of the drainage network components and its contributing basin surfaces [24]. It shows an

increasing trend with the rise in stream order, indicating that higher-order streams generally cover larger distances and have a more extensive drainage network.

Bifurcation ratio (Rb): The bifurcation ratio (Rb) is a measure that expresses the ratio of the number of stream segments in a given order to the number of stream segments in the next higher order [19]. Typically, bifurcation ratios range from 3.0 to 5.0 in basins where geological structures do not significantly influence the drainage pattern [24]. This ratio tends to remain fairly consistent across different regions unless strong geological controls are present, which can cause variations.

In the study area, the mean bifurcation ratio (Rbm) is 4.19, (Table 3) suggesting minimal structural disturbance in the drainage basin. When the bifurcation ratio varies between orders, it indicates that the irregularities are influenced by the geological and lithological development of the basin [24]. Lower bifurcation ratio values are characteristic of structurally less disturbed watersheds with undistorted drainage patterns, while ratios between 3 and 5 imply that geologic structures have not distorted the basin's drainage pattern. Higher bifurcation ratios indicate higher runoff, lower infiltration, and a more mature topography, which are often the result of variations in higher and lower order stream segments. Such higher values may also signify pronounced structural control, leading to the development of elongated and narrow drainage basins.

Table 3: Bifurcation ratio of Shaliganga watershed.

Stream Order (u)	Number Of Streams (Nu)	Bifurcation Ratio (Rb)	Mean Bifurcation Ratio
1	55	$\frac{55}{12} = 4.58$	4.19
2	12	$\frac{12}{2} = 6$	
3	2	$\frac{2}{1} = 2$	
4	1		

B. *Areal aspects of watersheds*

This section covers the description of the results derived under Areal aspects of Shaliganga watershed.

Stream frequency (Fs): Stream frequency, also known as channel frequency (Fs), is defined as the total number of stream segments of all orders per unit area [5]. It is a measure of the number of streams per unit area and indicates the relationship between drainage e characteristics and surface runoff. Higher stream frequency values are generally associated with greater surface runoff, while lower values suggest less runoff and potentially higher infiltration rates.

In the Shaliganga watershed, the stream frequency is 0.43. Low values of stream frequency typically indicate the presence of permeable subsurface materials and low-relief terrain [18]. This characteristic signifies that the area has a relatively high capacity for water infiltration, resulting in lower runoff and less channel development.

Drainage density (D): Drainage density (D) is a key concept introduced by Horton [5] and serves as an important indicator of the linear scale of landform elements in stream-eroded topography.

It is defined as the ratio of the total length of all channel segments in a basin to the basin area, expressed in terms of km/km². Drainage density provides a quantitative measure of the average length of stream channels for the entire basin and indicates the closeness of channel spacing. Regions with low drainage density are characterized by coarse drainage texture, typically occurring in areas underlain by resistant and permeable materials with significant vegetative cover and low relief. Conversely, high drainage density suggests fine drainage texture, which is common in areas with weak, impermeable subsurface material, sparse vegetation, and mountainous relief [24].

Langbein [10] highlighted that drainage density values between 0.55 and 2.09 km/km² correspond to humid regions. The drainage density value of 0.92 km/km² in the study area suggests that the Shaliganag watershed is underlain by highly permeable material. Drainage density is influenced by various factors such as resistance to weathering, rock permeability, climate, and vegetation cover.

Drainage texture (Rt): Drainage Texture is a key factor in drainage morphometric analysis and is influenced by the underlying lithology, infiltration capacity, and relief characteristics of the terrain. It is defined by Horton [6] as the ratio of the total number of stream segments of all orders to the perimeter of the watershed. In the Shaliganga watershed, the drainage texture value is 0.70, which falls under the category of very coarse drainage texture.

Smith [25] classified drainage texture into five categories: values less than 2 indicate very coarse texture, 2 to 4 indicate coarse texture, 4 to 6 indicate moderate texture, 6 to 8 indicate fine texture, and values greater than 8 indicate very fine drainage texture.

Circularity ratio (Rc): The Circularity Ratio (Rc) is defined as the ratio of the area of a watershed to the area of a circle that has the same perimeter as the watershed. Miller [15] established that a circularity ratio ranging from 0.4 to 0.5 signifies a basin that is strongly elongated and consists of highly permeable, homogeneous geological materials. This metric is influenced by a variety of factors, including the length and frequency of streams, geological formations, land use and land cover patterns, climatic conditions, and the slope of the watershed.

In the current study, the circularity ratio value for the watershed is measured at 0.2. This value, although slightly lower than Miller's indicated range, still supports the conclusion that the watershed exhibits an elongated shape. Such a shape typically correlates with lower runoff discharge, indicating that the basin experiences less rapid water flow, which can be attributed to the high permeability of the subsoil conditions present in the area.

Form factor (Ff): Form factor is the ratio of the basin area to the square of its basin length, as defined by Horton [5]. Its value is always less than 0.7854, which corresponds to a perfectly circular basin. A lower form factor value indicates a more elongated basin. The Shaliganga watershed has an Ff value of 0.99, suggesting that the basin is elongated. Such elongated basins tend to produce peak flows that are lower but sustained over a longer period. As a result, flood management is more feasible compared to circular basins, which tend to generate sharper and higher peak flows.

Elongation ratio (Re): The elongation ratio (Re) is defined by Schumm [19] as the ratio between the diameter of a circle with the same area as the drainage basin and the maximum length of the basin. Analyzing the elongation ratio helps determine that areas with higher values have a greater capacity for infiltration and reduced surface runoff. A circular basin is generally more effective at discharging runoff compared to an elongated one [21]. Typically, the elongation ratio ranges from 0.6 to 1.0 across various climatic and geological settings. Values nearing 1.0 are characteristic of regions with very low relief, whereas values between 0.6 and 0.8 are indicative of areas with high relief and steep slopes [24]. The elongation ratio values are categorized as follows: (a) circular (>0.9), (b) oval (0.8 to 0.9), and (c) less elongated (<0.7). In the present study area, the elongation ratio is 0.35, placing the catchment in the less elongated category.

C. Relief aspects of watersheds

Relief (Bh): Relief (Figure 3), refers to the difference in elevation between the highest and lowest points within a watershed. It is a measure of the overall topographical variation and steepness of the terrain. Relief is often expressed in terms of total relief (difference in elevation) or relative relief (elevation change per unit area), which helps in assessing the erosional potential and slope stability of the region.

Range of Relief Values: The values of relief can vary significantly depending on the watershed's geomorphology. In mountainous regions, relief values are typically high (e.g., > 1000 meters), while in flat or gently undulating terrains, relief values are low (e.g., < 100 meters).

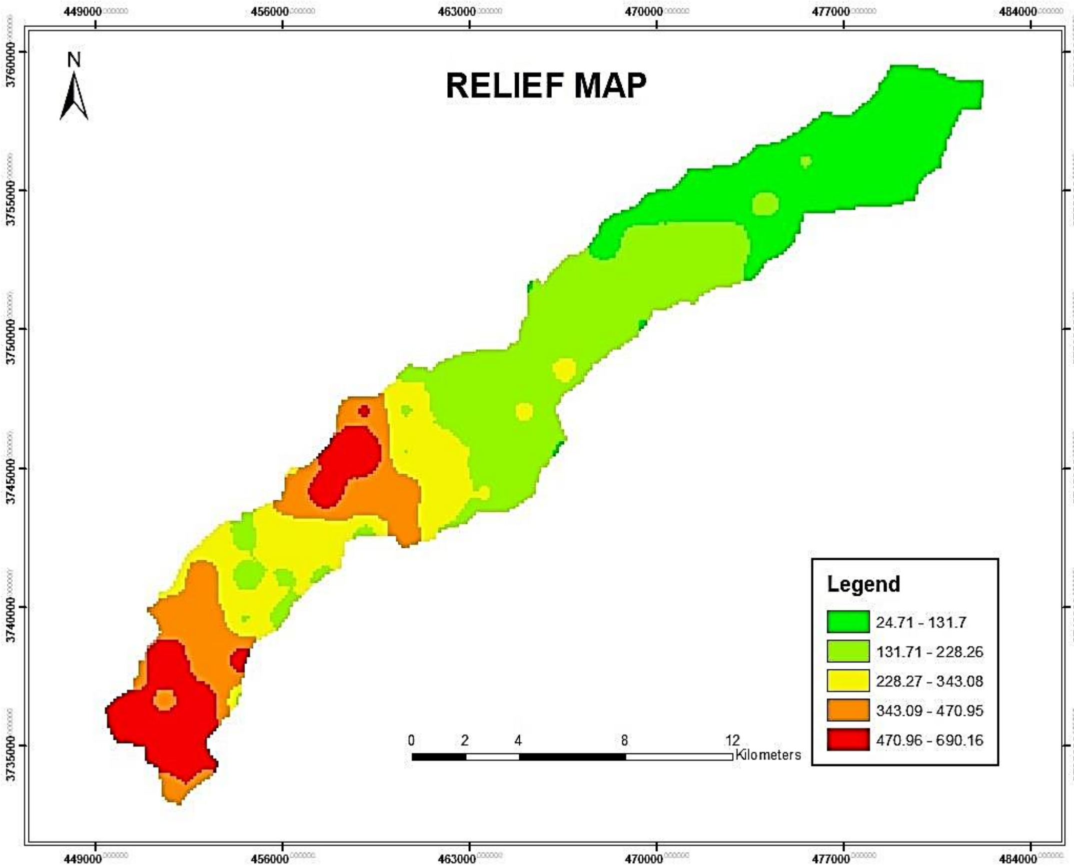

Figure 3: Relief map of Shaliganga watershed.

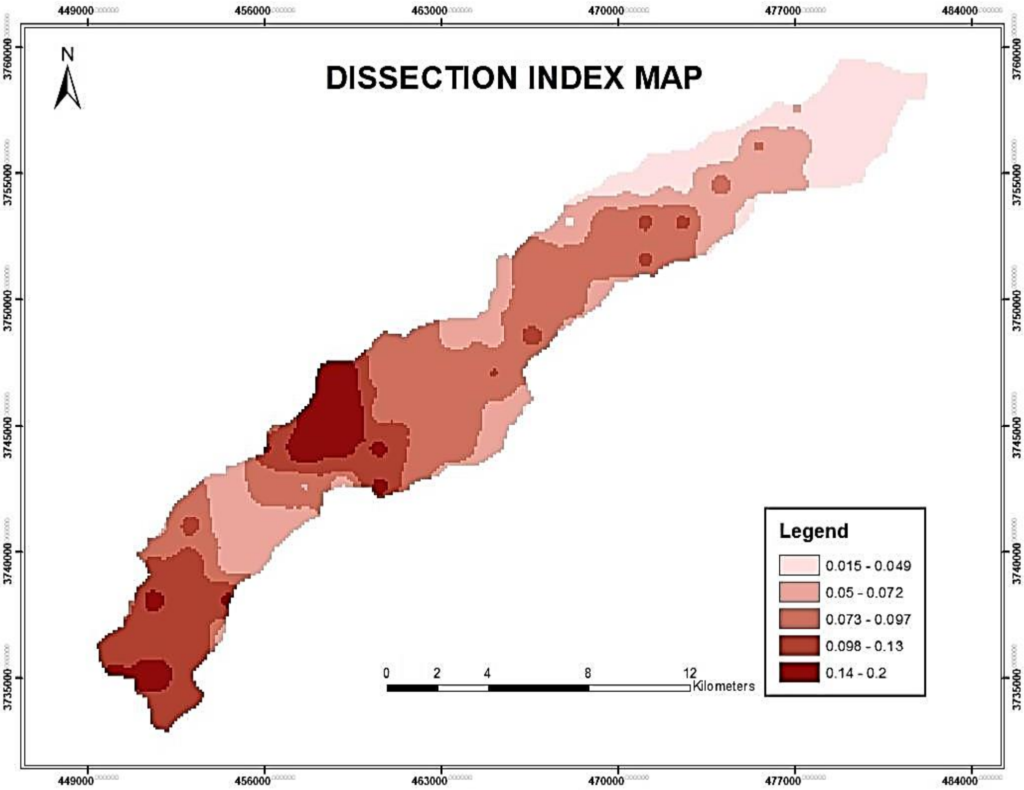

Figure 4: Dissection index map of Shaliganga watershed

Dissection Index (DI): The Dissection Index (DI) quantifies the degree of vertical erosion and landform dissection within a watershed. It is calculated as the ratio of total relief to the length of the basin, providing an indication of how deeply the landscape has been incised by erosion processes (Figure 4).

Range of Dissection Index Values: The DI values typically range from 0 to 1. A value close to 0 indicates a nearly flat or slightly dissected terrain, whereas a value closer to 1 signifies a highly dissected and rugged landscape with significant vertical erosion.

Interpretation:

- Low relief and low DI values: Represent gently sloping areas with minimal erosion, often found in plains or plateau regions.
- High relief and high DI values: Indicate steep and rugged terrains, usually associated with high erosion rates and active geological processes, such as in mountainous or hilly regions.

V. CONCLUSION

The morphometric analysis of Shaliganga watershed provides comprehensive insights into the region's physical characteristics. Situated in the Pir Panjal range of Himalayas, Shaliganga watershed, with an area of approximately 162 sq. kms forms a part of Dudganga sub catchment (one of the major left bank tributaries of Jhelum River. The watershed is divided into three distinct landform zones - plain, Karewas, and Kandi - each with unique geomorphological and hydrological characteristics.

The morphometric analysis revealed that the Shaliganga watershed has a dendritic to sub- dendritic drainage pattern, indicative of a relatively homogeneous lithology and moderate structural control. Key morphometric parameters such as stream order, bifurcation ratio, drainage density, and relief ratio were calculated to assess the watershed's geomorphological response and hydrological behavior. The bifurcation ratio values suggest that the watershed is less susceptible to flooding due to its structural stability and effective drainage network. The drainage density and stream frequency values indicate moderate to low permeability, implying that the watershed has good water infiltration capacity, which aids in groundwater recharge and minimizes surface runoff. The Circularity Ratio (Rc) for the Shaliganga watershed is measured at 0.2, which is notably lower than the standard range of 0.4 to 0.5 as established by Miller [15]. The Elongation Ratio (Re) of the watershed is found to be 0.35, placing it in the "less elongated" category. This value is significantly below the standard range of 0.6 to 1.0, which further confirms that the watershed has an elongated shape. The overall shape and slope of the watershed, as derived from the analysis, suggest that the area is relatively stable but requires attention in certain zones to prevent soil erosion and degradation.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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