

Morphometric Analysis of Beshigram Watershed in Swat Valley, Eastern Hindukush, Using GIS and Remote Sensing Techniques

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Abstract

Morphometric analysis quantitatively evaluates a drainage basin's linear, aerial, and relief parameters. This study uses various stream attributes to examine the characteristics of the Beshigram watershed, a key eastern tributary of the Swat River that joins it near Madyan. Data sources include ASTERGDEM-V3 (30m resolution) from the NASA website and toposheet 43 A/12. The Arc Hydro tool in ArcGIS 10.8.2 is employed for drainage extraction and empirical analysis. The watershed spans 151.52 km² and contains 294 streams arranged in a dendritic pattern, with the Beshigram River classified as a fifth-order stream. Key morphometric parameters include an average bifurcation ratio of 3.94, a drainage density of 1.40 km/km² (indicating moderate to sparse vegetation, impermeable rocks, and high runoff potential), a circulatory ratio of 0.623, a form factor of 0.489, and an elongation ratio of 0.8. These values suggest an oval-shaped basin with mature topography and moderate to high relief. The aerial aspects highlight the influence of relief on drainage development and the potential for prolonged high-discharge flooding. Geologically, 90% of the watershed is comprised of impermeable rocks. The DEM-derived stream network closely matches the manually digitized toposheet data. The findings demonstrate the utility of morphometric analysis in geological, hydrological, groundwater, flood forecasting, soil erosion, and flood management studies. The analysis reveals that the Beshigram watershed is vulnerable to floods and erosion, highlighting the need for management strategies like reforestation and check dams for flood risk mitigation.

Keywords: Morphometry, Bifurcation Ratio, Circulatory Ratio, Geographic Information System, Beshigram Watershed.

Introduction

A watershed is a region in which all surface water gathers and flows to a single spot before joining another stream of water. It is often served by a major stream and its associated smaller streams. The watershed ranges in size from a square kilometer to hundreds of kilometers in area. (Chopra et al., 2005; Khurana et al., 2024). Morphometry is an

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empirical representation of the shape and layout of landforms, especially watersheds (Tabunshchik et al., 2025). Morphometry is the numerical study of several basin characteristics (Roy et al., 2025).

Strahler (1964) and Thomas et al. (2010) have done extensive research on delineating watershed morphometry. Soil, geomorphology, structural geology, rock type, and plant cover all influence the evolution of drainage patterns. Morphometric analysis is the description of a watershed in terms of its linear and areal features (Horton, 1945). Horton (1932) is a pioneer in the contemporary approach to the qualitative investigation of drainage basins. Strahler (1964), Schumm (1956), Smith (1950), Miller (1953), and Shreve (1966) have modified the morphometric technique. The majority of the scholars empirically analyzed the drainage basin for landscape analysis (Ramu et al., 2013; Ghosh et al., 2021; Shit et al., 2022; Zheng et al., 2023).

The most frequently conducted procedure for morphometric analysis involves the extraction of the drainage network and watershed delineation. Geospatial techniques are used to outline the watershed from a Digital Elevation Model (DEM), which gives a good depiction of topography (Taloor et al., 2024) and may be efficiently utilized to extract various drainage basin characteristics (Ali et al., 2024). It is a quick and efficient approach to morphometric analysis (Martins and Giga, 2015; Chowdhury, 2024). The Texas Natural Resources Conservation Commission created the approach for GIS watershed delineation in 1997 (TNRCC, 1998). Globally, remote sensing and geographic information systems, with their capacity to integrate diverse data sources and analyze geographical data, are frequently employed for morphometry by various researchers (Shekar et al., 2024; Memon et al., 2024).

Morphometry is crucial for hydrological and groundwater investigations (Sahoo et al., 2024), prevention of soil erosion and land reclamation (Singh et al., 2021), Flash flood risk assessment (Taib et al., 2024), and soil and water conservation (Mohammed et al., 2025). Morphometric analysis is important in watershed management because it provides critical data for planning, conservation, and long-term development. It facilitates determining drainage patterns (dendritic, trellis, radial, etc.) that affect water flow and soil erosion (Chopra et al., 2005). The analysis of morphometric parameters helps forecast flood-prone locations. Identifies areas with significant runoff potential and helps with flood control approaches. Similarly, slope and relief analysis aid in the identification of erosion-prone areas (Shekar and Mathew, 2024). The length of the overland flow (Lo), and the roughness number (Rn) reflect the possibility for sediment transfer. Drainage density (Dd) and stream order (U) are used to determine groundwater recharge potential. in this

regard, the morphometry can help identify suitable locations for rainwater harvesting, percolation tanks, and reservoirs (Khurana et al., 2024). Furthermore, morphometric analysis may identify places appropriate for agriculture, afforestation, or urban growth based on slope and soil stability, as well as aid in watershed prioritizing for conservation efforts and hydrological research. It also supports climate resilience planning by comprehending hydrological responses (Bagwan and Grvali, 2021). Morphometric analysis is an essential technique in watershed management, allowing for effective resource usage, disaster mitigation, and environmental sustainability. Modern tools like GIS and remote sensing have improved the accuracy and usefulness of morphometric research in watershed planning (Singh et al., 2023).

This current study utilizes GIS and RS technologies to determine the morphometric parameters of the Beshigram watershed in the Swat River basin, Khyber Pakhtunkhwa, Pakistan. The primary goal of this research is to investigate basin features using measurements of numerous stream parameters. The study will be valuable in determining the hydrological characteristics of the Beshigram watershed.

Study Area

The Swat Valley is located in Pakistan's Khyber Pakhtunkhwa province, on the eastern slopes of the Hindukush Mountains. This region is made up of eight administrative subdivisions (tehsils): Bahrain, Barikot, Babuzai, Charbagh, Kalam, Khwaza Khela, Matta, and Mingora, which together form the Swat River watershed. The district covers an area of 5,337 km², and the study area, Beshigram watershed, is situated in the eastern part of the Bahrain Tehsil. Beshigram Lake, located east of the Beshigram watershed near Madyan at an elevation of around 3,000 meters, is accessible by partially paved roads, with the remaining portions usable by 4WD vehicles. According to historical records, catastrophic flooding occurred in July 2010, when severe precipitation caused damaging water surges that destroyed riverfront infrastructure throughout the study region (Bazai et al., 2025). Figure 1 illustrates the regional location map, and Plate 1 illustrates the orientation of the Beshigram Watershed.

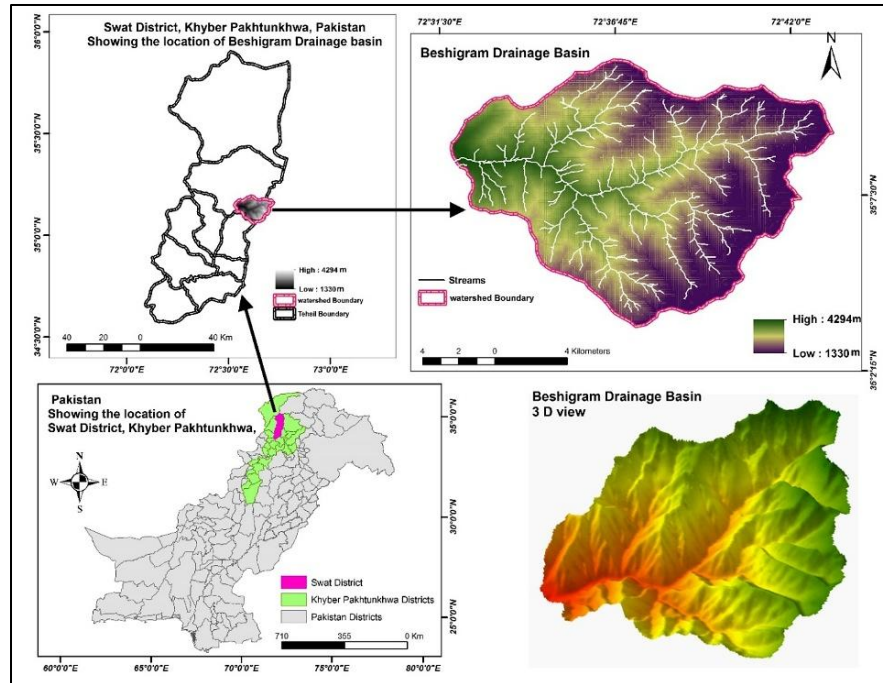


Figure 1: Showing the Location and 3-dimensional view of the study area, Beshigram Watershed, District Swat.

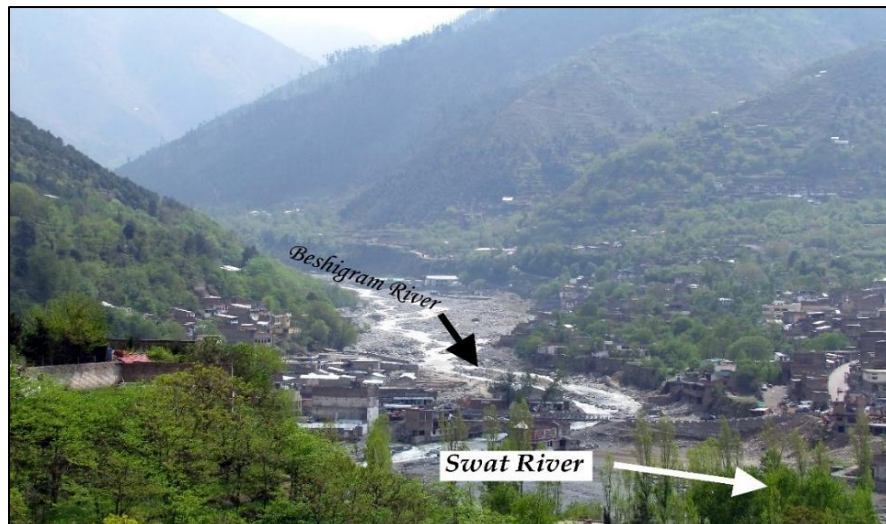


Plate 1: The picture shows the mouth of the Beshigram River, taken from the village of Shagram facing north.

Materials and Methods

This study utilized a combined approach involving the Survey of Pakistan's toposheet 43 A/12 (1:50,000 scale) and ASTERGDEM-V3 (30m resolution) to delineate the Beshigram watershed and extract its drainage network. The toposheet is scanned, georeferenced in ArcMap 10.8.2, and used as a base map for digitizing stream networks and watershed boundaries. The digital elevation model (DEM) is obtained from ASTERGDEM-V3 (released August 5, 2019; source: NASA's ASTER website), which offers enhanced accuracy with increased stereo-pair coverage and reduced anomalies compared to previous versions.

Before stream network extraction, sink removal is performed to eliminate depressions that disrupt hydrological flow modeling. This process, commonly executed using the ArcHydro extension (Azizian & Shokoohi, 2015; Lindsay, 2016; Awasthi, 2025), ensures a continuous flow path. A flow accumulation grid is generated from the flow direction grid, and a 1% threshold (following Azizian & Shokoohi, 2015; Bashir & Alsalman, 2024) is applied to derive the stream network. The Strahler (1964) method, widely adopted for its simplicity, is employed for stream ordering. Stream counts and lengths are recorded for each order, and morphometric parameters (linear, aerial, and relief) are computed using established equations (Horton, 1945; Strahler, 1964; Schumm, 1956; Shreve, 1966; Jenson & Dominque, 1988). Figure 2 illustrates the methodological workflow, adapted from Grohmann et al. (2007), Panhalkar (2014), and Shekar & Mathew (2024).

Results and Discussions

Linear Aspects of the Drainage Basin

Stream Order (U)

Several stream ordering systems have been developed for quantitative drainage network analysis in geomorphology, including those by Horton (1945), Strahler (1964), Shreve (1966), and Hodgkinson et al. (2006). This study adopts the Strahler method due to its simplicity and widespread application. In this hierarchical system:

- First-order streams represent unbranched headwater channels
- Confluence of two first-order streams forms a second-order channel
- The highest-order stream (receiving tributaries from all lower orders) constitutes the main channel

The Beshigram River is classified as a fifth-order stream within its watershed. The dendritic drainage pattern observed suggests homogeneous surface texture and minimal structural influence on channel

development. Complete drainage network characteristics are presented in Table 2.

Table 1: Morphometric parameters and their mathematical formulas.

Morphometric Parameters		Formula/Definition	References	
A Drainage network				
Linear Aspects	1	Stream order (u)	Ranking of Streams	Strahler (1964)
	2	Number of Streams (N _u)	N=N ₁ +N ₂ +.....+N _n	Horton (1945)
	3	Stream Length (Km) (L _u)	L _u = L ₁ + L ₂ + ... + L _n	Strahler (1964)
	4	Stream length ratio (R _L)	$R_L = L_u / (L_{u-1})$ Where L _u is the stream length and L _{u-1} stream length of the next lower order	Horton (1945)
	5	Bifurcation ratio (R _b)	$R_b = N_u / N_{u+1}$ Where N _u is the stream number, and N _{u+1} is the number of streams in the next higher order	Schumm (1956)
B Drainage Texture Analysis				
Texture Aspects	6	Stream Frequency (F _s)	$F_s = N_u / A_u$ Where N _u is the Sum of all the stream numbers, and A _u is the Drainage Basin Area	Horton (1945)
	7	Drainage Density (D _d)	$D_d = L_u / A_u$ Where Lu is the sum of the length of all the stream segments within a drainage basin, and Au is the drainage area	Horton (1945)
	8	Drainage Intensity (D _i)	$D_i = F_s / D_d$ Where F _s stream frequency and D _d is the drainage density.	Faniran (1968)
	9	Length of Overland Flow (L _o)	$L_o = 1/2D_d$ Where D _d is the drainage density.	Horton (1945)
C Basin Geometry				
Aerial Aspects	10	Basin length Km (L _b)	Length of the basin (km)	Horton (1945)
	11	Basin area km ² (A)	Area of the watershed (km ²)	Horton (1945)
	12	Basin perimeter km (P)	Perimeter of the watershed (km)	Horton (1945)
	13	Form factor (ratio) (R _f)	$R_f = A / L^2$ Where A is the Drainage basin area, L ² Length of the Drainage basin	Horton (1945)
	14	Elongation ratio (R _e)	$R_e = D_o / L_b$ Where D _o diameter of the circle with the same area as that of the basin, L _b maximum basin length	Schumm (1956)
	15	Shape factor (B _s)	$B_s = L_b^2 / A$ Where L _b maximum basin length and A is the area of the basin	Horton (1945)
	16	Circulatory Ratio (R _c)	$R_c = A_u / A_c$ Where A _u is the Drainage basin area and A _c Circle area with the same perimeter as the basin	Strahler (1964); Faniran (1968)
	17	Drainage Texture (D _t)	$D_t = N_u / P$ Where N _u is the total number of streams of all orders, and P perimeter of the basin (km)	Horton (1945)
D Relief characteristics				
Relief Aspects	18	Basin Relief (B _h) ot total Relief (H) In meter	$B_h = h-h_1$ Where h is the maximum and h ₁ is the minimum height of the basin in meters.	Schumm (1956)
	19	Relief ratio (R _r)	$R_r = B_h / L_b$ B _h basin relief and L _b basin length	Strahler (1964)
	20	Ruggedness number (R _n)	$R_n = D_d * (B_h / 1000)$ Where D _d is the drainage density and B _h basin relief	Strahler (1964)

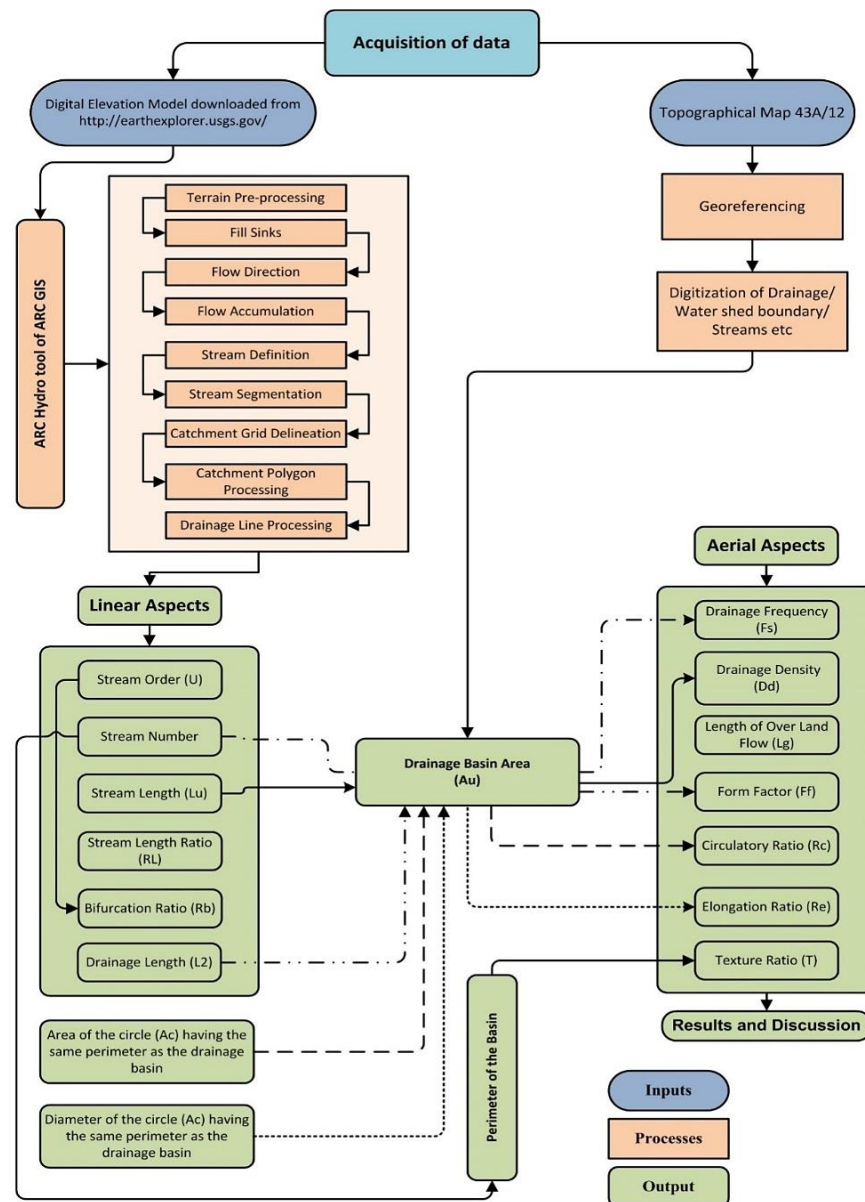


Figure 2: Methodology adopted for morphometric analysis of Beshigram Watershed in ArcMap 10.8.2. Arc Hydro tool.

Table 2: Drainage Network Characteristics of Beshigram Watershed.

S. No	Stream Order (N_u)	Stream Number	Bifurcation Ratio (R_b)	Total Stream Length (L_u) km	Mean Stream Length km
1	1 st Order	232	-	109.61	$109/232 = 0.47$
2	2 nd Order	44	4.14	48.03	$48.03/44 = 1.09$

3	3 rd Order	13	4.30	29.04	$29.04/13 = 2.23$
4	4 th Order	04	3.25	13.10	$13.10/04 = 3.20$
5	5 th Order	01	4.0	12.78	$12.78/01 = 12.78$

Source: ASTERGDEM-V3, processed in the Arc Hydro tool of ArcGIS 10.8.2.

Stream Number (N_u)

The stream number quantifies the total channel segments within a given stream order of a watershed. This metric demonstrates an inverse logarithmic relationship with stream order, as stream order increases, the corresponding number of channels decreases significantly. Higher stream frequency typically reflects geological conditions characterized by impermeable lithology, reduced infiltration capacity, and consequently increased surface runoff potential.

Through comprehensive drainage network analysis, the Beshigram watershed is found to contain 294 distinct stream segments distributed across orders as follows:

- 232 first-order channels
- 44 second-order channels
- 13 third-order channels
- 4 fourth-order channels
- 1 fifth-order channel (the Beshigram River main stem)

This hierarchical distribution confirms the typical drainage network structure where lower-order streams dominate the channel population.

Bifurcation Ratio (R_b)

The bifurcation ratio (R_b) represents a fundamental morphometric parameter that quantifies the relationship between successive stream orders within a watershed. Mathematically, it is expressed as equation 1:

$$R_b = N_u / N_{u+1} \quad (1)$$

Where, N_u = total number of streams of a given order.

N_{u+1} = total number of streams in the immediately higher order

This dimensionless parameter serves as a key indicator of drainage network structure. For the Beshigram watershed, analysis yielded an average R_b value of 3.92 (Table 1), with observed variations across different stream orders. These fluctuations primarily reflect the variations in watershed morphology and geological heterogeneity within the basin.

While the ideal minimum value is 2.0, natural watersheds seldom exhibit this ratio in practice. Homogeneous geological formations typically show consistent R_b values (Zaremotlagh et al., 2016). Watersheds with minimal lithological influence generally demonstrate R_b values between 3-5 (Gokhale, 2005). Basin shape significantly influences R_b values. Higher R_b values in elongated basins correlate with prolonged but attenuated peak discharges (Harinath and Raghu, 2013). The ratio

directly affects runoff characteristics and flood potential of a particular watershed. The observed Rb patterns in the Beshigram watershed suggest moderate geological control on drainage development, with basin morphology playing a predominant role in shaping hydrological responses.

Stream Length Ratio (RL)

Horton's law of stream length establishes a geometric relationship between successive stream orders through the Length Ratio (R_L) parameter. This fundamental principle demonstrates that average stream lengths typically exhibit an inverse relationship with increasing stream order (Figure 3). The mathematical expression for the Length Ratio is given by Equation 2:

$$RL = L_u / L_{u-1} \quad (2)$$

Where, L_u = mean length of streams in a given order

L_{u-1} = mean length of streams in the preceding lower order

Analysis of the Beshigram watershed revealed significant variations in length ratios: 5.0 between first and second-order streams and 1.01 between third and fourth-order streams. The decreasing length ratio pattern aligns with Horton's theoretical framework. The substantial difference between lower-order (1st-2nd) and higher-order (3rd-4th) ratios suggests distinct geomorphological controls on channel development and varying erosional processes across different stream orders. The near-unity ratio (1.01) for higher orders indicates relative stability in channel dimensions and Mature drainage characteristics in upper watershed sections.

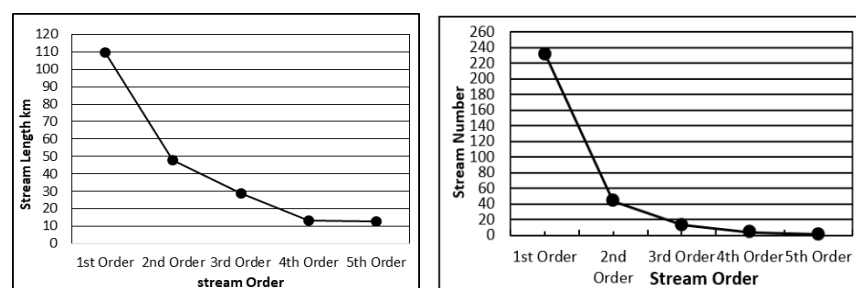


Figure 3: Relation between Stream Length, Stream Number, and Stream Order of Beshigram Watershed.

Watershed Area (A_u)

A watershed represents the complete land area that contributes surface water flow to a common outlet point through a network of streams and their tributaries. This hydrological unit collects all precipitation and

runoff, channeling it toward a single discharge location, typically the basin's terminal point. For the Beshigram River system, the analysis reveals that the total watershed area is 151.52 km². The quantified watershed dimensions provide essential baseline data for hydrological modeling, water resource management, flood risk assessment, and ecological studies.

Aerial Aspects

Drainage Frequency (Fs)

Horton (1945) established stream frequency (Fs) as a fundamental morphometric parameter representing the number of stream segments per unit area (km²). This metric serves as a critical indicator for evaluating:

- Groundwater recharge potential of a specific watershed
- Lineament density patterns
- Watershed hydrological characteristics

The parameter reflects the combined influence of:

- Geological composition
- Soil infiltration capacity
- Topographic relief
- Drainage network configuration and Precipitation characteristics (Pareveen et al., 2012).

The computational formula is expressed as Equation 3:

$$Fs = \Sigma Nu / Au \quad (3)$$

Where, ΣNu = total number of stream segments (294)

Au = drainage basin area (151.52 km²)

For the Beshigram watershed:

$$Fs = 294 / 151.52 = 1.94 \text{ streams/km}^2$$

The calculated frequency value (1.94 streams/km²) indicates steep topographic gradients (high relief, dominance of impermeable lithologies, enhanced surface runoff generation, and increased flood susceptibility).

Drainage Density (Dd)

Drainage density (Dd), a fundamental morphometric parameter, quantifies the total stream length per unit watershed area. The parameter is mathematically defined as Equation 4:

$$Dd = \Sigma Lu / Au \quad (4)$$

Where, ΣLu = total stream length (212.56 km)

Au = drainage basin area (151.52 km²)

For the Beshigram watershed:

$$Dd = 212.56 / 151.52 = 1.40 \text{ km/km}^2$$

The drainage density reflects the interaction between:

- Basin morphology
- Active surface processes (Gregory & Walling, 1973).
- Watershed hydrological characteristics, D_d , directly correlate with runoff potential (Rogers, 1971)
- Serves as an erosion capacity indicator
- Measures drainage network efficiency
- Lithological properties (Rao et al., 2009)
- Vegetation coverage extent (Zaremotlagh et al., 2016)
- Infiltration capacity of underlying strata

The computed D_d ($D_d = 1.40 \text{ km/km}^2$) suggests the predominance of impermeable lithologies (low porosity), sparse vegetative cover, enhanced surface runoff generation, indicating watershed susceptibility to rapid hydrological response and significant erosional potential.

Figure 4 illustrates the impact of geology on drainage density, revealing the Dominance of igneous bedrock, characteristically low porosity lithology, limited infiltration capacity, and strong structural control on drainage development.

Form Factor (Rf)

The form factor (R_f), introduced by Horton (1932), represents a fundamental morphometric parameter that quantifies the relationship between a watershed's area and its axial length. The parameter is calculated as equation 5:

$$R_f = A / Lb^2 \quad (5)$$

Where, A = total drainage area (151.52 km^2)

Lb = basin length (17.59 km)

For the Beshigram watershed:

$$R_f = 151.52 / (17.59)^2 = 0.489$$

The form factor interprets the watershed shape characteristics. The calculated R_f value (0.489) suggests a semi-elliptical basin morphology. The values <0.5 indicate watershed elongation, while perfectly circular basins typically exhibit $R_f >0.78$ (Harinath & Raghu, 2013). The runoff response implications of the computed R_f value suggest reduced peak discharges, prolonged flow duration, sharper flood peaks, and shorter duration hydrographs. Morphometric Significance of the intermediate R_f value (0.489) indicates a moderate basin elongation, balanced runoff characteristics, and transitional morphology between circular and elongated forms.

Circulatory Ratio (RC)

The circularity ratio (RC), as defined by Herinath and Raghu (2013), represents a quantitative measure comparing a watershed's actual

area to that of a circle with equivalent perimeter length. The parameter is calculated as equation 6:

$$Rc = Au / Ac \quad (6)$$

Where, Au = actual basin area (151.52 km²)

Ac = area of an equivalent – perimeter circle (243.11 km²)

For the Beshigram watershed:

$$Rc = 151.52 / 243.11 = 0.623$$

According to Bahrami and Stokes (2023), lower values (<0.6) are indicative of highly elongated basins with structural control, higher values (>0.7) suggest well-developed, circular basins, and moderate values (0.6-0.7) suggests transitional morphology with moderate relief.

The geomorphological interpretation of the circulatory ratio (0.623) suggests intermediate topographic relief, with a moderately developed drainage network, fan-shaped watershed morphology, and enhanced runoff potential. The values approaching 1.0 suggest advanced geomorphic maturity of the watershed (Pareveen et al., 2012). The hydrological Implications suggest Balanced erosional development, a transitional stage between youth and maturity and moderate stream network organization.

Elongation Ratio (Re)

Schumm (1956) established the elongation ratio (Re) as a key morphometric parameter that compares a watershed's geometry to an equivalent-area circle. The parameter is mathematically defined as equation 7:

$$Re = [2 \times (Au/\pi)^{0.5}] / Lb \quad (7)$$

Where, Au = basin area (151.52 km²)

Lb = maximum basin length (17.59 km)

Theoretically, the elongation ratio ranges between 0.6 to 1.0. It varies with variation in geological composition, climatic influences, and watershed geomorphic evolution stage. According to Waikar & Nilawar (2014), the elongation value of 0.9 is indicative of a circular watershed, 0.8-0.9 indicates an oval shape, and <0.7 suggests an elongated watershed. The calculated Re value of Beshigram Watershed is 0.8, which indicates an oval-shaped watershed morphology with moderate to steep slopes (Strahler, 1964). It also indicates an intermediate stage of geomorphic development and balanced hydrological response characteristics. The hydrological implication of the computed Re value reveals moderate drainage network integration, transitional watershed form between circular and elongated, heterogeneous lithology, moderate relief conditions with active erosional processes.

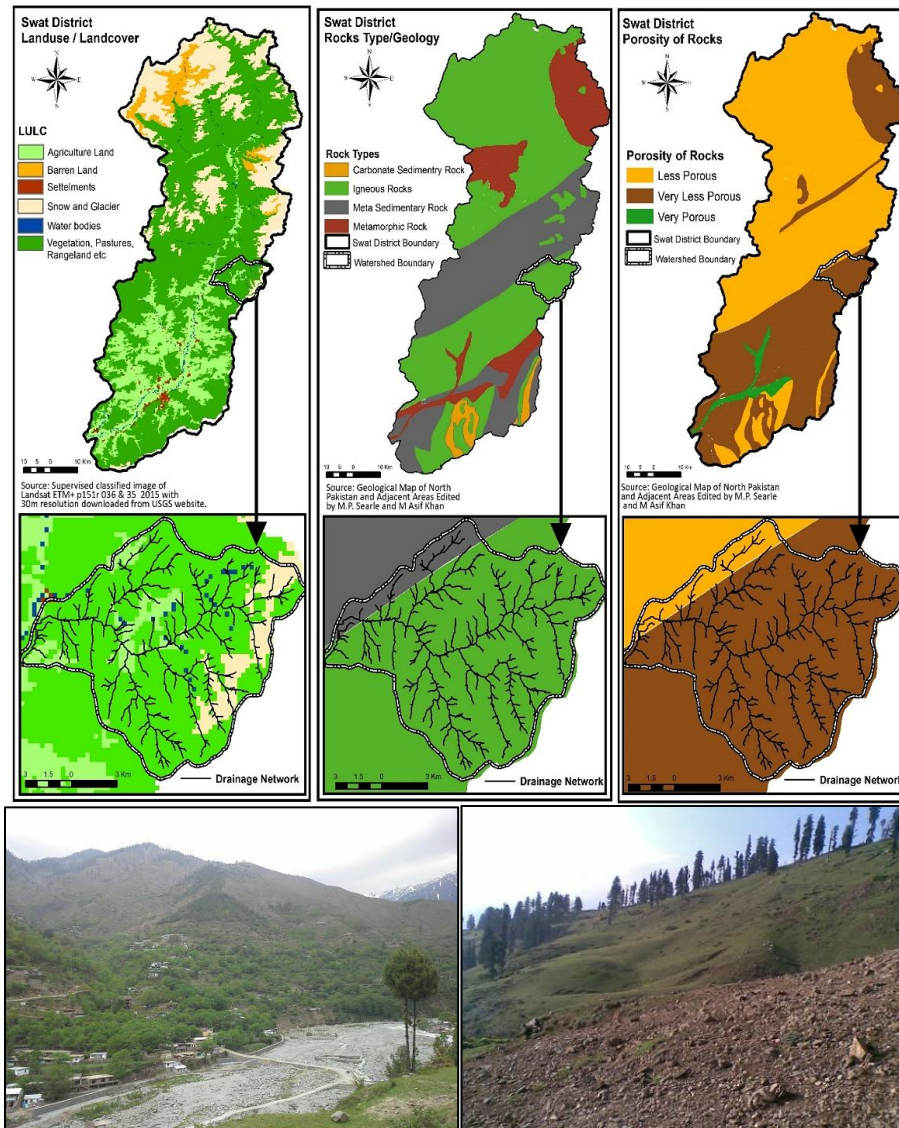


Figure 4: shows the relationship between Land use / Land cover (vegetation), Geology rock type and porosity of rock with the drainage network. The pictures are showing the sparse vegetations of Beshigram watershed.

Shape Factor (B_s)

Schumm (1956) introduced the shape factor (B_s) as a critical morphometric parameter that relates basin length to drainage area. This dimensionless ratio provides insights into sediment transport dynamics and is calculated as Equation 8:

$$Bs = Lb / Au \quad (8)$$

Where, Lb = maximum watershed length (km)

Au = total drainage area (151.52 km²)

The calculated Bs value for the Beshigram Watershed is 2.04, which suggests an elongated watershed morphology with extended sediment transit times. The hydrological implications of the computed Bs value reveal a longer basin configuration, which leads to reduced sediment transport efficiency, increased deposition potential, decreased peak sediment yields, and gradual sediment accumulation patterns. Higher Bs values (>2.0) characterize linear watershed configurations, extended concentration times, and reduced flood peaks. The lower Bs values (<1.5) indicate compact watershed forms, rapid sediment mobilization, and flashier hydrological response (Rana et al., 2021).

Drainage Texture (Dt)

Horton (1932) established drainage texture (Dt) as a fundamental morphometric parameter calculated as the ratio of total stream segments to watershed perimeter. This metric provides valuable insights into landscape dissection patterns. Equation 9 expressed the Dt mathematically:

$$Dt = (\sum Nu) / P \quad (9)$$

Where, $\sum Nu$ = cumulative stream count (all orders)

P = watershed perimeter length (km)

According to Smith (1950), texture Classification, the Dt value of >8 streams/km suggests very fine, 6-8 streams/km fine, 4-6 streams/km moderate, 2-4 streams/km coarse, and Dt value of <2 streams/km is the indicative of very coarse drainage texture. The computed Dt value for the Beshigram watershed is 5.26, which suggests moderate drainage texture with moderate slope gradients, balanced stream spacing, and moderate dissected terrain. The drainage texture is influenced by precipitation intensity and distribution, vegetation density, and soil infiltration capacity. According to Kasi et al., (2020), the higher Dt values (>6) suggest steep terrain, high drainage density with rapid runoff response, while the lower Dt values (<4) indicate the gentle slopes and wider stream spacing, with reduced hydrological response

Relief Characteristics

The basin relief (Bh) represents a fundamental topographic parameter that quantifies the vertical difference between the highest and lowest points within a watershed. This metric serves as a critical indicator of geomorphic energy potential and, in turn, determines the gravitational energy available for sediment transport and thus influences the rate and

intensity of erosional processes. Hydrologically, it signifies the control of runoff velocity and stream competence and affects sediment delivery ratios. The basin relief is calculated as Equation 10:

$$Bh = H - h \quad (10)$$

Where, H = maximum elevation (4,294 m)

h = minimum elevation (1,330 m)

The computed basin relief for the Beshigram watershed is 2,964 m, suggesting extremely high energy environment and significant erosion potential and enhanced sediment transport capacity. The high basin relief indicates that during intense precipitation events, the watershed may have accelerated hillslope processes, increased mass wasting potential and high sediment yields. The long-term geomorphic consequences include rapid landscape evolution, deep valley incision, and pronounced topographic contrasts.

Relief Ratio (Rh)

Schumm (1956) developed the relief ratio (Rh) as a key morphometric parameter that relates vertical relief to horizontal basin dimensions. This dimensionless index provides critical insights into landscape dynamics. Equation 11 mathematically expressed the relief ratio.

$$Rh = Bh / Lb \quad (11)$$

Where, Bh = total basin relief (2,964 m)

Lb = maximum basin length (19.95 km)

The calculated Rh value for the Beshigram watershed is 0.148, which suggests a youthful geomorphic stage, a high-energy environment, significant landscape instability, significant slope gradients throughout the watershed, high-intensity erosional processes, and high sediment production potential. Geomorphologically, it directly correlates with sediment yield per unit area (Schumm, 1956), indicating dominant erosion mechanisms and mass wasting potential. The hydrological implications of the computed Rh value suggest rapid runoff generation, high stream velocities, with increased sediment transportation capacity.

Ruggedness Number (Rn)

The ruggedness number (Rn) is a geomorphological index defined as the product of drainage density (Dd) and basin relief (Bh), divided by 1000 (Strahler, 1964). In the study area, the calculated Rn value is 4.14, suggesting moderately undulating topography. Higher Rn values typically correlate with increased vulnerability to soil erosion, landslide occurrences, and elevated surface runoff during intense precipitation events.

The formula for computing R_n is expressed as equation 12:

$$R_n = Dd \times (Bh / 1000) \quad (12)$$

Applying the given values, $R_n = 1.40 \times (2964 / 1000)$

$$R_n = 1.40 \times 2.964 = 4.14$$

The R_n value (< 1.0) indicates gentle, low-relief terrain with negligible risk of erosion and low runoff potential. The moderate R_n value (1.0–5.0) suggests undulating to moderately steep topography with moderate erosion and runoff potential. The high R_n value (> 5.0) reflects rugged, mountainous terrain highly susceptible to soil erosion, landslides, and flash floods during intense rainfall (Ganie et al., 2022; Bashir and Alsaman, 2024).

Conclusion

The Beshigram watershed's drainage network comprises of 294 streams, hierarchically structured into 232 first-order, 44 second-order, 13 third-order, and 4 fourth-order channels. The drainage pattern is predominantly dendritic, indicating minimal structural influence, with the Beshigram River representing the highest order as a fifth-order stream. The morphometric indices—mean bifurcation ratio ($R_b = 3.92$), elongation ratio ($R_e = 0.8$), and circularity ratio ($R_c = 0.627$)—collectively suggest an oval-shaped basin. The elevated basin relief (B_h), steep gradients, and semi-rounded morphology, coupled with a high bifurcation ratio, indicate rapid peak discharge and heightened runoff potential.

The drainage density ($D_d = 1.40 \text{ km/km}^2$) reflects sparse vegetation, low permeability, and substantial surface runoff, consistent with the region's igneous geology and land use patterns (Figure 4). Additionally, the form factor (0.396) denotes an elongated basin with prolonged water flow duration. The high relief (2964 m), relief ratio (0.148), and ruggedness number (4.14) further confirm undulating terrain with significant erosion risks, particularly during intense precipitation.

The hydrological and geomorphological implications of the study underscore the utility of watershed morphometry in evaluating topographic characteristics, including geology, slope, permeability, and erosion dynamics. The findings aid in assessing aquifer recharge potential, flood susceptibility, and runoff behavior.

The watershed's high stream density, steep slopes, and rugged terrain amplify its vulnerability to flash floods, landslides, and soil erosion, particularly in deforested zones. These insights emphasize the need for integrated watershed management, including afforestation to enhance infiltration and reduce runoff, slope stabilization measures to mitigate landslides, and check dam construction to control sediment flow and regulate water discharge.

This research provides critical data for flood and erosion mitigation, supporting sustainable land-use planning in geologically active regions. The morphometric approach offers a cost-effective and efficient means of assessing hydrological risks, aiding policymakers in disaster preparedness and environmental conservation. The use of ArcGIS 10.8.2 hydrology tools proved effective for morphometric analysis, with digitally derived stream networks closely matching manual delineations.

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