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

Muhammad Jamal Nasir[*], Anwar Saeed Khan[†], Said Alam[‡], Kashif Mehmood[§]

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 comprise 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

---

[*]Corresponding Author: Department of Geography & Geomatics, University of Peshawar, Peshawar 25120, Pakistan, drjamal@uop.edu.pk

[†]Department of Geography & Geomatics, University of Peshawar, Peshawar 25120, Pakistan, asaeed_geo@uop.edu.pk

[‡]Department of Geography & Geomatics, University of Peshawar, Peshawar 25120, Pakistan, saidalamgeo@gmail.com

[§]Department of Geography, Government College University Faisalabad, Faisalabad 38000, Pakistan, kashif.mahmood@gcuf.edu.pk

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 Bashigram 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.

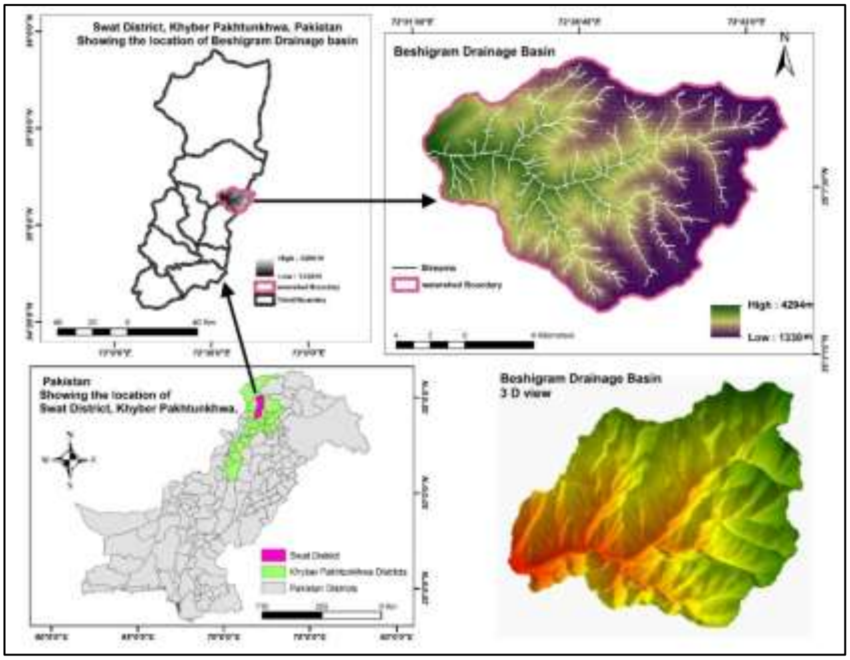

Figure 1: Showing the Location and 3-dimensional view of the study area, Beshigram Watershed, District Swat.

Plate 1: The picture shows the mouth of the Bishigram 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)	$N=N_1+N_2+\ldots+N_n$	Horton (1945)
	3	Stream Length (Km) (L_u)	$L_u = L1 + L2 + \cdots + Ln$	Strahler (1964)
	4	Stream length ratio (R_L)	$R_L = L_u / (L_u\text{-}1)$ *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)	$Dd = Lu/Au$ *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)	$R_e = D_c/L_b$ *Where D_c, 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 Au 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	$B_h = h\text{-}h_1$ *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)

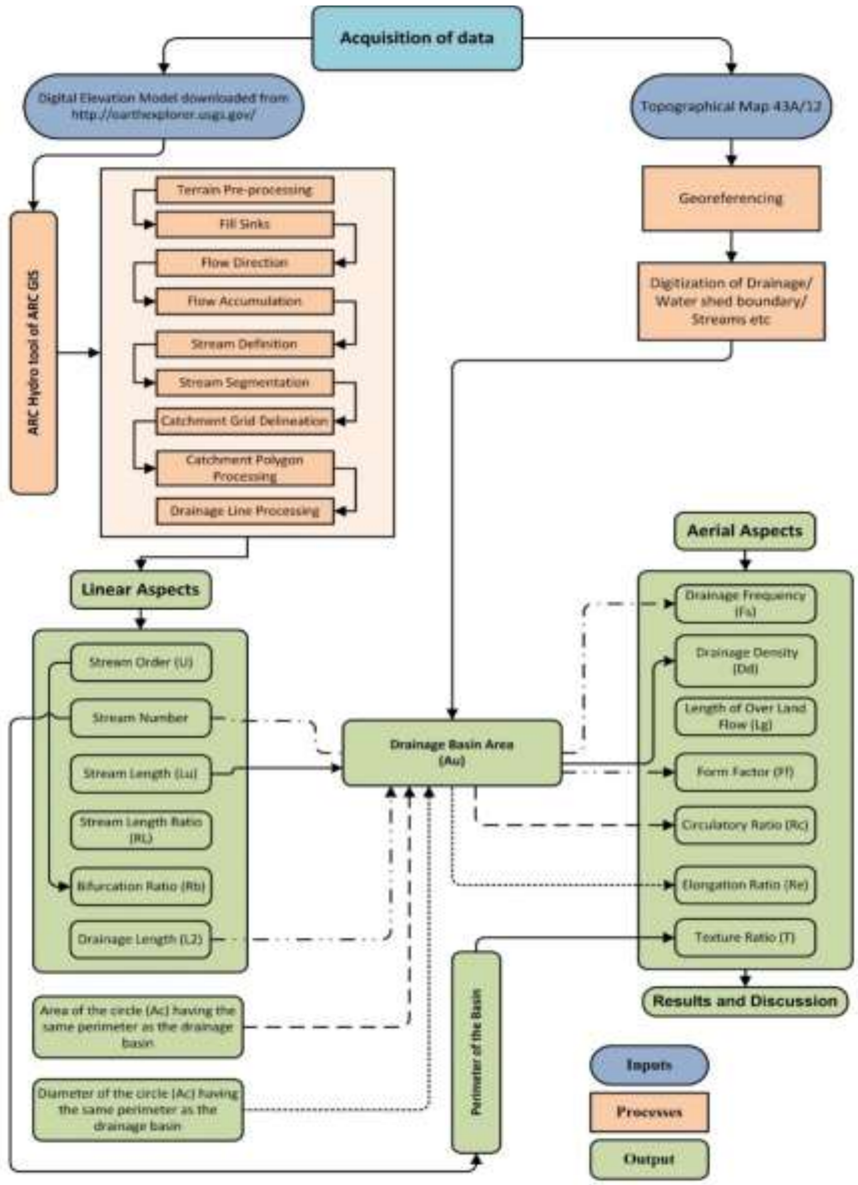

Figure 2: Methodology adopted for morphometric analysis of Beshigram Watershed in ArcMap 10.8.2. Arc Hydro tool.

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	1st Order	232	-	109.61	109/232 = 0.47
2	2nd Order	44	4.14	48.03	48.03/44 = 1.09
3	3rd Order	13	4.30	29.04	29.04/13 = 2.23

4	4th Order	04	3.25	13.10	13.10/04 = 3.20
5	5th 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 (Rb)

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

$$Rb = Nu / Nu + 1 \quad (1)$$

$Where, Nu = total\ number\ of\ streams\ of\ a\ given\ order.$

$Nu + 1 = total\ number\ of\ streams\ in\ the\ immediately\ higher\ order$

This dimensionless parameter serves as a key indicator of drainage network structure. For the Beshigram watershed, analysis yielded an average Rb 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 Rb values (Zaremotlagh et al., 2016). Watersheds with minimal lithological influence generally demonstrate Rb values between 3-5 (Gokhale, 2005). Basin shape significantly influences Rb values. Higher Rb 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:

$$RL = Lu / Lu - 1 \tag{2}$$

$Where, Lu = mean\ length\ of\ streams\ in\ a\ given\ order$

$Lu - 1 = mean\ length\ of\ streams\ in\ the\ preceding\ lower\ order$

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.

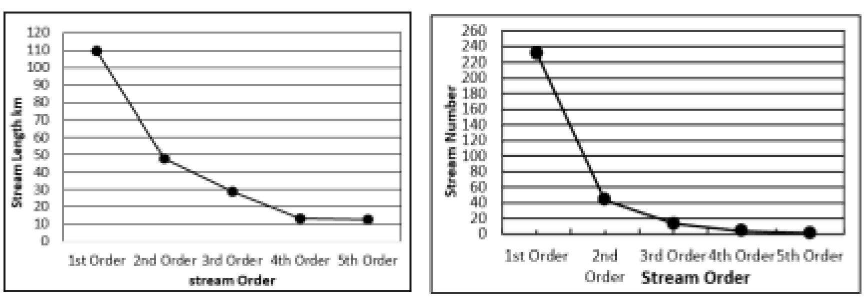

Figure 3: Relation between Stream Length, Stream Number, and Stream Order of Beshigram Watershed.

Watershed Area (Au)

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:

$$Fs = \Sigma Nu / Au \tag{3}$$

$Where,\ \Sigma Nu = total\ number\ of\ stream\ segments$ (294)

$Au = drainage\ basin\ area$ (151.52 km^2)

For the Beshigram watershed:

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

The calculated frequency value (1.94 streams/km^2) 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:

$$Dd = \Sigma Lu / Au \tag{4}$$

$Where, \Sigma Lu = total\ stream\ length$ (212.56 km)

$Au = drainage\ basin\ area$ (151.52 km^2)

$For\ the\ Beshigram\ watershed$:

$$Dd = 212.56 / 151.52 = 1.40\ km/km^2$$

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 Dd (Dd = 1.40 km/km²) 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 (Rr)

The form factor (Rf), 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:

$$Rf = A / Lb^2 \tag{5}$$

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

$Lb = basin\ length\ (17.59\ km)$

$For\ the\ Beshigram\ watershed:$

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

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 Rf >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:

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

$Where, Au = actual\ basin\ area\ (151.52\ km^2)$

$Ac = area\ of\ an\ equivalent - perimeter\ circle\ (243.11\ km^2)$

$For\ the\ Beshigram\ watershed:$

$$Rc = 151.52 / 243.11 = 0.623$$

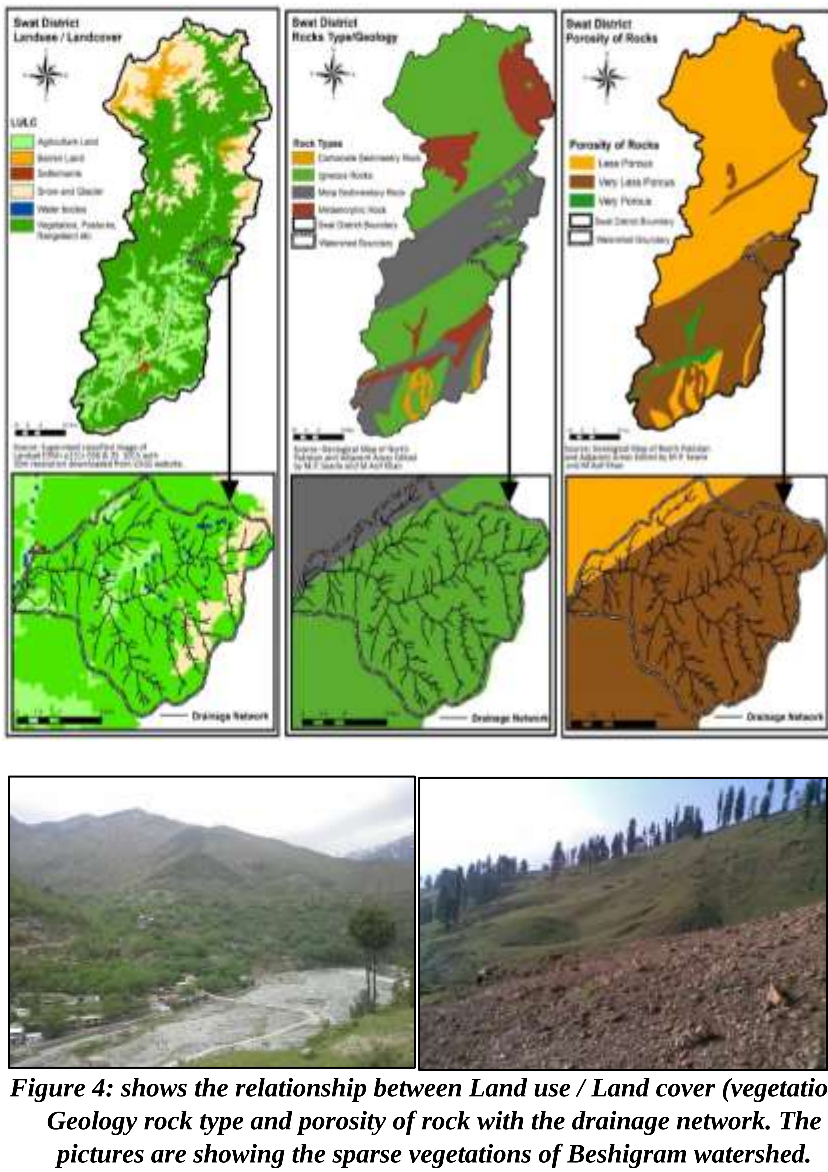

Figure 4: shows the relationship between Land use / Land cover (vegetation), Geology rock type and porosity of rock with the drainage network. The pictures are showing the sparse vegetations of Beshigram watershed.

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:

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

$Where, Au = basin\ area\ (151.52\ km^2)$

$Lb = maximum\ basin\ length\ (17.59\ km)$

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.

Shape Factor (Bs)

Schumm (1956) introduced the shape factor (Bs) 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:

$$Bs = Lb \,/\, Au \qquad (8)$$

$Where, Lb = maximum\ watershed\ length\ (km)$

$$Au = total\ drainage\ area\ (151.52\ km^2)$$

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:

$$Dt = (\sum Nu)\ /\ P \tag{9}$$

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

$P = watershed\ perimeter\ length\ (km)$

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:

$$Bh = H - h \tag{10}$$

$Where, H = maximum\ elevation\ (4{,}294\ m)$

$h = minimum\ elevation\ (1{,}330\ m)$

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.

$$Rh = Bh / Lb \tag{11}$$

$Where, Bh = total\ basin\ relief\ (2{,}964\ m)$

$Lb = maximum\ basin\ length\ (19.95\ km)$

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 Rn is expressed as equation 12:

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

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

$$Rn = 1.40 \times 2.964 = 4.14$$

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 Alsalman, 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 (Rb = 3.92), elongation ratio (Re = 0.8), and circularity ratio (Rc = 0.627)—collectively suggest an oval-shaped basin. The elevated basin relief (Bh), steep gradients, and semi-rounded morphology, coupled with a high bifurcation ratio, indicate rapid peak discharge and heightened runoff potential.

The drainage density (Dd = 1.40 km/km²) 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.

References

Ali, R., Sajjad, H., Masroor, M., Saha, T. K., Roshani, & Rahaman, M. H. (2024). Morphometric parameters-based prioritization of watersheds for soil erosion risk in Upper Jhelum Sub-catchment, *India. Environmental Monitoring and Assessment, 196*(1), 82.

Awasthi, M. P. (2025). Application of ArcHydro Tool, Geospatial Technologies and Digital Elevation Model for Watershed Modeling: A Case Study in Budhiganga Watershed of Nepal Himalaya. *International Journal of Environment and Geoinformatics*, *12*(1), 1-14.

Azizian, A., Shokoohi, A. (2015). Effects of data resolution and stream delineation threshold area on the results of a kinematic wave-based GIUH model. *Water SA, 41*(1), 61-70.

Bahrami, S., & Stokes, M. (2023). Analyzing drainage basin orientation and its relationship to active fold growth (Handun anticline, Zagros, Iran). *Geomorphology*, *426*, 108605.

Bagwan, W. A., & Gavali, R. S. (2021). An integrated approach for the prioritization of subwatersheds in the Urmodi River catchment (India) for soil conservation using morphometric and land use land cover (LULC) factors. *Journal of Sedimentary Environments*, *6*(1), 39-56.

Bashir, B., & Alsalman, A. (2024). Morphometric Characterization and Dual Analysis for Flash Flood Hazard Assessment of Wadi Al-Lith Watershed, Saudi Arabia. *Water, 16*(22), 3333.

Bazai, N. A., Alam, M., Cui, P., Hao, W., Khan, A. P., Waseem, M., ... & Ahmed, T. (2025). Dynamics and impacts of monsoon-induced geological hazards: a 2022 flood study along the Swat River in Pakistan. *Natural Hazards and Earth System Sciences, 25*(3), 1071-1093.

Chopra, R., Dhiman, R.D., Sharma, P.K. (2005). Morphometric Analysis of sub-watersheds in Gurdaspur District, Punjab using remote sensing and GIS techniques. *Journal of the Indian Society of Remote Sensing, 33*(4), 531-539.

Chowdhury, M. S. (2024). Morphometric analysis of Halda River basin, Bangladesh, using GIS and remote sensing techniques. *Heliyon, 10*(7).

Faniran, A. (1968). The Index of Drainage Intensity-A Provisional New Drainage Factor. *Australian Journal of Science, 31*: 328-330.

Ganie, P. A., Posti, R., Kunal, K., Kunal, G., Sarma, D., & Pandey, P. K. (2022). Insights into the morphometric characteristics of the Himalayan River using remote sensing and GIS techniques: a case study of Saryu basin, Uttarakhand, India. *Applied Geomatics*, *14*(4), 707-730.

Ghosh, P. K., Mukhopadhyay, R., & Jana, N. C. (2021). Quantitative analysis of drainage basin parameters towards better management of Damodar River, Eastern India. *Journal of the Geological Society of India*, *97*(7), 711-734.

Gregory, K.J., Walling, D.E. (1973). *Drainage Basin Form and Processes: A Geomorphological Approach*, Edward Arnold, London.

Grohmann, CH., Riccomini, C., Alves, F.M. (2007). SRTM-Based Morphotectonic Analysis of the Pocos de Calda.s Alkaline Massif, Southeastern Brazil. *Computers & Geosciences, 33*, 10-19.

Gokhale, K.V. (2005). Principles of Engineering Geology, B.S. Publications, Hyderabad.

Harinath, V., Raghu, V. (2013). Morphometric analysis using Arc GIS techniques: A case study of Dharuryagu, South Eastern part of Kurnool District, Andhra Pradesh, India. *International Journal of Science and Research (IJSR), 2*(1), 182-187.

Horton, R.E. (1932). Drainage Basin Characteristics. *Transaction American Geophysical Union.13*: 350-361.

Horton RE. (1945). Erosional development of streams and their drainage basins: Hydro physical approach to quantitative morphology. *Geological Society of America Bulletin. 56*, 275-370.

Hodgkinson, J.H., Mcloughlin, S., Cox, M.E. (2006). The influence of structural grain on Drainage in a metamorphic sub-catchment: Laceys Creek, southeast Queensland, Australia. *Geomorphology, 81*, 394-407

Jenson, S.K., Domingue, J.O. (1988). Extracting Topographic Structure from Digital Elevation Data for Geographic Information System Analysis, *Photogrammetric Engineering and Remote Sensing. 54*(11) 1593-1600.

Kasi, V., Pinninti, R., Landa, S. R., Rathinasamy, M., Sangamreddi, C., Kuppili, R. R., & Dandu Radha, P. R. (2020). Comparison of different digital elevation models for drainage morphometric parameters: a case study from South India. *Arabian Journal of Geosciences*, *13*, 1-17.

Khurana, L., Kumar, K., & Sing, D. P. (2024). Exploring Watersheds: Assessing Drainage Basin Characteristics and Management Approaches for Channel and Overland Flows. *International Journal of Landscape Planning and Architecture*, *10*(1), 24-34p.

Lindsay, J. B. (2016). Efficient hybrid breaching-filling sink removal methods for flow path enforcement in digital elevation models. *Hydrological Processes*, *30*(6), 846-857.

Martins, A.K., Giga, B.L. (2015). Hydrological and Morphometric Analysis of Upper Yadzaram Catchment of Mubi in Adamawa State, Nigeria. Using Geographic Information System (GIS). *World Environment*, *5*(2), 63-69

Memon, A. V., Patel, Y. S., & Parangi, T. (2024). Exploring watershed dynamics: a comprehensive review on morphometric analysis and geospatial techniques. *ISH Journal of Hydraulic Engineering*, *30*(5), 744-757.

Miller, V. C. (1953). A quantitative geomorphic study of drainage basin characteristics in the Clinch Mountain area, Virginia and Tennessee, Technical Report 3., Department of Geology, Columbia University, New York.

Mohammed, J. A., Gashaw, T., & Yimam, Z. A. (2025). Identification of erosion-prone watersheds for prioritizing soil and water conservation in a changing climate using morphometric analysis and GIS. *Natural Hazards*, *121*(4), 4171-4189.

Parveen, R., Kumar, U., Singh, V.K. (2012). Geomorphometric Characterization of Upper South Koel Basin, Jharkhand: A Remote Sensing & GIS Approach. *Journal of Water Resource and Protection 4*, 1042-1050.

Panhalkar, S.S. (2014). Hydrological Modeling Using SWAT Model and Geoinformatic Techniques. *The Egyptian Journal of Remote Sensing and Space Science*, *17*, 197-207.

Rana, V. K., & Suryanarayana, T. M. V. (2021). Estimation of flood influencing characteristics of watershed and their impact on flooding in data-scarce region. *Annals of GIS*, *27*(4), 397-418.

Ramu, B., Mahalingam, P., Jayashree. (2013). Morphometric analysis of Tungabhadra drainage basin in Karnataka using GIS. *Journal of Engineering, Computers & Applied Science*, *2* (7).

Rao, L.A.K., Rehman, Z., Sadique, M., Zahoor, I. (2009). Hydro geomorphological Studies for groundwater prospect: using IRS ID, LISS-III image, in parts of Agra district along the Yamuna

River. *Journal of Environmental Research and Development. 3*(4), 1204-1210.

Rogers, W.F. (1971). Hydrograph analysis and some selected geomorphic variables. In Morisawa, M. *Quantitative Geomorphology: Some Aspects and Applications*, 245-257.

Roy, D., Desai, V. R., & Aithal, B. H. (2025). A GIS-based integrated assessment of geomorphometry with land use dynamics for topographically harsh ungauged watershed. *Journal of Earth System Science*, *134*(2), 1-21.

Sahoo, S., Ramole, M. M., Dahiphale, P., Awasthi, S., & Pateriya, B. (2024). Geospatial technology based morphometric analysis and watershed prioritization of lower Satluj basin in India for groundwater recharge potential. *Tropical Ecology*, *65*(1), 43-58.

Shekar, P. R., & Mathew, A. (2024). Morphometric analysis of watersheds: A comprehensive review of data sources, quality, and geospatial techniques. *Watershed Ecology and the Environment*, *6*, 13-25.

Shit, P. K., Bera, B., Islam, A., Ghosh, S., & Bhunia, G. S. (2022). Introduction to drainage basin dynamics: Morphology, landscape and modelling. Drainage Basin Dynamics: An Introduction to Morphology, *Landscape and Modelling*, 1-9.

Singh, W. R., Barman, S., & Tirkey, G. (2021). Morphometric analysis and watershed prioritization in relation to soil erosion in Dudhnai Watershed. *Applied Water Science*, *11*(9), 151.

Singh, M. C., Satpute, S., & Prasad, V. (2023). Remote sensing and GIS-based watershed prioritization for land and water conservation planning and management. *Water Science & Technology*, *88*(1), 233-265.Strahler, A.N. (1957). Quantitative Analysis of American Geomorphology”, *Transaction American Geophysical Union*, *38*, 913-920

Smith KG. (1950). Standards for grading texture of erosional topography. *American Journal of Science, 248*, 655-668.

Shreve, R.L. (1966). Statistical law of stream numbers. *Journal of Geography 74*, 17-37.

Strahler, A.N. (1964). Quantitative geomorphology of drainage basins and channel networks. In: V.T. Chow (Ed.), Handbook of Applied Hydrology. McGraw-Hill, New York, 439-476.

Schumm, S.A. (1956). Evolution of drainage systems and slopes in Badlands at Perth Amboy, New Jersey. *The Bulletin of the Geological Society of America 67*, 597-646.

Taib, H., Hadji, R., Bedri, K., Defaflia, N., Hamed, Y., Gentilucci, M., ... & Pambianchi, G. (2024). Morphometric analysis and risk assessment of flash floods in the Atlas chain of eastern Algeria and the Algerian–Tunisian borders. *Euro-Mediterranean Journal for Environmental Integration*, 1-15.

Texas Natural Resource Conservation Commission (TNRCC). (1998). WAM: Water Availability Modeling, an Overview. http://www.tnrcc.state.tx.us/admin/topdoc/gi/245/

Tabunshchik, V., Dzhambetova, P., Gorbunov, R., Gorbunova, T., Nikiforova, A., Drygval, P., ... & Kiseleva, M. (2025). Delineation and Morphometric Characterization of Small-and Medium-Sized Caspian Sea Basin River Catchments Using Remote Sensing and GISs. *Water, 17*(5), 679.

Taloor, A. K., Sharma, S., Jamwal, J., & Kumar, S. (2024). Quantitative and qualitative study of the Tawi basin: Inferences from Digital Elevation Model (DEM) using geospatial technology. *Quaternary Science Advances, 14*, 100182.

Thomas, J., Joseph, S., Thrivikramaji, K.P. (2010). Morphometric Aspects of Small Tropical Mountain River System, The Southern Western Ghats, India. *International Journal of Digital Earth*, *3*(2), 135-156.

Waikar, M. L., & Nilawar, A. P. (2014). Identification of groundwater potential zone using remote sensing and GIS technique. *International Journal of Innovative Research in Science, Engineering and Technology*, *3*(5), 12163-12174.

Zaremotlagh, S., Hezarkhani, A., & Sadeghi, M. (2016). Detecting homogenous clusters using whole-rock chemical compositions and REE patterns: A graph-based geochemical approach. *Journal of Geochemical Exploration*, *170*, 94-106.

Zheng, B., Wu, S., Song, X., Huang, Y., Wu, H., Liu, Z., ... & Wan, W. (2023). Impacts of landscape pattern evolution on typical ecosystem services in Ganjiang River Basin, China. *Environmental Science and Pollution Research, 30*(51), 110562-110578.