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RESEARCH

Morphometric parameters based prioritization of watersheds for soil erosion risk in Upper Jhelum Sub-catchment, India

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Abstract Soil erosion is the inherent and destructive threat affecting agricultural production and livelihood of million mouths. The increased frequency of floods and land use/land cover changes has made Upper Jhelum Sub-catchment susceptible to soil erosion risk. Morphometric based watershed prioritization for soil erosion risk may help in sustainable management of natural resources. Thus, this paper endeavors to prioritize watersheds of Upper Jhelum Sub-catchment in India based on morphometric parameters for soil erosion risk using geospatial techniques. Weights to the morphometric parameters were assigned through a multi-criteria decision method. The watersheds in the Sub-catchment have been categorized into low, medium, high and very high priority classes based on prioritization ranks that were determined by computing the compound value for the soil erosion risk, based on prioritization ranks obtained through compound value for the soil erosion risk. The results revealed 1E1D3 and 1E1D8 watersheds accorded very high priority. The watersheds namely IE1D2 and IEID4 were found under high priority. Medium priority for soil erosion risk was determined in IEID5 and IED7 watersheds while 1E1D1 and IE1D6 watersheds were identified for low priority. The study calls for implementing soil conservation practices in the Sub-catchment. The Sub-catchment can be made less hazardous for the soil erosion risk by implementing contour farming, building check dams, terrace farming, afforestation and limiting large scale overgrazing. The findings of this study may offer valuable insights for stakeholders for conservation of soil resource. The approach utilized in the study may be linked with soil loss estimation for effective conservation of natural resources in further future studies.

Keywords Morphometric parameters · Prioritization · Soil erosion risk · Upper Jhelum Sub-catchment

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Introduction

Soil is of paramount importance as it sustains agriculture, biodiversity, and ecosystem health. It is also vital for carbon storage, water storage, and overall environmental balance (Keesstra et al., 2016; Thakkar

& Dhiman, 2007). It takes long time to form one centimeter layer of soil, but it can be eroded within a short period of time. Soil erosion occurs in response to both anthropogenic and natural processes. It has caused environmental degradation and affected the agricultural sector (Sinha & Eldho, 2021). Deforestation, flood, absence of dams, overgrazing practices, and land use/land cover transformation have significantly increased the rate of soil erosion (Nasir et al., 2023; Kuhn et al. 2012; Hlaing et al., 2008). Soil erosion has the potential to negatively impact the water quality, agricultural production, and hydrological systems (Hlaing et al., 2008). The soil erosion is projected to increase at the rate of 75 billion tons per year globally (Pimentel & Burgess, 2013). The impact of soil erosion is more complex in the regions of the undulated topographic regions particularly in the Himalayas (Altaf et al., 2013). Thus, conservation of soil and its management are essential for ensuring the long-term sustainability of natural resources (Benzougagh et al., 2022; Mushtaq et al., 2015; Pourghasemi et al., 2021; Sadhasivam et al., 2020).

A watershed as a hydrological unit serves as the basic unit for the effective management of resources (Arulbalaji & Padmalal, 2020). It is naturally occurring hydrological structure where run off is directly channelized into rivers (Altaf et al., 2013). The formation of landforms within a drainage basin relies upon its characteristics and environmental conditions. Hence, the geomorphology of a basin can be understood by identifying its various characteristics (Saha et al., 2022). The planning for basin management can aim to mitigate soil erosion within the basin (Prakash et al., 2019). Although there are numerous factors that affect soil erosion, its major driver is water (Sadhasivam et al., 2020). The implementation of the watershed management has proved an effective method in conserving and managing natural resources (Ahmed et al., 2018). A watershed is a hydrological unit where most of run off flows into a single outlet and serves as the appropriate unit for assessing natural resources (Rahaman et al., 2023; Shekar et al., 2023). Morphometric analysis plays an important role in prioritizing watershed based on water, soil, and vegetation (Altaf et al., 2013; Bezinska & Stoyanov, 2019). Soil erosion, sedimentation, run off, and drainage patterns are manifestations of geomorphic and hydrological processes (Singh et al., 2013; Panda et al., 2019; Gajbhiye et al. 2014). Various scholars have attempted the morphometric characteristics of the hydrological units (Horton, 1932; Strahler, 1952; Schumm, 1956; Strahler, 1957 and Strahler, 1964). Together, they have established the structure for the discipline of quantitative fluvial geomorphology (Kouli et al., 2007).

Quantitative assessment of morphometric parameters within a watershed may help in its prioritization for water and soil conservation (Chandrashekar et al., 2015). Morphometric evaluation describes the systematic evaluation of drainage systems, understanding of the comprehension of landforms, soil development processes, and types of erosion (Kavian et al., 2014). Assessment of morphometric features of drainage basin provides insights of interaction among drainage behavior and hydrological characteristics (Arulbalaji & Padmalal, 2020; Bhatt & Ahmed, 2014; Erosemiah & Viji, 2023; Iqbal et al., 2013). Prioritizing watersheds through morphometric analysis holds significance in conservation of water and soil both at micro- and macro-level planning (Panhalkar et al., 2012; Pathare and Pathare 2020). Various scholars have applied morphometric parameters to prioritize watersheds for effective flood management (Sinha & Eldho, 2021; Mohammed et al., 2018; Bhat et al., 2019 and Sankriti et al., 2021). The geospatial techniques have significant role in analyzing hydrological components at varied scales (Dimple et al., 2022; Kaliraj et al., 2015; Singh et al., 2020; Tribhuvan et al., 2016; Withanage et al., 2015). A systematic approach of using geospatial technology assumes significance for evaluating relief, areal and linear characteristics within catchment and prioritizing watersheds (Kushwaha et al., 2022; Odiji et al., 2021; Pandey & Das, 2016). The digital elevation model (DEM) enables the determination of morphometric parameters for any drainage basin (Jothimani et al., 2020; Kumar Dubey, 2015). Various scholars have utilized different soil loss estimation methods for evaluating and predicting soil erosion (Benzougagh et al., 2022 and Masroor et al., 2022). Other scholars have proposed multi-criteria decision method and weighted sum analysis for prioritizing and planning of land use/land cover in the watersheds (Jothimani et al., 2020; Mahmoodi et al., 2023; Rakesh et al., 2023; Sadhasivam et al., 2020).

The Upper Jhelum Sub-catchment is vulnerable to soil erosion due to alterations in land use/land cover, high intensity of rainfall and increased frequency of floods (Bhat et al., 2019). Earlier studies have focused on prioritizing watersheds for controlling floods, land management and water resource management but watershed prioritization for soil erosion risk is less explored. Prioritization of watersheds may help in reducing soil erosion and making agriculture sustainable. Thus, the study aims to prioritize watersheds based on soil erosion risk using morphometric analysis in Upper Jhelum Sub-catchment in India. The insights of this study may provide valuable insights for stakeholders in mitigating soil erosion risk.

Study area

The Upper Jhelum Sub-catchment encompasses the southern region of the Kashmir in India and is located between 33°20′ and 34°10′ N latitudes and between 74°30′ and 75°30′ E longitudes (Fig. 1). The Sub-catchment spreads over a total area of 5201 km^2. The Sub-catchment is bordered by the Geater Himalayas in the East and South-east and the range of Pir Panjal in the South and South-west (Mattoo et al., 2023). The Jhelum River rises in the spring Verinag, Anantnag district, lying in the Pir-Panjal range. The Sub-catchment has been divided into eight watersheds (IEID1–1E1D8). The Sub-catchment possesses unique climatic characteristics for being located at high altitude. The Sub-catchment is surrounded by mountains on all sides (Altaf et al., 2013). It predominantly receives its rainfall and snowfall during winter season. Towards the end of summer, the Sub-catchment experiences the influence of South-west monsoon with low magnitude and intensity. The total population of the Sub-catchment is 2.06 million. The clean and fresh aquatic ecosystems play crucial hydrological roles in the Sub-catchment and are continuously deteriorating due to increase in urbanization. Rising population has additionally exerted pressure on the cultivable agricultural land leading to its transformation into residential areas. In recent decades, there has been a substantial alteration of the Sub-catchment's landscape, with land being converted to the other uses without consideration for its inherent suitability. There has been a notable transition in the area under land use from agriculture to horticulture in the Sub-catchment, primarily due to economic factors. The area under paddy crops has witnessed a significant decrease over the span of four decades (Rather et al., 2016). Diminishing grasslands, deforestation, shrinking glaciers and depleted water bodies have affected processes associated with weather pattern, erosion and hydrology in the Sub-catchment. This transformation has also led to decline in streamflow, increase in nutrient and sediment load and degradation of the water quality in the Sub-catchment (Romshoo et al., 2015). The observed changes in the land system of the Sub-catchment have significant consequences for the hydrological processes at both upper and downstream scales (Rather et al., 2016). Large scale deforestation in the Sub-catchment driven by the demand for wood has diminished the ability of forest to retain water (Badar et al., 2013). The developmental activities associated with urbanization have altered the natural flow path of rivers and their tributaries.

The prioritization of watersheds in upper Jhelum Sub-catchment is of vital importance due to various benefits offered to the communities and ecosystem. Most of the people in the Sub-catchment are engaged in agricultural and allied activities. Prioritization of the catchment may help in controlling the soil erosion by implementing the various techniques. This is necessary in the Sub-catchment to prevent the loss of top fertile soil and prevent sedimentation of watersheds. A balance between the environmental conservation and human needs can be achieved by prioritizing watersheds for soil erosion risk and making the Sub-catchment more sustainable and resilient.

Database and methodology

Morphometric analysis was conducted to prioritize watersheds for soil erosion risk within the Sub-catchment. The watersheds were delineated using Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) DEM for the year 2023 with 30-m spatial resolution obtained from Earth Data NASA. The parameters of morphometry were determined according to the methodologies outlined by Schumm (1956), Horton (1945), and Horton (1932). The linear aspects (constant of channel maintenance, drainage density, mean bifurcation ratio, mean stream length ratio, stream order and stream frequency), the areal parameters (drainage texture ratio, form factor, compactness constant, elongation ratio, circulatory ratio, length of overland flow and dissection index), and the relief parameters (relief ratio, absolute relief and relative relief) were considered for analysis (Table 1).

Watersheds were prioritized for soil erosion risk using multi-criteria decision method. This approach

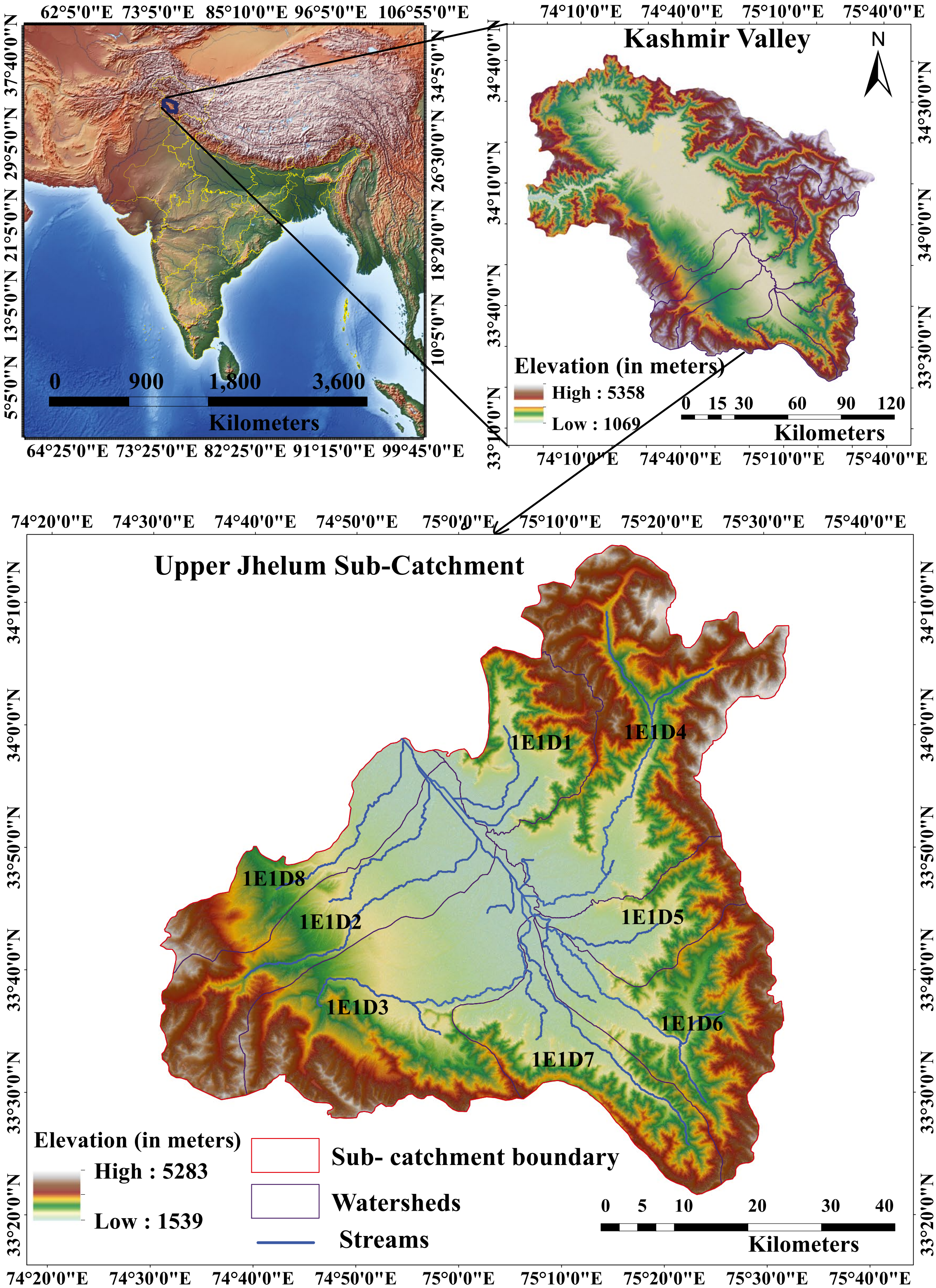

Fig. 1 Location of the study area

Table 1 Mathematical equations utilized for various morphometric parameters in the watersheds

Sl. no	Morphometric parameters	Computation	References
Linear			
1	Stream order	Hierarchal rank	Strahler (1964)
2	Stream number		
3	Stream length (Lu)	Length of the stream	Horton (1945)
4	Mean stream length (Lsm)	Lsm = Lu/Nu	Strahler (1964)
5	Stream length ratio (Rl)	Rl = Lu/Lu_{-1}	Horton (1945)
6	Bifurcation ratio (Rb)	Rb = Nu/Nu + 1	Schumm (1956)
7	Mean bifurcation ratio (Rbm)	Rbm = average of bifurcation ratios	Strahler (1957)
8	Stream frequency (Fs)	Fs = Nu/A	Horton (1932)
9	Drainage density (D)	D = Lu/A	Horton (1932)
Areal			
10	Drainage texture ratio (Rt)	Rt = Nu/P	Horton (1945)
11	Length of overland flow (Lg)	Lg = 1/D × 2	Horton (1945)
12	Circulatory ratio (Rc)	Rc = 4 × π × A/P^2	Strahler (1957)
13	Elongation ratio (Re)	Re = 2 × Sqrt (A/π) Lb	Schumm (1956)
14	Form factor (Rf)	Rf = A/Lb^2	Horton (1932)
15	Area of the watershed (A)	GIS analysis	-
16	Perimeter of the watershed (P)	GIS analysis	-
17	Compactness constant (Cc)	0.2821 × P/A × 0.5	Horton (1945)
Relief			
15	Relief ratio (Rh)	Rh = H/Lb	Schumm (1956)
16	Relative relief or total relief	Maximum elevation minus minimum elevation	Strahler (1952)

relies on knowledge-driven modeling principles and translates qualitative comprehension into a statistical estimation (Todorovski & Džeroski, 2006). All the morphometric parameters were assigned weights for soil erosion risk based on the prior knowledge and expert opinion in the study area following Sinha and Eldho (2021). For the relief and linear aspects, the weights were assigned from highest to lowest whereas the areal aspects were weighted from lowest to highest. The linear and relief aspects of the watersheds were ranked based on their values. The highest value was given rank one followed by the next highest value receiving rank two and process continues till all the values were ranked. Based on these ranks, the compound value (CV) for each watershed in the Sub-catchment was determined following Altaf et al. (2014):

$$\mathrm{Cv} = {}^{1}/_{n} \sum_{i=1} R\,(i)$$

where Cv is the compound value, R_i is the rank of morphometric parameter, n is the total number of parameters.

Higher the compound values, lower will be the risk of soil erosion. Following the computation of compound value, the watersheds in the Sub-catchment have been categorized into four erosion risk classes namely low, medium, high, and very high. Very high priority was accorded to the watersheds with the lowest compound value, denoted by number 1. Following the procedure, the watersheds were given high, medium and low priority and were denoted by number 2, 3, and 4 respectively. Detailed methodological framework is shown in Fig. 2.

Results and discussions

Linear parameters of the watersheds

The watersheds' stream ordering was established using Strahler's (1952) methodology. This process of stream ordering determines the hierarchy structure of tributaries. The unbranched streams as well as the smallest finger type streams were designated as the

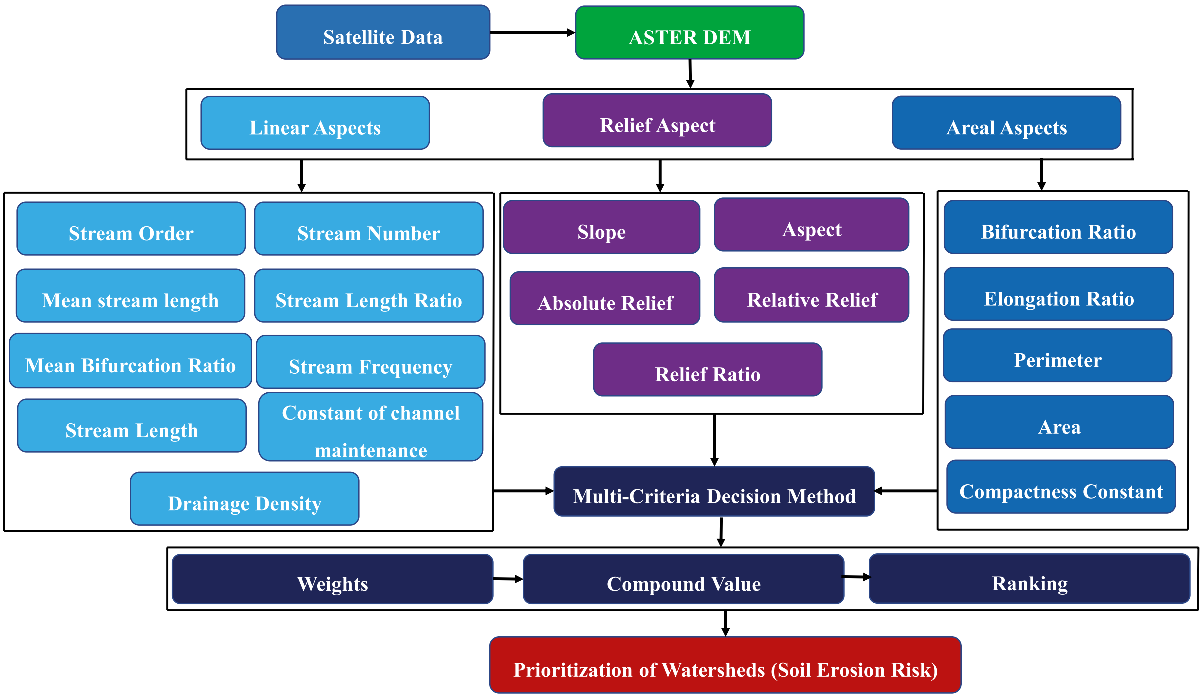

Fig. 2 Methodological framework of the study

first stream order. The first order of the two streams when joined together form second order stream just below their junction (Ganie et al., 2023). Following the same rule, the third stream order was determined. Stream ordering of the watersheds revealed that 1E1D2 and 1E1D3 watersheds have the sixth order, watershed 1E1D4, 1E1D5, 1E1D6, 1E1D7, and 1E1D8 have fifth order, while watershed 1E1D1 has fourth stream order (Table 2 and Fig. 3). Thus, the streams of the watersheds 1E1D2 and1E1D3 have an excess potential for the discharge.

Stream number (N_u) represents the quantity of segments in a stream within a specific order (Strahler, 1957). The maximum number of streams (633) were found in the watershed 1E1D4 followed by 583 streams (1E1D3), 392 (1E1D2), 352 (1E1D6), 285 (1E1D7), 239 (1E1D1), and (233) were found in the watershed 1E1D8. It means that the watershed 1E1D4 attains instantaneous overflow discharge of water during the rainstorm events. There is direct correlation between a multitude of streams and the high overflow discharge of water (Gajbhiye, 2015; Pasham et al., 2022). The total length of each stream in the watersheds was calculated by using the Arc GIS software 10.8. The maximum and minimum length of stream was found in the watershed 1E1D4 and watershed 1E1D7 respectively (Table 2). Generally, stream length tends to decrease with increase in stream order (Latief et al., 2015). Inverse relationship was found between length and order of stream in the watersheds.

Mean stream length is expressed as the ratio between the length of the stream and the number of streams (Dubey and Jha, 2022). The watershed 1E1D8 exhibited the maximum average stream length whereas watershed 1E1D3 displayed the lowest mean stream length (Table 3). The average length from one order to the subsequent lower stream segment was calculated for determining the ratio of stream length (Rai et al., 2018). It is closely related to both the erosional stage and the surface movement of water in a catchment (Rajasekhar et al., 2020; Sutradhar, 2020). The ratio of stream length of the watersheds in the Sub-catchment is presented in Table 4. Schumm (1956) defined bifurcation ratio as the proportion of streams to total number of a particular order to the number of streams of the subsequent higher order. It represents integration of streams orders and is a dimensionless property. It serves as a measuring parameter for assessing the dissections and

Table 2 Stream ordering, stream length and stream number of watersheds

Watershed code	Area (km^2)	1st order		2nd order		3rd order		4th order		5th order		6th order		Total	
		No	Length (Kms.)	No	Length (Kms.)	No	Length (Kms.)	No	Length (Kms.)	No	Length (Kms.)	No	Length (Kms.)	No	Length (Kms.)
1E1D1	419	126	191	49	68	35	46	29	25	-	-	-		239	330
1E1D2	716	193	343	85	174	52	55	49	90	11	17	2	5	392	524
1E1D3	993	285	483	135	204	110	159	26	43	20	40	7	8	583	937
1E1D4	1212	322	448	162	418	66	83	44	43	39	46	-	-	633	1038
1E1D5	301	95	122	50	63	31	36	12	18	4	4	-	-	192	243
1E1D6	677	177	255	78	122	48	65	31	40	18	33	-	-	352	515
1E1D7	497	143	168	57	76	48	43	32	21	5	4	-	-	285	312
1E1D8	382	103	399	56	109	22	41	18	41	7	6	-	-	233	596
Upper Jhelum Sub-catchment	5197	1444	2409	672	1234	412	528	241	321	104	150	9	13	2909	4495

Source: Authors' calculation

relief of the watershed (Horton, 1945). The formation of the new stream segments serves as an indication of continuous flow of surface water (Strahler, 1957).

The basins with an elongated and circular shapes exhibit a low bifurcation and high bifurcation respectively. Bifurcation ratio of the watersheds in the Sub-catchment ranges between 0.486 and 4.455. The primary and subsequent order streams had the lowest while the fourth as well as fifth order streams had the highest bifurcation ratio. This suggests presence of highest discharge and overland flow in these streams (Table 5). High values of the bifurcation ratio determined the control of the structure on the watersheds. The average bifurcation ratio across various watersheds in the Sub-catchment ranges from 1.71 to 2.99 (Table 5). This suggested a lesser degree of structural influence on the drainage development within the watersheds.

The maximum and minimum mean bifurcation ratio was noticed in the watershed 1E1D2 and 1E1D1 watershed respectively. Drainage density is the measurement of proximity of stream channels distributed within a basin (Bhat et al., 2019; Horton, 1945). It is used for understanding the network of streams and rivers within a watershed. The factors that affect the drainage density include vegetation density and geology (Latief et al., 2015). Drainage density indicates the erosive potential of the soil and overland flow. Thus, the rivers with high drainage have greater risk of soil erosion (Lama & Maiti, 2019). The total drainage density of the Upper Jhelum Sub-catchment was found to be 7.062 km/km^2. The watershed 1E1D3 exhibited the highest drainage density at 0.943 km/km^2 whereas the watershed 1E1D8 displayed the lowest drainage density at 0.641 km/km^2. Moreover, high drainage density ranging from 0.958 to 0.762 km/km^2 was found in the watersheds namely 1ED2, 1E1D5, and 1E1D6. Low drainage density was also found 0.587 km/km^2 in the watersheds 1E1D4 (Table 6 and Fig. 4).

Constant of channel maintenance (C_{cm}) represents the value of surface area needed for maintaining a stream segment within a length of 1 km. It was first determined by Schumm (1956). The highest value of C_{cm} (1.70 km/km^2) was found in 1E1D4 watershed followed by (1.56 km/km^2) in 1E1D7, 1.27 km/km^2 in 1E1D1 and 1.23 km/km^2 in 1E1D5 watershed (Table 6). Stream frequency also referred to as drainage frequency is calculated through counting streams per unit area irrespective of any order. Drainage density decreases as the number of streams increases (Rai et al., 2018). The development

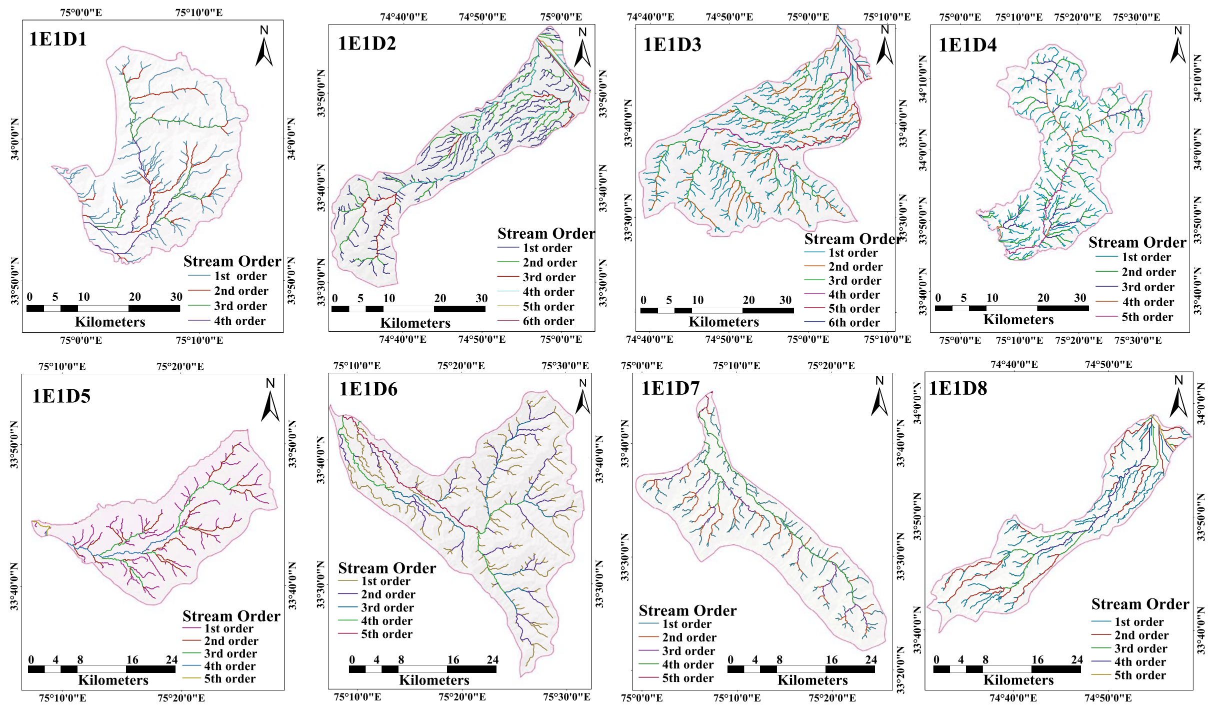

Fig. 3 Stream order of the watersheds

of the stream network relies on the topography such as nature of rocks, permeability of soil, vegetation cover, and the amount of rainfall (Latief et al., 2015). The highest stream frequency of 0.635 km^2 was found in the watershed 1E1D5 whereas the lowest frequency of 0.518 km^2 was observed in the watershed 11E1D6 (Table 6). High stream frequency in the watersheds implies high risk of excess run off and soil erosion (Al-Saady et al., 2016; Umrikar, 2017). It exerts influence over factors such as sediment yield, run off pattern and other characteristics of the watershed (Ogarekpe et al., 2020).

Areal parameters of the watersheds

The length of overland flow (L_o) is measured as the flow of water over the surface area before entering the main river of the watershed. It affects the physiography and geohydrological characteristics of the hydrologic

Table 3 Mean stream length of the watersheds

Watershed code	Mean stream length (kms.)						
	1st order	2nd order	3rd order	4th order	5th order	6th order	Total
1E1D1	1.52	1.39	1.30	0.85	-	-	5.06
1E1D2	1.78	2.05	1.06	1.84	1.55	2.5	10.78
1E1D3	1.68	1.50	1.45	1.64	2	1.13	9.40
1E1D4	1.38	2.58	1.26	0.98	1.18	-	7.38
1E1D5	1.27	1.26	1.15	1.50	1	-	6.18
1E1D6	1.43	1.55	1.34	1.28	1.82	-	7.42
1E1D7	1.16	1.32	0.90	0.66	0.8	-	4.84
IE1D8	3.86	1.95	1.85	2.28	0.86	-	10.8
Upper Jhelum Sub-catchment	14.08	13.6	10.31	11.03	9.21	3.63	61.86

Source: Authors' calculation

Table 4 Stream length ratio in the watershed

Watershed code	Stream length ratio				
	II/I	III/II	IV/III	V/IV	VI/V
1E1D1	0.90	0.94	0.64	-	-
1E1D2	1.14	0.52	1.72	0.83	1.29
1E1D3	0.88	0.97	1.12	1.22	0.57
1E1D4	1.87	0.49	1.74	1.20	-
1E1D5	0.98	0.90	1.30	0.67	-
1E1D6	1.07	0.85	1.2	1.41	-
1E1D7	1.14	0.67	0.96	1.20	-
IE1D8	0.51	0.95	1.22	0.38	-
Upper Jhelum Sub-catchment	8.49	6.29	9.9	6.91	1.86

Source: Authors' calculation

unit. Highest L_o was found 0.78 km in the watershed 1EID7 whereas the low L_o was found 0.31 km in the watershed 1E1D8. High L_o was observed in 1E1D1 and 1E1D5 watersheds. Low L_o was found in 1E1D4 and 1E1D2 watersheds (Table 6).

Form factor is expressed as ratio of the area to the square of the length of the basin (Horton, 1932). The values of the form factor are always be less than 0.7845 (perfectly circular basin). The form factor of the watersheds in the Sub-catchment ranged from 0.001 to 0.005. The Sub-catchment experiences lower peak flows due to lower values of form factor. Conversely, watersheds characterized by high form factor values tend to exhibit intense peak flows over shorter durations (Bhat et al., 2019). This indicates greater risk of soil erosion in the Sub-catchment. Low form factor was found in 1E1D2, 1E1D3, 1E1D4, and 1E1D6 watersheds whereas 1E1D1, 1E1D5, 1E1D7, and 1E1D8 watersheds have high form factor (Table 7). The elongation ratio was first determined by Strahler (1957) as the ratio of the maximum length to the diameter of a circle (Bilewu et al., 2015). Elongation ratio varies from 0 (maximum elongated) and 1 (maximum circulatory). High elongation ratio (0.81) was found in 1E1D1 watershed while the low elongation ratio (0.03) was determined in 1E1D7 watershed. The circulatory ratio is defined as the ratio of the basin area to the area of a circle with a perimeter equal to that of the basin (Strahler, 1957). Slope, geological structure, stream frequency, and stream length influence circulatory ratio (Iqbal et al., 2012). The circulatory ratio for all the watersheds varied from 0.08 to 0.71 (Table 7). Its values range between 0 and 1. The 0 value indicates the minimum circulatory, and the value of 1 indicates the maximum circulatory. The maximum circulatory ratio was found in 1E1D1, 1EID3, 1E1D6, and 1E1D7 watersheds whereas the minimum circulatory ratio was found in 1E1D2, 1E1D4, 1E1D5, and 1E1D8 watersheds.

The relationship between circular basin with same area and hydrological basin is expressed by compactness constant. The basin having circular shape is considered to be the most hazardous because of shorter concentration period to reach peak flow (Bhat et al., 2019; Iqbal et al., 2012). The compactness constant

Table 5 Bifurcation ratio of the watersheds

Watershed code	Bifurcation ratio between different stream orders					Mean bifurcation ratio
	1st order and 2nd order	2nd order and 3rd order	3rd order and 4th order	4th order and 5th order	5th order and 6th order	
1E1D1	2.56	1.4	1.21	-	-	1.71
1E1D2	2.26	1.64	1.05	4.44	5.5	2.99
1E1D3	2.10	1.23	4.22	1.30	2.86	2.33
1E1D4	1.99	2.43	1.5	1.13	-	1.75
1E1D5	1.9	1.60	2.57	3	-	2.27
1E1D6	2.27	1.63	1.55	1.71	-	1.79
1E1D7	2.51	1.19	1.5	6.4	-	2.9
1E1D8	1.84	2.55	1.1	2.56	-	2.0
Upper Jhelum Sub-catchment	17.43	13.67	14.7	20.54	8.36	17.74

Source: Authors' calculation

Table 6 Stream frequency, length of overland flow, drainage density, and constant of channel maintenance in the watersheds

Watershed code	Stream frequency (Km^2)	Drainage density Km/km^2	Constant of channel maintenance (Km^2/Km.)	Length of overland flow (km.)
1E1D1	0.56	0.79	1.27	0.62
1E1D2	0.55	0.72	1.39	0.68
1E1D3	0.59	0.93	1.08	0.53
1E1D4	0.51	0.88	1.14	0.43
1E1D5	0.64	0.81	1.22	0.61
1E1D6	0.52	0.76	0.32	0.66
1E1D7	0.56	0.63	1.59	0.78
1E1D8	0.61	1.56	0.63	0.31
Upper Jhelum Sub-catchment	4.563	7.08	8.64	4.45

Source: Authors' calculation

in the watersheds in the Sub-catchment ranges from 0.06 to 0.34 (Table 7). High compactness constant was found in 1E1D8 and 1E1D5 watersheds whereas the low constant compactness constant was found in 1E1D4 and 1E1D3 watersheds. Drainage texture represents relative spacing of drainage streams. It can be represented as the ratio of the perimeter of the basin to the total number of first order streams (Horton, 1945). It depends upon the relief, infiltration capacity, aspect of the terrain and underlying lithology (Latief et al., 2015). The total perimeter of the Upper Jhelum Sub-catchment is 1181.89 km^2. The high drainage texture in the watersheds of Sub-catchment was found in 1E1D3, 1E1D4, IEID6, and 1E1D7 watersheds whereas the low drainage texture ratio was found in 1EID5 and 1E1D8 watersheds (Table 7).

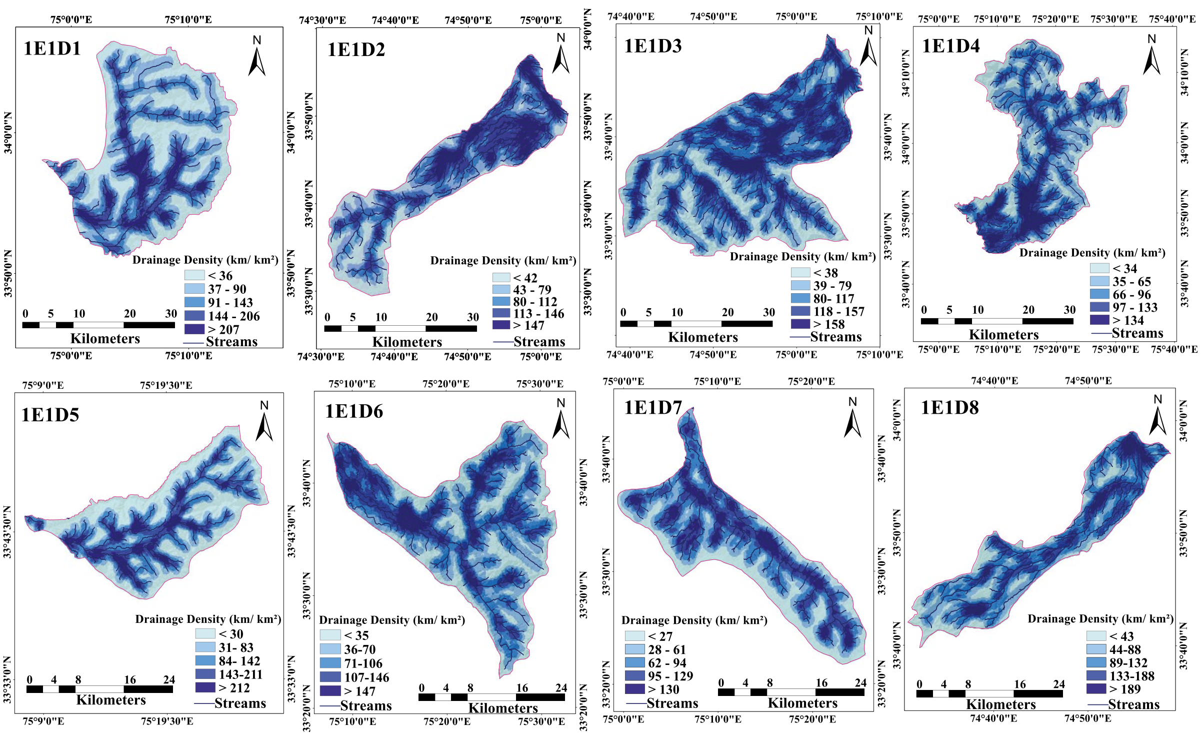

Fig. 4 Drainage density of the watersheds

Table 7 Statistics of areal morphometric parameters

Watershed code	Perimeter (km^2)	Form factor	Elongation ratio	Circulatory ratio	Compactness Constant	Texture ratio
1E1D1	92.62	0.003	0.81	0.60	0.11	2.57
1E1D2	151.12	0.002	0.06	0.38	0.12	2.58
1E1D3	132.98	0.001	0.04	0.71	0.08	4.37
1E1D4	174.45	0.001	0.04	0.50	0.07	3.63
1E1D5	166.20	0.005	0.07	0.14	0.31	1.14
1E1D6	132.40	0.002	0.06	0.49	0.06	2.66
1E1D7	103.72	0.005	0.03	0.57	0.12	2.76
1E1D8	228.40	0.001	0.04	0.08	0.34	1.02
Upper Jhelum sub-catchment	1181.89	0.02	1.16	3.47	1.21	20.37

Source: Authors' calculation

Relief parameters of the watersheds

Slope is characterized as the angular inclination of a plane and is one of the most important factors for understanding the physiography of a region. It is expressed in degree or percent (Latief et al., 2015). Slope map was prepared using ASTER DEM. The slope determines the rate of erodibility of a river. The steep slope results into a high risk of erosion (Rai et al., 2018; Rao et al., 2023). The slope of each watershed was categorized into five classes by using the natural break system (Fig. 5). Steep slope was found in 1E1D2, 1E1D4, and 1E1D1 watersheds. The watersheds namely 1E1D5 and 1E1D6 represented the same degree of slope. The low degree of slope was found in 1E1D8 and 1E1D7 watersheds (Fig. 5). Thus, 1E1D2, 1E1D4, and 1E1D1 watersheds have experienced high rate of erosion whereas 1E1D7

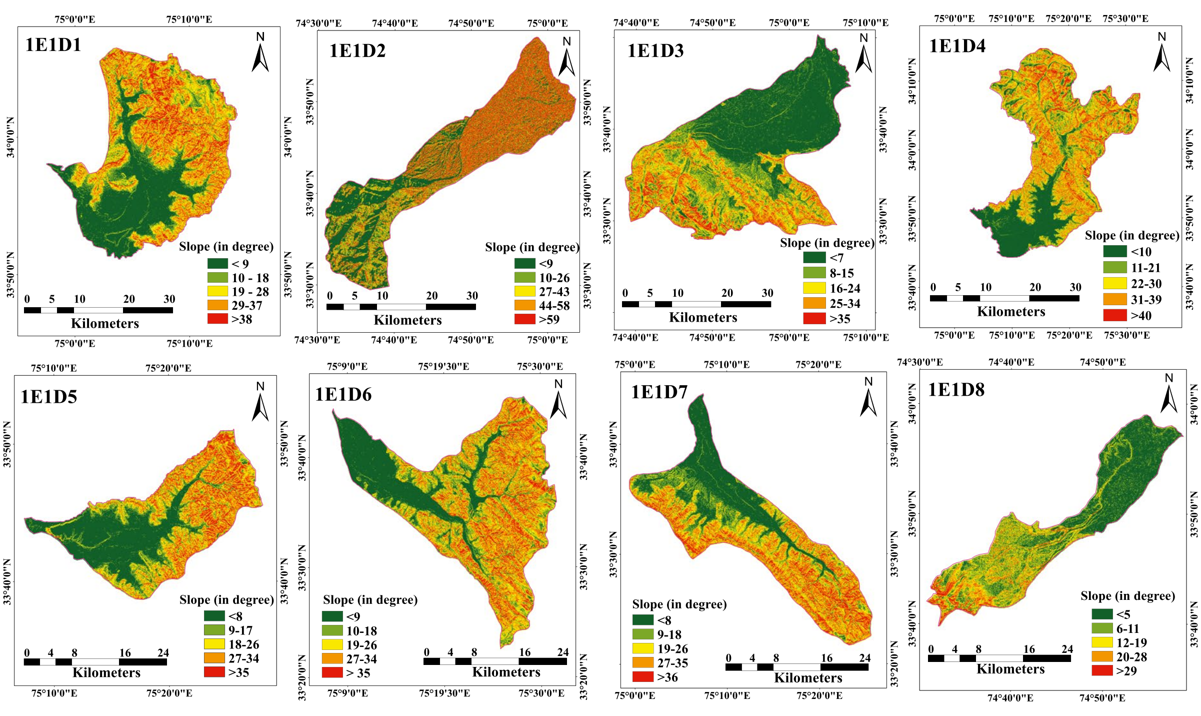

Fig. 5 Slope of the watersheds

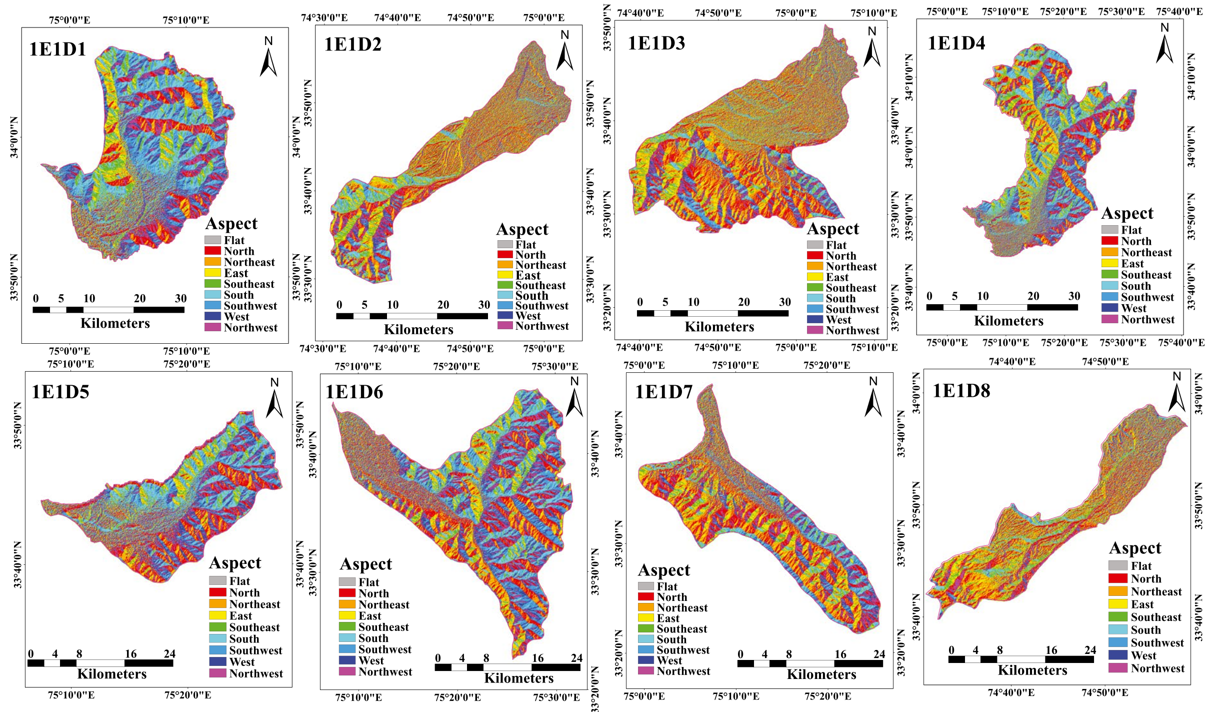

Fig. 6 Aspect of the watersheds

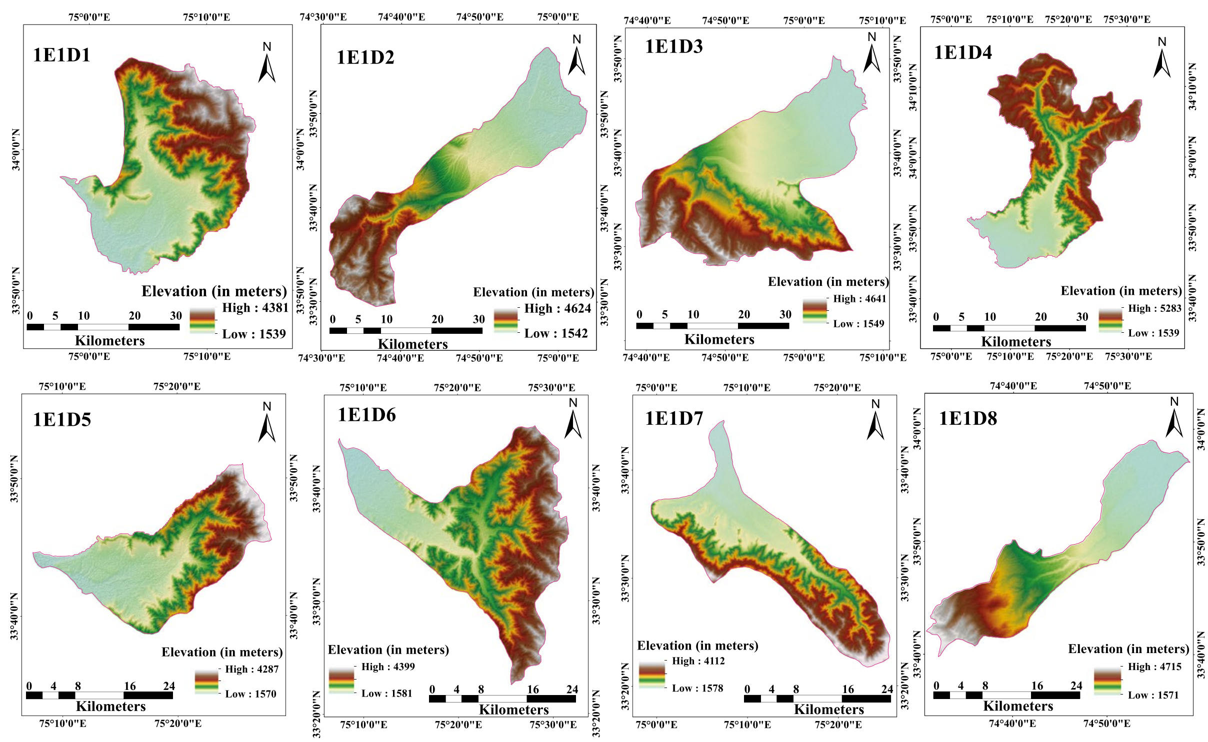

Fig. 7 Elevation of the watersheds

Table 8 Statistics of relief morphometric parameters of the watersheds

Watershed code	Absolute relief	Relative relief	Relief ratio	Dissection index
1E1D1	4381	2842	8.59	0.65
1E1D2	4624	3082	4.48	0.67
1E1D3	4641	3092	3.29	0.66
1E1D4	5283	3744	3.60	0.71
1E1D5	4287	2717	11.01	0.62
1E1D6	4399	2818	5.44	0.64
1E1D7	4112	2534	9.86	0.62
1E1D8	4715	3144	5.25	0.67
Upper Jhelum sub-catchment	76442	23973	51.52	5.24

Source: Authors' calculation

watershed had a low rate of erosion. The orientation of a slope is known as aspect. The aspect map of the watersheds was prepared by the Arc GIS 10.8 software using ASTER DEM (Fig. 6).

The absolute relief for the watershed in the Sub-catchment was calculated by the Arc GIS 10.8 software using the ASTER DEM data. High absolute relief was found in 1E1D4 watershed whereas low absolute relief was found in 1EID1 watershed (Fig. 7 and Table 8). The absolute relief is determined by the geomorphological features, geological composition and drainage characteristics of a basin (Latief et al., 2015). It serves as an erosional progression within a watershed (Bera et al., 2018) Thus, the high elevated areas of the basin may have more erosional processes than the low elevated areas of the basin. Also, the high elevated areas may result into accumulation of snow which in turn into the formation of glaciers (Latief et al., 2015). The relative relief is examined as the variation in the altitude between the maximum and minimum elevation of any region (Strahler, 1952). High relative relief was observed in 1E1D4 watershed while as the low relative relief was observed in 1E1D7 watershed (Table 8). It is useful for measuring and understanding the local variations in elevation within a specific area. Relief ratio refers to the proportion of total relief in relation to the extent of the principal drainage line (Schumm, 1956). The maximum and minimum relief ratio was found in 1E1D5

Table 9 Weights assigned to morphometric parameters for soil erosion risk in the watersheds

Parameters	1E1D1	1E1D2	1E1D3	1E1D4	1E1D5	1E1D6	1E1D7	1E1D8
Mean bifurcation ratio	1.71 [8]	2.99 [2]	2.33 [1]	1.75 [7]	2.27[4]	1.79 [6]	2.9 [3]	2.0 [5]
Mean stream length ratio	5.06 [7]	10.78 [2]	9.40 [3]	7.38 [5]	6.18 [6]	7.42 [4]	4.84[8]	10.8 [1]
Stream frequency	0.56 [5]	0.55[6]	0.59 [3]	0.51 [7]	0.64[1]	0.52 [8]	0.56 [4]	0.61 [2]
Drainage density	0.79 [5]	0.72 [7]	0.93 [2]	0.88 [3]	0.81 [4]	0.76 [6]	0.63 [8]	1.56 [1]
Drainage texture ratio	2.57 [6]	2.58 [5]	4.37 [1]	3.63 [2]	1.14 [7]	2.66 [4]	2.76 [3]	1.02 [8]
Constant of channel maintenance	1.27 [3]	1.39 [2]	1.08 [6]	1.14 [5]	1.22 [4]	0.32 [8]	1.59 [1]	0.63 [7]
Absolute relief	4381 [6]	4624 [4]	4641 [3]	5283 [1]	4287 [7]	4399 [5]	4112 [8]	4715 [2]
Relative relief	2842 [5]	3082 [4]	3092 [2]	3744 [1]	2717 [7]	2818 [6]	2534 [8]	3144 [3]
Relief ratio	8.59 [3]	4.48 [6]	3.29 [8]	3.60 [7]	11.01 [1]	5.44 [5]	9.86 [2]	5.25 [4]
Circulatory ratio	0.60 [7]	0.38 [3]	0.71 [8]	0.50 [5]	0.14 [2]	0.49 [4]	0.57 [6]	0.08 [1]
Elongation ratio	0.81[8]	0.06 [6]	0.04 [4]	0.04 [3]	0.07 [7]	0.06 [5]	0.03 [1]	0.04 [2]
Form factor	0.003 [6]	0.002 [4]	0.001 [3]	0.001 [2]	0.005 [7]	0.002 [5]	0.005 [8]	0.001 [1]
Compactness constant	0.11 [4]	0.12 [6]	0.08 [3]	0.07 [2]	0.31 [7]	0.06 [1]	0.12 [5]	0.34 [8]
Dissection index	0.65 [4]	0.67 [6]	0.66 [5]	0.71 [8]	0.62 [2]	0.64 [3]	0.62 [1]	0.67 [7]
Length of overland flow	0.62 [6]	0.68[3]	0.53 [4]	0.43 [2]	0.61 [5]	0.66 [7]	0.78 [8]	0.31 [1]

Source: Authors' calculation

Table 10 Ranking, compound values, and prioritization of watersheds for the soil erosion risk

Parameters	1E1D1	1E1D2	1E1D3	1E1D4	1E1D5	1E1D6	1E1D7	1E1D8
Mean bifurcation ratio	8	2	1	7	4	6	3	5
Mean stream length ratio	7	2	3	5	6	4	8	1
Stream frequency	5	6	3	7	1	8	4	2
Drainage density	5	7	2	3	4	6	8	1
Drainage texture ratio	6	5	1	2	7	4	3	8
Constant of channel maintenance	3	2	6	5	4	8	1	7
Absolute relief	6	4	3	1	7	5	8	2
Relative relief	5	4	2	1	7	6	8	3
Relief ratio	3	6	8	7	1	5	2	4
Circulatory ratio	7	3	8	5	2	4	6	1
Elongation ratio	8	6	4	3	7	5	1	2
Form factor	6	4	3	2	7	5	8	1
Compactness constant	4	6	3	2	7	1	5	8
Dissection index	4	6	5	8	2	3	1	7
Length of overland flow	6	3	4	2	5	7	8	1
Sum of rankings (x)	83	66	56	60	71	77	74	53
Total number of parameters	15							
Compound value (x/y)	5.52	4.40	3.72	4	4.72	5.12	4.92	3.52
Ranking	8	4	2	3	5	7	6	1
Final priority for soil erosion risk	Low	High	Very high	High	Medium	Low	Medium	Very high

Source: Authors' calculation

and 1E1D3 watersheds respectively (Table 8). The dissection index is calculated as the ratio between absolute and relative relief. It explains the phases of landform evolution and the vertical erosion of any physiographic region. The dissection index varies from 0 to 1 (Table 8). There is an absence of vertical erosion when the value of the dissection is 0 and the value of 1 represents the vertical erosion (Rai et al., 2018). Watershed 1E1D4 exhibited high dissection index while the low dissection index was found in 1E1D5 and 1E1D7 watersheds.

Morphometric watershed prioritization for the soil erosion risk in Upper Jhelum Sub-catchment

Morphometric parameters have been widely utilized by many scholars for prioritizing watersheds based on soil risk erosion (Ahmed et al., 2018; Ganie et al., 2023; Shekar & Mathew, 2022; Wakode et al., 2013). A soil erosion risk map was prepared using these parameters. Bifurcation ratio, drainage texture, stream frequency, and drainage density were the main influencing parameter for the soil erosion, Jothimani et al., 2020; Mushtaq et al., 2015; Ahmed et al., 2018). The minimum values of the areal parameters such as circulatory ratio, elongation ratio, compactness constant, form factor, and shape index have the most erodible capacity and risk of soil erosion. Thus, the areal parameters with the minimum value were given the

Table 11 Level of priority for soil erosion risk in various watersheds

Watershed code	Total area under priority (km^2)	Priority (soil erosion risk)
IE1D3	993	Very high (3.52–3.72)
IE1D8	382	
IE1D2	716	High (3.73–4.40)
IE1D4	1212	
IE1D5	301	Medium (4.41–4.92)
IE1D7	497	
IE1D1	419	Low (4.93–5.52)
IE1D6	677	

Source: Authors' calculation

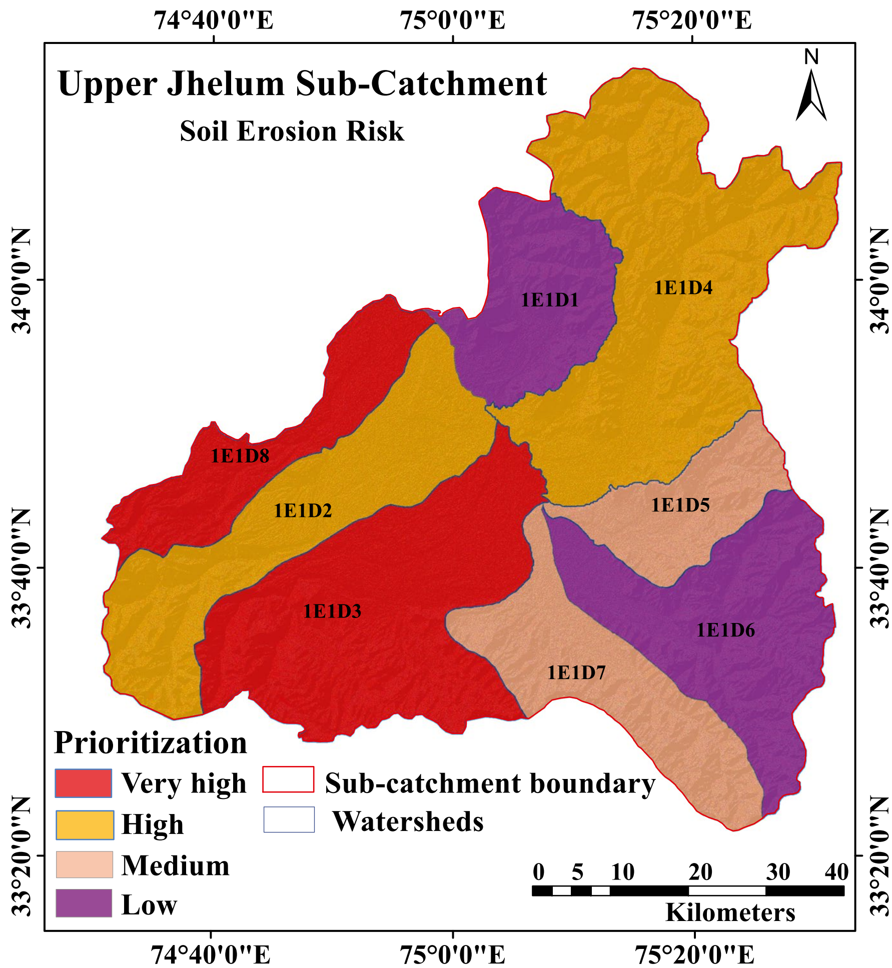

Fig. 8 Prioritization of the watersheds for the soil erosion risk

rank of one, and the next minimum value was given the rank of 2 and so on. The relief and linear parameters were assigned a rank of 1 for the highest value followed by next maximum value (rank 2) till all the values were covered (Table 9). The areal parameters of the watersheds were assigned a rank of 1 for the minimum value of the morphometric parameter, the next minimum value was ranked as 2, third minimum value was ranked 3, and so on. After assigning the ranks of all parameters, the compound value (CV) was computed by averaging the ranking values of all watersheds (Table 10).

The watersheds were categorized into very high (3.52–3.72), high (3.73–4.40), medium (4.41–4.92), and low (4.93–5.52) based on compound value ranks and final priority (Table 10). The lowest compound value among the watersheds in the Sub-catchment was assigned as rank 1. The subsequent lowest compound value was given rank 2, and the same procedure has been followed to other morphometric parameters (Karmokar & De, 2020). The watersheds IEID3 and 1E1D8 having compound values ranging between 3.52 and 3.72 were given the very high priority. Watersheds 1E1D2 and 1E1D4 were given high priority with compound values ranging between 3.73 and 4.40. The watersheds 1E1D5 and 1E1D7 with compound values ranging between 4.41 and 4.92 were given medium priority. The low priority was accorded in the watersheds 1EID1 and 1E1D6 with compound values ranging between 4.93 and 5.52 (Table 11 and Fig. 8).

Thus, the watersheds IEID3, 1E1D8, 1E1D2, and 1E1D4 are vulnerable due to high peak flow, run off, and soil erosion. High and very high priority in these watersheds was attributed to high stream frequency, relief ratio, texture ratio, and drainage density. Moderate priority was given to 1E1D5 and 1E1D7 watersheds.

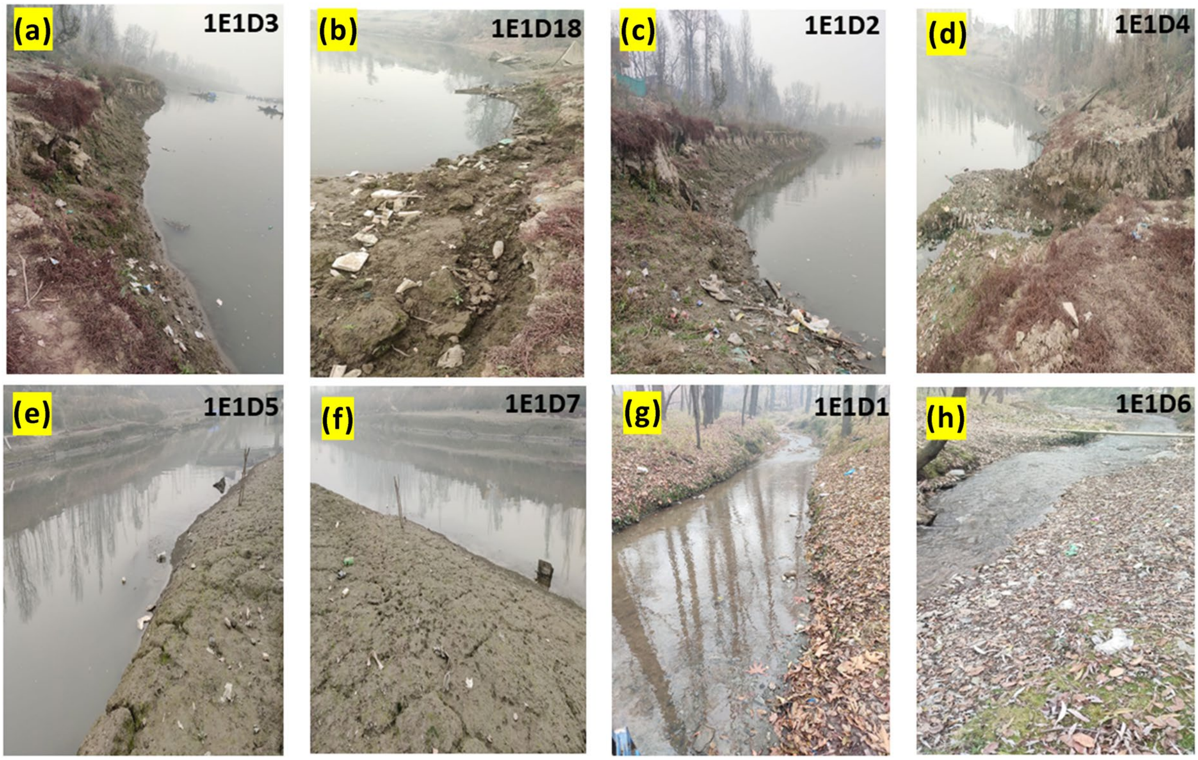

Fig. 9 Field photographs showing soil erosion risk in Upper Jhelum Sub-catchment. **a-b** Very high soil erosion in 1E1D3 and 1E1D8 watersheds, **c-d** high soil erosion in 1E1D2 and 1E1D4 watersheds, **e-f** moderate soil erosion in 1E1D5 and 1E1D7, **g-h** low soil erosion in 1E1D1 and 1E1D6 watersheds

Medium priority of these two watersheds was accorded due to the minimum values of drainage density, circulatory ratio and relief ratio. The other two watersheds 1E1D1 and 1ED6 of Sub-catchment fall under the low priority because of their location in plain areas and low values of the morphometric parameters namely, length of overland flow, texture ratio and CCM (Fig. 9).

These parameters produced least influence on the land degradation, soil erosion, peak flow, and run off. These two watersheds also have a low relief ratio and the smooth surface.

Conclusion

Remote sensing and multi-criteria decision approaches were used for carrying out morphometric analysis and prioritizing watersheds in Upper Jhelum Sub-catchment of India for the soil erosion risk. The linear, areal and relief aspects were utilized for assessing soil erosion risk and prioritizing watersheds. The study emphasizes the significance and implementation of the MCDM approach utilizing compound value for prioritizing watersheds susceptible to soil erosion risk. The results revealed that very high priority for soil erosion risk was accorded to 1E1D3 and 1E1D8 watersheds. The watersheds namely 1E1D2 and 1E1D4 fall under high priority. High relief ratio, drainage density, and stream frequency were identified as the main determining parameters for high and very high priority in these watersheds. Watersheds 1E1D5 and 1E1D7 fall under the medium priority. These watersheds accorded moderate priority for being located partially in plain and hilly areas where the values of the morphometric parameters such as circulatory ratio, drainage density and relief ratio showed lower values. Low priority was given to1E1D1 and 1E1D6 watersheds. Stream length, texture ratio, stream frequency, absolute relief, bifurcation ratio, and relative relief have not much affected the erosion in these watersheds. Thus, concerted efforts are essential in thematic areas of prioritization for implementing and developing the optimal practices for water and land conservation. The optimization of resource allocation may allow stakeholders to reduce vulnerability to soil risk erosion in the Sub-catchment. Contour farming, afforestation, plantation, and construction of check dams are suggested for soil conservation. The methodology used in this study has proved effective for prioritizing watersheds for soil resource management. This methodological framework may be employed in further researches in different geographical regions for devising suitable conservation strategies for natural resources.

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Author contribution Rayees Ali: conceptualized and drafted the main manuscript. Md Masroor and Tamal Kanti Saha: performed the analysis and prepared the figures. Roshani and Md Hibjur Rahaman: contributed in formal analysis and investigation. Haroon Sajjad: supervised, reviewed, and edited the manuscript.

Data availability The dataset used or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval All authors have read, understood, and have complied as applicable with the statement on ethical responsibilities of authors. This research does not involve human participation and animals.

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interest.

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