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Morphometric Behavior of Shahzad Watershed, Lalitpur District, Uttar Pradesh, India: A Geospatial Approach

Tanzeel Khatoon[1*], Akram Javed[2]

[1]Interdisciplinary Department of Remote Sensing and GIS Applications, Aligarh Muslim University, Aligarh, India
[2]Department of Geology, Aligarh Muslim University, Aligarh, India
Email: *tanzeelsiddiqui@outlook.com

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Abstract

Morphometric parameters are an important aspect for understanding the hydrological and morphological behaviour of the watershed. The present study is carried out in the region of the Bundelkhand region (India) which is socio-economically backward and has a history of frequent drought hence studying the watershed characteristics with reference to morphometric analysis becomes important. The remote sensing and GIS technique has been utilized to mathematically quantify the parameters of the Shahzad watershed. The watershed is mainly fed by the Shahzad River (a tributary of Jamini River) flowing from south to north direction contributing the area of 1100 km^2. The various morphometric aspect viz., linear, aerial, relief and morpho-tectonic parameters indicate that the watershed is elongated in shape and is slightly uplifted from the right side in the southern part. Moreover, the watershed experiences low dissection and low run-off discharge there by indicating less erosion in the area. The other factors like drainage density, drainage frequency, infiltration number and length of over land flow indicate that the watershed has high permeability and infiltration capacity. Through this study, it can be concluded that remote sensing and GIS can be fruitfully utilized in analysing the morphometric behaviour of the region. This helps the researcher, planner and stakeholders to establish the relationship between watershed characteristics, thereby resulting in watershed management and sustainable resource management.

Keywords

Shahzad Watershed, Morphometric Analysis, Watershed Characteristics, Remote Sensing, GIS

1. Introduction

Morphometry is a systematic, quantitative and mathematical analysis of watershed dynamics in term of its topological pattern of the surface expression, geomorphology, landforms and shape [1] [2] [3] [4]. It has a major contribution in characterizing the soil erosion, water resource, flood conditions and geomorphological processes [5]. Hydrological and morphological character of the drainage basin is well explained by the implication of various aerial and relief morphometric parameters, whereas the linear aspects including the surface arrangement of streams provide the idea about the structural and lithological influence in the basin [6] [7] [8]. Cumulative result of the morphometric approach provides the idea about the evolution, fluvial processes and erosional behaviour of drainage basin [9] [10] [11] [12]. The morphometric analysis of the watershed is important to understand the geo-hydrological impression including denudational history, maturaty status of the basin, water potential, soil properties and erosional condition [13] [14].

Quantitative description of a drainage system is provided by the morphometric analysis of the watershed, which is one of the important aspects of the characterization of watershed [15]. The development of landforms and drainage system depends upon the bed rock lithology and structures associated with them, thus reliable information about geology, hydrology, geomorphology and land use of the area can be obtained from the drainage pattern and texture [16]. The morphometric analysis provides an idea about the basin geometry, river morphology, recent diastrophism, geological and geomorphological history of the watershed [17].

With the advancement in the technology the remote sensing and GIS technique has become a robust tool in geo-spatial approach. Previous conventional method of extracting drainage from topographic map and tracing on mylar sheets for its analysis is now replaced by advanced geospatial techniques. Several researchers like [14] [18]-[30] have used remote sensing and GIS for systematic morphometric analysis of the watershed.

The study area falls in Bundelkhand region (India) which has complex geological and topological landscape. The area is socio-economically backward and is affected by frequent drought and famine hence draws prime focus for management financial assistance and development plan by the State and Central government as well. Lalitpur is classified into metrological drought, though Shahzad and Govindsagar reservoirs are built on main river and several surface waterbodies are present in the watershed, even then quite often it faces water scarcity in case of deficient rainfall. The aim of the study is to evaluate morphometric aspect of Shahzad watershed in Lalitpur district, India using remote sensing and GIS environment. A detailed study using geo-spatial technique is important for assessing the morphometric character of watershed, which in return helps the planners and decision-makers to think in a better and more sustainable way to manage the land, soil and water resource within the watershed.

2. Study Area

Shahzad watershed falls in the Lalitpur district of Bundelkhand region of Uttar Pradesh extending from 24˚25'N - 25˚03'N latitudes to 78˚17'E - 78˚39'E longitudes covering a total geographical area of about 1100 km^2. Figure 1 shows the

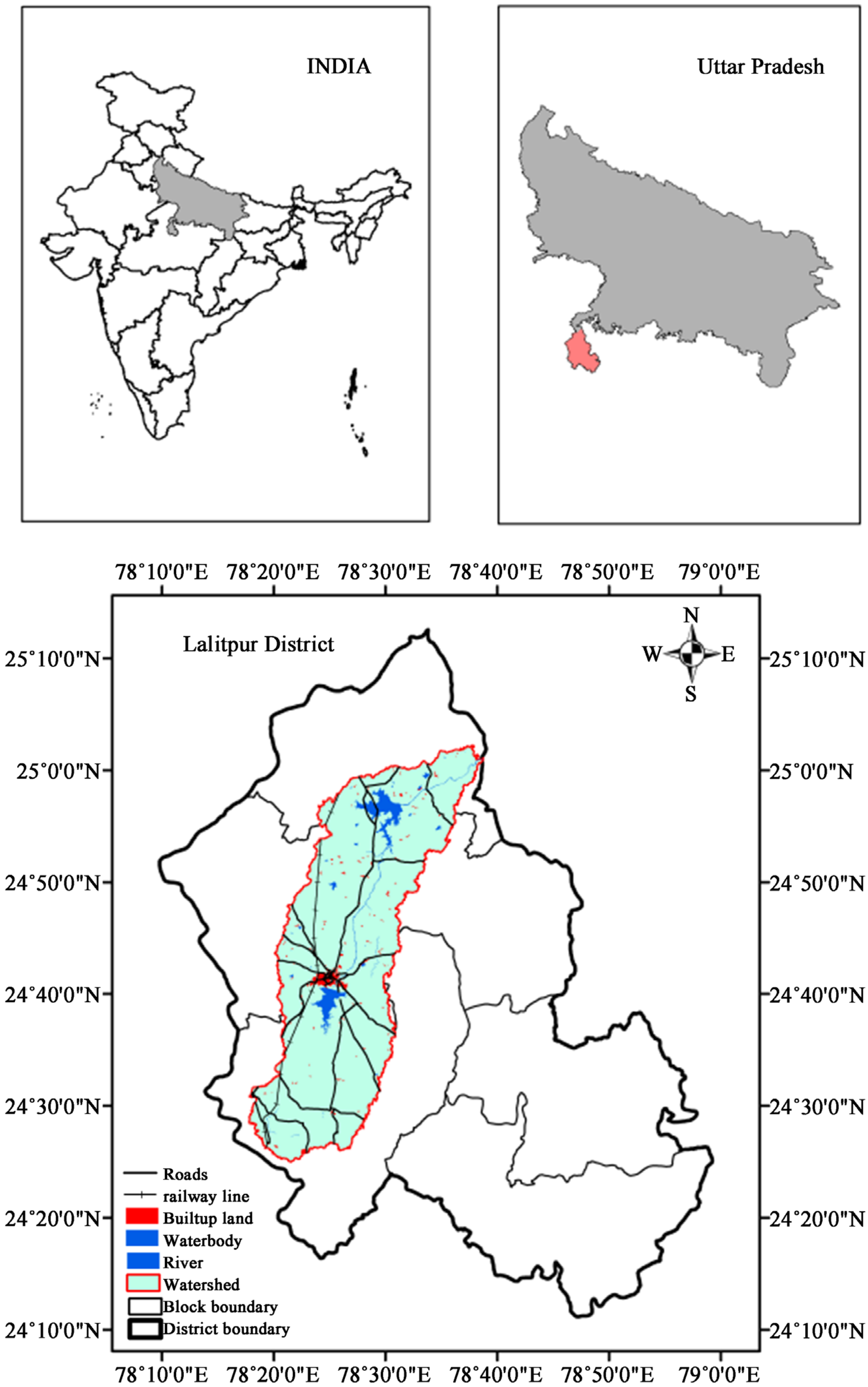


Figure 1. Location map of study area.

location of study area. Shahzad River is the main river of the watershed, which originates in southern Vindhyan plateau and flows towards north and divides watershed into eastern and western halves. The river and its tributary streams follow dendritic to sub dendritic drainage pattern. The streams originated in the western half follows straight line which may be due to prominent structural features [31].

Topographically the watershed is characterised by plains, plateau, hills and ridges. Vindhyan plateau with undulating topography is exposed in the south and denudational hills are present in the northern part of the watershed. Rest of the watershed has almost flat plains with small dotted stony outcrops spread throughout the basin. The highest and lowest elevations encountered in the study are 280 m and 495 m amsl respectively, whereas the slope of the area ranges from 0˚ - 48˚. Figure 2 shows 3D model of the watershed.

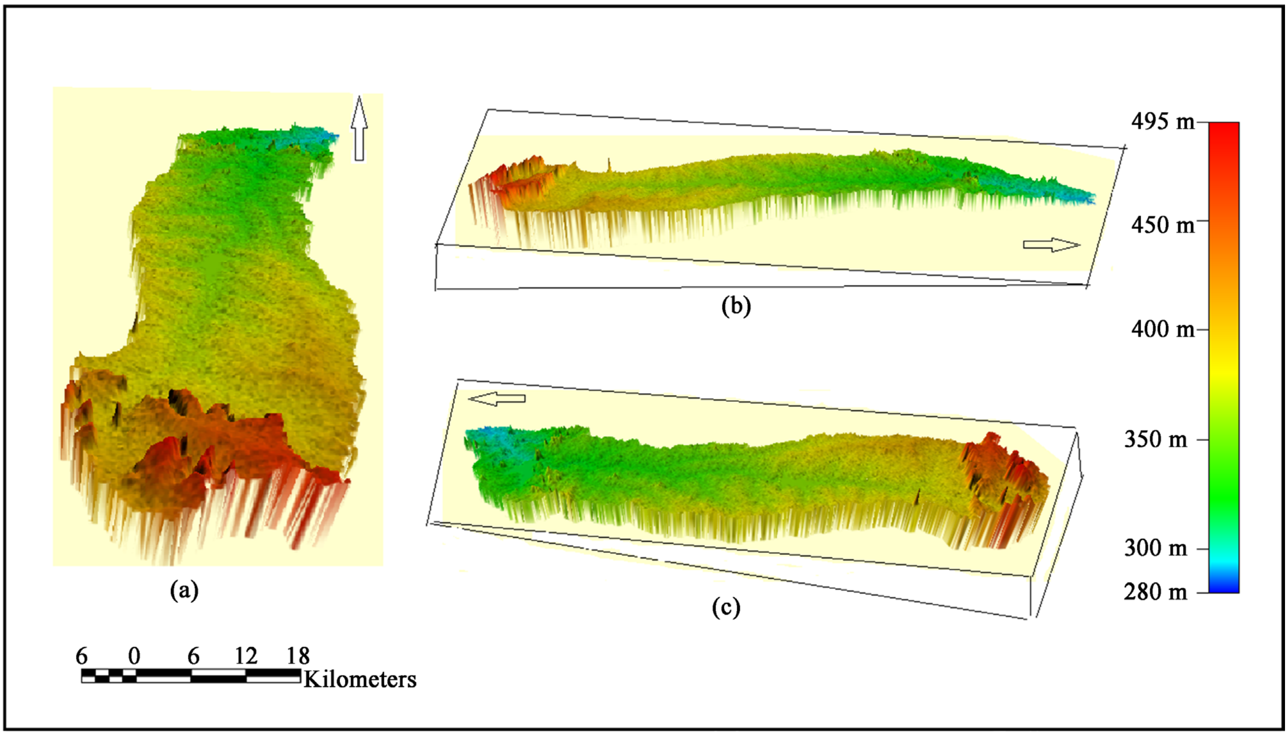


Figure 2. 3D map of Shahzad watershed with its (b) left profile (c) right profile.

Geology of Shahzad watershed is broadly contributed by Bundelkhand Granitic complex comprising of granites and granitic gnisses in the northern part of the watershed and discrete plateau of Vindhyan sandstone and shale in the southern periphery. Pile of Banda alluvium overlies the BGC basement (Figure 3).

The geomorphic units encountered in the Shahzad watershed are denudational hills, pediments/pediment inselberg complex, buried pediments, moderately weathered buried pediplain, shallow weathered buried pediplain, butte, valley fills, dissected plateau and linear ridges (Figure 4).

May is the hottest month of the season having average maximum temperature

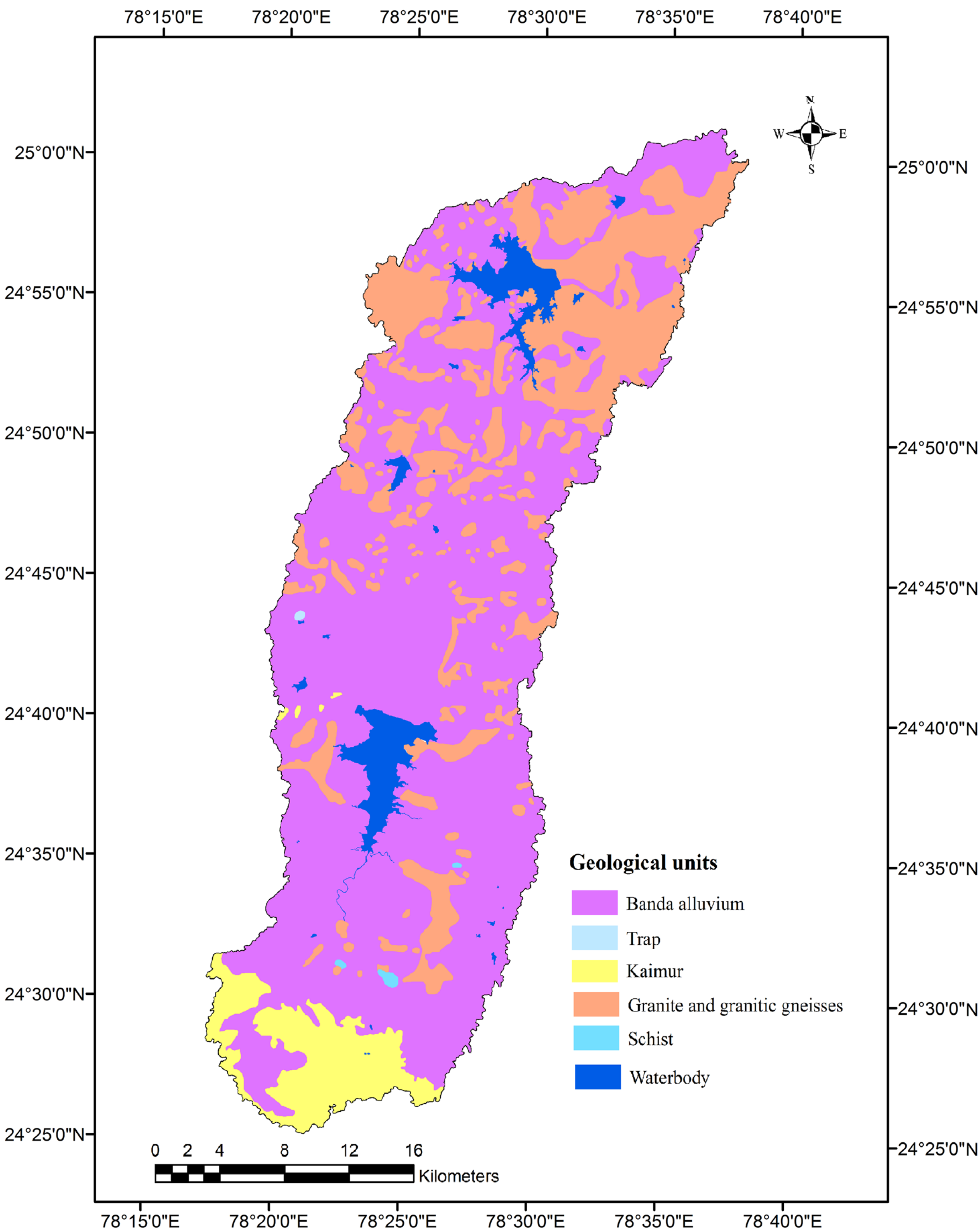


Figure 3. Geological map of Shahzad watershed (Source: GSI, 2008).

of 45.5˚C, whereas average minimum temperature is 5˚C in the month of January. About 80% of the total rainfall occurs in the months of July and August, with average annual rainfall being 806.25 mm. The standard deviation of annual rainfall is about 280.81 mm with the coefficient of variance is 34.82%. Govindsagar and Shahzad dams are built on the Shahzad River in the south and north respectively which serves as a major surface water resource in the watershed.

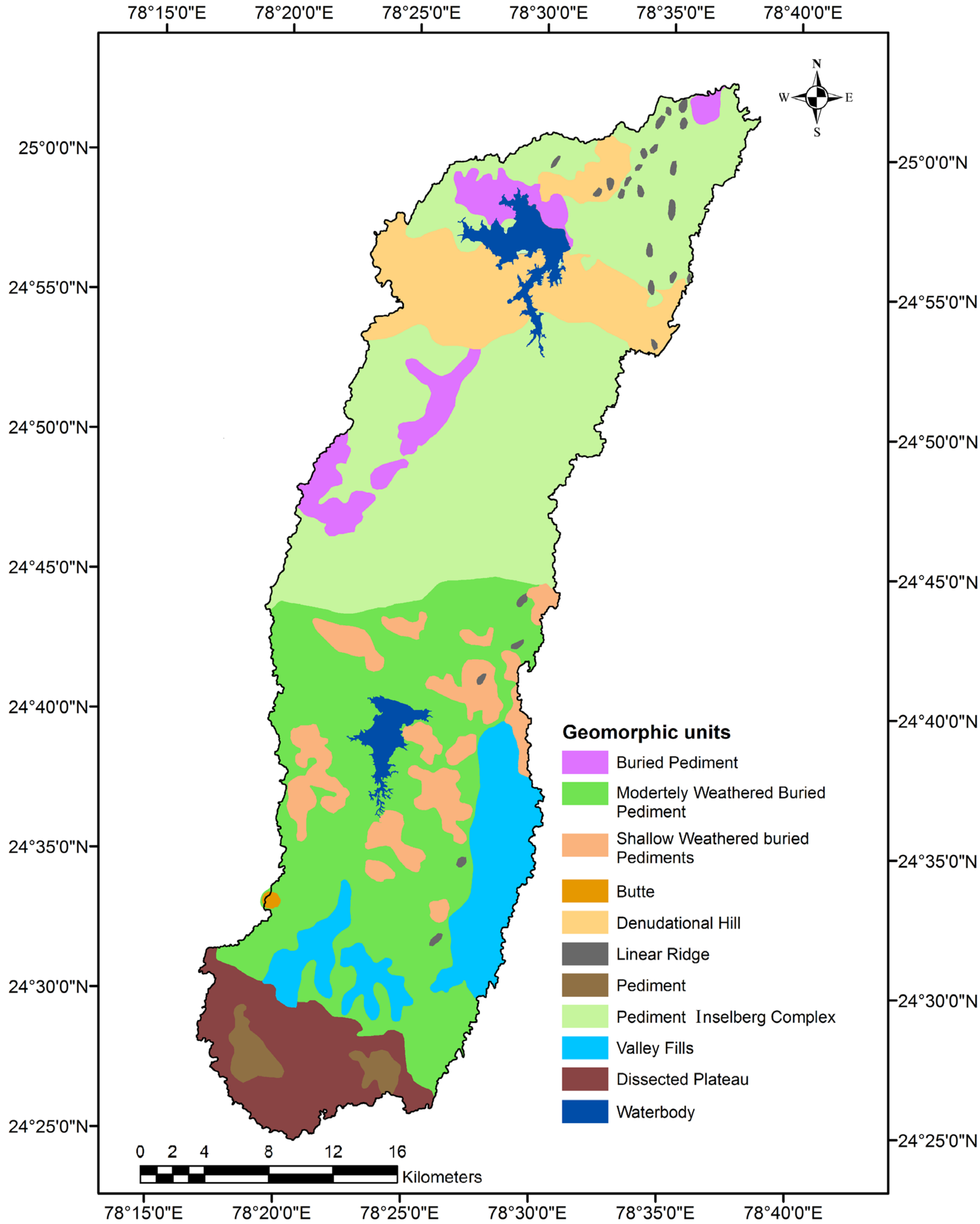


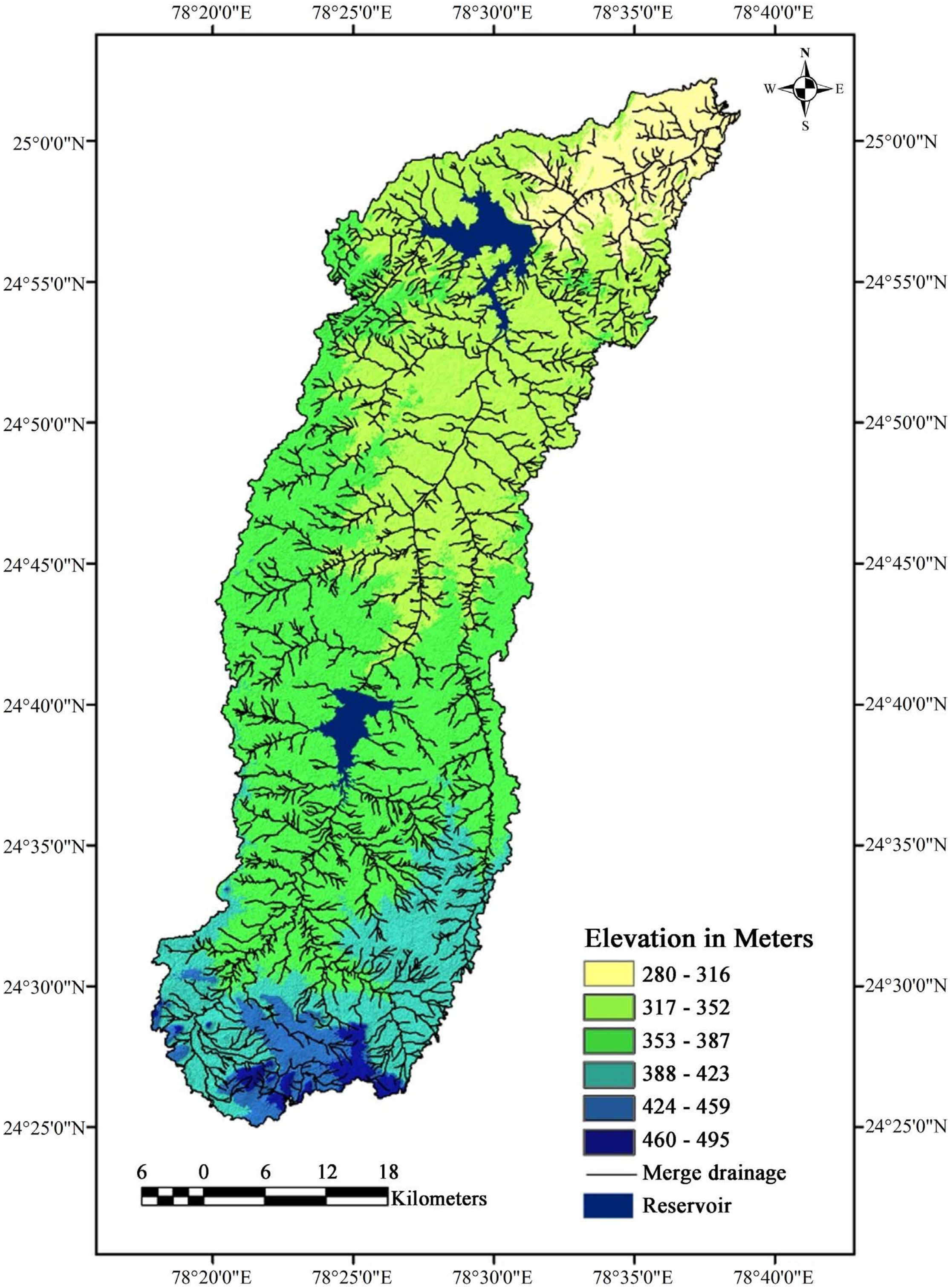
Figure 4. Geomorphological map of Shahzad watershed (Source: Haldar and Rajarajan, 2000).

Canals are connected through the reservoirs for irrigation, and drinking purposes.

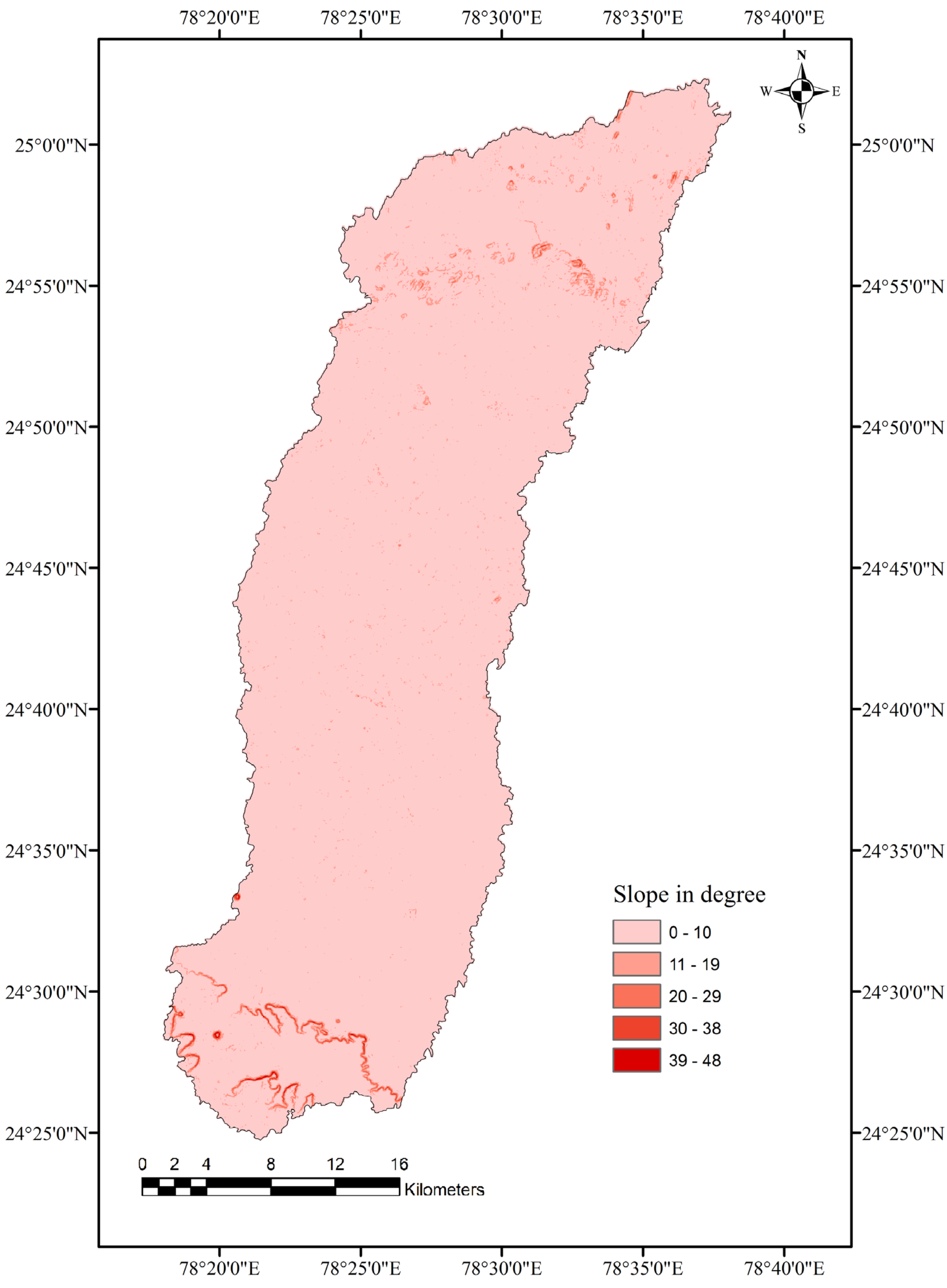
3. Materials and Methodology

A systematic approach involving multiple steps was followed to carry out the present work. Survey of India topographic maps (54 L/5, L/6, L/7, L/9 and K/12) on 1:50,000 scale were utilized to extract relevant information. The Shuttle Radar

Topography Mission (SRTM) data of 30 meter resolution was used for generation of Digital Elevation Model (DEM) and subsequent derivative like slope. Figure 5(a) shows the drainage of the area superimposed on the DEM and Figure 5(b) shows the slope of the study area



(a)



(b)

Figure 5. (a) Drainage superimposed on DEM; (b) Slope map.

3.1. Delineation of Watershed

The Shuttle Radar Topography Mission (SRTM) data of 30 meter resolution was used for delineation of the basin boundary. Various modules of ArcMap 10 were utilised for the automatic extraction of watershed. SRTM tiles were mosaicked and by using spatial analyst (hydrology tool) various raster data like Fill DEM, Flow direction, flow accumulation, stream order, stream to feature and basin were generated. Thus, the basin produced in raster format was converted into polygon feature and subsequently saved as shape (.shp) file. Streams digitised from Survey of India toposheets were later on updated by satellite image IRS-R2 LISS III (2015) was also correlated by automatic generated streams. The resultant stream was ordered according to the Strahler (1964) scheme of ordering.

3.2. Drainage Network and Morphometric Analysis

The mosaicked and clipped watershed from Survey of India toposheets was used to manually digitize the drainage and was subsequently updated using IRS-R2 LISS III FCC data of 2015. Onscreen digitization was carried out by creating a new vector file (.shp) as line coverage, this created vector layer was assigned different unique ids for various streams orders and digitization errors (if any) were edited and removed using edit module available in ArcMap. Each stream segment was assigned a stream order following Horton's method [32] and later modified by Strahler (1952) to compute linear, aerial and relief aspects by using standard formulae and methods. Figure 6 shows the systematic flow chart of the study.

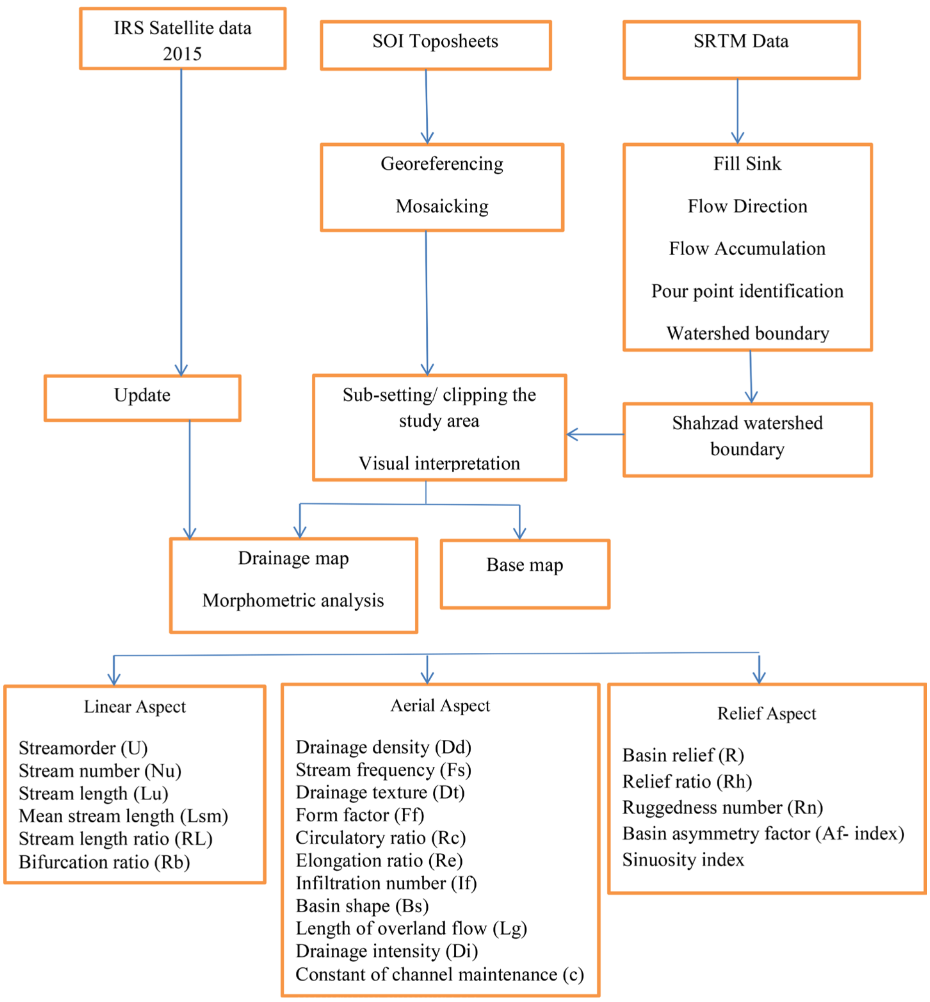


Figure 6. Flow chart of the study.

4. Morphometric Analysis

Remote sensing data and techniques coupled with GIS platform are conveniently used to compute the morphometric parameters. The morphometric analysis is carried out in linear, aerial and relief aspect. Linear aspect includes stream order (U), stream number (Nu), stream length (Lu), mean stream length (Lsm), stream length ratio (RL) and bifurcation ratio. Aerial aspect include drainage density (Dd), stream frequency (Fs), drainage texture (Dt), form factor (Ff), circulatory ratio (Rc), elongation ratio (Re), infiltration number (If), basin shape (Bs), length of overland flow (Lg), drainage intensity (Di) and constant of channel maintenance (c). Relief aspect consists of basin relief (R), relief ratio and ruggedness number (Rn). Besides some morphotectonic parameters like basin asymmetry factor (Af-index) and sinuosity index have also been computed. Table 1 shows the formulae used to compute Morphometric and morphotectonic parameters of the watershed and Figure 7 shows the drainage map of the area with different stream orders.

Table 1. Morphometric/morphotectonic parameters and their formulae

Morphometric parameters	Unit	Formula	Reference
Linear aspect			
Stream order (u)	-	Hierarchical rank	Strahler (1964) [15]
Stream number (Nu)	-		
Stream length (Lu)	-	Length of the stream	Horton (1945) [32]
Mean stream length (Lsm)	km	Lu/Nu	Strahler (1964) [15]
Stream length ratio (RL)		Lu/Lu − 1	Horton (1945) [32]
Bifurcation ratio (Rb)		Nu/Nu + 1	Schumm (1956) [41]
Mean bifurcation ratio (Rbm)		Average of bifurcation ratios of all orders	Strahler (1957) [34]
Aerial aspect			
Dainage density (Dd)	km/km^2	Lu/A	Horton (1932) [45]
Stream frequency (Fs)		Nu/A	Horton (1932) [45]
Drainage texture (Dt)		Nu/P	Horton 1945 [32]
Form factor (Rf)		A/Lb^2	Horton (1932) [45]
Circulatory ratio (Rc)		$12.57\ A/P^2$	Miller (1953) [55]
Elongation ratio (Re)		$1.128\ A^{0.5}/Lb$ or $(2/Lb)*(A/pi)^{0.5}$	Schumm (1956) [41], Nookaratnam et al. 2005 [44]
Infiltration number (If)		Dd*Fs (Drainage density* stream frequency)	Faniran (1968) [57]
Basin shape (Bs)		Lb^2/basin area (A) (basin length)	Horton (1945) [32]
Length of overland flow (Lg)	km	1/2 of reciprocal of dd or 1/2 Dd	Horton (1945) [32]
Drainage Intensity (Di)		Fs/Dd	Faniran (1968) [57]
Constant of Channel Maintenance (C)	km^{-2}	1/Dd	Schumm (1956) [41]

Continued

Relief aspect			
Basin relief (R)	m	H-h (max elevation-min elevation)	Strahler (1952) [9]
Relief ratio		R/Lb (basin relief/max length of basin)	Schumm (1956) [41]
Ruggedness number (Rn)		drainage density*basin relief/1000	Patton (1988) [47]
Morphotectonic and geomorphic indices			
Assynetry factor (Af-factor)		(Ar/At)*100	Hare and Gardner (1985) [63]
Sinuosity index		Curvilinear/straight distance of river	_

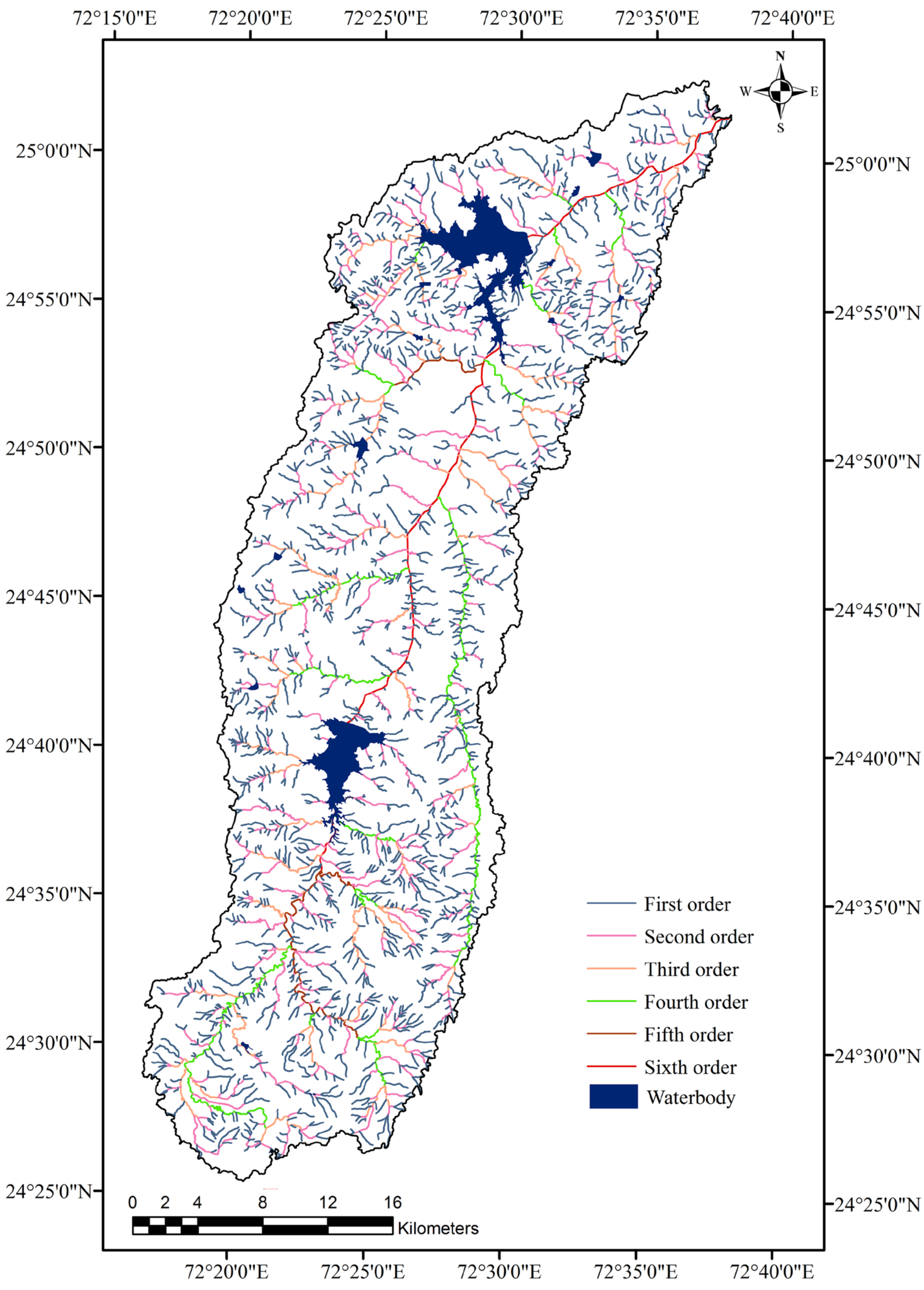


Figure 7. Drainage map of Shahzad watershed.

4.1. Linear Aspect

Linear parameters like stream order (u), stream number (Nu), stream length (Lu), mean stream length (Lsm), stream length ratio (RL) and bifurcation ratio (Rb) and mean bifurcation ratio (Rbm) have been computed for Shahzad watershed.

4.1.1. Stream Order (U)

Stream ordering is the first and the basic step in morphometric analysis. Different classifications of stream ordering have been suggested by [32] [33] [34] [35] [36]. But for the sake of simplicity, Strahler classification for stream ordering has been adopted. According to the Strahler ordering system the smallest unbranched stream segment is designated as first order, where two first order segments meet it forms second order, where two second order segments meet it constitutes a third order and so on [15]. The highest order stream is the trunk stream where all the water and sediment discharge of catchment accumulates and passes through it. Sixth order is the highest order stream encountered in the Shahzad watershed.

4.1.2. Stream Number (Nu)

The total number of stream segment present in each order is termed as stream number and the value of stream number decreases with increasing stream order. According to Horton (1945) "law of stream number", the logarithms of the stream number plotted against the stream order follows the inverse geometric sequence and the points lie on the straight line although some of the points may show little deviation from the linear path. In Shahzad watershed, there are 1500 first order streams, 349 are of second order, 82 are of third order, 18 of fourth order, 3 of fifth order and one (main Shahzad stream) is of sixth order. Figure 8 shows the negative correlation when stream order is plotted against the stream number.

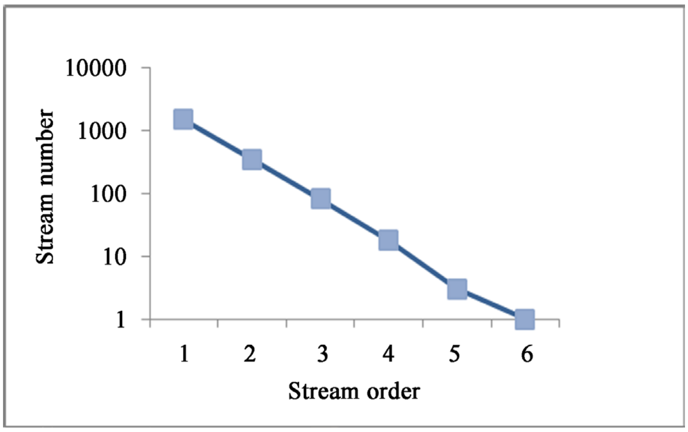


Figure 8. Regression plot showing (−ve) correlation between Stream number and Stream order.

4.1.3. Stream Length (Lu)

Cumulative length of all stream segments of a particular order is the stream length of that order. Stream length is generally higher in lower orders, as stream number increases the length of the stream decreases and vice-versa. Large number of stream with shorter length develops on the bed rock of less permeable formations as compared to the well-drained watershed where small number of relatively longer streams are developed [37]. According to the Horton's (1945), "law of stream length", the length of streams of each order in a drainage basin tends closely to approximate a direct geometric ratio. Plotting of stream order against stream length follows the linear pattern which indicates the homogeneous rock material exposed to weathering and erosion. The deviation from the general pattern is an indication, that the terrain is characterized by the variation in lithology and topography. Longer length of the streams is indicative of flatter gradient [38]. The stream length of all orders are individually measured in Arc GIS 10, the stream length value of first, second, third, fourth, fifth and sixth orders are 943.20 km, 366.36 km, 199.64 km, 124.33 km, 28.77 km and 61.8 km respectively. The regression plot of stream order against stream length (**Figure 9**) shows the deviation in stream length at sixth order (which should be smaller than fifth order stream length in case of general pattern) may be due to the uniform lithology, gentle slope and low gradient in the topography.

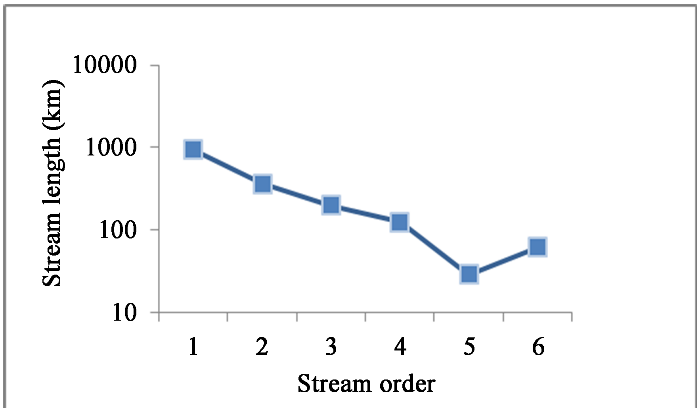


Figure 9. Regression plot of Stream order vs Stream length.

4.1.4. Mean Stream Length (Lsm)

Mean stream length is the dimensional property which reveals the characteristics of drainage network and its contributing basin surface [15]. It is the ratio of total stream length of a particular order to the number of streams of that order. With the increase in stream order the value of mean stream length increases, the two show positive correlation (**Figure 10**).

4.1.5. Stream Length Ratio (RL)

Stream length ratio is calcutated by the ratio of mean length of streams of a given order to that of the next lower order [32]. The value of stream length ratio ranges from 0.231 (for V/IV) to 2.148 (for VI/V). The decimal value of stream length ratio indicates that mean length of the streams of higher order is less than the stream length of next lower order. The variation in the stream length ratio

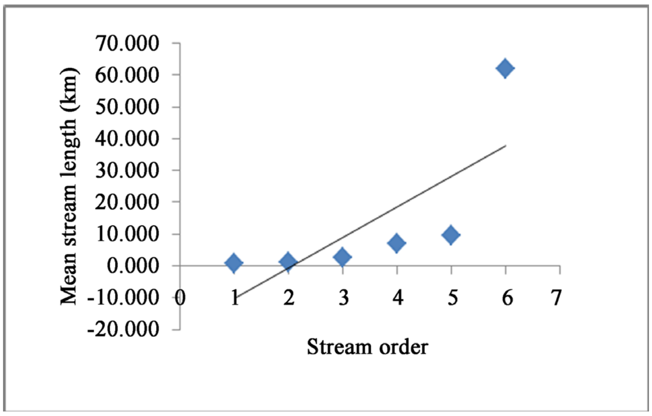


Figure 10. Mean stream length vs Stream order.

may be due to change in topography and slope, indicating the late youth stage of geomorphic development in the streams of the concernt area [19] [39] [40].

4.1.6. Bifurcation Ratio (Rb)

Bifurcation ratio is defined as ratio of number of stream segments in a given order to that of the number of stream segments of next higher order [41]. The bifurcation ratio is regarded as the sign of relief and dissection [32]. The watershed where geometric structures do not distort the drainage pattern, their value of bifurcation ratio ranges between 3 to 5 [42]. The lower value of Rb indicates that the watershed is structually less dominated without distortion in the drainage pattern [43]. According to Strahler (1957) the value of Rb shows small variation in different regions or different environment except where powerful geological structures dominate.

In Shahzad watershed the value of bifurcation ratio ranges from 3 to 6 (**Table 2**), higher values indicate that the drainage is structurally controlled in some part of the watershed while the lower values show small variation among them and indicate less structural disturbances. Mean Rb of the watershed is 4.422.

Table 2. Linear aspects of Shahzad watershed.

Stream order (u)	Stream number (Nu)	Stream length (Lu)	Mean stream length (Lsm)	Stream length ratio (RL)		Bifurcation Ratio (Rb)	
1	1500	943.2	0.629	II/I	0.388	I/II	4.298
2	349	366.36	1.050	III/II	0.545	II/III	4.256
3	82	199.64	2.435	IV/III	0.623	III/IV	4.556
4	18	124.33	6.907	V/IV	0.231	IV/V	6
5	3	28.77	9.59	VI/V	2.148	V/VI	3
6	1	61.8	61.8	Mean RL	0.787	Mean Rb	4.422

4.2. Aerial Aspect

Aerial aspect includes various morphometric parameters like drainage density

(Dd), Stream frequency (Fs), Drainage texture (Dt), Form factor (Rf), Circulatory ratio (Rc), Elongation ratio (Re), Infilteration ratio (If), Basin shape (Bs), Length of overland flow (Lg), Drainage intensity (Di) and Constant of channel maintainace (C).

The area and the perimeter of the basin are the basic criterion for the analysis of drainage basin. The area of the basin may be defined as the horizontal plane between the water divides where stream segments of all order are well networked. The perimeter is the periferal boundary of the watershed which is automatically calculated in GIS environment. The basin length is the longest dimension of the basin along the principal stream of the same basin; it is calculated by the formula proposed by Nookaratnam *et al.* [44].

4.2.1. Drainage Density (Dd)

The concept of drainage density was proposed by Horton [45] as the closeness of spacing between the stream segments. Drainage density is the measurement of total stream length of all order in the given basin to the per unit area. Drainage density is indicative of landscape dissection, runoff potential, vegitation cover, climatic condition, runoff potential, infilteration capacity of land, rock and soil property of the basin [46]-[51]. Low drainage density is produced in the areas of highly resistant or permeable sub surface material, dense vegetation and low relief. The high drainage density generally occurs in areas of impermeable and weak sub surface material, high relief and sparse vegetation [43]. Langbein [52] recognized the importance of drainage density as a factor of determining the time of travel by water in a given basin. Low drainage density leads to coarse drainage texture, whereas high drainage density results in fine drainage texture.

The overall drainage density of the Shahzad watershed is 1.567 (low) however the higher drainage density is observed in the areas where impervious granite and gnisses are exposed (**Figure 11**). Low drainage density is found in the southern periphery where resistant and permeable rocks are present. The third zone is characterized by the wide stretch of alluvium, where in general the drainage density is very low except in areas where stream segments of all orders reach to principal stream, thereby increasing the drainage density in a particular area. The drainage density in the alluvial part of the watershed is low due to high permeability and infiltration.

4.2.2. Stream Frequency (Fs)

Stream frequency is the total number of streams of all orders per unit area (Horton, 1932). Like drainage density, stream frequency is also a similar parameter to measure the drainage network of the basin. High stream frequency is generally related to impermiable sub surface material, low infilteration capacity, sparse vegitation and high relief [50] [51] [53]. In Shahzad watershed, stream frequency is 1.77 (low) which suggests that large part of the watershed is covered with permeable lithology i.e alluvium. However stream frequency is locally high, especially in those parts of the basin where granite and gnisses are exposed.

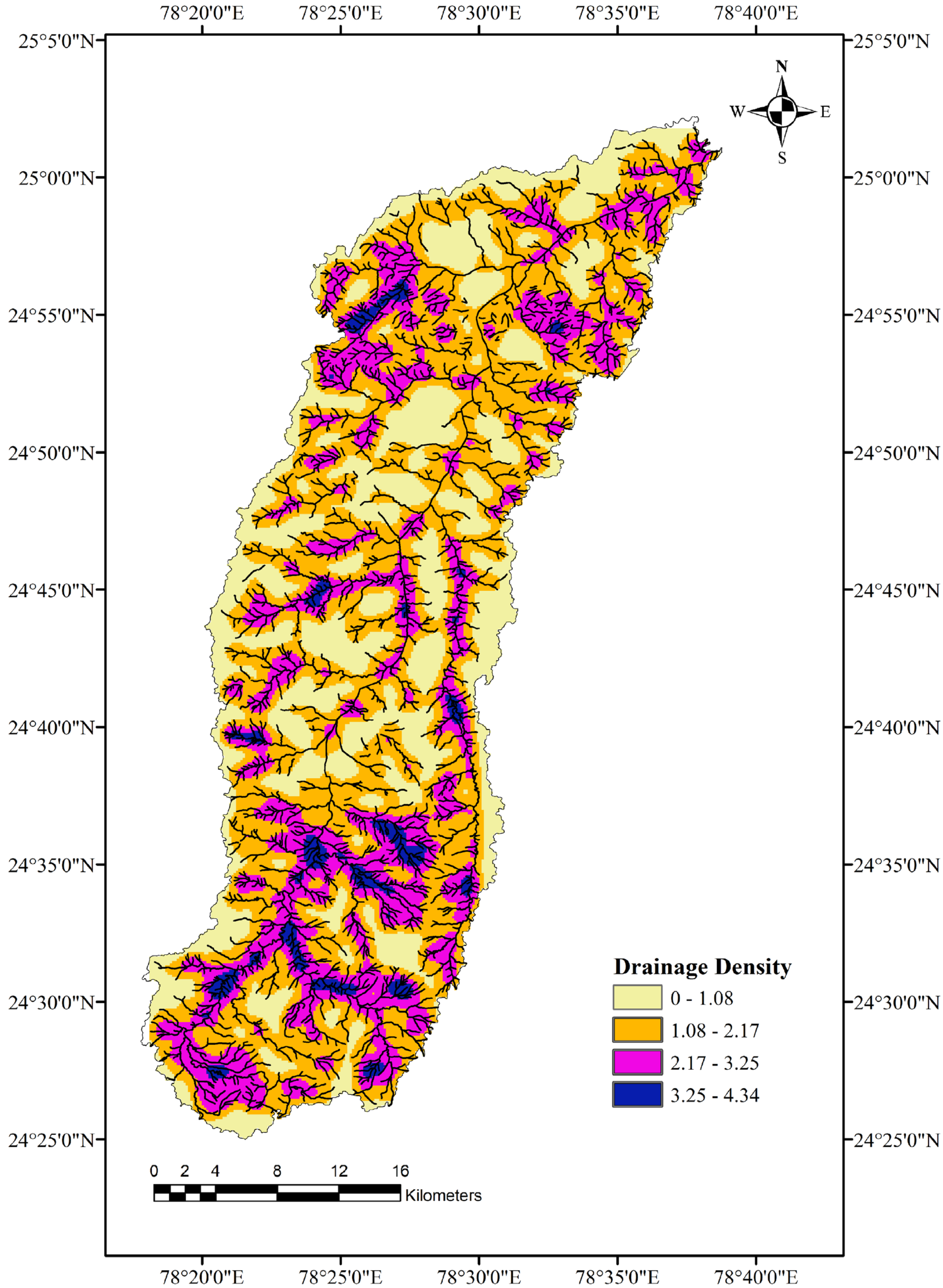


Figure 11. Drainage density map of the watershed.

4.2.3. Drainage Texture (Dt)

Drainage texture depends upon climate, rainfall intensity, infiltertion, soil type, vegetation and climate [54]. In the initial stage of erosion cycle the drainage texture is found to be coarse in nature. Smith (1950) classified drainage texture into three categories, *i.e.* below 4 is course texture, from 4 to 10 is medium texured and above 10 is fine textured. The value of drainage texture in Shahzad watershed is 7.698 which falls in the medium textured category (**Table 3**).

4.2.4. Form Factor (Rf)

Form factor is defined as the ratio of area of the basin to the square of its basin length [45]. The value of form factor will always be greater than 0.7854 for a perfectly circular basin, whereas samller value is indicative of more elongated basin. The circular basin will have high peak flow for the shotter duration, whereas an elongated basin with small form actor, has low peak flow for longer duration. The value of form factor in the Shahzad watershed is low (0.224) indicating the elongated shape of the basin, further it also suggests that the area has low peak flow value for longer duration which can be easily managed as compared to a circular basin.

4.2.5. Circulatory Ratio (Rc)

Circulatory ratio as the ratio of the river basin area to the area of a circle has the same perimeter [55]. It is a dimensionless ratio to express the boundary of the basin; its value varies from 0 to 1 in line and circle respectively [15]. The variation is influenced by the frequency and length of stream, geological structures, climate, vegitation, slope and relief of the basin. In the present case the circulatory ratio of Shahzad watershed is 0.215 which is indicative of low relief and less structurally controlled drainage network.

4.2.6. Elongation Ratio (Re)

Elongation ratio is a ratio between the diameter of the circle of same area as that of drainage basin and the maximum length of the basin. The value of elongation ratio defines the shape of the basin and depends on the climate and topography of the basin [15]. The value generally varies from 0.6 to 1, where 0.9 - 1.0 is circular, 0.8 - 0.9 (oval), 0.7 - 0.8 (less elongated), 0.5 - 0.7 (elongated) and <0.5 (more elongated). The elongated basin is less efficient in run-off discharge than a circular basin (Singh and Singh, 1997). In Shahzad watershed the value of elongation ratio is 0.533, which indicates that the watershed is elongated.

4.2.7. Infilteration Number (If)

The infilteration number is the product of drainage density and stream frequency. It is observed that higher values of infilteration number indicate low infilteration and high runoff [56]. The low infilteration capacity results in high drainage density which indicates the impervious sub surface material and vice versa. The value of infilertation number in the study area is low (2.783), which indicates high infilteration capacity and less drainage density. The alluvial region has high infilteration capacity, thus the drainage density in this region of Shahzad watershed is low, and hence it suggests low surface runoff.

4.2.8. Basin Shape (Bs)

The basin shape is the ratio of square of the basin length to its area and mainly governs the rate at which water is supplied to its principal channel. The value of basin shape of the study area is 4.45 (Table 3).

4.2.9. Length of Overland Flow (Lg)

Horton (1945) describes the length of overland flow, as the length of the water flow path over the ground before it confluences to the adjecent stream channel. The length of overland flow is nearly half of the reciprocal of drainage density. Lg is inversally proportional to the average slope of the channel and is synonymous with the length of sheet flow to a large degree. Rainfall intensity, infiltration rate, soil, landuse/cover, slope etc are the factors that affect the value of Lg. Maximum length of overland flow marks the youthful stage whereas lower value of Lg at the old stages [27]. The length of overland flow in the watershed is 0.319, indicating low drainage density and high infiltration, thereby suggesting into less surface runoff.

4.2.10. Drainage Intensity (Di)

Drainage intensity is defined as the ratio of stream frequency to the drainage density [57]. Low values of drainage intensity indicate little effect of drainage density and steam frequency on the extent to which the surface has been lowered by the agent of denudation. The value of drainage intensity in Shahzad watershed is 1.132. The low value of drainage density, stream frequency and drainage intensity suggest that the surface runoff is slowly removed from the basin.

4.2.11. Constant of Channel Maintenance (C)

The term constant of channel maintenance (C) is defined as the inverse of drainage density [41]. The drainage basin with a higher value of C will have low value of drainage density and vice-versa. The low value of drainage density results into higher value of C reveals the control of lithology with surface of high permeability. In Shahzad watershed the overall value of C is 0.638, indicaes low value

Table 3. Aerial aspects of Shahzad watershed.

Dainage density (Dd)	1.567
Stream frequency (Fs)	1.775
Drainage texture (Dt)	7.698
Form factor (Rf)	0.224
Circulatory ratio (Rc)	0.215
Elongation ratio (Re)	0.533
Infiltration number (If)	2.783
Basin shape (Bs)	4.459
Length of overland flow (Lg)	0.319
Drainage Intensity (Di)	1.132
Constant of Channel Maintenance (C)	0.638

of drainage density as larger part of the basin is dominated by alluvium which possess higher permeability hence, resulting into higher value of C.

4.3. Relief Aspect

The relief aspects like basin relief (R), relief ratio (Rh) and ruggedness number (Rn) have been computed for the Shahzad watershed (**Table 4**), and are discussed as under:

4.3.1. Basin Relief (R)

Basin relief is calculated by taking the difference between the elevation of the highest and the lowest points within the watershed. Basin relief is an imporant parameter to understand the morphology of drainage development, surface and sub-surface water flow direction, erossional character like volume of sediments transported and landform development in a basin [58] [18]. The basin relief of the Shahzad watershed is 215 m which suggest less difference in elevation.

4.3.2. Relief Ratio (Rh)

Relief ratio is a dimensionless parameter and defined as the ratio between the basin relief and longest dimension of the basin parallel to principal stream [41]. Relief governs the conversion of potential energy to kinetic energy of water that flows through the basin [59]. It is a measure of gradient aspect of the watershed, indicating the intensity of erosion processess operated on the slope of the basin. The high value of relief ratio indicates steep slope and high relief and vice-versa. The value of relief ratio in the watershed is low (0.003) indicating the gentle slope and low relief resulting into low peak basin discharge and less erosion.

4.3.3. Ruggedness Number (Rn)

Strahler (1964) defined the ruggedness number, as the product of the basin relief and drainage density. The high value of ruggedness number not only indicates steeper slope but longer length as well. Rn in the Shahzad watershed is 0.336 showing low value with gentle sloping area and low stream frequency. Since the ruggedness number in the basin is low thus the erossion and the dissection in the Shahzad basin is also low.

Table 4. Relief aspects of the Shahzad watershed.

Maximum elevation (m)	495
Minimum elevation (m)	280
Perimeter (km)	253.7
Basin length (km)	70.04
Basin relief (R) (m)	215
Relief ratio (Rh)	0.003
Ruggedness number (Rn)	0.336

4.4. Morphotectonic and Geomorphic Indicators

Several Morphotectonic and geomorphic indices are also important parameters to describe the characteristics of a river basin. Morphotectonic analysis by using geomorphic indices has been developed as a basic tool for identifying the tectonic activity or variation in tectonic activity in a particular area [60] [61] [62]. Basin asymmetry factor (Af-index) and sinuosity index have been computed for the Shahzad watershed, and are discussed as under:

4.4.1. Asymmetry Factor (Af-Index)

The asymmetry factor is calculated to establish the relation between the lateral shifting in a basin with reference to main water course. It is used to evaluate the tectonic tilting of the basin along with the direction of tilt [63]-[69]. This index includes the direction of differential tectonic activity and is also sensitive to uplift and subsidence of discrete blocks versus broad tilting [70]. The Af-index is calculated by the following formula

$$Af = (Ar/At)\ 100$$

where Ar is the area of right side of the basin along the trunk stream (facing downstream) and At is the total area of the basin. If Af > 50, it suggests that river has shifted towards the left side of the downstream and the basin has uplifted from the right side. When Af value is <50, it indicates that the river has shifted towards the downstream right side and has uplifted from the left in the drainage basin, whereas Af value equals to 50 shows perfect symmetry with no tilting. Variation in Af value lesser or greater than 50 indicates tilting either due to active tectonic or lithological control [64]. The main Shahzad River was considered to calculate the Af index of the watershed, further the basin was divided into northern and southern halves to calculate the amount and direction of tilting at local level. The Af factor of Shahzad watershed is 50.69 indicating that the river has shifted towards the left, and the basin is slightly uplifted from the right (**Figure 12**), which confirm to the findings by Prakash *et al.* (2016). Further, when the basin is divided into northern and southern zone, it has been observed that the Af-index is 60.15 in the southern zone indicating the uplifting at the right side where as in the northern zone Af-index is 35.85 indicating the subsidence at right side.

4.4.2. Sinuosity Index

The sinuosity of a river is defined as the curvilinear distance to the linear distance between the ends of the curve or the degree to which the river has departed from the straight line. The river with the sinuosity index greater than 1.5 is referred as meandering river, whereas <1.5 is considered as sinuous river [71]. The channel index calculated in this investigation is the length of a reach as measured along the channel divided by the airline distance between the two end points of the reach [72] [73].

In the study area, the main river channel is divided into three segments viz.,

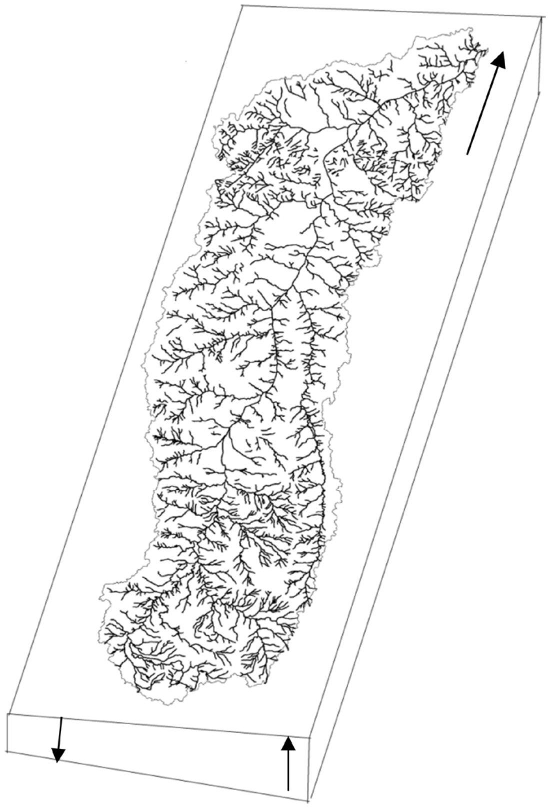


Figure 12. Block diagram showing the effect of Af-index with the right side upliftment of the watershed.

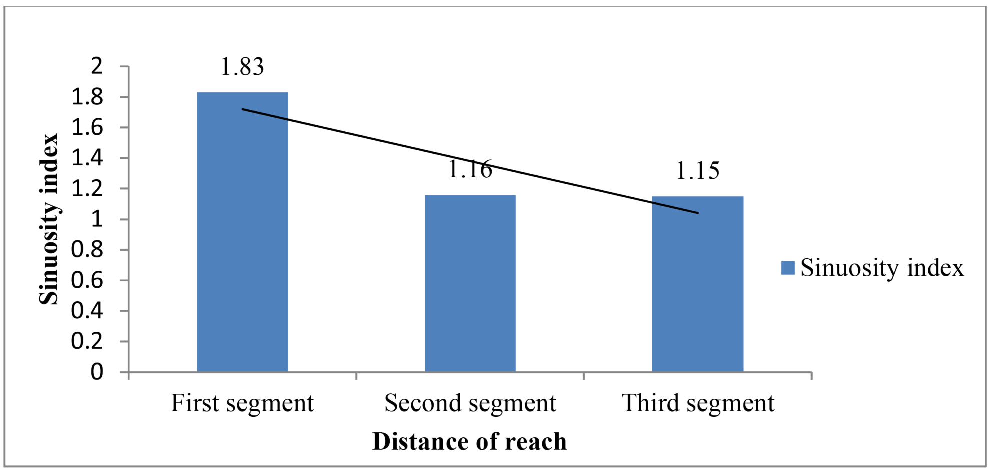


Figure 13. Sinuosity index at different segments of the Shahzad River.

First segment (head to pre Govindsagar reservoir), Second segment (Govindsagar to pre Shahzad reservoir) and the third segment (post Shahzad reservoir to the mouth). The values of channel index for first, second and third segments are 1.83, 1.16 and 1.15 respectively (Figure 13). The river at the first segment is highly meandering in its pattern, as it flows between the dissected plateau where the surface runoff is higher resulting in erosion of alluvium over, whereas in the second segment it continues to flow on alluvium but the volume and velocity of water is restricted by the Govindsagar dam, hence resulting into low sinuosity value. The third segment has the lowest value of channel index, probably due to short distance and the resistant bed rock on which the river flows. **Figure 14** shows the sinuosity status at different reaches of the Shahzad River.

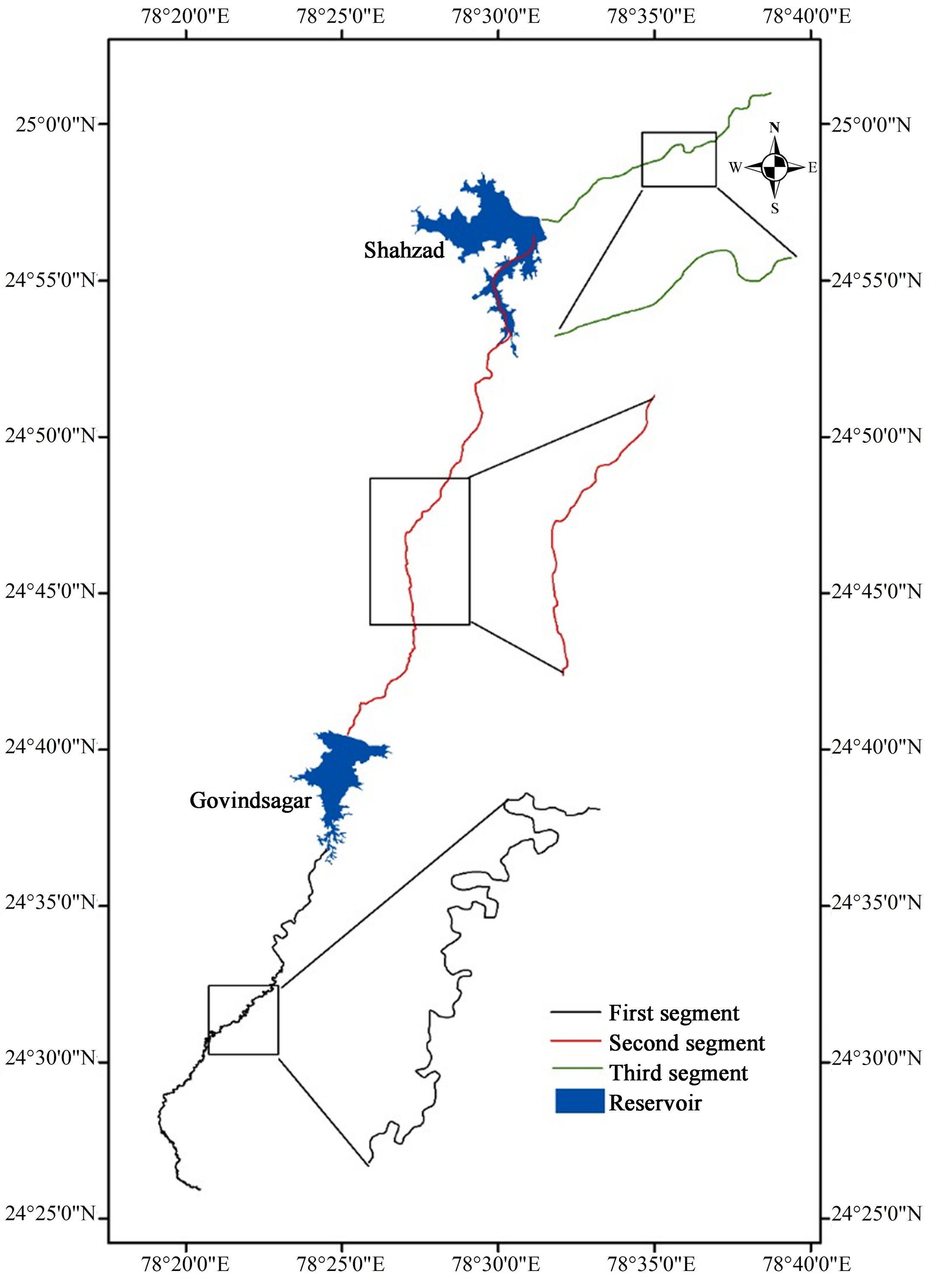


Figure 14. Sinuosity of the Shahzad River at different reaches.

5. Conclusion

The present study demonstrates the morphometric parameters of the watershed using GIS and remote sensing data. It secondarily provides the information about the hydrology, sub surface lithology, soil and erosion condition. On the basis of the various morphometric parameters like drainage density and drainage frequency it is indicated that Shahzad watershed has high permeability *i.e.* it is covered by the alluvium with high infiltration capacity. The other factor like infiltration number and length of overland flow also indicated the high infiltration thereby resulting in low surface runoff. The elongation ratio shows that the watershed is elongated in shape and thus has low run-off discharge thereby indicating less erosion. This is also supported by other parameters like relief ratio and ruggedness number. The asymmetry factor indicates that the watershed has uplifted from the right side in the southern zone and subsides in the northern zone. The sinuosity of the Shahzad River has a mixed influence on human interference due to the construction of dam as well as the subsurface geology.

It can be concluded that the remote sensing technique when coupled with GIS functions provides a powerful and effective way to understand the behaviour of watershed. Such studies can be used as input by different researchers for establishing the relationship between various watershed characteristics and moreover helps in planning and managing the watershed.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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