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Evaluation of Morphometric Parameters Studies in Middle-West Part of Kushtia District, Bangladesh, Using Remote Sensing and GIS Techniques

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Abstract

This study finds 1D, 2D and 3D morphometric parameters of the middle-west part of Kushtia district, Bangladesh to implement groundwater potential. For this purpose, the SRTM (DEM) data were used to compute different parameters in GIS environment. The values of 1D parameters like stream order, stream length and mean bifurcation ratio was calculated as 6, 1774.72 km and 2.08 respectively. The computed values of drainage density (0.01 - 23.06 km/km^2), stream frequency (1 - 5.64 per km^2), drainage texture (0.25 - 0.70 km/km^4), length of overland flow (0.02 - 45.05 km^2/km), constant of channel maintenance (0.04 - 90.04 km^2/km), circularity ratio (0.39 - 0.84), form factor (0.35), elongation ratio (0.62), relief ratio (0.00 - 1.81) and ruggedness number (0.04 - 214.72) disclose the morphometrical conditions of the study area. The results revealed from this study on drainage morphometry can be a great assistance for understanding the hydro-geomorphological character of the area.

Keywords

GIS, SRTM (DEM), Morphometric Parameters, Groundwater

1. Introduction

Quantitative analysis of the earth geometry well known as morphometry is frequently used in hydro-geomorphological analysis like the assessment of groundwater potential, groundwater management and basin management. R.E. Horton pioneered the hydrologic and hydro-morphometric analysis of basin and provided a rational and systematic place (Brinson, 1993). Smith (1950), Miller (1953), Schumm (1956), Strahler (1964), Mueller (1968) and many other researchers followed him.

Morphometric analysis requires measurement of 1D, 2D and 3D features using traditional methods (Horton, 1945; Strahler, 1957, 1964). In the last few decades, many GIS software evolved in such a way that millions of data analyses and data representation are done rapidly and cost effectively. Remote sensing data is used in GIS software in such a way that this pair became one of the strongest tools for natural resource survey and management. Using these tools, high accuracy was obtained by Moore et al. (1991) when he extracted information from DEM and analyzed for morphometric parameters in the riverine areas. Later different riverine areas of India were researched to find morphometric parameters successfully by using DEM and satellite image data (Nautiyal, 1994; Srivastava, 1997; Nag, 1998; Srinivasa Vittala et al., 2004; Sreedevi et al., 2005, 2009, 2012; Banerjee et al., 2015; Asode et al., 2016).

Significant, reliable and high accuracy results were also obtained by Sreedevi et al. (2005, 2009), Avinash et al. (2011), Altaf et al. (2013), Rao et al. (2015), and Prakash et al. (2016a, 2016b). Kumar Rai et al. (2017) found that the morphometric study with the aid of GIS software was cheaper and highly acceptable when compared to other conventional methods. So far, no morphometric analysis has been carried out in and around the area using remote sensing techniques and GIS. In this study, SRTM DEM data were used in GIS environment to evaluate 1D, 2D and 3D morphometric parameters to find groundwater potential.

2. Methodology

SRTM DEM data set (30 m resolution) was used for computing 1D, 2D and 3D morphometric parameters collected from http://earthexplorer.usgs.gov. The data set coupled with ArcGIS 10.2.1 software used here to carry out the analysis. These parameters have been calculated for identifying groundwater recharge potentiality of the study area. Flowchart of the methodology is shown in **Figure 1**.

The investigation was carried out on an area of greater Kushtia district of Bangladesh. It has an international border with India and located in the northern side of the southwest part of Bangladesh. This study comprised three Upazilas (Sub-districts) namely, Mirpur, Bheramara and eastern parts of Daulatpur upazilla under Kushtia district covering 539.82 km^2 areas within geographical coordinates of 23˚45'08" - 24˚07'52"N and 88˚51'53" - 89˚06'18"E as shown in **Figure 2**. It consists of several villages, two Upazila towns. The Ganges (Padma) river and its distributary, the Hisna are the main surface water sources here.

The Ganges is flowing in the extreme north-northwest sides of the study area, whereas the Hisna is flowing through the center from the northwest corner to the southwest. Mostly the deltaic silt formed this area. The northern side is formed by alluvial sands whereas the southern is by deltaic sands.

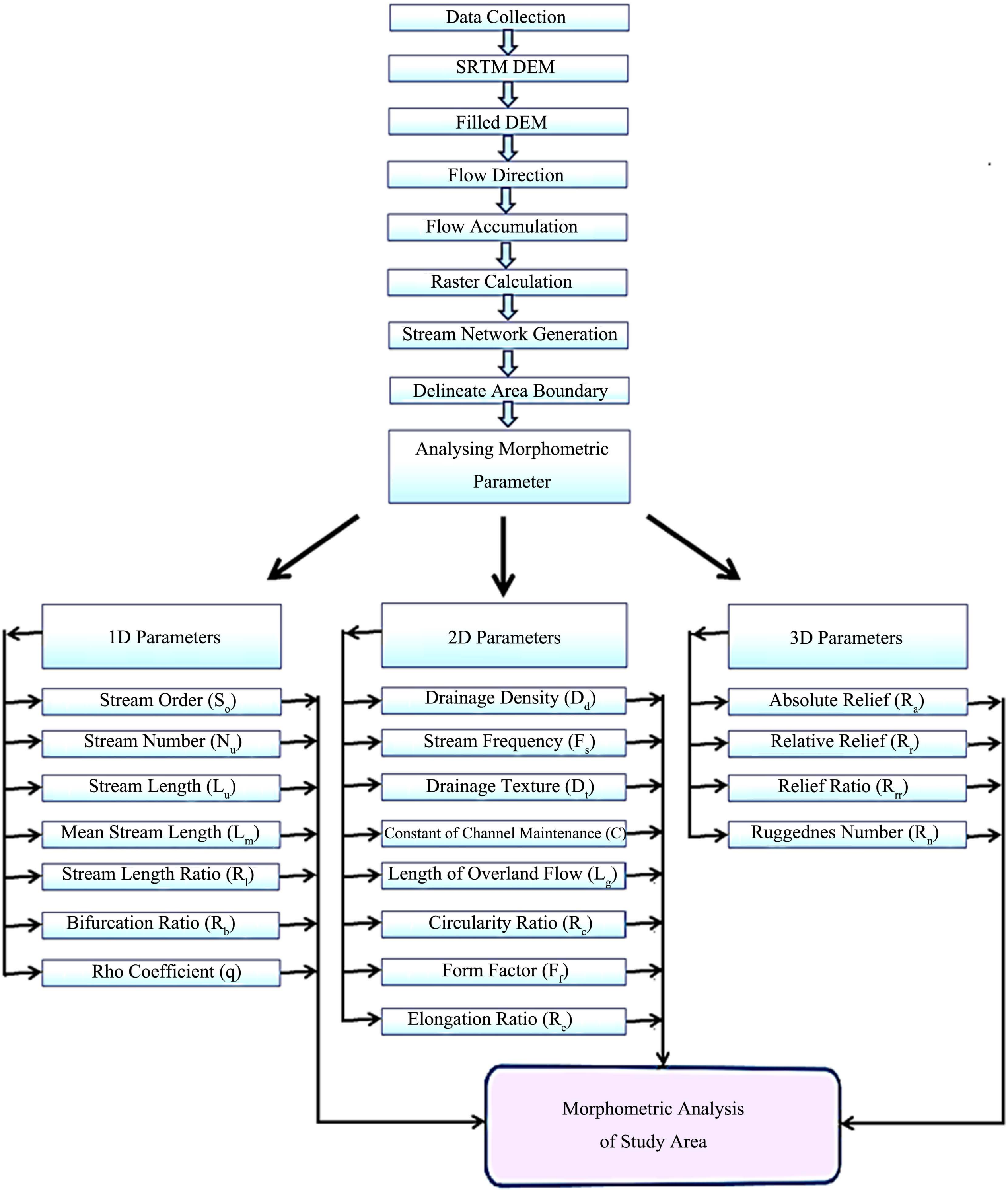

Figure 1. Flow chart of the methodology.

2.1. 1D Parameters

Stream Order (S_u): In order to find out stream order in this study the hierarchical ordering method of Strahler (1957) was utilized. The water body branching level is generally denoted by a positive whole number.

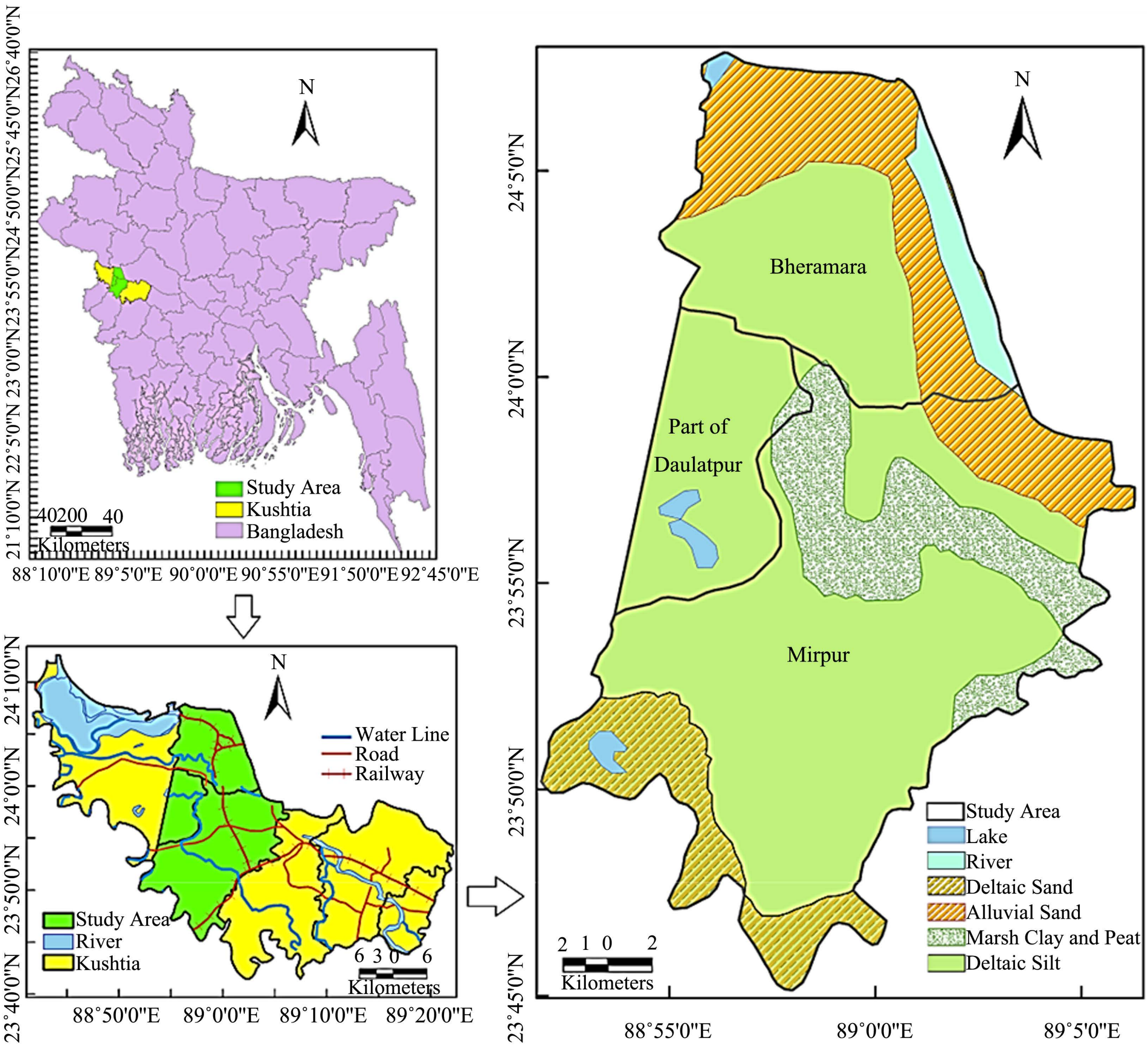

Figure 2. Location map of the study area.

Stream Number (N_u): It is also an integer which indicates streams population for a particular stream order. In 1945, Horton informed that stream numbers reduce with increasing stream orders. Generally large stream number indicate maximum drainage in an area meaning higher runoff and less suitable for groundwater recharge.

Stream Length (L_u): Physical drainage length of water bodies in an area is known as stream length. Shorter streams generally found to be more stepper than that of longer streams which are mainly flat in nature. It was calculated in GIS environment according to Horton (1945).

Mean Stream Length (L_m): Streams of a specific order can have different lengths. Averaged value of which is mean stream length given in Equation (1). This unitless parameter indicates components' characteristic size of drainage network.

$$L_m = \frac{L_u}{S_u} \tag{1}$$

Stream Length Ratio (R_l): This unitless parameter was initially introduced by Horton (1945). This ratio is obtained by dividing entire stream lengths of two consecutive streams in descending orders as shown in Equation (2).

$$R_l = \frac{L_u}{L_{u-1}} \tag{2}$$

Here, the numerator and denominator are the stream length in descending orders.

Bifurcation Ratio (R_b): Horton (1945) introduced this drainage parameter. It is found by dividing stream numbers of two consecutive orders given by the Equation (3).

$$R_b = \frac{N_u}{N_{u+1}} \tag{3}$$

where N_u and N_{u+1} are total stream numbers of two consecutive orders. It can be different at different areas and different environments.

Rho Coefficient (q): This is a very important parameter indicating the storage capacity of a drainage network (Horton, 1945), hence the groundwater potential. Mathematically, it can be obtained by dividing stream length ratio by bifurcation ratio which is ultimately unitless given in Equation (4).

$$q = \frac{R_l}{R_b} \tag{4}$$

Higher the value of q, higher chance of flooding in that area and very good change for groundwater recharge.

2.2. 2D Parameters

Drainage Density (D_d): Sum of stream lengths per unit area is known as drainage density (Horton, 1945) given in the Equation (5). It is very important parameter for drainage analysis of an area.

$$D_d = \frac{L}{A} \tag{5}$$

where entire length of streams and unit area are denoted by L and A respectively. Areas with lower density are good for groundwater recharge potential and flooding.

Stream Frequency (F_s): It is defined as the population of streams per unit area (Horton, 1945) as mentioned in Equation (6).

$$F_s = \frac{N}{A} \tag{6}$$

N indicates entire population of streams in area A. Lower stream frequency is good for better groundwater recharge.

Drainage Texture (D_t): This parameter is formulated as the product of D_d and F_s (Smith, 1950) as given in Equation (7).

$$D_t = D_d \times F_s \tag{7}$$

Lower drainage texture indicates the higher infiltration and lower run-off.

Constant of Channel Maintenance (*C*): This parameter was introduced by Schumm (1956), which is the reciprocal of drainage density given in Equation (8).

$$C = \frac{1}{D_d} \tag{8}$$

The constant indicates the area required per kilometer long streams of all orders. Larger value of *C* is better for groundwater recharge.

Length of Overland Flow (L_g): It is the measure of length of water over the ground surface before being concentrated into particular channels of streams. Mathematically it is half of *C* (Horton, 1945) which in turn related to drainage density given in Equation (9). It is actually run off length of rainwater before reaching a channel.

$$L_g = \frac{C}{2} = \frac{1}{2D_d} \tag{9}$$

Circularity ratio (R_c): This ratio can be found by dividing area of study by a circle area having equal perimeter (Miller, 1953) given by the Equation (10).

$$R_c = \frac{4\pi A}{P^2} \tag{10}$$

where perimeter of the circle is *P*. The ratio value close to unity means area is circular and less favorable for groundwater recharge.

Form Factor (F_f): The value of the parameter can be found by dividing area of study by the area made from the maximum length of the study area. Most cases F_f values are found to be smaller than 0.754. The smaller value of this factor designates elongated area which is more suitable for groundwater recharge. It is used by Horton (1945) given in Equation (11).

$$F_f = \frac{A}{L_b^2} \tag{11}$$

where L_b is the length of the study area.

Elongation Ratio (R_e): This 2D parameter is defined as the ratio of a circle diameter formed by the area investigated to its maximum length (Schumm, 1956). Mathematically it can be written as Equation (12) below.

$$R_e = \frac{2\sqrt{\frac{A}{\pi}}}{L_b} \tag{12}$$

More the value of this parameter more the area will be circular which is less favorable for groundwater recharge.

2.3. 3D Parameters

Absolute Relief (R_a): It is defined as elevation of given location. Generally, we obtain it from DEM data directly.

Relative Relief (R_r): Schumm (1956) used the formula given below in Equation (13) to find relative relief of an area. It is actually defined by the Equation (13):

$$R_r = H - h \quad (13)$$

where, maximum and minimum elevation within the unit area are denoted as H and h respectively.

Relief Ratio (R_{rr}): Ratio of relative relief to the length of study area (Schumm, 1956) is known as relief ratio which is given in Equation (14).

$$R_{rr} = \frac{R_r}{L_b} \quad (14)$$

Its lower value indicates lower gradient and favorable for groundwater recharge.

Ruggedness Number (R_n): Relative relief and drainage density product gives ruggedness number of the area of study (Strahler, 1958) as shown in Equation (15).

$$R_n = R_{rr} \times D_d \quad (15)$$

The low ruggedness value means less susceptible to soil erosion that results higher chance of groundwater recharge.

Different 1D, 2D and 3D morphometric parameters have been calculated for identifying groundwater recharge potentiality for the study area.

3. Results and Discussion

Quantitative analyses of earth geometry are immense assistance in managing and utilizing water resources properly. Remotely sensed data set were used to perform the morphometric analysis. The study area has been investigated for different morphometric characteristics by computing different 1D, 2D and 3D parameters. At first drainage pattern of the area was depicted using GIS software as shown in **Figure 3**.

3.1. 1D Parameters

In this investigation, seven 1D parameters have been calculated using different tools in GIS environment. Details of these parameters are discussed below:

3.1.1. Stream Ordering (S_u)

It is usual that streams of different size, shape and order flow in an area. It is seen that streams merged together to form bigger streams. So, it is important to know the order of a stream and how do it position in the stream's hierarchy, and stream order is the way to know that (Horton, 1945; Strahler, 1957). Actually, morphometric analysis starts with the finding out of stream orders. It provides very important information regarding drainage network of an area. Strahler's (1964) method for stream ranking was used here in GIS environment. It was found that there are 3420 streams of different ranks flowing as drainage network in the investigated area. Highest rank of the stream order is 6. Lower ranked streams mostly found in the relatively elevated regions compared to higher rank. Figure 4 showed the stream ordering of the area of study.

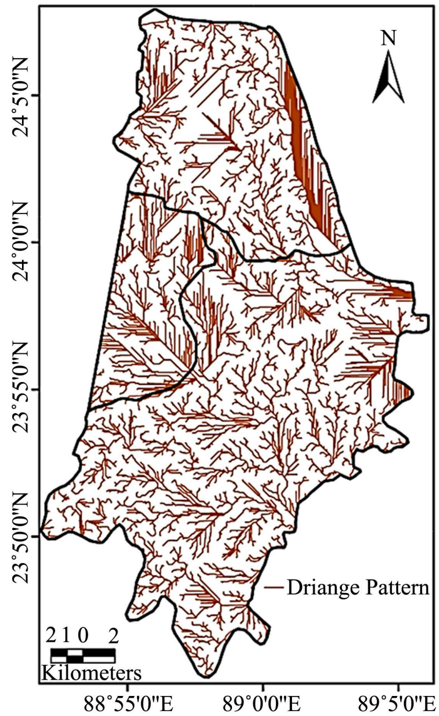

Figure 3. Drainage pattern of study area.

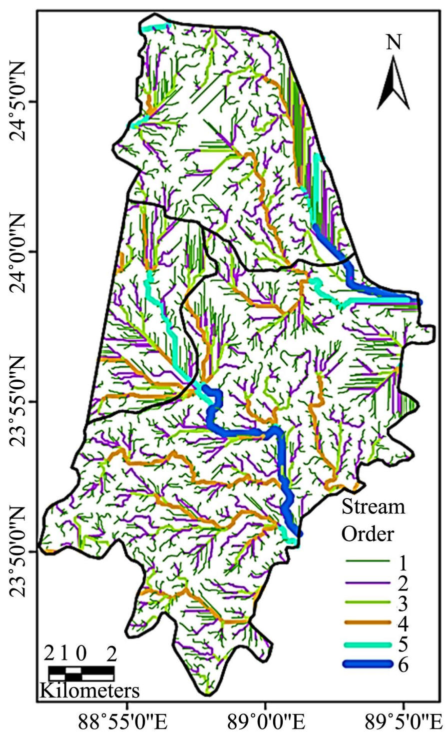

Figure 4. Stream order.

3.1.2. Stream Number (N_u)

In this investigation, the maximum number of streams is observed in the first-order and counted to 1745, whereas the minimum number of 81 streams is observed for 6th order. Second order streams are 820. The third and fourth order was relatively close with numbers 374 and 318. Fifth order is counted to 82 and very close to the 6th order. It is closely observed that stream numbers significantly decreasing with increasing stream orders. Table 1 and Figure 5 showed stream ordering and stream numbers. The first three as well as fifth stream orders show normal tendency of stream branching, but it was not found for the fourth and sixth stream orders. This type of stream branching results a poor drainage network, and often cause flooding or slow stream flow which makes the study area a good potential for groundwater recharge.

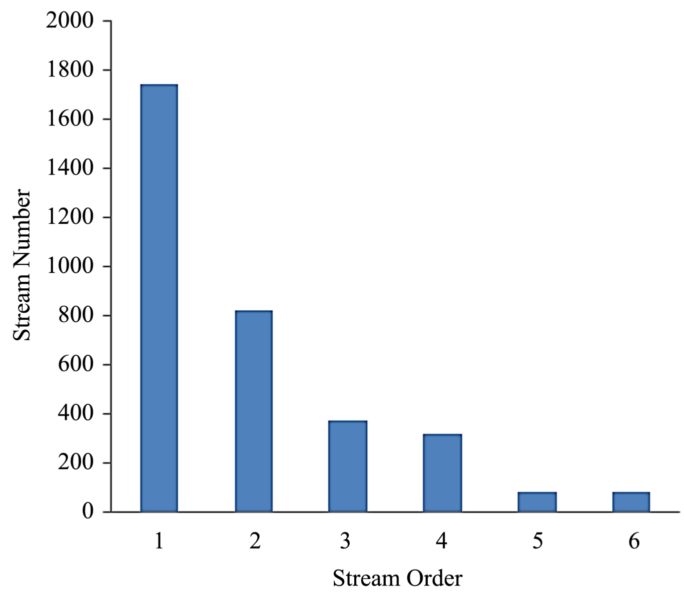

Figure 5. Steam order and stream number.

Table 1. Stream order (S_u), stream number (N_u), bifurcation ratio (R_b), number of streams used in the ratio (N_{u-r}), weighted mean bifurcation ratio(R_{bwm}), mean bifurcation ratio (R_{bm}) and q is the Rho coefficient of study area.

S_u	N_u	R_b	N_{u-r}	$R_b \times N_{u-r}$	R_{bwm}	Q
1	1745	-	-	-	2.12	
2	820	2.13	2565	5458.45		0.18
3	374	2.19	1194	2617.86		0.18
4	318	1.18	692	813.86		0.61
5	82	3.88	400	1551.22		0.06
6	81	1.01	163	165.01		0.73
Total	3420	10.39	5014	10606.40		
Mean		2.08				

3.1.3. Stream Length (L_u)

GIS environment profoundly used to calculate and measure stream length in the area of study and tabulated in Table 2. It showed different stream lengths for different stream orders. Surface runoff characteristics significantly influenced by stream length which actually consider as an important hydrological parameter. Smaller streams are found in areas with steep slope. Flatter plain provides opportunity to have longer stream lengths (Strahler, 1964). Stream length of 1031.90 km measured in the first order found to be maximum among the total extracted lengths of 1774.72 km. Sixth order streams have the minimum length of 23.95 km. Among others second, third, fourth and fifth order streams occupied 405.61 km, 162.86 km, 117.97 km and 32.42 km respectively. It is closely observed that stream lengths shrank with increasing stream order (Figure 6).

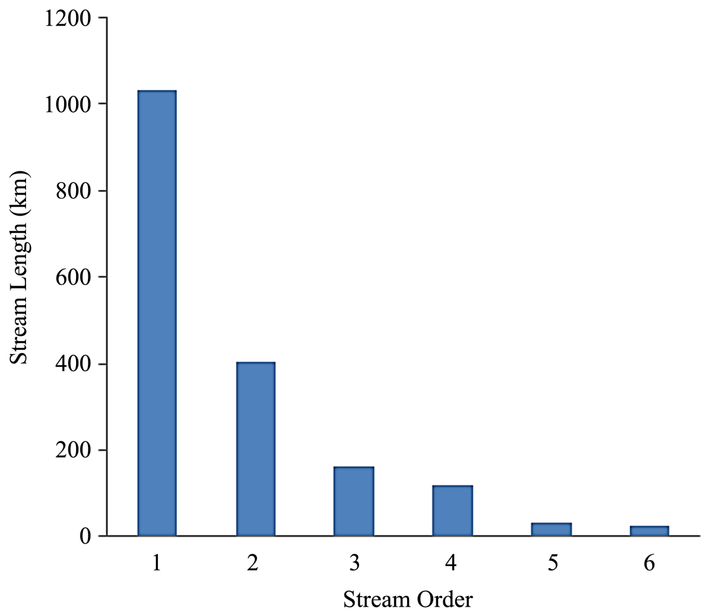

Figure 6. Steam order and stream length.

Table 2. Stream order (S_u), stream length (L_u), mean stream length (L_m), stream length ratio (R_l), stream length used in the ratio (L_{ur-r}) and weighted mean stream length (L_{uwm}).

S_u	L_u (km)	L_m	R_l	L_{ur-r}	$L_{ur} \times L_{ur-r}$	L_{uwn}
1	1031.90	0.59	-	-	-	0.43
2	405.61	0.49	0.39	1437.52	565.05	
3	162.86	0.44	0.40	568.47	228.25	
4	117.97	0.37	0.72	280.83	203.43	
5	32.42	0.40	0.27	150.39	41.32	
6	23.95	0.30	0.74	56.37	41.64	
Total	1774.72		2.53	2493.58	1079.70	
Mean			0.42			

3.1.4. Mean Stream Length (L_m)

The characteristics of an area are revealed from mean stream length and have significant influence on the surface. It can be found by different component analysis of drainage network (Strahler, 1964). It was calculated using Equation (1). It revealed that L_m values confined in the 0.59 to 0.30 range. The L_m value of 0.59 was found for first order and 0.30 for sixth order. Other values of 0.49, 0.44, 0.37 and 0.40 associated with second, third, fourth and fifth order respectively (Table 2).

3.1.5. Stream Length Ratio (R_l)

With the help of Equation (2) this parameter has been calculated and tabulated in Table 2. Highest and lowest value of this parameter were 0.74 and 0.27 observed for sixth order and fifth order stream respectively, the average being 0.42. Higher value of R_l indicates the abnormality in drainage network. Abnormalities are found in between stream 4 and stream 3 lengths as well as in streams 6 and stream 5. These types of drainage network often cause very low drainage water movement, which facilitates a good chance for water to percolate.

3.1.6. Bifurcation Ratio (R_b)

It is very important morphometric parameter which can predict flood prone zones (Prabhakaran & Raj, 2018). Using Equation (3), this parameter has been estimated and shown in Table 1. Highest and lowest value of the parameter was 3.88 and 1.01 found for fifth order and sixth order stream respectively, whereas the average value was 2.08. Lower mean bifurcation ratio means the area is flat or rolling surface more likely to be affected by the flood and highly favorable for groundwater recharge. Higher bifurcation ratio is seen near areas near close to rivers.

3.1.7. Weighted Mean Bifurcation Ratio (R_{bwm})

Proposed method of Schumm (1956) was used here to calculate this parameter. The R_{bwm} found in this study is 2.12 (Table 1). It is close to average value of bifurcation ratio. Low value of this parameter indicates areas with very low slope and often affected by flood.

3.1.8. Rho Coefficient (q)

It is considered to be a vital parameter in morphometric analysis of an area. Here, it was calculated using Equation (4) and tabulated in Table 1. Higher the value of q, the more is the storage in the drainage network which in turn can cause flooding. Parameter value confined in between 0.06 and 0.73. The zones having lower slope and faulty drainage pattern with higher stream order facilitate low water current. Hence, it makes a greater scope of flooding and groundwater recharge.

3.2. 2D Parameters

3.2.1. Drainage Density (D_d)

It is one of the most significant morphometric parameters of an area. Groundwater recharge potentiality exclusively depends on this factor as well. It indicates how closely drainage channels are distributed in an area. Its value depends on many surface and sub-surface parameters. Low permeability of subsoil materials, flat or very small steepness of lands and high vegetation results very small drainage density (Nag, 1998). Low drainage density values provide higher chance of flooding and groundwater recharge hence good groundwater potentiality. High relief, small vegetation and higher permeability provide good reasons for higher drainage density. The D_d value of the area ranging from 0.01 to 23.06 km/km^2 (**Figure 7**) was calculated using Equation (5). It is seen that most of area has lower drainage in the range of 0.01 to 4.90 km/km^2. North-east part of the area near to the river Gorai has very high drainage density value ranging from 8.80 to 23.06 km/km^2. Gentle drainage density from 3 to 5 km/km^2 is seen in one-third areas distributed evenly.

3.2.2. Stream Frequency (F_s)

Here Equation (6) was used to calculate this parameter. F_s values of this study are in the range of 1.00 - 5.64 no. of streams per km^2. The stream frequency values as shown in **Figure 8** were positively correlated with D_d values of the area. It was revealed that the regions of lower D_d had lower stream frequency and higher D_d were followed by higher F_s. But higher stream frequency having range of 3.36 to 5.64 is distributed in the area sporadically. It is due to streams of very small lengths.

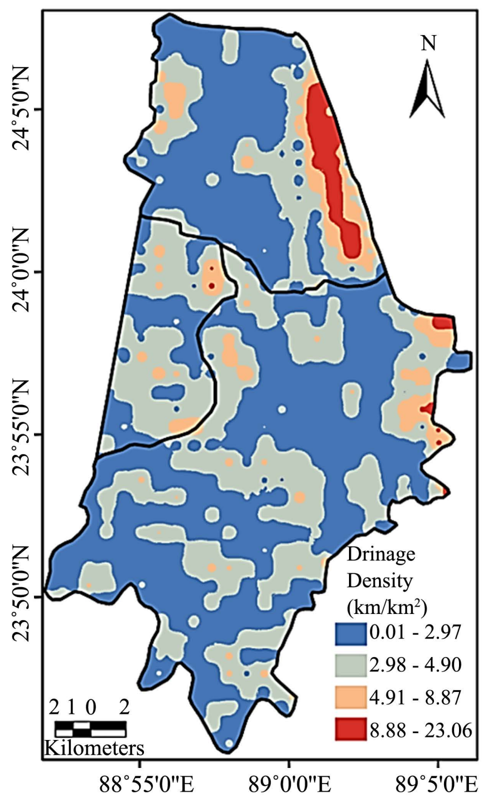

Figure 7. Drainage density.

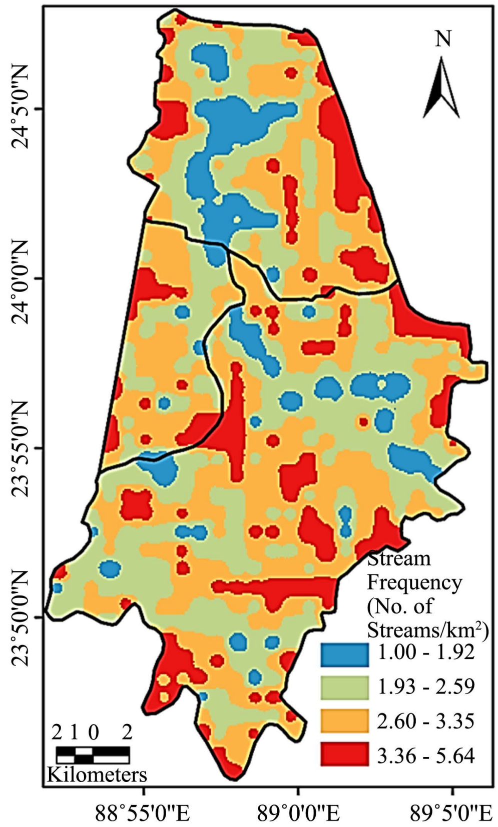

Figure 8. Steam frequency.

3.2.3. Drainage Texture (D_t)

It denotes relative positioning of drainage network. Smith (1950) classified drainage texture to 5 categories based on drainage density. In this study, D_t values were calculated using Equation (7) and depicted in **Figure 9**. The parameter varied in between 0.25 to 7.70, and it lies in the range of very coarse to moderate coarse based on drainage density. It is revealed from the results that it followed a very closer drainage texture pattern.

3.2.4. Constant of Channel Maintenance (C)

This morphometric parameter was calculated using Equation (8) and represented in **Figure 10**. The C values of this area are in the range of 0.04 to 90.09 km^2/km. In most of the areas C value is below 0.24 m and next channel length is as much as 28.25 m covers almost entire area. Areas with lower C values mean quick water discharge hence less favorable for groundwater recharge and vice versa.

3.2.5. Length of Overland Flow (L_g)

The calculated values of L_g using Equation (9) are shown in **Figure 11**. It is seen that L_g values for the area are ranging from 0.02 km to 45.05 km. But comparatively low relief having values of 0.02 km to 0.24 km is dominating most of the area. It means the area is densely populated with streams of all orders. Overland flow length above 14.12 m is hardly seen.

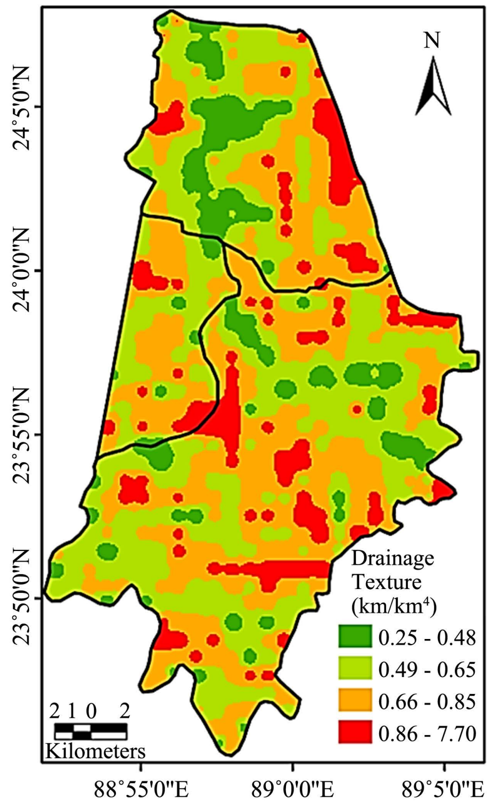

Figure 9. Drainage texture.

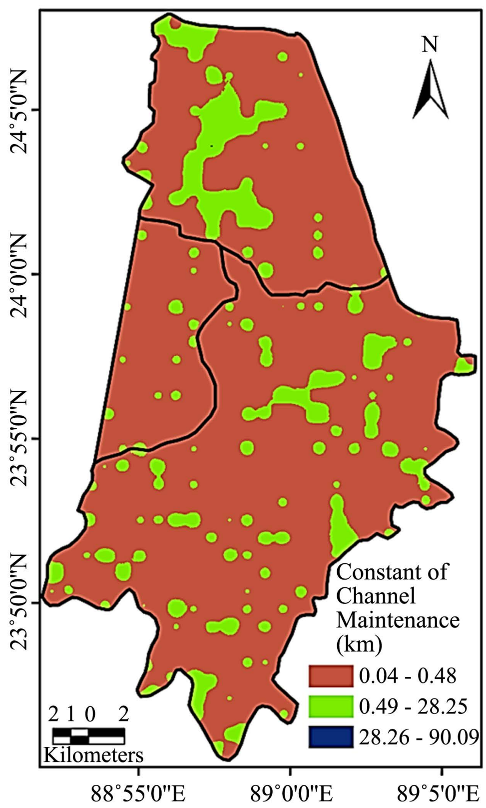

Figure 10. Constant of channel maintenance.

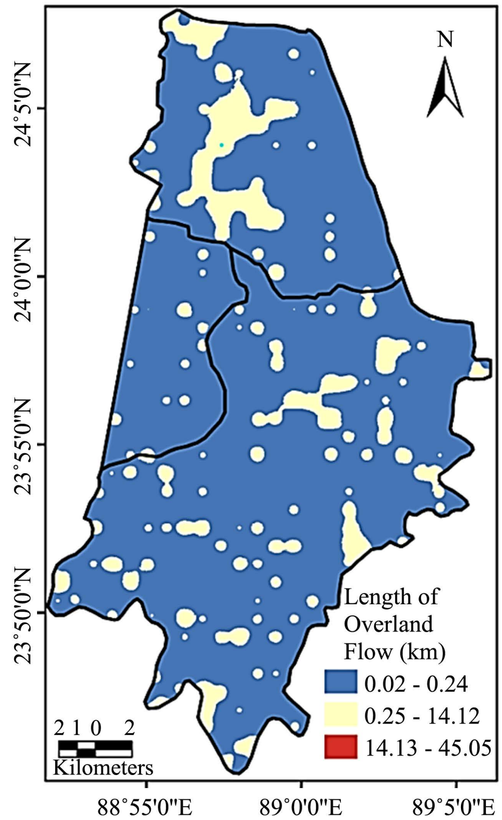

Figure 11. Length of overland flow.

3.2.6. Circulatory Ratio (R_c)

The estimated circulatory ratio of the area using Equation (10) is shown in **Figure 12**. Here, R_c values varied from 0.39 to 0.84. Low R_c values indicate mainly elongated areas whereas a value close to unity means more circular area. Most of the areas have higher R_c values ranging from 0.77 to 0.84, and hence relatively quick flow through the unit area results. Somehow it is less favorable for percolation.

3.2.7. Form Factor (F_f)

This morphometric parameter measures different types of erosional process, movements of sediments, flood formation and corridor of flood. For a perfect circle F_f value is 1, when it is nearing zero it means elongated area. Here it was calculated using Equation (11) and found its value as 0.31 which indicates the area slightly elongated in shape. Hence, flood probability is high as transport rate is low. This area is favorable for groundwater recharge potential.

3.2.8. Elongation Ratio (R_e)

Generally, R_e values lie between 0.6 to 1 depending on different climatic and geologic types (Rudraiah et al., 2008). Equation (12) was used to calculate this parameter, and its value is 0.62 for the area studied. So, this area is moderately elongated. It provides relatively larger time to travel from one side to another of the study area, which in turn preferable for groundwater recharge.

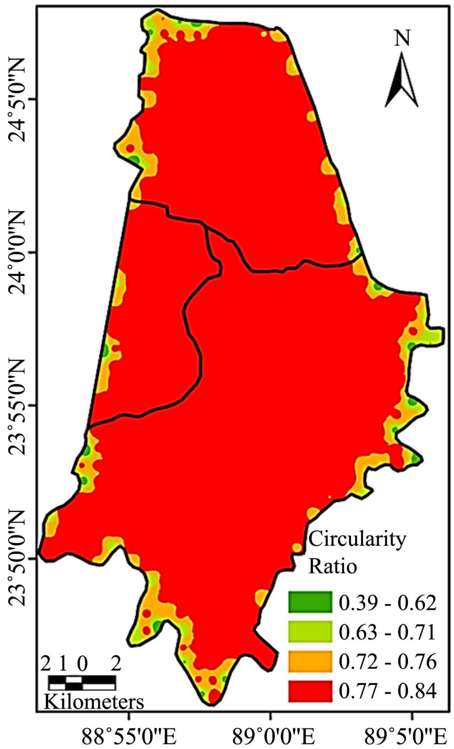

Figure 12. Circulatory ratio.

3.3. 3D Parameter

3.3.1. Absolute Relief and Relative Relief

Absolute relief and relative relief are 3D morphometric parameters of an area. Absolute relief was readily available from SRTM (DEM) data. It was presented in **Figure 13**. The relative relief was estimated using Equation (13) with the help of GIS software and depicted in **Figure 14**. Areas with low relative relief increase the probability of surface water body, flooding and groundwater recharge.

3.3.2. Relief Ratio (R_r)

Overall steepness of an area is described by the relief ratio, a key indicator of entire erosional process of an area. Relief ratio calculated using Equation (14) for this study is found to be 0 - 1.81 (**Figure 15**). It is highly connected with the hydrologic character of the study area and erosional process. This value is high near rivers whereas the remaining areas are mostly flat indicating the favorability for groundwater recharge.

3.3.3. Ruggedness Number (R_n)

This morphometric parameter mostly used to measure undulation of surface topography (Selvan et al., 2011). This parameter was calculated using Equation (15). Ruggedness number of the area studied ranges from 0.04 to 214.72 as shown in **Figure 16**. When drainage density is high with high relief of a basin, the ruggedness number of that river basin will also be high (Chow, 1964). High R_n value is observed in the riverine area where dominant part is below the value 25.24 spreading over the area.

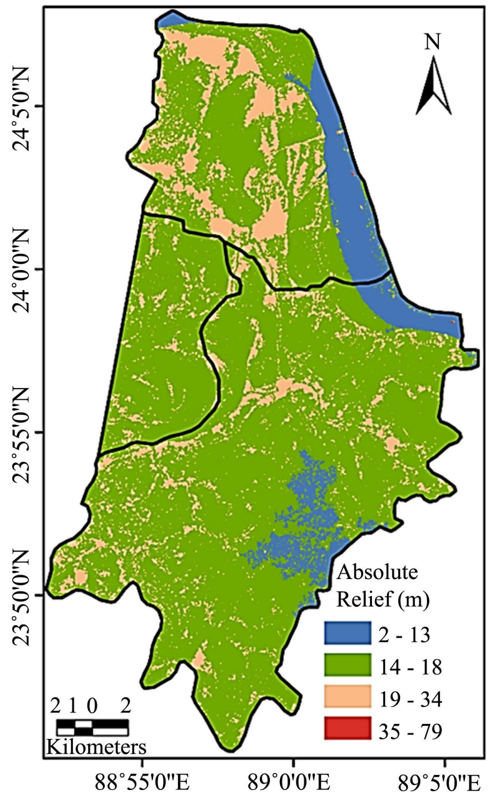

Figure 13. Absolute relief.

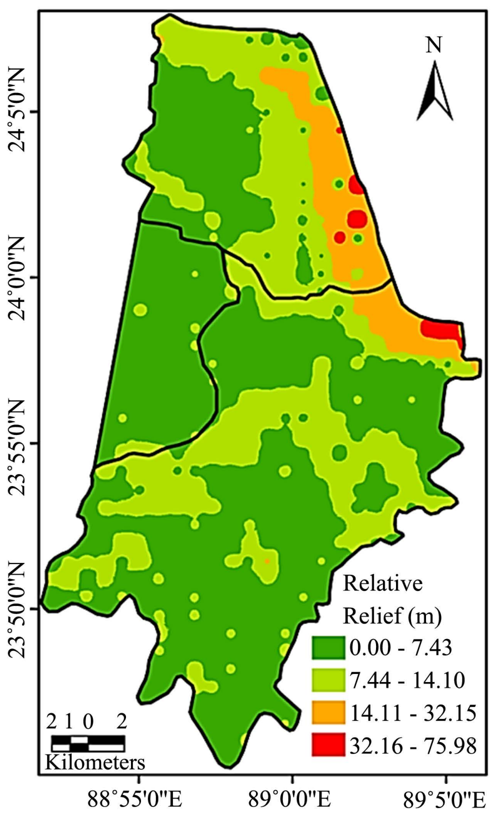

Figure 14. Relative relief.

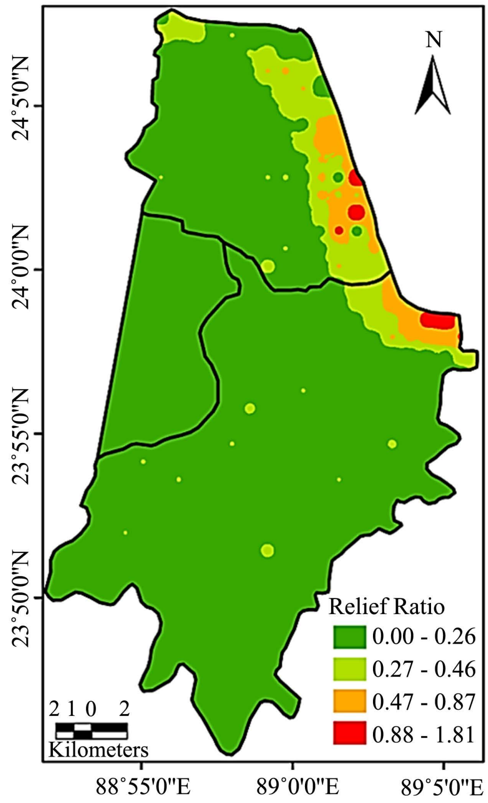

Figure 15. Relief ratio.

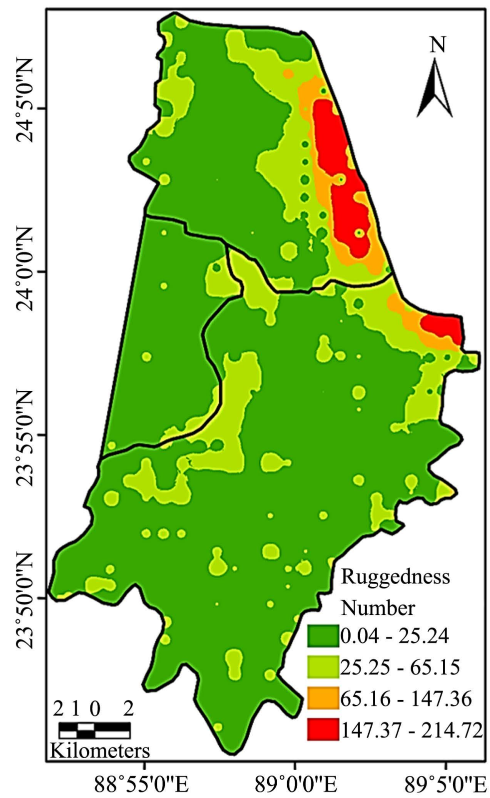

Figure 16. Ruggedness number.

4. Conclusion

The morphometric analysis provides very useful information to evaluate surface water resource conservation, and their management. It can be applied to even smaller areas. The evolved drainage is dendritic in nature. The highest number of streams is found for lower order occupying most drainage lengths. The lower value for weighted mean bifurcation ratio increases the chance of flooding and groundwater recharge. Moderately elongated shape of the area was verified by form factor, circulatory ratio and elongation ratio values, which in turn provide high groundwater potential.

This study also showed efficient use of GIS techniques coupled with SRTM (DEM) data to evaluate 1D, 2D and 3D morphometric parameters which might be of great help for planners and decision-makers to develop sustainable strategies for water resource management.

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Conflicts of Interest

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

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