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Quantification of Morphometric Characterization for Watershed Management Planning in a Western Himalayan Basin, India

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Keywords

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Synopsis

To prepare a comprehensive watershed development plan, it becomes necessary to understand the topography, erosion status and drainage pattern of the area. Spatial technologies viz., remote sensing (RS) and Geographical Information System (GIS) have proved to be the efficient tools in delineation of drainage pattern and water resources management and its planning. Morphometric analysis helps to quantify and understand the hydrological characteristics and results are essential inputs for a comprehensive water resource management plans.

This study was undertaken to quantify the morphometric characteristics of Tawi river basin up to Jammu (area 2161 km2). GIS and image processing techniques have been adopted for the identification of morphological features and analyzing the linear, areal and relief aspects of the Tawi river, Himalaya in Jammu and Kashmir State, India. The digital data format from the ministry of economy, trade, and industry (METI) of Japan and the United States national aeronautics and space administration (NASA) jointly with 30 m spatial resolution, ASTER GDEM (Advanced Space borne Thermal Emission and Reflection Radiometer Global Digital Elevation Model) has been used in ArcGIS 9.3. The Strahler's method of stream ordering has been adopted for ordering the streams. Tawi basin is a 6th order drainage basin and the drainage density is pretty high as 1.92 km/km2, which indicates the basin is well drained and having high permeable subsoil. The circularity ratio value 0.4 reveals that the basin is strongly elongated and highly permeable homogenous geologic materials. The results of this study with prioritization of watersheds of the basin would help to different stakeholders such as agriculturists and natural resources managers for better decisions making to utilize and manage the water resources in more sustainable manner.

Quantification of Morphometric Characterization for Watershed Management Planning in a Western Himalayan Basin, India

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KEYWORDS
Morphometry, Tawi basin, Western Himalaya, GIS, Stream order

ABSTRACT:
Watershed development and management plans are very important for harnessing surface water and groundwater resources. To prepare a comprehensive watershed development plan, it becomes necessary to understand the topography, erosional status and drainage pattern of the area. Spatial technologies viz. remote sensing (RS) and Geographical Information System (GIS) have proved to be the efficient tools in delineation of drainage pattern and water resources management and its planning. Morphometric analysis helps to quantify and understand the hydrological characteristics of a river basin and the results are essential inputs for a comprehensive water resource management plans. It has wide applications such as watershed management, cumulative effects assessment and analysis, watershed prioritization, hydraulic and sediment relations, engineering design concepts and geomorphologic instantaneous unit hydrograph developments etc. This study was undertaken to quantify the morphometric characteristics of Tawi river basin up to Jammu (area 2165 km^2). GIS and image processing techniques have been adopted for the identification of morphological features and analyzing the linear, areal and relief aspects of the Tawi river basin of western Himalaya in Jammu and Kashmir State, India. The digital data format from the ministry of economy, trade, and industry (METI) of Japan and the United States national aeronautics and space administration (NASA) jointly with 30 m spatial resolution, ASTER GDEM (Advanced Space borne Thermal Emission and Reflection Radiometer Global Digital Elevation Model) has been used for deriving the river basin morphometric parameters using ArcGIS 9.3. The Strahler's method of stream ordering has been adopted for ordering the streams. The most of the area under the basin is highly undulating and mountainous in nature. Tawi basin is a 6^{th} order drainage basin and drainage pattern mainly is sub-dendritic to dendritic type. The drainage density of the basin is pretty high as 1.04 km/km^2 which indicates the basin is well drained, and having high permeable subsoil. The circularity ratio value 0.4 reveals that the basin is strongly elongated and highly permeable homogenous geologic materials. The results of this study with prioritization of watersheds of the basin would help to different stakeholders such as agriculturists and natural resources managers for better decisions making to utilize and manage the water resources in more sustainable manner.

1. INTRODUCTION

Watershed morphology plays a vital and governing role in river hydrology. Many studies have been done for the analysis of the basin morphometric characteristics of the various basins using conventional (Horton, 1945; Smith, 1950; Strahler, 1957) and remote sensing and GIS methods (Krishnamurthy and Srinivas, 1995; Srivastava and Mitra, 1995; Agarwal, 1998; Biswas et al., 1999; Narendra and Nageswara Rao, 2006). Morphometric analysis is basic and important aspect of hydrological and hydrogeological studies. Various important hydrologic occurrences can be correlated with the morphometric and physiographic characteristics of drainage basins such as size, shape, slope of drainage area, drainage density, size and length of the contributories. The quantitative analysis of drainage system is an important aspect of characteristics of a river basin (Strahler, 1964). Drainage pattern refers to spatial relationship among streams or tributaries of the rivers, which may be influenced in their erosion by variations of slope, soils, rock resistance, structure and geological history of a region. Morphometric analysis will help to quantify and understand the hydrological characters and the results can be useful inputs for a comprehensive water resource management plan (Jawahar raj et al., 1998; Sreedevi et al., 2001). In the present study, Tawi River, which is a part of Indus basin has been considered. It plays a vital role as it is major source of water supply to Jammu and Udhampur city which contributes 17% of total population of Jammu and Kashmir State as well as main source of supply for agricultural and industrial purposes in the region. With the described backdrop this study was conducted with an objective to compute morphometric characteristics for various parameters using advance remote sensing and GIS techniques.

2. STUDY AREA

Tawi river is one of the major tributary of the Chenab river of Indus basin lays within the 74^0 35' - 75^0 45' E longitude and 32^0 35' - 33^0 05' N latitude. It rises from the lapse of Himalayan Glaciers at a place named Kalikundi and adjoining area, situated on the south-west of Bhaderwah in the Doda district. The river incorporated with sub-river basins of Chenani, Ramnagar, Udhampur and Domel claims an area of 2165 km^2 that falls under three districts of Jammu and Kashmir state viz. Jammu, Udhampur and Doda (Fig. 1). The upper part of the catchment is characterized by rugged mountainous topography; whereas lower catchment consists of low hills and aggradatioal plain. The average elevation of the catchment is about 2200 m above m.s.l. The catchment elevation varies from 4000 m in the upstream to about 300 m above m.s.l in the plains. Long term average annual rainfall in the basin is 1200mm with a mix contribution from south-west Monsoon and western disturbances. Tawi is primarily a mountainous basin bound by Peer Panjal mountain range as north eastern basin boundary, Shiwaliks mountain range is at south western part and Dualadhar mountain range at central part.

3. MATERIALS AND METHODS

The digital elevation data with 1 arc degree (30 m) spatial resolution, ASTER GDEM was used to meet the requirements of area under study. ArcHydro a sub-module of ArcGIS 9.3 has been used for hydro-geoprocessing of the Digital Elevation Model (DEM) (Fig. 2). First of all the sinks in surface raster satellite image in form of DEM was filled to remove small imperfections in the data. Then the flow accumulation grid was performed that contains the accumulated number of cells upstream of a cell, for each cell in the input flow direction grid, which creates a raster of flow direction from each cell to its steepest down slope neighbor.

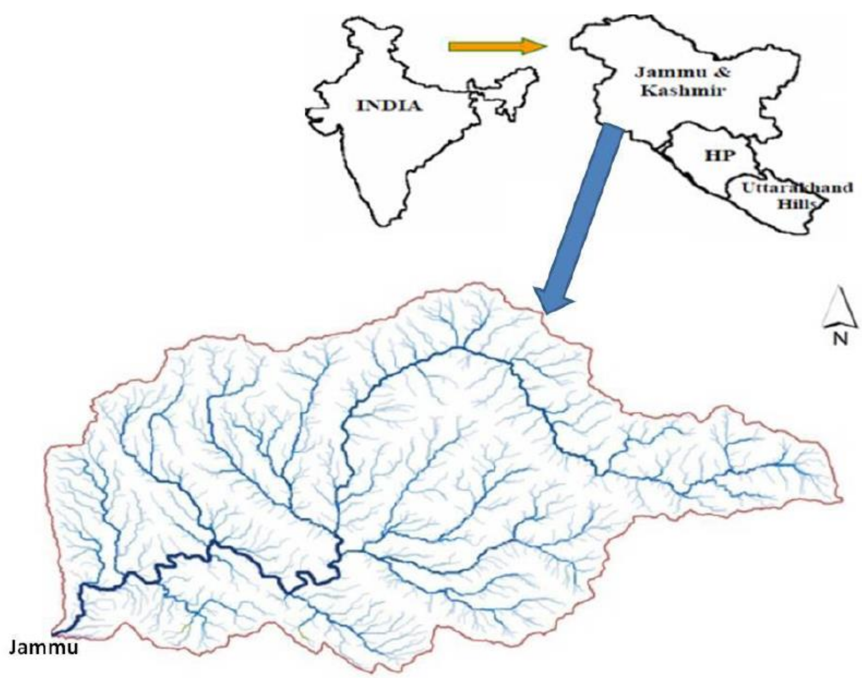

Figure 1. Location Map of Tawi River Basin

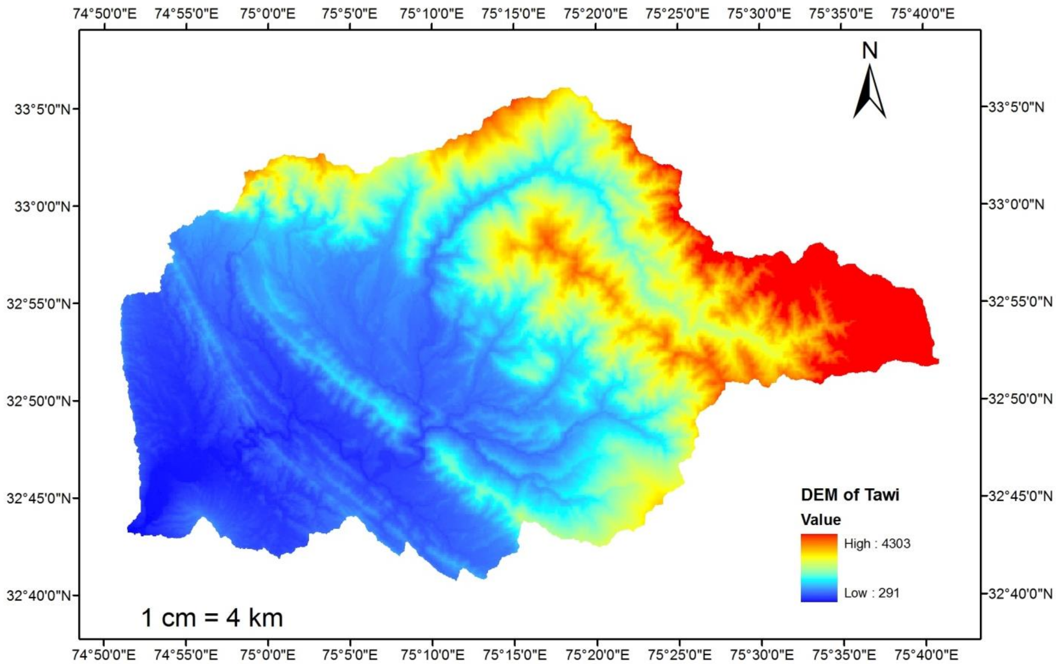

Fig. 2: Digital Elevation model (DEM) of the Tawi Catchment

The GIS assigns unique values to streams of a raster linear network between intersections and a numeric order to segments of a raster representing branches of a linear network. Finally it determines the contributing area above a set of cells in a raster. Fig. 1 shows the drainage pattern in the Tawi catchment. The quantitative analyses of the basin which include stream orders, stream numbers, stream lengths, bifurcation ratios, basin circularity, drainage density, drainage frequency etc. These characteristics of the catchments have been analyzed using a ArcGIS, which determines the geomorphic stage of development of the area .The drainage network of the basin is analyzed as per laws of Horton (1945) and stream ordering is made after Strahler (1964). The different morphometric parameters have been determined as shown in table1.

Table 1. Morphometric parameters with formula

S. No.	Morphometric parameters	Formula	Reference
1	Stream order (N_u)	Hierarchical rank	Strahler (1964)
2	Stream length (L_u)	Length of the stream	Horton (1945)
3	Mean stream length (L_{sm})	$L_{sm} = L_u / N_u$ Where, L_u = total stream length of order u N_u = total no. of stream segments of order u	Strahler (1964)
4	Bifurcation ratio (R_b)	$R_b = N_u / N_{u+1}$ Where, R_b = Bifurcation ratio N_u = No. of stream segments of a given order and N_{u+1}= No. of stream segments of next higher order	Schumn (1956)
5	Mean bifurcation ratio (R_{bm})	R_{bm} = Average of bifurcation ratios of all orders	Strahler (1957)
6	Drainage density (D_d)	$D_d = L_u / A$ Where, Dd = Drainage density. Lu = Total stream length of all orders and A = Area of the basin (km2).	Horton (1932)
7	Drainage frequency (F_s)	$F_s = N_u / A$ Where, F_s = Drainage frequency. L_u = Total no. of streams of all orders and A = Area of the basin (km2).	Horton (1932)

4. RESULTS AND DISCUSSIONS

The Tawi river basin drains a total geographical area of 2165 km^2. The drainage pattern of the basin is mainly from dendritic to sub-dendritic except at south-western part where it's parallel. General stream flow direction is from southwest to northeast. The various morphometric parameters were determined for Tawi as well as four sub-catchments and are summarized in Table 2 and 3.

Table 2. Morphometric parameters of Tawi River basin

Stream order	No. of streams	No. of stream %	Total length (Km)	Mean length (Km)	Bifurcation Ratio
1	1282	76.17	1129.10	0.88	
2	303	18.00	576.05	1.90	4.23
3	77	4.58	218.18	2.83	3.94
4	16	0.95	159.44	9.97	4.81
5	4	0.24	103.71	25.93	4.00
6	1	0.06	58.99	58.99	4.00

Table 3. Basic Morphometric parameters of sub basins of Tawi River basin

Name of sub-basin	Stream Order wise Number of Streams							Bifurcation Ratio						
	1st	2nd	3rd	4th	5th	6th	Total	1st	2nd	3rd	4th	5th	6th	Average
Chenani	435	91	24	3	1	0	554	-	4.8	3.8	8.0	3.0	0.0	3.9
Ramnagar	289	73	19	4	1	0	386	-	4.0	3.8	4.8	4.0	0.0	3.3
Udhampur	162	42	12	3	1	0	220	-	3.9	3.5	4.0	3.0	0.0	2.9
Domel	396	97	22	6	1	1	523	-	4.1	4.4	3.7	6.0	1.0	3.8
Tawi River	1282	303	77	16	4	1	1683	-	4.2	3.9	4.8	4.0	4.0	4.2

4.1 Linear aspects of the drainage system

4.1.1 Stream order (N_u): Strahler (1964) stream ordering method has been adopted in this study. According to Strahler, the smallest tributaries are designated as order first when two first order streams join, a stream segment of second order is formed; when two second order streams join, a segment of third order is formed, and so on. The Tawi river basin was found to be a sixth order drainage basin (Fig.3) and drainage pattern mainly is sub-dendritic to dendritic type. The main stream through which all discharge of water and sediment passes is therefore the stream segments of highest order.

4.1.2 Bifurcation ratio (R_b): Horton (1945) and Strahler (1952) has defined the bifurcation ratio as the ratio of the number of streams of one order to the number of the next higher order. Strahler (1957) demonstrated that bifurcation ratio shows a small range of variation for different regions or for different environment except where the powerful geological control dominates. It can be observed from the Table 1, the bifurcation ratio is not same from one to another. These irregularities are dependent upon the geological and lithological development of the drainage basin (Strahler, 1964). The mean bifurcation ratio may be defined as the average of bifurcation ratios of all orders, and all sub-watersheds fall under normal basin category (Strahler, 1957) which was found to be 4.20 for Tawi river basin.

4.1.3 Stream Length (L_u): The stream lengths of the various segments are measured with the help of GIS software. For all the sub-watersheds and Tawi river basin the total length of stream segments is maximum in first order streams and decreases as the stream order increases. The mean length of channel Lu of order u is the ratio of the total length to the number of streams of a given order, it is a dimensionless property, characterizing the size aspects of drainage network and its associated surface (Strahler, 1964). Due to variation in slope and topography in the basin, the table 2 shows the mean stream length of the given order is greater than that of the lower order and less than that of its next higher order.

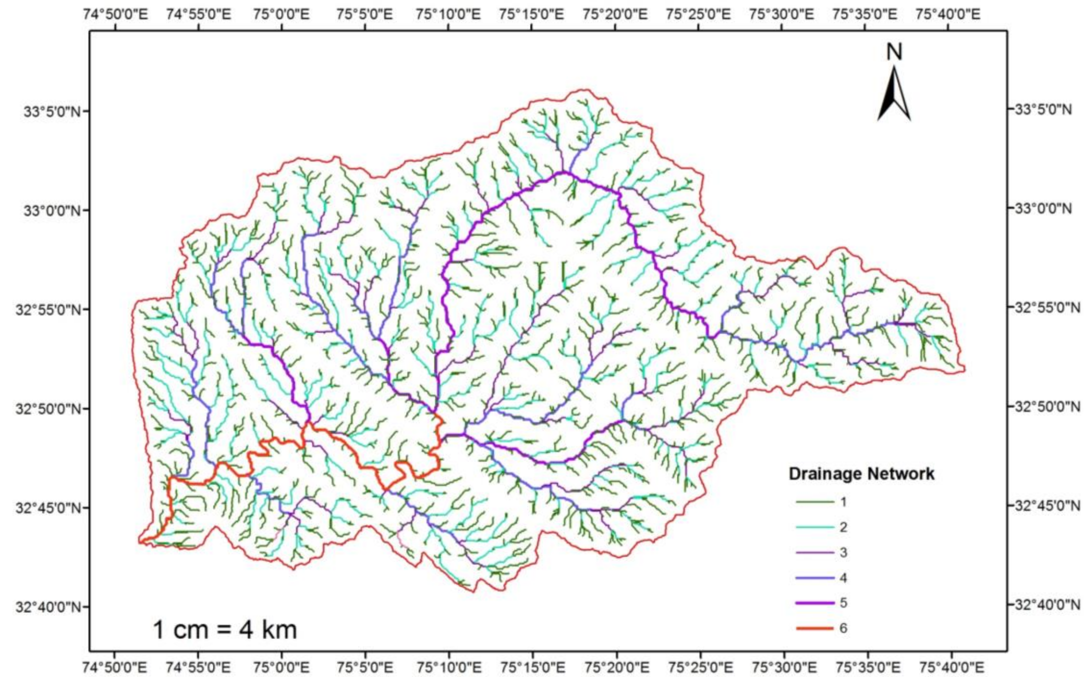

Figure 3. Morphometric Map of Tawi River showing streams of different order

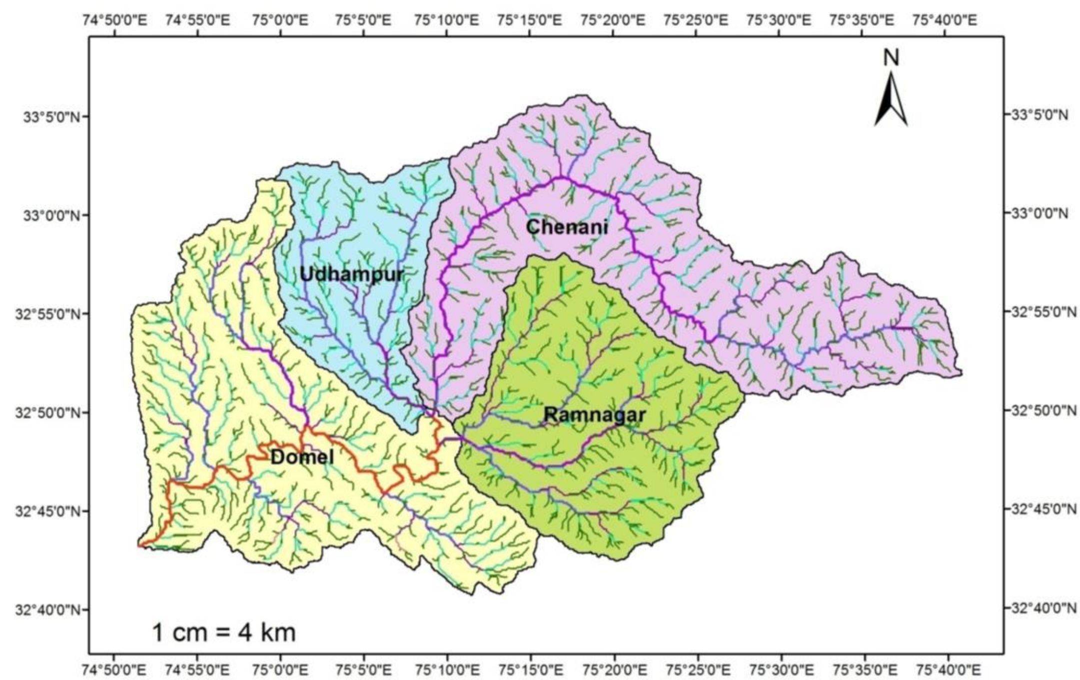

Figure 4. Sub-basin map of Tawi River basin

4.2 Areal Aspects of the Drainage Basin

The area of Tawi river basin (A_u) is 2165 km^2, which is considered to be a small size therefore it is likely that rainwater will reach the main channel more rapidly than in a larger basin, where the water has much further to travel. Lag time will therefore be shorter in the smaller basin. The longest stream length of the Tawi basin (L_b) from the remotest point in the catchment to the point confluence was found 150km.

4.2.1 Drainage Density (D_d): Horton (1932), introduced the drainage density (D_d) is an important indicator of the linear scale of landform elements in stream-eroded topography and is a better quantitative expression to the dissection and analysis of landform, although a function of climate, lithology and structures and relief history of the region. The Drainage Density (D_d) is defined as the length of streams per unit area. It is observed that the drainage density value of the study area is 1.04 km/km^2 which indicates the basin is well drained, and having high permeable subsoil and thick vegetative cover (Nag, 1998). In general, high D_d is characteristic of regions having nonresistant or impermeable subsurface materials, sparse vegetation and mountainous relief; whereas low D_d indicates regions of highly resistant rock or highly permeable subsoil materials under dense vegetative cover, where the relief is low.

4.2.2 Stream Frequency (F_s): Stream frequency or channel frequency (F_s) is the total number of stream segments of all orders per unit area (Horton, 1932). The stream frequency values of the sub-basins varies from 0.75 to 0.81 with a basin average of 0.78 (Table 4). The value of stream frequency (F_s) for the basin exhibit positive correlation with the drainage density value of the area indicating the increase in stream population with respect to increase in drainage density.

Table 4. Morphometric parameters of sub-basins of Tawi River basin

Name of sub-basin	Area km^2	Perimeter, km	Total Length of Stream, km	Total Number of Stream	Drainage Density	Drainage Frequency	Drainage Texture	Circularity Ratio	Elongation Ratio
Chenani	715	225	710	554	0.99	0.77	1.93	0.18	0.20
Ramnagar	479	124	486	386	1.01	0.81	2.33	0.39	0.16
Udhampur	274	107	287	220	1.05	0.80	1.51	0.30	0.12
Domel	697	202	762	523	1.09	0.75	1.96	0.22	0.20
Tawi River	2165	259	2245	1683	1.04	0.78	4.95	0.41	0.35

4.2.3 Elongation Ratio (R_e): Schumm (1956) used an elongation ratio (R_e) defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. It is a very significant index in the analysis of basin shape which helps to give an idea about the hydrological character of a drainage basin. The varying slopes of watershed can be classified with the help of the index of elongation ratio, i.e. circular (0.9-0.10), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (< 0.5).The value R_e of the study area is 0.35 indicates that the low relief of the terrain and very much elongated in shape.

$$R_e = (2/L_b)*\sqrt{(A/\pi)} \qquad (1)$$

4.2.5 Circularity Ratio (R_c): Miller (1953) defined a dimensionless circularity ratio (R_c) as the ratio of basin area to the area of circle having the same perimeter as the basin. He described the basin of the circularity ratios range 0.4 to 0.5 which indicates strongly elongated and highly permeable homogenous geologic materials. The circularity ratio value (0.41) of the Tawi basin corroborates the Miller's range which indicating that the basin is elongated in shape, low discharge of runoff and highly permeability of the subsoil condition.

$$R_c = 4\pi A/P^2 \qquad (2)$$

4.2.6 Drainage Texture (D_t): Drainage texture is one of the important concept of geomorphology which means that the relative spacing of drainage lines. Drainage texture is on the underlying lithology, infiltration capacity and relief aspect of the terrain. D_t is total number of stream segments of all orders per perimeter of that area (Horton, 1945). (Smith, 1950) has classified drainage texture into five different textures i.e., very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (>8). In the present study, the drainage texture of the watershed is 4.95 (Table 4). It indicates that category is moderate drainage texture.

4.2.7 Form Factor Ratio (R_f): It is the ratio of a basin area A_u (Horton, 1932) to the square of the basin length L_b. For Tawi river basin, the form factor is 0.10. A form factor nearer to zero indicates a highly elongated shape and the value that is closer to 1 indicates circular shape. The basins with high form factor value have high peak flow for short duration whereas elongated basin with low form factor will have a flatter peak flow of longer duration. Flood flows in elongated basins are easier to manage than that of the circular basins (Nautiyal, 1994).

$$R_f = A_u / L_b^2 \qquad (3)$$

5. CONCLUSION

The quantitative analysis of morphometric parameters has enormous importance in river basin evaluation, watershed prioritization for soil and water conservation, and natural resources management and planning at micro level. Watershed as a basic unit of morphometric analysis has gained importance because of its topographic and hydrological unity. GIS techniques characterized by very high accuracy of mapping and measurement prove to be a competent tool in morphometric analysis. The morphometric analysis carried out in this study for the Tawi river basin shows that the basin is having low relief of the terrain and elongated in shape. Drainage network of the basin exhibits as mainly sub-dendritic to dendritic type which indicates the homogeneity in texture and lack of structural control. The average bifurcation ratio of 4.20 reveal that drainage network in study area is well developed stage. The law of lower the order higher the number of streams is implied throughout the catchment. The total length of stream segments is maximum in first order streams and decreases as the stream order increases. Similar studies in conjunction with high resolution satellite data can help in better understanding the landforms and their processes and drainage pattern demarcations for basin area planning and management.

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