IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Vol. 7, Issue 3, March 2020

Morphometric Characterisation of Atagad Watershed of Uttarakhand

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Abstract: The study of the morphometric analysis of the watershed indicates the important factors for estimating the possible groundwater areas, controlling water supplies, conveniently identifying the place for the drainage system's water storage systems, runoff and geographic character. Morphometry is the approximation and mathematical interpretation of the configuration of the surface, shape, dimension of its landforms. For the current research, the morphometric analysis usually consists of dimensional, aerial, and relief aspects. The Remote Sensing and Geographic Information System (GIS) is used to handle and interpret the data present spatially. As mentioned above, the ArcGIS 9.3 has been accustomed to extrapolating various necessary parameters. Digital Elevation Model (DEM) is a 3D terrain conditions visualization. This analysis could also be functional in fields like regional planning, agriculture and forestry. Keeping the above in sight, this study was conducted to properly characterize the Atagad watershed for its morphological properties, in order on the premise of suitable watershed management plan which are often considered by the Government.

Keywords: Digital Elevation Model, GIS, Morphology, Relief Aspects, Shape Factor, Slope Map, Watershed Delineation.

I. INTRODUCTION

Water, which is a precious resource, is vital for the existence of all kinds of life on this planet, for number of reasons including infiltration rates, erosion, uneconomical needs, extraction of natural resources from surface water reserves, etc.; due to changes in land use dynamics and land cover deterioration. Watershed is a natural, hydrological laboratory. It could be defined as the zone that drains all the precipitation into a given stream. Proper planning and management of accessible natural resources is vital for the development and economic growth of agriculture, which is the main stay of people living the hilly area. A Geographic Information System (GIS) is a software-based approach for monitoring and analysing instances of earthly features. GIS technology incorporates maps with common operations like query and statistical analysis. GIS improves calculations for watershed characteristics, flow statistics, de-bris flow probability, and facilitates the watershed by using Digital Elevation Models (DEMs). ArcGIS provides the flexibleness to mix watershed datasets from one map source with stream and river networks. Remote sensing is the science of obtaining information from either a distance on objects or regions, generally from aircraft or satellites. Remote sensed imagery is incorporated within GIS. The evaluation of the morphometric watershed mod-el provides the valuable metrics for evaluating groundwater potential areas, defining sites for water harvesting systems, controlling water quality, runoff and drainage system geo-graphic features. Morphometry is the calculation and mathematical study of the surface, shape, and proportions of the earth's landform structure. This analysis may be useful in fields like regional planning, agriculture and forestry. This study was conducted for Atagad watershed in Uttarakhand region.

II. MATERIALS AND METHODS

A. *Study Area*

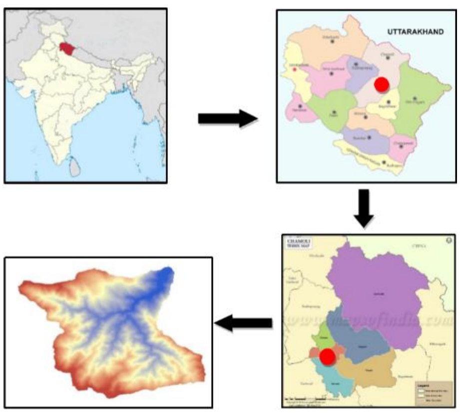

Fig. 1 Location of Atagad Watershed

 DOI 10.17148/IARJSET.2020.7304

IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

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- Location and Extension

The Atagad Watershed is a constituent of the Pindar river basin and is located near Karnprayag in Chamoli district in the state of Uttarakhand. The watershed is bounded within 30o 5' 28" N to 30o 13' 45" N and 79o 6' 27" E to 79o 15' 40" E covering an area of 182.4 km2. Karnprayag has an average elevation of 1,451 m from mean sea level. The Chamoli district is bounded by Uttarkashi district in North, Rudraprayag district in the West, Bageshwar and Almora district in South and Pitoragarh district in East.

- Rainfall

In the August and September months, Chamoli experiences moderate precipitation. During the monsoon period the highest rainfall is reported, i.e. between July to September. During the monsoon season the relative humidity is high, generally exceeding 70 percent on average. The driest phase of the year is the pre-monsoon span when the afternoon moisture will drop to 35 percent. Rainfall is very small in November during the non-monsoon season and raises from December to March. In the southern half of the district, 70 to 80 per-cent of annual precipitation appears and in the northern half, 55 to 65 per cent.

B. *Materials*

- Data

Satellite Image
DEM: CartoDEM Arcsec 1
Satellite: CARTOSAT-1
Resolution: 30 meters
Date: April 26, 2019

A CARTOSAT1 Digital Elevation Model (DEM) dated 26 April 2019 has been obtained from the Chamoli District website of the National Remote Sensing Center (NRSC) in Bhuvan. A national DEM created by the Indian Space Research Organization (ISRO) is the Virtual Elevation Model Cartosat-1 (CartoDEM). It is extracted from the stereo payload Cartosat-1, launched in May 2005.

- Software

ArcGIS 9.3: Developed by ESRI, this software is a profession-al GIS tool intended to create maps, facilitate geographical assessment and sharpen intelligent visualizations for better decision making. Arc view 9.3 Power GIS software was used to build, maintain, and produce various layers and maps.

C. *Methodology*

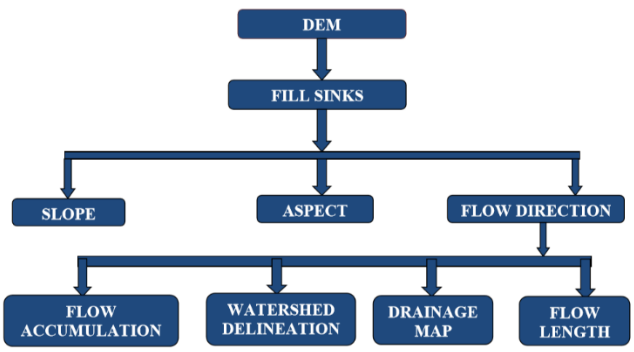

Fig 2. Schematic Representation of Methodology used

III. RESULTS AND DISCUSSION

The present study was conducted for land and water resource management and planning in Atagad watershed in district Chamoli of Uttarakhand, using GIS. Numerous thematic maps for this purpose viz. Using GIS software Arc Map 9.3, aspect chart, slope chart, drainage map, stream order map etc. was prepared. Morphometric characterization was performed by evaluating linear, areal and relief aspects of the basin us-ing the experiment area drainage chart. The digital elevation model in GIS environment with UTM projection was used for extracting the drainage network and watershed boundary.

A. *Digital Elevation Model*

A digital elevation model (DEM) is a digital model or 3D representation of the surface area of a landscape. DEMs basically consist of a measured range of elevations at evenly spaced intervals for a number of ground positions. This

IARJSET
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represents the Watershed relief variability. The elevation of the Atagad Watershed varied between 781 m above mean sea level (amsl) to 3011 m above as represented in the figure (Fig 3).

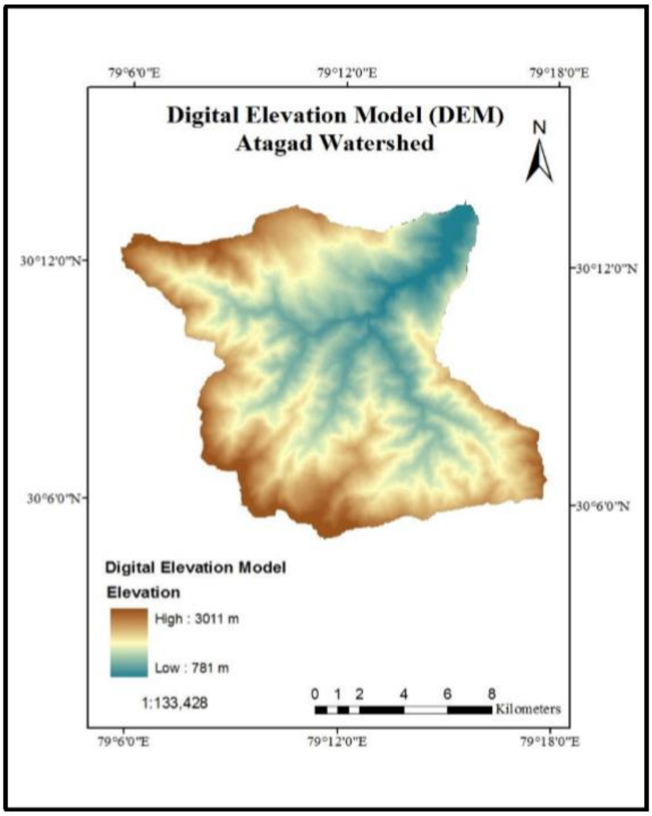

Fig. 3 Digital Elevation Model of Atagad Watershed

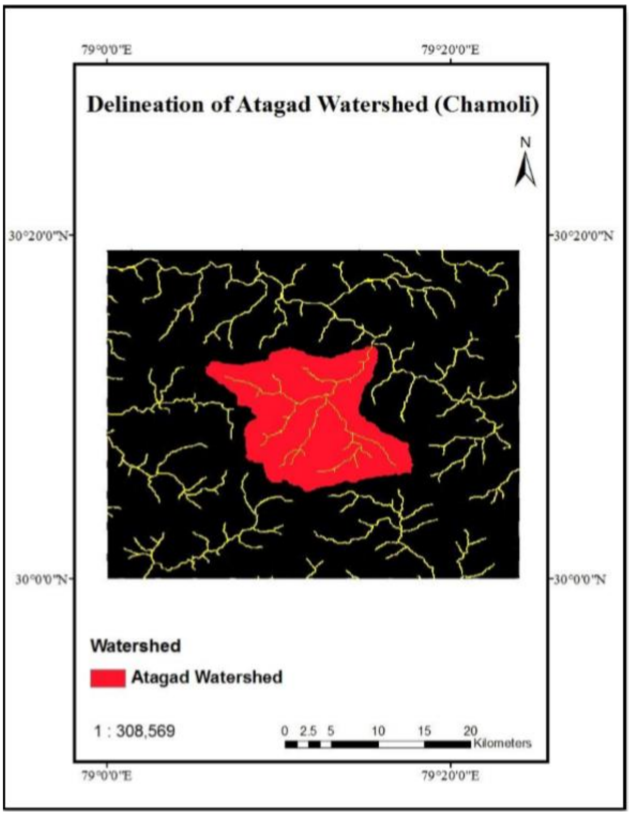

Fig. 4 Delineated Atagad Watershed

B. *Watershed Delineation*

The Watersheds were outlined in ArcGIS to extract the DEM of the Atagad Watershed (Fig. 4).

C. *Slope Map*

The Atagad Watershed slope map is obtained by carrying out the DEM in ArcGIS. The slope map is divided into five classes: flat, gentle, moderate, steep and very steep slope as shown in the undermentioned table (fig. 5).

TABLE 1 SLOPE CLASSIFICATION

Slope Classes	Slope Values (degree)
Flat	0-10
Gentle	10-25
Moderate	25-40
Steep	40-60
Very Steep	>60

D. *Aspect Map*

The aspect map shows which side is oriented toward the slope. An aspect value of 0 indicates the slope faces north. Atagad Watershed's aspect map is shown in below figure. It shows the slope facing north and south in different colors (fig. 6).

E. *Flow Direction*

The flow direction map was obtained by processing the DEM in Arc GIS. The flow direction indicates the direction of flow of stream and is useful to the modeler to infer drainage areas, flow lengths and delineate watersheds (fig. 7).

F. *Flow Accumulation*

The flow direction graph was obtained by processing the DEM in Arc GIS. The flow direction represents the flow path of the stream and is helpful for the modeler to infer drainage areas, flow lengths and delineate watersheds (fig. 8).

 DOI 10.17148/IARJSET.2020.7304

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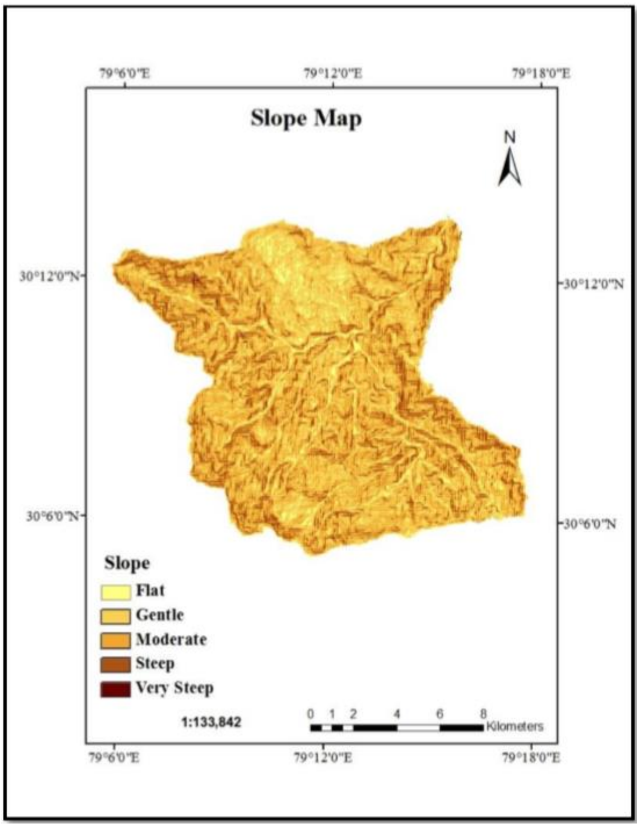

Fig. 5 Slope Map of Atagad Watershed

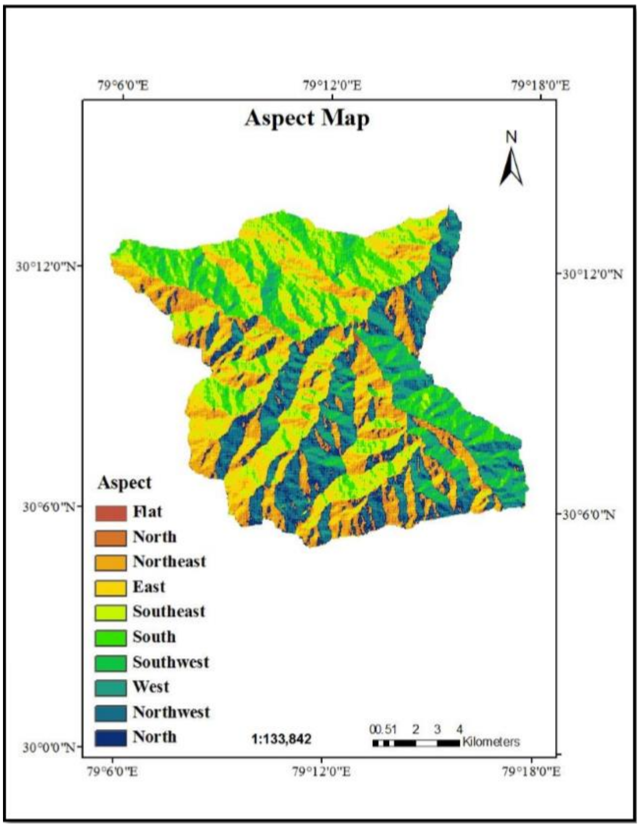

Fig. 6 Aspect Map of Atagad Watershed

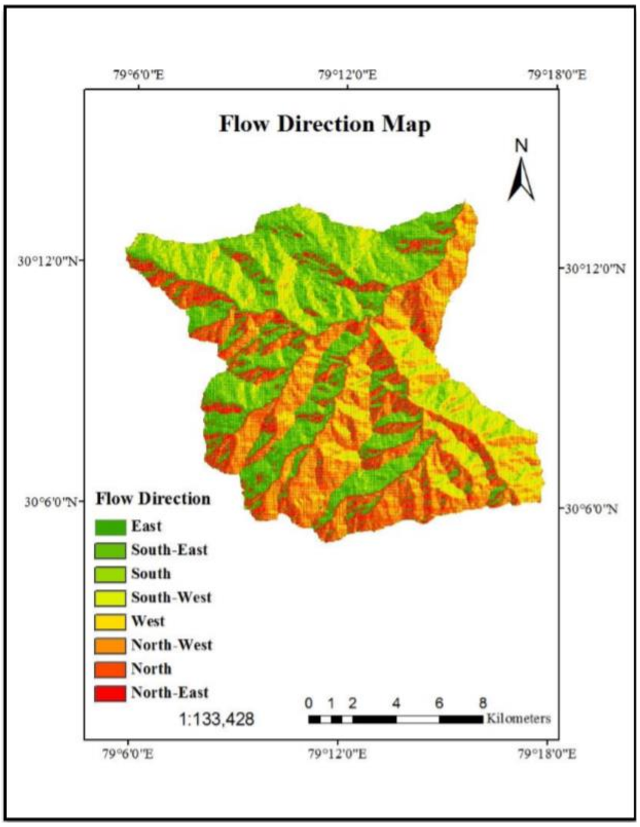

Fig. 7 Flow Direction Map of Atagad Watershed

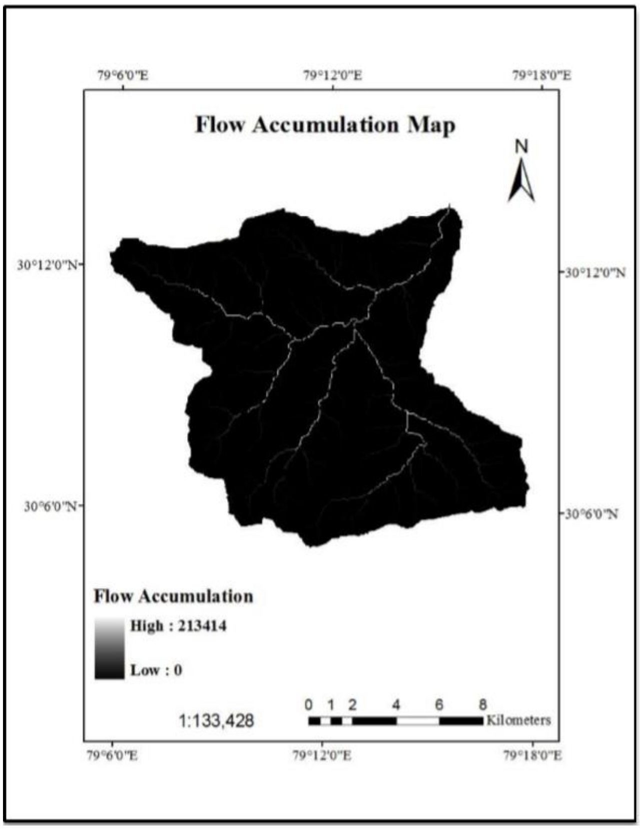

Fig. 8 Flow Accumulation Map of Atagad Watershed

G. *Linear Aspects of Atagad Watershed*

The Atagad watershed drainage network is clearly illustrated in the image (Fig. 9). Depending on the value given in the condition, the conditional tool (Con) generates various Stream Flow Maps. Drainage map of the study area (Con Value > 3000), as shown in Fig. 9 Alone and its stats are listed out in Table 3.2. The number of Order streams I, II, III and IV were 19, 5, 2 and 1 respectively. The length of the shortest drain of order I was 0.1724 km, while 6.1314 km was found to be the longest drain. The mean length of the order streams I, II and III and IV was 1,688 km, 2,5585 km, 2,0454 km, and 2,0289 km respectively.

TABLE 2 STATISTICS OF DRAINAGE NETWORK

Watershed Length (km)						
S. No.	Order	Maximum	Minimum	Average	Sum	Standard Deviation
1.	I	6.131	0.173	1.689	32.087	1.469
2.	II	7.109	0.165	2.558	30.702	1.910
3.	III	3.593	0.498	2.045	4.091	2.188
4.	IV	2.529	1.271	2.029	8.115	0.549

- Stream length (L_u)

The total length of the first, second, third and fourth order stream segments was found to be 32,087 km, 30,702 km, 4,091 km, and 8,115 km respectively (Table 2). Table 3.2 also shows that in first order streams the total length of stream segments was maximum while in higher-order streams it was lower. Also satisfied was Horton's general statement "The number of stream segments of increasing or-der forms an inverse geometric series with order number". The mean stream length for the watershed was found to be 1.689 km, 2.558 km, 2.04 km, and 2.03 km for first, second, third and fourth order streams, respectively.

- Stream length ratio (R_l)

The length ratio of the stream was determined and the difference in the length ratio attributed to the topography slope indicates the youth stage of the geo-morphic growth in the study region streams (Singh and Singh, 1997, Vittala et al., 2004) R_l ranged from 3.635 to 3.968 (Table 3).

- Bifurcation ratio (R_b)

The Bifurcation ratio is of great im-portance in the study of the drainage basin, as it is the primary parameter to connect a watershed's hydrological regime under topological and climatic conditions (Raj et. al., 1999). It helps to provide an idea about the shape of the basin as well as deciphering the behaviour of the runoff. The mean bifurcation ratio of Atagad watershed was found to be 2.77 as shown in Table 3. It is seen that the bifurcation ratio of 1st and 2nd order stream is higher than the other ratios. The values were 3.80, 2.50 and 2.0 For I/II, II/III and III/IV order respectively.

- Stream Order (U):

Categorization of stream order is critical for indexing basin size and scale. The drainage of the watershed has been classified according to Strahler's stream ordering system, and the mainstream is found to be of IVth order. The maximum frequency for the first order streams was 19, and was found to be 5, 2 and 1 respectively for second third and fourth order streams (Table 3.3 This stream order is used to measure other watershed characteristics. In the image below, the streams of various orders are shown in different colors. (Fig. 10).

- Flow Length

The Atagad Watershed flow length raster produced from the flow direction raster is shown in below (Fig. 11). The flow length values vary from low (0 m) to high (25141.1 m) and are distinguished by different shades of color in the plot. Hence the maximum value of flow length gives the basin length.

- Perimeter (P) and Basin length (L)

The perimeter and basin length of the Atagad watershed was found to be 69.89 km and 25.141 km, respectively (Table 3).

- Length of the overland flow (Lg)

The length of overland flow carries an important relationship with the constant of channel maintenance and drainage density. The length of the overland flow is inversely proportional to the pattern of run-off, longer the Lg slower will be the runoff process and vice-versa. Lg of the watershed was found to be 1.216 km (Table 3). Table 3 also shows that the fineness ratio of the Atagad watershed was found to be 0.360.

IARJSET

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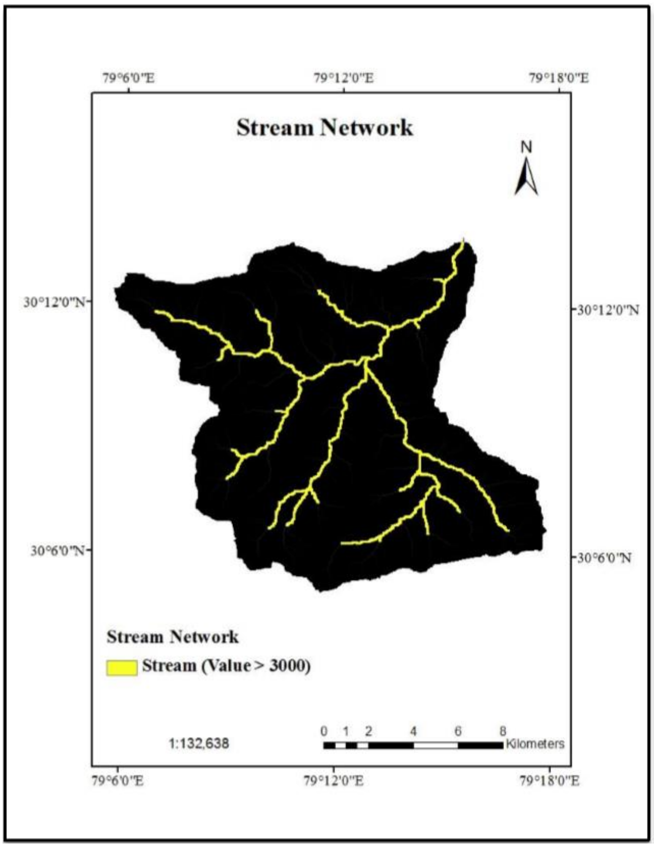

Fig. 9 Drainage Network [Con (value)>3000]

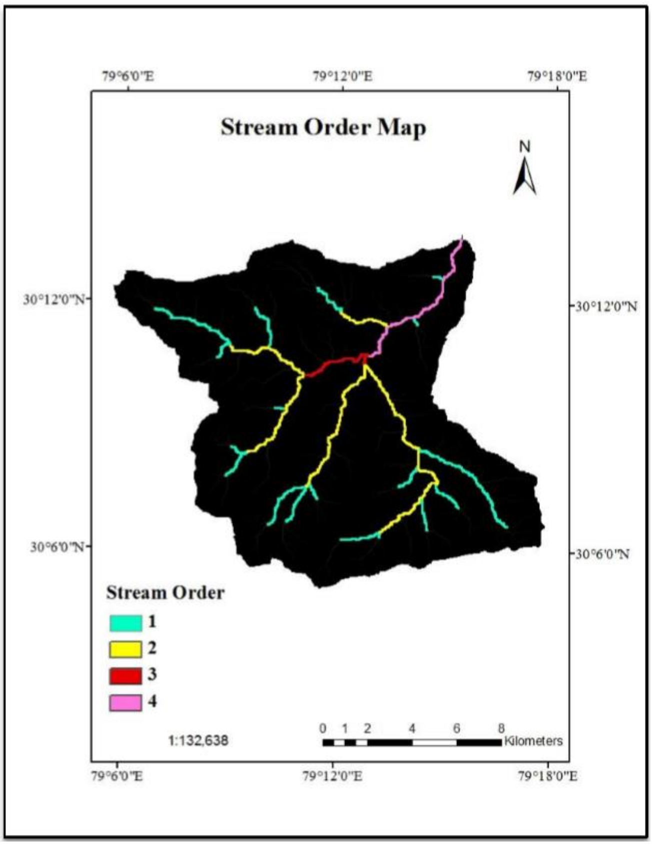

Fig. 10 Stream Order Map for Atagad Watershed

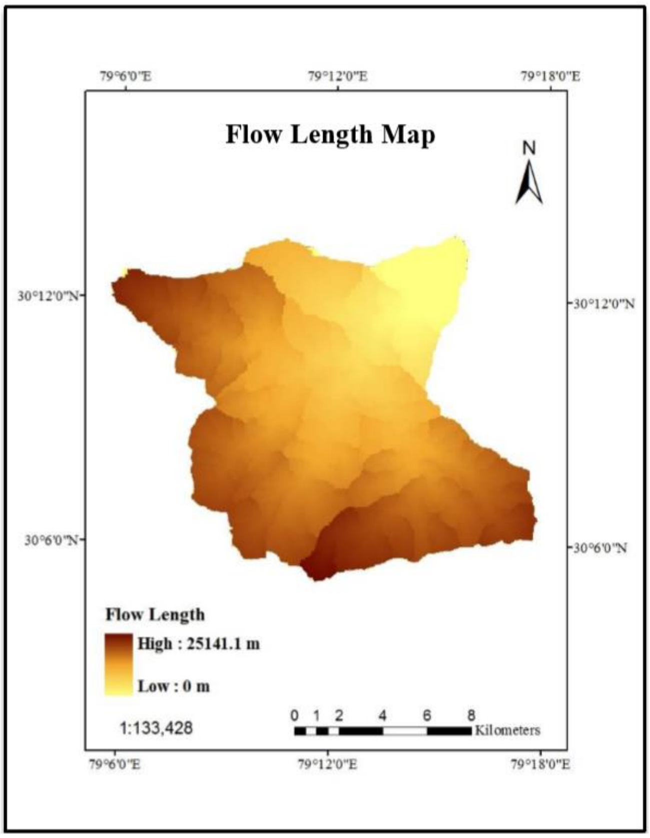

Fig. 11 Flow Length Map for Atagad Watershed

 DOI 10.17148/IARJSET.2020.7304

TABLE 3 SALIENT FEATURES OF LINEAR ASPECTS OF ATAGAD WATERSHED

S. No.	Parameters	Definition/ Formula	Values			
			I	II	III	IV
1.	No. of streams (N_u)	Hierarchical order	19	5	2	1
2.	Stream length (L_u) (km)	Length of the stream	32.087	30.702	4.091	8.115
3.	Mean Stream Length (L_{sm}) (km)	$L_{sm} = L_u/N_u$	1.689	6.140	2.045	8.110
4.	Bifurcation ratio (R_b)	$R_b = N_u/N_{u+1}$	I/II	II/III	III/IV	Mean
			3.80	2.50	2.00	2.77
5.	Stream Length Ratio (R_L)	$R_{L=} L_{smu}/L_{smu-1}$	II/I	III/II	IV/III	Mean
			3.635	0.333	3.968	2.645
6.	Basin Length (L_b) (km)	L_b=1.312x $A^{0.568}$	25.141			
6.	Length of overland flow (L_o) (km)	$L_o = 1/D_d * 2$	1.216			
7.	Fineness ratio (R_{fn})	$R_{fn}=L_b/P$	0.360			
8.	Total length of all channels (km)	Sum of length all channels of the watershed	74.995			

H. *Areal Aspects of Watershed*

- Drainage density (D_d)

Drainage density during a rainstorm can affect the shape of an inverse hydrograph. Higher drain-age density shows greater chance of flooding. The drainage density was 0.411 km / km2 (Table 4) for Atagad watershed. Drainage density ranging from 0.3km-1 to around 2.5km-1 is considered small, and therefore these areas have a high habitat potential. The stream frequency of the watershed was 0.141km-2 for orders I to IV.

- Constant of channel maintenance (C)

Channel maintenance operations are performed regularly to make sure that the channel's capacity and operational capability to hold sufficient continuous flow is properly maintained. It was found to be 2.433 km2/km which is the reciprocal of drainage density (Table 4).

- Circulatory ratio (R_c)

It is determined by the watershed's length and frequency of streams, geological structures, land use/land cover, weather, relief and gradient. In the current study Table 4, shows that for Atagad watershed the R_c value was 0.469.

- Elongation ratio (R_e)

The varying watershed slopes can be categorized using elongation ratio index, i.e. Circular (0.9-1.0), oval (0.8-0.9), less elongated (0.7-0.8), wider (0.5-0.7), lengthier (< 0.5). The value of the elongation ratio ranges between 0.6 and 1.0 across a wide range of climatic and geological regimes. The elongation ratio was estimated to be approximately 0.606 suggesting high relief and steep slope of the ground (Table 4), and the watershed can be labelled elongated.

- Form factor (F_f)

For a perfectly circular watershed, the form factor value will always be lower than 0.754. The smaller the form factor, the watershed will be more elongated. For Ata-gad watershed form factor value was 0.289 (Table 4). This indicates the watershed was more or less elongated. The elongated watershed with low value of Ff shows a flatter peak flow of longer duration for the basin. Flood flows in these elongated basins can be handled more effectively than from the circular basin. The unity shape factor and the water-shed shape factor of the watershed have been estimated as 1.861 and 1.649 respectively, suggesting the elongated form of the watershed.

- Drainage texture (T)

For a watershed, the drainage texture or texture ratio is one of the essential geomorphology concepts which means the drainage lines are fairly spaced out. The value of drainage texture T was determined to be 0.386km-1 (Table 4), which represents a low value and clearly indicates a small runoff from the area. In general, the low drain-age level results in extremely permeable subsoil material and dense vegetation (Nag, 1998).

TABLE 4 SALIENT FEATURES OF AREAL ASPECTS OF ATAGAD WATERSHED

S. No.	Parameters	Units	Definition/ Formulae	Results
1.	Texture Ratio (T)	km^{-1}	$T = N_u/P$	0.386
2.	Drainage Density (D)	km/km^2	$D = L_u/A$	0.411
3.	Stream frequency (F_s)	km^{-2}	$Fs = N_u/A$	0.148
4.	Area of a basin (A)	km^2	Area enclosed within the boundary of the Watershed divide.	182.4
5.	Perimeter (P)	km	Length of watershed divide which surrounds the basin	69.85
6.	Form Factor (R_f)	-	$R_f= A/L_b^2$	0.289
7.	Circulatory Ratio (R_c)	-	$R_c= 4\pi A/P^2$	0.469
8.	Elongation Ratio (R_e)	-	$Re=(2/L_b)*(A/\pi)^{0.5}$	0.606
9.	Coefficient of compactness (K_c)	-	$K_c= 0.2821P/A^{0.5}$	1.460
10.	Constant of channel maintenance (C)	km	$C=1/D_d$	2.433
11.	Unity shape factor (R_u)	-	$R_u=L_b/A^{0.5}$	1.861
12.	Watershed shape factor (W_s)	-	$W_s=L_m/D_c$	1.649
13.	Basin Shape (B_s)	-	$B_s=L_b^2/A$	3.465

I. *Relief Aspects of Watershed*

- Total Relief (H)

The difference in elevation between the highest and lowest points on the valley floor of a watershed is known as the watershed's total relief. The relief of the Ata-gad watershed was 2230 m (Table 5).

- Relief ratio (R_h)

There is a clear connection between the relief and the gradient of the channel, according to Schumm (1956). This tests the watershed's total steepness and is also considered an indicator of the erosion process severity occur-ring in the watershed. Table 5 shows that the value of relief ratio Rh for the Atagad watershed was 0.089.

- Relative Relief (R_r)

Relative relief has a benefit over relief ratio as it is not based on the length of the basin which is a dubious parameter in oddly formed basins. The value of relative relief for Atagad watershed was calculated to be 0.032 (Table 5).

TABLE 5 SALIENT FEATURES OF RELIEF ASPECTS OF ATAGAD WATERSHED

S.No.	Parameters	Units	Definition/ Formula	Value
1.	Total Relief (H)	metres	Maximum vertical distance between the lowest and highest points on the valley floor of a watershed	2230
2.	Relief Ratio (R_h)	-	$R_h = H/L_b$	0.089
3.	Relative Relief (R_r)	-	$R_r = H / P$	0.032
4.	Ruggedness number (R_n)	-	$R_n = H \times D_d$	0.92

- Ruggedness number

Low-relief yet high drainage density areas are as ruggedly textured as higher-relief areas with less density. It was found as 0.92 for the Atagad watershed (Table 5). This figure reflects that the average horizontal distance from the drainage divide to the adjacent channel is decreased if the drainage density increases, keeping the relief as constant. In the other side, as the relief increases, the elevation difference between the drainage divide and the adjacent channel would increase by keeping the drainage level as constant.

IV. CONCLUSION

This small study indicates the region is in a young stage, geomorphologically. Atagad watershed drainage density was found to be 0.411 km-1 thus there is less flood risk and high biodiversity potential. It also indicates that the necessary channel maintenance is small. Lower drainage density and frequency of the stream are correlated with a permeable material of the subsurface. These suggest the watershed has fairly low runoff capacity. Low form factor value indicates the watershed has a flatter peak flow for longer duration. The computed elongation ratio implies that the form of the watershed is almost elongated and has a high relief and steep slope to the ground. Findings also suggest that the area has low runoff and thus high levels of erosion. It can also be implied that morphometric analysis is a viable technique for identifying the hydrological response nature of the watershed. It is also well acknowledged that remote sensing of satellites is evolving as the most reliable, timesaving and efficient approach or technique for morphometric assessment for a basin watershed until now.

We also observed that geomorphological study through GIS technique has several advantages:

1. The typical morphometric analytical methods are time-consuming, exhausted and prone to mistakes, whereas the use of GIS methodology enables the measurement of equivalent watershed parameters in a very precise and accurate manner.

2. The approximate parameters of geomorphology could be useful for testing the geomorphic model as a DEM.

3. The layout of proper development plans, slope stabilization plan, emergency recovery plan and protection for natural hazards and man-made hazards will be easy to make for decision makers, rural or neighbourhood developers.

4. However, its drainage models assist to evaluate drainage and hydro project possibilities as well as other infrastructure facilities such as road configurations, national parks, reserve forests, and several more initiatives and government plans.

5. The basin's geomorphic attributes were long assumed to be the essential surface-process indices. Such parameters have been operated in numerous geomorphology and surface-water hydrology studies, including flood dynamics, sediment yield, and basin morphology evolution.

ACKNOWLEDGMENT

The researchers show their esteemed regard and deep admiration to their project adviser **Dr. P.S. Kashyap**, Associate Professor, Department of Soil and Water Conservation Engineering for his invaluable guidance, continuous motivation, positive advice, countless assistance, worthy support and ample counsel.

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