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AUTOMATED DRAINAGE CHARACTERIZATION OF DUDGANGA WATERSHED IN WESTERN HIMALAYAS

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Abstract

Morphometric analysis of a drainage basin demonstrates the dynamic equilibrium that has been achieved due to interaction between matter and energy. It helps to understand the prevailing geo-hydrological characteristics of a catchment. The traditional manual approach for large scale watersheds is time consuming. Using an elevation raster or DEM as input to GIS it is possible to automatically delineate a drainage system and quantify the characteristics of the system. In the present study automatic delineation and drainage characterization of Dudganga catchment has been carried out for detailed analysis of its linear and areal parameters using ASTER Digital Elevation Model (DEM) together with hydrologic analysis tools in ArcGIS Spatial Analyst. Further Strahler's scheme was used for stream ordering. The results reveal that the total number of streams is 890 belonging to different stream orders with the highest order of 6. The mean bifurcation ratio (Rb) value of 3.89 indicates that the geological structures are less disturbing the drainage pattern. The basin had medium drainage density (D) 1.21/Km^2 indicating the moderately permeable subsoil and moderate vegetation cover. The stream frequency (Fs) of 1.41 exhibits a positive correlation with the drainage density value of the area indicating an increase in stream population with respect to increase in drainage density.

Keywords: Dudganga, morphometry, watershed, Western Himalayas, DEM, drainage

Introduction

Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Agarwal, 1998; Reddy *et al., 2002).* A major emphasis in geomorphology over the past several decades has been on the development of quantitative physiographic methods to describe the evolution and behavior of surface drainage networks (Horton, 1945; Leopold and Maddock, 1953; Abrahams, 1984). In fact, they are the fundamental units of the fluvial landscape and a great amount of research has focused on their geometric characteristics, including the topology of the stream networks and quantitative description of drainage texture, pattern and shape (Abrahams, 1984). Morphometric analysis requires measurement of linear features, areal aspects, gradient of channel network and contributing ground slopes of the drainage basin (Nag, 1998). Traditionally this job was done manually from contour lines of topographical maps but with the availability of moderate resolution terrain data in digital format and advanced image processing techniques, traditional methods are quickly replaced by automated approaches. The advantages of automatic delineation approach include process reliability and reproducibility and cost-effectiveness (Akram *et al*, 2012). Also results in digital format can be linked with other data sets easily.

A watershed is an area from which runoff resulting from precipitation flows past a single point into large streams, rivers, lakes or oceans. The morphometric characteristics at the watershed scale may contain important information regarding its formation and development because all hydrologic and geomorphic processes occur within the watershed (Singh and Singh, 1997). Morphometric analysis of a watershed provides a quantitative description of the drainage system which is an important aspect of the characterization of watersheds (Strahler, 1964). The morphometric parameters of a watershed are reflective of its hydrological response to a considerable extent and are helpful in synthesizing its hydrological behavior because it enables us to understand the relationships among different aspects of the drainage pattern of the basin, and also to make a comparative evaluation of different drainage basins developed in various geologic and climatic regimes.

Study Area

Dudganga- the Milky stream (Fig.1) rises in Pir Panjal range of Western Himalayas from Tatakoti and Sangi Safed peaks at an altitude of 4500m above mean sea level. The two streams join near Damodar kerawa (Wathore village), from here it flows through the city of Srinagar and drains into Hokersar wetland. The watershed has a total catchment area of 635Km^2 and lies between geographical coordinates of 33º 42´ 08" to 34º 06´ 32" N latitude and 74º 27´ 02" to 74º 54´ 54" E longitude. The altitude of the study area ranges from it s lowest of 1595m at its mouth to the highest of 4500m above mean sea level at its origin. The major land use categories of the watershed are agriculture, horticulture, built-up, forests and barn land.

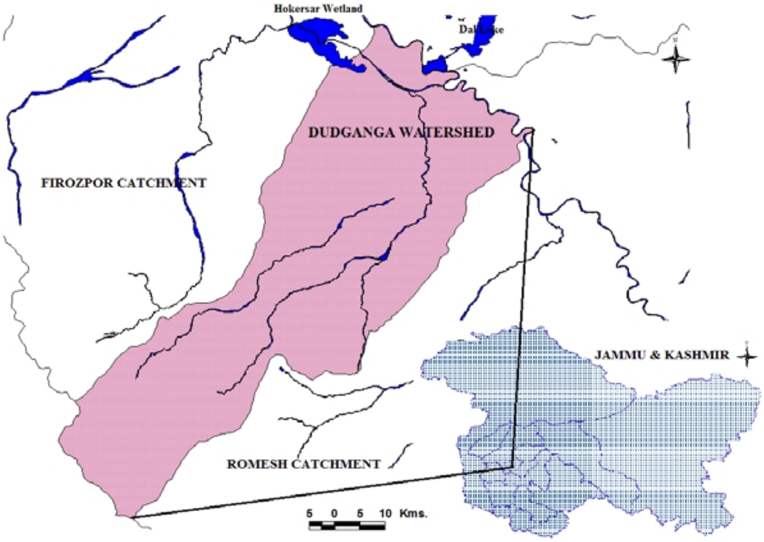

Fig 1: Location Map of the Study Area

Materials and Methods: The Study was carried out in two phases;

1. Delineation of catchment and drainage network from DEM through following steps:

i. Fill Sinks: A sink is usually an incorrect value lower than the values of its surroundings. To ensure proper drainage mapping, these depressions were filled using the Fill tool and a fill DEM was prepared. Depressions are filled by increasing elevations of depression points to their lowest outflow point.

ii. Calculate Flow Direction: The fill DEM prepared in the step 1 is treated as input here and the Flow directions were calculated using the eight-direction (D8) flow model (O’Callaghan and Mark, 1984) which assigns flow from each grid cell to one of its eight adjacent cells, in the direction with a steepest downward slope.

iii. Calculate Flow Accumulation: The output flow direction raster created in step 2 has been used as input. Using the Flow Accumulation tool, the number of upslope cells flowing to a location were calculated here.

iv. Define Stream Network: A common method of extracting channel networks from DEM is to specify a critical support area that defines the minimum drainage area required to initiate a channel using a threshold value (Bertolo, 2000). For this study many trials were run with different threshold value and the DEM extracted channel were match with the lines depicted on topographic maps for validation.

v. Stream Segmentation: After derivation of stream network, a unique value was assigned for each section of the stream line, associated with a flow direction.

2. Morphometric Analysis following Strahler’s classification scheme: Strahler’s system of stream analysis is probably the simplest, most used system and same has been adopted for this study. According to this scheme each finger-tip channel is designated as a segment of the first order. At the junction of any two first-order segments, a channel of the second order is produced and extends down to the point where it joins another second order channel,where upon a segment of third order results. The various morphometric parameters were computed using standard methods and formulae given in table 1.

Table 1: Formulae for the Computation of Morphometric Parameters

S.No	***Parameter***	***Symbol/Formula***	***Description***	***Reference***
1	Stream Order	Hierarchical Rank		**Strahler (1964)**
2 **3**	Mean Stream Length (Lsm)	$Lsm= Lu/Nu$	Lu=Total stream length of order u; Nu=Total no. of stream segment of order u.	
4	Stream length ratio (RL)	$RL=Lu/ Lu-1$	Lu-1=Total stream length of its next lower order	**Horton (1945)**
5	Drainage Texture (Rt)	$Rt=Nu/P$	P= perimeter(Km)	
6	Length of Overland Flow (Lg)	$Lg=1/D*2$	D=Drainage density	
7	Bifurcation Ratio (Rb)	$Rb=Nu/Nu+1$	Nu+1=No. of segments of next higher order	**Schumm (1956)**
8	Elongation Ratio (Re)	$Re=(2/Lb)*(A/Pi)^{0.5}$	$Pi=\pi$; A=Area of basin(Km2)	
9	Mean Bifurcation Ratio (Rbm)	Rbm=Average Rb of all orders		**Strahler (1957)**
10	Drainage Density (D)	$D=Lu/A$	Lu=Total stream length of order u, A=Area of basin (Km2)	**Horton (1932)**
11	Drainage Frequency (Fs)	$Fs=Nu/A$	Nu=Total no. of stream segments of order u. A=Area of basin (Km2)	
12	Form Factor (Rf)	$Rf=A/Lb^2$	A=Area of basin (Km2) Lb= Basin Length	
13	Circulatory Ratio (Rc)	$R_c=4\pi*A/P^2$	A= Area P= Perimeter	**Miller (1953)**
14	Basin Length (Lb)	$Lb=1.312*A^{0.568}$	A= Area	**Nooka Ratnam et al. (2005)**
15	Compactness Coefficient (Cc)	$Cc= 0.2821P/A^{0.5}$	P= Perimeter A= Area	

Table 2: Description of Indicators

Linear Parameters	
Parameter	Characteristics
Stream order Mean Stream Length (Lsm)	It is defined as a measure of the position of a stream in the hierarchy of tributaries The mean stream length is the characteristic property related to the drainage network and its associated surfaces. Generally higher the order, longer the length of streams is noticed in nature.
Drainage Texture (Rt)	It is the total number of stream segments of all orders per perimeter of the area.
Length of Overland Flow (Lg)	Length of overland flow is the length of water over the ground before it gets concentrated into definite stream channels. This factor relating inversely to the average shape of channel is quite synonymous with the length of the sheet flow to a large degree. Generally higher value of Lg is indicative of low relief and where as low value of Lg is an indicative of high relief.
Bifurcation Ratio (Rb)	Bifurcation ratios characteristically range between 3.0 and 5.0 for basins in which the geologic structures do not distort the drainage pattern.
Drainage Density (D)	Drainage density (Dd) shows the landscape dissection, runoff potential, infiltration capacity of the land, climatic conditions and vegetation cover of the basin. High drainage density is the resultant of weak or impermeable subsurface material, sparse vegetation and mountainous relief. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture.
Stream Frequency (Fs)	Stream Frequency is the total number of stream segments of all orders per unit area. Generally, high stream frequency is related to impermeable sub-surface material, sparse vegetation, high relief conditions and low infiltration capacity.
Shape Parameters	
Form Factor (Rf)	Form factor is defined as ratio of basin area to the square of basin length The value of form factor would always be less than 0.7854 (for a perfectly circular basin) Smaller the value of form factor, more elongated will be the basin. The basins with high form factors have high peak flows of shorter duration, whereas, elongated watershed with low form factors have lower peak flow of longer duration.
Circulatory Ratio (Rc)	It is defined as the ratio of basin area to the area of circle having the same perimeter as the basin and is dimensionless. Circulatory Ratio is helpful for assessment of flood hazard. Higher the Rc value, higher is the flood hazard at the peak time at the outlet point.
Elongation Ratio (Re)	Elongation ratio (Re) is 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. Values near to 1.0 are typical of regions of very low relief.
Compactness Co efficient (Cc)	Compactness Co efficient (Cc) is used to express the relationship of a hydrological basin with that of a circular basin having the same area as the hydrologic basin.

Results and Discussions

The watershed and drainage network generated from ASTER DEM is shown in Fig.2 and Fig.3 respectively. The main challenge in digital extraction of watershed outline and stream network was the fixation of threshold value which is referred to as flow accumulation threshold area or the minimum contributing area. Several attempts with different threshold values were made and the digitally delineated watershed boundary and drainage network were validated using SoI toposheets as reference data to compare the extracted channels from DEM. This comparison helped to fix up the best threshold value for drainage network delineation. Area of a basin (A) and perimeter (P) are the important parameters in quantitative morphology. Basin area is hydrologically important because it directly affects the size of the storm hydrograph and the magnitudes of peak and mean runoff. It is interesting that the maximum flood discharge per unit area is inversely related to size (Chorley, et al., 1957).

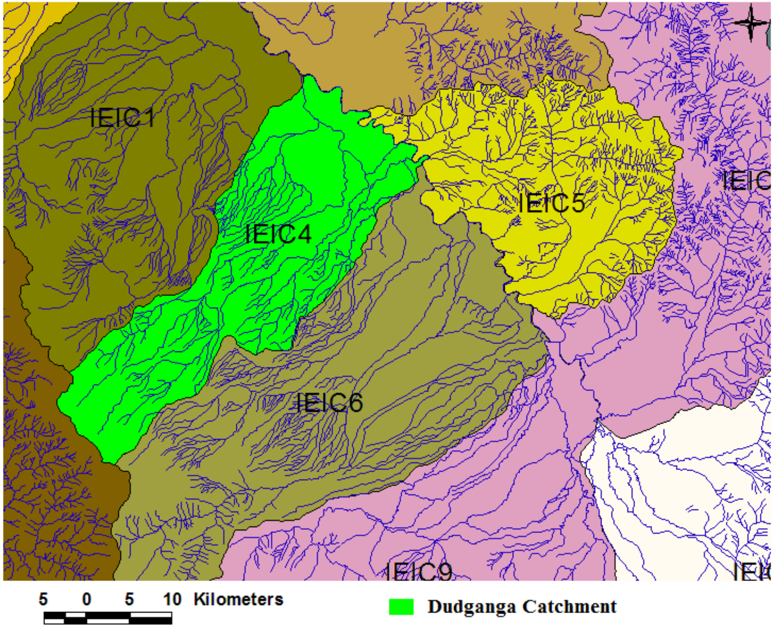

Fig. 2: Automated delineation and drainage extraction using ASTER- DEM

Linear Parameters

Drainage parameters (Fig.3) such as bifurcation ratio, drainage density, stream frequency, drainage texture and length of overland flow are reflected in Table 3 and are discussed below:

Stream order (Nu)

In the drainage basin analysis the first step is to determine the stream orders. In the present Study, the channel segment of the drainage basin has been ranked according to Strahler's stream ordering system (Fig.3). According to Strahler (1964), the smallest fingertip tributaries are designated as order 1. Where two first order channels join, a channel segment of order 2 is formed and where two of order 2 joins, a segment of order 3 is formed, so on and so forth. The trunk stream through which all discharge of water and sediment passes is therefore the stream segment of highest order. The study area is a 6th order drainage basin. The total number of 890 streams were identified of which 696 are 1st order streams, 148 are 2nd order, 36 are 3rd order, 7 in 4th order, 2 in 5th order and one 6th order streams.

Bifurcation Ratio (Rb)

The term bifurcation ratio (Rb) is used to express the ratio of the number of streams of any given order to the number of streams in next higher order (Schumn, 1956). Bifurcation ratios characteristically range between 3.0 and 5.0 for basins in which the geologic structures do not distort the drainage pattern (Strahler, 1964). Bifurcation ratio shows a small range of variation for different regions/s except where the powerful geological control dominates. If the bifurcation ratio is not same from one order to its next order, then these irregularities are dependent upon the geological and lithological development of the drainage basin (Strahler, 1964). In the study area mean bifurcation ratio (Rbm) is 3.89 which suggest less structural disturbance.

Table 3: Number of Streams and Bifurcation Ration in Dudganga Watershed

<table>
<tr><td colspan="2">tream Order u</td><td colspan="2">Number of Streams N_u</td><td>Total Length of Streams L_u</td><td>Mean Stream Length (Km)</td></tr>
<tr><td colspan="2">1</td><td colspan="2">696</td><td>451.82</td><td>0.65</td></tr>
<tr><td colspan="2">2</td><td colspan="2">148</td><td>124.56</td><td>0.84</td></tr>
<tr><td colspan="2">3</td><td colspan="2">36</td><td>83.6</td><td>2.32</td></tr>
<tr><td colspan="2">4</td><td colspan="2">7</td><td>32.7</td><td>4.67</td></tr>
<tr><td colspan="2">5</td><td colspan="2">2</td><td>62.54</td><td>32.27</td></tr>
<tr><td colspan="2">6</td><td colspan="2">1</td><td>11.64</td><td>11.64</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td><td></td><td></td></tr>
<tr><td colspan="5">Bifurcation Ratio</td><td>Mean Bifurcation Ratio</td></tr>
<tr><td>1st order/ 2nd order</td><td>2nd order/ 3rd order</td><td>3rd order/ 4th order</td><td>4th order/ 5th order</td><td>5th order/ 6th order</td><td rowspan="2">3.89</td></tr>
<tr><td>4.71</td><td>4.10</td><td>5.14</td><td>3.50</td><td>2</td></tr>
</table>

Drainage Density (D)

Horton (1932) introduced the drainage density (D), an important indicator of the linear scale of landform elements in stream eroded topography. It is the ratio of total channel segment lengths cumulated for all orders within a basin to the basin area, which is usually expressed in terms of Km/Km^2. The drainage density indicates the closeness of spacing of channels, thus providing a quantitative measure of the average length of stream channel for the whole basin. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture (Strahler, 1964). Langbein (1947) recognized the significance of drainage density as a factor determining the time of travel by water and suggested that drainage density values between 0.55 and 2.09 Km/Km^2 correspond to humid regions. A drainage density value of 1.21 in the study area suggests that Dudganga watershed is underlined by highly permeable material.

Stream Length (Lu)

Stream length is one of the most significant hydrological features of the basin as it reveals surface runoff characteristics. Streams of relatively smaller lengths are characteristics of areas with larger slopes and finer textures. Longer lengths of streams are generally indicative of flatter gradients. Generally, the total length of stream segments is maximum in first order streams and decreases as the stream order increases. As reflected in table 3, the order wise mean stream length in the study area for the first order is 0.65 Kms, 0.84 Kms for second order, 2.32 Kms for third order, 4.67 Kms for fourth order, 31.27 Kms for fifth order and 11.64 Kms for the trunk stream (6th order).

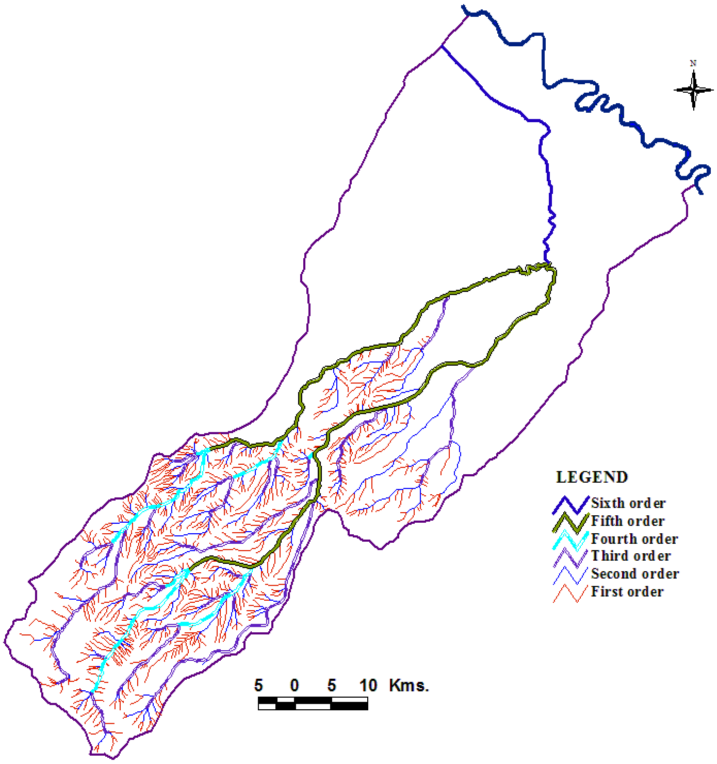

Figure 3: Stream Ordering Map of Dudganga Watershed

Stream Frequency (Fs)

Stream frequency or channel frequency (Fs) is the total number of stream segments of all orders per unit area (Horton, 1932). Stream frequency values of the Dudganga watershed is 1.41. Low values of stream frequency Fs indicate presence of a permeable subsurface material and low relief (Reddy *et al*. 2004a)

Drainage Texture (Rt)

Drainage Texture (Rt) is an important factor in the drainage morphometric analysis which is depending on the underlying lithology, infiltration capacity and relief aspect of the terrain. Horton (1945) defined drainage texture as the total number of stream segments of all orders divided by the perimeter of the watershed. In terms of drainage texture Dudganga (Rt:4.69) falls in the category of moderate drainage texture. Smith (1954) classified drainage density into five different classes of drainage texture, i.e. < 2 indicates very coarse, between 2 and 4 is coarse, between 4 and 6 is moderate, between 6 and 8 is fine and greater than 8 is very fine drainage texture.

Length of Overland Flow (Lo)

Length of overland flow is referred to as the distance of flow of the precipitated water, over the land surface to reach the stream. The calculated value for the study area was 0.41 Kms. Length of overland flow is one of the most important independent variables affecting hydrologic and physiographic development of drainage basin. The average length of overland flow is approximately half the average distance between stream channels and is therefore approximately equal to half of reciprocal of drainage density (Horton, 1945).

Table 4: Morphometric Analysis of Dudganga Watershed

Morphometric parameter	Symbol/formula	Calculated value
Area (km^2)	A	635
Perimeter (km)	P	148.38
Basin length (km)	$L_b=1.312*A^{0.568}$	51.18
Stream Frequency	$F_s=N_u/A$	1.41
Form Factor	$R_f=A/L_b^2$	0.24
Elongation Ratio	$R_e=(2/L_b)*(A/Pi)^{0.5}$	0.15
Circularity Ratio	$R_c=4\pi*A/P^2$	0.36
Texture Ratio	$T=N_1/P$	4.69
Drainage Density (Km/Km^2)	$D=L_u/A$	1.21
Length of Overland Flow	$L_g=1/D*2$	0.41

Shape Parameters

Drainage parameters such as basin shape, form factor, circularity ratio, elongation ratio and compactness coefficient (Table 4) have been automatically extracted through GIS and are discussed below:

Form Factor Ratio (Rf)

Horton (1932) defined form factor (Rf) as a dimensionless ratio of basin area (A) to the square of basin length (Lb). The value of form factor would always be less than 0.7854 (for a perfectly circular basin). The basins with higher form factor are normally circular and have high peak flows for shorter duration, whereas elongated basins with lower values of form factor have low peak flows for longer duration. The form factor value for Dudganga watershed is 0.24 indicating an elongated basin in shape which is also visualized in Fig.2. The elongated basin with low form factor indicates that the basin will have a flatter peak of flow for longer duration. Flood flows of such elongated basins are easier to manage than of the circular basin (Nautiyal, 1994).

Circularity Ratio (Rc)

Circularity Ratio is the ratio of the area of a basin to the area of circle having the same circumference as the perimeter of the basin. Miller (1953) described the basin of the circularity ratios range 0.4 to 0.5 which indicates strongly elongated and highly permeable homogenous geologic materials. It is influenced by the length and frequency of streams, geological structures, land use/land cover, climate and slope of the watershed. The circularity ratio value (0.3) of the Watershed corroborates the Miller’s range which indicating that the catchment is characterized by elongated shape, low discharge of runoff and high permeability of the subsoil conditions.

Elongation Ratio (Re)

Schumm (1956) used an elongation ratio (Re) defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length and is found generally varying from 0.6 to 1.0 depending upon vagaries of climate and geology. 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 Elongation Ratio (Re) of the watershed is 0.15. Re values which are characterized by high susceptibility to erosion and sediment load (Reddy et al., 2004b).

Conclusion

The automated extraction of drainage characteristics using GIS has facilitated a reliable cost/effort effective methodology for drainage delineation and morphometric analysis especially in case of large basins. However the resolution of terrain data (DEM) and the selection of threshold value play a vital role in determining the accuracy of the results. A wrong threshold value may result into an inaccurate delineation. The morphometric analysis has shown that Dudganga watershed is composed of impermeable sub-surface materials, sparse vegetation and high mountainous relief causing higher surface run off, and a higher level of degree of dissection. The mean bifurcation ratio (Rb) value of 3.89 indicates that the geological structures are less disturbing the drainage pattern. The Watershed had medium drainage density (D) 1.21 Km/Km^2 indicating the moderately permeable subsoil and moderate vegetative cover. The stream frequency (1.41) exhibits a positive correlation with the drainage density value of the area indicating an increase in stream population with respect to increase in drainage density.

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