MORPHOMETRIC ANALYSIS OF OF GAGAS RIVER VALLEY WATERSHED IN ALMORA DISTRICT OF UTTARAKHAND USING REMOTE SENSING AND GIS

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ABSTRACT

The measurement of morphological parameters is laborious and cumbersome by the conventional methods, but using the latest technology like GIS, the morphometric analysis can be better achieved. Morphometric parameters play very important role in generating water resources action plan for location recharge and discharge areas. Nowadays, integration of Remote Sensing and GIS is helpful in planning and management of land and water resources for adoption of location specific technologies. In the present study, Morphological characteristics of the Gagas river valley watershed are described and their inter-relationship has been established. Drainage morphology along with slope map is also explored for locating and selecting the water harvesting structure like percolation tank, pond, check dams etc.

Keywords: Watershed, GIS, Morphology and Drainage Network

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Introduction

Proper planning and management of available natural resources is necessary for progress and economic development in agriculture which are main stay of people living in the hilly region. The morphometric analysis of watershed can play a vital role in predicting the hydrological behaviour of a watershed, engineering and site suitability aspect. Watershed deterioration is the common phenomena in most parts of the world. Among several causes for this, improper and unwise utilization of watershed resources is the main. Low discharge of the natural springs, faulty land use system, soil erosion and lack of proper water harvesting methods are to be controlled as they are major reasons which hinder the development & management of watershed in these areas. GIS (Geographical Information System) has become an effective tool in planning and development of watershed, as remote sensing derived information and the conventional database can be integrated and analysis of spatial, multi-layered information can be done. With this approach morphometric analysis of Gagas river valley watershed of Almora district of Uttarakhand state in India was done using remote sensing and GIS to generate location specific watershed development plans.

Study area

The Gagas river, in Almora district of Uttarakhand, spans 14 major gadheras (streams) on both banks, and its river basin comprises over 500 sq km with a population of over 120,000 spread in 350 villages. Gagas river valley watershed comprises of an area 63.51 sq km and perimeter 41.2 km. Study area is located enroute to Kausani-Bageshwar road in district Almora of Uttarakhand state. It lies between 79° 26' 20''–79◦ 31’ 50'' E long and 29° 45' 01''–29° 50' 32'' N lat. The topography of the region varies from 2750 m above mean sea level in the head reaches in the north-eastern part to 1226 m above mean sea level at the outlet in the southern part of the basin. Geologically the study area is a part of Lesser Himalayan Zone, Valdiya, (1989). Morphologically, the region is characterized by a series of deeply incised river valleys and high ridges. When the river is heading towards the south it cuts deep into rocks resulting into floodplains. More than 80% of the annual precipitation in the region occurs during the south-western monsoon, which starts in the third week of June and last upto mid-October (Asthana, 2003). Of the remaining 15% rainfall is caused by cyclones and 5% by thunderstorms distributed over the rest of the year (Jalal, 1988). The temperature of the region varies from above 30^o in summer to about -2^o C in winter.

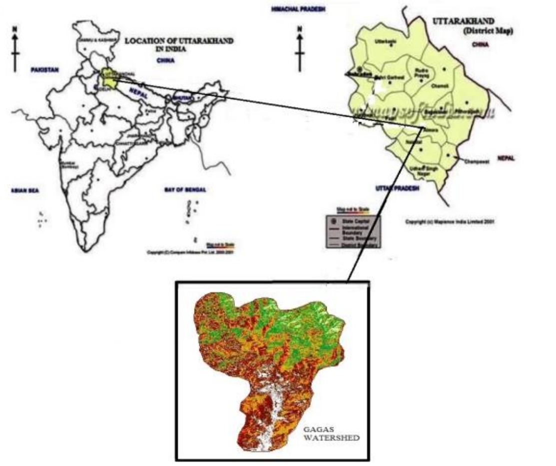

Fig 1 Location map of Gagas River Valley Watershed

Methodology

SOI Toposheet no: 53O5, 53O6, 53O9 and 53O10 were procured from the office of Surveyor of India, Dehradun to carry out the present work. Study area (Gagas River Valley Watershed) was identified from the topsheets. Base map was prepared using Survey of India (SOI) Toposheets. Digitization and geo-referencing of the toposheets was done using ArcGIS software. DEM data from SRTM were downloaded from Earth Explorer (USGS on the 30 m by 30 m spatial resolution. Watershed was delineated from the base map prepared using Arc GIS Spatial Analyst Hydrology Tool and drainage channels were classified into different orders using Strahlers's 1964 classification. Other basin parameters such as basin area, basin perimeter, basin length and stream length were calculated which were further used to calculate the different ratios namely Drainage Density, Drainage Texture, Bifurcation Ratio, Stream Length Ratio, Stream Frequency, Form Factor, Elongation Ratio and Circulatory Ratio, etc were found out for watershed management planning also termed as erosion risk assessment parameters.

Results and discussion

The total area of the Gagas basin is 63.51 sq km and perimeter is 41.2 km. The basin demarcation has been carried out in ArcGIS using the DEM data obtained from SRTM. The drainage pattern is dendritic in nature.

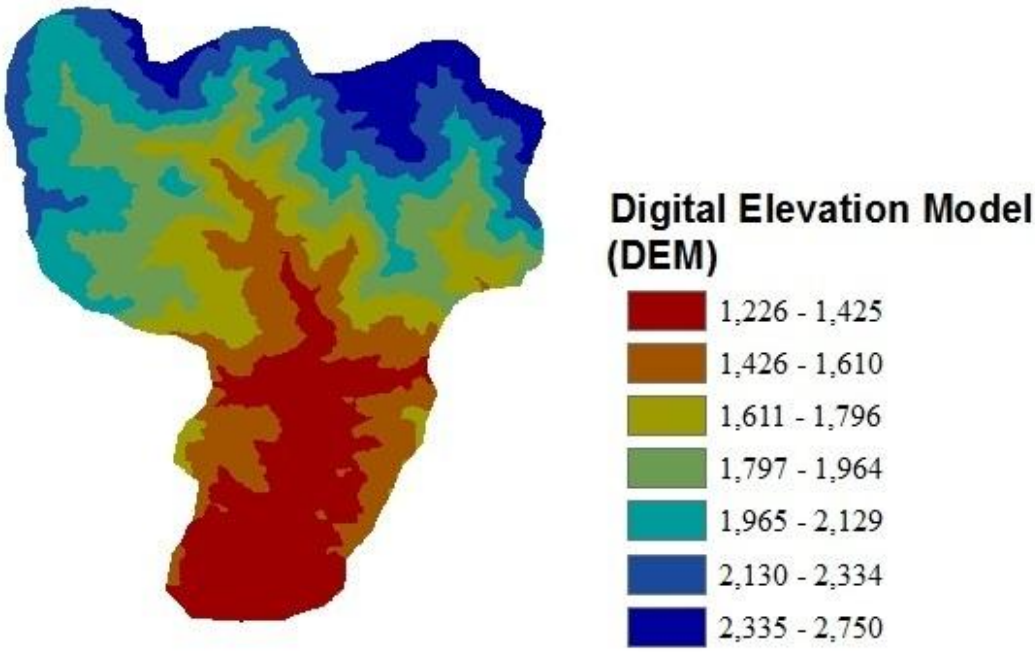

Figure 1 Digital Elevation Model of Gagas River Valley Watershed

Table-1: Morphological parameters of Gagas River Valley Watershed

Parameter	**Function/Formula**	**Value**
Area	A	63.51 km^2
Perimeter	P	41.2 km
Stream Length	L_b	-
1st Order		48.368 km
2nd Order		28.009 km
3rd Order		15.457 km
4th Order		11.31 km
Total		103.14
Number of Streams	N_u	-
1st Order		129

2^{nd} Order		33
3^{rd} Order		5
4^{th} Order		1
Total		168
Drainage Density	$D = \frac{\sum_{i=1}^{w}\sum_{j=1}^{N_i} L_{ij}}{A}$	1.62 km/km^2
Drainage Texture	$D \times F_s$	4.30
Bifurcation Ratio	$R_b = \frac{N_u}{N_{u+1}}$	5.17
Stream Length Ratio	$R_L = \frac{L_u}{L_{u-1}}$	II/I (1.73) III/II (1.81) IV/III (1.37)
Stream Frequency	$F_s = \frac{N_u}{A}$	2.65/km^2
Basin Length	----	13.6 km
Form Factor	$R_f = \frac{A}{L_b^2}$	0.34
Elongation Ratio	$R_e = \frac{2\sqrt{A/\pi}}{L_b}$	0.66
Circulatory Ratio	$R_C = \frac{A}{A_C}$	0.47
Relief Ratio	$R_h = H \times L$	0.11
Ruggedness Number (Rn)	$R_n = H \times D$	3.67

Drainage Density: Drainage density is defined as the total stream length in a given basin to the total area of the basin, (Horton, 1932, 1945). Strahler (1964) noted that low drainage density is favoured when basin relief is low and vice-versa. The drainage density of the study area is 1.62

km/km^2 . A low drainage density indicates permeable subsurface strata and is a characteristic feature of coarse drainage which generally shows values less than 5.0. (Table 1)

Drainage Texture: Drainage Texture is a product of drainage density and stream frequency. The drainage texture of the study area is found to be 4.30 which falls in intermediate category as per classification of Smith 1950.

Bifurcation Ratio: Bifurcation Ratio is defined as the ratio of the number of streams of any given order to the number of streams in the next lower order (Horton, 1932). The bifurcation ratio of the study area is estimated as 5.17. The bifurcation ratio indicated that there will be little chance of flooding as the water will tend to accumulate in one channel along with spreading out.

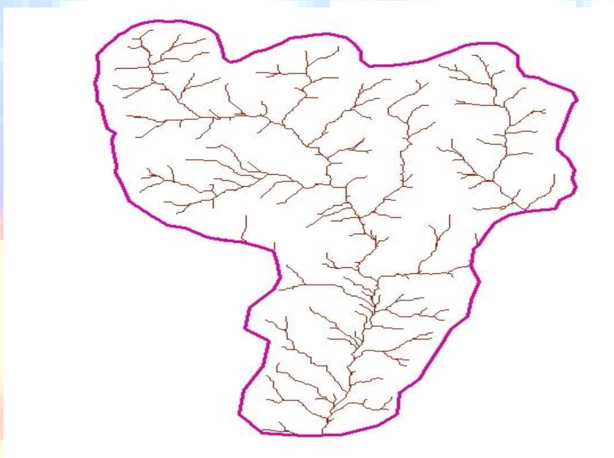

Figure 2 Drainage Network of Gagas River Valley Watershed

Stream Order: Stream Order has been demarcated on basis of Strahler (1964) stream ordering system. The number of streams gradually decreases as the stream order increases. The study area has been designated as 4th order basin with 168 number of streams. Less number of streams shows the presence of a mature topography and larger number show that topography is still undergoing erosion.

Stream Length: Horton's law of stream length states that geometrical similarity is maintained in basins of increasing orders. The length of stream is maximum in case of first order. The lengths of I, II, III and IVth order streams are 48.37, 28.10, 15.46 and 11.31 respectively with a total of 103.24 km. Gregory and Walling (1973).

Stream Length Ratio: The stream length ratio is the ratio between the lengths of streams in a given order to the total length of streams in the next order. It varies as 1.73, 1.81 and 1.37 for 1 /2, 2/3 and 3 /4 stream length ratios, respectively and strongly dependent on topography and slope and has important relationship with the surface flow discharge and the erosion stage of the basin.

Stream Frequency: According to Horton (1945) stream frequency is defined as the ratio of total number of stream segments of all the orders in the basin to the total area of the basin. The stream frequency is found to be 2.65/km^2 for the study area. The stream frequency is dependent on the rainfall and temperature of the region.

Basin Length: According to Gregory and Walling (1973) basin length is the longest length of the basin from the head water to the point of confluence. The Gagas River originates in the Pandukholi forests and its length is13.60 km to the outlet.

Form Factor: Form factor is defined as the ratio of the basin area to the square of the basin length. Long narrow basins have larger lengths and hence smaller form factors. Circular basins have intermediate form factors, which are close to one. Short wide basins have largest form factors. The study area has a form factor 0.34 which come in category of long narrow basin.

Elongation Ratio: It is defined as the ratio of the diameter of a circle with the same area as the basin to the basin length. The elongation ratio of the study area is 0.66. It depends on the thrusting and faulting forces in the basin.

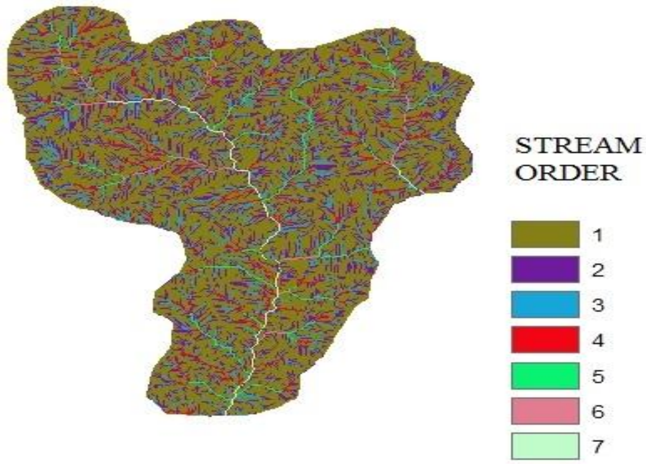

Figure 3 Stream order map of Gagas River Valley Watershed

Circulatory Ratio: It is defined as the ratio of basin area to the area of circle having the same perimeter as the basin. This is influenced by the litho logical characteristics of the basin. The low, medium and high values of circulatory ratio are indication of the young, mature and old stages of the life cycle of the tributary basins. Circulatory Ratio of the study area is 0.47 which falls in the category of medium stage of life cycle of the basin.

Relief Ratio: It is defined as the ratio between relief (vertical distance between lowest i.e. outlet and highest points in the watershed) and the distance over which the relief is measured. The relief ratio (R_h) was found to be 0.11. The R_h normally increased with the decreasing drainage area and size of the watersheds for a given drainage basin (Gottschalk, 1964). It measures overall steepness of watershed and also considered as an indicator for the intensity of erosion process occurring in the watershed.

Ruggedness Number (R_n): Ruggedness number (R_n) is a product of relief (H) and drainage density (D) in the same unit. The areas of low relief but high drainage density are regarded as ruggedly textured and areas of higher relief have lesser dissection. Rn was found to be 3.67 km.

This number represents that if drainage density is increased, keeping relief as constant then average horizontal distance from drainage divide to the adjacent channel is reduced. On the other hand, if relief increases by keeping drainage density as constant, the elevation difference between the drainage divide and adjacent channel will increase.

Slope: Due to rugged nature of terrain the area shows a high relief ratio The outlet is having a IVth order stream, so it is a potential site for construction of check dams and recharge structures. From DEM, It was found that elevation varies from 1226 to 2750 m (Figure 1). Slope of a region and degree and direction of the slope are vital parameters in deciding suitable land use it can support. The slope categories in the study area are shown in Figure 4. Morphometric parameters coupled with integrated thematic map of drainage density and slope can help in decision making process for water resources management.

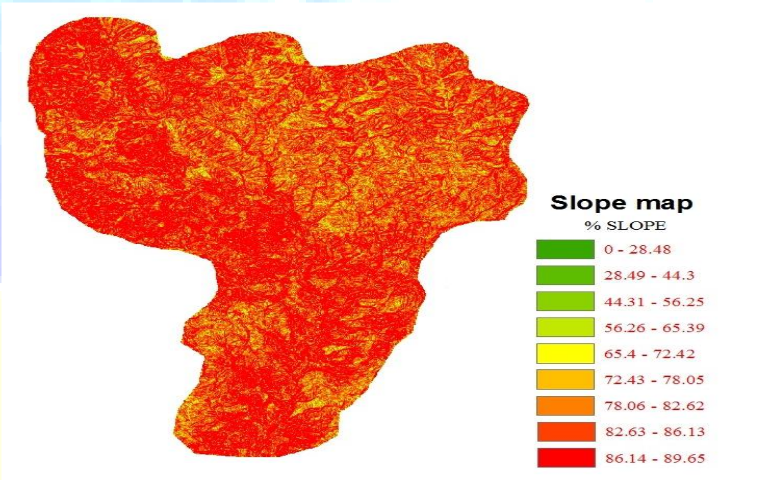

Figure 4 Slope map of Gagas River Valley Watershed

Inter-relationship between morphological parameters

Linear Aspect: The linear aspects of the channel system are stream order (U), stream length (L_u), stream length ratio, bifurcation ratio, basin length, basin perimeter. Classification of streams is important to index the size and scale of watershed. The number of streams of various orders in watershed was counted and their lengths from mouth to drainage divide were measured with the help of GIS software. The statistics of drainage network of the watershed is shown in table 1. After analysis of the drainage network, it was found that Gagas river valley watershed is of 4th

order and drainage pattern is dendrite. The total length of stream segments of 1st, 2nd 3rd and 4th order streams were found to be 48.368,28.009, 15.457 and 11.31 km respectively. It also showed maximum total length of stream segments for 1st order streams (Table 1). This is satisfying Horton's second law. The stream length ratio (R_L) was estimated as 1.73, 1.81 and 1.37 for II/I, III/II and IV/III orders, respectively. The increasing trend in R_L from lower order to higher order indicates matured geomorphic stage and change from one order to another order indicated late youth stage of geomorphic development of streams (Singh and Singh, 1997).

The natural drainage system of watershed was classified according to Strahler's system of stream ordering and the main stream was found as of 4th order. It shows that frequency in case of 1st order is 129 and for the 2nd and 3rd order, it is 33 and 5 respectively. It is also noticed that there is decrease in stream frequency with the increase in stream order (Table 1). This satisfies the Horton's law of stream numbers. This stream order is used in the study of other characteristics of watershed. Horton (1945) considered the bifurcation ratio (R_b) as an index of relief and dissections. The value of R_b normally varies 2 to 5 and tends to be more for elongated basins (Beaumont, 1975). It is a useful index for hydrograph shape for watersheds similar in all other respects. In the present study, R_b was estimated of 3.91, 6.6 and 5 for I/II, II/III and III/IV orders, respectively with an average of 5.17. The high value of R_b indicates structural complexity and low permeability (Pankaj, 2009). It also indicates that the value of R_b is not same from one order to next order. The higher value of R_b indicated strong structural control on the drainage pattern. This shows its usefulness for hydrograph shape for watersheds similar in other respect. An elongated watershed has higher bifurcation ratio than normal and approximately circular watershed (Singh, 2003). It is indicated that the watershed chosen for the study is not circular in shape and would produce delayed peak flow. The basin length and basin perimeter were found to be 13.6 and 41.2 km respectively. Surface runoff follows a system of down slope flow path from the basin perimeter to the nearest channel. Horton (1945) defined length of over land flow as the length, projected to the horizontal, of non channel flow from a point on the drainage divide to a point on the adjacent stream channel.

Areal Aspect: Areal aspect of morphometric study of the watershed includes the description of arrangement of areal elements, law of stream area, relationship between stream area and stream length, relation of area to the discharge, basin shape (form factor, circulatory ratio, and elongation ratio), drainage density etc. Drainage area represents the area enclosed within the boundary of the watershed divide. It is probably the single most important characteristic. The drainage density was found to be 1.62 km/km^2. Lower drainage density of the basin indicates towards coarse drainage pattern and humid climate of the study area. The coarse texture gives more time for overland flow and hence to ground water recharge. A low value of the drainage density indicates a relatively low density of streams and thus a slow stream response (Singh, 2004). Drainage texture is one of the important concepts of geomorphology which means the relative spacing of drainage lines. Drainage lines are numerous over impermeable areas than permeable areas. Horton defined drainage texture is the total number of stream segments of all orders per perimeter of that area. He recognized infiltration capacity as the single important factor which influences drainage texture. It includes drainage density and stream frequency. In the present study, drainage texture ratio is 4.3 which indicate the drainage is of coarse texture (Smith, 1950).

The constant of channel maintenance (C) was found to be 0.62 km which is the reciprocal of drainage density. It indicates that magnitude of surface area of watershed needed to sustain unit length of stream segment. The value of C indicated that Gagas river valley watershed is under the influence of high structural disturbance, low permeability, steep to very steep slopes and high surface runoff. Horton (1932) introduced stream frequency or channel frequency (F_s) which is ratio of the number of stream segments of all orders per unit area of the watershed. The stream frequency was found to be 2.65. The low value of F_s indicated the low relief and low infiltration capacity of the bed rocks pointing towards the decrease in stream population which indicates erodibility of the rock surface as moderate to high nature (Pankaj, 2009). The circulatory ratio (R_c) was estimated to be 0.47 whereas, form factor and elongation ratio were found to be 0.34 and 0.66 respectively. The value of R_c is influenced by the length and frequency of streams, geological structures, land use/land cover and slope of the basin. Smaller the value of form factor more will be elongated basin and high peak flows of shorter durations (Javed, 2009). Elongation ratio of 0.64 confirmed that the study area is having high relief and steep ground slope and having elongated shape (<0.7). The drainage area is characterized by high to moderate relief and the drainage system is structurally controlled (Pankaj, 2009). A circular basin is more efficient in the discharge of runoff than that of an elongated basin (Singh and Singh, 1997).

Relief Aspect: The relief ratio (R_h) was found to be 0.11. The R_h normally increased with the decreasing drainage area and size of the watersheds for a given drainage basin (Gottschalk, 1964). It measures overall steepness of watershed and also considered as an indicator for the intensity of erosion process occurring in the watershed. The high value of relief ratio is characteristics of hilly region. Strahler (1957) defined a dimensionless number, called ruggedness number (R_n), as a product of relief (H) and drainage density (D) in the same unit. The value of total relief (H) was found to be 1.524. The areas of low relief but high drainage density are regarded as ruggedly textured as areas of higher relief having less density. In the present study, R_n was found to be 2.52 km. This number represents that if drainage density is increased, keeping relief as constant then average horizontal distance from drainage divide to the adjacent channel is reduced. On the other hand, if relief increases by keeping drainage density as constant, the elevation difference between the drainage divide and adjacent channel will increase.

DEM and Slope analysis: From DEM, it was found that elevation varies from 1226 to 2750 m (Figure 1). Slope of a region are vital parameters in deciding suitable land use as the degree and direction of the slope to decide the land use that it can support (Figure 4). The dominant slope categories in the Gagas river valley watershed were moderately steep slope followed by steep sloping. It was also noticed that slope of major area of agricultural land varied from very gently sloping to moderately sloping, whereas forest areas were mainly located on higher slope. (Figure 4). Dense forest was observed mainly in northern aspects and at higher altitude whereas, major agricultural activities were taken up mainly in southern aspects The cultivation had also been extended even to steep slope.

Morphometric parameters coupled with integrated thematic map of drainage density, and slope can help in decision making process for water resources management. Additional surface water resources can be developed by constructing different water harvesting structures under different land use/cover units and also by increasing the storage capacity of the existing major tanks within the watershed area. Apart from agriculture, care should also be taken in the waste land area to reduce the runoff rate and conserve the soil and water within the watershed. Small water harvesting structures, such as percolation tanks may be constructed to bring the waste land under cultivation and to improve the ground water recharge. Farm ponds can be constructed in areas having flat topography and locations having low soil permeability.

Summary and conclusion

The morphometric characterization of Gagas river valley watershed was achieved using Remote Sensing and GIS techniques for determining the linear aspects such as stream order, bifurcation ratio, stream length and areal aspects such as drainage density, drainage texture and relief aspects like total relief, relative relief, relief ratio and ruggedness number. The morphometric study of the Gagas river valley watershed shows their relative characteristics with respect to hydrologic response of the watershed. Morphometric parameters coupled with integrated thematic map of drainage density and slope can help in decision making process for water resources management.

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