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# Assessment of morphometric parameters of Khulgad watershed using geographical information system and remote sensing

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■ **ABSTRACT :** Khulgad watershed is the constituent of the Kosi river basin and is located to the west of the Almora town in the Hawalbagh Development Block of Almora district in the Uttarakhand. The watershed is bounded within 79°32'20.71" to 79°37'11.19" E longitude and 29°34'30.20" to 29°38'48.03"N latitude, covering an area of 32.57 km$^2$ and having cool temperature climate with an annual average temperature of 20°C. To achieve the Morphometric analysis, toposheet No. 63 C/2 Survey of India (SOI) in 1:50000 scales are procured and the boundary line is extracted by joining the ridge points. This will serve as area of interest for preparing base map and thematic maps. The drainage map is prepared with the help of geographical information system tool and morphometric parameters such as linear, aerial and relief aspects of the watershed have been determined. These dimensionless and dimensional parametric values are interpreted to understand the watershed characteristics. From the drainage map of the study area dendritic drainage pattern is identified. Strahler (1964) stream ordering method is used for stream ordering of the watershed. The mean bifurcation ratio of the watershed is 3.49.

■ **KEY WORDS :** Khulgad watershed, GIS, Remote sensing, Morphometric parameters (linear, areal, relief)

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Watershed is a natural laboratory of hydrology. It may be defined as the area that drains the entire precipitation into a particular stream outlet. In other word it is the catchment's area from which all precipitation *i.e.* rainfall as well as snow drain into a common stream.

Ridges and hills that separate two watersheds are called the drainage divide. The watershed consists of surface water such as lakes, streams, reservoirs, and wetlands such as and all the underlying ground water. Larger watersheds contain many smaller watersheds. It all depends on the outflow point; all of the land that drains water to the outflow point is the watershed for that outflow location. Hydrological parameters such as slope, aspect, flow direction, flow accumulation can play a decisive role in watershed management.

In emerging technology paradigm, "Geographical Information System (GIS)" has emerged as powerful tool which has potential to organize complex spatial environment with tabular relationships. The emphasis is on developing digital spatial database, using the data sets derived from precise navigation and imaging satellites, aircrafts, digitization of maps and transactional database.

Remote Sensing (RS) is the art and science of making measurements of the earth using sensors on airplanes or satellites. These sensors collect data in the form of images and provide specialized capabilities for manipulating, analysing, and visualizing those images. Remote sensed imagery is integrated within a GIS.

A Geographic Information System (GIS) is a computer-based tool for mapping and analysing feature events on earth. GIS technology integrates common database operations, such as query and statistical analysis, with maps. GIS manages location-based information and provides tools for display and analysis of various statistics, including population characteristics, economic development opportunities, and vegetation types. Additionally, it provides tools to visualize, query, and overlay those databases in ways not possible with traditional spread sheets. These abilities distinguish GIS from other information systems, and make it valuable to a wide range of public and private enterprises for explaining events, predicting outcomes, and planning strategies. Geographic information systems (GIS) technology has played critical roles in all aspects of watershed management, from assessing watershed conditions through modelling impacts of human activities on water quality and to visualizing impacts of alternative management scenarios. The field and science of GIS have been transformed over the last two decades. Advancements in computer hardware and software, availability of large volumes of digital data, the standardization of GIS format sand languages, the increasing interoperability of software environments, the sophistication of geo-processing functions have increased the utility and demands for the GIS technology.

Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimensions of its landforms. Morphometric analysis brings out the basic characters on the geometrical and mechanical aspects of the river basin which in turn would be helpful in understanding the hydrology, sediment and evolution of landscapes in the basins. 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. A number of researchers have done morphometric analysis of various watersheds that have been devoted in the use of watershed management. Morphometric analysis using remote sensing and GIS techniques have been well demonstrated by some of the researchers (Nautiyal, 1994; Shrivastava, 1995; Shrivastava, 1997; Nag, 1998; Agarwal, 1998; Biswas *et al*., 1999; Sreedevi *et al*., 2001 and 2004; Vittala *et al*., 2004; Hlaing *et al.*, 2008; Pareta, 2011; Kanth and Hassan, 2012; Aravinda and Balakrishna, 2013; Manjare *et al.*, 2014; Kant, 2015 and Gopinath *et al.*, 2014). The morphometric analysis examines linear, relief and areal aspects of the drainage networks. Drainage characteristics have been studied using conventional methods (Horton, 1945; Miller, 1953 and Strahler, 1964)

In this study, an attempt has been made to obtain different parameters of morphometric characteristics of the Khulgad watershed located in the Hawalbagh Development Block of Almora district in Uttarakhand, using Arc-G.I.S v 9.3 software.

**Study area :**

The Khulgad watershed is the constituent of the Kosi river basin and is located to the west of the Almora town in the Hawalbagh Development Block of Almora district in the Uttarakhand. The watershed is bounded within 79°32'20.71" to 79°37'11.19"E longitude and 29°34'30.20" to 29°38'48.03"N latitude, covering an area of 32.57 km². Almora is one of mountainous districts of Uttarakhand state. The elevation varies from 1082 m to

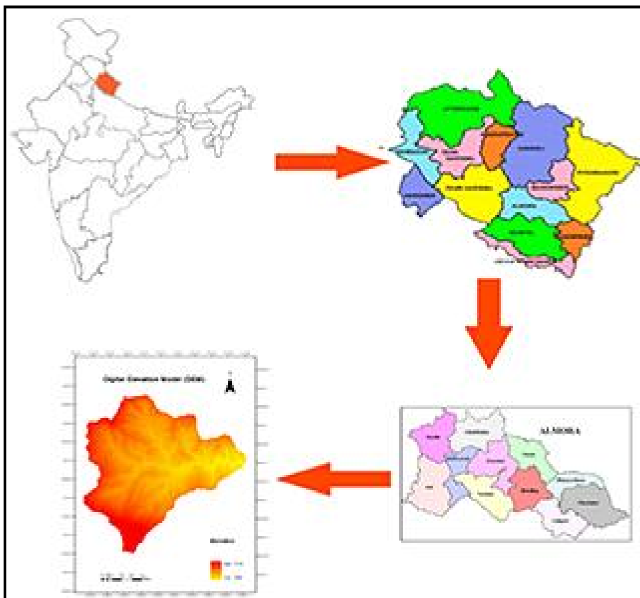

**Fig. A : Map of study area**

2140 m above mean sea level. Almora district is bounded by Bageshwar in the North, Pithoragarh district in the East, Nainital district in the south and Dehradun in the west. Khulgad is a tributary of the Kosi River which joins the Western Ramganga in the plains of Uttar Pradesh. A large part of the watershed has moderately shallow soil where the soil depth varies between 25 and 50 cm. The annual maximum, minimum and average temperature of the Khulgad Watershed stand at 23.9°C, 12.4°C and 18.5°C, respectively. The watershed receives about 913 mm annual rainfall. Fig. A shows the map of study area.

## METHODOLOGY

Survey of India Toposheet No. 63 C/2 of the scale 1: 50,000, was used for the analysis of the study area, classification and watershed delineation. The study area was scanned (*tiff format*), translated to pixel format using utility option of the software and geo-referenced using Arc-G.I.S v 9.3 software. For the purpose of geo-referencing, the positions of longitude and latitude of some points were recorded. The geo-referenced map was used to delineate the boundary of the watershed.

Geo-coded satellite data were downloded from NRSC BHUVAN web site, details of which are as follows: Aster Digital Elevation Model (DEM) having spatial resolution of 30 m for extraction of, aspects, drainage network and elevation information of watershed. The satellite imagery of CARTOSAT at 10 per cent cloud cover was downloded from the same website. Before processing of any digital data, it was reprojected to UTM projection using projection and transformation option of the software. Then, the area of interest was masked with watershed boundry using clipping / subsetting facilities of the software.

Base maps for the study area were prepared using Survey of India (SOI) toposheet No. 63 C/2 of 1: 50000 scale and Digital Elevation Model (DEM) (Fig. C) downloaded from NRSC BHUWAN website with the use of Arc-G.I.S v 9.3.

Different basic thematic maps were prepared using surface option of spatial analysis tool of Arc-G.I.S v9.3 software. Thematic maps include DEM classes map, drainage map (Fig. B), slope map (Fig. D) and aspect map (Fig. E) of watershed from toposheet and imagery.

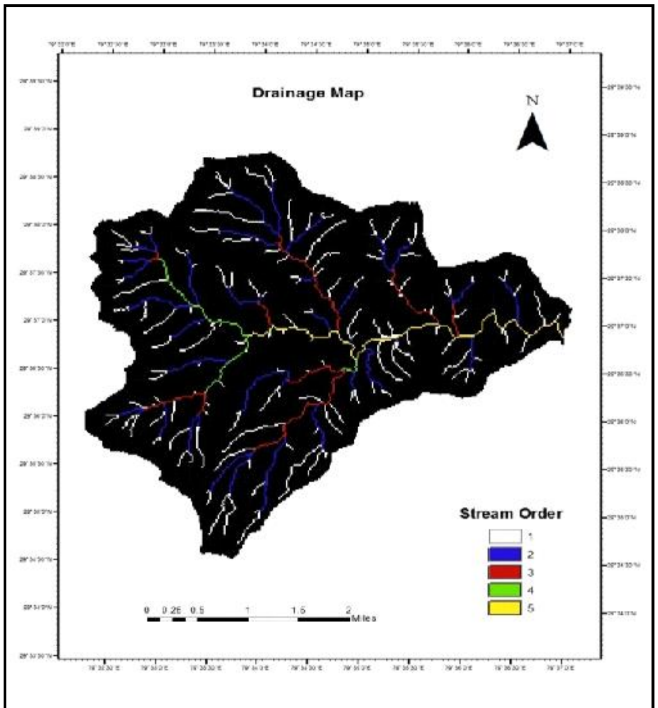


Fig. B : Drainage map of Khulgad watershed

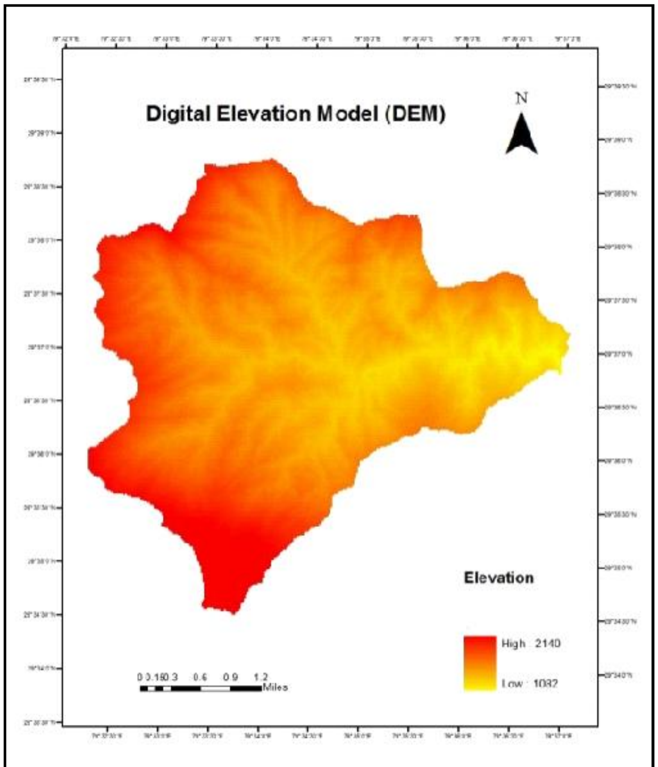


Fig. C : Digital elevation model of Khulgad watershed

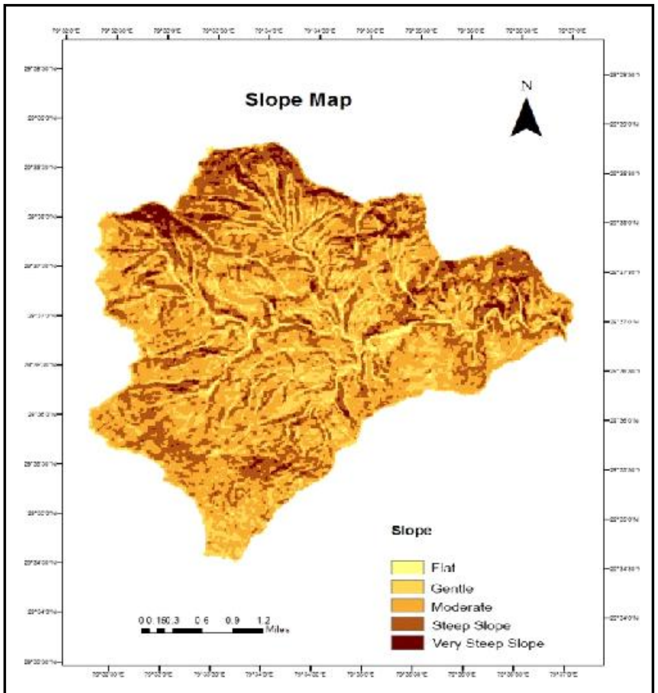


**Fig. D : Slope map of Khulgad watershed**

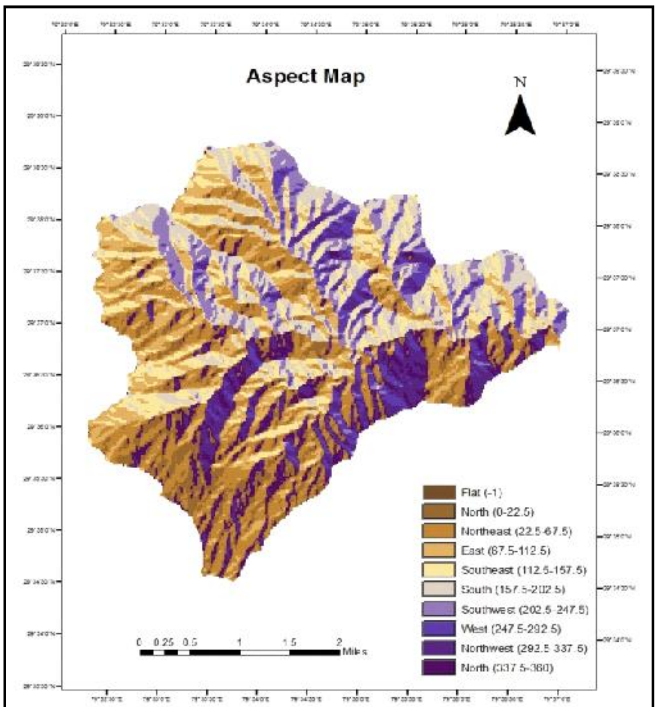


**Fig. E : Aspect map of Khulgad watershed**

## RESULTS AND DISCUSSION

### Morphometric analysis :

The term Morphometry is derived from a Greek word, where “morpho” means earth and “metry” means measurement, so together it is measurement of earth features. This is an important factor for planning any watershed development.

Morphometric analysis also provides description of physical characteristics of the watershed which are useful for environmental studies, such as in the areas of land use planning, terrain elevation, soil conservation and soil erosion.

Morphometric analysis for the present study is grouped into three classes such as linear aspects, areal aspects and relief aspects.

### Linear aspects :

In linear aspects, the parameters representing length were considered.

*Number of streams of given orders ($N_u$):*

The quantity $N_u$ represents total number of all streams, counted as the stream segments, having the order ‘u’ present in the watershed.

*Bifurcation ratio ($R_b$):*

Bifurcation ratio characteristically ranges between 3 and 5 for watersheds in which the geologic structures do not distort the drainage pattern. The theoretical minimum possible value of 2 is rarely approached under natural conditions. Because the bifurcation ratio is a dimensionless parameter, and because drainage systems in homogeneous materials tend to display geometrical similarity, it is not surprising that the ratio shows only a small variation from region to region (Aravinda and Balakrishna, 2013).The Rb was computed using Horton’s law of stream numbers which stated, “The number of stream segments of each order form an inverse geometric sequence with order number”.

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

*Length of main channel ($L_m$):*

It is the length along the longest water course from the outflow point of designated sub basin to the upper limit of the catchment boundary.

*Mean stream length ($L_{sm}$):*

It is a characteristic property related to the drainage network components and its associated basin surfaces

(Strahler, 1964). It is the total length of all streams of order 'u' in a given drainage basin divided by number of streams of order 'u'.

$$L_{sm} = \frac{\sum_{i=1}^{N_u} L_i}{N_u}$$

*Stream length ($L_u$):*

It is one of the most significant hydrological features of basin as it reveals surface runoff characteristics streams of relatively smaller lengths are characteristics of area with larger slopes and finer texture. Longer length of streams is generally indicative of flatter gradients. Generally, the total length of stream segment is maximum in first order streams and decreases as the stream order increases.

*Stream length ratio ($R_L$):*

This was estimated as the ratio of mean stream length of order 'u' to the mean stream segment length of order (u-1) expressed mathematically as:

$$R_L = \frac{\bar{L}_u}{\bar{L}_{u-1}}$$

*Length of overland flow ($L_g$):*

Horton (1932) defined length of overland flow $L_g$ as the length of flow path, projected to the horizontal, non-channel flow from a point on the drainage divide to a point on the adjacent stream channel. It is approximately equal to one half the reciprocal of the drainage density. The shorter the length of overland flow, the quicker the surface runoff from the streams.

$$L_g = \frac{1}{2D}$$

*Basin length ($L_b$):*

It was calculated as the distance between outlet and farthest point on the basin boundary.

*Basin perimeter (P):*

It was taken as the length of watershed divide which surrounds the basin.

*Fineness ratio ($R_{fn}$):*

It was considered as the ratio of channel length to the length of the basin perimeter as defined by Melton (1957).

$$R_{fn} = \frac{L_m}{P}$$

**Areal aspects :**

In areal aspects different morphologic parameters were considered which represented the area. Some of them are given below in brief:

*Drainage area (A):*

It is represented by the area enclosed within the boundary of the watershed divide. It is the most important characteristic for hydrologic design.

*Drainage density (D):*

It indicates the closeness of spacing of channels (Horton, 1932). In the areas of higher drainage density the infiltration will be less and surface runoff will be more. Low drainage density generally results in the areas of

**Table 1 : Linear morphometric parameters for Khulgad watershed**

| Stream order | Number of streams ($N_u$) | Stream length in km ($L_u$) | Mean stream length in km | Stream length ration ($R_L$) | | | | Bifurcation ratio ($R_b$) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | II/I | III/II | IV/III | V/IV | I/II | II/III | III/IV | IV/V |
| 1 | 2 | 3 | 4 | 5 | | | | 6 | | | |
| I | 147 | 52.14 | 0.35 | 1.94 | 1.47 | 1.40 | 5.17 | 3.86 | 3.8 | 3.33 | 3 |
| II | 38 | 25.84 | 0.68 | | | | | | | | |
| III | 10 | 10.72 | 1.0 | | | | | | | | |
| IV | 3 | 4.21 | 1.40 | | | | | | | | |
| V | 1 | 7.24 | 7.24 | | | | | | | | |

**Table 2 : Linear morphometric parameters of Khulgad watershed**

| Mean bifurcation ration ($R_{bm}$) | Length of the overland flow ($L_g$) in km | Basin length ($L_b$) in km | Basin perimeter (P) in km | Fineness ratio ($R_{fn}$) | Length of main channel ($L_m$) in km |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| 3.49 | 0.16 | 8.91 | 35.85 | 0.29 | 10.64 |

highly resistant or permeable sub-soil material, sparse vegetation and mountainous relief. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture.

The drainage density was estimated as the ratio of total length of channels of all orders in the basin to the drainage area of the basin.

$$D = \frac{\sum_{i=1}^{w}\sum_{j=1}^{N_i} L_{ij}}{A}$$

*Constant of channel maintenance (C):*

It was calculated as the ratio between the area of the drainage basin and total length of all the channels expressed as square meter per meter. It was also equal to reciprocal of drainage density.

$$C = \frac{1}{D}$$

*Stream frequency ($F_s$):*

It was calculated as the number of streams per unit area. Melton (1957) gave following relationship between drainage density and stream frequency:

$$Fs = 0.694D^2$$

where D is the drainage density

*Circulatory ratio ($R_c$):*

It is the ratio between the area of watershed to the area of circle having the same circumference as the perimeter of the watershed (Miller, 1953). The value ranges from 0.2 to 0.8, greater the value more will be the circularity ratio. It is the significant ratio which indicates the stage of dissection in the study region.

$$R_C = \frac{A}{A_C}$$

*Elongation ratio ($R_e$):*

It is defined as the ratio between the diameter of a circle with the same area as the basin and basin length (Schumn, 1956).

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

*Form factor ($R_f$):*

For a perfect circular watershed the value of form factor would always be less than 0.7854 (Aravinda and Balakrishna, 2013). The watershed with higher form factor would normally be circular and have high peak flows for shorter duration, whereas elongated watershed with lower values of form factor have low peak flows for longer duration. The form factor is calculated as the ratio of basin area (A) to the square of basin length ($L_b$) as defined by Horton (1932).

$$R_f = \frac{A}{L_b^{\,2}}$$

*Unity shape factor ($R_u$):*

It was estimated as ratio of the basin length, $L_b$ to the square root of the basin area.

$$R_u = \frac{L_b}{\sqrt{A_w}}$$

*Watershed shape factor ($W_s$):*

The watershed shape factor was estimated as the ratio of main stream length, $L_m$ to the diameter, $D_c$ of a circle having the same area as that of watershed.

$$W_s = \frac{L_m}{D_C}$$

*Drainage texture ratio (T) :*

It is the relative spacing of drainage lines in the watershed and one of the important concept of geomorphology. Drainage lines are numerous over impermeable areas than permeable areas. Drainage texture ratio (T) was estimated as the ratio of total number of stream segments ($N_u$) of all orders to the perimeter (P) of that area Horton (1945). He recognized infiltration capacity as the single important factor which influences the drainage texture.

$$T = \frac{N_u}{P}$$

## Relief aspects :

In basin relief aspects, the parameters evaluated are given below in brief.

*Total relief (H):*

The basin relief or total relief is the maximum vertical distance between the lowest (outlet) and the highest (divide) points in the watershed. Schumn (1956) measured it along the longest dimension of the basin parallel to the principle drainage line, and Strahler (1952 and 1964) obtained it by

**Table 3 : Areal morphometric parameters for Khulgad watershed**

| Sr. No. | Parameters | Obtained values |
|---|---|---|
| 1. | Drainage/basin area (A) in km$^2$ | 32.57 |
| 2. | Drainage density ($D_d$) in km/km$^2$ | 3.07 |
| 3. | Constant of channel maintenance (C) | 0.32 |
| 4. | Stream frequency ($F_s$) per km$^2$ | 6.56 |
| 5. | Circulatory ratio ($R_c$) | 0.31 |
| 6. | Elongation ratio ($R_c$) | 0.72 |
| 7. | Form factor ($R_f$) | 0.41 |
| 8. | Unity shape factor ($R_u$) | 1.56 |
| 9. | Watershed shape factor ($W_s$) | 1.65 |
| 10. | Drainage texture ratio(T) | 5.52 |

**Table 4 : Relief morphometric parameters of Khulgad watershed**

| Sr. No. | Parameters | Obtained values |
|---|---|---|
| 1. | Total relief (H) in km | 1.05 |
| 2. | Relief ratio ($R_h$) | 0.11 |
| 3. | Relative relief ($R_p$) | 0.02 |
| 4. | Ruggedness No. ($R_n$) | 3.25 |

determining the mean height of the entire watershed divide above the outlet. Relief is an indicative of the potential energy of a given watershed above a specified datum available to move water and sediment down slope.

Relief ratio ($R_h$):

It is estimated as the ratio between the relief and the distance over which the relief was measured. It measures the overall steepness of the watershed and can be related to its hydrologic characteristics.

Relative relief ($R_p$):

It was estimated as the ratio of basin relief (H) to the length of the perimeter (P) as defined by Melton (1957). It is an indicator of general steepness of the basin from summit to mouth.

$$R_p \, Z \, \frac{H}{P}$$

Ruggedness number ($R_n$):

Melton (1957) and 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. It combined slope and length characteristics in one expression. The areas of low relief but high drainage density were as ruggedly textured as areas of higher relief having less dissection. The ruggedness number was estimated using the following formula :

$$R_n = H \times D$$

## Conclusion :

From the study, it is observed that the basin forms the dendritic pattern of drainage. Average bifurcation ratio is calculated for the watershed as 3.49. The value of Rb in the present case indicates that watershed has suffered less structural disturbance and the watershed may be regarded as the elongated one. Drainage density reflects land use and affects the infiltration and the watershed response time between the precipitation and discharge. For the present study the drainage density is evaluated to be 3.07 km/sq.km which indicates that the area has drainage texture.

The circularity ratio for the watershed is 0.31, which indicates youth nature of topography. Its low, medium and high values area correlated with youth, mature and old stage of watershed of the region. The elongation ratio is 0.72, which indicates that the watershed is elongated. The stream frequency obtained for the study area is 6.56 No./Sq.km. On the whole, the watershed has a total relief of 1.05 Km. The relief aspect shows that the watershed has steepslope for runoff.

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## ■ REFERENCES

**Agarwal, C.S. (1998).** Study of drainage pattern through aerial data in Naugarh area of Varanasi district, U.P. J. *Indian Soc. Rem. Sens.,* **26**(4): 169-175.

**Aravinda, P.T. and Balakrishna, H.B. (2013).** Morphometric analysis of Vrishabhavathi Watershed using Remote Sensing and GIS. *Internat. J. Res. Engg. & Technol.,* **2** (13) : 514-522.

**Biswas, S., Sudhakar, S. and Desai, V.R. (1999).** Prioritization of sub watersheds based on morphometric analysis of drainage basin - A remote sensing and GIS approach. *J. Indian Soc. Rem. Sens.,* **27**(3): 155–166.

**Cruise and Miller (1993).** Hydrologic modelling with remotely sensed databases. *Water Resources Bulletin*, **29**(6): 997-1002.

**Gopinath, G., Ambili, G.K., Gregory, S.J. and Anusha, C.K. (2014).** Drought risk mapping of south-western state in theIndian peninsula - A web based application *J. Environ. Mgmt.* pp. 1-7. http://dx.doi.org/10.1016/j.jenvman.2014.12.040.

**Hlaing, T.K., Haruyama, S. and Aye, M.M. (2008).** Using GIS-based distributed soil loss modeling and morphometric analysis to prioritize watershed for soil conservation in Bago river basin of Lower Myanmar. *Front Earth Sci China*, **2** : 465–478.

**Horton, R.E (1932).** Drainage basin characterist ics. *Am. Geophys. Union*, **13** : 350 – 360.

**Horton, R.E. (1945).** Erosional development of streams and their drainage basins hydrophysical approach to quantitative morphology. *Bull. Geol. Soc. Am.*, **56** : 275370.

**Kant, Shri (2015).** Morphomeetric analysis of Sonar sub basin using SRTM data,GIS, *African J. Agric. Res.*, **10**(12):1401-1406.

**Kanth, T. A. and Hassan, Z. (2012).** Morphometric analysis and prioritization watersheds for soil and water resource management In Wular Catchment using Geo-Spatial Tools. *Internat. J. Geology, Earth & Environ. Sci.,* **2**(1): 30-41.

**Manjare, B.S., Padhye, M.A. and Girhe, S.S. (2014).** Morphometric Analysis of a Lower Wardha River sub basin of Maharashtra, India using ASTER DEM Data and GIS. In :15th Esri India User Conference 2014.

**Martin, D. and Morgan (1984).** Integrated approach of using remote sensing and GIS to study watershed prioritization and productivity. *J. Indian Soc. Remote Sensing,* **35**(1): 321-330.

**Melton, M.A. (1957).** An analysis of the relations among elements of climate, surface properties and geomorphology. Proj. NR 389-042, Tech. Rep. 11, Columbia University, Department of Geology, ONR, NEW YORK, U.S.A.

**Miller, V.C. (1953).** A quantitative geomorphic study of drainage Basin characteristics in the Clinch Mountain area, Virginia and Tennessee. Technical report, 3, Office of Naval Research, Department of Geology, Columbia University, NEW YORK, U.S.A.

**Nag, S.K. (1998).** Morphometric analysis using remote sensing techniques in the Chaka sub-purulia district, West Bengal." *J. Indian. Soc. Rem. Sens*., **26** : 69–76.

**Nautiyal, M.D. (1994).** Morphometric analysis of drainage basin using aerial photographs, a case study of Khairkuli basin, district Dehradun.U.P. *J. Indian Soc. Rem. Sens.,* **22**(4):251-261.

**Pareta, K (2011).** Geo-Environmental and geo-hydrological study of Rajghat Dam, Sagar (Madhya Pradesh) using Remote Sensing Techniques. *Internat. J. Scient. & Engg. Res.,* **2**(8) : 1-8.

**Rawat, J.S. (2010).** Database management system for Khulgad Watershed, Kumaun Himalaya, Uttarakhand, India, *Curr. Sci.*, **98** (10) : 1340-1348.

**Sreedevi, P.D., Srinivasulu, S. and Raju, K.K. (2001).** Hydrogeomorphological and groundwater prospects of the Pageru river basin by using remote sensing data. *Environ. Geol.,* **40** :1919–1924.

**Sreedevi, P.D., Subrahmanyam, K. and Ahmed, S. (2004).** The significant of morphometric analysis for obtaining groundwater potential zones in a structurally controlled terrain. *Environ. Geology,* **47**:412-420.

**Srivastava, V.K. and Mitra, D. (1995).** Study of drainage pattern of Raniganj Coalfield (Burdwan District) as observed on Landsat TM / IRS LISS II imagery, *J. Indian Society. Remo. Sens.*, **23**: 225-235.

**Shrivastava, V.K. (1997).** Study of drainage pattern of Jharia coalfield (Bihar), India, through remote sensing technology. *J. Indian Soc. Rem. Sens.,* **25**(1): 41-46.

**Strahler, AN. (1952).** Quantitative geomorphology of erosional landscape. In:19th International Geological Congress, Algiers, Section 1952; **33**:341-354.

**Strahler, A.N. (1957).** Quantitative analysis of watershed geomorphology. *Trans. Am. Geophys. Union.,* **38**: 913-920.

**Strahler, A.N. (1964).** Quantitative geomorphology of drainage basins and channel networks. In : *Handbook of Applied Hydrology* (ed. Chow, V. T.), McGraw Hill, USA.

**Vittaala, S., Srinivas, G., Gowda, S. and Honne, H. (2004).** Morphometric Analysis of Su-watershed in the Pavagada area of Tumkur district, South India using Remote Sensing and GIS technique. *J. Indian Soc. Rem. Sens.,* **32**(4): 351-362.