



Morphometric Analysis of Khag Micro-Watershed in North-West Himalayas of Kashmir Using GIS and Remote Sensing Techniques

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Authors' contributions

This work was carried out in collaboration among all authors. Author RY designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors MIB and FUR managed the analyses of the study. Authors SAB, RA, TRG and PKB managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Morphometric analysis is of vital importance in any hydrological research and is inevitable in development and management of watershed. Using the watershed as the main unit of morphometric characterization is the most logical choice, as well as geomorphological and hydrological processes take place within the drainage basin. A critical assessment and evaluation of morphometric parameters of Khag micro-watershed was accomplished through measurement of

relief, linear and aerial aspects using Geographical Information System (GIS). The watershed boundaries, aspect, slope, digital elevation model (DEM), profile graph of topography, drainage order and drainage density maps were generated for detailed study of micro-watershed using Shuttle Radar Topographic Mission (SRTM) data. The study area was designated as fourth order basin with the drainage area of 34.32 km² and shows dendritic drainage pattern. The total length, drainage density and mean bifurcation ratio (Rb) were found to be 38.84 km, 1.13km/km² and 1.73, respectively. The Khag micro-watershed showed the greater Rb value, which directs a strong structural control in the runoff pattern. A decrease in the stream frequency of flow was also observed with an increase in the order of flow. The shape parameters such as circulatory ratio, elongation ratio, length of over land flow, form factor and drainage texture of Khag micro-watershed were 0.42, 0.56, 0.43 km, 0.24 and 1.66, respectively. The Khag micro-watershed is elongated in shape and dendritic in drainage pattern. This can be attributed to the fact that the lithology and structural controls are more or less uniform. Relative relief and ruggedness number were 0.065 and 2.39 and are likely to subject the micro watershed to maximum soil erosion that demands, instantaneous soil conservation measure to be taken by watershed managers for its stability and sustainability. These studies are advantageous for the planning of rainwater harvesting and the management of the catchment area.

Keywords: Drainage morphometry; khag basin; DEM; SRTM data; watershed; geo-spatial techniques.

1. INTRODUCTION

The Micro-watersheds are ideal entities to oversee natural resources to mitigate the impact of natural hazards, and achieve sustainable management [1]. It is a natural hydrological unit, which accords surface runoff to a defined channel, river or stream and drain, at a specific point [2]. Watershed management is the technique of formation carrying out a course of action that embroils alteration in the natural system of micro-watershed to accomplish specified objectives [3]. It further entails proper use of water and land resources of a watershed for optimal production with least hazard to natural resources [4].

Morphometric analysis assists in quantifying and understanding the hydrological characters and their consequences constitute useful input for a comprehensive source of management planning. Morphometry is the quantitative exploration of the surface configuration of the Earth, shape and dimension of its landforms [5,6,7]. Morphometric analysis of the drainage network aims to acquire precise data of quantifiable features of a watershed. Basin morphometric over characterization requires preparation of drainage basin map; stream ordering; delineating and measuring the basin area, length of drainage channels and perimeter; detecting the drainage density and stream frequency; computing bifurcation ratio, form factor, texture ratio, elongation ratio, relief ratio and circulatory ratio; and

evaluating constant channel maintenance to understand the nature of drainage basins [8-15].

The remote sensing is a convenient technique for morphometric characterization as the satellite imagery provides a synoptic interpretation of a large extent and is very useful in the study of drainage basin morphometry. The GIS was used in evaluation of Linear, Areal and Relief morphometric parameters [16,17]. The GIS-based assessment by using SRTM data has given a precise, fast and an inexpensive way for analyzing hydrological systems [18-20]. The processed Digital Elevation Model was used successfully for creating the stream network and other supporting layers [21,22]. The digital elevation model (DEM) of the area was generated to assume the morphometric parameters. The Geographical Information System (GIS) and remote sensing (RS) techniques are ascertained to be proficient tools for morphometric characterization of Micro-watershed [23,24]. The positioning of water harvesting structures through GIS and remote sensing will save a lot of expenditures, labors and time particularly in the remote and inaccessible areas.

The present study was undertaken to calculate numerous parameters of morphometric characteristics through GIS and RS. The use of these geo-techniques helps to save a lot of time and other expenses over the traditional method of calculating morphometric parameters through topo-sheets, extensive surveys etc. The computed morphometric characteristics are used to predict characteristics such as

geomorphology, topography and other important characteristics of water shed that reflect its hydrological behavior, stability etc. and the conservation it might need for further stabilization for sustainable use.

2. MATERIALS AND METHODS

2.1 Study Area

The Khag micro-watershed lies between 74° 34' 24" - 74° 28' 23" E and 34° 03' 96" - 34° 01' 14" N with 34.32 km² geographical area (Fig.1) and 31.82 km in perimeter and lies between the Pir Panjal range in the north-west extremity of Budgam district almost at the confluence of Budgam, Baramulla and Pooch districts of Jammu and Kashmir. The elevation varied from 1640 to 3741 m above mean sea level (amsl). The predominant minerals noticed in the study area were lignite and lime stone in addition to slate stone. The climate of the study area is of the cool temperate type with high snowfall in the upper mountain area in winter with an annual precipitation of about 669.15 mm. Winter precipitation is most abundant in the form of snow. The SMCS (Soil Moisture Control Section) of Khag micro-watershed region falls under the udic moisture regime with mesic thermal regime. Scattered vegetation consisting of natural local grasses and naturally grown shrubs/hedges with majority of *Dactylis glomerata*, *Trifolium pretense*, *Cynodon dactylon* are found in the study area. The generally observed tree species in the study area are popular (*Populus alba*), Acacia species, Willow (*Salix alba*), Chinar (*Plantanu orientalis*), Kiker (*Rubinia pseudo-acacia*), plum, walnut, apple, mulberry trees, Pinus sp., Deodar (*Cedrus deodara*) etc. The total land area of Khag micro-watershed is 3432.00 ha.,out of which 1071.00 ha is suitable for agriculture. Owing to moderately steep slopes and lack of assured irrigation facilities, limited area of Khag micro-watershed is under paddy crop. Being predominantly rainfed, maize and oats (fodder crops) and pulses are grown in the major portion of the investigated area. Whereas, apple and walnut trees dot the horticultural landscape of the area. The hills of the area covered by moderately dense to dense forests.

2.2 Data Collection and Methodology

In this study, the base map of catchment area were prepared using Survey of India (SOI) toposheet 1961 (1:50,000 scale), and the digital elevation model (DEM) of Shuttle Radar

Topographic Mission (SRTM) of 30 m × 30 m resolution and LANDSAT-8 at 13 per cent cloud cover and data downloaded from <https://earthexplorer.usgs.gov> website was used to delineate the boundary and streams of the micro-watershed. The SRTM DEM is a fast and inexpensive way for regional hydrological and geomorphological analysis. The SRTM data were analysed in the ArcGIS ver.10.2 software. SRTM has created an unparalleled data set of global elevations that is easily accessible for modeling and environmental applications [25]. Based on the data prepared the aspect, slope and topographic digital elevation maps with contours for the Khag micro-watershed.

2.3 Morphometric Analysis

Morphometric analysis is the systematic description of watershed and stream geometry and measurements to understand the linear aspects of the drainage system, the surface aspects of the watershed, and the landform (relief) aspects of the stream system [26]. Morphometric analysis of a drainage system requires delineation of all existing streams. The stream delineation in present study was done digitally in ArcGIS version 10.2(GIS and Image analysis software) and the catchment boundary was also determined. Strahler's classification was used to obtain the stream ordering which showed that Khag micro-watershed, as a fourth-order hydrological unit. In morphometric analysis of Khag basin, the stream ordering (u) is the primary process. Stream ordering (u) is a kind of designation allotted to the streams prevailing within the watershed boundary. For stream ordering (u), Horton [27] and Strahler [28] introduced a method, in which drainage networks of basin are clearly delineated on the topographic map of the micro-watershed along with the denoting of the outlet.

There are numerous examples of latest studies which have followed Strahler's classification method for morphometric analysis of micro-watershed [22,24,29,30,15]. According to Strahler's classification system [26], frequency and length of the stream of many orders were first noted for the morphometric characterization. Then, primary morphometric parameters such as perimeter, drainage area, basin length and mean stream length were calculated (Table 1). Using these primary parameters, other morphometric parameters like over land flow, bifurcation ratio, mean bifurcation ratio, mean stream length, drainage density, circulatory ratio,

elongation ratio, constant of channel ruggedness number were assessed with the help of established mathematical equations (Table3) (Table 2). Relief-related parameters like total basin relief, relative relief, relief ratio and

Table 1. Formula’s adopted for computation of linear parameters

S. No	Parameter	Formula	Reference
1	Stream Order (O)	Hierarchical Rank	Strahler [26]
2	Stream Number (Nu)	Total numbers of streams	Horton [27]
3	Stream Length (L)	Length of stream	Horton [27]
4	Stream Length Ratio (RI)	RI = Lu/ Lu-1 Lu = total stream length of order ‘u’ Lu-1= Total stream length of its next order	Horton [27]
5	Mean Stream Length (Lsm)	Lsm = Lu/Nu Lu = Total stream length of order ‘u’ Nu= Total no. of stream segments of order ‘u’	Strahler [26]
6	Bifurcation Ratio (Rb)	Rb = Nu/ Nu+1 Nu = Total no. of stream segments of order ‘U’ Nu+1= Total no. of segments of next higher order.	Schumn [35] Schumm
7	Mean bifurcation Ratio (Rbm)	Rbm = Average of bifurcation ratios of all orders	Strahler [31]
8	Length of Overland Flow (Lg)	Lg = 1/D√2 Lg = Length of overland flow, D =Drainage Density	Schumn [35] Schumm
9	Basin perimeter	Length measured along the basin boundary	

Table 2. Formulae adopted for computation of aerial parameters

S. No.	Parameter	Formula	Reference
1	Drainage area (A)	Basin area	
2	Drainage Density (Dd)	D =Lu/A Lu = Total Stream Length of all orders, A = Area of the Basin (km ²)	Horton [32]
3	Drainage Texture (Dt)	Rt = Fs × D Fs= Stream Frequency, D = Drainage Density	Smith [36]
4	Circularity Ratio (Cr)	Cr= 4 x π x A/P ² π = ‘Pi’ value i.e. 3.14, A= area of the Basin P= Perimeter (km ²)	Miller [34]
5	Stream Frequency (Df)	Fs = Nu/A Nu =Total no. of streams of all orders, A = Area of the basin (km ²)	Horton [32]
6	Form Factor (Ff)	Ff = A/Lb ² A = Area of the Basin (km ²), Lb ² =Square of the basin Length	Horton [32]
7	Elongation ratio (Re)	Re = 2√(A/π /Lb) A = Area of the basin (km ²), π = ‘Pi’ value of i.e. 3.14 Lb = Basin Length	Horton [27]
8	Constant channel maintenance (C)	Inverse of drainage density 1÷ D	Horton [32]

Table 3. Formulae adopted for computation of relief parameters

S. No.	Parameter	Formula	Reference
1	Basin Relief (H)	Altitude difference between highest point and outlet in the basin.	Schumm [35]
2	Relief ratio (Rh)	Basin relief / distance between the highest point and outlet in the basin	Schumn [35]
3	Relative Relief (Rp)	Basin relief / Basin perimeter	Melton [37]
4	Ruggedness Number (Rn)	Product of the basin relief and drainage density	Melton [37] (1957)

Location Map of Study Area Showing Khag Micro-watershed

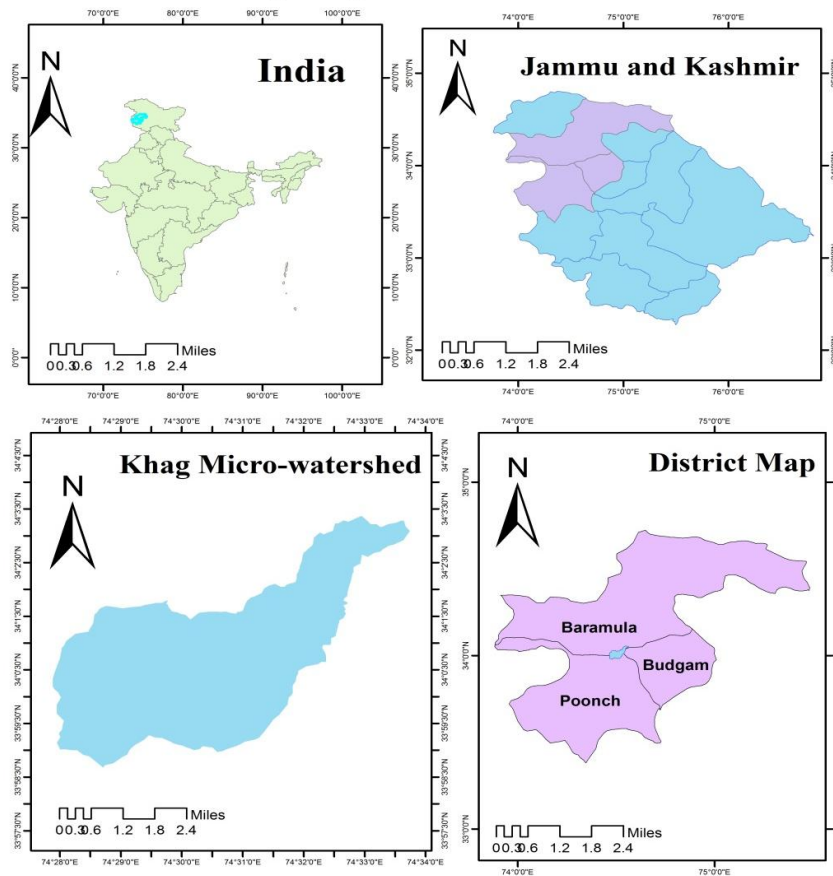


Fig. 1. Location map of study area

Drainage density (Dd) is assessed as the ratio of the total length of channels of all orders in a basin to the total drainage area of the watershed [32]. The lesser value of Dd shows that overland flow predominates in the watershed, while greater value of Dd shows that stream flow predominates in the watershed. Kumar et al. [33] observed that the Dd denotes channel

development in the watershed and the proximity of the distance between stream channels. The lithology, compactness of sub-surface, vegetation and topography, control the drainage density. Stream frequency (Fs) also known as channel frequency is calculated as the ratio of the total number of river segments of all orders in the unit area of the basin [32]. The circularity

ratio (Rc) is the ratio of the area of the catchment to the area of a circle of the same circumference as the basin [34]. The value of Rc ranges from 0.2 to 0.8 or ≤ 1 . A greater value (> 0.5) designates extra circularity and greater homogeneity in the geological material. A lesser value (< 0.5) directs an elongated shape of the catchment. Elongation ratio (Re) is demarcated as the ratio of the diameter of a circle with the same area as the basin divided by the maximum length of the basin [32,35]. In broad-spectrum, the value of Re ranges from 0.4 to 1.0 or ≤ 1.0 over a wide variety of climatic and geologic regimes. If the value of elongation ratio is close to 1.0 indicates a region with very low relief, while the value of Re is from 0.4 to 0.8 designates a region with very strong relief and steep ground slope. Drainage texture ratio (Rt) is estimated as the ratio of total number of stream segments (Nu) of all orders to the perimeter (P) of that basin area [27,36]. He recognized infiltration capacity as the only important factor which influencing the drainage texture. The basin relief or total relief is the maximum vertical distance between the lowest point of the basin area (outlet) and the highest points (divide). Schumn [35] measured it along the longest side of the basin parallel to the main drainage line, and Strahler [28,26] determined it by determining the average elevation of the entire basin above the drainage. Relief is an indication of the potential energy of a given catchment above a given datum available to move water and sediment downslope. Relief ratio is estimated as the ratio of the relief to the distance over which the relief was measured. It measures the overall steepness of the catchment and can be related to its hydrological characteristics [36]. The relative relief is estimated as the ratio of basin relief (H) to the length of the perimeter (P). It is an indicator of the overall slope of the basin from the top to the mouth [37]. Strahler [2,31] defined a unit less number, called ruggedness number (Rn) as the product of relief (H) and drainage density (Dd) of the same unit. It combined slope and length characteristics in one expression. The areas with low topography but high drainage density have the same rugged texture as areas with higher relief and less dissection.

3. RESULTS AND DISCUSSION

3.1 Thematic Maps of the Study Area

The digital elevation model (DEM) of Shuttle Radar Topographic Mission (SRTM) 30 m resolution downloaded from USGS website, was

used for the preparation of thematic maps as aspect map, slope map, drainage order map of the study area using spatial analyst tool of ArcGIS ver. 10.2.

3.2 Digital Elevation Model (DEM)

A Digital elevation model (DEM) is a three-dimensional representation of topographic elevations of a ground location. It is a raster that represents the elevations of the ground and objects. In addition to providing a source of elevation, the digital elevation model can be used for terrain information, flow pattern, identification of flood risk areas and determining accessibility. In the present study the DEM of Khag micro-watershed were generated using the spot heights. This was prepared in ArcGIS using the Spatial Analyst Tool Bar. The Digital Elevation Model of Khag micro-watershed is presented in Fig. 4 and Fig. 5, which were divided into five elevation classes and elevation of the entire micro-watershed varying from 1640 to 3741 m. The topographic variation across the micro-watershed is depicted in the Profile Graph Fig. 6 with maximum and minimum elevation. It observes that the greatest area of micro-watershed was under the elevation of 1640-2000 m., which occupied about 40.37 per cent of the study area, where agricultural activities were dominant. The remaining four classes of elevation mostly occupied by forest followed by barren land (Table 4).

3.3 Slope

Slope analysis is an important parameter in the study of the geomorphology of watershed development and is of great importance for morphological analysis. In turn, the slope element is controlled by climatic variability processes in areas with different resistance rocks [22,38,29]. The slope map were prepared from Digital Elevation Model of the study area using Slope tool (Arc Toolbox under Spatial analyst tools - >Surface feature) Arc GIS ver. 10.2. Slope gradient is identified as "the maximum rate of change in value from each cell to its neighbors" [39]. The slope map of Khag micro-watershed is shown in Fig. 3 and areal extent of various slope classes of the Khag micro-watershed presented in Table 5. The slope of the Khag micro-watershed has been classified into nine classes as per the Integrated Mission for Sustainable Development (IMSD) guidelines. It revealed that 57.51 percent area comes under nearly level to gentle slope class (0-5%) and rest part of the Khag micro-

watershed comes under moderate to extremely slope classes (5 to more than 50 percent slope). Gentle slope favours infiltration of rainwater as it has more time to enter the aquifer zone while higher slope in the Khag micro-water shed indicates faster runoff, higher erosion rate and less potential for ground water recharge. Higher slope is identified in north-west part of the Khag watershed. It was also observed that the slope of the foremost area of agriculture, horticulture land varied from nearly level to gently sloping, whereas forest regions were mainly found on higher slope classes.

3.4 Slope Aspect

The Slope Aspect were derived from DEM of the area using Aspect Tool (Arc Toolbox under Spatial analyst tools - > Surface) Arc GIS 10.2. An aspect map indicates to which way the mountain side is directed. The aspect identifies the direction of descent of the maximum rate of change of value from each cell to its neighbors. It can be thought of as the direction of the slope. The values of each cell in the output raster indicate the compass direction that the surface faces at that location [22]. The amount of sunlight that hits a hillside depends on the orientation of the slope; slopes facing north receive little or no sunlight; slopes facing east and west receive sunlight for part of the day (unless blocked by another hill or mountain); slopes facing south receive the most sunlight [29]. The spatial distribution of several aspect classes of Khag micro-watershed are presented in Fig. 3. However, areal extent of different aspect classes and their percentage have been illustrated in Table 6. The study revealed that maximum area (973 ha) was under North-East aspect (28.35 %) followed by North aspect (16.61%). Amongst all classes West aspect had minimum area (2.97 %). The cumulative areas occupied by South-East, South and South-West occupied 20.98 per cent (720 ha) whereas, North-1, North-East, North-West and North-2 were 62.44 per cent area (2143 ha), rest part of the area was occupied by East aspect (13.61%) and West aspect (2.97 %). Study showed that the aspect had a bearing on the land use pattern. The agricultural activities were mainly concentrated in the southern aspects as these aspects (South, South-East and South-West) have longer daylight hours than the northern aspects (North, North-East and North-West).

3.5 Morphometric Analysis

A morphometric analysis was carried out to assess the characteristics and properties of the drainage networks. These morphometric parameters were classified into linear parameters (stream order, stream length, stream length ratio, mean stream length, basin perimeter, length of overland flow and bifurcation ratio), areal parameters (drainage area, drainage density, drainage texture, stream frequency, form factor, constant of channel maintenance, elongation ratio and circularity ratio), and relief parameters (basin relief, relief ratio, relative relief and ruggedness number). The quantitative value of linear, areal and relief parameters are given in Tables 7, 8 and 9, respectively.

3.5.1 Linear morphometric parameters

A drainage network carries water and sediment through a single drain marked as the highest order in the basin, and usually the highest available order stream in the basin is considered to be the basin order. The size of streams and watersheds varies considerably with the order of the basin. Stream ordering is the first stage of watershed analysis.

3.6 Stream Order (O) and Number of Stream (Nu)

The Classification of stream order is important to indicator of the size and scale of the watershed. As per the Strahler's [26] classification of stream ordering, the natural drainage system of the watershed were categorized and it was found that, the Khag micro-watershed is designated as fourth order basin (Fig.7). In accordance with Horton's law [27] of stream numbers, "In a given drainage basin, the number of streams of different orders tends to an inverse geometric series, where the first term is uniform and the ratio is the bifurcation ratio". The number of streams of different orders and the total number of streams in the watershed were counted and calculated on a GIS platform. During computations, it was also found that the number of streams decreased as stream order increased; the variation in stream order and differences in micro-watershed size depended largely on the physiography, geomorphology, and geology of the area [24,29]. The main stream was found as 4th order stream and drainage pattern is dendrite [40]. The maximum frequencies in case of first order streams were 28 and that for second, third and fourth order streams were found as 10, 8

and 7, respectively (Table 7). This stream order is used to evaluate the other morphometric parameters of the Khag micro watershed.

3.7 Stream Length (L), Mean Stream Length (Lsm) and Stream Length Ratio (RI)

The stream length (L) is a characteristic that reveals the distinctive dimensions of the components of the drainage network and the catchment surfaces that contribute to it. Stream length of drainage basin was calculated using the law proposed by Horton [27] for the watershed analysis. The stream length is a measure of the hydrological characteristics of the bedrock and the extent of drainage. Where bedrock and rock formations are highly permeable, only a small number of relatively long streams form in well-drained watersheds, while a large number of streams of smaller lengths develop where bedrock and rock formations are less permeable [41]. The total length of stream segments of first, second, third and fourth order streams were found as 20.72, 6.62, 6.89 and 4.81 km., respectively (Table 7). The total length of the channel segment was maximized in the first-order channel and decreased as the order of the channel increased. The variation designated that the flow of streams was from high elevation with lithological differences and moderate steep slopes [42].

The mean stream length (*Lsm*) for the Khag micro-watershed was also calculated by dividing the total stream length of order 'u' by the number of stream segments in the order [26] (Table 1). The mean stream length for the Khag micro-watershed were found as 0.74, 2.072, 2.59 and 2.96 km. for first, second, third and fourth order streams, respectively (Table 7). It is noted that the *Lsm* value of any stream order is greater than that of the lower order and less than that of its subsequent higher order in the catchment. The *Lsm* value varies from catchment to catchment as it is proportional to the size and topography of the catchment [29].

The stream length ratios (RI) were assessed to be 0.319, 1.04 and 0.69 for II/I and III/II and IV/III orders, respectively. The trend of increasing stream length ratio from lower to higher orders shows the mature geomorphic stage, while the change from one order to another is the youthful stage of stream geomorphic development [43,42,29]. Nevertheless small stream length ratio of higher order shows the larger stream

length of II order as compare to III order stream of Khag micro-watershed (Table 7).

3.8 Bifurcation Ratio (Rb) and Mean Bifurcation Ratio (Rbm)

The bifurcation ratio (*Rb*) is a relief and dissections index [27], while Strahler ([31] opined that *Rb* exhibits only small variations from region to region and from environment to environment except where strong geological control dominates. As per Horton [27], value of bifurcation ratio often varies from 1 to 3 and reaches towards higher side for elongated basins. In the present investigation, bifurcation ratio was estimated to be 2.8, 1.25 and 1.14 for I/II, II/III and III/IV orders, respectively, with a mean value of 1.73. In the Khag micro-watershed the higher value of bifurcation ratio showed structural complexity and low permeability whereas the lower values indicate structurally less disturbed micro-watershed without any distortions [26,44,42,2,45]. It also showed that the value of bifurcation ratio were not same from one order to next order. Study showed that Khag micro-watershed was not circular and so it would lead to delayed peak runoff. This indicated its helpfulness for hydrograph shape for micro-watersheds similar in other respect.

3.9 Basin perimeter (P), Basin Length (Lb) and Length of Over Land Flow (Lg)

Basin perimeter and basin length of Khag micro-watershed were found as 31.82 km and 11.78 (Table 7). Surface overflow follows a down slope flow path system from the perimeter of the drainage basin to the nearest network. Horton [27] defined *Lg* as the length of flow channel, projected to the horizontal, of non-channel/network flow from a point on the drainage divide to a point on the contiguous stream network. The *Lg* is one of the most significant independent variables influencing physiographic and hydrological development in the drainage basin. The *Lg* for Khag micro-watershed was 0.44 km (Table 7). The smaller the length of over land flow, the rapider will be surface runoff [46].

3.9.1 Areal parameters of khag micro-watershed

Areal aspect of morphometric parameter of the micro-watershed includes the description of arrangement of areal parameters, drainage

density, and relation of area to the discharge, basin shape (circulatory ratio, form factor and elongation ratio), drainage texture, drainage area, stream frequency, constant of channel maintenance, relation of area to the stream length, etc. (Table 8).

3.10 Drainage Area (A), Drainage Density (Dd) and Drainage Texture (Rt)

Drainage area characterizes the area enclosed within the boundary of the micro-watershed divide. It is probably the single most important feature in hydrologic design. Using Geographic Information System (GIS) software, it was found that drainage area of the Khag micro-watershed was 3432 ha (34.32 km²) (Table 8).

Strahler [47,26] showed that the drainage density (Dd) in a given basin is the ratio of the total length of a stream to the total area of the basin and depends on geological and climatic factors, decreasing with the proportional increase in the size of each drainage unit. It is known that drainage density varies with climate and vegetation [48], soil and rock characteristics [49], topography [50] and landscape evolutionary processes. Drainage densities at the study site decreased as stream orders increase in the Khag micro-watershed (Fig. 8). The drainage density was calculated to be 1.13 km / km² (Table 8). Drainage density affects the flow pattern; a high drainage density rapidly discharges outflowing rainwater, reducing the delay time and increasing the peak value in the graph. The drainage density controls the flow rate after the drainage during the storm period. The higher the drainage density, the greater the outflow (Kale and Gupta, 2000). The lower drainage density indicates a coarser drainage pattern in the study area and a greater influence of cool humid climate. The coarse texture permits more time for overland flow and ground water recharge. The low Dd results in a slow stream response [51].

Horton [27] well-defined Drainage texture (Rt) as the ratio of total number of channel segments of all orders to the perimeter of their drainage area. Horton [27] recognized infiltration capacity as the only important factor which effecting the drainage texture (Rt). Smith [36] shows that Rt depends upon a number of natural factors such as climate, vegetation, rainfall, rock and type of soil, infiltration capacity, topography and stage of development. Drainage texture (Rt) was estimated to be 1.66 (Table 8), as per

explanation assumed by Horton [27]. According to Smith's [36] classification, the Rt of the entire catchment is classified as coarse textured.

3.11 Constant of Channel Maintenance (C), Form Factor (Rf) and Stream Frequency (Fs)

The constant of channel maintenance (C) was estimated to be 0.87 km (Table 8); it is demarcated, as the surface area required sustaining unit length of stream segment in micro-watershed. The value of constant of channel maintenance showed that Khag micro-watershed was undergoing maximum structural disturbance with low permeability having steep to very steep slopes with maximum surface runoff.

Horton [32] stated that the form factor is the ratio of the basin area to the square of the basin length. For perfectly circular basins, the value of the form factor is always greater than 0.78. The smaller the Rf value, the more elongated the basin [52,29]. The form factor (Rf) was calculated to be 0.24 (Table 8) as per explanation assumed by Horton [32]. It showed that the drainage basin was elongated and that the peak flow decreases over a longer period of time [32] defined stream or channel frequency as the ratio of the number of channel segments of all orders in a unit area of a watershed. Reddy, et. al., [53] stated that smaller values of F indicate occurrence of a permeable subsurface material and low relief. The stream frequency (Fs) for Khag micro-watershed was estimated to be 1.54 (Table 8). Fs depend mainly on the bedrocks or lithology of the catchment and reflects the texture of the drainage network [29].

3.12 Circulatory Ratio (Rc) and Elongation Ratio (Re)

Miller [34] defined circulatory ratio as a significant ratio that indicates the dendritic stage of a watershed. This is mainly due to the diverse slope and topographic configuration of the watershed. The circulatory ratio (Rc) was assessed to be 0.42 (Table 8). When these values approach or exceed 1.0, the profile of the drainage channel approaches a circle [54]. This is an important ratio of that indicates the dendritic stage of the watershed.

The values of elongation ratio (Re) vary from 0.6 to 1.0 in various climatic and geological conditions. Typical values are close to 1 for very

lower relief areas and between 0.6 to 0.9 for strong relief and steep ground slope areas. The lowest value of elongation ratio (Re) (< 0.5) designates great relief and steep slope while very high values of elongation ratio (Re) (≥ 1) showed plain areas with low relief and slope. The assessed value of elongation ratio (Re) for the Khag micro-watershed was 0.56, which showed that the studied area was elongated with high relief and steep ground slope. Circular drainage basins are better at discharging overflow than elongated drainage basins [43].

3.13 Relief Parameters of Khag Micro-watershed

3.13.1 Total relief (H), relief ratio (Rh) and relative relief (Rp)

The basin topography or total relief (H) is the maximum vertical distance between the lowest point of the outlet and the highest (divide) points of the catchment. In the present investigation, basin relief was estimated to be 2.1 km (Table 9). Total relief of the basin is a key factor in understanding the denudational features of the watershed. The relief ratio (Rh) was estimated as 0.17 (Table 9). Lower relief ratio is mainly due to the resistant basement bedrocks of the basin and lower slope [55]. The relief ratio usually increases with decreasing basin area and the area of a

given drainage basin [56]. It measures overall steepness of the micro-watershed and is an indicator of the intensity of erosion processes within the watershed. Low values of relief ratio (Rh) are the features of the pedi-plains and valleys while high values are characteristic of hilly areas. The relative relief (Rp) was estimated to be 0.06 (Table 9).

3.13.2 Ruggedness number (Rn)

Strahler (1952) defined a unit less number, called the ruggedness number (Rn), as the product of maximum basin relief and drainage density. Areas of low relief but high density have the same strength as areas of higher relief with lower drainage densities. In the present investigation, ruggedness number was estimated to be 2.39 (Table 9). This figure indicates that if the drainage density is increased while keeping the topography constant, the average horizontal distance from the drainage divide to the adjacent stream will decrease. On the other hand, if the topography is increases while keeping the drainage density constant, the difference in elevation between the drainage divide and the adjacent streams will increase. The high ruggedness value of the watershed indicates that the area is more susceptible to erosion and has inherent structural complexity related to topography and drainage density [24].

Table 4. Areal extents of various slope classes in the study area

S. No.	Slope Class	Slope (%)	Area (sq. km)	Area (ha)	Area (%)
1	Nearly level	0-1	6.56	655.57	19.10
2	Very gentle	1-3	7.71	770.76	22.45
3	Gentle	3-5	5.48	547.90	15.96
4	Moderately	5-10	4.46	445.69	12.98
5	Strongly	10-15	3.46	345.79	10.07
6	Moderately steep	15-25	2.79	278.84	8.12
7	Steep	25-33	1.88	188.48	5.49
8	Very steep	33-50	1.73	172.59	5.03
9	Extremely steep	>50	0.27	27.32	0.80
Total			34.32	3432	100

Table 5. Areal extents of various aspect classes in the study area

S. No.	Elevation range (m)	Area (sq km)	Area (%)	Area (ha)
1	1640-2000	13.86	40.37	1386
2	2100-2400	9.26	26.98	926
3	2500-2700	5.06	14.74	506
4	2800-3200	4.44	12.93	444
5	3300-3741	1.70	4.98	170
Total		34.32	100.00	3432

Table 6. Areal extents of various DEM classes in the study area

S. No.	Aspect	Area (sq km)	Area (%)	Area (ha)
1	North - 1 (0° - 22.5°)	5.70	16.61	570
2	North - East (22.5° - 67.5°)	9.73	28.35	973
3	East (67.5° - 112.5°)	4.67	13.61	467
4	South (157.5° - 202.5°)	3.90	11.36	390
5	South - East (112.5° - 157.5°)	2.27	6.61	227
6	South - West (202.5° - 247.5°)	1.03	3.01	103
7	West (247.5° - 292.5°)	1.02	2.97	102
8	North - West (292.5° - 337.5°)	2.80	8.16	280
9	North - 2 (337.5° - 360°)	3.20	9.32	320
Total		34.32	100	3432

Table 7. Linear aspect of khag micro-watershed

Stream order	No. of Stream	Stream length (km)	Mean stream length (km)	Stream length ratio	Bifurcation ratio	Mean bifurcation ratio	Length of overland flow (km)	Basin Length (km)	Perimeter (km)
I	28	20.72	0.74	0.31	2.8	1.73	0.43	11.78	31.82
II	10	6.62	2.072	1.04	1.25				
III	8	6.89	2.59	0.69	1.14				
IV	7	4.81	2.96						
Total	53	39.04	8.362	2.04	5.19				

Table 8. Aerial aspect of khag micro-watershed

Drainage area(km ²)	Drainage density (km/km ²)	Constant of channel maintenance	Stream frequency	Circulatory ratio	Elongation ratio	Form factor	Drainage texture
34.3	1.13	0.87	1.54	0.42	0.56	0.24	1.66

Table 9. Relief Aspect of khag micro-watershed

Total relief (km)	Relief ratio	Relative relief (%)	Ruggedness number
2.1	0.17	0.065	2.39

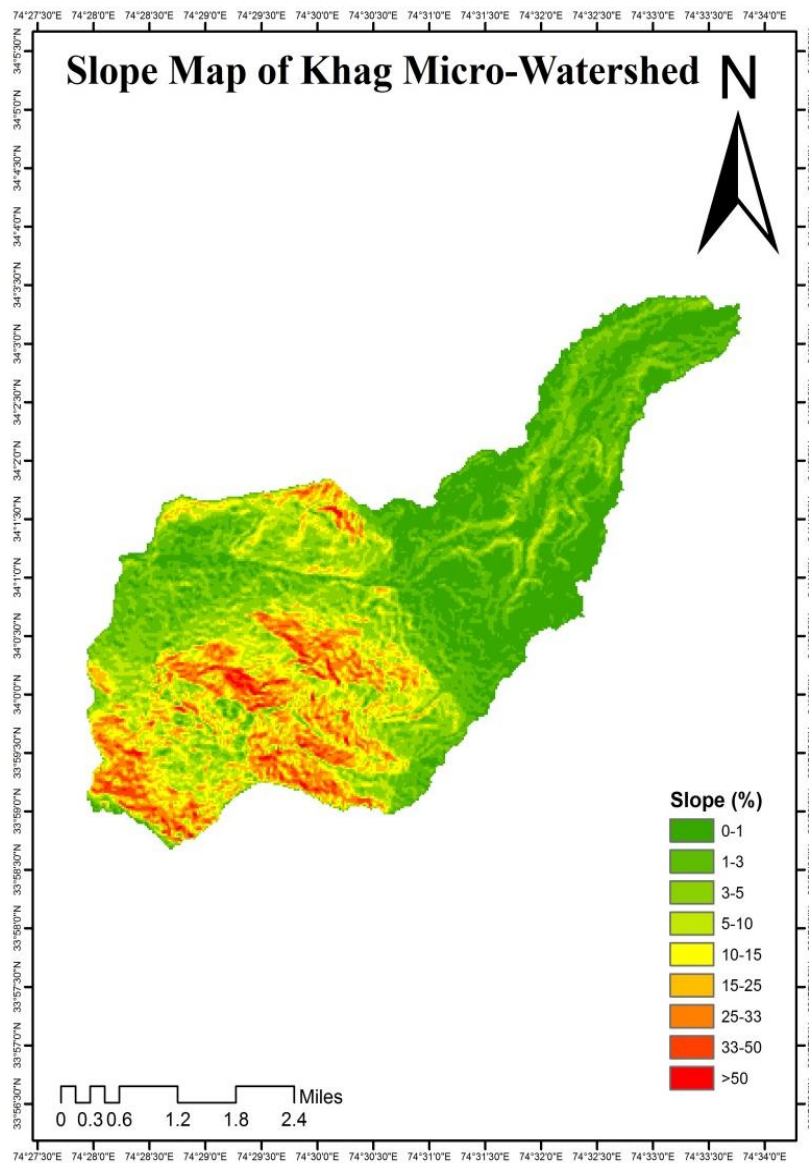


Fig. 2. Slope map of study area

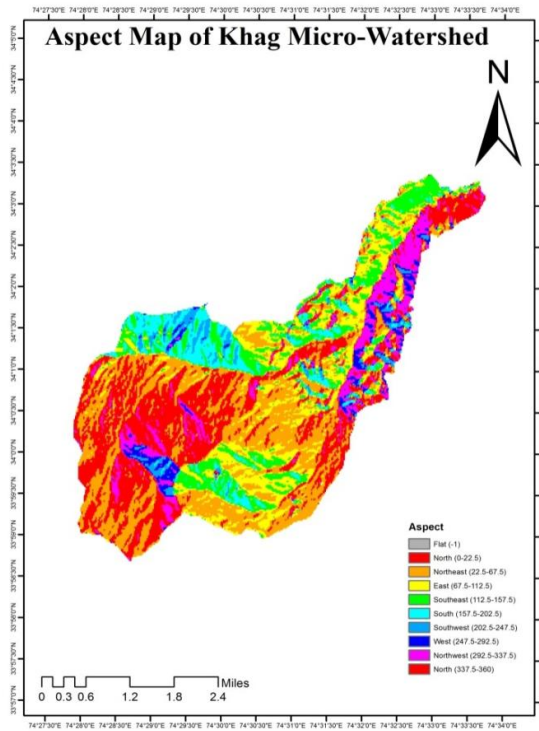


Fig. 3. Aspect map of study area

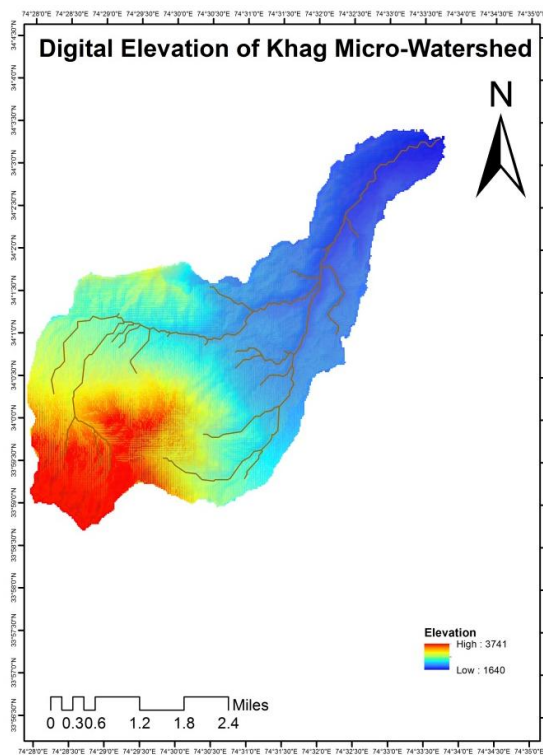


Fig. 4. DEM Map of study area

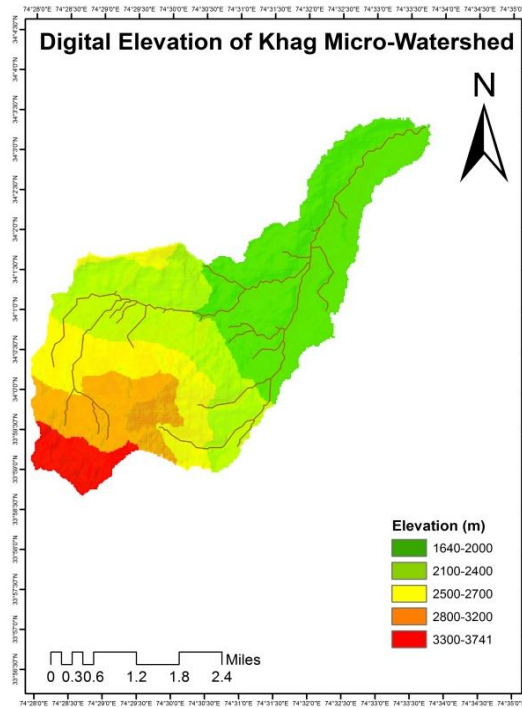


Fig. 5. Elevation classes of study area

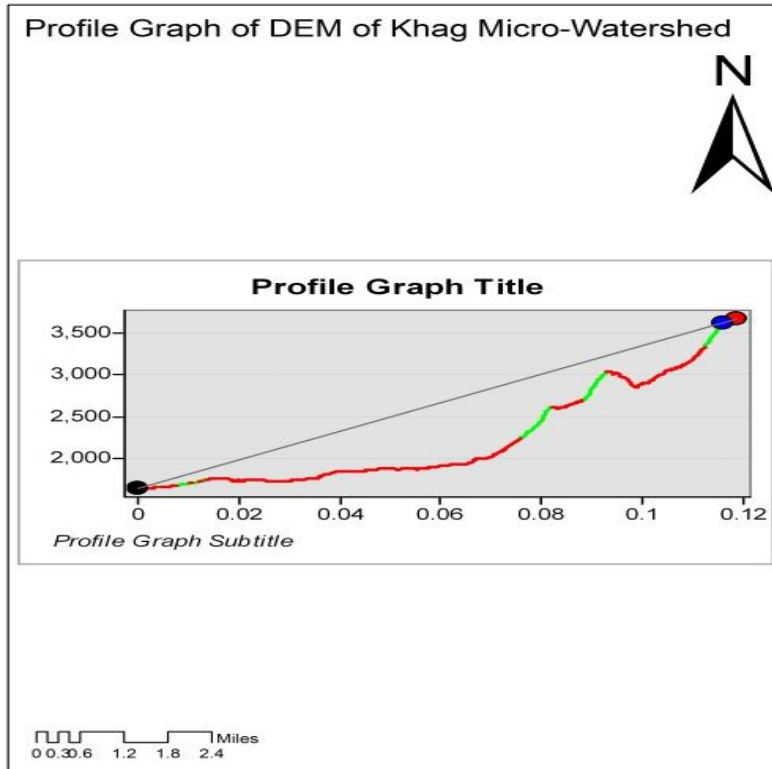


Fig. 6. Profile graph of DEM of khag micro-watersheds.

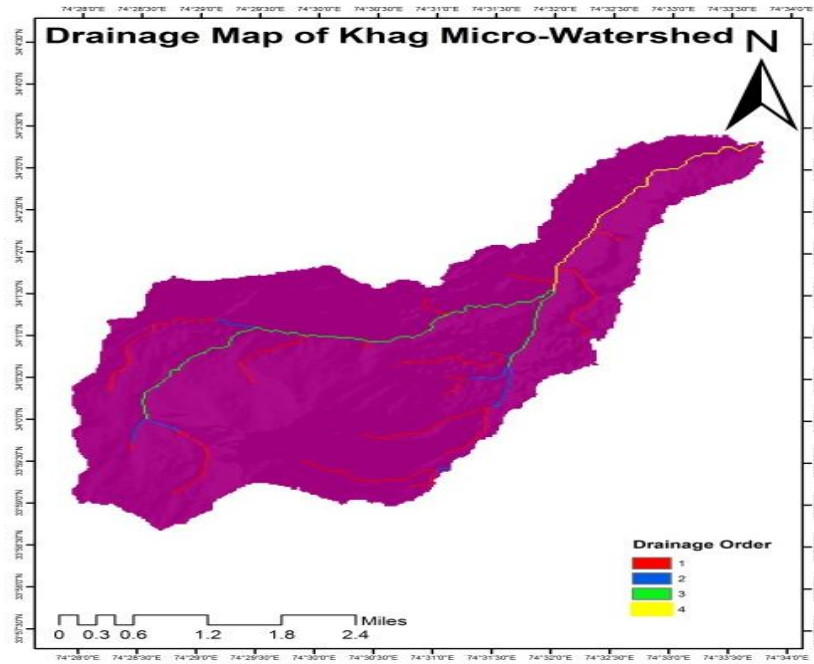


Fig. 7. Drainage ordering of khag micro-watersheds

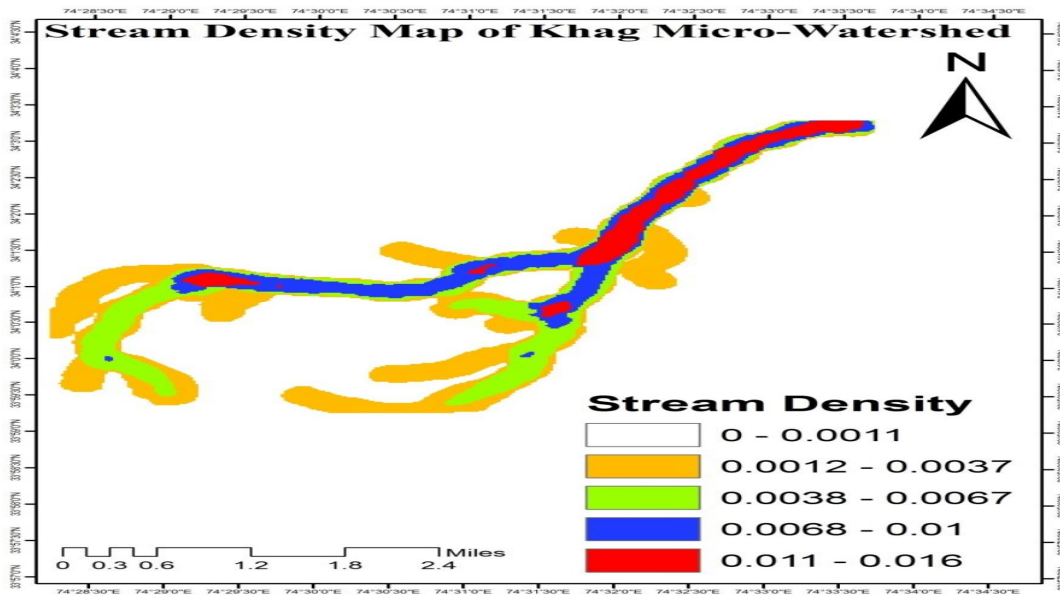


Fig. 8. Stream density map of khag micro-watersheds

4. CONCLUSION

Morphometric analysis of the drainage network aims to acquire precise data of quantifiable features of stream basin and the use of remote sensing augmented GIS is very powerful tool to achieve the desired objective quickly with high precision. Based on the drainage order the Khag

micro-watershed has been classified as fourth order micro watershed, it is dendritic in pattern with structural complexity and low permeability in hilly areas of micro-watershed whereas as there are also structurally less disturbed micro-watershed areas without any distortions. The Drainage density of Khag micro watershed shows that the subsurface layers are permeable,

which is a representative of coarse drainage because the Dd values are less than 5.0. The study indicates that the drainage area of the micro watershed is experiencing the early maturation stage of the fluvial geomorphic cycle (Neither field evidence nor the authors carried out the hypsometric analysis then on what basis they are concluding the drainage area is in early maturation stage). Most of the micro-watersheds dominated by low-order streams. The elongated shape of the micro watershed is mainly due to the guiding effect of thrusting and faulting. The morphometric analysis is powerful tool in river basin management and planning, watershed prioritization, soil and watershed conservation and management of natural resources at different levels. The occurrences of 1st and 2nd order streams on steep sloping areas restrict the use of check dams for their treatment.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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