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Hypsometry and erosion in a sub-watershed of lower Alaknanda basin: A case study of lesser Garhwal Himalaya

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Abstract
To identify befitting measures for soil and water conservation, appraisal of erosion rates on watersheds is a pre-requisite as far as integrated watershed management in mountainous terrain is concerned. The hydrological study in the Himalayan terrain is a risky and time consuming task, and requires sufficient time, planning, man power and funds. Hypsometric analysis, one of the essential morphometric tools, quantifies the geologic stages of development and erosion-proneness of watersheds.
The present paper incorporates the operational phase and the preliminary results of the hydrological response in study basin. In the present study, a sub-watershed named Chandrabhaga in the Lower Alaknanda basin was considered for hypsometric analysis. Results of hypsometric analysis executed on this watershed shows that the study area is in mature stage geomorphologically. Furthermore, the estimated sediment yield over the year 2015 was 2.17 Tons added to the total sediment yield of Alaknanda River.
The landscape of the watershed is favourable for high run-off and erosion due to geological configuration, paucity of natural vegetation and land use. The surface gradient is very steep at the source (North) which generally decreases downstream (south). The mean slope of the whole watershed is 23.5, along with the mean elevation of 1218.06 m.

Keywords: Hypsometry, watershed degradation, erosion status, geologic stage

Introduction
The Himalayan watersheds are highly susceptible to erosion owing to high Monsoon rainfall, intense pre-monsoon storms and rainfalls caused by western disturbances. So as to identify befitting measures for soil and water conservation, appraisal of erosion rates on watersheds is a pre-requisite as far as integrated watershed management in mountainous terrain is concerned. A watershed or catchment, an area therefrom all water drains to a common point, is an attractive unit for technical efforts to harness scarce water resources and conserve soil for agricultural production and natural resource conservation (Kerr, J., 2002) [2].
People and livestock are the integral part of watershed, and their activities affect the productive status of watersheds and vice-versa. From the hydrological point of view, the different phases of hydrological cycle in a watershed are dependent on various natural features and human activities.
Watershed is not simply the hydrological unit but also socio-political-ecological entity which plays crucial role in determining food, social, and economical security and provides life support services to rural people (Wani *et al*. 2008) [7]. The fluvial-erosional landforms, the largest proportion of the earth's land surface, are extremely complex.
The runoff components are a function of the basin hypsometric form. In general, a relatively less eroded (convex) basin exhibits higher total runoff that is more dominated by subsurface processes, while a relatively more eroded (concave) basin shows less total runoff with a higher fraction of surface response (Vivoni *et al*., 2008) [6].
Lindstrom *et al*. (1992) carried out a research to quantify soil movement by tillage on a hill-slope landscape. Fox *et al*. (1999) [8] made attempt to investigate the relationship between slope gradient and runoff velocity for inter-rill conditions. Montgomery *et al*. (2002) conducted study to see the topographic controls on erosion rate in Olympic Mountains.

Khadri *et al*. (2015) [9] conducted G.I.S. based hypsometric analysis to understand the erosional topography. Ascertaining the distinctive nature of the hydrological environment of a watershed should be a basis for all planning proposed or carried out for sustainable development of water resources. In order to physically explore the nature of steady-state topography, basin hypsometry is useful. Kuang-Yu Cheng *et al*. (2012) [10] carried out an empirical study in Taiwan, which concluded that when topography is in a steady state, the basin hypsometry is scale independent and vice versa.
Singh O., (2009) [3] made efforts to determine the geological stages of development and its impacts on the behavior yielding sediments of Sanj and Tirthon watersheds and their sub-basins in the Lessor Himalayan region employing hypsometric curves and hypsometric integrals.

The study area

The study watershed falls under the right bank of Lower Alaknanda river system in Lesser Garhwal Himalaya. The Chandrabhaga catchment is a fifth order stream covering a total area of 46.66 km^2. The area extends between between 30^{0}13′09″-30°18′26″ N Latitudes and 78^{0}36′23″-78^{0}41′03″ E Longitudes. The altitude of the watershed ranges between 500 m and 2260 m., as shown in fig.1.
The landscape of the watershed is favourable for high run-off and erosion due to geological configuration, paucity of natural vegetation and land use attributes. The surface gradient is very steep at the source (North) which generally decreases downstream (South). The mean slope of the whole watershed is 23.5, along with the mean elevation of 1218.06 m.
Over the study period, the mean daily maximum temperature in study area rises up to 37.3°C in summers, while mean daily minimum temperature can be as low as 5.4°C in winters. An average annual rainfall is 504 mm. The main crops are predominantly wheat and rice irrigated by gools (canal) stemmed from main Gad and Gadheras. Geologically, Chandrabhaga Gad catchment comprises of a variety of rock types and belongs to Pre-Cambrian to Eocene periods.

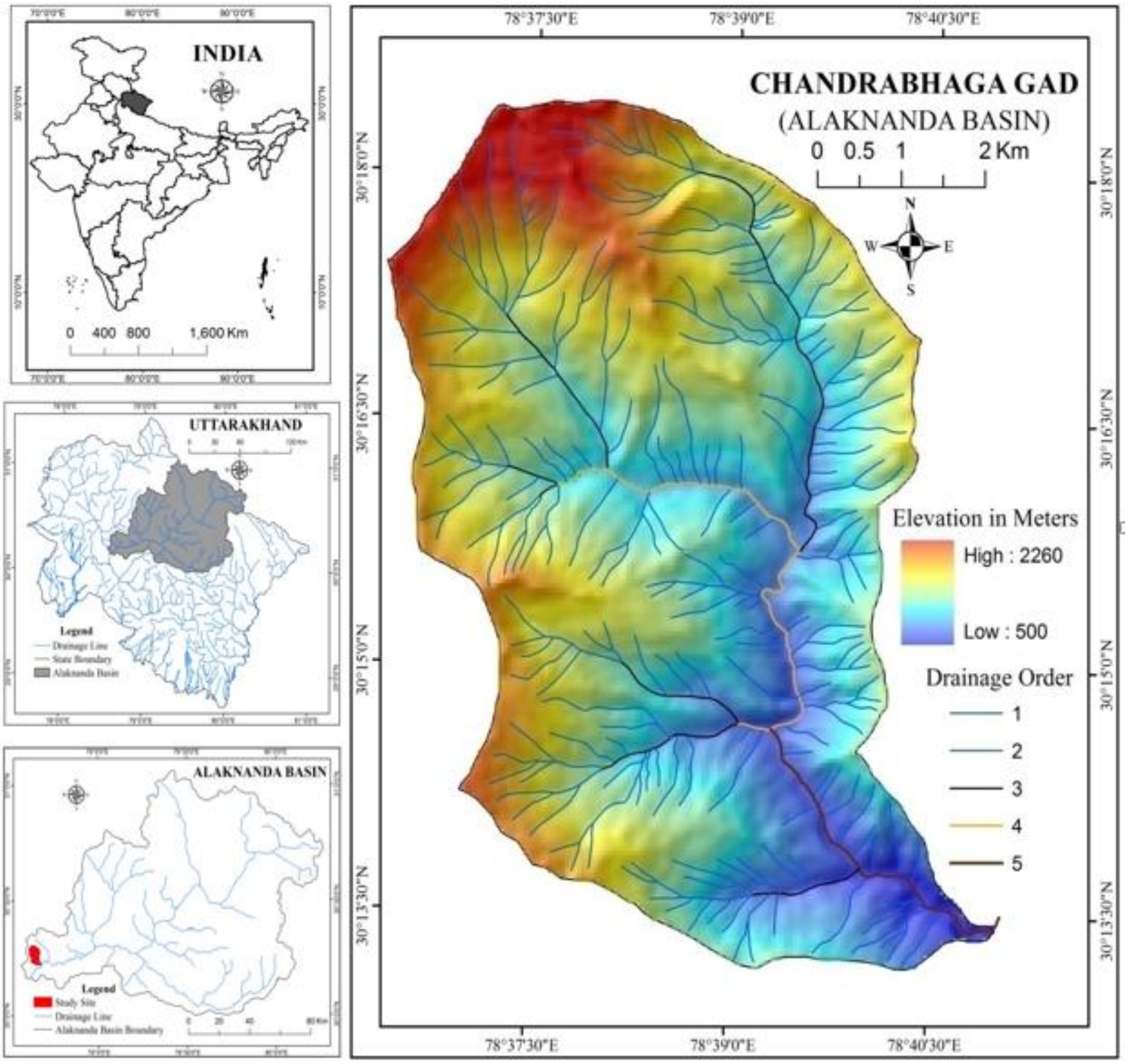


Fig 1: Location, altitude, drainage order of Chandrabhaga Gad Catchment

Geology of the study watershed

The rocks, found in the study area, belong to Pre-Cambrian to Eocene periods. This area experienced geological deformation multi times on account of the internal tectonic movements. Therefore, the area has the rocks of different grades over which various structural features viz. faults, folds, joints, cracks, fractures, etc., have been developed over time.

Regionally, North Almora Thrust (NAT) is the main tectonic unit which passes through NW to SE direction ~3 km north off the northern boundary of study watershed. The Garhwal group of rocks consisted of Sandra, Deoban (upper, middle and lower) and Damta formation; belong to the northern half of NAT. This sequence is characterized by extensive occurrence of meta-basic rock (sill, dyke as lava flow). Damta group of rocks are found parallel to the NAT in the southern margin equivalent to Shimla formation. These rocks are highly fractured and weathered. Some time in some places these became arrenecious type.

The study watershed constitutes the southern zone of NAT which is charactrised by Chandpur group of rocks which are consisted of ferruginous quartzite in the upper section, dolomite lime stone in the middle section and chloride schist, phylite and slate in the lower section. Chandpur formation of rocks is predominantly found in the study watershed. Lithologically, the area is dominated by low grade upper proterozoic phyllite which merge with flaggy quartzite towards north (Sati *et al*. 2007). Basically, Chandpur formation of rocks is classified into three types i.e. arenacious, carbonacious and micacious which are well exposed in the study area. This group of rocks is composed of phyllite in which slate and quartzitic veins are found. Foliation and lamination are well developed in the phyllite. Out of that bright luster, puckering and chabron folds are also seen along the foliation plane. Large number of folds, fractures, faults, lineaments and joints control the drainage landform pattern of the watershed.

Materials and Methods

Watershed delineation

The present study watershed was designated as sub-watershed following the IMSD Technical Guidelines (NRSA, 1995) according to which watershed was classified into sub-watershed (± 30-50 km^2), mini-watershed (± 10-30 km^2) and micro-watershed (± 5-10 km^2), though, as per the guidelines of AIS&LUS (1990), the mean area of watershed is less than 500 km^2 (± 500 km^2).

Generation of DEM from topological information

The topological data of the study area were extracted employing the tools of Arc Info and ArcGIS. The present study is based on the digitised and geo-referenced 1/50,000 topographical sheets (53J/11 and 53J/12) and field observation.

These topo maps were geo-referenced and projected in Universal Transverse Mercator projection (datum WGS 1984, 44N zone). Firstly, the contours were digitized to generate the line feature class in ArcGIS which was further processed to generate digital elevation model (DEM), using the spatial analyst module, representing the watershed terrain topology. Drainage lines were ordered according to Strahler's method. Stream number, length and all linear aspects of each order of the whole basin were calculated in ArcGIS 9.3 environment. The basin was divided into 243 numbers of ½ km^2 grids. A Global Positioning System (GPS) was used to record the longitudinal, latitudinal positions and altitudinal point of water sampling site which are 78^0 38' 23.99" E, 30^{o}15'21.02" N and 505 m MSL respectively.

Slope analysis

The slope may be defined as the vertical inclination between the hill top and valley bottom, stands with the horizontal line and expressed generally in the degrees.

Table 1: Slope Angles

Class	Remarks	Area (km^2)	Area (%)
<10	Very low	1.62	3.47
10-20	Low	12.79	27.39
20-30	Medium	23.75	50.87
30-40	High	7.89	16.90
40>	Very high	0.64	1.37
Total		46.69	100.00

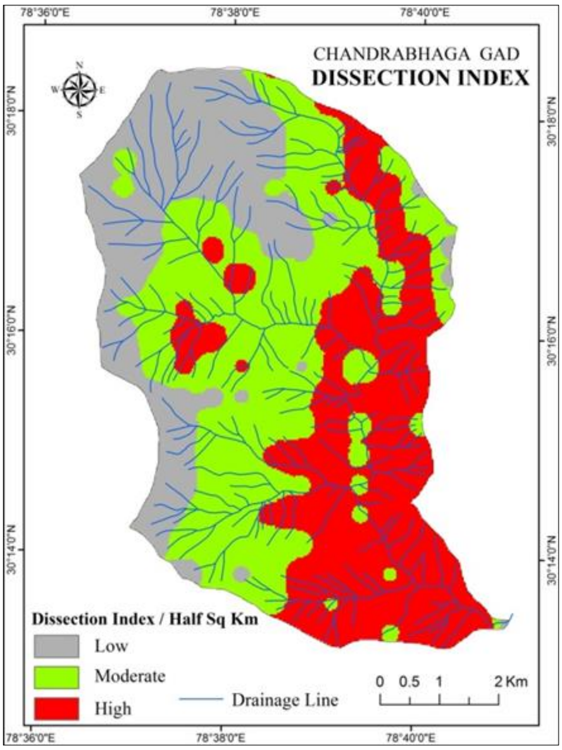
As far as the slope angles is concerned, the study area has been categorized into five groups i.e., very low, low, medium, high and very high. As per table-1, a slightly more than 50% area is moderately sloppy, merely 3.47% and 1.37% of the study area has very low and very high slope gradient respectively and low and high slope gradients are found on 27.39% and 16.90% of the total study area respectively. In terms of slope gradient, the study area falls into the category of low to medium sloppy.

Dissection index (DI)

In the present study, the 'Grid Method' was used to compute dissection index in which values vary between 0 and 1 (Table-2). Low dissection index over the northern and upper north-western part of the study watershed shows lack of structural differences. The Southern, South-Eastern, North-Eastern and Eastern parts are characterized by high dissection index which exhibits high degree of run-off.

Table 2: Dissection index

Class	Remark	Area (Km^2)	Area (%)	Mean
0.05 - 0.15	Low	11.82	25.34	0.18±0.04
0.15 - 0.2	Moderate	18.61	39.89	
0.2 - 0.37	High	16.22	34.77	
Total		46.65	100.00	



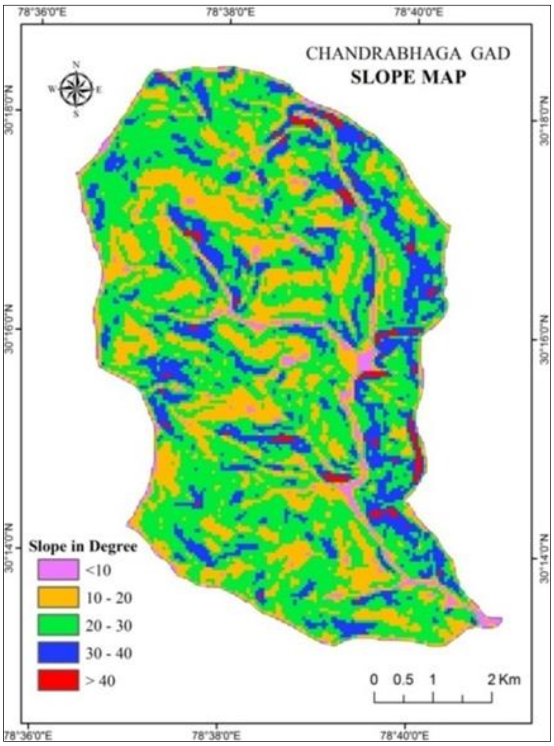


Fig 2: Dissection Index

Fig 3: Slope Map

Hypsometric curves (HC) and hypsometric integrals (HI) of study area

Hypsometric curves and hypsometric integrals are important indicators which show the condition of a watershed (Ritter *et al*., 2002). Hypsometric analysis has been carried out using GIS techniques by several researchers in India so as to deal with erosional topography (Pandey *et al*., 2004; Singh *et al*., 2008a, Singh *et al*., 2008b; Sharma and Seth 2010 and Sharma *et al*., 2011, Sharma *et al*., 2013) [11]. Hypsometric curves have their practical application in different branches of hydrology, geomorphology, soil erosion, and other branches of earth sciences.

In hypsometric analysis, a relationship is developed between horizontal cross-sectional area of the watershed and its elevation in a dimensionless form.

Hypsometric analysis, or the relation of horizontal cross-sectional drainage basin area to elevation, was developed in its modern dimensionless form by Langbein *et al*. (1947) who applied it to quite large watersheds. It has since been applied to small drainage basins of lower order to determine how the mass is distributed within a basin from base to top (Strahler, 1952; Miller, 1953; Schumm, 1956; Coates, 1956) [4].

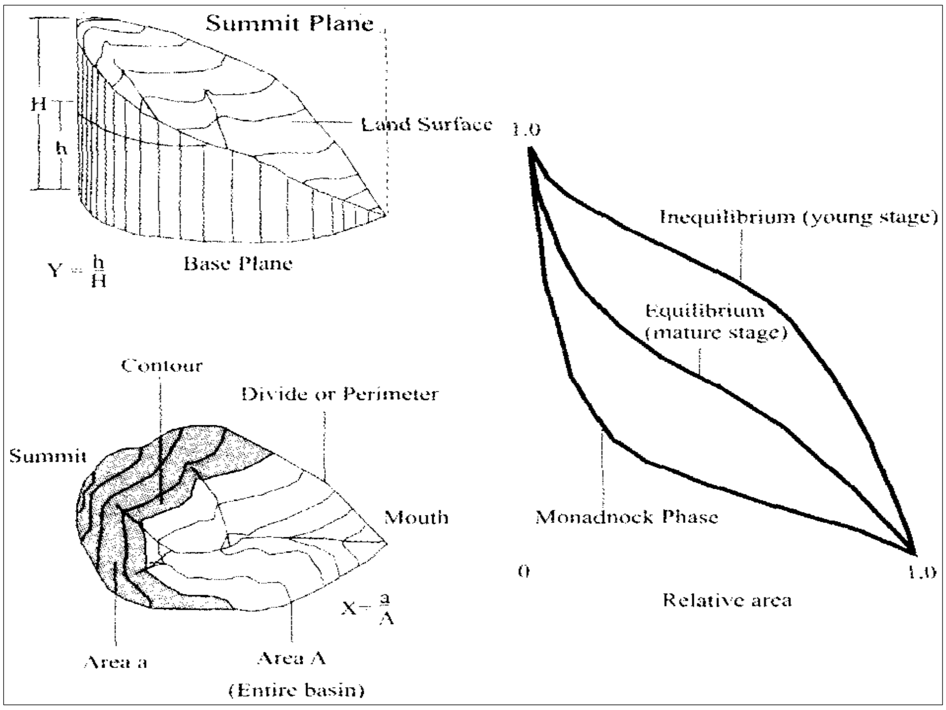


Fig 4: The Concept of Hypsometric Analysis and the Model Hypsometric Curves (Ritter *et al*. 2002).

Hypsometric curve is a plot having relative area on the abscissa and relative elevation along ordinate. Relative area is calculated as ratio of the area above a specific contour (a) to the entire area of the watershed (A) including outlet. Taking into consideration the watershed area to be bounded by vertical sides and a horizontal base plane passing via outlet (fig. 2), relative elevation is obtained as the height of a particular contour (h) from the base level to the maximum elevation (H) of basin (upto the extreme upper point of watershed from the confluence point) (Singh, 2009) [12]. The digitised contour map was employed to obtain the data required for analysis of relative area and elevation.

Hypsometric curve shapes indicate the erosion status of a watershed. In accordance with the interpretation of hypsometric curves (made by Strahler (1952) [4] through studying numerous drainage basins), there are three types of shapes of hypsometric curves that indicate three types of basins- first- *youth basin* which are convex upwards curves, second- *mature basins* which are 'S'-shaped hypsometric curves which are concave upwards at the high elevation and convex downwards at the elevations, and third- *peneplan or distorted basins* which are concave upwards curves. The stage of landscape evolutions can be described by hypsometric shapes. The hypsometric curve of Chandrabhaga Gad catchment is 'S'-shaped which suggested that the Chandrabhaga Gad basin, geomorphologically, is mature catchment, moderately prone to erosion, hence, in the equilibrium stage.

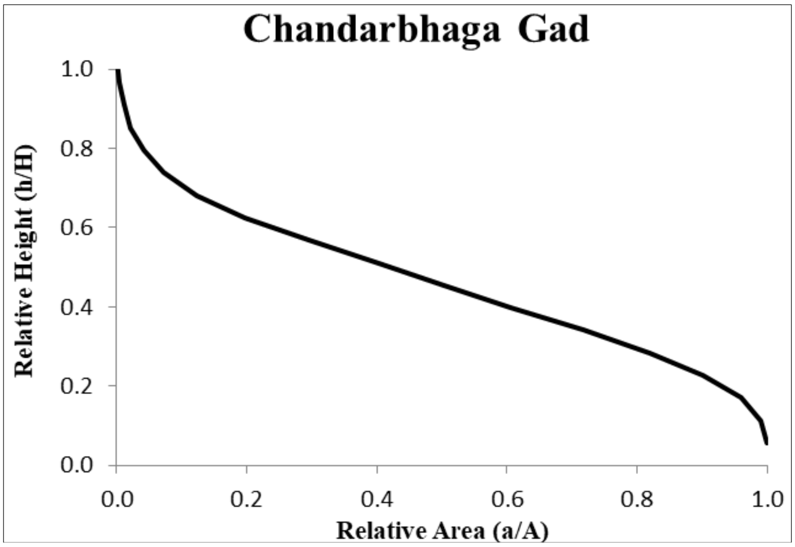


Fig 5: Hypsometric curve of chandrabhaga gad watershed

The hypsometric integral is obtained from the hypsometric curve and is equivalent to the ratio of the area under the curve to the area of the entire square formed by covering it. It is expressed in percentage units and is obtained from the percentage hypsometric curve by measuring the area under the curve. This provided with a measure of the distribution of landmass volume remaining beneath or above a basal reference plane.

In the present study, the method of elevation-relief ratio, proposed by Pike and Wilson (1971), was used so as to derive the hypsometric integrals. The relationship is expressed as below:

$$E \approx H_{si} = \frac{Elev_{mean} - Elev_{min}}{Elev_{max} - Elev_{min}}$$

Here, E stands for the elevation-relief ratio and H_{si} for the hypsometric integral. E is equivalent to H_{si}. $Elev_{mean}$ is the weighted mean elevation of the watershed obtained from the identifiable contours of the delineated sub-watershed. $Elev_{min}$ and $Elev_{max}$ are the minimum and maximum elevations respectively within the water-divides of study watershed.

Table 3: Elevation-Relief Ratio

Watershed	Max Elev.	Mini. Elev.	Range	Mean Elev.	Mean Slope	Hypso. Integ. (HI)
Chnadrabhaga Gad	2260	500	1760	1218	23.5	0.41

The values of hypsometric integrals can be grouped into three categories each representing one of the typical stages of basin dissection, viz, (i) Youthful stage (60%- 100%) (ii) Mature stage (35%-59%) and (iii) Old stage (below-35%).

The basin produced a mean hypsometric curve with a low integral ~0.41 (Fig. 02 and Table 03). Inflection point (a change of curvature from convex to concave) is situated at the low point at the curve. Beyond the inflection point upwards, more than two third of the upper curve is in a broadly concave shape (Fig. 02). Above mentioned hypsometric intergral of Chandrabhaga Gad catchment proposed that the Chandrabhaga Gad basin/catchment, geomorphologically, is a mature catchment and in the equilibrium stage, less prone to erosion.

Sediment yield estimation

The hydrological responses of the study area are affected by various natural and anthropogenic factors. An urgent need is there in order to explore the consequences of environmental and human induced effects on erosion for the sake of future-oriented planning with the objective of sustainable development. In the present study, the hydrological data as to water discharge and sediment flux were monitored near the confluence point at Bagwan. Measurement of water discharge (by float method) and collection of water samples (one liter sample every time) were done weekly/monthly during summer (March-June) and winter (October-Feb) and on daily basis during Monsoon (June-September) throughout year w.e.f.—Feb, 2015 - Jan, 2016. The peak run-off data during rain storms were monitored on hourly basis and more than two water samples were taken for the sake of analysis.

The collected samples were then tested and analysed in the laboratory following a standard techniques of APHA (1995) and Gregory and Walling (1979) to estimate the suspended sediment concentration by adopting gravimetric method.

$$Sq = W_2 - W_1$$

Where, *Sq* is concentration of suspended sediment in mg/liter water, W_1 is the weight of filter paper and W_2 is the weight (mg) of filter paper with suspended particles. Whatman filter papers were employed to extract suspended sediments from the collected samples taking 100 ml each, in the laboratory. Though, the SSC was calculated for one liter of collected water sample. The water samples were collected from the gaugin site where instrumentations were established.

Table 4: Location and altitude of the gauging site

Watershed	Gauging site	Latitude	Longitude	Elevation (m) MSL
Chnadrabhaga Gad	Bagwan	30°15’21.02” N	78^0 38’ 23.99” E	505

The suspended sediment concentration (SSC) for the whole year was derived by multiplying average suspended concentration and average discharge rate recorded over the different periods of the year (winter, summer, and monsoon). The dissolved sediment load was extracted by evaporation process using the heater with the tray. The total sediment was derived adding the dissolved load and sediment load.

Table 5: Sediment yield: seasonal distribution (2015-16)

Watershed	Sediment yield (Ton)			
	Summer	Monsoon	Winter	Total Sediment Load
Chandrabhaga Gad	0.09	2.04	0.04	2.17

The study area lies in the region which is influenced by the Monsoon winds. Hence, the study area received maximum rainfall during Monsoon season. Consequently, the study Gad experienced maximum flow during this season and generate maximum amount of sediment yield. However, the Garhwal Himalayan region is also influenced by the Western disturbances but comparatively received less rainfall, less stream flow and less sediment than monsoon period.

In the study watershed, maximum sediment was produced over the months of mid-June, July, august and September mid, which is 2.04 tons followed by 0.09 tons and 0.04 tons during the months of Mid-March, April, May and Mid-June and October, November, December and January respectively during 2015-16.

Conclusion

As far as the slope aspect is concerned, the study area falls into the category of low to medium sloppy with more than 50% area is moderately sloppy, low slope gradient is found on 27.39% of the total study area. Low dissection index is found over the northern and upper north-western part of the study watershed which is upper concave part. It shows lack of structural differences**.** South and eastern parts are characterized by high dissection index. It may be due to lower convex part which exhibits high degree of run-off.

The stage of landscape evolutions can be described by hypsometric shapes. The hypsometric curve of Chandrabhaga Gad catchment is ‘S’-shaped which suggested that the Chandrabhaga Gad basin, geomorphologically, is mature basin, moderately prone to erosion, hence, in the equilibrium stage.

Furthermore, a year-long study (over the year 2015) of the present watershed estimated sediment yield of 2.17 Tons added to the total sediment yield of Alaknanda River. The Garhwal Himalayan region is influenced directly by the Monsoon and the Western Disturbances during summers and winters respectively. This region received maximum amount of rainfall during summers and experienced maximum flow and consequently received maximum sediment over the monsoon period.

IMSD: Integrated Mission for Sustainable Development

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