

## Slope and land use in western doon of Dehra, Uttrakhand (India)

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### Abstract

The study of slope of the terrain of a geomorphic unit is very significant. slope may be expressed in two dimensions. These are the magnitude and direction of the slope. Study of both the dimensions are equally important particularly in mountainous regions. Magnitude of slope not only helps in terracing genetic history of geomorphic units but also determines the land use pattern and developmental activities in the area. Similarly, slope direction determines the land use and erodibility of slope faces. Doon of Dehra is a very important geomorphic unit in terms of both natural and cultural point of view Dehradun, which is the capital city of Uttarakhand is also situated in this geomorphic unit. Topographical sheets published by the government of India are the database of study. Wentworth's method of average slope has been used to calculate the magnitude of slope. The slope of this area varies from little more than 0° to 39.5°. Minute study of isopleths of slopes at the interval of 2° and 5° reveals that there are certain breaks of slope at the zone of 25° to 30°, 10° to 15°, 5° to 10°. Regional breaks of slopes are also observed in Nun, Sitla and Bin basins. Pattern of slope also changes rapidly at the extreme western portion of basin, near the mouth of Yamuna in the study area. These major changes of slopes may be related to thrust, faults and lineaments. In this basin, sunny, eastern-sunny and western-sunny slopes cover about 51.47% of the total mountainous region. These sunny slopes exhibit 92.2% of total cultivated land, 94.7% of total settlement and 28.7% of total forested area of this morpo-unit (mountainous region). More than 92% of total barren land is found on these sunny slopes. This may be attributed to the fact that these facets may have steep and unstable slopes due to more weathering of rocks by heating of the surface due to sun-rays.

**Keywords:** Blucher; Dehra; Morphometry Mussoorie Shady; Slope; Wentworth

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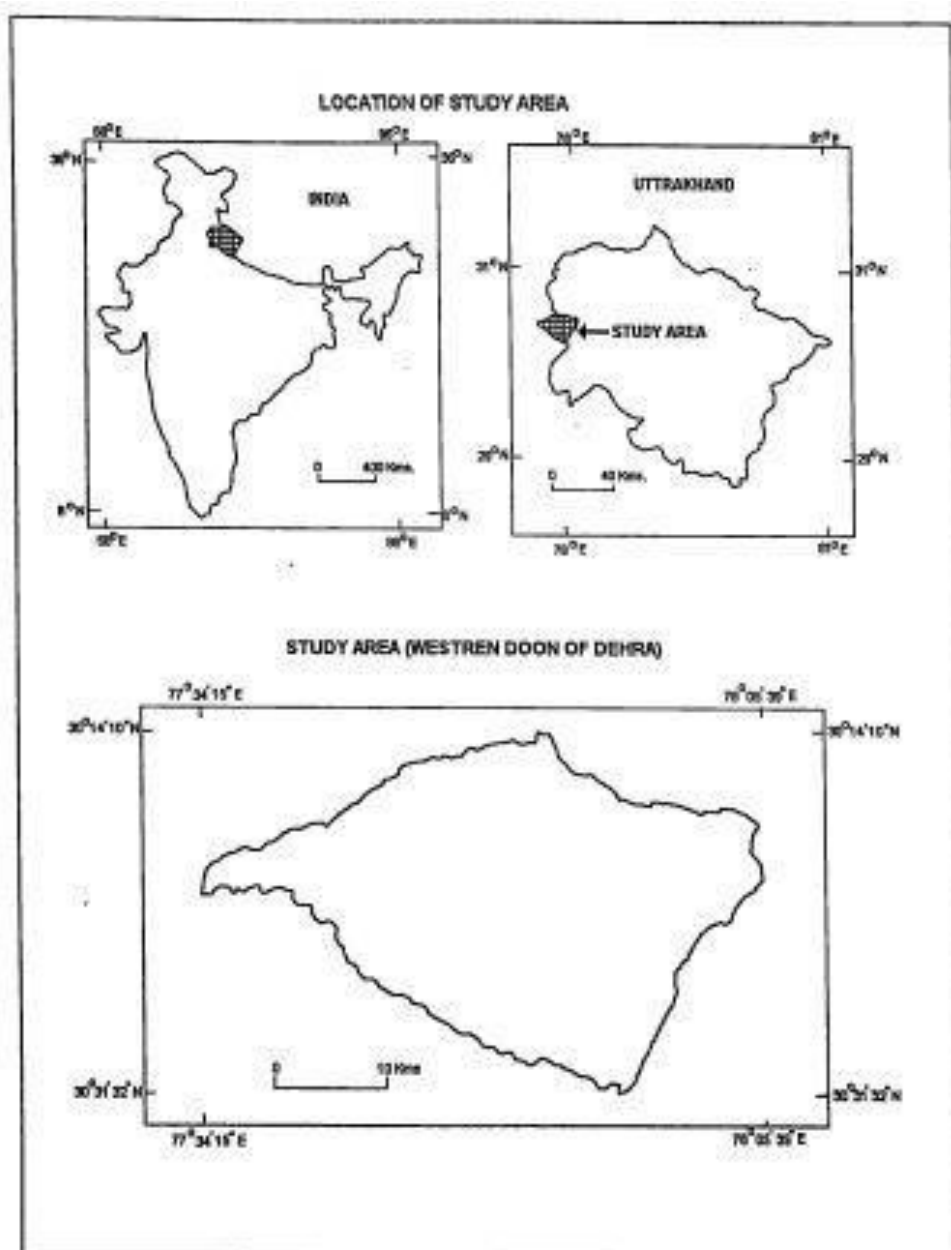
### 1. Introduction

The study of slope aspects of a geomorphic and study of its relation with land use is very significant for scenic evaluation of the area. Patterns of slope also enlighten some of its tectonic history. Doon of Dehra is a very important geomorphic unit in terms of both natural and cultural point of view. Dehradun which is the capital city of Uttarakhand is also situated in this geomorphic unit, so the study of this geomorphic unit becomes important.

This Doon is a structural valley that extends in the NW to SE direction flanked by Lesser Himalayas in the north and Siwaliks in south. Song water divide in the east and Yamuna in north-west and west make the boundaries of Western Doon of Dehra. This doon covers an area of 834.28 square kilometers. The latitudinal extension of the area is from 30° 14' 10" to 30° 31' 32" north. Its longitudinal extension is from 77° 34' 15" to 78° 05' 39" east (Figure-1). Politically, this area falls in Dehradun district of Uttarakhand. Asan is the major stream in this geomorphic unit. The height of this area ranges between 357 metres. to 2229 meters. The heights and slopes of Lesser Himalayas are more as compared to Siwaliks in the south. Bhadraj peak at the northern boundary of the study area has maximum height. Blucher hill (2191 m), Cloud End (2153 m), and Gun Hill (2142 m) are major peaks in respect of height in the north eastern part of the study area. In Siwaliks, the highest peak is Amsort (957 m) followed by the peak having a height of 918 meters near Shakumbhari- pass.

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**Figure 1** Study Area

Asan is the major stream in this geomorphic unit. It is a sixth order stream. Six fifth order tributaries - Upper Asan, Nun, Darer, Sitla Rao, Tons, Surna join the major stream (Asan). Bin is also a fifth order stream in the area, but it directly joins Yamuna. It is not a tributary of Asan. (Figure -2)

The average slope in the study area is steep to gentle, ranging from little more than 0° to 39.5°. The Doon slopes down from north east to south west direction. The general trend of slope is different in different regions. It is north to south in the eastern Himalayas, north-east to south-west in the basins of Naro and Bin which occupy the north western part of the study area. The general trend of slope in the lower part of the region (south of Asan River) is from north to south.

The quantitative and qualitative analysis of slope of the mountainous region was pioneered by Davis (1892, 1898, 1932) which has further been extended by different scholars all over the world during the last about hundred years. Among the early scholars, Penck (1924), Finsterwalder (1890), C.K. Wentworth (1930), G.H. Smith (1935), E. Raize and Henry (1937), Wood A. (1942) A.H. Robinson (1948), Strahler A.N. (1950, 1952, 1956). Schumn (1956), Scheidegger (1956,1961) Morisawa (1959), Maxwell (1960), Chorley (1962), King L.C. (1962), Young A. (1972), Small (1978), Miller

(1981), Spark (1986) and their associates published a number of research papers establishing the base of slope analysis. Following these ideas quantitative study of general slope aspects of Doon of Dehra has been carried out.

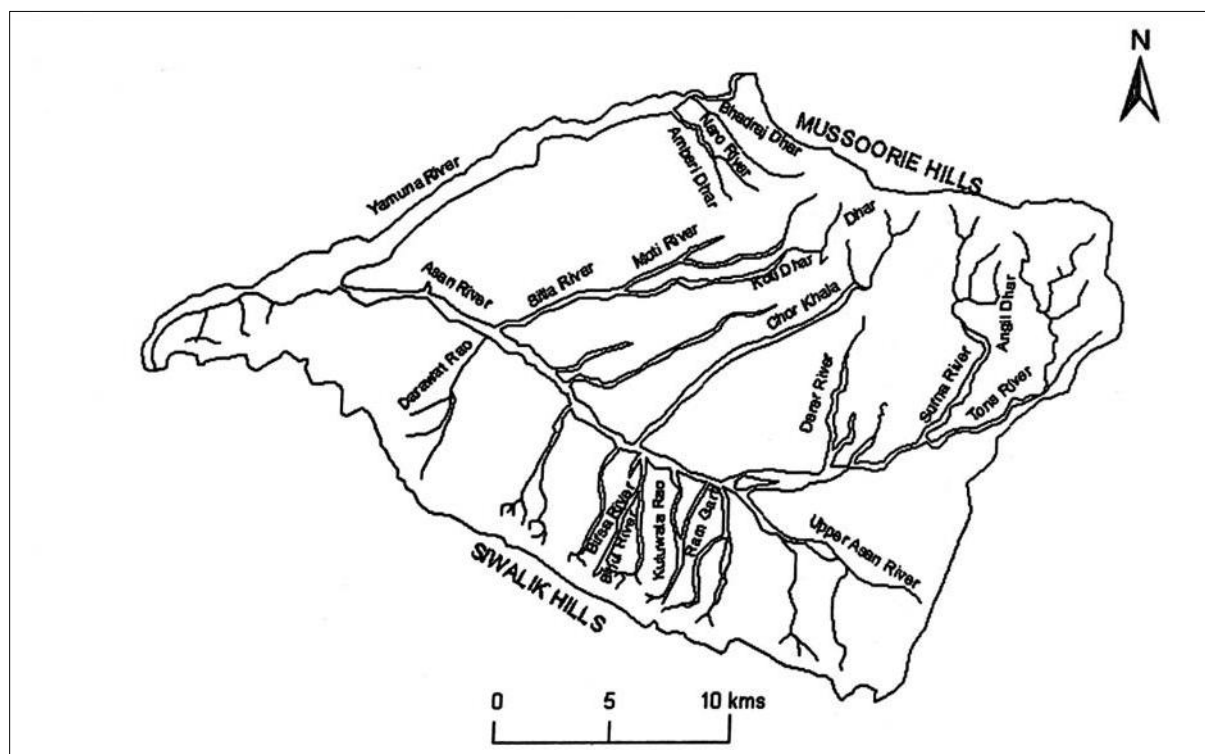


Figure 2 Major Hills and Drainage

## 2. Database and methods

Topographical sheets published by the government of India are the database of study. The topographical sheets bearing sheet numbers - 53F/10, 53F/11, 53F/15, 53F/14, 53J/3 covers the Western Doon of Dehra. The scale of these sheets is 1:50000. Various methods of slope analysis have been suggested by different scholars, like S. Finsterwalder (1890), C.K. Wentworth (1930), G.H. Smith (1935), E. Raize and Henry (1937), A.H. Robinson (1948), A.N. Strahler (1956). In the present study the method proposed by C.K. Wentworth (1930) has been used, as this gives a satisfactory picture of average slope. The formula has been changed into a metric system. The formula used is as under:

$$\tan\theta = (\text{No. of contour cutting per km} \times \text{contour interval} \times 3.3) / 3361$$

## 3. Analysis and interpretation

### 3.1. Spatial Pattern of Average Slope

The magnitude of slope has been categorized in five classes viz., very gentle ( $0^\circ$ - $2^\circ$ ), gentle ( $2^\circ$ - $5^\circ$ ), moderate ( $5^\circ$ - $10^\circ$ ), moderately steep ( $10^\circ$ - $20^\circ$ ) and steep ( $> 20^\circ$ ). Gentle slope, which includes a very gentle and gentle slope extends to 446.81 sq. Km in the study area. This area constitutes more than 53% of basins. This category of gentle slope is found on both sides of Asan River on flood plains and younger Doon gravels. North-western portion of the study area in the west of Bin- catchment, bordering Yamuna River, also exhibits gentle slopes (Figure-3). This area is characterized by fine alluvial soil, younger doon gravels and alluvial terraces. The accumulation of debris is very heavy in this area. It is seen in the shape of the piedmont zone. These deposits are poorly cemented and loose. So the migration of river channels and lateral erosion are rapid. Lithologically, this zone of gentle slope consists of sand, gravels, pebbles and boulders. This zone is characterized by low absolute relief, low relative relief, low drainage density and frequency. This is the zone of intensive agriculture in lower parts along Asan and the area bordering Yamuna River.

Steep slopes ( $> 20^\circ$ ), which occupy more than 15% (180 sq. km.) area, extends on Pre-Tertiary, Lower Tertiary and limited upper portions of Middle Siwaliks (Figure-3). This is the zone of high hills. According to geologists this zone is

much disturbed by tectonic movements. Mass wasting is most common in this area. This zone is also covered by high level fans at a few places. Deep and narrow valleys, scarp faces, waterfalls, dendritic to sub-dendritic drainage patterns, high to moderate drainage density and frequency are the characteristics of this region. The lower part of this zone is almost covered with forests and shrubs, except for a few patches of agricultural land. The upper reaches of this category are barren. This category of slope is poorly settled, except the eastern portion of the ridge, where Mussoorie is located.

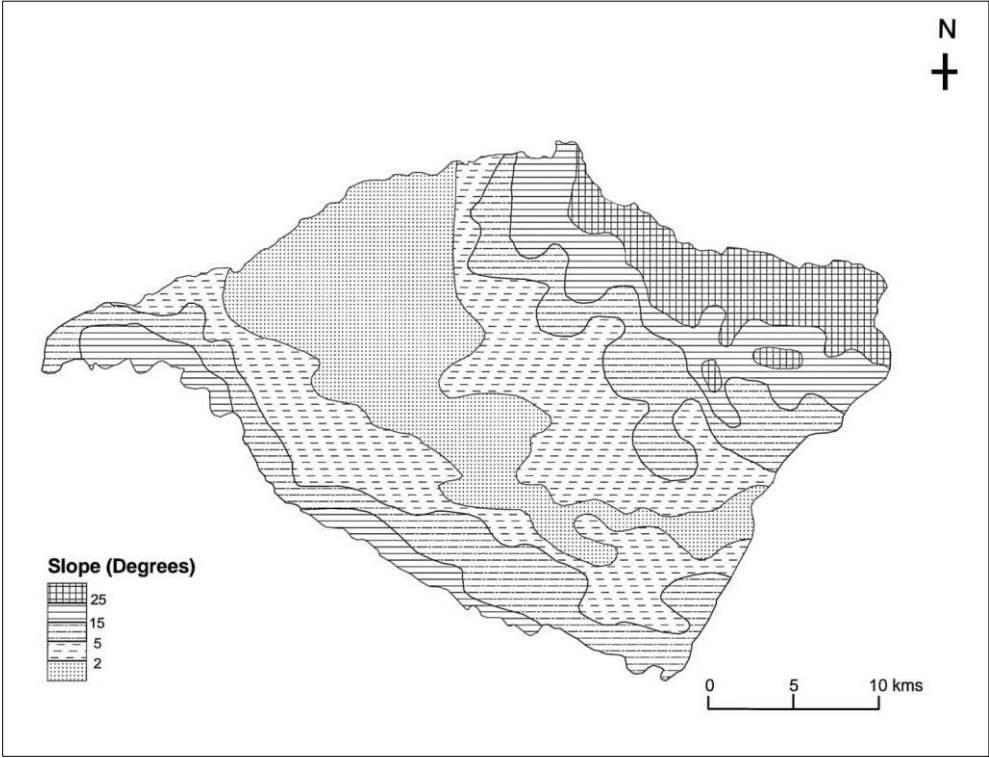


Figure 3 Average Slope of Western Doon of Dehra

In-betweens these two zones of gentle and steep slopes, there is the zone of moderate (5°-10°) and moderately steep (10°-20°) slopes. These slopes cover 14.43% and 16.43% of the total study area, respectively. These slopes extend on the middle and upper parts of Siwalik range in south of Asan and in upper parts of younger Doon gravel, older Doon gravels, hillocks and erosional hills. This zone has transitional character of the above discussed two categories. Maximum portion of this zone is covered by forests.

Table 1 Areal Distribution of Average Slope

| Slope (Degrees)                                | Area in Km2 | Percent Area | Cumulative Area | Cumulative percentage |
|------------------------------------------------|-------------|--------------|-----------------|-----------------------|
| < 2                                            | 227.7       | 27.28        | 227.7           | 27.28                 |
| 2 – 5                                          | 219.11      | 26.26        | 446.81          | 53.54                 |
| 5 – 10                                         | 120.13      | 14.43        | 566.94          | 67.97                 |
| 10 – 15                                        | 63.64       | 7.63         | 630.58          | 75.6                  |
| 15 – 20                                        | 73.44       | 8.8          | 704.02          | 84.4                  |
| 20 – 25                                        | 50.26       | 6.02         | 754.28          | 90.42                 |
| 30 – 35                                        | 30.89       | 3.7          | 827.85          | 99.23                 |
| > 35                                           | 6.43        | 0.77         | 834.28          | 100                   |
| Mean: 9.83°; Coefficient of Variation = 177.52 |             |              |                 |                       |
| Standard Deviation = 17.45; Variance = 340.50  |             |              |                 |                       |

It is observable from the table (1) that the value of average slope is  $9.83^\circ$  and the standard deviation is 17.45. The value of standard deviation is far above the mean value of average slope. This indicates the high variation in the distribution of slopes from the mean slope. This fact is also supported by the high value of coefficient of variation (177.52%). The statistical analysis reveals the non-homogeneity of terrain in respect of distribution of slopes.

Minute study of isopleths of slopes at the interval of  $2^\circ$  and  $5^\circ$  reveals that there are certain breaks of slope at the zone of  $25^\circ$  to  $30^\circ$ ,  $10^\circ$  to  $15^\circ$ ,  $5^\circ$  to  $10^\circ$ . Regional breaks of slopes are also observed in Nun, Sitla and Bin basins. Pattern of slope also changes rapidly at the extreme western portion of basin near the mouth of Yamuna in the study area. These major changes of slopes may be related to thrust, faults and lineaments.

**Table 2** Spatial Distribution of Land Uses in Various Categories of Average Slope

| Average Slope in Degree s (Classes) | Area in square kilometres |                  |                             |              |        | Percentage of each land use in category |                  |                             |              |        |
|-------------------------------------|---------------------------|------------------|-----------------------------|--------------|--------|-----------------------------------------|------------------|-----------------------------|--------------|--------|
|                                     | Forest ed Area            | Cultivat ed Land | Barren & Uncultivat ed Land | Settleme nts | Total  | Forest ed Area                          | Cultivat ed Land | Barren & Uncultivat ed Land | Settleme nts | Tot al |
| 0-2                                 | 36.23                     | 142.81           | 37.11                       | 10.55        | 227.70 | 15.91                                   | 63.12            | 16.30                       | 4.63         | 100    |
| 2-5                                 | 126.04                    | 69.66            | 18.20                       | 5.21         | 219.11 | 57.52                                   | 31.79            | 8.31                        | 2.38         | 100    |
| 5-10                                | 80.16                     | 24.71            | 12.74                       | 2.52         | 120.13 | 66.73                                   | 20.57            | 10.6                        | 2.10         | 100    |
| 10-15                               | 36.25                     | 16.48            | 6.94                        | 4.27         | 63.64  | 56.48                                   | 25.90            | 10.91                       | 6.71         | 100    |
| 15-20                               | 51.95                     | 11.22            | 10.03                       | 0.24         | 73.44  | 70.73                                   | 15.28            | 13.66                       | 0.33         | 100    |
| 20-25                               | 36.49                     | 6.19             | 7.25                        | 0.33         | 50.26  | 72.60                                   | 12.32            | 14.43                       | 0.65         | 100    |
| 25-30                               | 15.31                     | 6.47             | 20.71                       | 0.19         | 42.68  | 35.87                                   | 15.16            | 48.52                       | 0.45         | 100    |
| 30-35                               | 4.25                      | 2.23             | 24.41                       | 0.00         | 30.89  | 13.76                                   | 7.22             | 79.02                       | 0.00         | 100    |
| > 35                                | 0.15                      | 0.00             | 6.28                        | 0.00         | 6.43   | 2.33                                    | 0.00             | 97.67                       | 0.00         | 100    |
| Total                               | 386.83                    | 279.47           | 144.67                      | 23.31        | 834.28 |                                         |                  |                             |              |        |

The areas having slope  $0^\circ$  to  $2^\circ$  are adhesive for settlements and cultivation. as table (2) depicts that more than 63% of total land in this category is under agriculture. This table also depicts the high concentration of settlements in this belt of slope. In the categories of moderate and steep slopes, the slopes ranging from  $10^\circ$  to  $15^\circ$  are favourable for the cultivation and settlements. the slopes from  $15^\circ$  to  $25^\circ$  are favoured slopes for forests. more than 70% of total land under this category is under the forests. High concentration of barren land is found in the slopes above  $30^\circ$ . These slopes must be brought under shrubs to check the incidences of landslides and excessive erodibility.

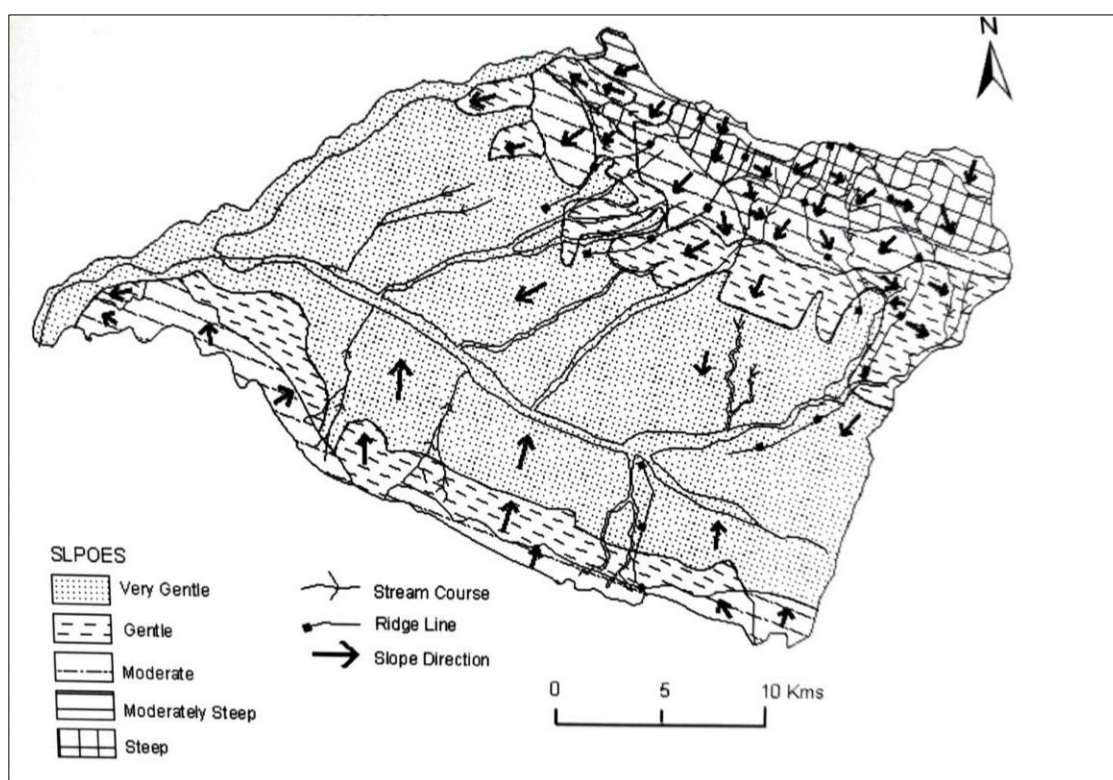
### 3.2. Slope Morphometry

Slope morphometry map (Figure-4) was prepared by dividing the topographical map into smaller units (facts) within which the contour lines have the same standard spacing. Facets are a part of the hill slopes, characterized by equally spaced contour lines and same slope direction. The distribution of different slopes have been given in table (3).

There is a large variation in the distribution of slopes in the area. The slope varies between  $<1^\circ$  and  $39.5^\circ$ . Fig ( 4 ) reveals that a large part of the area in the north contains steep slopes; whereas, the central and north western region bordering Yamuna is marked by gentle slopes. Southern uplands exhibit moderately steep slopes.

**Table 3** Morphometric Distribution of Slope

| Description            | Slope angle (degree) | Area (Km <sup>2</sup> ) |
|------------------------|----------------------|-------------------------|
| Very gentle slope      | 0 – 2                | 493.19                  |
| Gentle Slope           | 2 – 5                | 155.78                  |
| Moderate Slope         | 5 – 15               | 107.28                  |
| Moderately steep slope | 15 – 25              | 45.14                   |
| Steep slopes           | > 25                 | 32.89                   |
| Total                  | —                    | 834.28                  |

**Figure 4** Slope Morphometry

### 3.3. Directions of Slope

Slope direction or slope angling is an important characteristic that should be considered in analysis of terrain, particularly in mountainous regions. In the present analysis the term slope-direction has been used to show the distribution of shady and sunny aspects of slopes. This aspect of study has greater functional utility. Shady slopes are not easily eroded, hence stable. Shady slopes are generally covered with forests; while sun facing slopes are covered with agriculture and settlements. These slopes are also easily erode able, hence less stable and may be developed into areas of steep slopes and zones of landslides. The area under study has been divided into shady (315°–45°), eastern shady (45°–90°), eastern sunny (90°–135°), sunny (135°–225°), western sunny (225°–270°) and western shady (270°–315°) slopes (Figure -5).

The total area under study is 834.28 sq. km. and out of this total area only 369.98 sq. km is mountainous that is needed to be studied in respect of slope angling. Table (4) reveals that a large part (51.47%) of the mountainous area has sunny slopes followed by shady slopes. A glance at the figure (5), shows that the sunny slopes are predominantly distributed in the central and eastern flank of Mussorrie hills; while shady slopes are mainly distributed in the northern slopes of Siwaliks. Sunny-western and shady-western slopes mainly occurred at western flank of Mussorrie hills. Shady-eastern and sunny-eastern slopes are distributed in form of small patches and strips in Mussorrie hills.

Table 4 Slope Segment and Landuse

| Slope Segment | Direction in Degrees | Value | Total Area (Km2) | Forests | Cultivated Land | Barren Land | Settlements | Drainage |
|---------------|----------------------|-------|------------------|---------|-----------------|-------------|-------------|----------|
| Shady         | 315° – 45°           |       | 146.34           | 138.22  | 2.23            | 0           | 0.2         | 5.69     |
| Shady (E)     | 45° – 90°            |       | 2.75             | 2.75    | 0               | 0           | 0           | 0        |
| Sunny (E)     | 90° – 135°           |       | 11.96            | 3.64    | 0.81            | 7.41        | 0.1         | 0        |
| Sunny         | 135° – 225°          |       | 132.78           | 47.24   | 23.69           | 54.82       | 5.28        | 1.75     |
| Sunny (W)     | 225° – 270°          |       | 45.69            | 14.79   | 17.41           | 10.03       | 1.99        | 1.47     |
| Shady (W)     | 227° – 315°          |       | 30.46            | 22.21   | 1.31            | 6.73        | 0.21        | 0        |
| Total         | —                    |       | 369.98           | 228.85  | 45.45           | 78.99       | 7.78        | 8.91     |

It has been stated in preceding text that human activities primarily develop on sunny slopes. In this basin, sunny, eastern-sunny and western-sunny slopes cover about 51.47% of the total mountainous region. These sunny slopes exhibit 92.2% of total cultivated land, 94.7% of total settlement and 28.7% of total forested area of this morpo-unit (mountainous region). More than 92% of total barren land is found on these sunny slopes. This may be attributed to the fact that

these facets may have steep and unstable slopes due to more weathering of rocks by heating of the surface due to sun-rays. The steep and unstable slopes negatively affect the growth of vegetation. These coincidences, confirm the dictum that the sunny slopes are favoured slopes for human activities and settlements. Table (4) also confirms the dictum that sun-facing slopes have steep slopes.

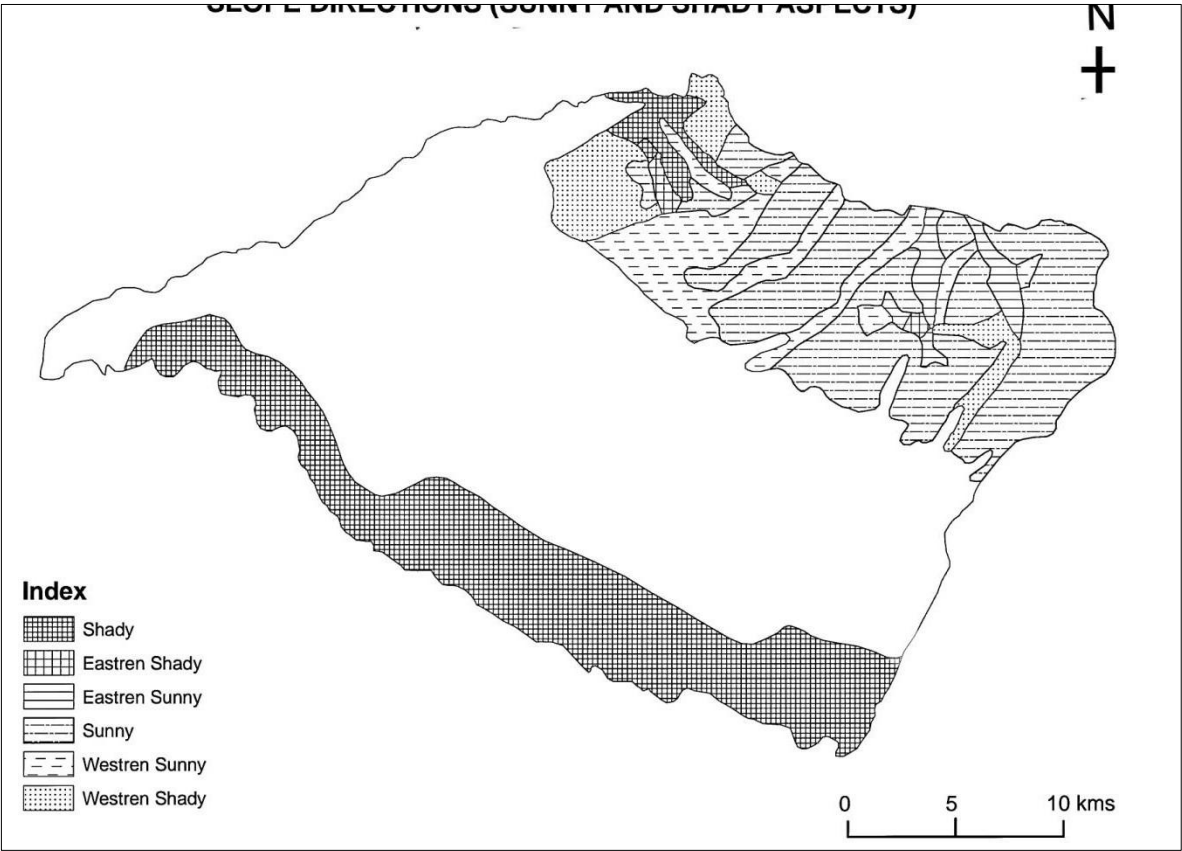


Figure 5 Slope Direction

In shady slopes, 4.2% area of total shady slopes have slopes more than 15° while in sunny slopes 36.5% area have slopes more than 15°. However, steepness of slope is not only the factor of sunny and shady aspects of slopes, various endogenic and exogenic factors may be responsible for steepness. Shady slopes cover 48.33% of the total area of this unit. More than 91% of total area under shady slopes is covered under forests (table-4). Cultivated land on these slopes has less than 2% of total area in this category. Similarly, these shady slopes have very less portion of total settled area in the mountainous region.

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#### 4. Conclusion

The average slope in the study area is steep to gentle, ranging from little more than 0° to 39.5°. Gentle slope (0-5°) extends over 53% (446.81 sq. Km) of basins. This category of gentle slope is found on both sides of Asan River on flood plains and younger Doon gravels. Steep slopes (> 20°), which occupy more than 15% (180 sq. km.) area, extends on Pre-Tertiary, Lower Tertiary and limited upper portions of Middle Siwaliks. Minute study of isopleths of slopes at the interval of 2° and 5° reveals that there are certain breaks of slope at the zone of 25° to 30°, 10° to 15°, 5° to 10°. These major changes of slopes may be related to thrust, faults and lineaments. The areas having slope 0° to 2° are adhesive for settlements and cultivation. In the categories of moderate and steep slopes, the slopes ranging from 10° to 15° are favourable for the cultivation and settlements. The slopes from 15° to 25° are favoured slopes for forests. The statistical analysis reveals the non-homogeneity of terrain in respect of distribution of slopes. More than 70% of total land under this category is under the forests. High concentration of barren land is found in the slopes above 30°.

Sunny slopes cover about 51.47% of the total mountainous region in the study area. The sunny slopes exhibit 92.2% of total cultivated land, 94.7% of total settlement and 28.7% of total forested area of this morpo-unit (mountainous region). Shady slopes cover 48.33% of the total area of this unit. More than 91% of the total area under shady slopes is covered under forests. Cultivated land on these slopes has less than 2% of total area in this category. Similarly, these shady slopes have very less portion of total settled area in the mountainous region.

To conclude it may be stated that breaks of slopes may be related to thrust, faults and lineaments. Sunny slopes bearing slopes from 10° to 15° are favourable for settlements and agriculture in mountainous regions. Shady slopes from 15° to 25° are favourable for forests.

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#### Compliance with ethical standards

##### *Disclosure of conflict of interest*

No conflict of interest to be disclosed.

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