# Appraisal of Fluvial Morphometry using RS and GIS Techniques; A Case Study of Lower Kosi Watershed, Central Himalaya

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*Abstract: The morphometric study of land forms is an indispensible part of watershed management. The infrastructure development and land use planning  in Himalayan terrain is controlled by the various geo – environmental factors, viz. the nature of rocks, slope, gradient, valleys, rock debris and streams etc. An attempt has been made to investigate the morphometric characteristics of study area. The data analysis and mapping have been done with the help of CARTOSAT-1 data (2.5m resolution), SOI toposheet No. 53 O/2, 53 O/3, 53 O/4, 53 O/6, 53 O/7 and QGIS software. Morphometric characteristics of the watershed has been analysed through measurement of linear, areal and relief aspects of the watershed. According to the hierarchy of orders, the seventh order Lower Kosi river provides existence to 2705 first order, 565 second order,133 third order, 24 fourth order, 4 fifth order, 1 six order and 1seventh order. The minimum bifurcation ratio (1) is found between six and seven order stream while maximum ratio (6) is found between third and fourth order streams. Minimum stream length ratio (1.51) found between first and second order stream length while maximum stream length ratio (3.63) has been found between fifth and six order stream. The basin perimeter of the watershed is 178.20 km, basin length is 58.95 km, form factor is 0.264, circularity ratio is 0.36 and elongation ratio is 0.56. Rest studied parameters also exhibit geomorphometric diversity, i.e. 224 m to 2575 m (absolute relief), 0.75 m to 705 m (relative relief), 0.001 – 0.44 (dissection index), 0° to 55° (Slope), 0 to 17 (stream frequency), 0 to 7.28 (drainage density). Fluvial morphometric analysis may be useful for micro level planning and management of Lower Kosi watershed.*

*IndexTerms* – **CARTOSAT-1, morphometry,watershed,watershed management,micro level planning.**

## I. INTRODUCTION

Morphometric analysis is very important for watershed management and such studies become more significant in reference to hilly area like Himalaya due the topographical diversity of the terrain. The construction activities by human being in hilly terrain are affected by the relief, slope and drainage of the area. The constructional activities and land use pattern in mountainous terrain is controlled by the various geo – environmental factors, viz. the nature of rocks, slope, gradient, valleys, rock debris and streams etc. All the above facts are indispensible part of morphometric study of land forms. Measurement of the shape, or geometry, of any natural form – it plant, animal or relief features– is termed morphometry but in geomorphology 'morphometry may be defined as the measurement and mathematical analysis of the configration of the earth surface and of the shape and dimensions of its landforms' (Clarke, 1966)**.**  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 (Singh, 1992). Morphometric analysis of a watershed provides a quantitative description of the drainage system, which is an important aspect of the characterization of watersheds (Strahler, 1964). Geomorphometry is an important component of terrain analysis and surface modelling. Its specific applications include measuring the morphometry of continental ice surfaces, characterizing glacial troughs, mapping sea-floor terrain types, guiding missiles, assessing soil erosion, analysing wildfire propagation, and mapping eco regions (Pike 1995, 1999).  Pareta and Pareta (2011) studied morphometric characteristics of Karawan watershed in Dhasan basin, computed more than 85 morphometric parameter. Murthy et al. (2014) studied morphometric analysis through measurement of linear, aerial and relief aspects of Cauvery sub basin.

## II. OBJECTIVE

An attempt has been made in this study to investigate the morphometric characteristics of study area.

## III. STUDY AREA

 The study region extends between the latitudes of 29° 9' 51" N and 29° 36' 22" N and the longitudes of 79° 2' 42" E and 79° 28' 21" E "Fig.1". The watershed lies in districts of Almora, Nainital and Udham Singh Nagar in Uttarakhand State and constitutes a part of West Ramganga drainage system of Uttarakhand Himalaya. The watershed encompasses an area of about 917.69 km² covering Lesser Himalaya, Outer Himalaya/Siwaliks and Foot-Hill Zone reaching a maximum elevation of 2575 m and a minimum of 225 m amsl. The watershed possesses diverse soil types, viz. Haplaquolls (Tarai soils), Ustorthents (Bhabar soils), Palehumults (brown, red, yellow soils) of Outer Himalaya/ Siwaliks and Hapludalfs (Submontane soils) of Lesser Himalaya. The watershed supports four major forest types, viz. Himalayan moist temperate forest, Sub-tropical pine forest, Moist mixed
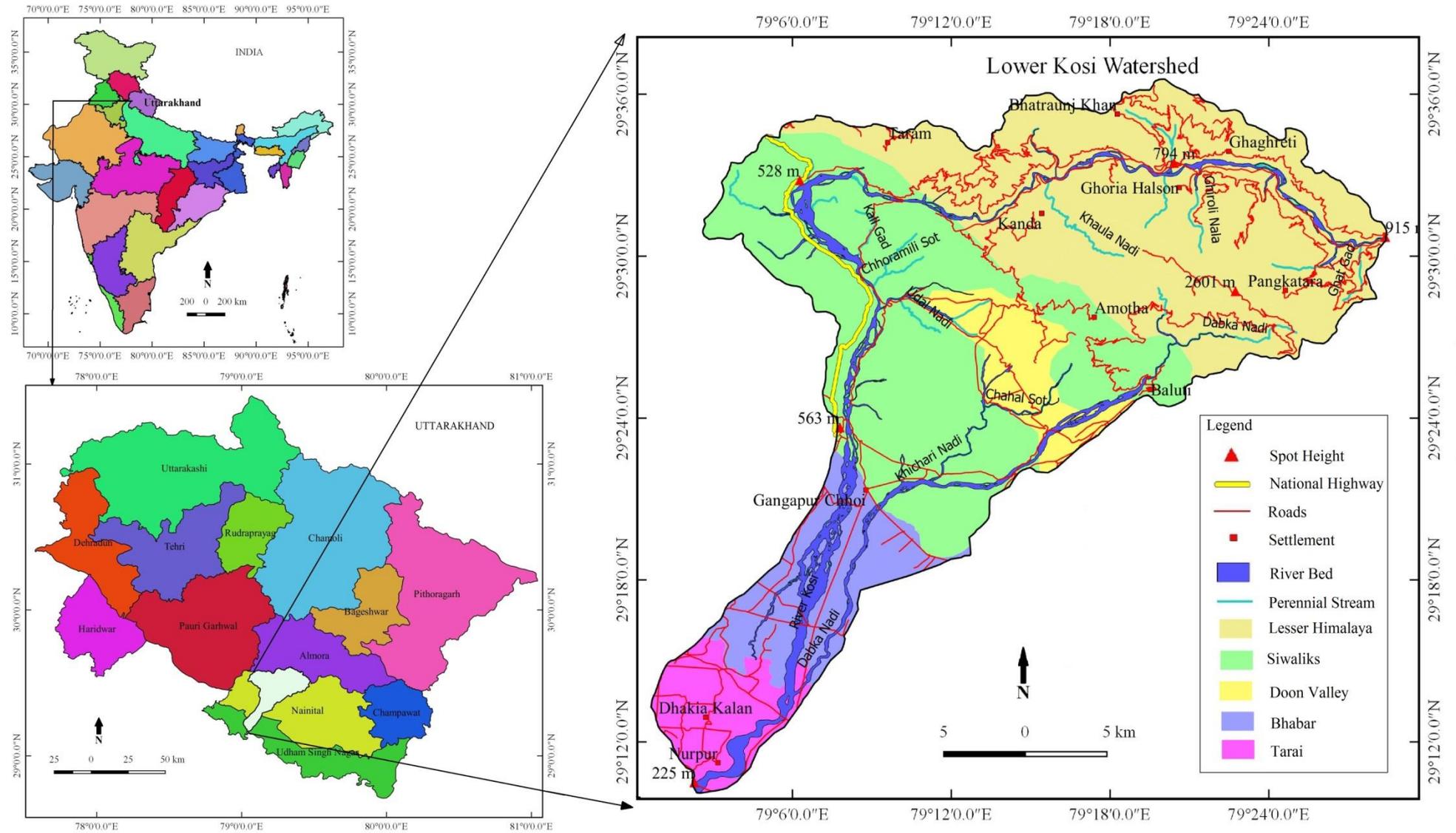
Fig..1 Lower Kosi Watershed: Location Map

deciduous forest, Moist bhabar dun sal forest. Seven types of land use/cover categories have been identified. 'Built-up area' covers, i.e. 1.23 km$^2$ (0.13%), 'River Bed' covers 44.5 km$^2$ (4.84%), 'Barren/Rocky Land' covers 100.28 km$^2$ (10.93%), 'Cultivated Land' covers 180.76 km$^2$ (19.70%), 'Open Forest' covers 54.15km$^2$ (5.90%), 'Dense Forest Land' covers 310.25 km$^2$ (33.08%), 'Moderately Dense Forest' covers 226.52 km$^2$ (24.68%) area of the watershed.

## IV. RESEARCH METHODOLOGY

The morphometric analysis of the Lower Kosi watershed is based on the Survey of India topographical sheet No. 53 O/2, 53 O/3, 53 O/4, 53 O/6, 53 O/7 (scale 1:50,000) and CARTOSAT-1 data using QGIS software. The Stream order is based on Strahler (1964). SOI toposheet no. 53 O/2, 53 O/3, 53 O/4, 53 O/6 and 53 O/7 has been used to determine the stream ordering of watershed. The computation of bifurcation ratio of each order basin is done with the help of the formula given by Horton (1932): Br = Nu/ Nu+1 Where, Br = Bifurcation Ratio, Nu = Number of stream segments of lower order, Nu+1 = Number of stream segments of higher order. The stream lengths of the various segments are measured with the help of QGIS. 4 The formula given by Singh (2014) is used to length ratio: Lr = Lu +1 / Lu Where, Lr = stream length ratio, Lu +1 =mean stream length of higher order, Lu = mean stream length of the lower order. The equation given by Horton (1945) is used to derive stream frequency: Sf = N / Ab Where, Sf = Stream frequency, N = Total number of streams, Ab = Area of the basin. With the help of QGIS software, the watershed has been divided into 927 grids of 1 km$^2$. The total number of streams per kilometre square has been measured. The formula given by Horton (1932, 1945) is used to derive drainage density: $Dd$ = L / Ab Where, Dd = Drainage density, L = total lengths of all stream segments of a basin, Ab = total area of the basin. The watershed has been divided into 927 grids of 1 km$^2$ and total length of streams per kilometre square has been measured with the help of QGIS software. The value of absolute relief is highest height in per kilometre square area has been measured which is based on CARTOSAT –I data. To obtain the value of absolute relief, the watershed has been divided into 927 grids of 1 km$^2$, with the help of QGIS software. The relative relief is obtained by Smith (1935) method: Rh = Max h – Min h Where, Rh = Relative height, Max h = Maximum height of the watershed, Min h = Minimum height of the watershed. The watershed has been divided into 927 grids of 1 km$^2$ and total length of streams per kilometre square has been measured with the help of QGIS software. The formula given by Nir (1957) is used to derive dissection index: $DI = \frac{RR}{AR}$ Where RR = Relative Relief, AR = Absolute Relief. The entire area of Lower Kosi watershed is covered by the grid of 1 km$^2$.

## V. RESULTS AND DISCUSSION

### 5.1 Stream Order

Streams are powerful geomorphic agents capable of eroding, carrying, and depositing sediment (Heggutt, 2007). Stream order is defined as a measure of the position of a stream in the hierarchy of tributaries (Leopold et. al., 1969). The first order streams are highest in all micro watersheds while highest order has the lowest number. The difference in order and size of the sub-watersheds is mainly due to physiographic and structural diversity of the area. Strahler's theory (1964) is applied in the present investigation. According to the hierarchy of orders, the seventh order lower Kosi river provides existence to 2705 first order, 565 second order,133 third order, 24 fourth order, 4 fifth order, 1 six order and 1 seven order streams in its drainage basin of 917.69 km$^2$ area **"Fig.2"**. The most noticeable thing is that the study area belongs to Lower Kosi Watershed and the trunk stream of Kosi determines 7$^{th}$ order from the Upper part of the study area (Rawat, 2007) so the Lower part of the trunk stream which belongs to the study area is considered as 7$^{th}$ order.

### 5.2 Stream Number

Horton (1945) suggested a technique to arrange the drainage network under different stream orders and concluded that the number of channel of each order of a given basin forms an inverse geometric series with the order beginning with a single segment of higher order and increasing according to a constant bifurcation ratio. His law of stream number can be expressed by the following equation:

$$Nu = R_b^{(k-u)}$$

Nu = Number of segments of a given order, R$_b$ = Bifurcation ratio, k = Order of trunk segment,
u = Stream order of the segment

He further observed that the total number of stream segments of the entire drainage basin can be expressed as follows:

$$Nu = Rbk – 1 / Rb - 1$$

Nu = the sum of segment within each order, Rb = Bifurcation ratio, k = order of the trunk segment

Table 1 illustrates that maximum number of streams (2705) are found in first order while least number of stream (1) is found in seventh order.

Table 1: Lower Kosi Watershed: Stream Number

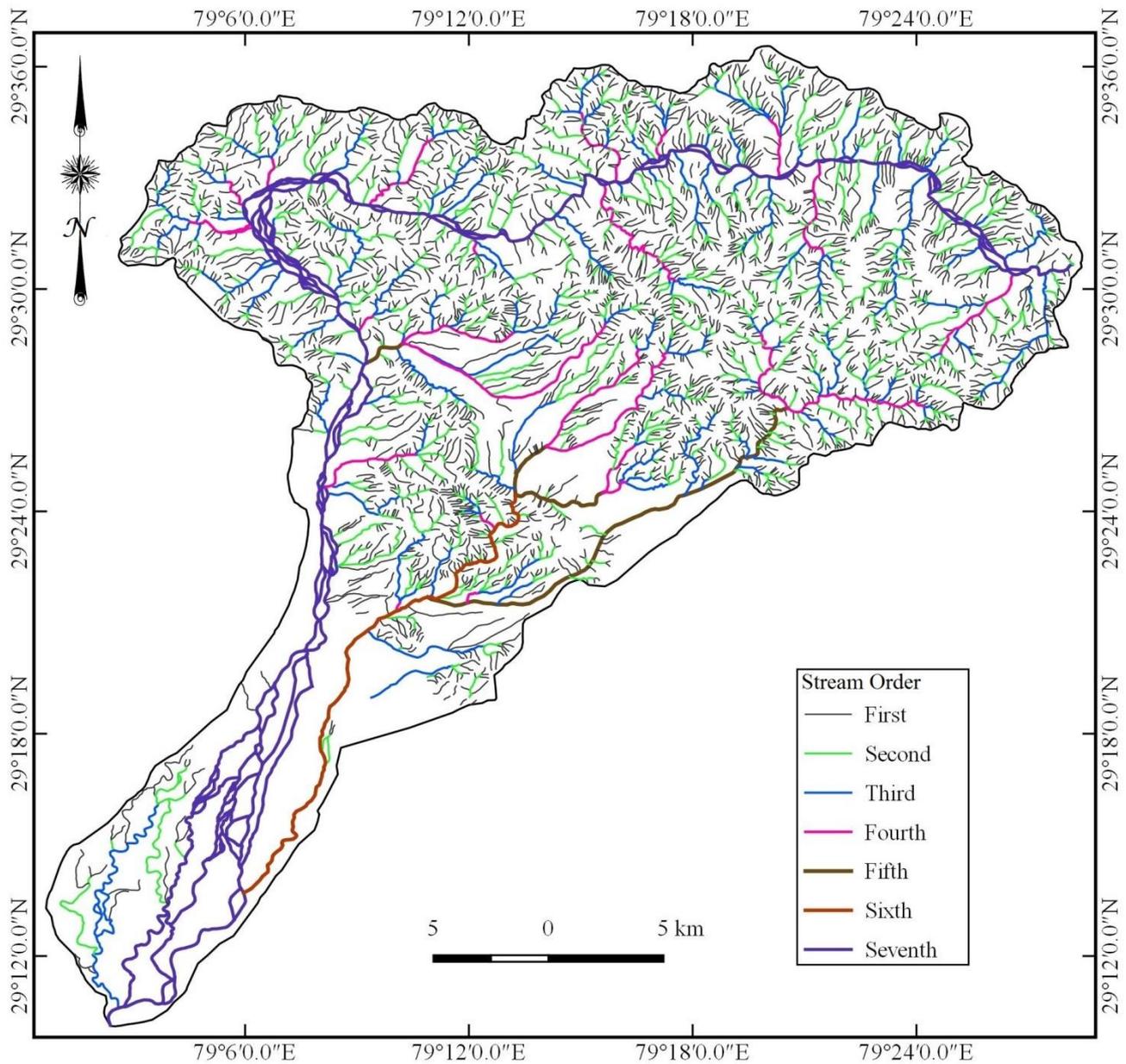| Stream Order | Number of Streams |
|---|---|
| First | 2705 |
| Second | 565 |
| Third | 133 |
| Fourth | 24 |
| Fifth | 4 |
| Six | 1 |
| Seven | 1 |

Fig.2 Lower Kosi Watershed: Spatial Distribution of Stream Order

**5.3 Bifurcation Ratio**

The bifurcation ratio is the ratio of the number of stream segments of certain order to the number of segments of next higher order. The introduction of bifurcation ratio was first brought out by Horton (1932). According to his views bifurcation ratio characteristically range between 3.0 and 5.0 for watershed in which geologic structure do not distort the drainage pattern. The theoretical minimum possible value of 2.0 is rarely approached under natural conditions. Because it is a dimensionless property and because drainage system in homogeneous materials tends to display geometrical similarity, it is not surprising that the ratio shows only a small variation from region to region. Abnormally high bifurcation ratio might expect in the regions of steeply dipping rock strata. Table 2 describes the extent of asymmetry in the distribution of bifurcation ratio.. The minimum ratio (1) is found between six and seven order stream while maximum ratio (6) is found between third and fourth order streams.

Table 2:  Lower Kosi Watershed: Bifurcation Ratio

| Stream Order | Number of Streams | Bifurcation Ratio |
|---|---|---|
| First | 2705 | 4.78 |
| Second | 565 | 4.24 |
| Third | 133 | 5.54 |
| Fourth | 24 | 6 |
| Fifth | 4 | 4 |
| Sixth | 1 | 1 |
| Seventh | 1 | - |

**5.4 Stream Length**

Stream length of watershed is depending on slope, lithology, and vegetation etc. Vegetation plays a very important role in stream length (Rawat, 1981). Low rainfall, producing semi-arid condition and gentle slope, seems to contribute to generally greater lengths of streams. In a relatively low rainfall area, the rivers have a large basin and consequently a greater length to maintain a channel. Rainfall, however, doesn't always remain the most important factor in stream lengths (Pande, 2014).

Table 3 illustrates that the total stream length decreases with increasing stream order while mean stream length increases with increasing order.

Table 3: Lower Kosi Watershed: Stream Length

| Stream Order | Total Stream Length (Km) | Mean Stream Length (Km) |
|---|---|---|
| First | 1423.1 | 0.52 |
| Second | 447.76 | 0.79 |
| Third | 274.57 | 2.06 |
| Fourth | 100.63 | 4.19 |
| Fifth | 30.46 | 7.61 |
| Sixth | 27.68 | 27.68 |
| Seventh | 91.76 | 91.76 |

## 5.5 Stream Length Ratio

The proportion of increases of mean lengths of stream segments of two successive basin orders is defined as length ratio (Singh, 2014).

The stream order and stream length have an opposite nature as the increasing behaviour of stream order indicates loss in the growth of stream length. The plain surface with horizontal rock beds causes enlargement of gullies (first order streams) and reduce the stream length ratio, consequently representing a contrary comparative relationship of stream length and stream order in different bed rock stratigraphy.

Under the impact of forest cover, slope basin shape and basin relief, the stream length ratio has a direct relation. The respective growth of these factors influences the positive growth rate of stream length ratio.

Table 4 illustrates that the stream length ratio of lower Kosi watershed. Minimum length ratio found between first and second order stream length while maximum length ratio has been found between fifth and six order stream length.

Table 4: Lower Kosi Watershed: Stream Length Ratio

| Stream Order | Mean Stream Length (Km) | Stream Length Ratio |
|---|---|---|
| First | 0.52 | 1.51 |
| Second | 0.79 | 2.6 |
| Third | 2.06 | 2.03 |
| Fourth | 4.19 | 1.81 |
| Fifth | 7.61 | 3.63 |
| Six | 27.68 | 3.31 |
| Seven | 91.76 | - |

## 5.6 Stream Frequency

Stream frequency is the measure of number of streams per unit area. Horton (1932, 1945) introduces stream frequency as the number of streams segments per unit area. In general, high stream frequency is related to solid sub surface material, sparse vegetation cover, high relief and low penetration capacity of the region.

Table 5 shows the value of stream frequency of study area. The whole watershed is divided into five categories and these categories are divisible into five stream frequency regions "**Fig3.**".

Table 5: Lower Kosi Watershed: Stream Frequency

| Stream Frequency (Stream No. /Km$^2$) | Area | | Cumulative Area | | Category |
|---|---|---|---|---|---|
| | (Km$^2$) | (%) | (Km$^2$) | (%) | |
| < 4 | 278.18 | 30.31 | 278.17 | 30.31 | Very Low |
| 4 - 8 | 452.32 | 49.29 | 730.5 | 79.6 | Low |
| 4 - 12 | 177.38 | 19.33 | 907.89 | 98.93 | Moderate |
| 12 - 16 | 9.50 | 1.04 | 917.39 | 99.97 | High |
| > 16 | 0.29 | 0.03 | 917.69 | 100 | Very High |

Maximum area is covered by low stream frequency zone constitutes 452.32 km$^2$ of the area. Excluding southern region, this zone is spread over maximum part of northern, western, middle and eastern region. Covering minimum area (9.50 km$^2$), high stream frequency group is visible in south east and central part of the watershed. One patch is also found in northern region.

## 5.7 Drainage Density

Drainage density refers to total stream lengths per unit area. Horton (1932, 1945) defined drainage density as "A ratio of total length of all stream segments in a given drainage basin to the total area of that basin."
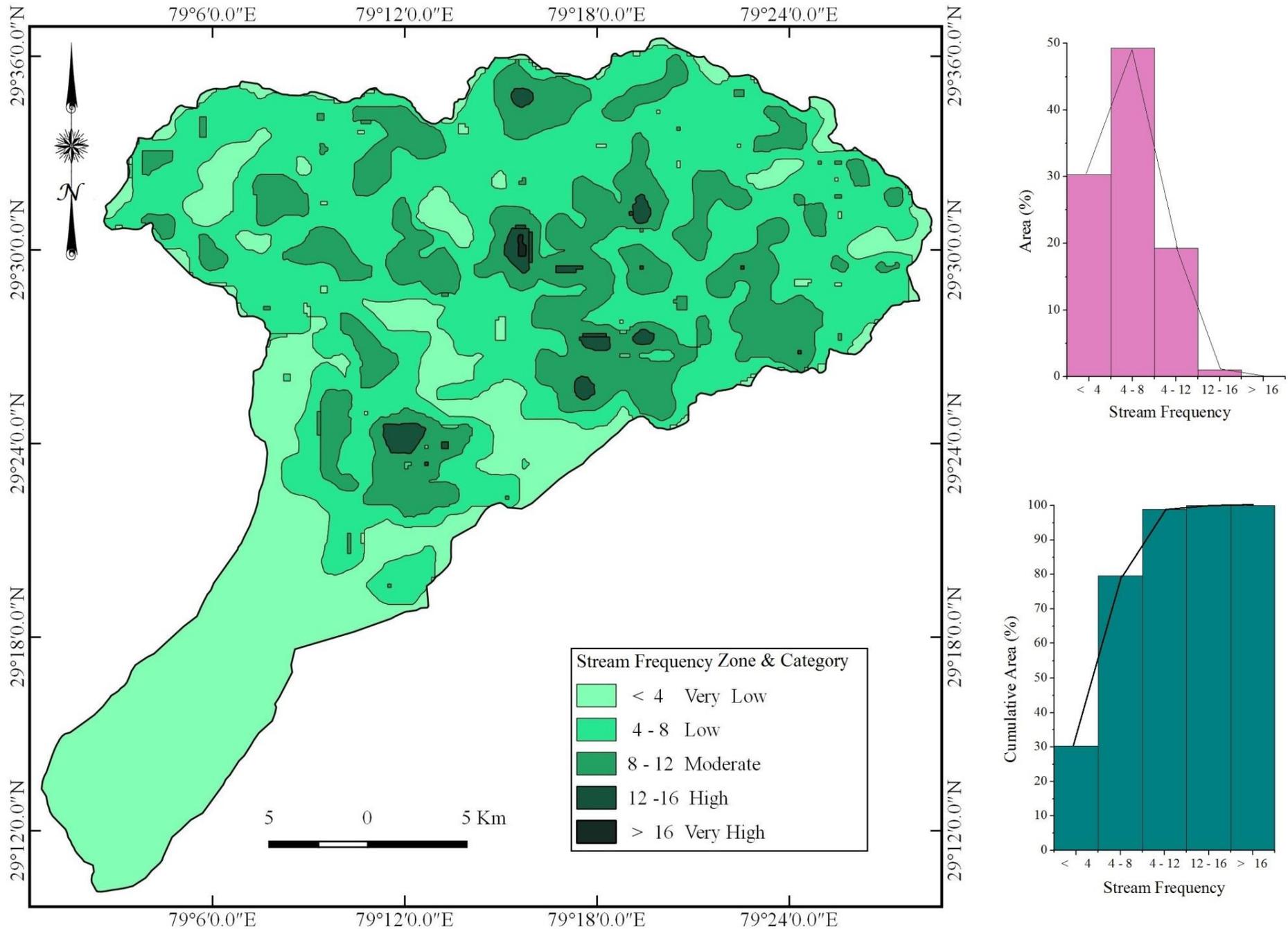
Fig.3 Lower Kosi Watershed: Spatial Distribution of Stream Frequency and Area under different Stream Frequency Zones
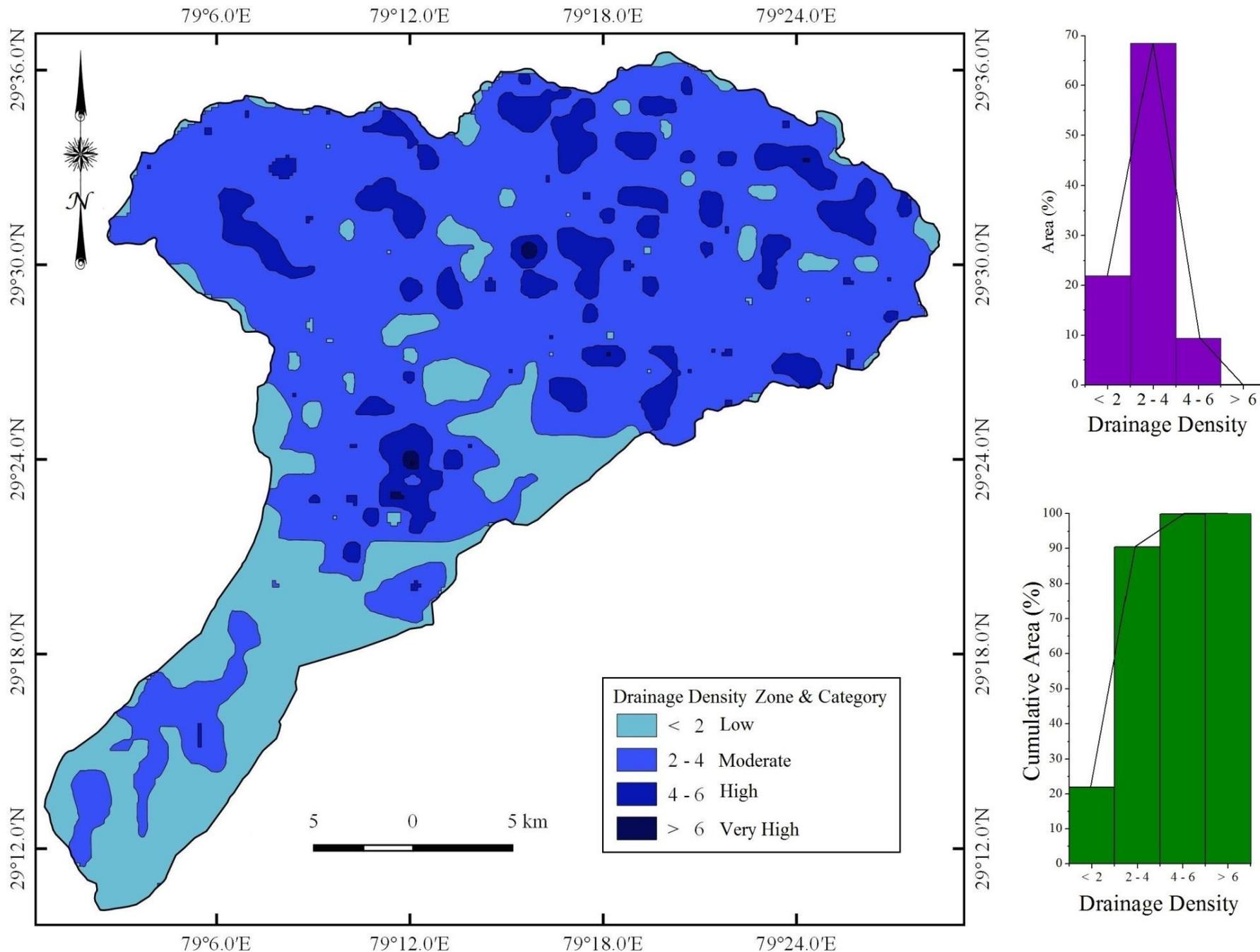
Fig.4 Lower Kosi Watershed: Spatial Distribution of Drainage Density and Area under different Drainage Density Zones
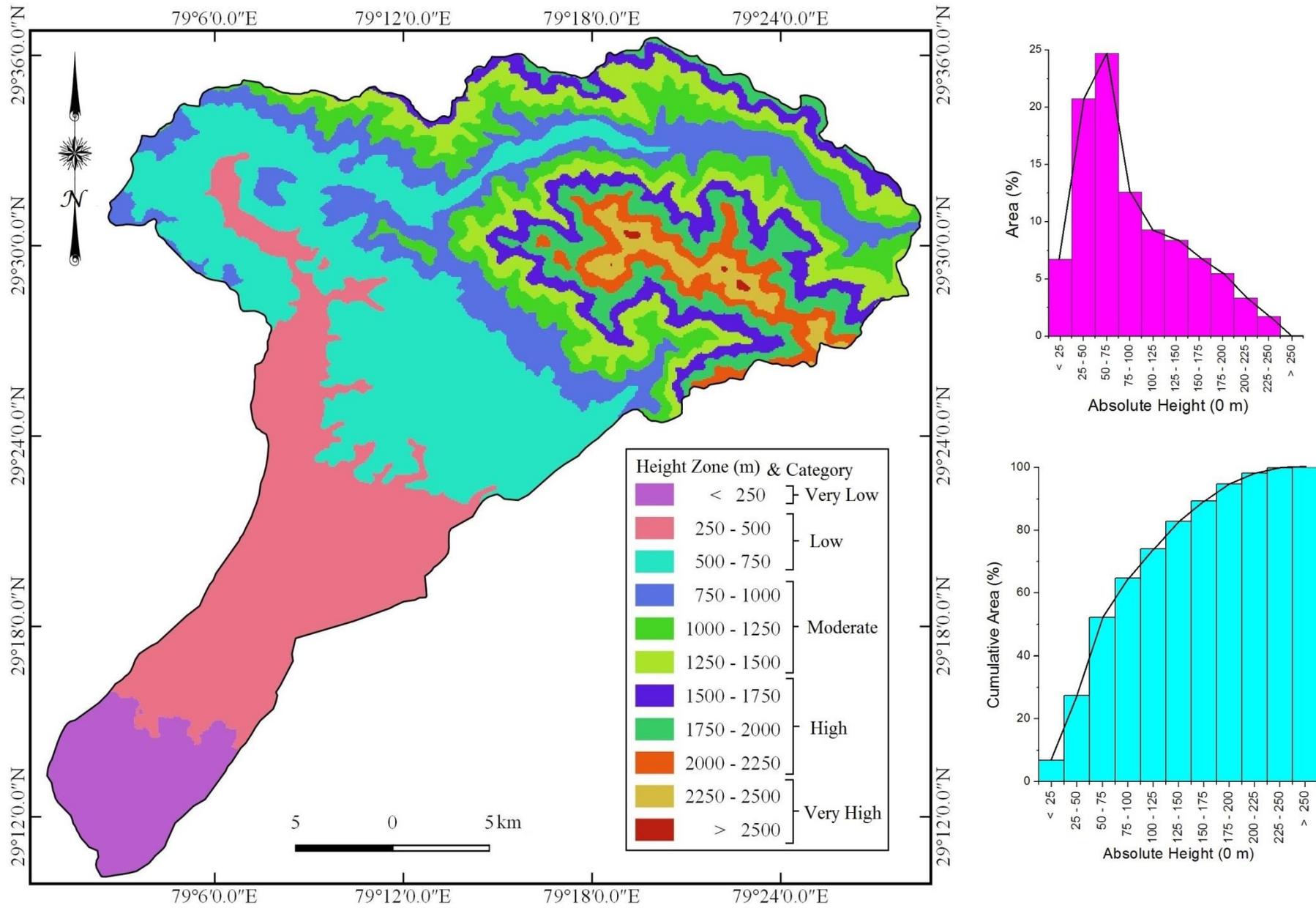
Fig.5 Lower Kosi Watershed: Spatial Distribution of Absolute Relief and Area under different Absolute Relief Zones

The drainage density indicates the closeness of spacing of channels, thus providing a quantitative measure of the average length of stream channel for the whole basin. It has been observed that low drainage density is more likely to occur in areas of high permeable subsoil material in dense vegetative cover while high drainage density is observed in areas of fragile or impermeable sub-surface materials, sparse vegetation and high mountain relief.

Table 6 represent the drainage density of lower Kosi watershed. It is divided into four categories. The maximum area of 68.53% occurs in moderate drainage density group, ranging in between the group of 2 – 4 km/km$^2$. The maximum portion of this zone is concentrated in the northern region. Some of its portion lies in the extreme southern region. Very high drainage density zone covers minimum area (1.28 km$^2$) area. Only three patches of this zone are visible in north, middle and middle south region of study area**"Fig.4"**.

Table 6: Lower Kosi Watershed: Drainage Density

| Drainage Density (Stream Length/Km$^2$) | Area | | Cumulative Area | | Category |
|---|---|---|---|---|---|
| | (Km$^2$) | (%) | (Km$^2$) | (%) | |
| < 2 | 201.16 | 21.92 | 201.16 | 21.92 | Low |
| 2 - 4 | 628.88 | 68.53 | 830.05 | 90.44 | Moderate |
| 4 - 6 | 86.37 | 9.41 | 916.42 | 99.86 | High |
| > 6 | 1.28 | 0.14 | 917.69 | 100 | Very High |

## 5.8 Relief Analysis

The relief aspects of the drainage basins are related to the study of three dimension features of the basins involving area, volume and altitude of vertical dimension of the landforms wherein different morphometric methods are used to analyze terrain characteristics, which are the result of basin processes. Absolute relief, relative relief, dissection index and slope are studied in the relief morphometry of watershed.

## 5.8.1 Absolute Relief

Per unit area maximum height above Mean Sea Level is known as absolute relief. The whole area has been divided into eleven zones at an interval of 250 meters. Table7 shows the absolute relief of the area which is ranges between 224 m to 2575 m. The maximum value (above 2500 m) of absolute relief is concentrated around the north eastern part of the watershed which covers the lowest area (0.09%) of the watershed **"Fig.5"**. 250 to 500 m zone covers maximum area (24.72 %)  of the study area.

Table 7: Lower Kosi Watershed: Absolute Relief

| Height (m) | Area | | Cumulative Area | | Category |
|---|---|---|---|---|---|
| | (Km$^2$) | (%) | (Km$^2$) | (%) | |
| < 250 | 61.94 | 6.75 | 61.94 | 6.75 | Very Low |
| 250 - 500 | 190.40 | 20.75 | 252.35 | 13.75 | Low |
| 500 - 750 | 226.86 | 24.72 | 479.21 | 52.22 | Low |
| 750 - 1000 | 115.30 | 12.56 | 594.50 | 64.78 | Moderate |
| 1000 - 1250 | 85.42 | 9.31 | 679.93 | 74.09 | Moderate |
| 1250 - 1500 | 77.13 | 8.40 | 757.06 | 82.50 | Moderate |
| 1500 - 1750 | 62.68 | 6.83 | 819.74 | 89.33 | High |
| 1750 - 2000 | 50.62 | 5.52 | 870.36 | 94.84 | High |
| 2000 - 2250 | 30.67 | 3.34 | 901.04 | 98.18 | High |
| 2250 - 2500 | 15.86 | 1.73 | 916.90 | 99.91 | Very High |
| > 2500 | 0.80 | 0.09 | 917.69 | 100.00 | Very High |

## 5.8.2  Relative Relief

Relative relief is defined as the difference in height between the highest and the lowest points (height) in a unit area, it may be grid square, rectangle or a minute – grid square (Singh, 2014). Relative relief is a very important morphometric variable which is used for the overall assessment of morphological characteristics of terrain and degree of dissection.

Table 8: Lower Kosi Watershed: Relative Relief

| Relative Relief Zone (m) | Area | | Cumulative Area | | Category |
|---|---|---|---|---|---|
| | (Km$^2$) | (%) | (Km$^2$) | (%) | |
| < 150 | 400.66 | 43.66 | 400.66 | 43.66 | Very Low |
| 150 - 300 | 164.00 | 17.87 | 564.67 | 61.53 | Low |
| 300 - 450 | 246.12 | 26.82 | 810.79 | 88.35 | Moderate |
| 450 - 600 | 102.88 | 11.21 | 913.67 | 99.56 | High |
| > 600 | 4.02 | 0.43 | 917.69 | 100 | Very High |

The relative relief of the watershed ranges between near about 0.75 m to 705 m wherein the larger part of the watershed (43.66%) falls under the very low relative relief zone **"Fig.6".** This height group stretches from central part to southern part of the watershed. Very high relative relief zone is concentrated around the north eastern part of the watershed. It covers the lowest area

(0.43 %) under study. It is obvious through the map that the very high relative relief zones of the watershed are mostly in the form of many small patches.

### 5.8.3 Dissection Index

Dissection index, expressing a ratio of the maximum relative relief of the maximum absolute relief is an important morphometric indicator of the nature and magnitude of dissection of terrain (Singh, 2014).

The value of dissection, so derived vary between 0 to 1 and the value of ratio can never be more than 1 except in the case of vertical cliff and similarly 0 value is possible only in theoretical framework. Dissection index is used as morphometric determinant of the stage of cycle of erosion wherein old, mature and young stage are related to dissection indices of less than 0.1, 0.1 to 0.3 and more than 0.3 respectively.

The value of dissection index ranges between 0.001 – 0.44. Maximum area (27.58%) of watershed is covered by moderate dissection index category and minimum area (12.52%) is covered by low dissection index category **"Fig.7".**

Table 9: Lower Kosi Watershed: Dissection Index

| Dissection Index Zone | Area | | Cumulative Area | | Category |
|---|---|---|---|---|---|
| | (Km$^2$) | (%) | (Km$^2$) | (%) | |
| <  0.07 | 176.15 | 19.20 | 176.15 | 19.20 | Very Low |
| 0.07 - 0.15 | 114.94 | 12.52 | 291.08 | 31.72 | Low |
| 0.15 - 0.22 | 253.12 | 27.58 | 544.21 | 59.30 | Moderate |
| 0.22 - 0.29 | 234.99 | 25.61 | 779.19 | 84.91 | High |
| >  0.29 | 138.50 | 15.09 | 917.69 | 100.00 | Very High |

### 5.8.4 Slope

Slope, defined as angular inclination of terrain between hill – tops and valley bottoms, resulting from the combination of many causative factors like geological structure, absolute and relative reliefs, climate, vegetation cover, drainage texture and frequency, dissection index etc. it is a very significant morphometric attribute in the study of landforms of a watershed (Singh, 2014). **"Figure 8"** depicts the distribution of slope within the area. In the watershed the slope ranges between 0° to 55 °. Table 10 shows distribution of slope of the study area. It reveals that the maximum area (50.69 %) falls in gentle slope zone and minimum area (0.40%) falls in very steep slope zone.

Table 10: Lower Kosi Watershed: Slope

| Slope Zone (°) | Area | | Cumulative Area | | Category |
|---|---|---|---|---|---|
| | (Km$^2$) | (%) | (Km$^2$) | (%) | |
| <    10 | 465.16 | 50.69 | 465.16 | 50.69 | Gentle |
| 10 - 20 | 215.06 | 23.43 | 680.22 | 74.12 | Moderate |
| 20 - 30 | 183.16 | 19.96 | 863.38 | 94.08 | Moderately Steep |
| 30 - 40 | 50.6 | 5.51 | 913.98 | 99.60 | Steep |
| >    40 | 3.71 | 0.40 | 917.69 | 100.00 | Very Steep |

### V. CONCLUSION

It can be concluded that the fluvial Morphometry is an outcome of physiographic diversity of the watershed:

i. Tarai area of watershed is constituted by Very Low Absolute Relief.  Bhabar, Doon Valley and lower part of Siwaliks is constituted by Low Absolute Relief whereas Lesser Himalayan region belongs to Moderate to Very High Absolute Relief category.

ii. Very Low Stream Frequency zone represents the Bhabar, Tarai and Doon Valley. Some small patches of Very Low Stream Frequency are also visible in Lesser Himalaya. Very High Stream Frequency zone is developed in Lesser Himalaya in form of a single small patch.

iii. Very Low Drainage Density zone represents the Bhabar, Tarai and Doon Valley. Some small patches of very low drainage density are also visible in Lesser Himalaya whereas Very High Drainage Density zone is developed only in Siwalik hills.

iv. Very Low Relative Relief zone is developed over the Bhabar, Tarai zone and maximum part of Siwalik hills whereas maximum area of Lesser Himalayan part of the watershed is constituted by Moderately High to Very High Relative Relief zone.

v. Bhabar, Tarai and Doon Valley is constituted by Very Low Dissection Index whereas Lesser Himalayan region belongs to Low to Very High Dissection Index category.

vi. Gentle Slope zone is constituted by the valley of Siwalik hills, Bhabar and Tarai region whereas Steep Slope zone belongs Lesser Himalayan part of Lower Kosi Watershed.
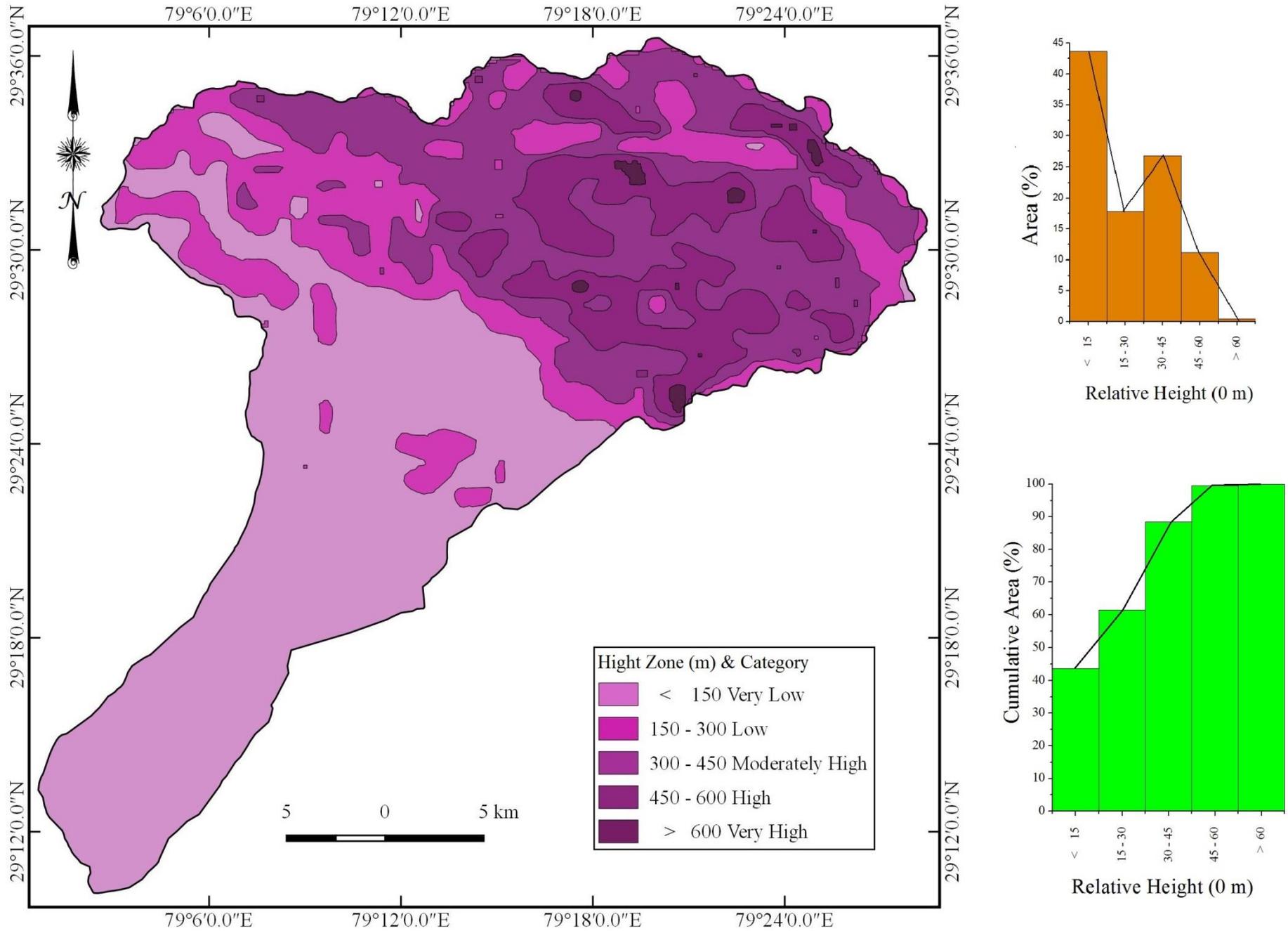
### VI. ACKNOWLEDGEMENT

Fig.6 Lower Kosi Watershed: Spatial Distribution of Relative Relief and Area under different Relative Relief Zones
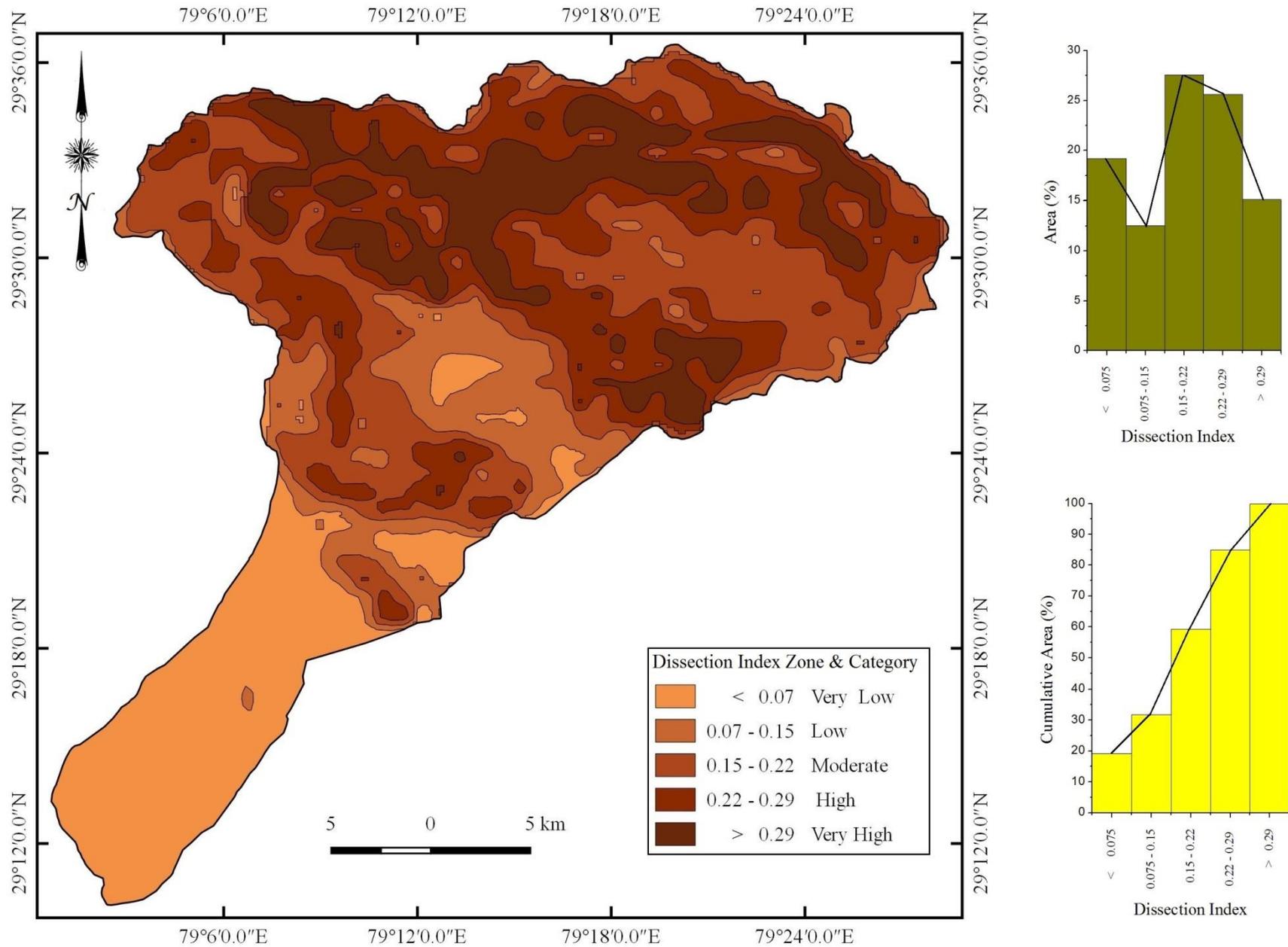
Fig.7 Lower Kosi Watershed: Spatial Distribution of Dissection Index and Area under different        Dissection Index Zones
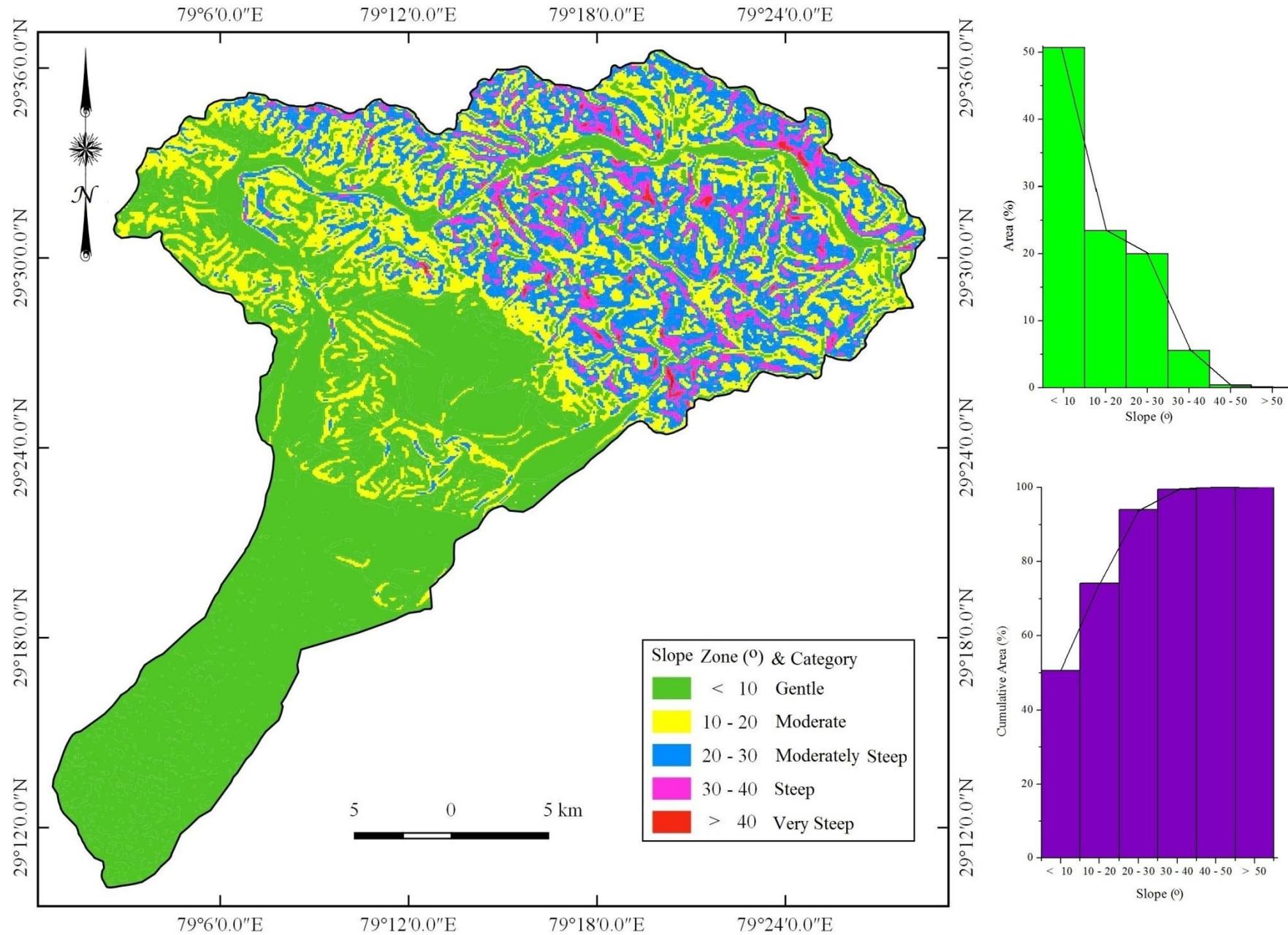
Fig.8 Lower Kosi Watershed: Spatial Distribution of Slope and Area under different Slope Zones

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