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Relief and Slope Analysis of the Upper Gori Ganga Basin, Central Himalaya

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Abstract: ***Relief and slope analysis play a fundamental role in understanding the geomorphological and environmental characteristics of mountainous regions. This study investigates the relief and slope dynamics of the Upper Gori Ganga Basin, a high-altitude Himalayan watershed, using Digital Elevation Models (DEMs) and Geographic Information System (GIS) tools. The basin's elevation ranges from 2,480 m to 7,151 m and is classified into eight altitudinal zones, with the 4,500-5,000 m zone dominating. Absolute and relative relief analyses reveal significant vertical variation, with absolute relief ranging from 4923 m to 7061 m and relative relief from 1105 m to 2651 m. Relief profiles (serial, superimposed, projected, and composite) illustrate the glacially sculpted valleys, ridges, and troughs. Slope analysis was conducted in both per cent and degree metrics, categorising the terrain from gentle (<20%) to extremely steep slopes (>100%). A significant portion (23.12%) of the basin exhibits extremely steep slopes, indicating a rugged and erosion-prone landscape. Aspect analysis shows south and southeast-facing slopes dominate the basin, influencing vegetation, snow melt, and microclimatic conditions. Overall, the study provides a detailed morphometric understanding of the Upper Gori Ganga Basin, aiding in ecological assessment, land use planning, and hazard vulnerability analysis in the fragile Himalayan terrain.***

Keywords: Relief, Slop, Upper Gori Ganga**,** Digital elevation model (DEM)

1. Introduction

Relief and slope analysis are essential for understanding the Earth's surface features, especially in geographical, environmental, and land-use studies **(Summerfield, 1991).** Relief can be defined as the difference in elevation of any part of the Earth's surface or the relative vertical inequality of land. These features are based on elevation differences and also reflect past geological events in the area **(Fairbridge,1968)**. Slope is crucial for understanding erosion, land stability, and land use suitability **(Strahler, 1950; Summerfield, 1991)**. **Singh (1975)** describes slope as the angular terrain between hilltops and valley bottoms. Several factors influence the formation of slope, including structure, climate, vegetation cover, drainage texture, drainage frequency, dissection index, and relative relief **(Evans, 1980; Moore et al., 1991).**

Both relief and slope are critical factors contributing to these issues in the Himalayan region. Therefore, relief and slope analysis are vital for studying such areas. Analysing relief and slope helps classify landforms into various morpho units and helps to understand their relations with geology, climate, and hydrology, leading to classifications such as absolute relief, slope, and relief profile. This article explores key aspects of relief and slope analysis, including the use of Digital Elevation Models (DEMs), categorisation of altitudinal zones, elevation profiles, and slope measurements, focusing on aspect, slope in degrees, and slope in per cent.

Digital Elevation Model

A digital elevation model (DEM) is a three-dimensional numerical representation of the terrain, depicted as a raster grid that records the elevation of each cell (MacKinnon, 2003; McCallum & Manson, 2011).

DEMs are important for the analysis of the spatial distribution of phenomena and processes on Earth's surface, by providing a three-dimensional perspective of topographical features at regional and smaller scales. In this study, the DEM is generated by digitising the Russian toposheet at a 1:200000 scale on 40 m contour interval, using open-source GIS software ILWIS 3.4. The DEM indicates that in the Upper Gori Ganga basin, elevation ranges from 2480 to 7120 meters. As shown in Fig. 1.1, the elevation is higher along the basin's boundaries due to tall mountain ranges, while the central part has a lower elevation because this part is dominated by river valleys.

Altitudinal Zones

Altitude is the crucial factor, responsible for the variation in climate, vegetation and slope in the hilly areas. Thus, the classification of the study area into various altitudinal zones is a critical aspect of relief analysis. The altitudinal zone map of the study area was prepared with the help of a digital elevation model. It defines the range of elevation above mean sea level. The elevation of upper Gori Ganga basin varies between 2480 meter (at the confluence of Gori ganga river and Ponting Gad) and 7151 meters (Hardeol peak). For detail study the entire basin is divided into eight altitudinal zones of 500meter contour interval, varying between less than 3000 meters and more than 6000 meters (fig. 1.2).

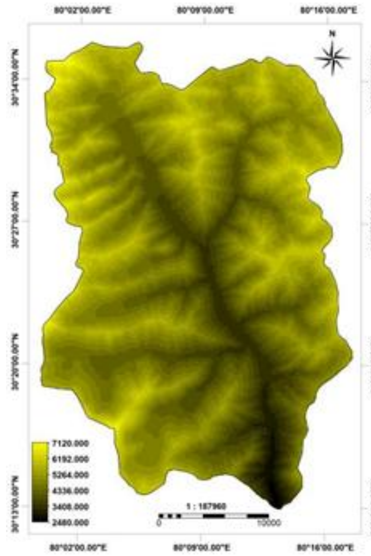

Fig 1.1: Digital elevation model (DEM) – Upper Gori Ganga Basin

Regional distribution: Regional distribution of altitudinal zone of upper Gori Ganga basin has been shown in table no. 1.1 and figure no. 1.2. Table reveals that maximum part of the basin falls under 4500 metres to 5000 metre altitudinal zone which is 24.95 percent of entire basin. Below <3000 m altitudinal zone occupied a less area which is only 0.92 percent part of basin. Altitude increases from south to north and north-west and north- east directions. At the altitude of 3000 – 5000 m, Cordyceps Sinensis is found. Figure 1.2 & Table 1.1 shows the description of the altitudinal zones of the study area.

Table 1.1 - Distribution of Altitudinal zones in the Upper Gori Ganga Basin

S. No.	Altitudinal Zones	Area (sq. Km^2.)	Area in %	Explanation
1.	<3000	8.20	0.920	Situated in the south-eastern part of the watershed. The confluence of Gori Ganga and potting Gad falls under this zone
2.	3000-3500	34.58	3.9	In this zone, forest cover decreases as the altitude increases. The size of trees becomes tiny, *Betula Utilis* and bushes are found.
3.	3500-4000	90.87	10.23	In this zone snouts of Milam (3580 m), Shalang (3909 m), Burphu (3943 m) Pachu (3941 m) glaciers are located.
4.	4000-4500	157.81	17.72	In this zone the snout of Kalganga glacier (4093 m) is located. Vegetation cover is mainly in the form of grasslands.
5.	4500-5000	222.22	24.95	The alpine vegetation land is only present in the bugyals/grasslands. Rata (4611 m) and Gonkha (4772 m) other high elevation zone glaciers have their snouts in this zone.
6.	5000-5500	195.59	21.93	This altitudinal zone has no forest cover and the entire zone is glaciated. Slope is steep to very high steep. In this zone many streams disappear in glacier without making a confluence.
7.	5500-6000	134.75	15.14	This zone is glaciated and covered with snow for the entire year of the basin
8.	>6000	46.38	5.21	This zone is the snow field of glaciers in the basin and has highest peaks such as Hardeol (7151m), Trishuli east (7074 m), Mangraon (6568), Deo Damla (6637), Sakram (6254 m.), Nanda Gond (6315 m.) and Nanda Pal (6306 m.). This zone works as a water divider from surrounding basins.
	Total	**890.40 km^2**	**100%**	

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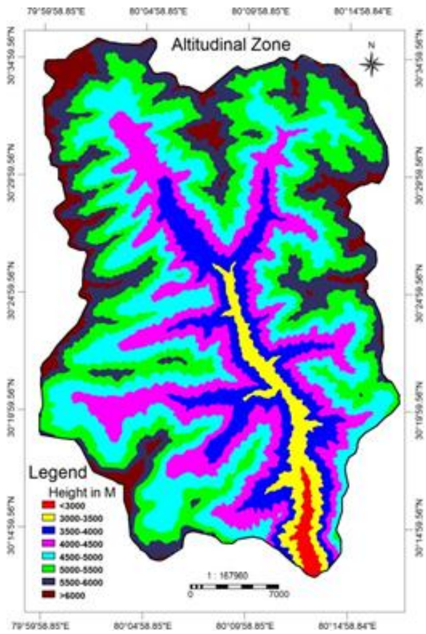

Fig. 1.2: Altitudinal Zone map of the study area.

Absolute Relief - Prasad (1985) states that the primary goal of studying absolute relief in the basin is to assess the amount of erosion relative to the current summits of the area. The absolute relief in the study area was determined using ALOS PALSAR 12 m DEM in ARCGIS 10.8. The study area has been divided into squares of 5*5 kilometres. Considering the range of elevations, four categories of absolute relief have been identified in the present study **(Fig 1.3).** In the Upper Gori Ganga Basin, the absolute relief varies from a minimum value of 4923 m in the south-eastern part and a maximum of 7061 m in the north-western part of the basin. About 23.80% of the basin has an absolute relief of <5500 m, 37.14% of the basin is characterized by 5500-6000 m in moderately absolute relief category, 34.56% of the basin area is under 6000- 6500 m of absolute relief and only a small portion, 4.50% of the area is at more than 6500 m. (Fig. 1.3 and Table 1.2).

Table 1.2: Distribution of Absolute Relief

S.no.	Range of Elevation (in m)	Area (sq. km)	Area (%)	Explanation
1.	<5500	211.971	23.80	Moderate
2.	5500-6000	330.727	37.14	Moderately high
3.	6000-6500	307.90	34.56	High
4.	>6500	40.151	4.50	Very high
Total		**890.40**	**100 %**	

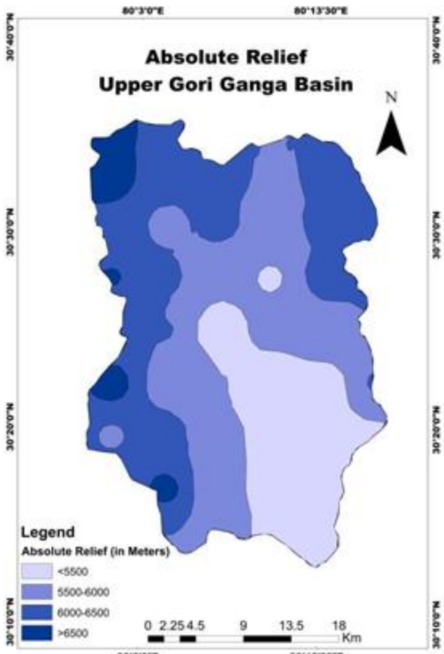

Fig. 1.3: Absolute refile of the upper Gori Gana basin

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Fig. 1.3 shows that in the Upper Gori Ganga basin, the northern and western zones have high absolute relief, exceeding 6500 meters. In contrast, the central and southeastern regions have reliefs below 5500 meters. There is a gradual transition from the high relief in the northwestern margins to the central areas. The elevated relief in the north and west aligns with the Himalayan high-altitude zones. At the same time, the central valleys are characterised by deeply incised river valleys, resulting in lower absolute relief.

Relative Relief - Relative relief refers to the difference in elevation between the highest and lowest points within a specific area. It serves as a key measurement in morphometry, used to describe the vertical variation of terrain in a region. Higher relative relief values indicate notable elevation differences, often associated with mountainous or hilly landscapes, while lower values suggest flatter or gently rolling terrain. Relative relief varies considerably across different parts of the basin. **(**Fig-1.4).

RR = MaxR – MinR (Smith,1935)

Within the Upper Gori Ganga basin, the lowest calculated relative relief is 1105 m and the highest value of relative relief is 2651 m. The average relative height of the basin is 2138 m. Further, the relative relief is divided into four (4) categories (Table 1.3 and figure 1.4).

Table 1.3: Distribution of Relative Relief Upper Gori Ganga Basin

S.no.	Range of Elevation (in m)	Area (sq. km)	Area (%)	Explanation
1.	<1500	30.85	3.46	Moderately low
2.	1500-2000	312.01	35.04	Moderate
3.	2000-2500	506.26	56.86	High
4.	>2500	41.28	4.64	Very high

The central part of the Upper Gori Ganga basin shows a large coverage (56.86%) of 2000-2500 m, which suggests moderate terrain ruggedness. Scattered high relative relief zones (>2500 m) cover an area of 4.64%, mostly in the northwestern, southwestern, and southeastern parts. 3.46% of the area falls under the <1500 m category in outer regions, indicating relatively gentler terrain. And 35.04% of the area falls under the 1500-2000 m moderate relative slope category **(Fig.1.4).** High relative relief indicates active fluvial incision and steep slopes, especially in the outer elevated ridges or spur zones.

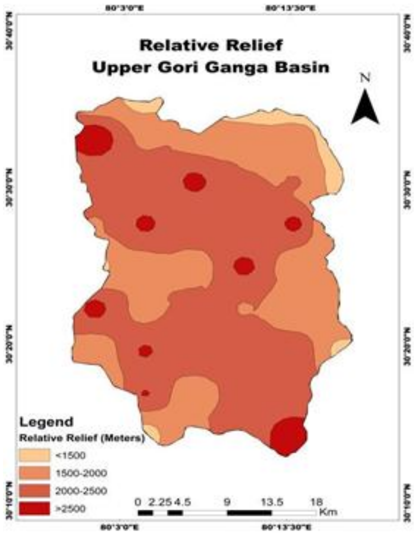

Fig. 1.4: Relative Relief of Upper Gori Ganga Basin

Relief Profiles - Relief profiles are a suitable tool for the study and analysis of terrain's morphological features of any region (Strahler,1952, Summerfield, 1991). It is a morphometric tool for determining erosional surfaces (Keller & Pinter, 2002, Sharma & Joshi, 2018). The study area cut into six slices along east to west with the help of an open-source GIS software ILWIS 3.4. The serial, superimposed, projected and composite profiles have been drawn along the east - west lines, this is to show a clear picture and also a panoramic view of the entire basin. Which presents a clear view of the landform of the entire upper Gori Ganga basin. The interpretation of the profiles of the upper Gori Ganga basin is as follows:

1. **Serial profiles -** Serial profiles present the true picture of the terrain in a particular area. To get the serial profiles of the study area, the whole basin is divided into six parallel lines (A-B, C D, E-F, G-H, I-J, K-L), then the profile lines are arranged in the vertical column representing a series from east-west (fig. 1.5), these profiles show convex slope, ridges, 'U' and 'V' shaped valleys, glacier troughs in the basin. Profile A-B shows steep ridges and incised valleys. The Small dips or secondary depressions near ridgelines indicate the possibility of the presence of cirque or a hanging valley. Profile C-D displays symmetrical ridges and troughs. Presenting wide and deep valley troughs. The deep 'V' shaped valley troughs indicate the presence of a river.

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Serial Profiles

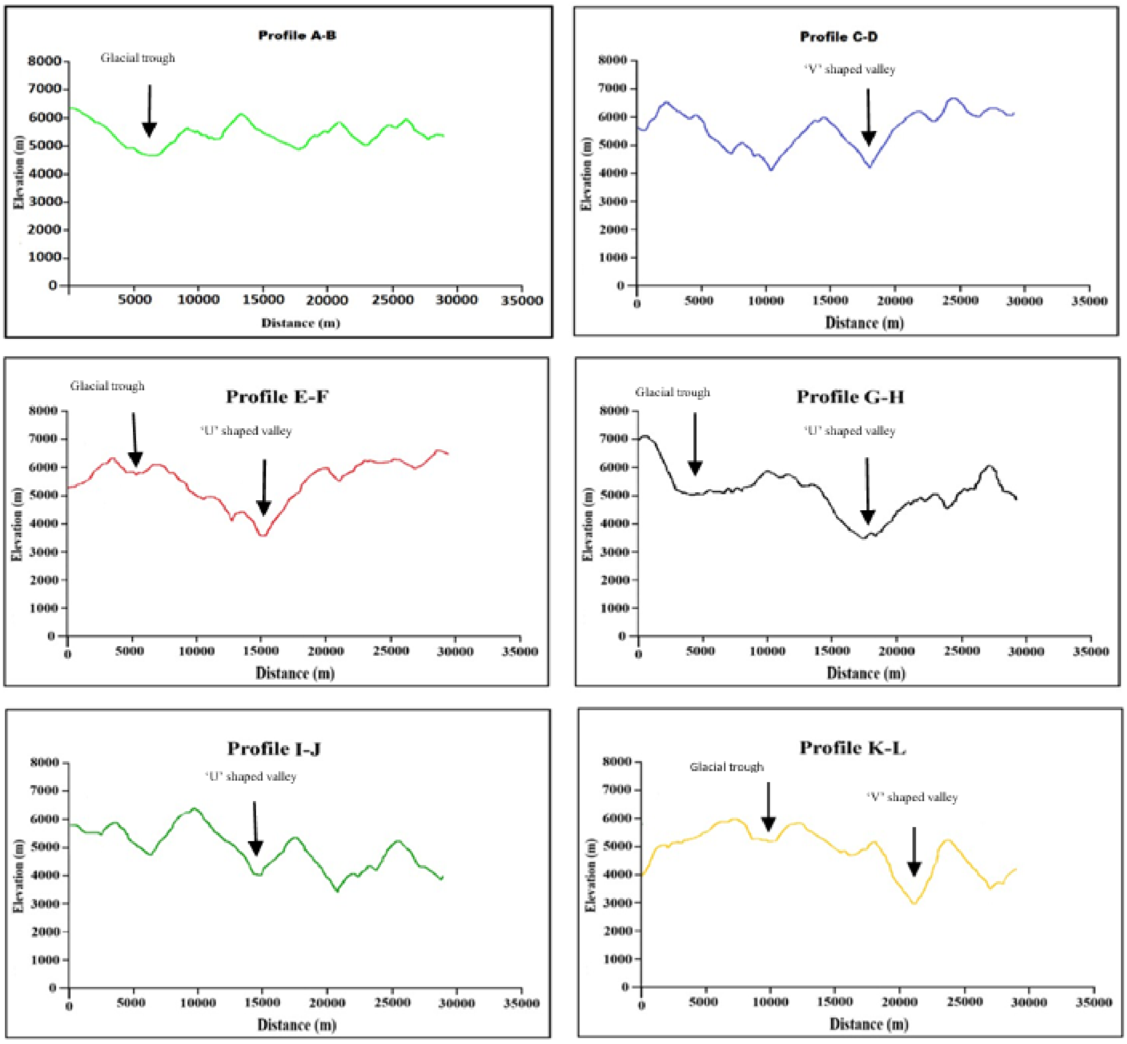

Fig. 1.5: Serial Profiles of Upper Gori Ganga Basin

Profile E-F, with a steep decent followed by a gentler rise, shows asymmetrical behaviour. A central deep trough (~4000 m) might be a major fluvial or glacio-fluvial valley. Profile G-H shows a glacial trough and a 'U' shaped valley. This profile shows a sharp elevation change, which suggests that this could be a deeply incised terrain. Profile I-J presents strong relief, where peaks reach to >6000 m and valleys dip to 4000 m. The secondary depressions near the ridgeline suggest it could be a cirque or a hanging valley. Profile K-L shows a wide glacial trough and a deep valley.

2. **Superimposed profile** – To draw superimposed profile all serial profiles were overlayed one upon another serially on a single frame following one common base line. Every serial profile line was marked by different colour to show their individual existence. This type of drawing represents approximately the true character of the landform. Figure 1.6 presents the panoramic view of the high peaks and deep valleys that shows the true characteristics of the entire region. The superimposed profiles disclose the erosional activities by the glaciers & streams and presents an overview of the relief characteristics of the upper Gori Ganga basin.

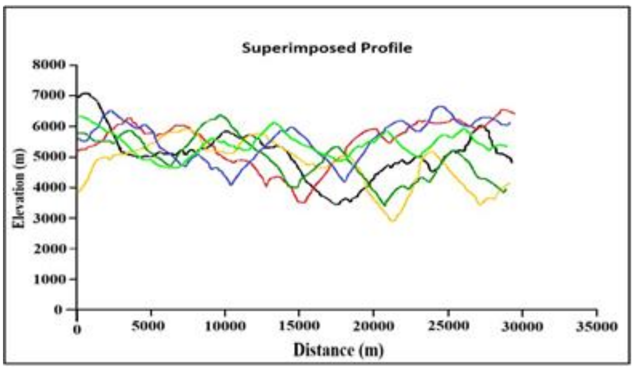

Fig. 1.6: Superimposed profile

3. **Projected profile** – The projected profile of the upper Gori Ganga catchment is drawn with the help of superimposed profiles. All the profiles which come under the succeeding profile are left untraced. Projected profiles depicted the rise and fall and undulating terrain visible in the basin. Figure 1.7 shows that the projected profile gives a realistic picture with a distant skyline, a middle ground and a foreground.

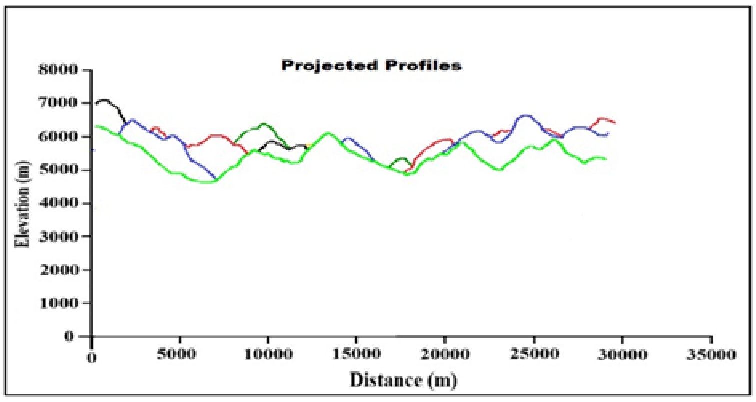

Fig. 1.7: Projected Profiles

4. **Composite profile –** The composite profiles show the highest summit levels as seen from a distant place. To create the composite profile, only the uppermost part of every serial profile was traced. The skyline of the upper Gori Ganga basin lies between 5000 metres to 7000 metres **(fig. 1.8).**

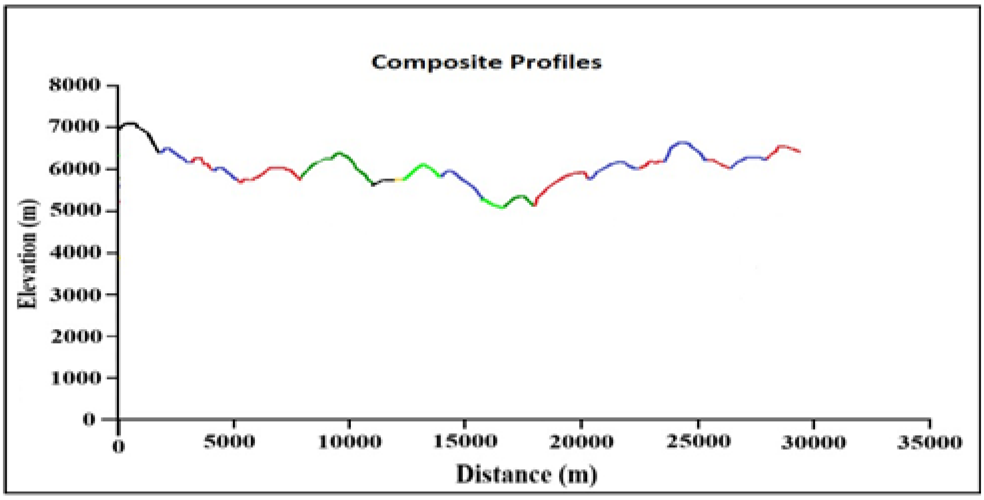

Fig. 1.8: Composite Profiles

SLOPE:

The steepness or inclination of terrain is slope. Slope is the result of collective work of the endogenetic and exogenic processes, which is mainly affected by the surface's geological setting. Slope analysis is the tool to know the topographical condition of an area, by measuring and interpreting the steepness or gradient of a surface. In geomorphic analysis, slope is a key factor that influences geomorphic processes, soil composition, vegetation cover, human settlement, road construction, and other factors. It can be expressed in several ways, including aspect, degrees, and percent, each providing different insights into terrain characteristics. From the prepared DEM, the slope of the study area was derived using GIS software.

Slope in Percentage - Slope in percent is a way to express the steepness of a surface. This is calculated by dividing the vertical interval by the horizontal equivalent and multiplying by 100. It is useful for assessing the potential for erosion, landslides, and the impact of slope on vegetation and human settlement. It is calculated by using the following formula.

Slope in Percent=(V.I./H.E.) ×100

Regional distribution - Fig. 1.9 and table 1.4 presents an overview of the distribution of slope in the study area, based on varying slope percent, the entire basin is divided into 6 slope categories, their description is as follows:

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Table 1.4: Distribution of Slope in percentage

S. No.	Slope %	Area (in sq. km)	Area (in %)	Slope Category	Explanation
1.	<20	73.74	8.28	Level and Gentle slope	In the study area level & gentle slope is found in the glacier troughs, river beds, gentle hill slopes and in the river terraces.
2.	20-40	88.77	9.97	Moderate Slope	Found around level & gentle slope zone in patches especially around the present prominent glacier troughs of the basin.
3.	40-60	163.22	18.33	Moderately Steep Slope	Moderate steep slope is found in entire watershed in small patches
4.	60-80	192.93	21.67	Steep Slope	It is the second largest slope category in the entire basin.
5.	80-100	165.88	18.63	Very Steep Slope	Unstable areas or areas prone to landslide.
6.	>100	205.86	23.12	Extremely Steep Slope	Highest peaks of the study area are situated in this slope zone.

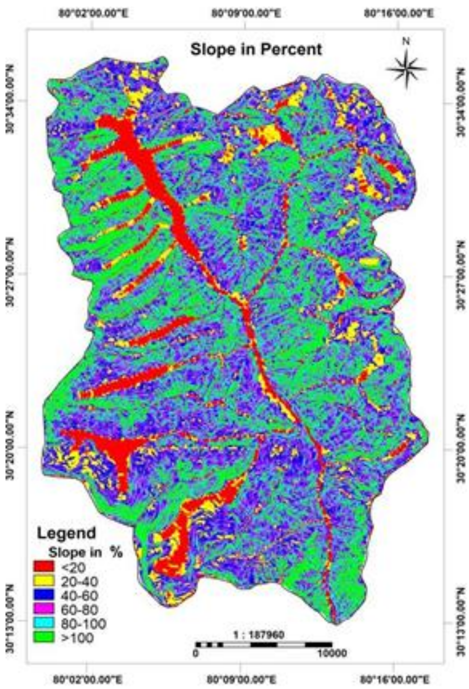

Fig. 1.9: Upper Gori Ganga Basin Slope Classification (in per cent)

Slope in Degree - The slope in degrees is a measure of the angle between the horizontal surface and the terrain. This is represented in degrees, where 0° indicates a flat surface, and values greater than 0° indicate an inclined surface. A slope of 90° represents a vertical surface, like a cliff (Fisher et al., 2006). Slope in degrees calculated through trigonometric functions, using the difference in elevation between two points and the horizontal distance e between them (Jones, 1998). Slope in degrees is used for understanding terrain roughness, stability, and the suitability of land for various activities (Florinsky, 2012; McCool et al., 1987).

Regional distribution - Based on derived slope (in degrees) classes, the study area is divided into six slope categories (Fig. 1.10 & table 1.5). Their details are as follows

Table 1.5: Distribution of slope in degrees in different categories

S. No.	Slope Degree	Slope Category	Area (in sq. km)	Area (in %)	Explanation
1	<9	Level to Gentle slope	56.10	6.30	This slope zone is scattered throughout the entire basin in small patches, mainly near the mouth of the river, glacier bed, and terraces of different altitudes. These areas constitute depositional landforms such as river terraces, fans and moraine deposits.
2.	9-18	Moderate Slope	69.87	7.84	This slope zone is situated around the moderate slope zone. These are the transition zones from valleys to low hills, which have moderate runoff and are moderately stable.
3.	18-27	Moderately Steep slope	117.34	13.18	This is common in mid-slope positions.
4.	27-36	Steep Slope	219.56	24.66	This zone is highly associated with dissected hill slopes, which are Prone to surface erosion and landslides.
5.	36-45	Very Steep Slope	221.77	24.91	This indicates unstable terrain, escarpments, and exposed hill faces.
6.	>45	Extremely Steep	205.76	23.11	This denotes the vertical or near-vertical terrain, especially cliffs, rock faces, which have high instability and are typically inaccessible.

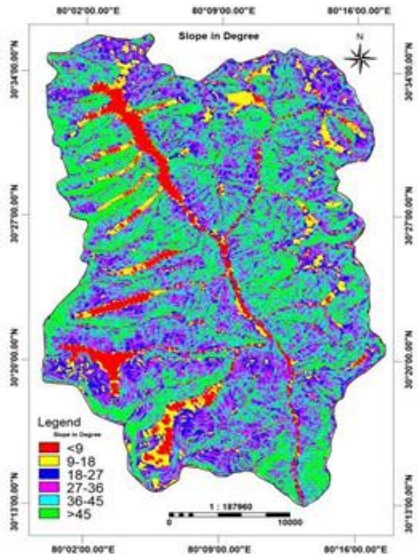

Fig. 1.10: Slope Classification (in degrees)

Slope Aspect: Aspect refers to the direction of a compass that a slope faces. It is an important feature in understanding the local climate conditions, as slopes facing the sun tend to be warmer and drier, while those facing away may be cooler and wetter (Wilson & Gallant, 2000; Moore et al., 1991). Table 1.6 shows the aspect categorisation of the Upper Gori Ganga basin, representing the compass direction of the aspect. Aspect is calculated based on the orientation of the slope with respect to the cardinal directions (north, south, east, west). Quantitatively, the north aspect is 0^o or 360^o, clockwise, the east aspect is 90^o, the south aspect is $180^{o,}$ and the west aspect is 270^o (Burrough & McDonnell, 1998). The aspect is also classified as northeast aspect (NE), southeast aspect (SE), northwest aspect (NW) and southwest aspect (SW) with every interval of 45^o in between the major directions. The plain terrain is classified as a flat surface having no angular direction (Jenness, 2006). The study of aspects helps to understand the pattern of sunlight exposure, vegetation, snow melt, erosion and microclimatic variations (Barry, 2008; Wilson & Gallant, 2000). The slope aspect influences the local climate and distribution of vegetation and biodiversity of any region **(Magesh et al., 2012).** The aspect map of the Upper Gori Ganga valley was generated using a Digital elevation model on the GIS platform. In Table 1.6 the entire basin is divided into nine (9) slope aspect categories.

Table 1.6: Classification of aspects in the Upper Gori Ganga Basin

S. No.	Aspect	Azimuth Range	Area (in sq. km)	Area (in %)	Remarks	References
1.	North	337.5°–360°	69.36	7.79	These slopes receive the least direct solar radiation, often remain cool and moist, with slower snow/glacier melt and more stable vegetation cover.	Iqbal (1983), Hancock, &
2.	North-East	22.5°–67.5°	109.25	12.27	These slopes area moderately dry. Often supports mixed vegetation and moderate melt rates.	Willgoose (2001),
3.	East	67.5°–112.5°	108.09	12.14	This slope group is warmer than NE but cooler than SE. Helps early vegetation growth.	Barry (2008) &
4.	South-East	112.5°–157.5°	139.52	15.67	These are warm, dry, and erosion-prone slope, may host sparse vegetation and faster melt rates of glacier.	Benn & Evans (2010)
5.	South	157.5°–202.5°	122.43	13.75	These slope gets strong sunlight all day, they are warmest, and driest slopes, often significant in glacier retreat, weathering, and soil instability.	
6.	South-West	202.5°–247.5°	97.85	10.99	These are slightly cooler than south, but still warm. These slopes faces afternoon melt and evaporation.	
7.	West	247.5°–292.5°	93.22	10.47	These slopes are slightly cooler than SW, with less erosion.	
8.	North-West	292.5°–337.5°	107.94	12.12	This slope category tends to be cool and moist, similar to north-facing. Have slower vegetation growth.	
9.	North2	0^0-22.5^0	42.74	4.80	These are coldest, most shaded slopes. Which receives least sunlight throughout the day. Snow/glacier persist longer. Often permafrost-like conditions is found in high altitudes.	

Figure 1.11 shows the colour-coded map of the Upper Gori Ganga basin representing the compass direction of the aspect. Table 1.6 and fig. 1.11 shows the area of different slope aspect groups in the Upper Gori Ganga basin. 15.67 % area of the basin falls under south-east aspect with account to an area of 139.52km2. The minimum area falls under north2 aspect in a very small patches of the basin, which covers 4.80% of the entire basin. South-East (15.67%) and South (13.75%), these warm-facing slope aspects, are vulnerable to erosion and glacier melt **(Benn & Evans, 2010).** North and North2 combinedly are cold-facing zones, these slopes are responsible for snow accumulation (Barry, 2008; Hancock & Willgoose, 2001**)**. Aspect distribution shows southern dominance, which is very common in the Himalayan basins.

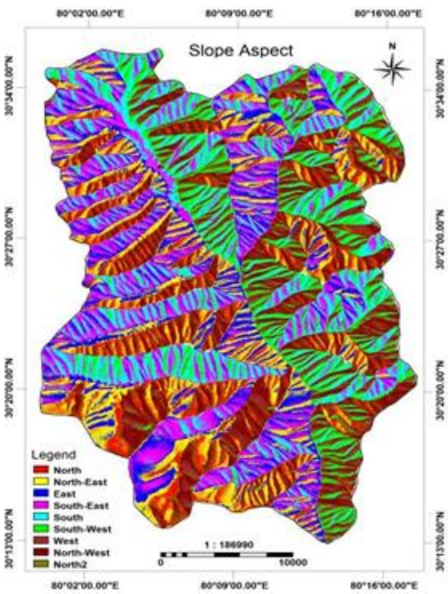

Fig. 1.11: Slope Aspect Map of Upper Gori Ganga Basin

2. Conclusion

Relief and slope analysis are essential for understanding the Earth's surface features. The DEM- derived slope (measured in degrees and percent), aspect classification, and topographic profiles highlight notable terrain variations across the study area, indicating structural complexity and geomorphic development. This terrain analysis offers insights into how climate, tectonics, and glacial-fluvial processes have shaped the Himalayan landscape. Slope analysis identified variations from less than 90° to over 450°. Aspect analysis shows a predominance of southern-facing slopes (SE, S, SW), which cover over 40% of the basin. These slopes receive more solar radiation, affecting processes like freeze-thaw cycles, snowmelt, and vegetation growth. Using these techniques in geographic studies can enhance understanding of the landscape, ultimately informing land-use planning and environmental conservation efforts.

References

[1] Balasubramanian, A. (2017). Digital Elevation Model (DEM) In Gis. https://doi.org/10.13140/ RG.2.2.23976.47369
[2] Barry, R. G. (2008). Mountain Weather and Climate (3rd ed.). Cambridge University Press.
[3] Benn, D. I., & Evans, D. J. A. (2010). Glaciers and Glaciation (2nd ed.). Hodder Education.
[4] Chang, K. T. (1989). "A comparison of techniques for calculating gradient and aspect from a gridded digital elevation model". *International Journal of Geographical Information Science*. **3** (4): 323–334. doi:10.1080/02693798908941519.
[5] Clarke, J. I. (1966). Morphometry from maps: Essays in geomorphology. London: B. T. Batsford Ltd.
[6] Dikau, R., Cavallin, A., & Jäger, S. (1996). Databases and GIS for landslide research in Europe. *Geomorphology*, *15*(3-4), 227-239.
[7] Evans, I. S. (1977). The selection of class intervals. Transactions of the Institute of British Geographers, (2), 98–124.
[8] Evans, I. S. (1980). Slope analysis. In R. J. Chorley (Ed.), Spatial Analysis in Geomorphology (pp. 17–90). Methuen.
[9] Fisher, P. F., Comber, A. J., & Wadsworth, R. A. (2006). Slope and aspect: Advances in land-surface parameterization. In P. Atkinson, G. Foody, S. Darby, & F. Wu (Eds.), GeoENV VI – Geostatistics for Environmental Applications (pp. 103–114). Springer.
[10] Florinsky, I. V. (2012). Digital Terrain Analysis in Soil Science and Geology (2nd ed.). Academic Press.
[11] Guth, P. L., Van Niekerk, A., Grohmann, C. H., Muller, J. P., Hawker, L., Florinsky, I. V., ... & Strobl, P. (2021). Digital elevation models: Terminology and definitions. *Remote Sensing*, *13*(18), 3581.
[12] Hancock, G. R., & Willgoose, G. R. (2001). The relationship between landform evolution and slope aspect: A simulation study. Earth Surface Processes and Landforms, 26(13), 1317–1332. https://doi.org/10.1002/esp.272.
[13] Hirano, A., R. Welch and H. Lang, 2003. Mapping from ASTER stereo image data: DEM validation and accuracy assessment. ISPRS J. Photogrammetry Remote Sens., 57: 356-370.
[14] Iqbal, M. (1983). An Introduction to Solar Radiation. Academic Press.
[15] Jones, K. H. (1998). A comparison of algorithms used to compute hill slope as a property of the DEM. Computers & Geosciences, 24(4), 315–323. https://doi.org/10.1016/S0098-3004(98)00032-6
[16] Keller, E. A., & Pinter, N. (2002). Active tectonics: Earthquakes, uplift, and landscape (2nd ed.). Prentice Hall.
[17] Lakshmi, S. E., & Yarrakula, K. (2018). Review and critical analysis on digital elevation models. *G eofizika*, *35*(2), 129-157.
[18] MacKinnon, E. (2003). Surface Modeling and LIDAR Validation. Middleton, Nova Scotia: *Graduate Thesis, Applied Geomatics Research Group, Centre of Geographic Sciences*.
[19] Magesh, N.S., Chandrasekar, N., Soundranayagam, J.P. (2011). Morphometric evaluation of Papanasam and Manimuthar watersheds, parts of Western Ghats, Tirunelveli district, Tamil Nadu, India: a GIS approach. Environment Earth Sciences September 2011. Vol. 64, issue 2, pp 373- 381.
[20] McCall1um, I., & Manson, A. (2011). Digital Elevation Models and Slope Analysis. Springer.
[21] McCool, D. K., Foster, G. R., Mutchler, C. K., & Meyer, L. D. (1987). Revised slope steepness factor for the Universal Soil Loss Equation. Transactions of the ASAE, 30(5), 1387–1396. https://doi.org/10.13031/2013.30576.
[22] McDermid, G.J. and Franklin, S.E. (1994) Spectral, Spatial, and Geomorphometric Variables for Remote Sensing of Slope Processes. Remote Sensing of Environment, 49, 57-71. https://doi.org/10.1016/0034-4257(94)90059-0.
[23] Moore, I. D., Grayson, R. B., & Ladson, A. R. (1991). Digital terrain modelling: A review of hydrological, geomorphological, and biological applications. Hydrological Processes, 5(1), 3–30. https://doi.org/10.1002/hyp.3360050103.
[24] Sharma, M. and Joshi, R.C. (2018). A Study of Relief and Slope of Bhimtal Gadhera Catchment, Kumaun Lesser Himalaya, Uttarakhand International journal of basic and applied research. Vol. 8 No. 3, ISSN 2249-3352 (P) 2278-0505 (E) pp. 88-100.
[25] Singh, S. (2008). Geomorphology (7th ed.). Prayag Pustak Bhawan.
[26] Strahler, A. N. (1950). Geomorphology and structure: An introduction to the study of landforms. American Journal of Science, 248(9), 655–668. https://doi.org/10.2475/ajs.248.9.655
[27] Strahler, A. N. (1952). Hypsometric (area-altitude) analysis of erosional topography. Geological Society of America Bulletin, 63(11), 1117–1142. https://doi.org/10.1130/0016-7606(1952)63 [1117: HAAOET]2.0.CO;2
[28] Summerfield, M. A. (1991). Global geomorphology. Longman Scientific & Technical.
[29] Wilson, J. P., & Gallant, J. C. (Eds.). (2000). Terrain Analysis: Principles and Applications. Wiley.