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An Overview of Geomorphological Mapping: A Case Study of Rimbi Chhu River Basin, Sikkim, India

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Geomorphology is the primary science which demonstrates the basic understanding and mapping of terrain features. A geomorphological map consists of scientific data and dynamic source of information on characteristics of landforms, their origin and evolution, which can be recorded in a map form. Basin hydrology also gets impacted by the terrain features of a basin as overland flow, stream flow and through flow is largely determined by the underneath surface. The configuration of the basin topography reflects the nature of the interaction between process and form. Profound understanding and in depth analysis of geomorphological features of a river basin can provide beneficial information for predicting, preventing and mitigating natural hazards; managing natural resources sustainably for future generation. Implementation of remote sensing and GIS techniques have fostered incredible improvements in landform recognition and accelerated the growth of geomorphological research. The river Rimbi Chhu has been selected as the study area in order to determine terrain configuration in relation with geomorphological features of the basin area. Visual representation of terrain (such as aspect, slope, channel networks, different river profiles, shaded relief and flow direction) and geomorphological (saddle, ridge line, convex-concave slope, rounded hills, fault for instance) derivatives is therefore illustrated, as well as a description of the challenges and crisis that can occur in this context.

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Keywords: Geomorphological features; GIS; hydrology; terrain configuration.

1. INTRODUCTION

The surface of the earth is a dynamic canvas that has been sculpted over millions of years by a variety of activities. In order to understand the complex patterns and processes that have shaped the landforms we see today, geomorphological mapping is an essential tool. The landform history and current processes that sculpt the surface of our world are revealed by geomorphological mapping, which shows us everything from massive mountains to winding rivers, from wide plains to complex coastline features. A geomorphological map consists of scientific data and dynamic source of information on landforms, their origin and evolution. It is a way to record the geomorphological characteristics of an area in a map form. Basin hydrology also gets impacted by the terrain features of a basin as overland flow, stream flow and through flow is largely determined by the underneath surface. The configuration of the basin topography reflects the nature of the interaction between process and form. By measuring various topographic attributes along with existing drainage network can give us the impetus for understanding the denudational history of the present topography as well as the evolution of drainage network [1]. The aim of terrain analysis is the explanation of the arrangement of the Earth's surface as well as their classification based on the surface pattern similarities [2]. Landforms can be defined as specific geomorphic features on the Earth, ranging from large scale features (plains and mountain ranges for instance) to minor features (such as individual gullies, faults and valleys), both man-made or from natural genesis which have a defined range of physical and visual characteristics [3]. Understanding Earth surface processes, geochronology, natural resources, natural hazards, and landscape development all depend on geomorphological mapping [4]. Using a variety of criteria, such as morphology (form), genetics (process), composition and structure, chronology, associations with environmental systems (land cover, soils, ecology), and spatial topological relationships of surface features (landforms), the terrain is divided into conceptual spatial units or entities. Traditionally, the foundation of geomorphological mapping has been the combination of remotely sensed data, cartographic map outputs, and multidisciplinary field knowledge. In order to categorize terrain types and features at the regional (physiographic) scale, regional-scale geomorphology and physiographic analysis and mapping relied on the interpretation of photos and smaller-scale maps [5]. Understanding the Earth's surface and the processes that shape it depends on geomorphological mapping [6,7]. Numerous scientific fields, such as geology, geography, hydrology, ecology, and archaeology, can benefit from the useful information it offers [8,9]. In order to control and reduce the risks associated with probable natural disasters such landslides, volcanic eruptions, and floods, geomorphological maps can be used [10,11]. Geomorphological mapping is also essential for managing and exploring natural resources. It offers important details about the structure, composition, and distribution of geological formations, such as groundwater aquifers, mineral deposits, and oil and gas reservoirs [12]. Making educated decisions about the extraction, preservation, and management of natural resources requires the knowledge in this article [13,14,15]. The subject of geomorphological mapping has seen a revolution in recent years thanks to developments in digital mapping techniques and remote sensing technologies, which have allowed scientists to create extremely accurate and detailed maps of the Earth's surface [16,17]. The study of geomorphology has undergone a revolution thanks to relatively recent advancements in remote sensing, geographic information science, geospatial technology, and numerical modelling of surface processes [18]. Today's geocomputational algorithms and techniques, along with new spatiotemporal data, allow Earth scientists to go far beyond traditional mapping. Quantification of landscape morphology is feasible now [19]. By doing this, we may improve our knowledge of the Earth's surface, its inhabitants, and its processes. We can also create long-term plans for the preservation and management of our planet [20,21]. The results of the study could have a big impact on how geomorphological mapping research is conducted in the future. The steady increase in research in this area shows how crucial it is to keep funding and working together in order to increase understanding and knowledge production. In order to encourage more egalitarian and cooperative research in geomorphological mapping, this work may contribute to the development of future research plans and funding priorities. Overall, identification and description of various landforms, such as mountains, valleys, rivers, lakes, glaciers, and coastal features, are made possible by geomorphological mapping. In addition, it aids in the identification of stratigraphic strata, folds, joints, and faults in the earth's crust, offering crucial data for geological research and land use planning. Geomorphological maps can be divided into two primary categories: derivative geomorphological maps and basic geomorphological maps [7]. Basic geomorphological maps, also known as analytical maps [22] are created by simply transferring data graphically from geological, soil, and vegetation maps, as well as directly from field surveys or aerial photograph interpretation. The two approaches of morpho-evolution maps and morphodynamic maps can be used to create basic geomorphological maps. This research paper is based on mixed approaches of traditional and modern tools of geomorphological mapping.

2. METHODS

2.1 Research Design

The prime objective of this study is to examine the geomorphological features in the basin area. In order to obtain the goal, the basic geographical features (drainage networks, soil, geology, elevation profiles) of the basin area are taken into consideration.

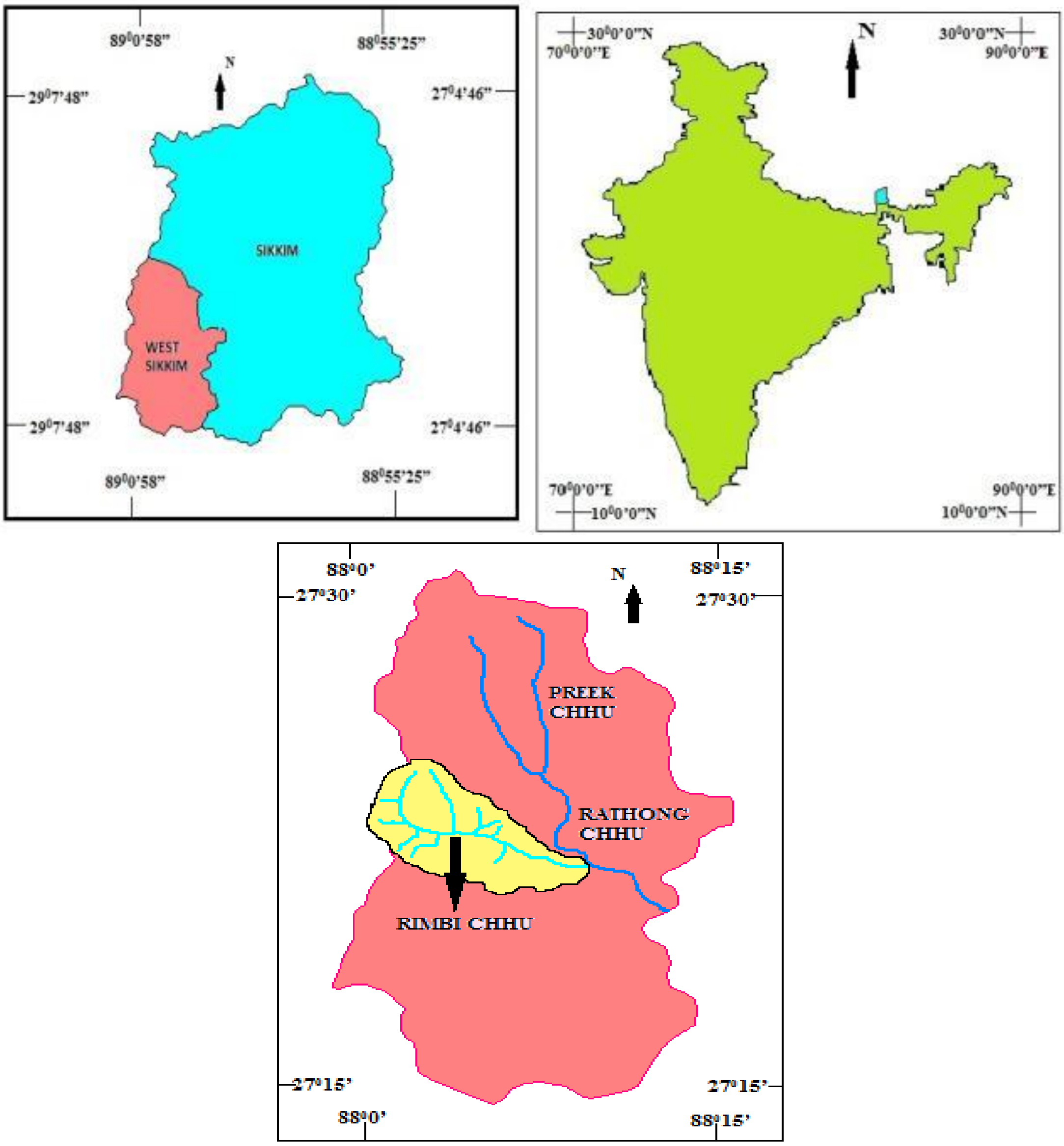


Fig. 1. Location Map of the Study Area

2.2 Study Area

One of the major rivers in this area is the Rimbi Chhu (Chhu meaning river in Tibetan and Bhutanese). The geography of the basin is made up of deep valleys, steep hills, and dense vegetation that are typical of the Himalayas. Along its journey, the river carves out the terrain, creating canyons and tumbling waterfalls [23]. The snowmelt and rains from the neighbouring mountains feed the Rimbi Chhu. The area is located in the West District of Sikkim between 27 ^{0} 17’ 21” N to 27 ^{0} 23’ 11” N latitude and 88 ^{0} 15’ 17” E to 88 ^{0} 38’ 49” E longitude covering an area of 1, 166 sq. km. The Field Survey was carried out on the lower part of Rimbi Chhu from the Rimbi Bridge. In the topographical map (produced by Survey of India) the river name is Ringbi Chhu but I used Rimbi as it is locally known as Rimbi Chhu and also in Administrative Atlas and official documents of Sikkim with the name Rimbi Chhu.

2.3 Database

Pre-survey data was collected from Topographical Map No. NG 45-3 (was prepared by United States Army Map Service in 1962). Simultaneously, we have used Google Earth Data for mapping Channel Form of the Rimbi Chhu Basin. Google Earth Data then transferred to Global Mapper 13, MapInfo and Surfer 13 for further mapping in GIS platform. In terms of secondary sources the Census of India Handbook [24,25,26] has been used as a principal reference along with Journals and Gazetteers published by the Department of Agriculture, Sikkim, Govt. of India [27]. In earth science, DEM data is progressively being used because of its multiple benefits and qualities e.g. cost effectiveness, continuous coverage of elevation data, high level of details, and automatic measurement of topographic properties [28]. The SRTM (Shuttle Radar Topography Mission) image covering the study area was obtained through the U.S. Geological Survey Earth Resources Observation and Science Centre (EROS) [29]. Global mapper (15) has been used for data processing and rectified the errors of those imageries using ENVI Classic (64 bit).

3. RESULTS AND DISCUSSION

3.1 Drainage Network

Ref. [27] explains that the Rimbi Chhu basin has been considered as the respective study area in Sikkim. Along with field survey, data has been collected using GIS Techniques. The main river in this region is Rangit. Rimbi Chhu (flows on the western border of the area), is the tributary of Rathong Chhu, which meets the river Rangit in the eastward direction. A good number of small streams and kholas are found on the northern part of the area like Prekk Chhu, Rel Chhu, Kalej Khola etc. although the eastern part is less marked by kholas and jhoras. Nine broad landform regions have been identified in this watershed viz. ridge, rocky cliff, escarpment, morainic zone, low mountain, narrow valley, mid mountain, high mountain and very high mountain. In this watershed high mountain occupies largest area of 40.7 per cent followed by mid. mountain, very high mountain and ride occupying 25.9, 21.7 and 7.2 per cent area respectively.

3.2 Geology

By merging geological information with geomorphological mapping, scientists can gain a deeper comprehension of the evolutionary trajectory of various environments. Landforms, valleys, and ridges are examples of geomorphological characteristics that frequently reveal underlying tectonic processes, rock kinds, and geological structures. The northern section of the basin is comprised of chungthang formation. In the extreme eastern corner chungthang formation [30] is found along with granite gneiss. In addition, the area surrounding chungthang displays glacial features such glacial lakes, moraines, and U-shaped valleys. Over geological time spans, glacial action has significantly shaped the himalayan environment. A patch of strike and dip formation, coal, polymetalic base metal is found along with buwa formation. The majority of basin is consists of Darjiling gneiss formation [31]. The Darjeeling Gneiss is thought to have originated during the Archean Aeon of Earth's geological history, some 2.5–2.6 billion years ago. As a result, the Darjeeling Gneiss is among the Indian subcontinent's oldest geological formations. It alternates between lighter bands of minerals rich in quartz and feldspar and darker bands of mafic minerals like biotite and amphibole, distinguished by its unique banding; due to the result of complicated folding and deformation brought on by tectonic pressures [27].

3.3 Soil

Geomorphological mapping and soil offer complimentary insights into the terrain. The formation and distribution of soil are influenced by geomorphological processes such erosion, deposition, and weathering, which also have an impact on soil texture, nutrient availability, and drainage patterns [32]. In contrast, soil characteristics including texture, depth, and fertility can alter sediment movement, vegetation growth, and erosion rates, all of which can have an impact on geomorphological processes [33]. The soils in the Rathong Chhu watershed have been mapped in [Fig. 3] into 10 units at the level of soil series association. These mapping units, which comprised 3,764.9 ha (13.5%), 34,524.4 ha (12.3%), and 3,079.4 ha (11.0%) of land, respectively, are composed of the Sajong – Tarnu series association, Lachung – Puchikongma – Byuma series association, and of Damthang – Chongrang – Rock. This type of soil makes up 21.7% of the watershed and is primarily found in sub-alpine climate zones. The high mountain soils accounts for 40.7%, mid-mountain soils cover 25.9%, and low-mountain soils make up 2.2%. of the total area. There are five distinct classes of soil depth have been discovered and mapped into eleven units. An area of 2,004.6 ha (42.9%) and an area of 5,694.4 ha (20.4%) are related with fairly shallow – deep association in the area. In the Rimbi Chhu Basin, ten surface soil textural classes [27] have been identified and mapped at the association level of surface textural class into ten mapping units. In the watershed, the dominating textural classes are sandy loam (sl) and silt loam (sl). The majority of the watershed (20.6%) is occupied by the silt loam-sandy loam association (mapping unit 16), which is followed by silt loam-loam (15%), sandy loam-loamy sand (12.6%), and sandy loam-gravelly silt loam (12.4%).

3.4 Digital Topography

The maximum elevation of any location above mean sea level is referred to as absolute relief [28]. Geotectonic processes, both constructive and destructive, result in Absolute Relief. Finding the erosion surface in relation to the current landforms is highly helpful. The intensity of denudational processes acting on any surface can be estimated using it. It gives motivation to evaluate the evolution of every surface's landscape. By analysing surface roughness, the land surface's hydrological shape, actual ridges, stream identification, and elevation, one can determine the true usefulness of DEMs for geomorphometric study [34]. The investigation of the slope, aspect, curvature, and other features of the terrain is needed in order to understand the stability of the landscape. A continuous function (f), with Z standing for elevation and X and Y for the cartesian coordinates, can be used to define the topographic surface. The simplest way to identify the distribution of various topographic characteristics is to estimate elevation by the following equation [2].

$$z = f\ (x, y) \qquad \text{Eq. 1}$$

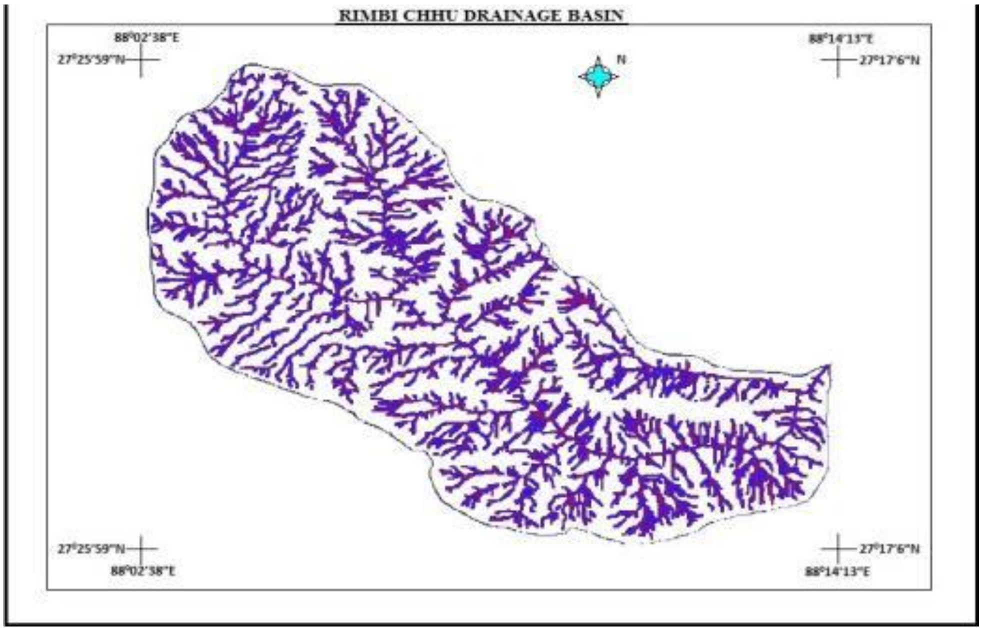


Fig. 2. Drainage Map of Rimbi Chhu Basin

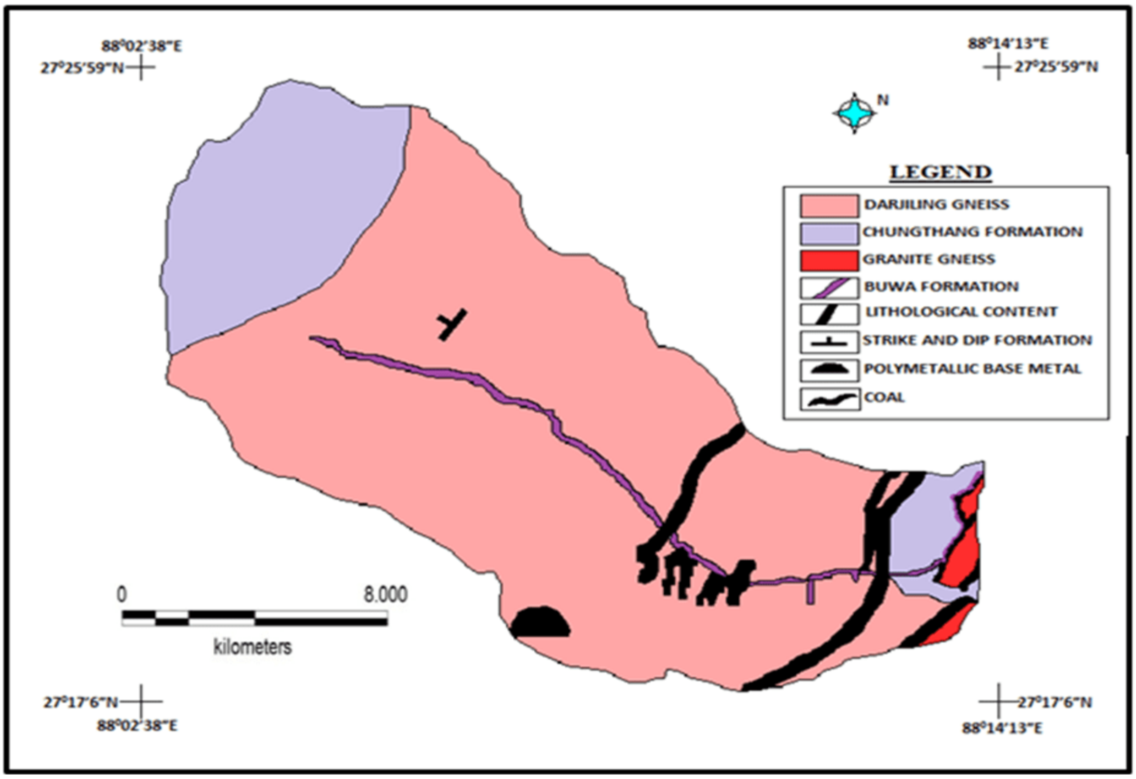


Fig. 3. Geological Map of Rimbi Chhu Basin

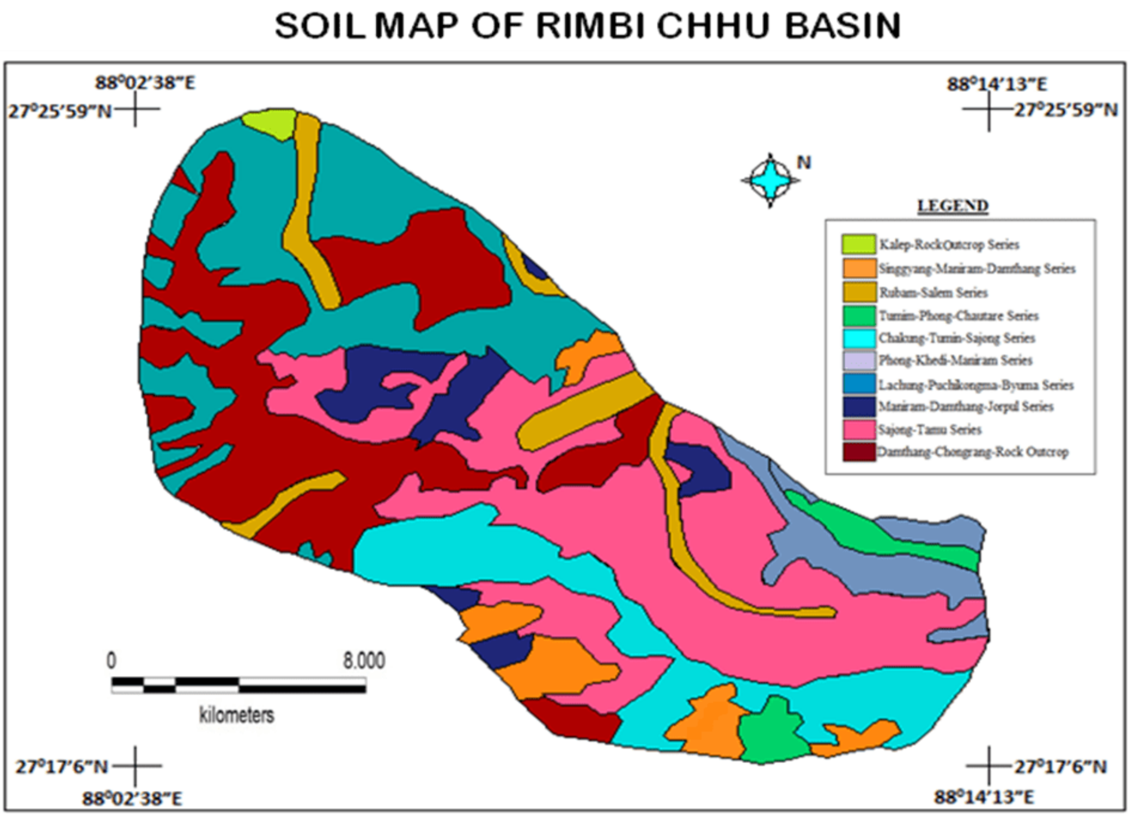


Fig. 4. Soil Map of the Study Area

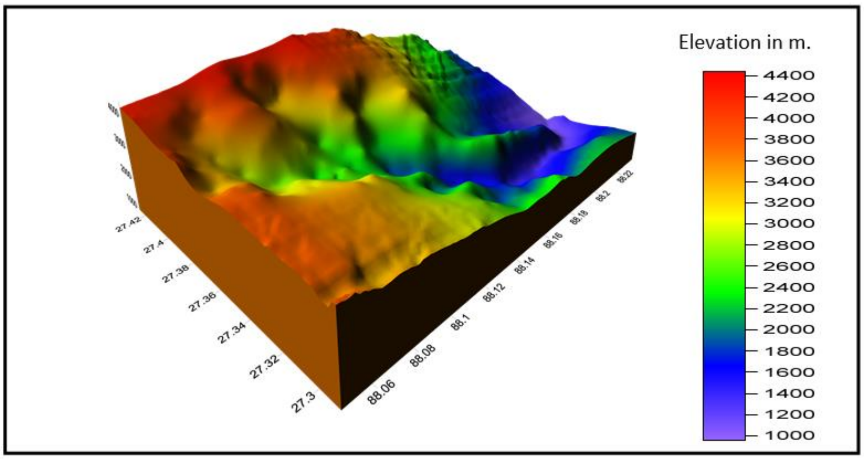


Fig. 5. Digital Terrain Map of the Study Area

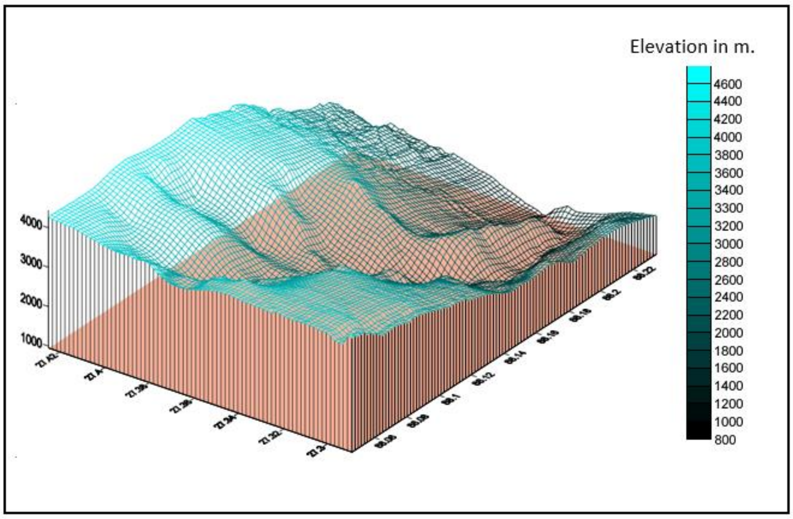


Fig. 6. Digital Terrain Net of Rimbi Chhu Basin

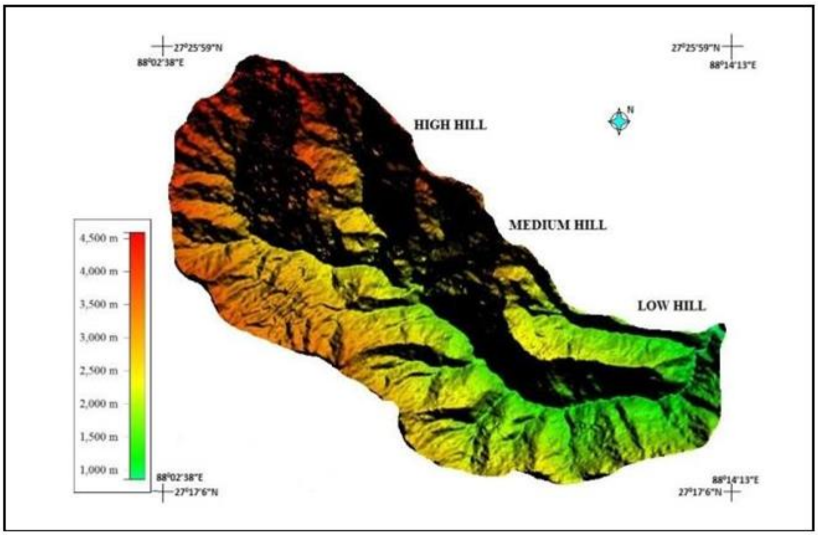


Fig. 7. Digital Elevation Model of Rimbi Chhu Basin

Contour lines [Fig. 8] are another type of visual representation of DEM data however interval of spacing these imaginary lines plays a vital role. The thumb rule is to twice the pixel size of DEM [35]. These show where one or more horizontal planes cross a surface, either hypothetical or real.

Relief Profiles

These profiles have been drawn to show the terrain configuration of the surface. Characteristics and variation of landform units from one place to another can easily be understood from these profiles. This line illustrates the elevation variations along the selected path, making it possible to visually assess the steepness, slopes, and relief of the terrain. Discovering fluctuations in slope, steepness, elevation gain or loss, and other characteristics pertinent to the particular goal or study is the task of this analysis [36]. In the given profiles all the elevation points are represented in meters and distance is in kilometers.

Profile 1: It is drawn near the mouth of the river basin. In this cross section a smooth gentle slope has joined with the ‘u’ shaped valley. Two conical hills are found along with two valleys and in the eastward side a rectilinear slope has been formed and then after the break of slope it has turned into a convex slope. It is the straightest and typically steepest section of the profile. When it is at the "characteristic angle," its gradient changes very little in a region with uniform rock types. Due to the fact that the slope angle essentially stays constant, it is also known as a constant slope. Rectilinear slopes are mainly found beneath free faces or cliffs; they are distinguished by a relatively constant slope angle and a straight profile [37].

Profile 2: In the second cross section, a convex slope is found in the westward direction along with a ‘u’ shaped valley. This valley appears to be widely spread. In the eastward side a dome shaped hill surface has been developed; characterised by a broad, U-shaped cross-sectional profile, is a distinct landform feature that is typically seen in glaciated mountainous regions [38].

Profile 3: This profile is showing a gentle convex slope in the westward side and in the eastern part it has slightly moved in the upward direction forming a ‘u’ shaped valley. Glaciers destroy the terrain by plucking and abrading as they advance, putting tremendous strain on the underlying bedrock. The valley becomes wider and deeper over time as a result of these erosional processes, forming a broad U-shaped profile with steep sidewalls and a comparatively flat bottom. A U-shaped valley with a number of glacially polished and striated surfaces, as well as a typical "trough" shape, is often left behind as a glacier retreats or melts away. The sidewalls of U-shaped valleys are usually steep and straight, with a gentle inward slope towards the valley bottom [26].

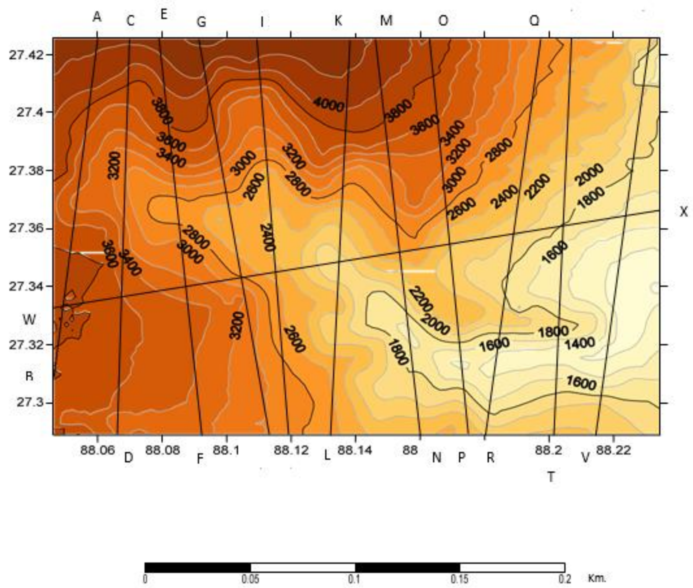
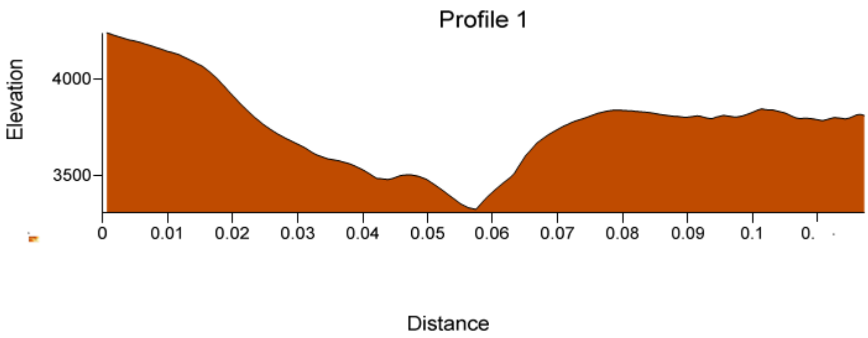
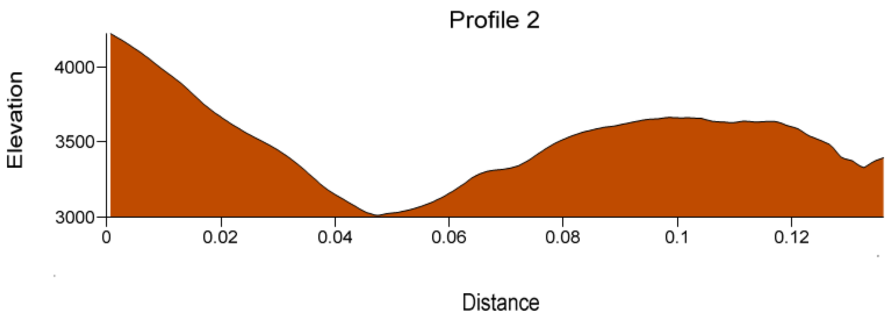


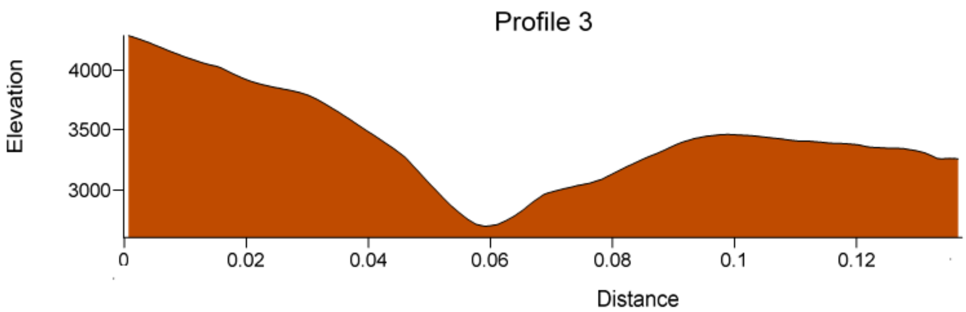
Fig. 8. Contour Map of Rimbi Chhu Basin and its surrounding area



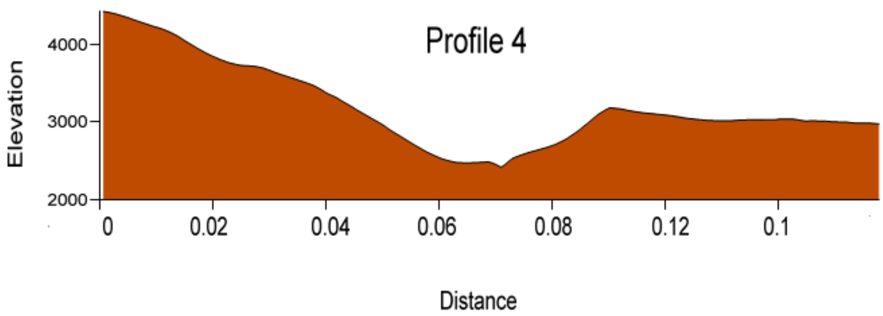
Profile 1. Mouth of the river basin



Profile 2. A convex slope is found in the westward direction



Profile 3. Gentle convex slope in the westward side and in the eastern part



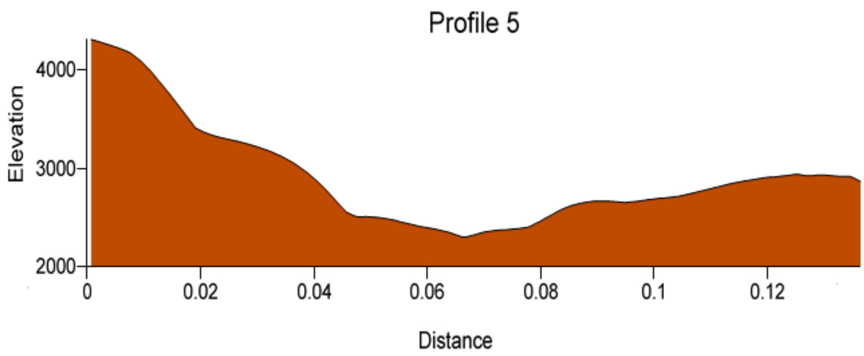
Profile 4. Continuation of the profile 3 in the upward direction

Profile 4: The continuation of the last profile in the upward direction has turned into a convex-concave slope and formed a widespread 'u' shaped valley. A headcut can be found in the middle of the profile and a homogeneous flat surface has been developed in eastward direction [39]. A knick point is a sudden change in a river's or channel's bed's slope that is frequently brought about by lithological variation or glacial erosion in the past. It is a sudden change in a river's or channel's bed's slope that is frequently brought about by lithological variation or glacial erosion in the past depicting a sudden change in a river's or channel's bed's slope that is frequently brought about by lithological variation or glacial erosion in the past.

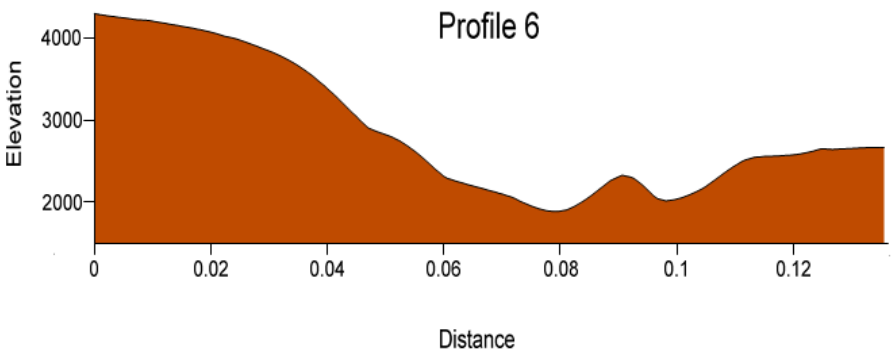
Profile 5: In this section, a continuous range of convex-concave slope has been formed, which appears to be an undulating widespread valley and the landform are slightly going uphill, in the eastern direction. Overall, it depicts a rugged topography. A terrain feature that is curved inward, resembling the interior of a bowl, is called a concave slope. The slope descends from more steep to less steep. Avalanching may occasionally be less likely on tiny concave slopes with strong slabs if there is sufficient compressive support [40]. On the other hand, convex slopes have a rounded or outward-curving profile, resembling a rounded hill as the surface gradually slopes away from a central point or axis. This entire profile is a classic example of composite profile.

Profile 6: This profile demonstrates a concave slope in the beginning with a much dissected undulating topography; a small rounded hill can be seen in the middle section where a hard resistant rock must be present underneath. The careful observation in the contour and geological map clearly indicates the drastic change in vertical elevation resulting into formation of undulating topography.

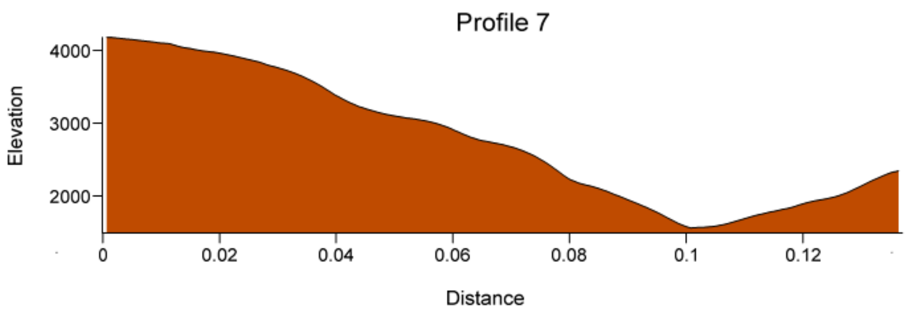
Profile 7: An elongated concave slope has been illustrated along with a 'u' shaped valley in the east. It describes a terrain feature where the slope progressively inclines along its length, resulting in a profile that is concave or bowl-shaped and spans a significant amount of space. Numerous erosion mechanisms, including wind, water, and glacier erosion, can create these slopes.



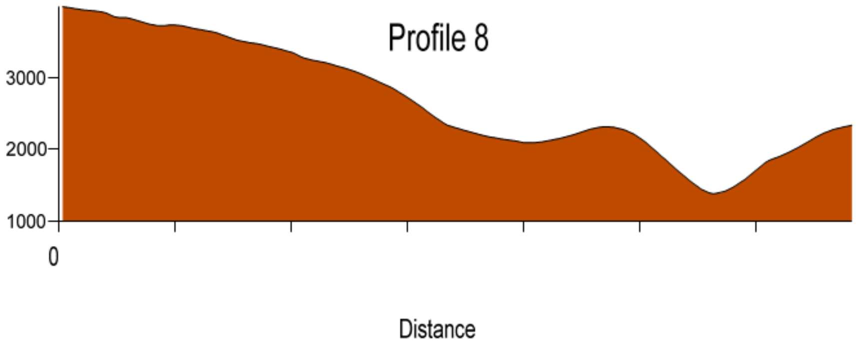
Profile 5. Continuous range of convex-concave slope



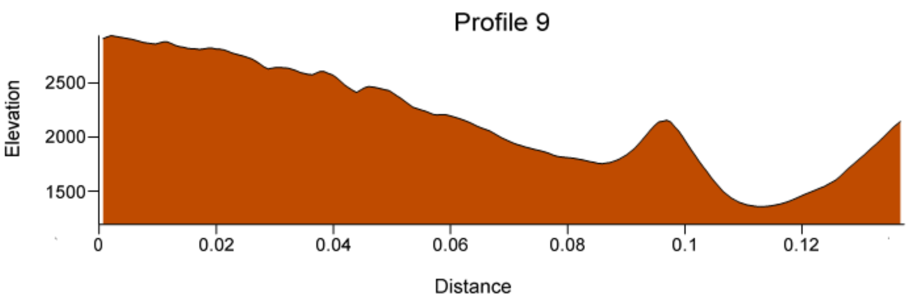
Profile 6. A concave slope in the beginning with a much dissected undulating topography



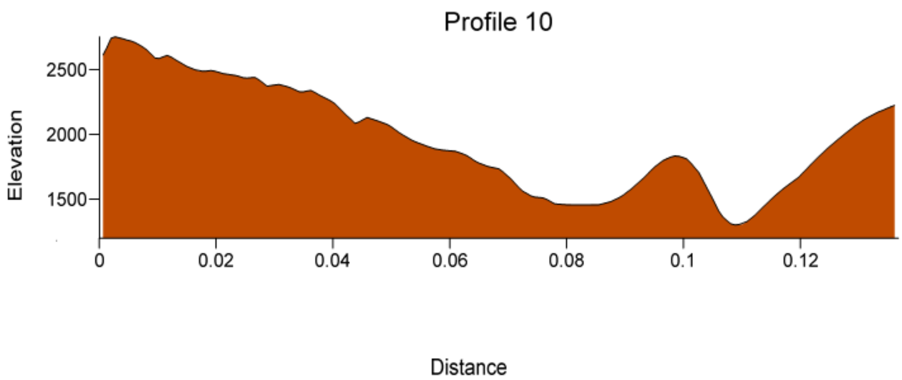
Profile 7. Elongated concave slope



Profile 8. Homogeneous concave slope



Profile 9. Westward side topography



Profile 10. Convex slope and ‘v’ shaped valley

Profile 8: A homogeneous concave slope has been developed in the western direction where the slope's profile is continuously concave or bowl-shaped over its whole length, followed by a convex slope, whereas a 'v' shaped valley with steep slope is being formed in the eastward section. In areas with uniform lithology or where the underlying rock layers have constant qualities, homogeneous concave slopes might be more prevalent.

Profile 9: In the westward side the topography has a rugged character and rest of the section is very much dissected and it might be due to some geological disturbances. A large 'u' shaped valley has been generated in the eastern corner. Variations in the morphology of slopes might result from the varying rates of erosion of different rock kinds and structures.

Profile 10: The overall topography is very much dissected together with a convex slope and 'v' shaped valley. Several knick points can also be traced, which indicates repeated cycles of erosional activities on the basin topography. The historical background has demonstrated the evidences of glacial erosional activities on this region of Sikkim.

Profile 11: A highly dissected topography has been developed in this cross section. Geological deformity might be another reason for this. It describes a terrain that is rough and uneven and is made up of a complex network of deeply carved valleys, gorges, ridges, and summits. While softer, more readily eroded materials may produce deep valleys and gorges, resistant rock types may produce noticeable ridges and peaks.

Profile 12: This cross-section profile was drawn horizontally to get an overall view of the river basin. Initially a convex slope has been generated followed by a concave slope. A 'v' shaped valley has been developed in the middle of the section; it went upward to form a conical hill and by the formation of gentle slope it is going downward.

Superimposed Profile: A superimposed profile [Profile12] is created by superimposing several cross-sectional river channel profiles onto a single graph or map. Using this method, the properties of the river may be seen as they change visually. It was drawn to represent approximately the true character of the landforms. It provides the panoramic view of the high peak and deep valleys. All the profiles drawn in this surface reveals the erosional process by perennial stream and the slope of the Rimbi basin. Additionally, it assists to comprehend the behaviour of the river, especially how it reacts to variations in the flow pattern, the availability of sediment, the stability of the channel, floodplain management, channel restoration, sediment management, habitat appropriateness, navigation, and ecosystem health.

Composite Profile: A composite profile [Profile 13] of a river is a picture that shows the features of its channel, including elevation, width, depth, velocity, and bed morphology, by combining profiles from several places throughout its path. It helps to determine the places with complex hydraulics, meandering, erosion, deposition, and channel stability. They also shed light on the behaviour of the river, the variety of its habitats, the mechanisms involved in the movement of sediment, and its susceptibility to both man-made and natural disturbances. It depicts only roughness of the sky line of the basin by representing the surface view in the summit levels from the infinite distance. The composite profile of Rimbi Basin exhibits the ruggedness of the sky line and the sharp topped summit at the higher altitude. It was mainly modeled to give a better understanding of gravitational processes.

Slope Facet: In layman's terms, a "slope facet" is a particular area or segment of a slope that is generally identified by certain attributes like aspect, gradient, or geological makeup. It depicts distinct sections or units of a sloping surface with generally uniform topographical features. Identifying and evaluating these aspects advances our knowledge of the dynamics of landscapes. Slope gradient is the one of the most significant tools to analyse terrain pattern. It is also referred as slope. For each line (hachure) representing a plane's 0–45° inclination, the ratio of black to white corresponds to the ratio of the doubled tilt angle to its complement at 90°, or the supplied slope angle to its complementary angle at 45°[41]. It is the angle G at a specific topographical surface point between the tangent plane P and the horizontal plane S. With the aid of the following equation, it is estimated [2].

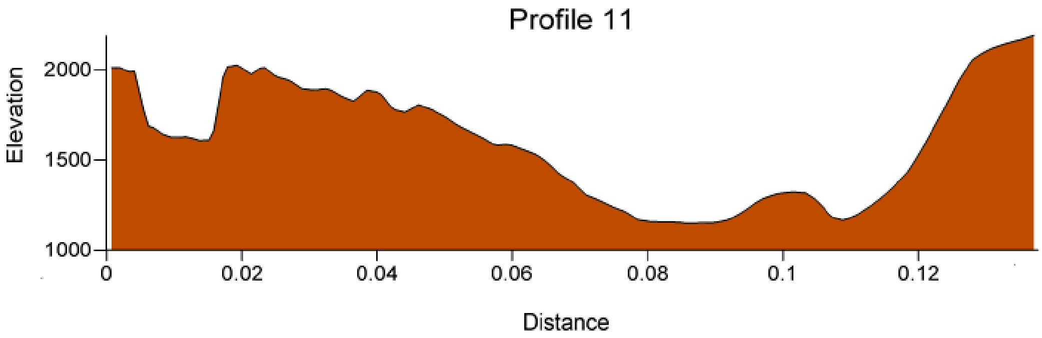
$$G = \arctan \sqrt{p^2+q^2} \quad \text{Eq.2}$$

Where,

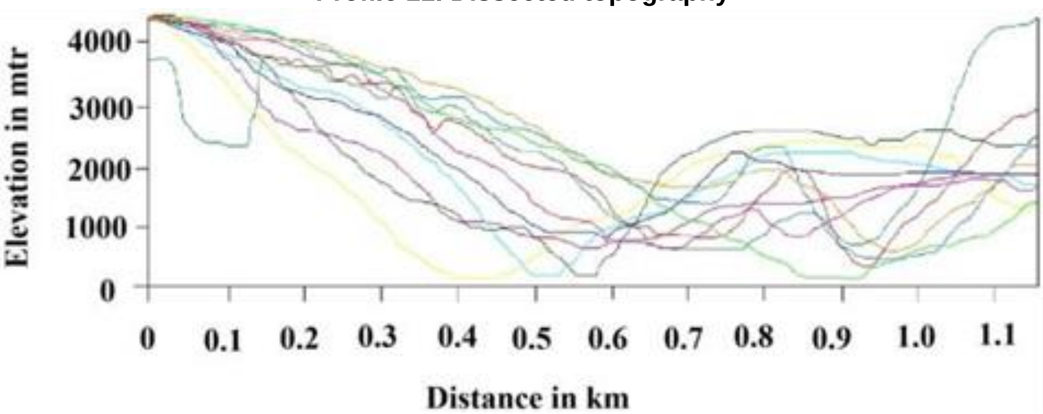
$p = dz/dx \qquad q = dz/dy$

While the calculation of 'Equation 2' is done in degrees, percentage values are also frequently used. It is important to remember that 100% equals 45°, as this is the angle at which there is equal variation in both the vertical and horizontal directions. [42]. Slope aspect (referred to from now on as *aspect*) is a clockwise angle A from north to a projection of the external normal n to the horizontal plane S at a given point of the earth's surface [2]. It determines measures of insulation, temperature, vegetation, soil characteristics and moisture. It is measured in degrees, whereby 0° is equal to North and 180° is equal to South. Local curvature is a measure of the surface roundness of an area. It can be divided into horizontal curvature (*plan curvature*) and vertical curvature (*profile curvature*) [43].

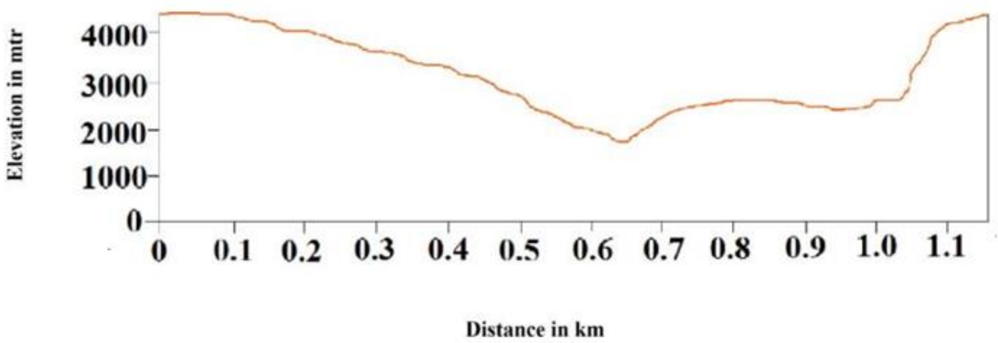
In the slope facet map, the values corresponded to the angles represents maximum slope of the relief.



Profile 11. Dissected topography



Profile 12. Superimposed Profiles



Profile 13. Composite Profile

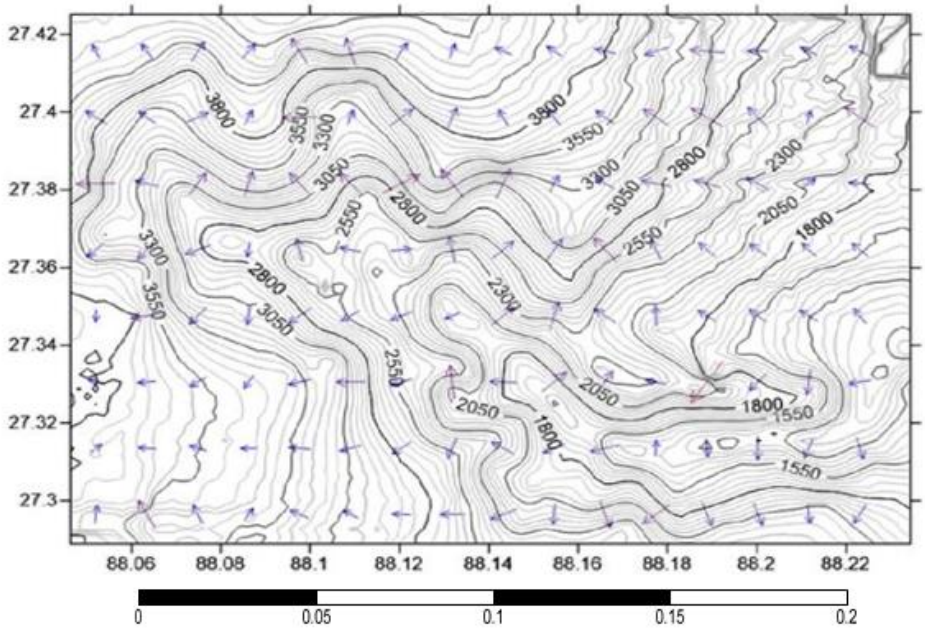


Fig. 9. Slope Facet Map of Rimbi Chhu Basin

Shaded Relief: On a two-dimensional map, the three-dimensional aspect of the terrain can be depicted using shaded relief. It creates the appearance of raised and lowered areas on the map surface by simulating the effects of light and shadow. Typically, a gray scale colour ramp is used in this technique to indicate altitudes, with darker shades denoting lower elevations and brighter tones signifying higher elevations. Shaded relief is often generated to increase the interpretability of elevation raster [44]. The relief in topographic maps is shaded to get a better impression of the third dimension [Fig. 10]. For such kinds of relief maps (hillshade), the illumination source is defined generally at an angle of 45° from the north-west [44]. Even though this position is very unrealistic for the northern hemisphere, it is known that this sun position gives the best impression of relief in the third dimension. For instance, at the following illustration, the relief shading, the brightest areas are oriented in north-west direction, while the darkest areas are oriented in south-east direction (away from the sun).The brightness of the shadow of a given surface element (either a grid cell or a TIN section) depends on the following properties:

1. Aspect and slope of the surface element: The direction of a slope's compass is referred to as its aspect. It shows how the slope is oriented in relation to the azimuths or cardinal directions, whereas a slope of a terrain refers to how steep or incline it is in relation to a horizontal plane.
2. Reflecting properties of the surface element: A surface element's ability to reflect light describes how the surface reacts to light that strikes it. These characteristics include colour, surface roughness, diffusivity, specularity, and reflectance.

Major Geomorphic Units: Because of the restricted terrain, the majority of the lands remain as wasteland. There is vegetation in some of the areas. This area has a small settlement patch and transportation infrastructure. There's a bridge at the eastern part. There are still areas of the river where boulders are being quarried. In this watershed, nine broad landform zones have been identified: low mountain, narrow valley, mid mountain, high mountain, very high mountain, ridge, rocky cliff, escarpment, and moraine zone. High mountains take up the most space in this watershed at 40.7%, followed by mid-mountains, very high mountains, and rides, which take up 25.9, 21.7, and 7.2 percent of the total area, respectively. It is the graphic portrait of different factors. Geomorphological mapping can be thought in different ways. It is a means by which the geomorphological characteristics of an area may be recorded in map form. Such a map has little direct practice value in environmental management for it will contain much that is not relevant to a particular problem. However a second approach is convert the geomorphological map into a purpose oriented map carrying only that information which is relevant for management need. From the foregoing morphometric analysis it became quite evident that a vastz of the basin is highly dissected. In the confluence point (where Rimbi chhu meets Rathong chhu) small amount of alluvium depositon can be found. In the entire river basin lots of boulders, pebbles, cobbles can be found. Some of the boulders are very large in diameter (around 12 meter).

Depending upon the google earth, topographical map and contour values and their composition the whole area has been divided into three units and other geomorphic units has been identified. Description of the major geomorphic units of this basin are given below, these are-

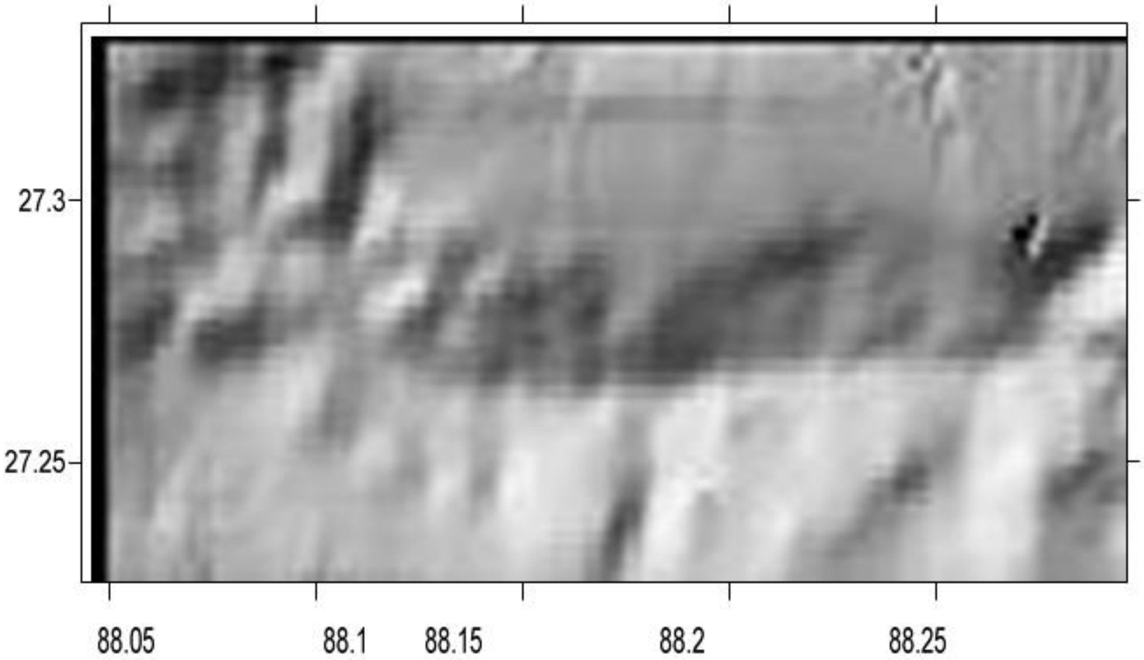


Fig. 10. Shaded Relief Map of Rimbi Chhu Basin

Plate 1. A Fragile Rock Structure

Plate 2. Size of Quartz Vein Vary due to Varying Range of Metamorphism

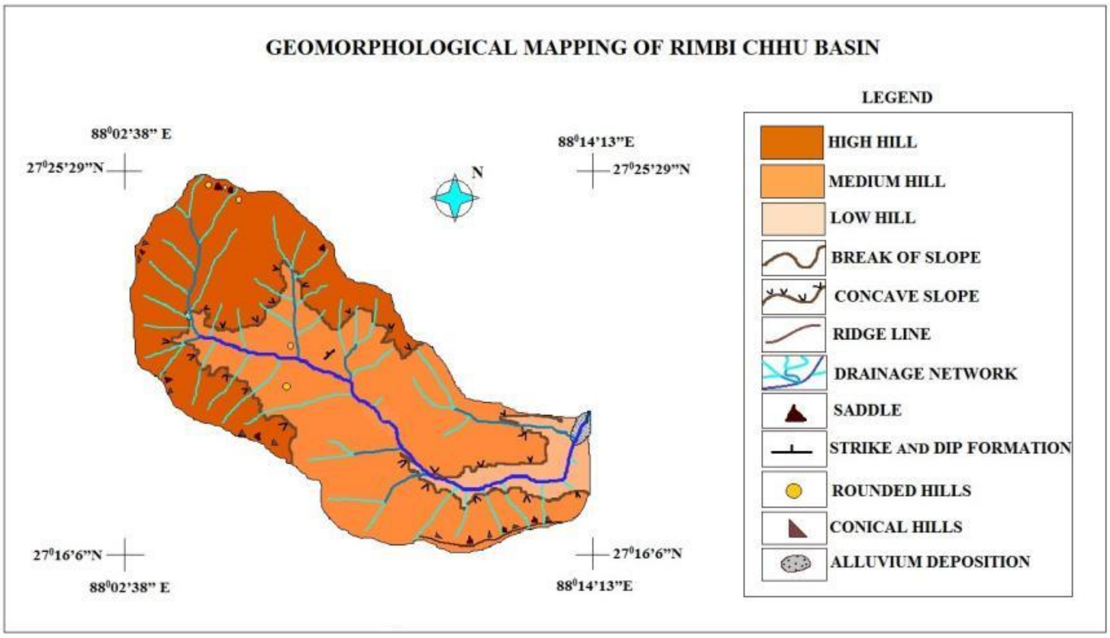


Fig. 11. Geomorphological Mapping of Rimbi Chhu Basin

1. Low Hill: Elevation is less here. The highest elevation is 1500 mtr. And lowest is 1200 mtr. This zone has mainly a rugged topography with a slight gentle sloping ground. The underlying geological formation is chungthang type. A low hill is a type of landform that is distinguished by its rounded or muted topography and relatively soft elevation. The slope gradients are typically mild, with inclines varying from a few to several degrees. The slopes may blend in seamlessly with the surroundings and are frequently gentle. They are crucial in forming landscapes, offering wildlife habitats, and adding to the surface of the Earth's overall geomorphic diversity.

2. Medium Hill: This zone is highly dissected and with the highest elevation of 2100mtr. The lowest elevation of this zone is 2500 mtr. This region is comprised of darjeeling gneiss fomation. Slope of this area is high but not like the high hill section. A medium hill is a type of landform that lies between low hills and higher mountains in terms of prominence and height, with a moderate elevation and topographic relief. It frequently has moderate slope gradients and moderate to high inclines. Over the hill's surface, the slopes may vary in steepness, with some parts having more gentle slopes and others having steeper ones. They might give animals a place to live, act as pathways for different species, and add to the general diversity and ecological resilience of the environment.

3. High Hill: Some of region is highly dissected but most of the part has rugged topography. Highest elevation of this part is 4500 mtr. And the lowest one is 3000mtr. So automatically it is visible that the slope is very high in this region as compare to the other regions. The chungthang and granite gneiss formation is occupying the lower segment of the basin whereas the darjeeling gneiss accounts for the rest. Although they are not as tall as mountains, high hills are distinguished by their noticeable elevation above the nearby plains or lowlands. It displays a range of slope slopes and inclines, from mild to sharp. It boasts rugged topography, unique geographical characteristics, and considerable relief and elevation fluctuations.

4. Saddle: Along with the conical hills and rounded hills saddles are found in the north, west and southern part of the map. A saddle is distinguished by its lower elevation in relation to the surrounding landscape. Saddle points act as organic links or passageways between neighbouring drainage basins or valleys.

They frequently delineate areas where water flows in different directions or indicate where watersheds are located. Numerous geological processes, such as erosion, glaciation, and faulting, can generate it. Saddle points divert runoff into distinct drainage basins, which affects how water moves across a landscape. They may also have an impact on how precipitation is distributed and how rivers and streams are formed. The underlying geology determines how steep or how gentle the slope is.

5. Strike and Dip: Almost in the middle section of the river, a strike and dip has been found along with the river bed. Here the horizontal expansion of river bed is also more. A horizontal line on the surface of a fault plane, folded or slanted rock layer, or other geological structure is called a strike. It shows how the feature is oriented in relation to true north. A rock layer's or geological structure's dip is its angle of inclination as measured from the horizontal plane. It shows the slope of the layer or structure, how steep or shallow. In order to assess rock formations, recognise geological risks, find mineral deposits or oil and gas reservoirs, and analyse rock layers, strike and dip together provide vital information on the orientation and geometry of rock layers and geological structures below the surface.

6. Rounded Hills: In some portions of the map the rounded hills are found here there. These hills usually have a more gentle, rounded appearance and don't have any steep slopes or jagged edges. The rounded hills' formation and features are influenced by the local geology. Hardy hill features can be formed by resistant rock types, whereas more easily weathered or softer rocks can result in more rounded and smoother landforms. The hills were shaped in large part by fluvial processes.

7. Conical Hills: There are a few conical hills on the map, mostly near the saddle and ridge line in the northern and southern regions. Conical hills are landforms distinguished by their pronounced conical or cone-shaped form, featuring steep to moderately sloping sides and a pointed peak. These hills can have symmetrical or asymmetrical shapes and usually rise sharply from the surrounding ground. Conical hills can also be produced by erosive processes like wind and water erosion, which wear down the surrounding terrain gradually and leave behind residual conical hill structures. These processes can also result from tectonic upliftment or depositional processes. These are stunning landforms that show how geological processes, environmental factors, and landscape evolution interact dynamically.

8. Ridge Line: In the extreme basin boundary near the southern section of the map a ridge line is found along with conical hills and saddles. It is an extended, narrow land elevation that parallels nearby lowlands or other low-lying terrain. In order to control water flow and sculpt the overall landscape, ridge lines are frequently used to demarcate the boundaries between adjacent drainage basins or watersheds. Numerous geomorphic processes, such as tectonic uplift, erosion, and deposition, might result in its formation.

9. Alluvium Deposition: Alluvium deposition has been found in the extreme north eastern part of the basin where Rimbi Chhu meets with Rathong Chhu, which is unusual in case of mountain rivers. The probable reason behind this feature can be the river Rimbi is smaller than Rathong. Each channel has different catchment characteristics and in the confluence, erosion of small river is becoming checked. Besides, there is a break-of-slope level of erosion which means a sudden downfall of gradient lowering the velocity of water flow and lessening the eroding capability, so the approximate level of the surface of the still water body is becoming Rimbi’s base level. Consequently, deposition will be enhanced resulting into alluvium deposition.

10. Concave Slope: The river basin has a concave slope as a whole. A sloping surface where the slope's curvature concaves towards the slope's middle or base is referred to as a concave slope in geomorphology. Concave slopes have a curvature that reduces the slope gradient as you go from the slope's base to its midpoint or crest. The slope seems concave or bowl-shaped due to this

curvature, with the ground sloping inward. It may have produced as a result of tectonic pressures, weathering, erosion, or mass wasting. However, its shape can be influenced by human activity, climate, environment, and geology.

11. Break of Slope: The basin has been classified into three broad groups having break of slope which depicts the change in slope from one section to other. A "break of slope" is a discrete variation or break in a slope's steepness or gradient. It denotes the separation of two slope segments with varying features or inclinations. Slope breaks are important for comprehending the morphology and dynamics of the landscape, and they can happen for a variety of causes. Here, knick points and elevation changes are connected to slope breaks. It acts as a border between several hydrological regimes, redirects flow, or creates areas of sediment accumulation or erosion to affect surface water runoff and drainage patterns. It also aids in the construction of alluvial fans.

4. CONCLUSION

The configuration of the earth surface has immense impact on the modification of human civilization. The terrain, slope, drainage, soil, etc. produce limits to the land mass available for different human activities among which 'drainage' keeps on transforming; navigation, transportation, water supply and irrigational activities totally depends on this. After investigating different constraints, possible land area can be extracted for future activities. The potential profile of land availability will further be examined for its suitability for anthropogenic activities. Due to larger limitations on available land, medium to very low slope areas could be considered for land development. The existence of steep slopes, vulnerability to landslides, large forest cover and inadequate access to most areas has been a major impediment to the natural and balanced growth of the area. The existing physical pattern has been dictated primarily by availability of land that is safe with respect to stability. In view of the development constraints like landform, topographical features, watercourses, drains, ecology and growth propensity, the future direction of growth needs to be spread over a larger area. Under developed areas within the notified city area need to be opened up for development through better accessibility and traffic and transport measures.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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