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Hypsometric analysis of the Tuirini drainage basin: A Geographic Information System approach

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ABSTRACT

Hypsometric analysis deals with measurement of the interrelationships between basin area and altitude of basin which has been used to understand the influence of climatic, geologic and tectonic factors on topographic changes. GIS provides advanced tools to obtain hypsometric information and also helps to estimate the associated parameters of landforms. The study of hypsometry has been performed to differentiate between erosional landforms at different stages during their evolution. The Tuirini basin is characterized by steep to very steep slopes whereas the altitude varies from 1905 m to 78 m above msl. The present study was carried out using ArcGIS - 10.2 tools. The entire study area was sub-divided into 22 sub-basins for hypsometric analysis and there area ranges from 4.75 to 65.64 sq.km. The hypsometric curve of the whole Tuirini basin reflects the mature geomorphic terrain whereas hypsometric integral indicates that the drainage basin has already eroded 58 per cent of land masses. The overall hypsometric results suggest that the sub-basins are in the mature stages of geologic development with moderately eroded landscapes and the entire basin is progressively approaching towards the monadnock phase of erosion.

Keywords: Hypsometry, Geologic stage, Drainage basin, GIS, Mizoram

1. Introduction

The landforms of Mizoram state is characterized by a large number of river networks passing through the hills and valleys where monsoon rainfall is high from June to September. The steep slopes of the mountains are composed of lose sedimentary rocks and are more prone to soil erosion in rainy season. Although the region is abundant in various natural resources, most parts of the areas remain inaccessible due to the mountainous nature of the terrain. Conservation of land and water resources are an important aspect of basin management. A drainage basin is the land surfaces from which all precipitation flows to a particular water body, such as tributary stream, river or sea and is considered as a fundamental geomorphic unit. The evolution of a landscape is the results of weathering processes, depositional processes, stream erosion patterns and tectonic processes that are acting upon it. Therefore, analysis of the drainage basin helps to understand the landform evolution through successive stages of geological time, fluvial process, lithologic character and hydrological behaviour of a basin as well as tectonic activity of a region.

The idea of hypsometry was first introduced by Langbein and Basil in 1947 to express the overall slope and the forms of drainage basin, and was later extended by Strahler (1952) to include the percentage hypsometric curve and the hypsometric integral. Hypsometry describes the measurement and analysis of relationships between the distribution of elevations across an area of land surface and basin area. Weissel et al. (1994) suggested that hypsometry may reflects the interaction between tectonic and degree of disequilibria in the balance of erosive, and could provide a valuable geomorphic index that constrains the relative importance of these processes. Hypsometric analysis is a useful method to identify the stage reached by a drainage basin in the present cycle of erosion and evaluate the erosional status of a basin, and also expresses the denudational processes over a region. Besides erosional stage of landform evolution, the influence of tectonic activity, climate change and lithological factors controlling on landform evolution can be analysed from hypsometric analysis (Lifton and Chase, 1992; Moglen and Bras, 1995; Willgoose and Hancock, 1998; Hurtrez and Lucazeau, 1999; Chen et al., 2003; Huang and Niemann, 2006). Thus, hypsometric analysis can be used as an estimator of erosional status of a drainage basin and prioritize them for taking up soil and water conservation measures, which is the prerequisite for planning and management of the basin. Geographic information system (GIS) and digital elevation model (DEM) have played an important role in in drainage basin analysis. Hence, GIS technique is used as a convenient tool for hypsometric analysis. The objective of the present study is to find out the geological stages of development and erosional status of the Tuirini basin and its sub-basins.

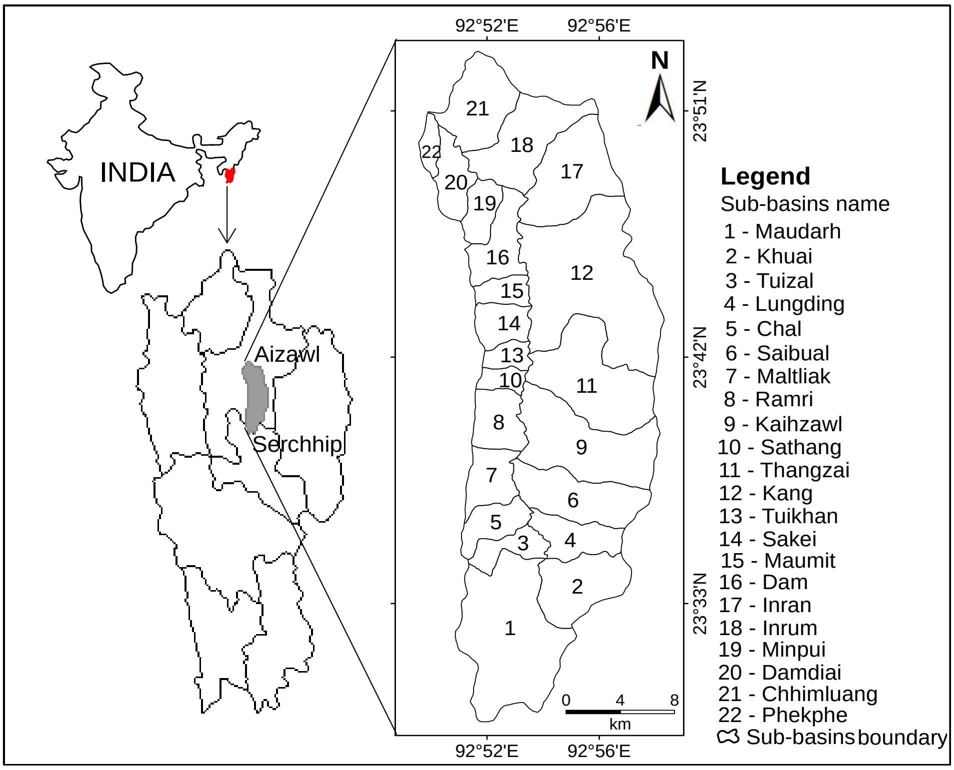

Figure 1: Location map of the study area

2. Characteristics of the study area

The study area extends between longitudes 92º49′34″– 92º58′22″E and latitudes 23º28′37″–23º53′20″N, which covers an area of about 420.07 sq.km with basin perimeter of 110.70 km. The Tuirini drainage basin forms parts of two districts viz. Aizawl district and a small part of Serchhip district of Mizoram in India (Fig. 1). The basin is extremely rugged terrain cut by deep valleys and crossed by hill ranges along with the average elevation of 830 m above mean sea level (msl). The entire study area is covered by thick sedimentary rocks constituting the Surma Group. Soils are mostly of red and yellow loamy with acidic in nature. The study area has been sub-divided into twenty two sub-basins based on the basin areas of Tuirini river and its major tributaries (Fig. 1). The climate of the basin area is influenced by the southwest monsoon system that brings heavy precipitation, more than 80 per cent of rainfall occurs during June to September. The temperature of the study area varies from a minimum of 10^0 C ~ to a maximum of 30^0 C ~ with average annual relative humidity is about 70 %.

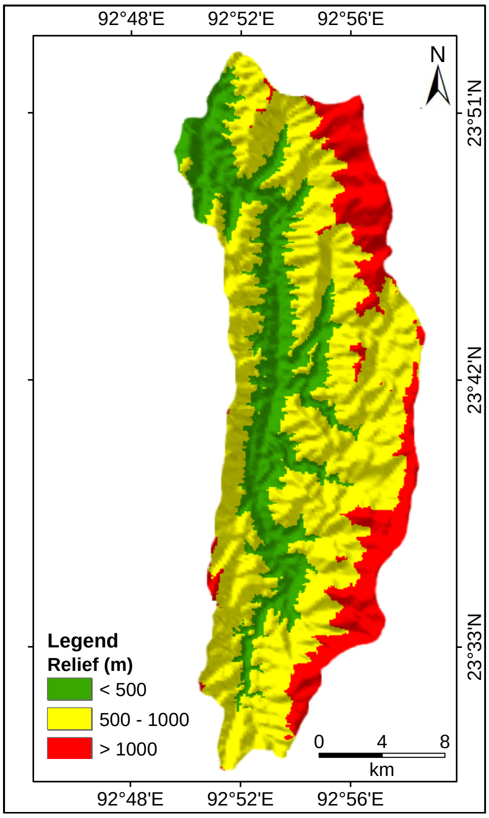

Figure 2: Relief map of the study area

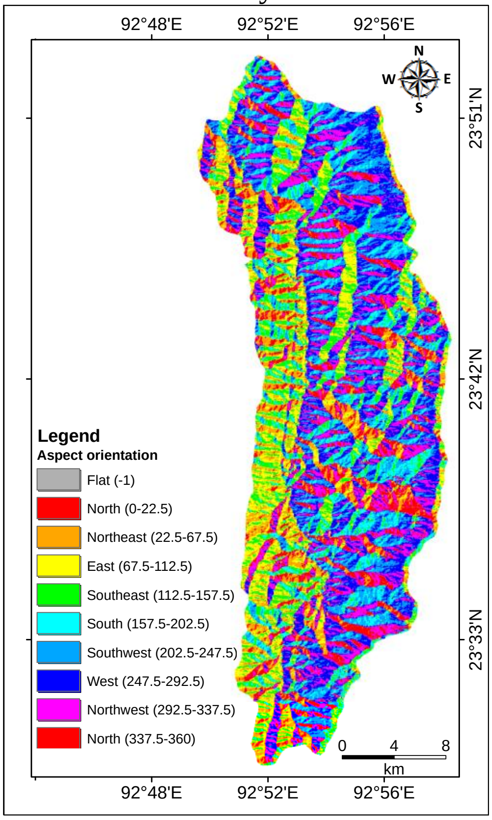

Figure 3: Aspect map of the study area

2.1 Relief

The term relief is used to describe the vertical dimension or amplitude of topography, which is mainly governed by erosional and tectonic processes of an area. In the present study, relief values have been grouped into three categories viz. high, moderate and low. The relief value < 500 m has been categorized as altitude of low relief zone occupy about 109.56 sq.km of the basin area, moderate relief region ranges from altitudes of 500 to 1000 m covers maximum area of about 243.13 sq.km and above 1000 m as high relief zone occupies about 67.34 sq.km of the total basin area. The relief map of the basin (Fig. 2) shows that major portion of the basin area falls under moderate relief (57.89 %) followed by low relief (26.08 %) and only 16.03 % of the total area characterize as high relief zone. The northeastern and southeastern parts of the basin are characterized by a higher altitude than the other parts.

2.2 Aspect

Aspect is azimuthal direction with reference to true north (zero degree) and indicates the maximum slope direction of a terrain to which it faces, and also provides clues about the direction of the water flow. It is influenced by vegetation, climate, precipitation patterns, agricultural productivity, snow melt and wind exposure. The aspect of a slope can create a very significant influence on its local climate because the sun's rays are in the west at the hottest time of day in the afternoon and so in most cases, a west-facing slope will be warmer than sheltered east-facing slope (Magesh et al., 2011). Generally, aspect is used in hilly region, because shadow plays an important role for determining the soil moisture regime. The entire study area is hilly region and there is very less flat area. From the aspect map (Fig. 3), it can be seen that east facing slopes mainly occur in the western part of the basin, whereas west facing slopes are seen in the eastern part of the basin. Therefore, east facing slopes have higher moisture content and lower evaporation rate then the west facing slopes.

3. Materials and methods

The Tuirini basin and its sub-basins boundary were delineated from rectified, mosaiced Survey of India (SoI) topographic maps no. 84A/13, 84A/14 and 84A/15 on the scale 1: 50,000 assigning UTM, WGS 1984, 46N zone projection system. Contour interval of 40 m was accurately digitized within GIS environment from the scanned SoI topographic maps and also spot heights were digitized. The digitized contours and spot heights were further processed in ArcGIS (Version 10.2) using the spatial analyst tools to generate the digital elevation model (DEM). From the DEM, relief and aspect maps have been prepared with the help of ArcGIS software. The hypsometric curves for the Tuirini basin and its sub-basins were prepared based on Strahler (1952) method. Hypsometric integrals of all the sub-basins have been calculated using empirical formula proposed by Pike and Wilson (1971).

4. Results and discussion

Hypsometry can be evaluated through the hypsometric curve and hypsometric integral. The shapes of the hypsometric curve and the values of hypsometric integral are important elements in the landform analysis. These can be explained in terms of degree of landscape dissection and relative landform age. The hypsometric curves and hypsometric integral values of the Tuirini basin and its sub-basins are discussed below.

4.1 Hypsometric curve

The hypsometric curve describes the distribution of elevations across an area of land, which has been used to evaluate the evolutionary status of landforms. It is related to the volume of the soil mass in the basin and the amount of erosion that had occurred in a basin against the remaining mass (Hurtrez et al., 1999). Hypsometric curves are related to geomorphic and tectonic evolution of drainage basins in terms of their forms and processes (Schumm, 1956; Strahler, 1964; Leopold et al., 1964; Hurtrez et al., 1999). A useful attribute of the hypsometric curve is that drainage basins of different sizes can be compared with each other because area and elevation are plotted as functions of total area and total elevation. That is, the hypsometric curve is independent of differences in basin size and relief (Strahler, 1952). A. N. Strahler (1952) has classified three types of landforms on the basis of shapes of the hypsometric curve, each denoting the three typical stages of basin dissection, namely (i) young stage, (ii) mature stage and (iii) old stage. Convex shaped curves are associated with young stage of basin, which indicate that the region is slightly eroded and undisseceted, mature stage is correspond to S shaped curves being concave upwards at higher elevations and convex downwards at lower elevations characterized by moderately eroded regions and old stage of basin is related to concave shaped curves indicate highly eroded and deeply dissected landscapes. With the progress of erosion, the shape of hypsometric curve changes from convex-up to essentially straight to concave-up (Schumm, 1956).

4.2 Plotting of hypsometric curves

The percentage hypsometric method has been used for the present study. There are two ratios involved in this method and plotted against each other on a graph. The ordinate represents the ratio of relative elevation (h/H) and the abscissa represents the ratio of relative area (a/A). The relative elevation is computed as the ratio of the height of a given contour (h) from the base plane to the maximum basin elevation (H). The relative area is obtained as a ratio of the area above a particular contour (a) to the total area of the basin above the outlet (A). The value of relative area (a/A) is in a range from one to zero. One at the lowest point in the drainage basin (h/H = 0) and zero at the highest point in the basin (h/H = 1).

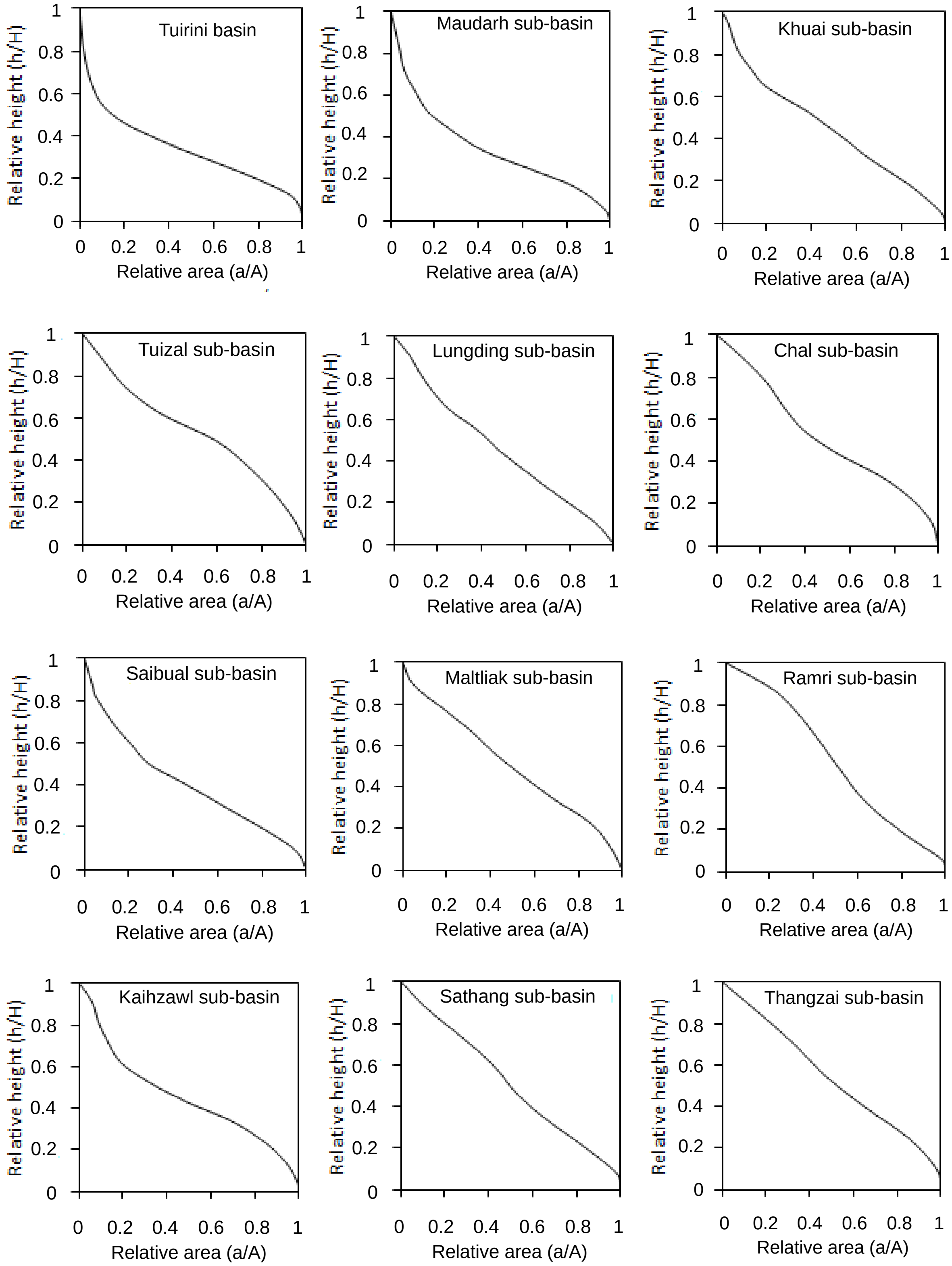

Figure 4a: Hypsometric curves of the Tuirini basin and its sub-basins

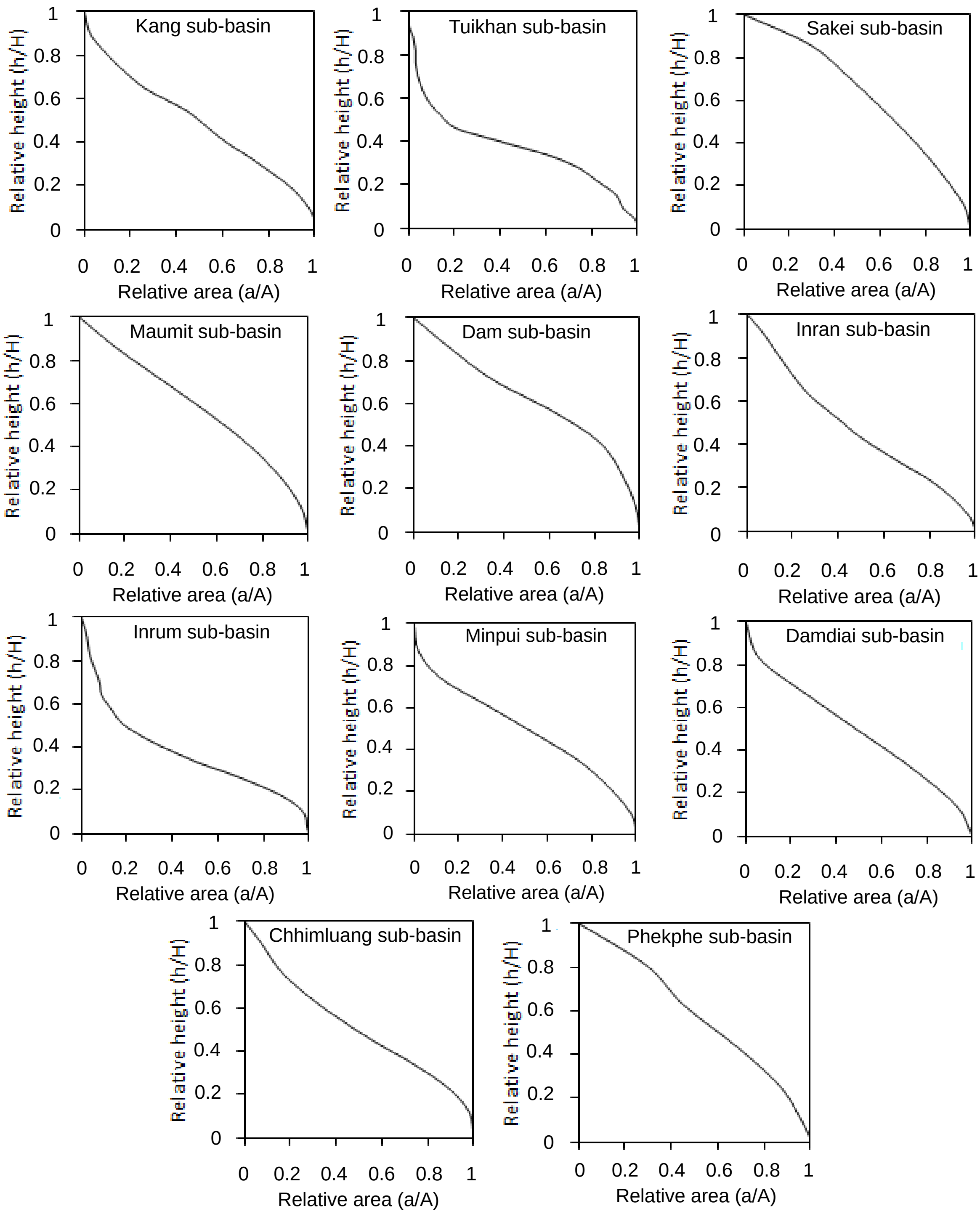

Figure 4b: Hypsometric curves of sub-basins of the Tuirini basin

In the present study, hypsometric curves have been prepared for the Tuirini basin and its 22 sub-basins as shown in figures 4a & 4b. The hypsometric curve of the entire Tuirini basin represents S-shape curve indicating a mature stage of landscape development. It was also observed from the figures (4a & 4b) that there was a combination of convex, concave and S-shape of curves, suggest that the sub-basins attain mature stage from the youth stage. The difference between the shapes of the hypsometric curve in the study area might be due to the lithological variations, incision of bed rock, down slope movement of eroded materials and removal of the sediments from the basin.

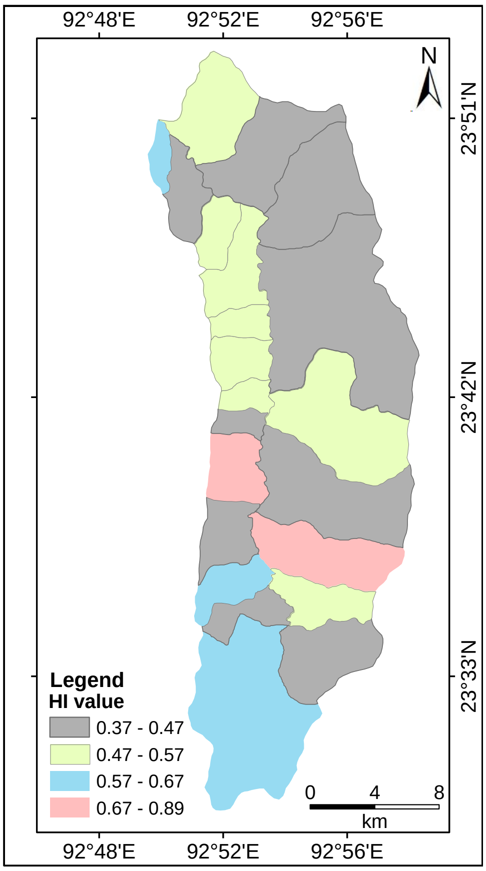

Figure 5: Hypsometric integral map

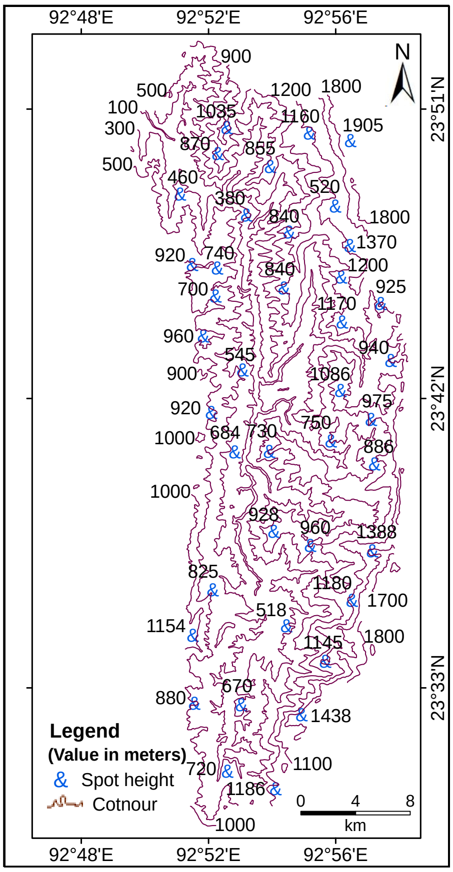

Figure 6: Contour map with spot heights

4.3 Estimation of hypsometric integral

Integration of the hypsometric curve gives the hypsometric integral (HI), which is equivalent to the elevation-relief ratio (E) as proposed by Pike and Wilson (1971). Mathematically, it is defined as $E \approx HI = [\text{Mean elevation } (E_{mean}) - \text{Minimum elevation } (E_{min})] / [\text{Maximum elevation } (E_{max}) - \text{Minimum elevation } (E_{min})]$. The hypsometric integral value is controlled by basin geometry, relief and area of drainage basin (Lifton and Chase, 1992; Masek et al., 1994; Hurtrez et al., 1999; Chen et al., 2003). It was also found by Strahler (1952) that the hypsometric integral is inversely correlated with total relief, slope steepness, drainage density and channel gradients. The geologic stages of landforms development and erosional status of the basins are quantified by hypsometric integral. High value of hypsometric integral indicates the youthful stage of less eroded areas and it decreases as the landscape is denuded towards the maturity and old stages. The HI is expressed as a percentage and is an indicator of the remnant of the present volume as compared to the original volume of the basin (Ritter et al., 2002). The hypsometric integral is also an indication of the 'cycle of erosion' (Strahler, 1952; Garg, 1983). The cycle of erosion is defined as the total time required for reduction of a land topological unit to the base level i.e. the lowest level. This entire period or the cycle of erosion can be grouped into three categories, each representing the three distinctive stages of the geomorphic cycle, viz.

(i) the monadnock or old stage if $HI \leq 0.35$, in which the basin is fully stabilized;

(ii) the equilibrium or mature stage if 0.35≤HI≤0.60, in which the basin development has attained steady state condition and
(iii) the inequilibrium or young stage if HI≥0.60, where the basin is highly susceptible to erosion and is under development (Strahler, 1952).

Table 1: Estimated hypsometric integral values of Tuirini basin and its sub-basins

Sub-basins name	Area (km^2)	Elevation (m)			Hypsometric integral (HI)	Geological stage
		Maximum	Minimum	Mean		
Maudarh	51.80	1145	350	875	0.58	Early maturity
Khuai	21.76	1837	348	1015	0.44	Middle maturity
Tuizal	8.87	1156	320	768	0.41	Middle maturity
Lungding	12.68	1460	310	982	0.49	Middle maturity
Chal	9.79	1150	300	850	0.64	Late youthful
Saibual	22.58	1775	290	1615	0.89	Early youthful
Maltliak	10.46	1288	270	860	0.42	Middle maturity
Ramri	11.67	1040	260	988	0.84	Early youthful
Kaihzawl	34.83	1392	250	795	0.45	Middle maturity
Sathang	4.87	1052	240	675	0.41	Middle maturity
Thangzai	5.58	982	235	595	0.48	Middle maturity
Kang	35.57	1170	230	865	0.50	Early maturity
Tuikhan	65.64	1905	225	885	0.38	Late maturity
Sakei	8.77	958	224	760	0.51	Early maturity
Maumit	5.86	960	222	692	0.51	Early maturity
Dam	13.93	921	220	695	0.53	Early maturity
Inran	24.82	1860	180	983	0.47	Middle maturity
Inrum	27.73	1866	150	887	0.37	Late maturity
Minpui	7.58	925	135	692	0.57	Early maturity
Damdiai	9.84	745	110	572	0.47	Middle maturity
Chhimluang	20.68	1064	100	677	0.49	Middle maturity
Phekphe	4.75	626	80	517	0.60	Late youthful
Tuirini basin	420.07	1905	78	830	0.42	Middle maturity

The hypsometric integral (HI) values obtained for the Tuirini basin along with their 22 sub-basins are shown in the fig. 5 and presented in Table - 1. The HI value of the Tuirini basin is computed to be 0.42, which reveals that only 42 per cent of the land masses remain in the basin to be eroded. The calculated HI values for all the sub-basins of Tuirini basin ranged from 0.37 to 0.89 (Table - 1). Out of the 22 sub-basins, only 4 sub-basins fall under younger stage, 2 sub-basins namely Saibual and Ramri belong to early youthful stage and 2 sub-basins namely Chal and Phekphe come under late youthful state of its development. The remaining 18 sub-basins belong to mature stage of landscape evolution. The 6 sub-basins viz. Maudarh, Kang, Sakei, Maumit, Dam and Minpui have just entered into early mature stage of erosional development. There are 10 sub-basins namely Khuai, Tuizal, Lungding, Maltliak, Kaihzawl, Sathang, Thangzai, Inran, Damdiai and Chhimluang are at middle maturity stage. Only Tuikhan and Inrum sub-basins represent late mature stage of landforms and reaching towards monadnock stage.

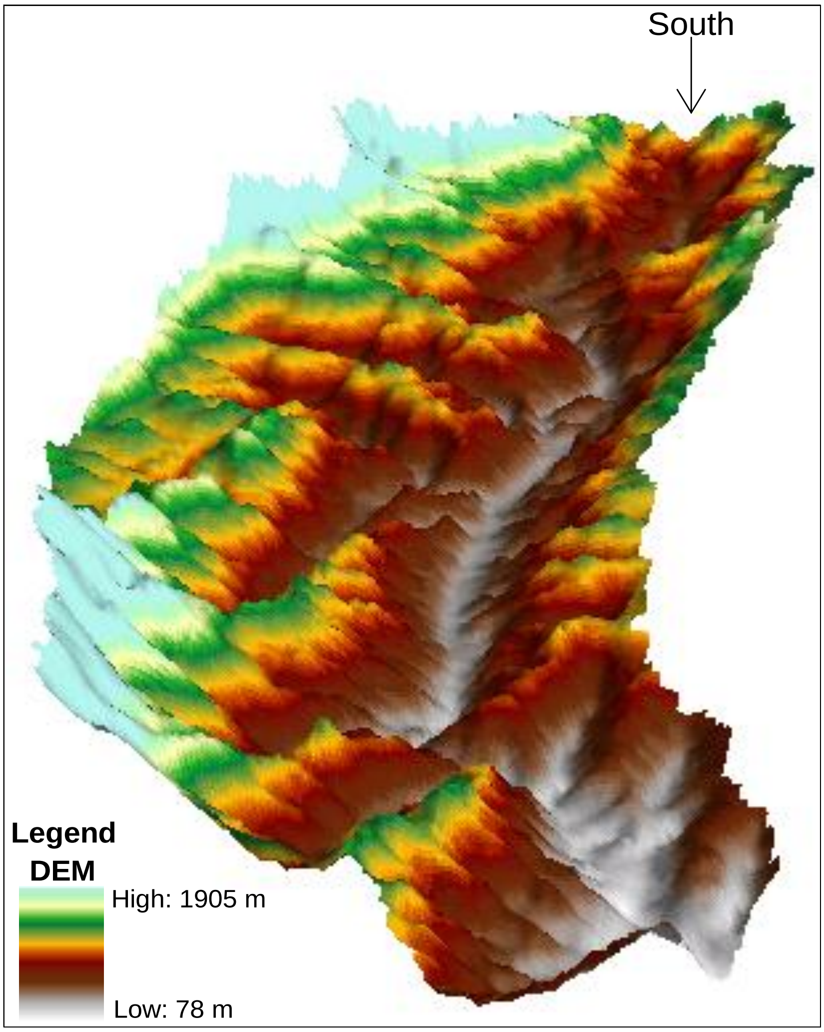

Figure 7: Topographic DEM of the study area

Figure 8: Field photograph showing **(a)** Vertical cliff faces of the hill and eroded sandstone beds along the Tuirini river (Red arrow indicates flow direction); **(b)** Deposition of unconsolidated gravels, pebbles and boulders in the left bank of the Tuirini river near its outlet.

Figure 9: Field photographs showing structural and dissected hills (erosional landforms) in the study area.

5. Conclusion

In order to understand the erosional stages and relative age of landforms, hypsometric analysis has been carried out for the Tuirini basin along with their twenty sub-basins. GIS is gaining importance as a powerful tool in the natural resources management and its conservative work. Thus, GIS technique has been used as a convenient tool for hypsometric analysis. The hypsometric curve and hypsometric integral value of the entire Tuirini basin reflects the mature stage of geomorphic cycle development. Among the twenty sub-basins, four sub-basins are found to be under younger geomorphic stages with high hypsometric integral values while the eighteen sub-basins are at mature state, which are moving towards stabilization, and also indicate the erosional process differs from one sub-basin to another. No sub-basin comes in the old state of dissection in the study area. This analysis will help to take appropriate measures to conserve soil and water resources for sustainable development of the basin area.

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6. References

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