Vol 6 Issue 9 June 2017

ISSN No : 2249-894X

Monthly Multidisciplinary Research Journal

Review Of Research Journal

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RNI MAHMUL/2011/38595 **ISSN No.2249-894X**

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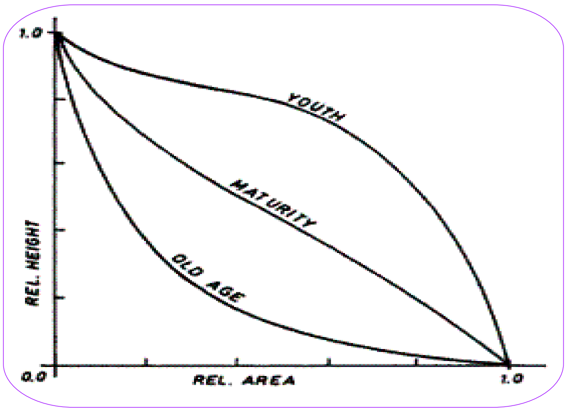
ISSN: 2249-894X Impact Factor : 3.8014(UIF)

Review Of Research

Volume - 6 | Issue - 9 | June - 2017

ANALYSIS OF THE HYPSOMETRIC INTEGRAL AND ESTIMATION OF STAGES OF LANDFORM DEVELOPMENT IN THE LODHAMA RIVER BASIN OF EASTERN DARJEELING HIMALAYA, INDIA USING GIS TECHNIQUES



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ABSTRACT:

Hypsometry of a river basin generally involves the assessment and investigation of the relationship between elevation and the degree of dissection of the particular area, which assist us to understand the phases of geomorphic advancement of the area. The present paper considers the Lodhama river basin located in the Eastern Darjeeling Himalayan region as a case study for the hypsometric analysis using Remote Sensing and Arc-GIS method. The study basically aims to identify the regional pattern of hypsometric curve, hypsometric integral and hypsometric anomaly existent in the study area and also tries to understand the impacts of various driving factors controlling the hypsometric integral of the study area. The elevation data are derived and analysed for sub-zones of Lodhama river basin from ASTER-DEM. The Slope and aspect map were prepared from ASTER DEM. Lodhama river basin consists of thirteen sub-river basins among them three sub-basin (A, B and J) belongs to the positive hypsometric anomalygroup. Tectonic influence map of Lodhama river basin has been prepared by Raster calculator based Weighed Linear Combination method with six selected parameters such as Gravity anomaly map, Isobase slope map, Seismic hazard map, Form factor, Sinuosity index map and Height map. The influence of the tectonic characteristics on the hypsometric of the river basin is moderate in nature. Hypsometric integral value for the entire Lodhama river basin varies from 35% to 75% and the erosional integral varies from 25% to 65%. The average hypsometric integral for the entire basin is 50.2 % which indicates that the area falls in the mature stage of geomorphic evolution with high erosional vulnerability.

KEYWORDS: Hypsometric curve, hypsometric integral, hypsometric integral anomaly, tectonic index, WLC, GIS, Lodhama river basin.

1.INTRODUCTION

Hypsometry is a geo-morphological parameter which is directly related to the proportional altitude of the basin and area of the basin. Generally, it is used for identifying the geomorphic evolution and the stages of landform development of the river basin. Hypsometric curve and hypsometric integral are very important parameter which indicates the basin health that is also used for the estimation of erosional status of the river basin and the level of cycle of erosion of a particular basin. The hypsometric integral also indicates the uneroded portion of the river basin with respect to the total area of the basin. Thus the analysis and study of the hypsometric integral forms a basic tool for characterizing an area into different stages of landform development groups. The Regional hypsometric integral is predominantly affected by the active tectonic activities, geological structure and climatic characteristics of a region. Due to its dimensionless character the Hypsometric analysis is one of the most widely used techniques for understanding the regional differences in the cycle of landform development.

The tectonic parameters or the tectonic index has a great impact on the hypsometric characteristics of an area. Tectonic geomorphology basically is a new branch of geomorphology, which may be defined as the study of the landforms produced by tectonic processes. So, it can be said that tectonic geomorphology has a rigid relationship with the surface and tectonic processes. At recent times the application of remote sensing and GIS has widened the scope of hypsometric analysis around the globe. A large number of scholars like Markose et al (2011), Nikoonejad et al (2015), Quanbari et al (2014), Ahmed et al (2016), Pérez-Peña et al (2008), Khadri et al (2015), J. V. Pérez-Peña et al (2008), O. Singh, et al (2008), Humdouni et al (2007) etc; has widely applied the remote sensing and GIS techniques in their studies of hypsometric analysis of various regions.

The present study has been undertaken to analyse the hypsometric integral and hypsometric integral anomaly to identify and categorized the stages of cycle of landform development in the different sub-basins of the Lodhama River basin in Eastern Darjeeling Himalayan region using remote sensing and geographical information system techniques.

LOCATION OF STUDY AREA AND ITS GEOLOGIC AND GEOMORPHIC SETTING

Lodhama River is an upstream tributary of Ramom River situated in Darjeeling Himalayan region of West Bengal, India. The basin extends from 88^0 1` E to $88^0$ 8` E and 27^0 0` to $27^0$ 7` 30`` N (Fig no: 1). The River Lodhama originates from Singalila range (3222 m) on the Nepal border and flows in the north easterly direction, draining the areas of Darjeeling Pul Bazar Block and falls into Great Rangit at Kankibong as its major right bank tributary. On the way it receives at least 12 tributaries; important among them are the Rithu khola, Monggong Khola, Dilpa Khola and Palmajhuwa Khola etc. The total catchment or geographical area of the river Lodhama is about 75.62 square kilometres. The highest and lowest elevation of the river basin ranges from 900 metre to 3222 metre. Geological composition of the river basin consists that of slate, schist, and quartzite and unclassified crystalline mainly gneisses rocks (Fig no: 3 and plate no: 4). the basic soils of the river basin falls into two categories such as gravelly loamy-coarse loamy and fine loamy-coarse loamy soils (Fig no: 2 and plate no: 2).

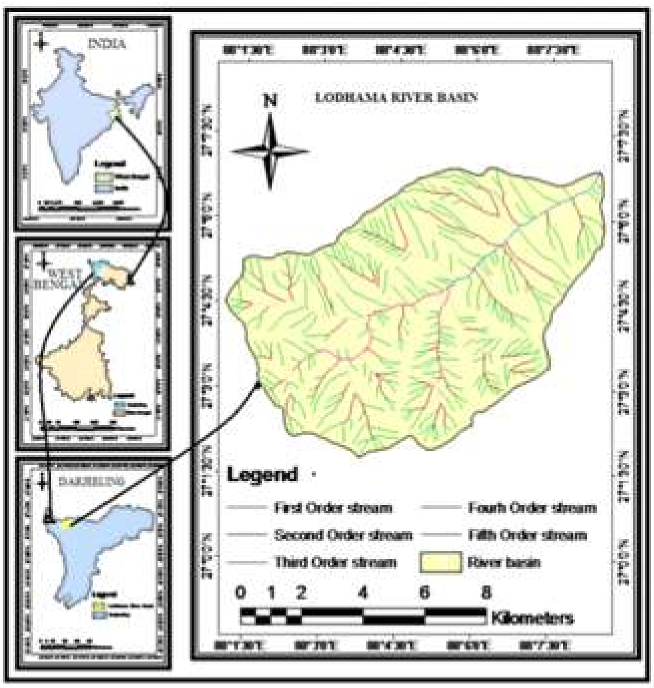

Fig no: 1 (Location of study area)

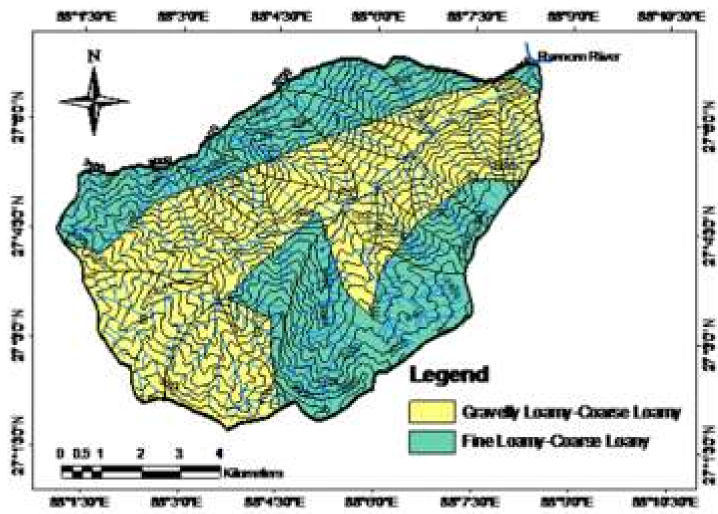

Fig no: 2 (Soil map of Lodhama River Basin)

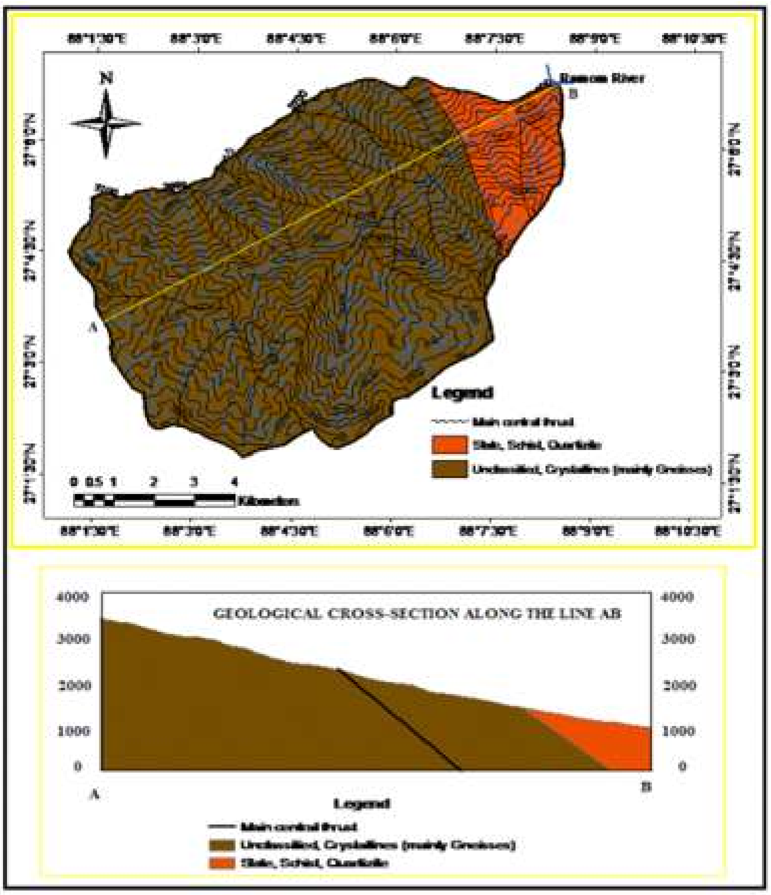

Fig no: 3 (Geological map of Lodhama River Basin)

MATERIAL AND METHODS

Hypsometric analysis and techniques: Hypsometric analysis involves the measurement of relationship between basin area and basin altitude. This according to Strahler 1952 is the comparative ratio of an area at various elevations on the surface of the earth. The analysis of hypsometric was first introduced by Langbein, 1947.There are different techniques of hypsometric analysis of basin such as; area height curve, hypsometric curve, percentage hypsometric curve etc.

a) Area-height curve: It indicates the actual areas between two successive contours. It means proportion of areas in different altitudinal zones in a basin. For the representation of area-height relationship percentage of basin area is represented in X axis while absolute height is shown in Y axis (Fig no: 4. a).

b) Hypsometric Curve: Through this curve proportion of surface areas are shown in different elevation zone but unlike area-height curve, cumulative basin area in the X axis is represented (Fig no: 4.b).

c) Percentage Hypsometric Curve: This curve is the graphical relationship between the ratio between relative height (h/H) and relative area (a/A). Strahler (1952) suggested two ratios of relative height and relative area. Relative height denotes the ratio of height between two successive contours (h) and total height (H) and relative area represents the ratio between areas between two successive contours (a) and total basin areas (A). Hypsometric integral (HI) and Erosional integral (EI) are two important measures which simply gives a clear idea about the cycle of erosion. These two integral denote the ratio of the volume of stable land (Ls) and the land area consumed by the dynamic wheel of the cycle of erosion (Fig no: 4.c).

$$HI = \frac{Ls}{Lus}$$

HI or EI values vary from 0-1 or in percentage 0-100%

$$EI = 1 - \frac{Ls}{Lus}$$

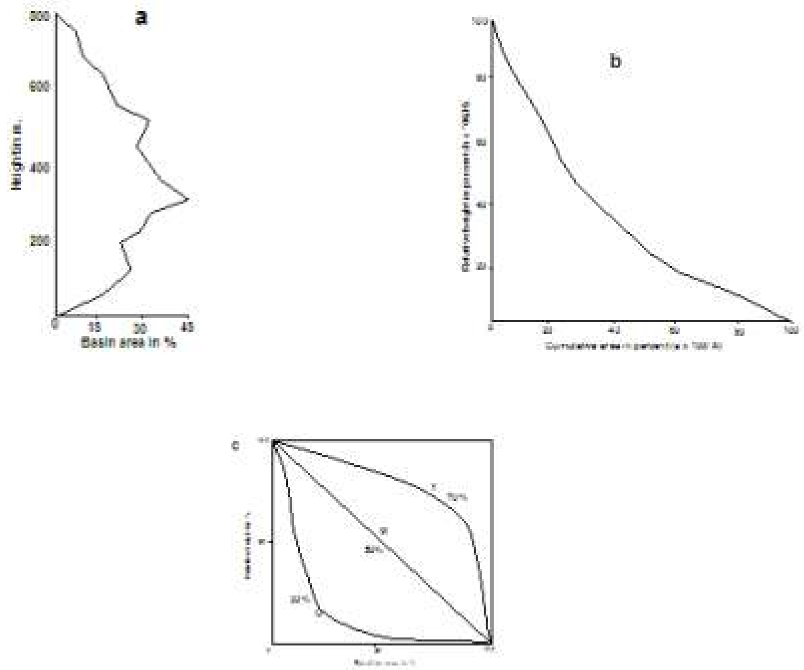

Fig no: 4 (a. Area height curve, b. hypsometric curve c. Percentage hypsometric curve)

A.N. Strahler (1952) assesses the relationship between HI and stage of drainage development in the following way.

HI is >0.6 or >60% which indicates Youthful stage

HI is 0.6-0.35 or 60%-35% which indicates mature stage

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HI is <0.35 or <35% which indicates old stage.

For the analysis in the present paper, all data were registered into UTM projection northern zone 45 datum W.G.S 84. The drainage basin map for the Lodhama River was prepared from toposheet map (74 A/4) issued by the Survey of India. Elevation and slope map were prepared from ASTER DEM (USGS). Hypsometric integral and hypsometric integral anomaly map were prepared with the help of percentage of hypsometric curve (A. N. Strahlar 1952) using ARC-GIS 9.3 software. Geological map was prepared from NATMO and soil map of the river basin was prepared from NBSS and LUP regional centre, Kolkata. Gravity anomaly map of the river basin was prepared from derived regional gravity anomaly map of India. Seismic hazard map was prepared from seismic hazard map of West Bengal (www.wbdmd.gov.in). Shape map of the river basin was prepared with the help of Horton's form factor (1932) equation. Tectonic index map was prepared by Raster based weighted linear combination (WLC) method with selected six parameters in ARC-GIS environment. WCL can be presented using the following formula.

$$\text{WLC} = \sum_{j=1}^{n} a_{ij} w_j$$

Where, aij = ith rank of jth attribute; wj = weightage of jth attribute.

RESULTS AND DISCUSSION

Hypsometric curve of the whole river basin

As per the Hypsometric analysis of the Lodhama river basin, the HI value is 50.2% and EI values is 49.8%. Looking at the derived Hyprometric Integral value and Erosional Integral value and also flowing the Strahler 1952 categorization the study area falls into the mature stage of its geomorphic evolution (Fig no: 5)

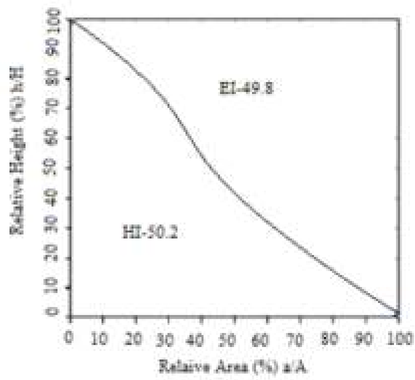


Fig no: 5 (Hypsometric curve of Lodhama river basin)

Regional Hypsometric Integral Pattern and Hypsometric Anomaly

Hypsometric integral is the ratio of volume or percentage of total volume of the basin area below the curve and in this way it reveals the volume of the area unconsumed by the dynamic wheels of erosion, whereas erosional integral is a proportionate area above the curve and thus indicates the volume of area which has been eroded by various erosional processes (S. Singh, 1998). Hypsometric integral map of the Lodhama river basin has been prepared based on the calculated HI (Strahlar, 1952) at different sub-basins. Hypsometric integral of the river basin is divided into four categories (Table no: 1). Maximum HI is found in three sub-basin among them, two sub-basin (A and B) are situated in the upper catchment of the Lodhama river basin and one sub-basin (J) is situated in the lower catchment of the river basin near the confluence part (Fig no: 6). High values of the HI are possibly related to young active tectonic and low values are related to older landscapes that have been more eroded and less impacted by recent active tectonics.

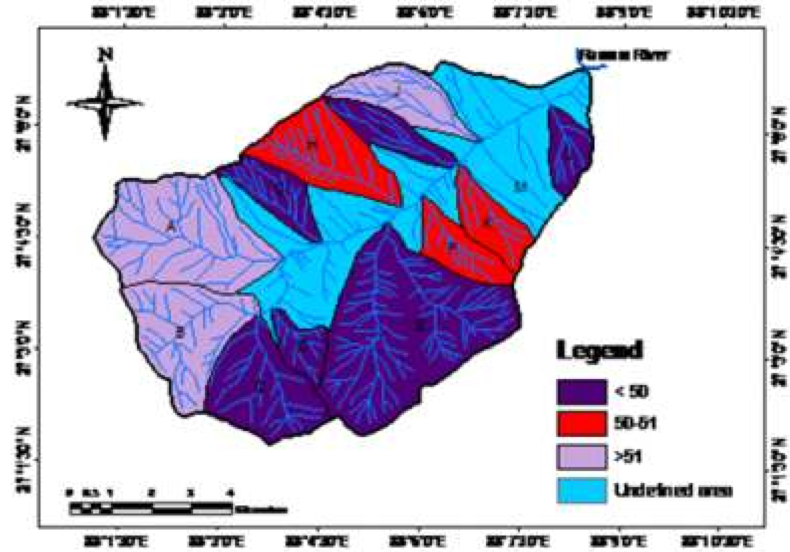


Fig no: 6 (Sub-basin wise hypsometric integral of Lodhama river basin)

Hypsometric anomaly map of the Lodhama river basin has been prepared based on the references to the calculated HI value of the entire river basin (52.8 %). Hypsometric anomaly of the sub-basin of the Lodhama river is divided into three categories (Table no: 2). Positive hypsometric anomaly is found in three sub-basins such as A (+0.2), B (+0.2) and J (+0.2). Negative hypsometric anomaly is found in nine sub-basins such as C (-4), D (-6), E (-5), F (-1), G (-6), H (-1), I (-4), K (-2), and L (-3) (Fig no: 8).

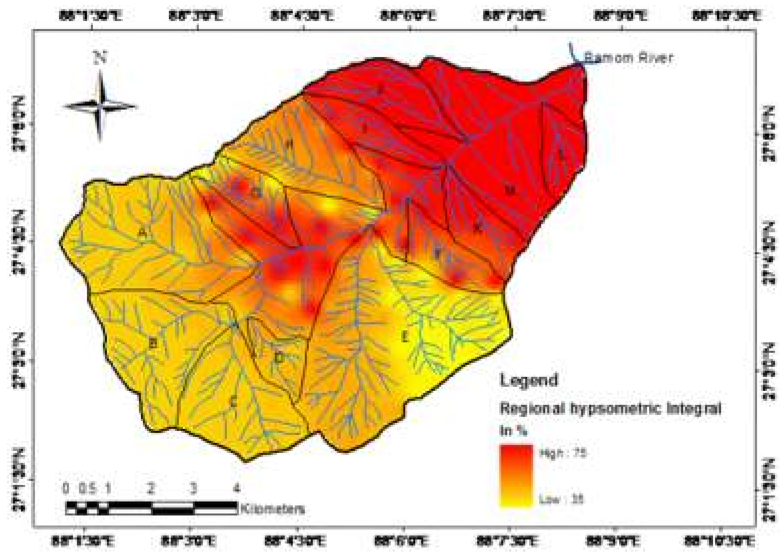


Fig no: 7 (Regional hypsometric integral of Lodhama river basin)

Table no: 1 (Hypsometric integral in different sub-basin of Lodhama river)

Hypsometric Integral ranges	Sub-basin ID and HI values	Number of sub-basins
<50	C (48), D (46), E (47), G (46), I (48) and L (49)	6
50 to 51	F (51), H (51) and K (50.8)	3
>51	A (53), B (53) and J (53)	3
Undefined area	M (52.8)	1

Table no: 2 (Hypsometric anomaly in different sub-basin of Lodhama river)

Hypsometric anomaly ranges	Sub-basin ID and HIA values	Number of sub-basin
Positive hypsometric anomaly (0 to +0.2)	A (+0.2), B (+0.2) and J (+0.2)	3
Negative hypsometric anomaly (0 to -6)	C (-4), D (-6), E (-5), F (-1), G (-6), H (-1), I (-4), K (-2), and L (-3)	9
Undefined area	M (0)	1

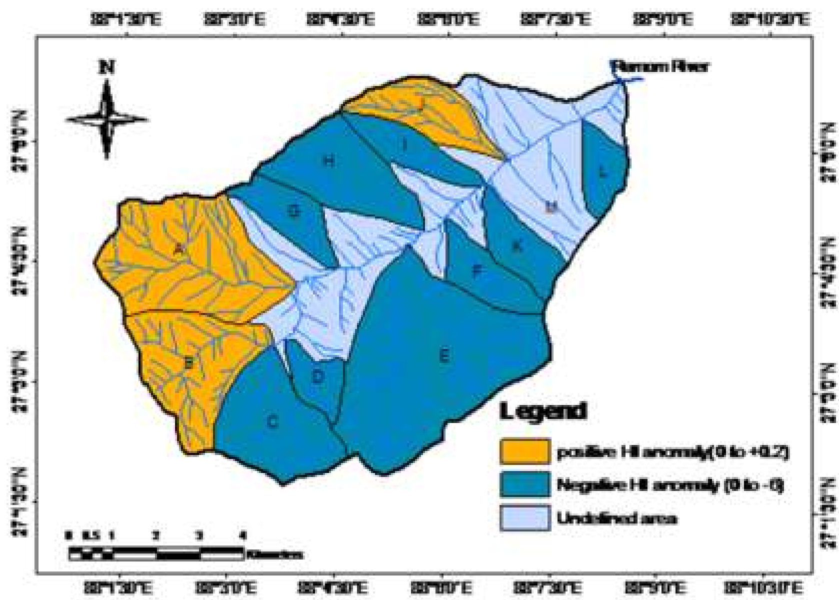


Fig no: 8 (Sub-basin wise hypsometric integral anomaly)

Regional Hypsometric Integral Pattern and Hypsometric Anomaly influenced by Active tectonic

Tectonic influence map of Lodhama river basin has been prepared by Raster calculator based Weighed Linear Combination method using six selected parameters such as Gravity anomaly map, Isobase slope map, Seismic hazard map, Form factor, Sinuosity index map and Height map (Fig no: 11). Tectonic influence of Lodhama river basin is divided into three categories such as high tectonic influence zone (57.09 to 59.64), moderate tectonic influence zone (55.32 to 57.09) and low tectonic influence zone (53.55 to 55.32) (Fig no: 9).

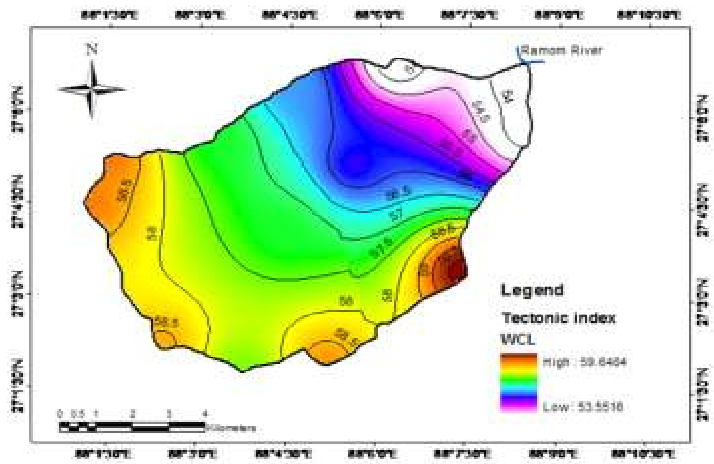


Fig no: 9 (Tectonic influence map)

High Weighted Linear combination value indicates the high tectonic influence zone. Maximum number of sub-basins of the study area are located in the moderate to low tectonic influence zone (Table no: 3) Positive hypsometric anomaly sub-basins like A and B are situated in the high to moderate tectonic influence zone and sub-basin J is situated in the low tectonic influence zone. But sub-basin M which is undefined area is situated in the moderate to low tectonic influence zone (Fig no: 10).

Table no: 3 (Tectonic influence zone and sub basins frequency under each zone, average HI within each zone)

Tectonic influence zone	WCL	Sub-basin ID and HI values	Sub-basin ID and Positive HIA values	Sub-basin ID and Negative HIA values	Sub-basin ID and Undefined HIA values	Frequency of sub-basin in Hypsometric integral	Average Hypsometric integral
High influence zone	57.09 to 59.64	A (53), B (53), E (47), and G (46)	A (+0.2) B (+0.2)	C (-4) and E (-5)		4	49.75
Moderate influence zone	55.32 to 57.09	A (53), B (53), C (48), D (46), E (47),F (51), G (46), H (51), M (52.8)	A (+0.2) B (+0.2)	C (-4), D (-6), F (-1), G (-6) and H (-1)	M (0)	9	49.08
Low influence zone	53.55 to 55.32	H (51), I (48), J (53), F (51), K (50.8), M (52.8) and L (49)	J (+0.2)		M (0)	7	50.8

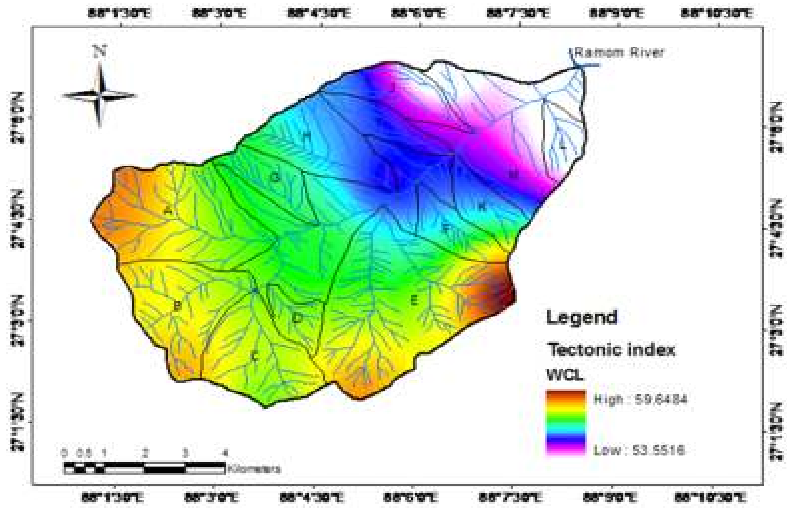
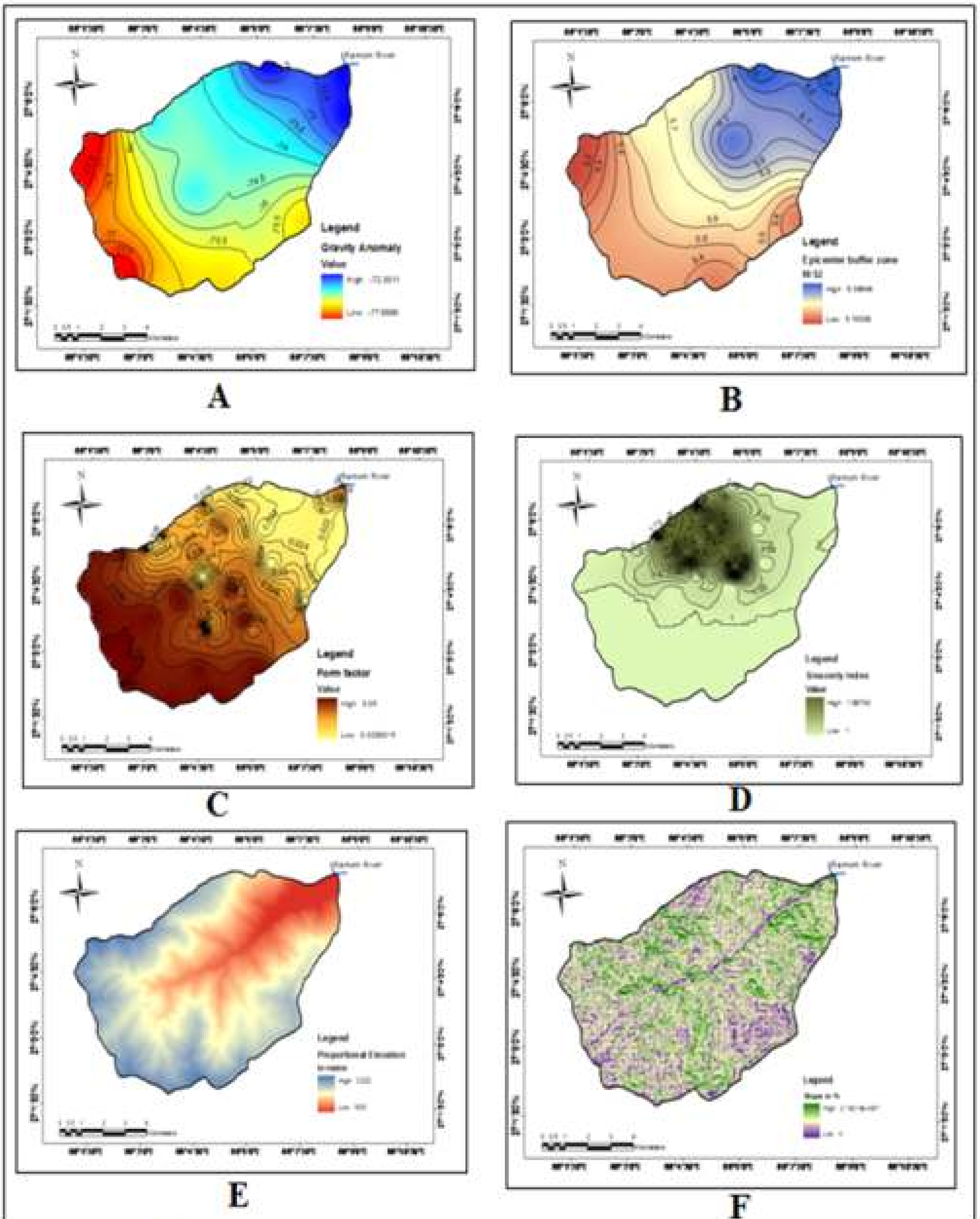


Fig no: 10 (Location of sub-basin on different tectonic influence zone)

Plate no: 1 (Deeply incised stream)

Plate no: 2 (Soil types



A: Gravity Anomaly map
B: Epicentre buffer zone map
C: Form factor map
D: Sinuosity index map
E: Height map (DEM)
F: Isobase slope map

Fig no: 11 (Components of tectonic influence map)

Plate no: 3 (Dissected relief)

Plate no: 4 (Geological rock strata)

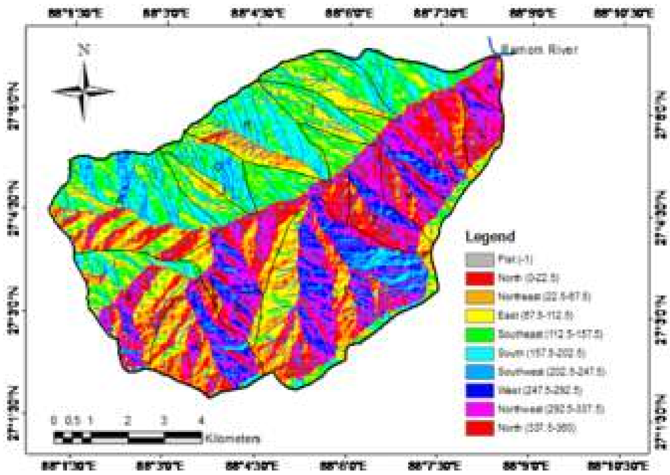


Fig no: 12 (Sub-basin overlay on aspect map)

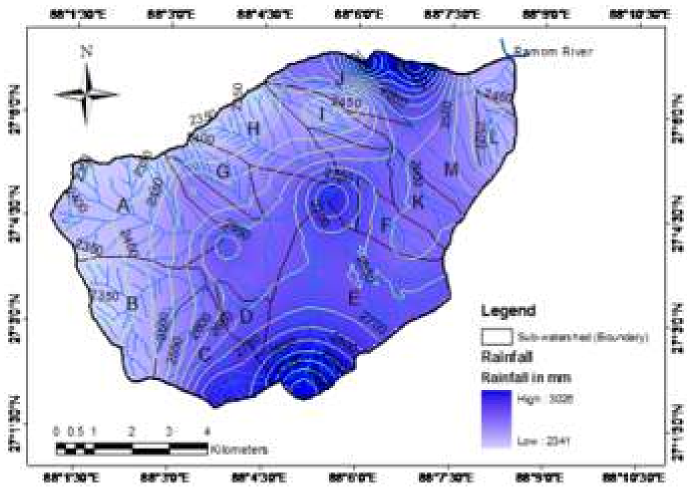


Fig no: 13 (Annual Rainfall distribution over the entire river basin)

CONCLUSION

In the present study, tectonic influence map of Lodhama river basin in Darjeeling District with integrated weighted linear combination method and GIS techniques has been developed to identifying tectonic influence on different sub-basin. Different elements of WLC were modelling using Raster calculator based overlay operation to explore the relationship among tectonic influence, hypsometric integral and hypsometric anomaly. Highest hypsometric integral and positive hypsometric anomaly are found in the three sub-basin such as A, B and J. Sub-basin A and B are situated in the high tectonic influence zone but Sub-basin J is located in the low tectonic influence zone. It is true that landscape development is not only determined by tectonic influence but it is also determined by local setting such as drainage system, climatic condition, geological structure, soil types, rainfall, slope, aspect, elevation, curvature of the land. From the result, it is cleared that maximum number of sub-basins of the Lodhama river basin belongs to the mature stage of geomorphic evolution and also determined by moderate and low tectonic influence zone.

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