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Hydrological Behavior of Umshing River, East Khasi Hills, Meghalaya

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Abstract

The morphometric and drainage basin analysis of the Umshing River is carried out quantitatively using remote sensing and GIS techniques. The results are presented concerning the hydrological behavior of Umshing river in order to define multi-scale geomorphometric landform types. The Umshing basin shows a sub-trellis drainage pattern indicating the litho-structural control on the drainage. Lithological, structural and geomorphological features control the directions of flow of the tributaries. It is observed and inferred that the Umshing river catchment is under the stage of creep or tilting and hence is vulnerable to geohazard.

Key words: hydrological behavior, morphometry, Umshing river, Shillong plateau, Meghalaya.

1. INTRODUCTION

The hydrological behavior is controlled by complex interactions between geomorphic, hydrological, hydrogeological, biological processes and land use practices in hillslope and small catchments. Linkages between hydrologic behavior and geomorphic soil attributes influence nonlinear or threshold responses of the hydrologic functions as runoff generation from open hillslope and colluvial hollows, expansion of preferential flow networks, redistribution of subsurface water storage in soils and groundwater contribution from the bedrock.

One of the major concerns of the 21st century will be the management and protection of the watersheds. The watershed is an area which receives, restores and discharges water at a single point in the form of a river. The hydrological behavior of a river is dependent upon the morphometry and quantitative morphometric studies of the river watershed, such as lithology and structural control of the watershed, relative runoff, recharge erosion aspects and stage of development of the watershed itself. The diversified landscapes with different altitudes, steep slopes and sub-tropical temperate climatic condition makes the Umshing river basin of East Khasi Hills, Meghalaya, a difficult place to study. To effectively interpret the hydrologic parameters, the remote sensing and GIS based techniques are used. Remote sensing technique is rapid, precise and effective. It outplays conventional studies because of their capability of understanding the dynamics of river basin characteristics due to perspective view. The linking of the geomorphological parameters with the hydrological characteristics of the basin provides a simple way to understand the hydrologic behavior of the Umshing river. Specific stream pattern develops in response to the initial topography of an area and the distribution of the rock types of varying erosion resistance. The shape of the pattern depends on rock, soil, climate and the changes made to the river. Drainage patterns are good indicator of the underlying rock types, structural features, nature of terrain and topography. The purpose of this work is also to discover holistic stream properties and hydrological behavior from the measurement of various stream attributes which gives the impetus to forecast the river discharge, drainage basin characteristics and simulation.

2. STUDY AREA AND METHODOLOGY

The study area is part of Survey of India Topographic Sheet no. 78 0/14 and is bounded by 25°36′00″ to 25°39′36″N latitude and 91°52′12″ to 91°55′12″E longitude (Fig. 1). The IRS 1C/1D LISS-III (February 2005) and PAN sharpened satellite image was used for linear, aerial and relief aspects for drainage basin analysis and interpretation (Fig. 2). The catchment area of the Umshing river microwatershed is 22.46 km^2. Figure 3 shows the digital elevation model (DEM) to be discussed later in this section. Geologically, the Umshing river micro-watershed is a part of the rigid massif of the Shillong plateau, a detached part of peninsular Gondwanaland cratonic block. Hydrogeologically, the basement gneissic granite formations are impermeable. The gneissic rocks showing polyphase folding concurrently with the multistage metamorphism are unconformably overlain by low grade metamorphic rocks of Shillong group belonging to pre-Cambrian age. Tertiary quartzites are the youngest permeable sediments exposed in the area (Fig. 4). The quartzites have a regional strike direction of north and north-east and dip at 20° to 45° at either direction. Four sets of joints have been noted in these quartzites with prominent

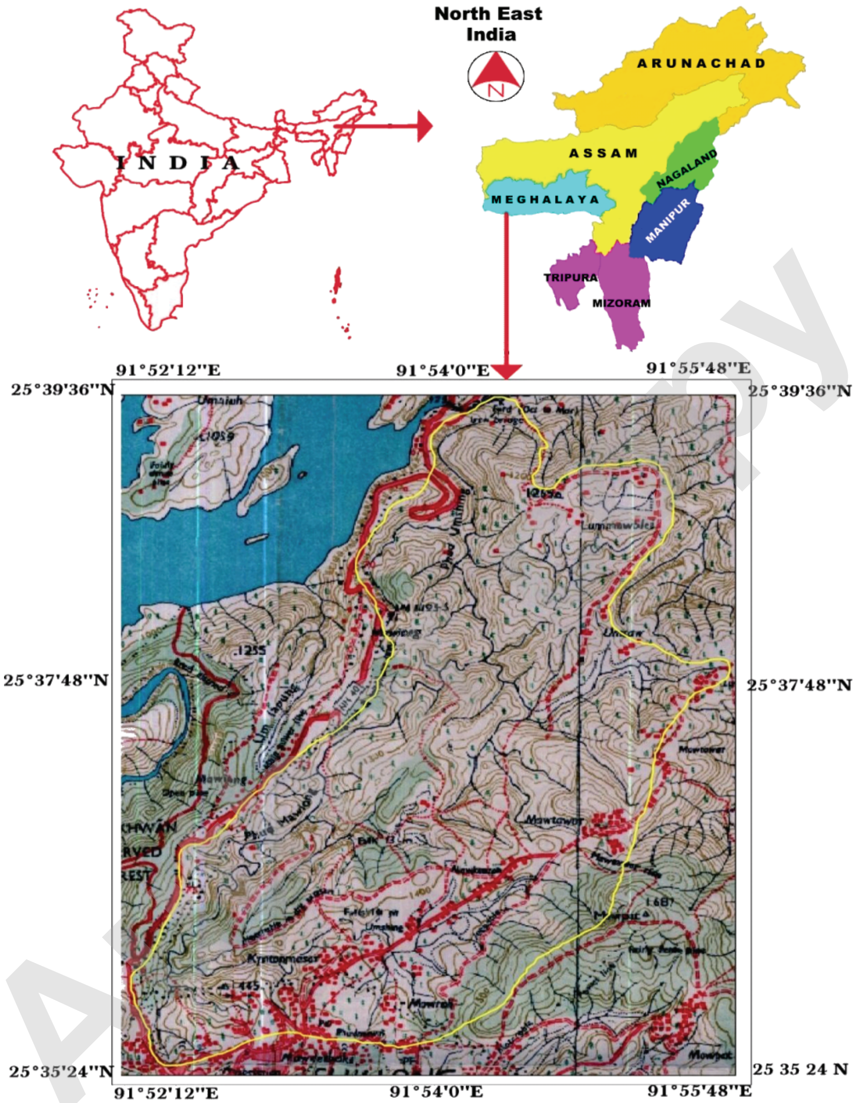

Fig. 1. Location map of the Umshing microwatershed. Colour version of this figure is available in electronic edition only.

NW–SE joint set, which have rendered them splintery at places where all the sets are intensely developed. The outcrops of the sheared rocks marking the shear zone are also noticed at few places along the river (Nandy 2001, Gokarn *et al.* 2008).

High relief and steep topography influence the amount and intensity of rainfall. The range of annual rainfall varies from 4.1 to 338.7 mm. The struc-

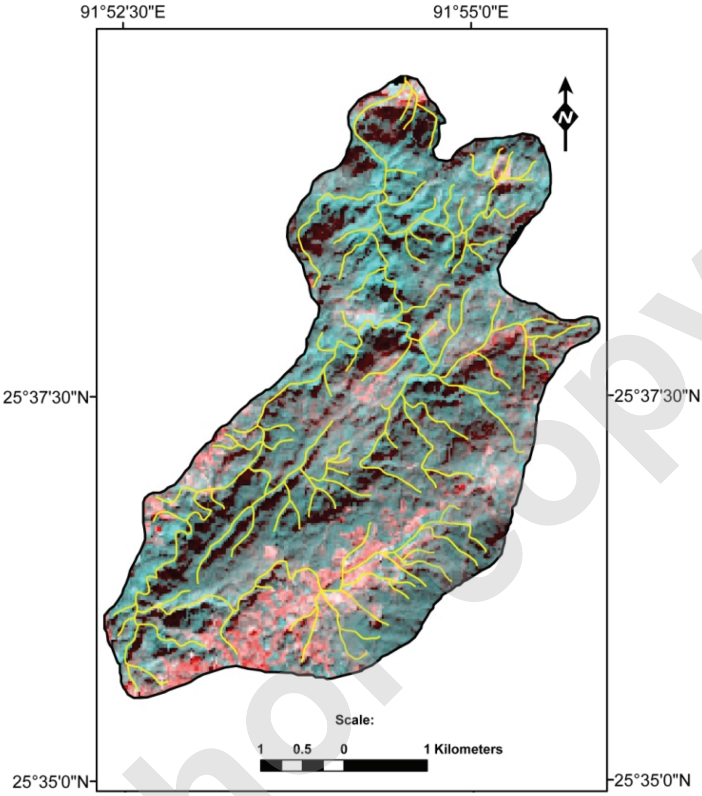

Fig. 2. Drainage network of Umshing microwatershed (LISS III Feb 2005 image).

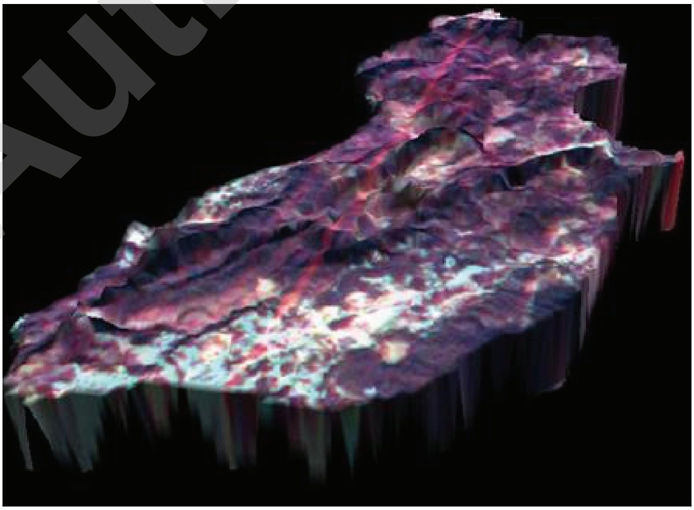
Fig. 3. Digital Elevation Model (DEM) of Umshing microwatershed.

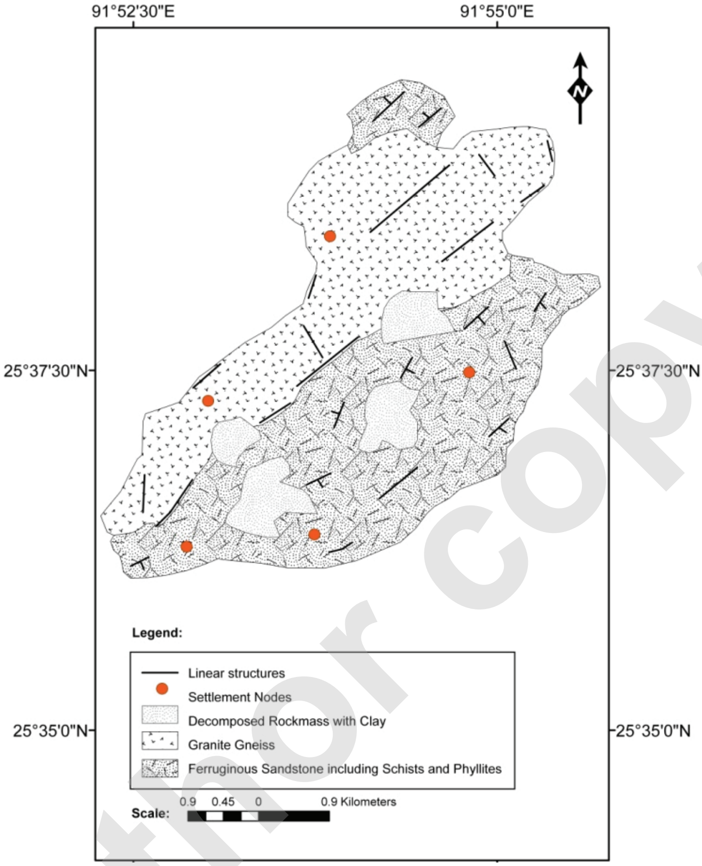

Fig. 4. Geological map of Umshing microwatershed.

tural and geomorphological features control the direction of flow of the tributaries. The northern part of the area is of low relief but has steep slopes (>25°). The southern part is higher in elevation but has a gentle slope (5° to 10°). The river Umshing flows towards SW and takes U-turn to flow towards NE. The drainage basin characteristics help in deciphering and understanding the interrelated relief and slope properties. The previously mentioned DEM (Fig. 3) is used for understanding the drainage basin characteristics. The area has a number of drainages and lies between the altitudes 1500 to 1200 m. The relative relief of the microwatershed is 1250 m and the highest point present in the area is Maupak (1687 m msl), whereas the lowest point is Lummawbleh (around 1169 m msl).

The available water in the watershed as a surface runoff is dependent upon the areal characteristics including rainfall, changes in soil moisture, shape, size, aspects and slope, stream characteristics such as frequency, length and base flow, soil and land use, and hydrological characteristics such as groundwater gains and losses, evapotranspiration, runoff coefficient which is 1.4 for the Umshing river.

Hydrologic analyses and maps have been computed using ERDAS Imagine 8.5 (Tables 1, 2 and 3).

3. QUANTITATIVE MORPHOMETRIC PARAMETER

Morphometry

Morphometry is the measurement and mathematical analysis of configuration of the earth surface and the shape and dimensions of its landforms (Thornbury 1969).

The drainage basin analysis is carried out quantitatively including linear aspects, and aerial and relief aspects. In the linear aspects, the stream order, stream length, bifurcation ratio, mean lengths of streams, stream length ratio, and mean stream length ratio are analyzed (Table 1). In the basin geometry, the factors such as circulatory ratio, elongation ratio, and form factor are calculated (Table 2). In aerial aspects, the factors such as drainage density, stream frequency, texture ratio, constant of channel maintenance and the length of the overland flow are studied whereas in the case of relief aspects the relief ratio and ruggedness number are evaluated (Table 3).

Table 1

Morphometric analysis of Umshing river basin

Stream order, U / Parameters	1st order	2nd order	3rd order	4th order	5th order
Number of streams, N_U	98	24	6	2	1
Total number of streams, ΣN_U	131				
Bifurcation ratio, R_B	–	4.08	4	3	2
Total length of streams, N_U	48.49 km	10.17 km	3.90 km	7.96 km	6.84 km
Stream length, L_U	0.49 km	0.43 km	0.67 km	3.98 km	6.84 km
Total length of streams, ΣL_U	77.361 km				
Drainage basin asymmetry, AF	74.47				
Stream frequency	4.9866				
Topographic symmetry factor, T	0.75				
Mountain front sinuosity, Smf	1.35				
Stream grade, Sg	16.33%				

Table 2

Aerial aspects of the Umshing drainage basin

Basin area, A_U	22.46 km^2
Length of the basin, L_B	7.435 km
Basin perimeter, P	23.39 km
Circulatory ratio, R_C	0.718
Form factor, R_F	0.41 km^{-1}
Drainage density, D_D	3.3142 km^{-1}

Table 3

Relief aspects of the Umshing drainage basin

Highest point, Z	1687 m
Lowest point, z	1169 m
Total basin relief, $H = Z - z$	518 m
Relief ratio, $R_H = H/L_b$	0.07
Ruggedness number, $R_N = D_D \times H$	1.72

Linear aspects

Stream order, U. The streams are designated the stream orders. Stream ordering not only indexes the size and scale, but also indexes the amount of stream flow produced by a drainage network (Horton 1945). Stream order number is directly proportional to the size of the contributing watershed, to channel dimensions, and to stream discharge at that place in the system. As water molecules travel from headwater streams toward the mouth, streams gradually increase their width and depth with increasing amount of water discharge. The Umshing river is of 5th order and has a flow rate of 2.20 m^3/s (Table 4, Fig. 5).

Stream number, N_U. The count of stream channels in its order is known as stream number (Horton 1945). Stream number is directly proportional to size of the contributing watershed, to channel dimensions. The number of streams of 1st order is 98, of 2nd order is 24, of 3rd order is 6, of 4th order is 2, and then the stream of the 5th order is the Umshing river. The number of stream segments decreases as the order increases. The higher stream order number indicates lesser permeability and infiltration.

Bifurcation ratio, R_B. Horton (1945) and Strahler (1964) had defined the bifurcation ratio as the ratio of the number of streams of an order to the number of those the next, higher order

$$R_B = N_U / N_{U+1} \quad .$$

Table 4

Umshing river and its tributaries stream flow rate

Elevation	Flow direction	Stream flow rate
1205 m	60°N	2.20 m^3/s
1345	48°	1.83
1475	70°	0.81
1345	20°	1.88
1395	46°	1.07
1425	283°	1.00
1250	10°	1.12
1255	62°	1.17
1325	192°	1.19
1385	38°	1.04
1450	31°	1.69
1345	48°	0.83
1355	230°	1.06
1385	228°	1.13

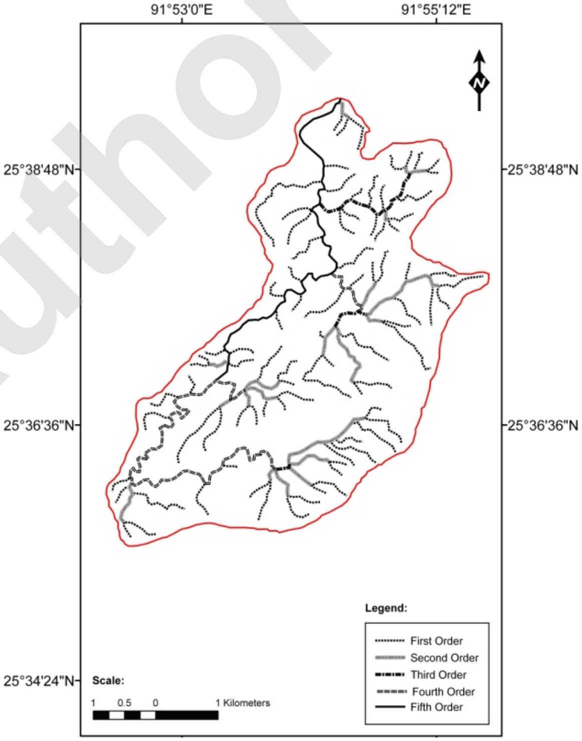

Fig. 5. Stream order map of Umshing microwatershed.

The bifurcation ratio varies with the variations in watershed geometry and lithology and displays geometric similarity. The bifurcation ratio is estimated to be 3.15; on the average, there are 3 times as many channel segments of any given order as of the next higher order. It varies between 2.0 and 4.0, which indicates the control of the lithology and geologic structures giving rise to the distorted trellis drainage pattern.

Stream length, L_U. The stream length, L_U, of order U, the total length of streams of order U divided by the number N_U (Horton 1945), reveals the characteristic size of components of a drainage network and its contributing basin surface.

The total length of stream decreases with increasing order of stream. The stream lengths of different order of streams of Umshing river basin are given in Table 1. The 3rd order streams length is less as compared to 4th order streams due to the geomorphological, lithological and structural control and contrast.

Aerial aspects

Basin area, A_U. The drainage basin area of the Umshing river is 22.46 km^2. The headward stream flows westwards and it takes U-turn from the edge of the watershed and then flows northeasterly.

Stream frequency, F_U. Stream frequency is the ratio of number of streams in a watershed to the area of the watershed (Horton 1945). The Umshing area has a stream frequency of 22.6 streams per ha. The impermeable litho-types at the headward region have less groundwater recharge capability whereas at places with the presence of shear zones the water percolates down faster reducing the stream frequency.

Form factor, R_F. The ratio of the basin area to the square of basin length is called the form factor. The form factor of the Umshing watershed is 0.41 km^{-1}. It is used as a quantitative expression of the shape of basin form which is stretched elliptical.

Circulatory ratio, R_C. Miller (1958) defined circulatory ratio R_C, as the ratio of basin area A_U to the area of circle A_C having the same perimeter as the basin. The circulatory ratio of the Umshing river area is 0.718.

Drainage density, D_D. Drainage density is the total length of all the streams in the watershed to the area of watershed. It helps in determining the permeability and porosity of the watershed and an indicator of landform elements in stream eroded topography. The drainage density of the Umshing river area is 3.3142 km^{-1}. High drainage density is due to the regions of weak or impermeable surface materials, sparse vegetation, and mountainous relief.

Relief aspects

Channel gradient. The channel gradient is estimated from the contour crossings in the topographical sheet. The channel gradient of the 1st order streams varies from 15 to 20 degrees, that of the 2nd order streams varies from 15 to 17 degrees, whereas that of the 3rd and higher order streams varies from 20 to 24 degrees. It helps in determining the downstream increase of discharge which enables the sediment load to be transported on progressively changing slopes and hence the transport capacity.

Relief ratio, R_H. It is the ratio of relief and length of the watershed (Schumm 1956). The relief ratio of the watershed of Umshing river is 0.07. Relief ratio indicates that the watershed is moderately sloping and the intensity of erosion process is low, but near the waterfalls the intensity of erosion process and slopes are high due to the presence of fault/shear zones and the structural control.

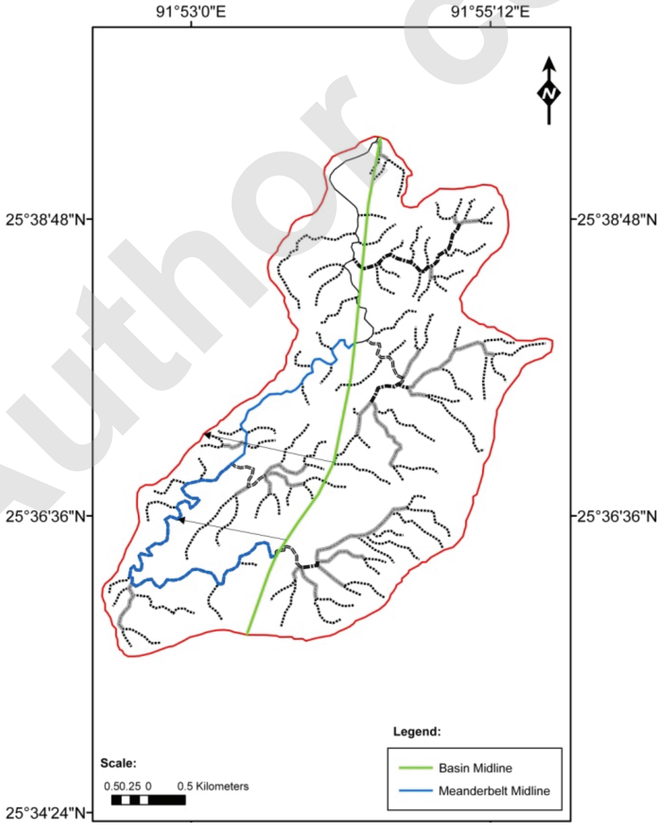

Fig. 6. Transverse topographic symmetry factor of Umshing river. Colour version of this figure is available in electronic edition only.

Ruggedness number, R_N . It is the product of relief and drainage density in order to define the slope steepness and length. The Umshing river watershed displays the ruggedness number as 1.72 and indicate that the area is extremely rugged with high relief and high stream density.

Drainage basin asymmetry, *AF*. The drainage basin asymmetry is used to calculate the presence of active tectonic deformation and was developed to detect the tectonic tilting at drainage basin scales. The Umshing river basin has the *AF* equal to 74.47 (Fig. 8). *AF* greater or less than 50 indicates the tilt and indicates that the tributaries on the right side of the main stream are long compared to the tributaries on the west (left) side and hence under intense tilting.

Transverse topographic symmetry factor is 0.75 (Fig. 6) and mountain-front sinuosity factor is 1.35 (Fig. 7), which also indicates that the basin is in the process of tilting.

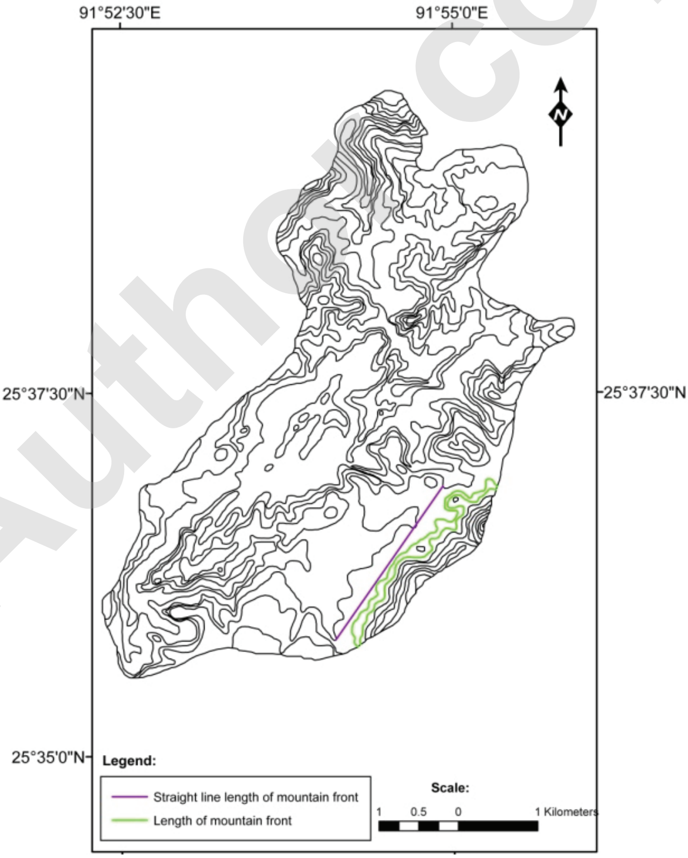

Fig. 7. Mountain-front sinuosity on the SW part of Umshing river. Colour version of this figure is available in electronic edition only.

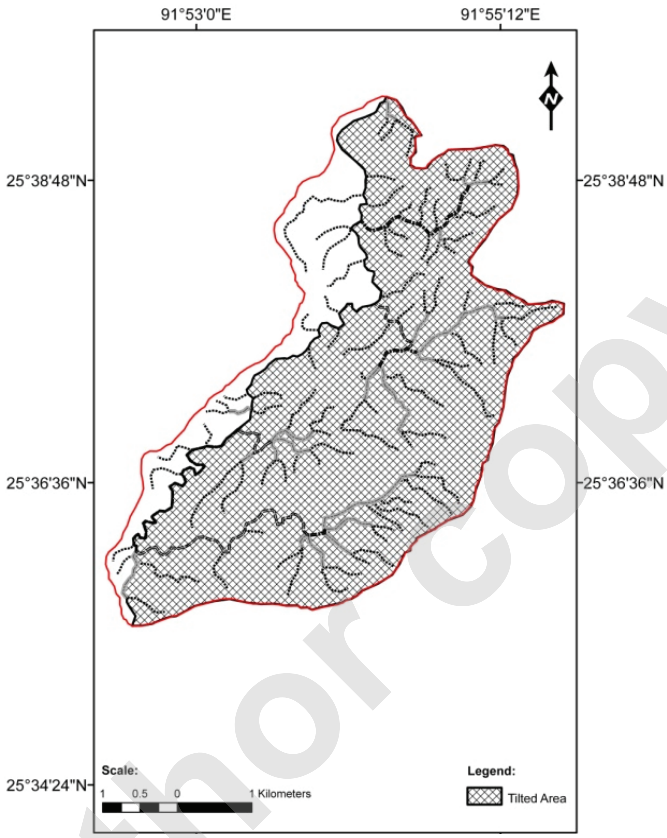

Fig. 8. Drainage basin asymmetry map of the Umshing microwatershed.

4. DISCUSSION

The relationship between geological fabric and drainage pattern is analysed using a topographic maps and digital elevation model. Regional and local trends of geological fabric are reflected in the variable orientation of channels of different rank in the catchment. The middle order channels most closely correlate with bedding, which dominates the fabric of this unit. The drainage pattern over the study area shows spectacular feature revealing extraordinary straight courses of the rivers and streams, evidently along joints and faults. The Umshing basin is dominated by two distinct drainage patterns, such as rectangular and sub-trellis drainage ones, which becomes very interesting in signifying their development in a tectonically active terrain, indicating the litho-structural control on the drainage. The present disorganized state of many streams in the Umshing watershed of East Khasi Hills has been attributed to a shift to the temperate climate and tectonic upliftment in the region. The satellite images of the area, however, indicate lineaments cutting across and at times the drainage disappearance and development of gullies appear related to these lineaments. The findings tend to confirm at least two episodes of Quaternary tectonic movement in the area, resulting in channel changes/obliterations and other drainage anomalies. The linear, aerial and relief aspects indicate that the basin is under the stage of creep and tilting as indicated by the presence of the shear-zone in the vicinity of the area or some hidden structure underneath. The preliminary hydrological behavior shows that the Umshing river microwatershed is in the process of evolution as the basin is in the process of tilting. The right (eastern) side of the basin has evolved earlier than the left (western) side.

5. CONCLUSION

The integration of remote sensing and GIS indicates that the Umshing river is under the stage of high runoff with crisscross lineaments followed by drainage disappearance but due to the presence of impermeable basement gneisses the water flows out as surface runoff. The terrain is one of the seismically active regions and displays high seismic activity, tilting and settlement of the river channel. The Umshing river microwatershed is in the process of evolution as the basin is in the process of tilting. Understanding the extent of geological controls on the morphology of a catchment may assist geo-hazard identification, land use planning, and civil engineering projects.

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