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Full Length Research Paper

Morphometric analysis of a highland microwatershed in East Khasi Hills District of Meghalaya, India: Using remote sensing and geographic information system (GIS) techniques

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Morphometric analysis of a highland microwatershed (Wah Umbah) area was carried out using remote sensing and geographic information system (GIS) techniques. Detailed drainage map of the area was prepared from the high resolution satellite image and Survey of India (SOI) toposheets which was updated using IRS-1D PAN sharpened LISS-III analog data. Updated drainage maps were used for the drainage pattern analysis of the study area, The Wah Umbah microwatershed shows a sub-trellis drainage pattern with moderate drainage texture. High bifurcation ratio indicates a strong structural control on the drainage pattern. Lithological, structural and gemorphological expression of the microwatershed control the flow direction of the entire drainage network. It has been noticed that Wah Shella microwatershed is under the category of creep or tilting and hence it is vulnerable to geohazard.

Key words: Morphometry, Wah Umbah, microwatershed, drainage, geographic information system (GIS), remote sensing, hydrological.

INTRODUCTION

Watershed is a natural hydrological entity which allow surface run-off to define channel, drain, stream or river at a particular point. It is the basic unit of the water supply which evolves over time. Different workers define watershed differently. In foreign literature, watershed has been defined as a drainage basin or catchment. The size of a watershed can vary from fraction of hectares to thousands of square kilometers. Watershed is also classified based on the area that a watershed contains. On the basis of area, watersheds can be classified as: micro watershed (0 to 10 ha), small watershed (10 to 40 ha), mini watershed (40 to 200 ha), sub watershed (200 to 400 ha), macro watershed (400 to 1000 ha), river basin (above 1000 ha). One of the major concerns of the present time is the management and protection of the watershed area. Morphometric analysis of watershed requires measurement of linear features, gradient of channel network and contributing ground slopes of drainage basin (Nautiyal, 1994). The diversified landscapes with different altitudes, steep slopes and subtropical temperate climatic condition makes the Wah Umbah microwatershed of East Khasi Hills, Meghalaya, a difficult place to study. To effectively interpret the morphometric parameters, the remote sensing and geographic information system (GIS) based techniques have been used. Remote sensing technique is rapid, precise and effective in modern day morphometric studies. Many workers have carried out morphometric analysis using remote sensing and GIS techniques. Srivastava (1997) studied drainage pattern of Jharia coalfields (Jharkhand) using remote sensing technology. Nag and Chakraborty (2003) studied the influence of rock types and structures in the development of drainage network in hard rock area. The linking of the geomorphological parameters with the hydrological characteristics of the basin provides a simple way to understand the morphometric characteristics of the Wah Umbah microwatershed. Specific stream pattern develops in

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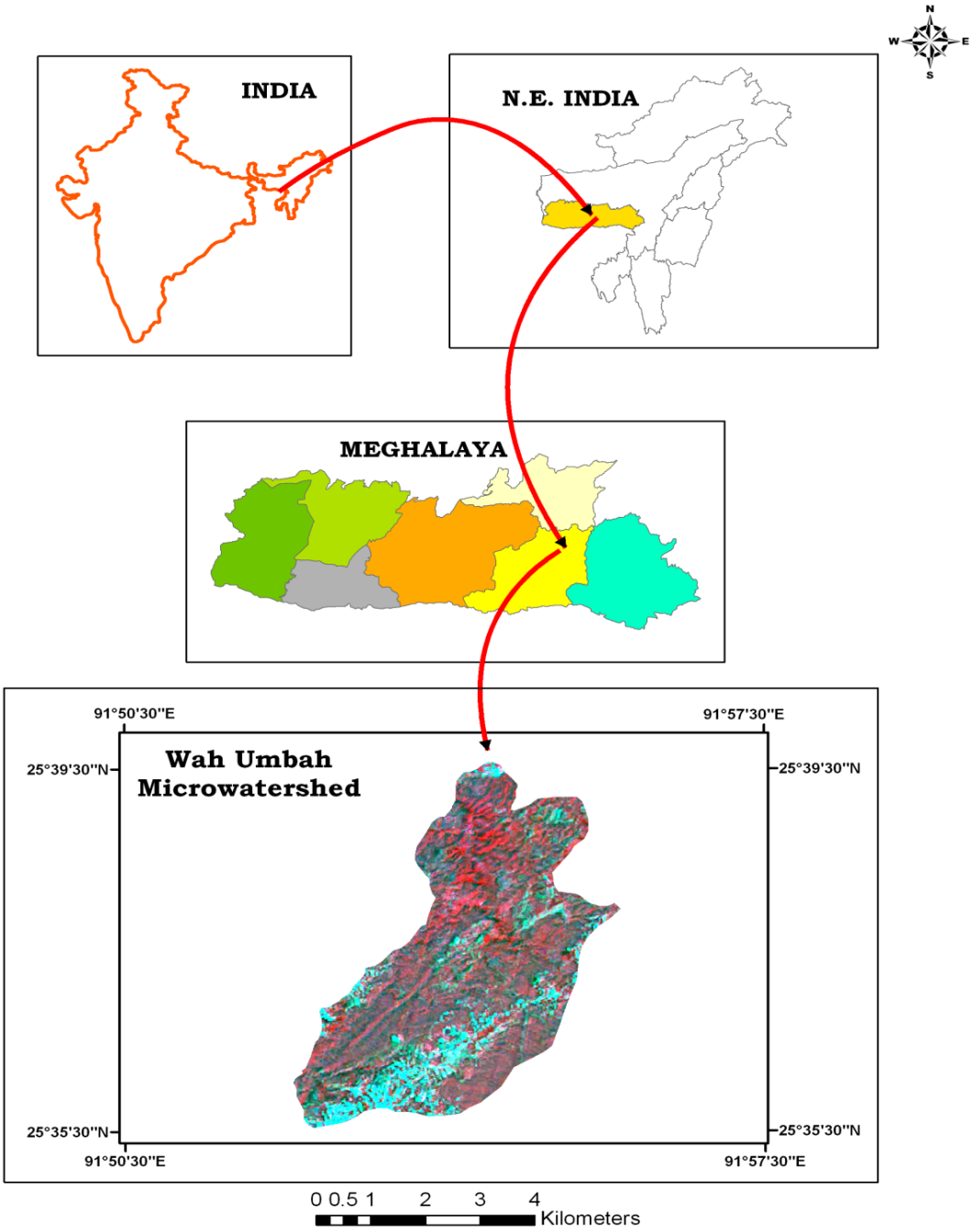

Figure 1. Location Map of Wah Umbah microwatershed. Source: IRS LISS- III P6.

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 identify the holistic stream properties and hydrological behavior from the measurement of various morphometric attributes which gives the impetus to forecast the river discharge, drainage basin characteristics and simulation.

STUDY AREA AND METHODOLOGY

The study area lies in the Survey of India Topographic Sheets No. 78 0/14 and 83C/2 is bounded by 25°34´0´´ to 25°39´0´´ N latitude and 91°55´30´´ to 92°4´30´´E longitudes (Figure 1). The IRS P6 LISS-III (March 2007) and IKONOS satellite image was used for

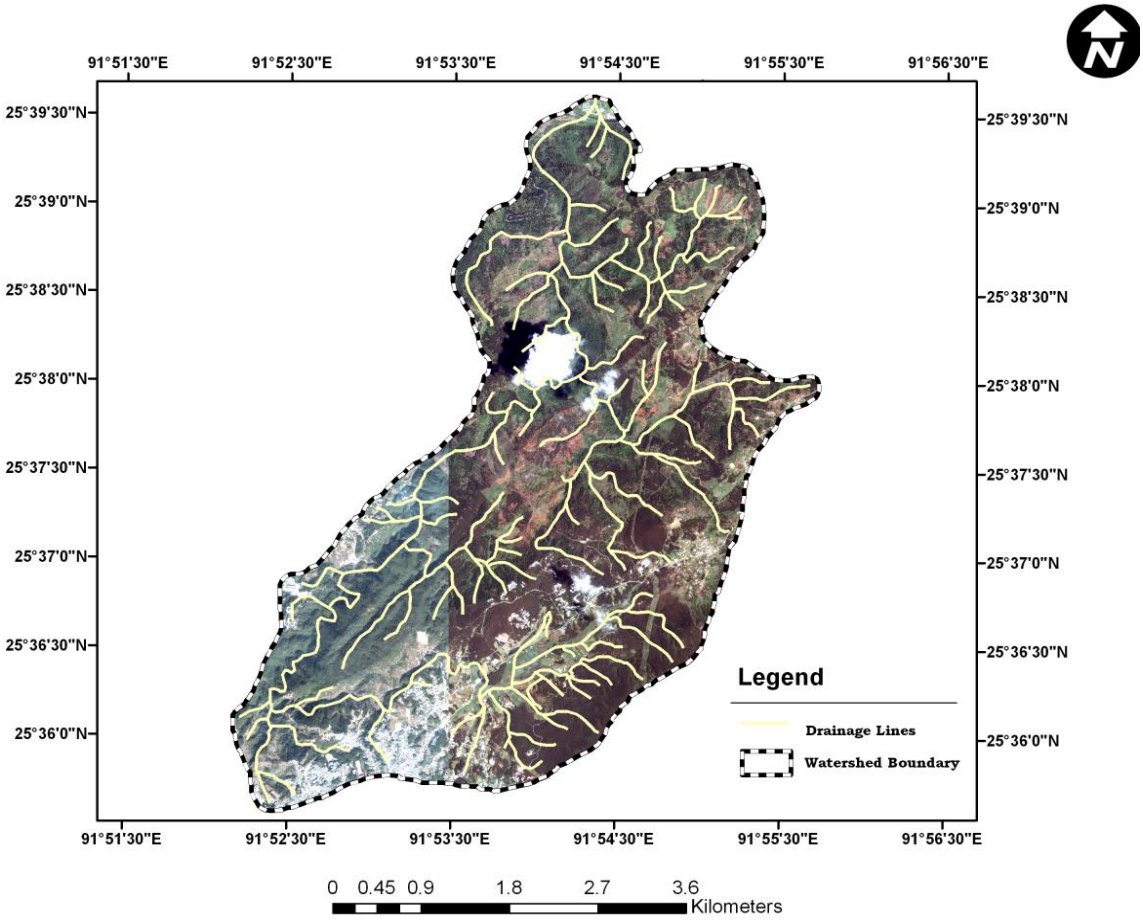

Figure 2. Drainage network of Wah Umbah microwatershed. Source: IKONOS image, 2nd March 2008.

linear, aerial and relief aspects for drainage basin analysis and interpretation (Figure 2). The standard image interpretation characteristics such as tone, texture, shape, size, pattern and association along with sufficient ground truth and local knowledge were used to finalize the maps of the microwatershed area. The maps were georeferenced and digitized using the Arc GIS 9.2 and Erdas Imagine 9.1 GIS softwares and attributes were assigned to create the digital database. The microwatershed area of the Wah Umbah River is 22.24 sq. km. Figure 3 shows the digital elevation model (DEM) and triangulated irregular network (TIN) that is subsequently discussed. Geologically, the Wah Umbah 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 (Figure 5). 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 NW to 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). High relief and steep topography influence the amount and intensity of rainfall.

The average annual rainfall of the area is 2500 mm. About 90% of the rainfall occurs during the period between May to October. The structural 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 (>30°). The southern part is higher in elevation but has a gentle slope (5° to 15°). The river Wah Umbah flows towards NW and SE (Figure 4). The drainage basin characteristics help in deciphering and understanding the interrelated relief and slope properties. The previously mentioned DEM and TIN (Figure 3) are used to understand the detail nature Wah Umbah micro watershed area. The average elevation of the micro watershed ranges between 919 to 1628 m (Figure 6) and this undulating topographic order has contributed immensely in developing a well developed drainage network.

Quantitative and morphometric parameters

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 of Wah Umbah microwatershed has been carried out quantitatively includ-ing 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

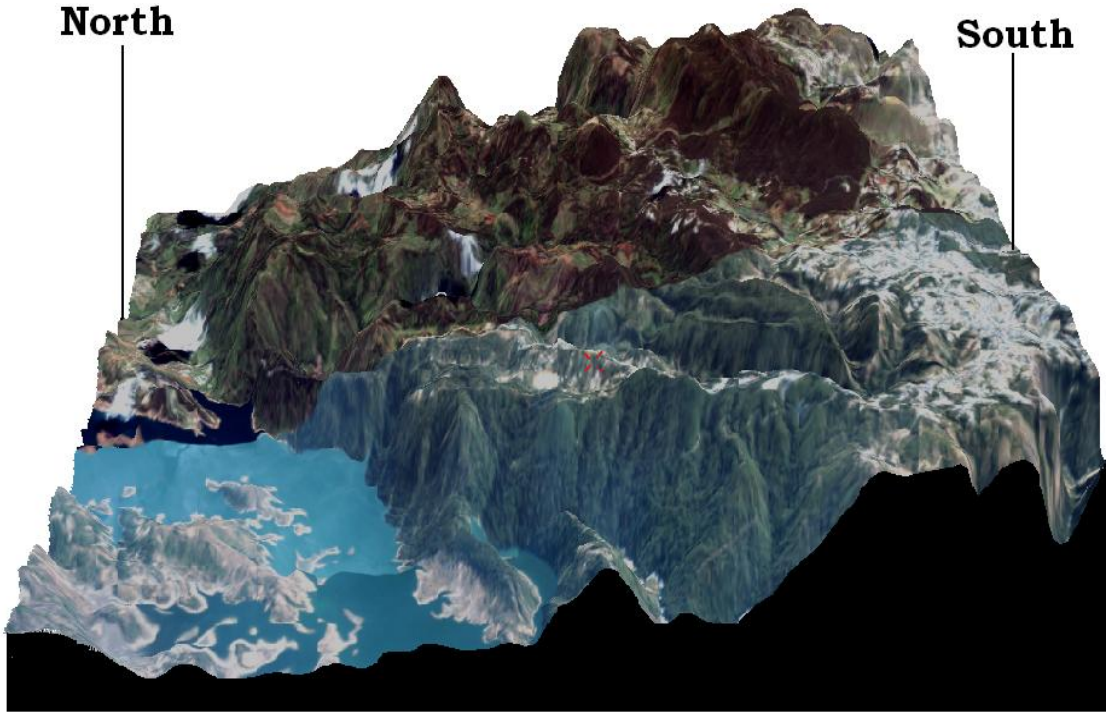

Figure 3. Digital elevation model of Wah Umbah microwatershed showing vertical profile of the area from south to north. Source: ASTER G-DEM.

Table 1. Linear aspects of Wah Umbah microwatershed area.

Parameter	Stream order, U				
	1st order	2nd order	3rd order	4th order	5th order
Number of streams, *Nu*	98	24	6	2	1
Total number of streams, *ΣNu*			131		
Bifurcation ratio, *Rb*	-	4.08	4	3	2
Total length of streams, *Nu*	48.49 km	10.17 km	3.90 km	7.96 km	6.84 km
Stream length, *Lu*	0.49 km	0.43 km	0.67 km	3.98 km	6.84 km
Total length of stream, *ΣLu*			77.36 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%		

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 overland flow are studied, whereas in the case of relief aspects the relief ratio and ruggedness number are evaluated (Table 3).

Linear aspects

Stream order (U): Designation of stream orders is the first step in drainage basin analysis. It is based on hierarchical ranking of streams proposed by Strahler (1964). 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 Wah Umbah River is of 5th order and has a flow rate of 2.20 m^3/s.

Stream number (Nu): 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

Table 2. Aerial aspects of Wah Umbah microwatershed.

Parameter	Value
Basin area, *Au*	22.46 km^2
Length of the basin, *Lb*	7.435 km
Basin perimeter, *P*	23.39
Circulatory ratio, *Rc*	0.718
Form factor, *Rf*	0.41
Drainage density, *Dd*	3.3142

Table 3. Relief aspects of Wah Umbah microwatershed area.

Parameter	Value
Highest point, *Z*	1687 m
Lowest point, *Z*	1169 m
Total basin relief, *H= Z- z*	518 m
Relief ratio, Rh = *H/ lb*	0.07
Ruggedness number, *Rn = Dd x H*	1.72

stream of the 5th order is the Wah Umbah River. The number of stream segments decreases as the order increases. The higher stream order number indicates lesser permeability and infiltration.

Bifurcation ratio (Rb): 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 in the next higher order.

Rb = Nu / Nu+1

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 (Lu): The stream length (Lu) of order U is obtained by the total length of streams of order U divided by the number NU. 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 Wah Umbah River microwatershed 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 (Au): The drainage basin area of the Wah Umbah 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 (Fu): Stream frequency is the ratio of number of streams in a watershed to the area of the watershed (Horton, 1945). The Wah Umbah 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 (Rf): The ratio of the basin area to the square of basin length is called the form factor. The form factor of the Wah Umbah 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 (Rc): Miller (1958) defined circulatory ratio Rc, as the ratio of basin area Au to the area of circle AC having the same perimeter as the basin. The circulatory ratio of the Wah Umbah River area is 0.718.

Drainage density (Dd): 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 Wah Umbah 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°, that of the 2nd order streams varies from 15 to 17°, whereas that of the 3rd and higher order streams varies from 20 to 24°. 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 (Rh): It is the ratio of relief and length of the watershed (Schumm, 1956). The relief ratio of the watershed of Wah Umbah 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

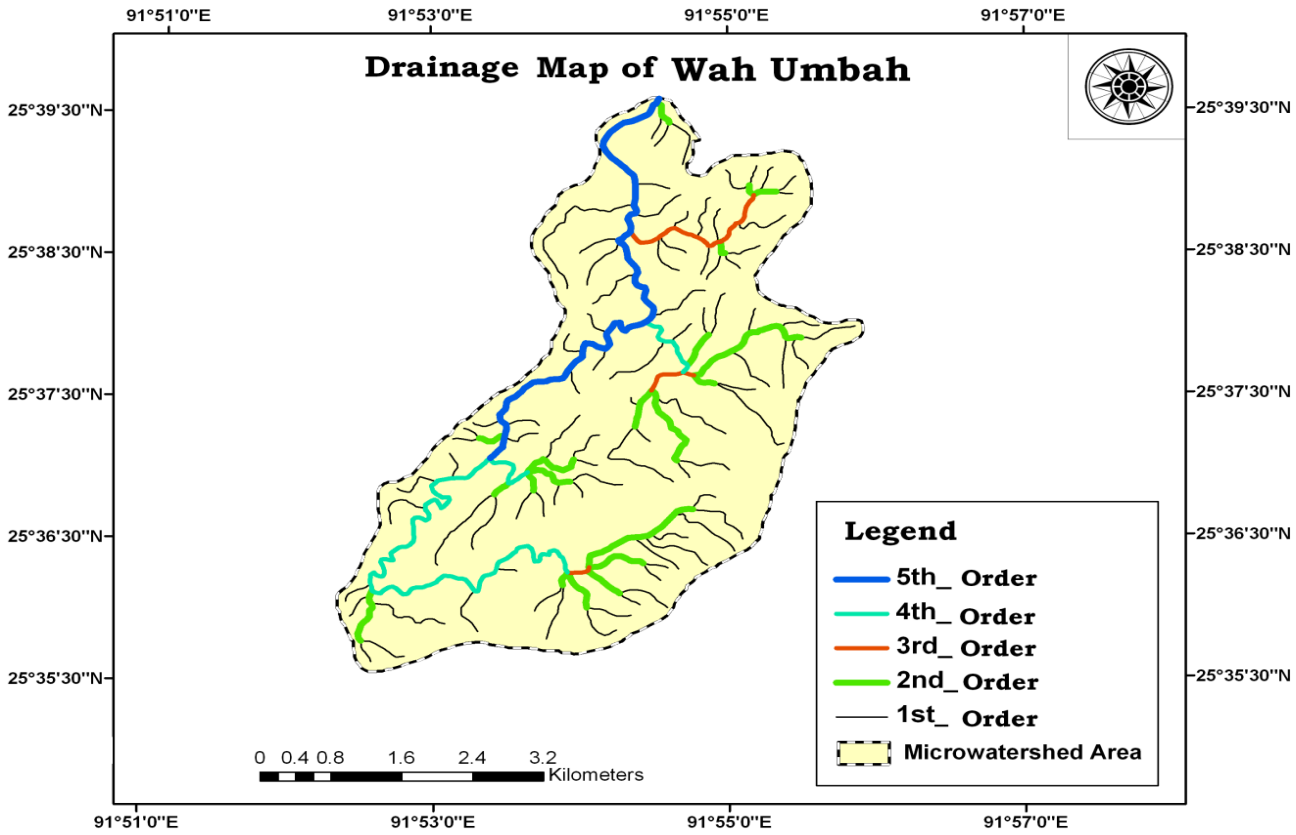

Figure 4. Drainage map of Wah Umbah microwatershed (Source: Survey of India toposheet).

are high due to the presence of fault/shear zones and the structural control.

Ruggedness number (Rn): It is the product of relief and drainage density in order to define the slope steepness and length. The Wah Umbah River microwatershed 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 Wah Umbah River basin has the Af equal to 74.47. 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 (Figure 7) and mountain front sinuosity factor is 1.35 (Figure 8), which also indicates that the basin is in the process of tilting.

DISCUSSION AND CONCLUSION

The relationship between geological setup and drainage pattern is analyzed using a topographic maps and triangulated irregular network (TIN). Regional and local trends of geological setup 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 Wah Umbah microwatershed 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 Wah Umbah microwatershed 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 quarternary 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 of river Wah Umbah shows that the microwatershed is in the process of evolution as the

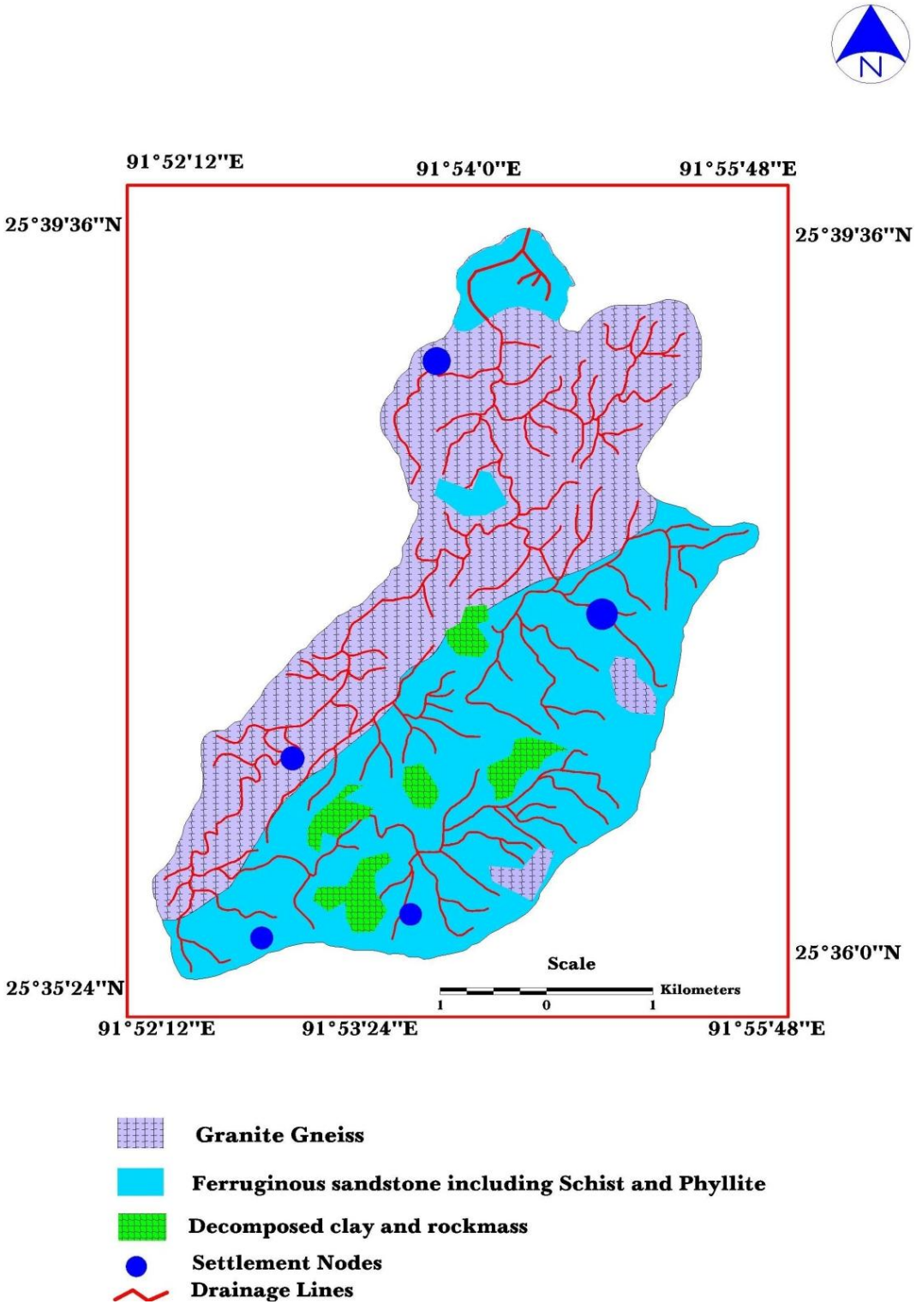

Figure 5. Map showing the geological set-up of Wah Umbah microwatershed.

the basin is in the process of tilting.

The Wah Umbah 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

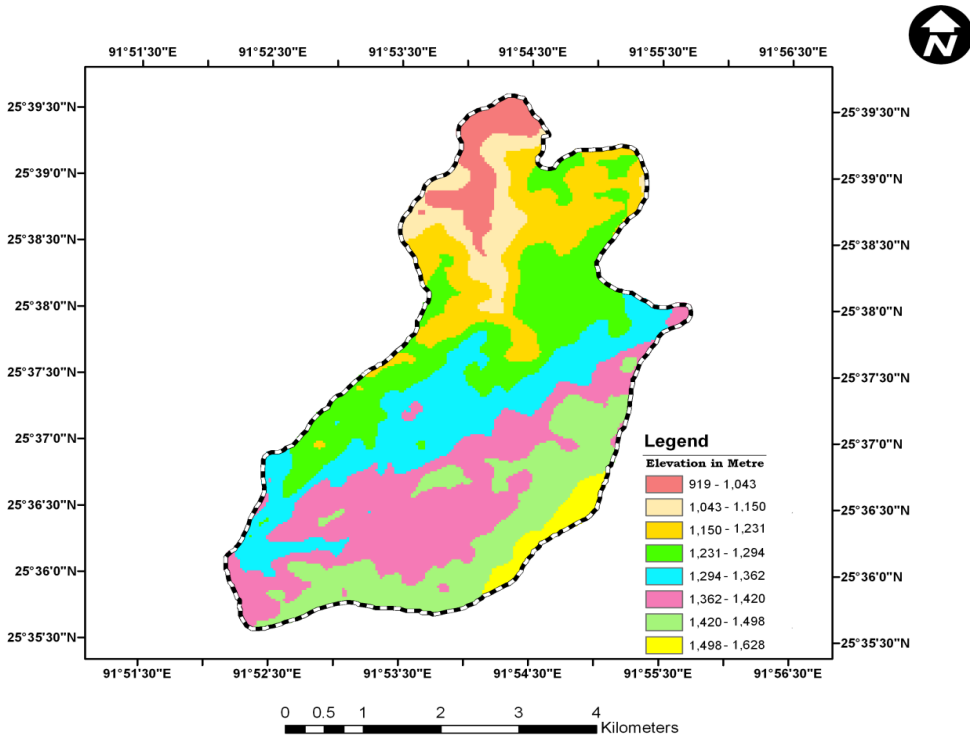

Figure 6. Relief pattern map of Wah Umbah microwatershed. Source: ASTER G-DEM.

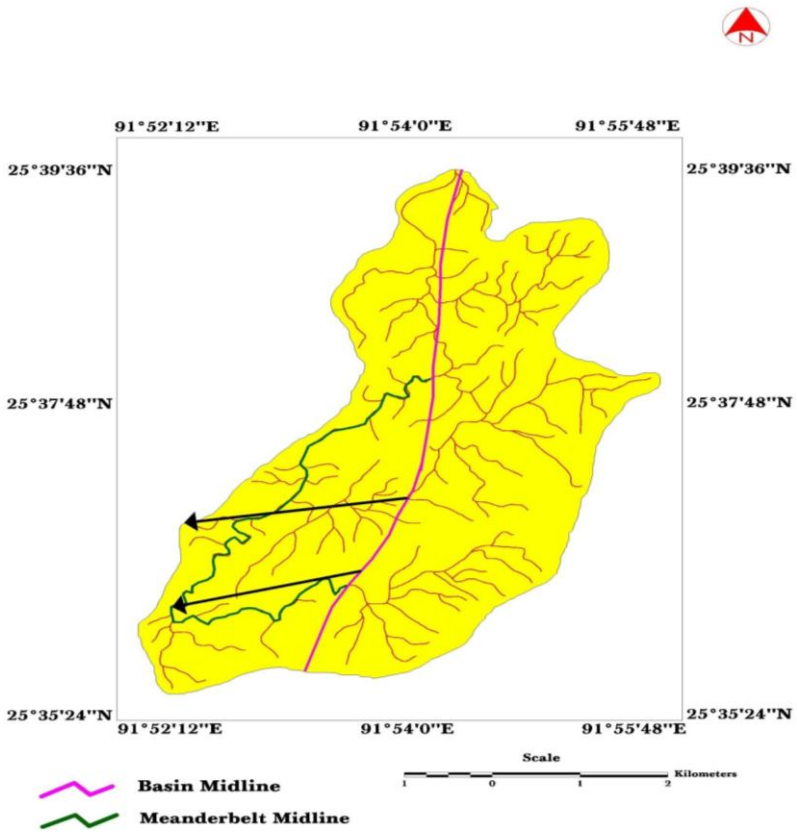

Figure 7. Transverse topographic symmetry factor map of Wah Umbah microwatershed.

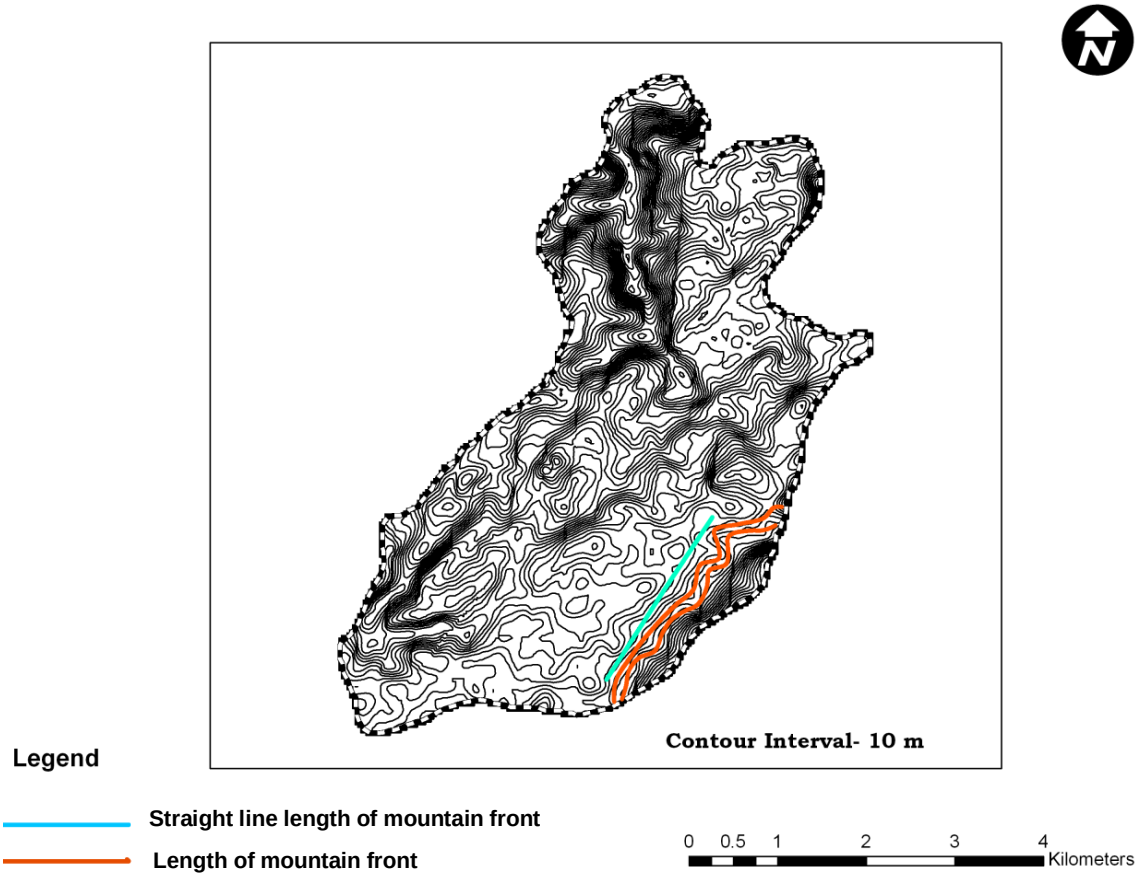

Figure 8. Mountain front sinuosity map of Wah Umbah microwatershed.

projects.

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