Morphometric Analysis on Two contrasting Litho-units of a southern part of West Khasi Hills district, Meghalaya, based on some Derived Aerial and Relief parameters, with special reference to Neotectonism

ABSTRACT

The present study area, occupying a major south-central part of the Jadukata river basin of the West Khasi Hills District of Meghalaya, predominantly comprises two contrasting litho-units viz., the Precambrian gneissic unit (PGU) towards the north of the study area and the Mahadek Formation constituted of sedimentaries (MFS) in the south. Derived areal and relief morphometric parameters have been analysed on five sub-basins two of which are in the PGU (Umlang and Umkyrtha) and the rest three (Umsophew, Wah-Phodthra, and Khandow) are predominantly in the MFS. The drainage density (D_d) stream frequency (F_s) values are relatively lower for the sub-basins PGU suggesting higher overland flow. This is substantiated by higher values of constant of channel maintenance (C) and length of overland flow (L_g). The relief ratio (R_r) and ruggedness number (R_n) are higher for the sub-basins of MFS implying more dissection. High hypsometric integral (HI) and pseudo-hypsometric integral (PHI) suggest youthful stage and neotectonic rejuvenation with a tilt towards west as indicated by asymmetry factor (AF) and topographic profile. Association of distinct knickpoints of longitudinal profiles with prominent lineaments indicates active fault. Preferred orientation of lower order streams in the PGU sub-basins suggests neotectonism. Deep incision by Umsophew, Wah-Phodthra, and khandow rivers, forming V-shaped valleys through the MFS is the result of neotectonic uplift which has been further substantiated by very low valley floor-to-height ratio (V_f) at nearby locations of the confluence of these rivers with the Kynshi.

Keywords: Morphometric areal and relief aspects; Tectonic uplift, tilting

1. INTRODUCTION

Quantitative analyses of drainage basins in terms of various morphometric parameters are necessary to elucidate the complicated relationship between the forms and processes. Application of quantitative analysis on river basin, first initiated by Horton [11], was later developed by Strahler [29].

Morphometric analysis is one of the most important tool and technique to determine and evaluate the drainage basin responses to climate change, drainage characteristics and flash flood hazard [22,23]. In regards to neotectonism, morphometric analysis serves as an important tool in evaluating the geomorphic developments of a basin to attest more precise uplift, incision, erosion and slip rates on faults, etc. even at small time scales [5,16,22]. It is used to determine patterns of rivers for assessing relative active tectonics of the basin [4].

The objectives of the present study are to investigate the influence of lithology on some derived morphometric variables and also to ascertain neotectonic activity primarily with the help of the derived relief parameters and some important geomorphic indices.

2. STUDY AREA

The study area is bounded by latitudes $25^0$15'N and $25^0$30'N and longitudes $91^0$0'E and $91^0$15'E. It falls in the southern part of West Khasi hills district and comprises a major south-central part of the Jadukata river basin (Fig. 1). Geologically, rocks belonging to the Precambrian gneissic complex are exposed in a major northern part of the study area, the southern part being occupied by the unconformable cover of sedimentary rocks, known as the

Mahadek Formation of the Cretaceous age (Fig. 2). The Mahadek Formation is constituted of medium to coarse-grained impure feldspathic sandstone. The Tertiary Shella Formation, consisting of moderately mature sandstone, conformably overlies the Mahadek Formation in some locations in the southern part of the district [9]. A small exposure of the Shella Formation occurs in the extreme west part of the study area.

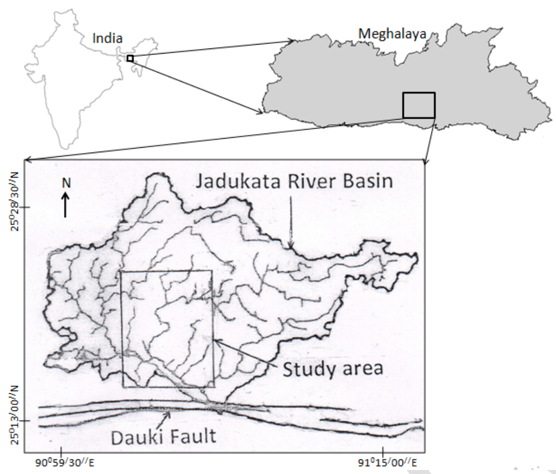

Fig. 1. Location map of the study area

Geomorphological characteristics of the study area are primarily the result of denudation and structural processes. The northern part is mainly denudational landform comprising of moderately dissected hilly topography developed in the crystalline Precambrian gneissic rocks, the dissection being mainly lineament controlled reflected by the existence of rectangular to sub-rectangular drainage pattern. The southern part of the area comprises horizontal to low dipping sedimentary sequences of Mahadek and Shella Formations. These sequences have produced structural plateau landforms where deep gorges have been cut by the prominent tributaries of the Kynshi river, such as Khandow, Wah-phodthra, and Umsophew giving rise to very conspicuous canyon topography where valley walls are highly steep. The predominant drainage pattern in this southern part is fine dendritic with occasional presence of trellis pattern.

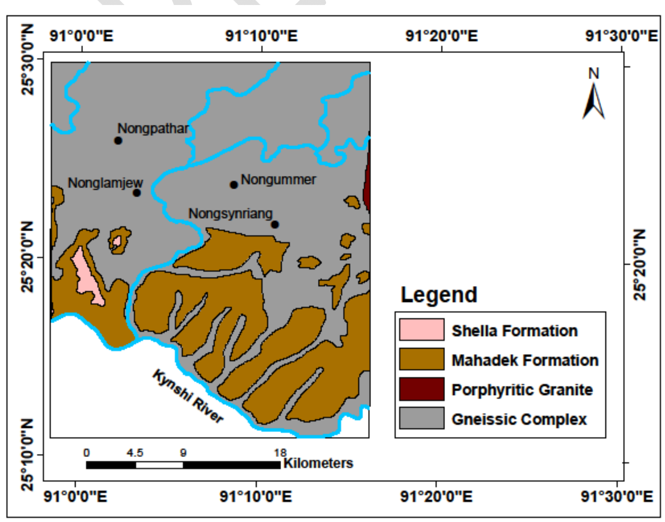

Fig.2. Geological map of the study area (modified after Gangadharan et al. 1991)

3. METHODOLOGY

In the present study, morphometric analysis had been carried out based on the digitization of drainage streams onscreen as line feature in shape form on georeferenced Survey of India (SOI) toposheet of 1:50,000 scale in Arc GIS 10.1 using Geographic Coordinate system, WGS-84. Drainage basin length, basin perimeter, and drainage divide were measured and delineated. Strahler's stream ordering method was followed while ordering the digitized streams. The number of streams of each order were counted and recorded. The drainage map along with basin boundaries was digitized as line coverage. Morphometric parameters were computed using standard methods and formulae [11,12,27,29]. The derived morphometric parameters were calculated based on the formulae proposed by different workers stated in Table 1.

In the present study five sub-basins located in the study area (Fig. 3) have been selected as representative sub-basins of the two litho-units for analysis. Of these, two sub-basins, namely Umlang and Umkyrtha, fall in the Precambrian gneissic unit (PGU), while the rest three, namely Wah-Phodthra, Umsophew, and Khandow, are located predominantly in the sedimentaries of the Mahadek Formation (MFS) towards the south of the area.

Table 1. Mathematical expressions for computation of morphometric parameters

Derived morphometric parameters	Formula	Reference
Drainage density (D_d)	$D_d = \Sigma L_u/A$; ΣL_u = total stream length; A = basin area	Horton (1932)
Stream frequency (F_s)	$F_s = \Sigma N_u/A$; ΣN_u = total stream number of all orders; A = basin area	Horton (1932)
Drainage Texture (T)	$T = \Sigma N_u/P$ Where, ΣN_u=Total number of streams of all orders, P=Perimeter of basin.	Horton (1945)
Constant of channel	$C = 1/D_d$	Schumm (1956)
Length of overland flow(L_g)	$Lg=1/2D_d$	Horton (1945)
Form factor (R_f)	$Rf=A/L_b^2$; L_b= maximum basin length	Horton (1945)
Elongation ratio (R_e)	$R_e = 2\sqrt{(A/\pi)}/L_b$.	Schumm (1956)
Circularity ratio (R_c)	$Rc=4\pi A/P^2$	Miller (1953)
Basin relief (R)	R = H-h; H = Maximum elevation of a basin; h = minimum elevation	Hadley & Schumm (1961)
Relief ratio (R_r)	$R_r = R/L_b$	Schumm (1963)
Ruggednesss number(R_n)	$R_n = Bh \times D_d$; where, Bh= Basin relief	Schumn (1956)

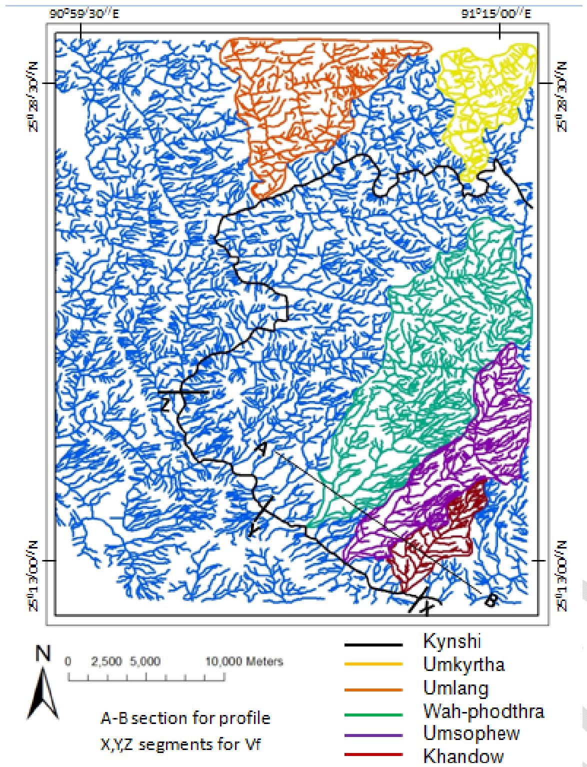

Fig.3. Drainage map of the study area

4. RESULTS AND DISCUSSION

The morphometric parameters considered for the present study are the derived parameters which are obtained from the interrelationship of basic parameters such as stream order, stream number, stream length, basin area, relief, etc.

The derived parameters considered in the present study are as follows:

Derived parameters of areal aspects: i) drainage density, ii) stream frequency, iii) drainage texture, iv) constant of channel maintenance, v) length of overland flow, and vi) shape parameters,

Derived parameters of relief aspects: i) relief ratio, ii) ruggedness number, iii) hypsometric analysis, and iv) longitudinal profile.

4.1 Derived parameters of areal aspects

i) Drainage density (D_d): Drainage density, defined as the total stream length per unit area, is an expression of closeness of spacing of channels. It is related to the amount and intensity of precipitation besides lithology. D_d values normally range from 1.5 to 6 km^{-1}. In the present study area D_d values range from 3.449 to 4.436 km^{-1}. Relatively lower values with respect to the sub-basins (SB) Umlang (3.449 km^{-1}) and Umkyrtha (3.785 km^{-1}) can be attributed primarily to lithological control, these being located in hard and resistant PGU (Table 2). Higher values have been obtained for the sub-basins located in the lesser resistant MFS.

ii) Stream frequency (F_s): This parameter indicates the number of stream segments (N_u) per unit area of a basin. The underlying lithological character can be understood from D_d and F_s values. The F_s varies from 5.814 km^{-2} (Umkyrtha SB) to 7.228 km^{-2} (Khandow SB). Usually high F_s is associated with weak and impermeable lithology.

Lower F_s values of the sub-basins occurring in the gneissic unit can be attributed to relatively hard and resistant lithology of the unit

The positive relation between D_d and F_s can be understood from the regression equation determined for the study area,

$$\text{Log } F_s = 0.333 \text{ Log } D_d + 0.625$$

iii) Drainage texture (T): Drainage texture, defined as the total number of stream segments of all orders per perimeter of the basin (Horton, 1945), is also a measure of closeness of the channel spacing. Smith (1950) classified drainage texture into five different classes i.e., very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8), and very fine (>8). The values, given in Table 2, suggest moderate to very fine texture. The sub-basins dominantly in MFS give variable values ranging from moderate (Khandow SB – 4.27) to very fine (Wah-Phodthra SB – 9.68) with Umsophew SB having an intermediate value (5.83). The sub-basins of PGU (Umkyrtha and Umlang) possess fine texture which may be attributed to closely placed lineaments influencing the formation of rectangular to sub-rectangular drainage pattern.

iv) Constant of channel maintenance (C): Defined as the reciprocal of D_d, this parameter is a quantitative expression of the minimum limiting area required for the development of drainage channel. Reciprocal relationship of C and D_d implies that a basin with high D_d will require smaller watershed area for maintaining a unit channel length. As shown in Table 2**,** the sub-basins located MFS have lower C values as compared to those located in the PGU thus implying that for maintenance of unit channel length, the contributing area is smaller in case of the former. This indicates higher overland flow for the sub-basins of the PGU.

v) Length of overland flow (L_g): This parameter is defined as the length of flow path, projected on the horizontal, of non-channel flow from a point on the drainage divide to a point on the adjacent stream channel [12]. It is approximately equal to half the reciprocal of drainage density. The L_g values for the sub-basins located in MFS are relatively lower indicating higher degree of drainage development.
Lower degree of drainage development in case of the PGU sub-basins also suggests higher overland flow.

vi) Shape parameters: The shape or outline of a drainage basin has been quantitatively expressed by different workers commonly in the form of three parameters, viz. form factor, elongation ratio, and circularity ratio.

a) Form factor (R_f): R_f ranges from 0 to 1. Higher R_f values indicate more basin circularity. The sub-basins located in MFS viz. Khandow, Umsophew, and Wah-Phodra are much elongated having R_f values 0.225, 0.173, and 0.214 respectively which are lower than those of Umkyrtha (0.346) and Umlang (0.311) located in PGU.

b) Elongation ratio (R_e): Like R_f, higher R_e values imply more circularity of a basin. The value of R_e approaches 1 if basin shape approaches a circle. The R_e values of the sub-basins located in MFS are relatively lower that those located in PGU implying more circular nature of the latter category (Table- 2).

c) Circularity ratio (R_c): This parameter, defined as the ratio of the area of a basin to the area of a circle with the circumference equal to the basin perimeter (P), also shows similar contrast as in case of R_f and R_e**.** Therefore, all the three shape parameters have quantitatively shown much elongation of the sub-basins located in MFS.

Table 2. Areal aspects of the sub-basins

Name of Sub-basins	A_u (km^2)	D_d (km^{-1})	F_s	T	R_f	R_e	R_c	C	L_g	AF
Umlang	34.79	3.449	5.864	6.56	0.311	0.629	0.453	0.289	0.145	16
Umkyrtha	18.30	3.785	5.814	6.63	0.346	0.664	0.494	0.264	0.123	28
Wah-Phodra	64.25	4.297	6.366	9.68	0.214	0.522	0.453	0.233	0.116	40
Umsophew	29.20	4.391	6.473	5.83	0.173	0.469	0.349	0.228	0.114	37
Khandow	10.10	4.436	7.228	4.27	0.225	0.536	0.435	0.225	0.113	49

4.2 Derived parameters of relief aspects

i) Relief ratio (R_r): It is a dimensionless parameter defined as the ratio of maximum basin relief to largest dimension of the basin parallel to the principal drainage line [22].Thus, it measures the overall steepness of a drainage basin and is an indicator of the intensity of erosion process operating on the slope of the basin [29]. In the present study, the relief ratio of the sub-basins ranges from 0.065 to 0.113 (Table 3). The values for the sub-basins located in PGU (Umlang and Umkyrtha) are relatively lower than those of the sub-basins belonging to MFS.

ii) Ruggedness number (R_n): Ruggedness number is a product of maximum basin relief and drainage density. It is a dimensionless value indicating steepness and the length of the steep slope surface [28]. Extremely high value of ruggedness number occurs when the variables are large, i.e, when the slopes are not only steep but long as well. Ruggedness number indicates the structural complexity of a terrain in association with relief and drainage density [8]. The R_n for the sub-basins belonging to PGU have been found to be 1.805 (Umkyrtha) and 2.373 (Umlang) which are relatively lower than those of the sub-basins in MFS implying more dissection on the latter category aided by relatively soft nature of the unit.

Table 3. Relief aspects of sub-basins

Name of Sub-basin	H (m)	h (m)	H-h (m)	L_b (km)	R_r	R_n	HI (%)	PHI (%)
Umlang	1310	622	688	10.568	0.065	2.373	68	53
Umkyrtha	1477	1000	477	7.271	0.066	1.805	75	32
Wah-Phodra	1420	100	1320	17.321	0.076	5.672	72	63
Umsophew	1220	100	1120	12.978	0.086	4.918	65	50
Khandow	860	100	760	6.696	0.113	3.371	55	52

iii) Hypsometric analysis: Hypsometric analysis involves the measurement and analysis of relationship between altitude and basin area for understanding the stage of landform evolution, the processes involved and also to assess the influence of tectonism on the topography. Hypsometric curves are drawn for the sub-basins by considering the relative area (a/A) along the X-axis and relative height (h/H) along the Y-axis [29]. A convex-up curve means that most of the area has relatively enhanced uplift with low erosion. A concave-up curve means that most of the area has relatively less uplift and high erosion. The area below the curve is called hypsometric integral (HI) and that above the curve erosion integral (EI). High HIs for the sub-basins of the study area, ranging from 55% to 75%, imply tectonic uplift (Table 3; Fig. 4).

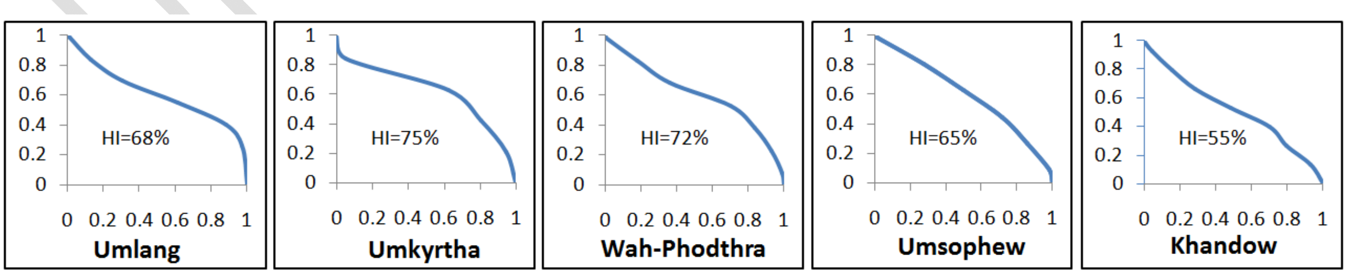

Fig.4. Hypsometric curves of the sub-basins

iv) Longitudinal profile: The traditional longitudinal profiles are drawn considering altitude as a function of horizontal distance from the source. Except for general gradient from source to mouth, no significant and quantifiable parameter can be extracted from this type of profile particularly of long rivers. On the other hand, normalized longitudinal profiles, prepared by normalizing the elevation and the distance from the source, are more informative than the traditional profiles [26]. In the present study, therefore, inferences have been drawn from normalized longitudinal profiles. When a river passes through zones of active tectonics, for example subsidence or uplift, its longitudinal profile shows the effects of deformation [17]. Pronounced and abrupt change in slope along a longitudinal profile resulting in knickpoints, may be indicative of active fault provided the lithology is homogeneous. The longitudinal profiles of the river channel Wah-Phodthra and Umsophew running through MFS and Umlang channel traversing PGU show prominent knickpoints (Fig. 5). The subdued longitudinal profile of Umkyrtha, despite having a high HI (75%) inferring neotectonic uplift, could be the result of efficient incision through the lineament L_6 (Fig. 7) along which a major upper part of the river flows.

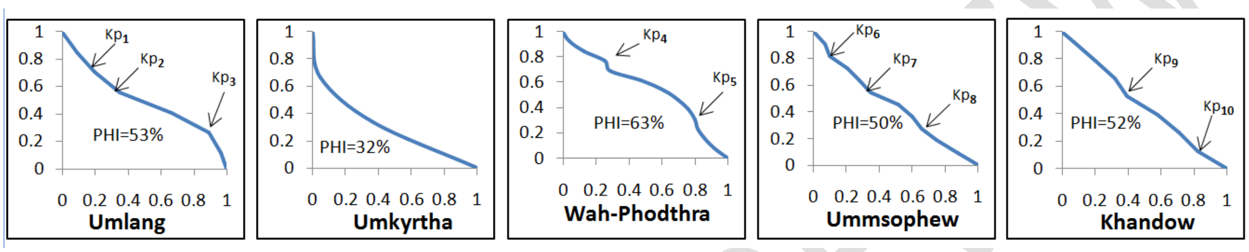

Fig.5. Normalized longitudinal profiles

4.3 Neotectonism

The present study area falls in the southern part of Shillong Plateau considered as a detached tectonically active pop-up continental block of a subducted wedge of the peninsular India in front of the Indian and Tibetan continental mass [7,15,20]. Although the entire Shillong Plateau is undergoing tectonic instability, however, behaviour of the Shillong Plateau is believed to be diverse in different segments. The central segment of the plateau is undergoing accelerated deformation/uplift [13] where the Jadukata basin is located. Such pronounced tectonic activity is expected to influence the drainage characteristics in the area. The present area has, therefore, been considered for neotectonic investigation based on some geomorphic indices and morphometric parameters associated with the drainage characteristics.

Evidences of neotectonism in PGU have been gathered from sub-basins Umlang and Umkyrtha. High hypsometric integral values of 68% and 75% respectively of these sub-basins and a general convex-up shape are suggestive of uplift besides stage of development. A notable feature of the hypsometric curve of the Umlang sub-basin is the steep toe of the curve. This implies relative movement along the major lineament L_5 trending NE-SW to which the Umlang river mouth is connected, whereby the part lying to the north of the lineament and comprising the Umlang sub-basin is a relatively upthrown block. A prominent break in slope of the hypsometric curve at the upper part of the Umkyrtha SB, is also indicative of tectonism. The longitudinal profile of Umlang river exhibits steep slope near the river mouth very similar to its hypsometric curve which also suggest neotectonic uplift north of the major lineament L_5 (Fig. 7). Furthermore, as depicted on the topomap no. 78 O/3, a 49 m falls exists at the northern contact of the PGU with the lineament L_5 indicating the lineament to be an active fault.

Preferred stream orientation generally indicates recent tectonic activity. The lower order stream orientations are the youngest component of the drainage network and preferred orientation correspond to the orientation related to the most recently active tectonic phase [6]. Preferred orientations mostly as parallel, rectangular to sub-rectangular, and sub-trellis drainage patterns exhibited by the first and second order stream segments in major parts of Umlang and Umkyrtha SBs (Fig 3), therefore, suggest recent tectonic activity.

In the southern part of the study area, the canyon topography resulting from the existence of deep gorges cut on the MFS creating V-shaped valleys by the Khandow, Wah-phodthra, and Umsophew rivers can be attributed to neotectonic uplift of the area. The topographic profile (Fig.6) along section A-B (section A-B shown in Fig.3) has revealed that the rivers Wah-Phodra and Umsophew have deeply incised through MFS exposing the gneissic unit as exhibited in Fig. 2. The contact between the MFS and PGU could be inferred. The rugged topography and V-shaped valleys in southern Shillong Plateau are not only products of monsoon climate driven erosion but also strongly influenced by active tectonics [2] causing deep incision by the rivers Wah-Phodthra, Umsophew, and Khandow. This may be attributed to pop-up (vertical displacement) of the Shillong plateau along the Dauki fault in the south and the Oldham fault in the north. The displacement is at the rate of 0.77-1.25 mm/yr along the Dauki fault and about 0.68 mm/yr along the Oldham fault. Faster displacement along the Dauki fault has caused $2^0 – 3^0$ northward tilting of the surface of the plateau [3].

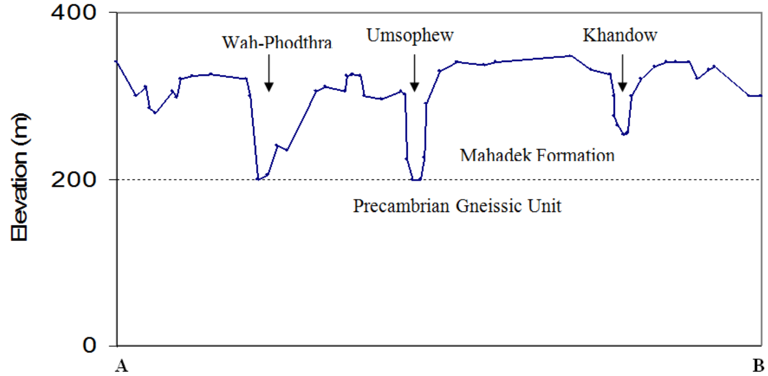

Fig.6. Topographic profile along section A-B.

The major lineaments in the study area shown in Fig. 7, have been drawn based on conspicuous straight stream channel course extending for long distances or identifiable linear traces formed from orientations of tributaries along preferred directions. Lineaments L_1, L_2, L_3, L_4, L_5, L_6, and L_7 traverse the PGU, whereas lineaments L_8, L_9, L_{10}, and L_{11}, and L_{12} are located partly in PGU and partly in MFS. Whether these lineaments are tectonically active cannot be judged from the planar view since they do not pass through the Quaternaries which are not present in the area. According to [14], the absence of younger rock formations above the Miocene is the result of rapid emergence of the massif since Mio-Pliocene time which prohibited sedimentation of later periods. Longitudinal profiles of these rivers, however, give clear evidence of active tectonism from the presence of distinct knickpoints approximately at locations where the rivers cross these lineaments. In the PGU, knickpoints kp_1, kp_2, and kp_3 of Umlang river profile occur where the lineaments $L_{2,}$ L_3, and L_4 intersect suggesting active fault trace. In the MFS, knickpoints kp_4 and kp_5 of Wah-Phodthra occur approximately where the lineaments L_8 and L_{10} intersect the rivers (Fig.7). However, no knickpoint occurs at the location where L_9 intersects the Wah-Phodthra river. The knickpoints kp_6 and kp_8 of the Umsophew profile can be associated with the prominent lineaments L_9 and L_{10}. Knickpoint kp_9 of the Khnadow river profile can be associated with lineament L_{10} but no major lineament appears to intersect at the location of kp_{10}. Lineament L_8 is a major structural element truncating MFS at near Nongsynriang such that no extension of this formation occurs north of the lineament. Streams flowing along lineament L_9 have incised the MFS forming steep gorge in the east-west direction exposing the gneissic rocks thereby indicating tectonic uplift. Since the Shillong Plateau has been accommodating horizontal shortening at the rate of 0.65-2.3 mm/yr [3], the lineaments in the study area can be considered to be thrusts. Rapid shortening and higher convergent rates of this eastern segment of the Indian plate (compared to the rest of the plate) has been reported by Banerjee et al. [1].

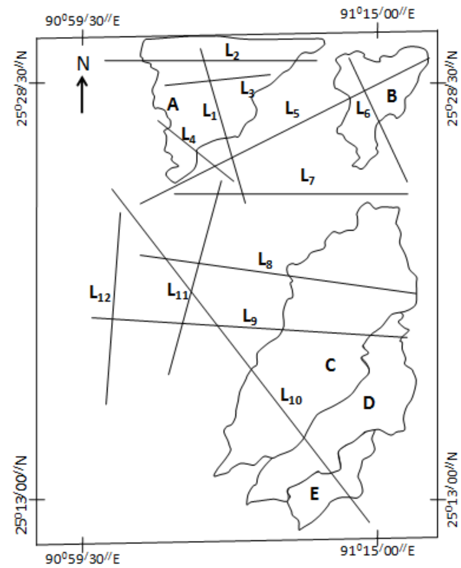

Fig.7. Diagram showing distribution of major lineaments

Pseudo-hypsometric integral (PHI): This parameter related to longitudinal profile, reflects the relative amount of deformation or degradation that has occurred in a river [21]. The PHI describes the overall shape of the long profile and is calculated as: PHI = Ap/Ar (expressed as percentage), where Ap is the area under the long profile and Ar is the area of the rectangle defined by height and length of the river basin [19]. Since, in the present study, normalized longitudinal profiles are used, Ar, therefore, is the area of the square. The PHI of the rivers (Table 3) in general have been found to be towards the higher side which imply that the study area has undergone neotectonic rejuvenation.

Asymmetry factor (AF): This parameter helps to evaluate drainage basin asymmetry. It is expressed as AF = 100(Ar/At), where Ar is the area of the basin to the right of the trunk channel facing downstream and At is the total area of the basin. The AF is sensitive to tilting perpendicular to the trend of the trunk stream [16]. A stable setting is implied where the AF is 50. Values higher than 50 suggest tilt to the left, whereas those lower than 50 suggest tilt to the right. AF values of 16 and 28 for Umlang and Umkyrtha sub-basins respectively belonging to the PGU suggest distinct tilt to the right (i.e towards west). The sub-basins Wah-Phodthra, Umsophew, and Khandow of the MFS show AF values of 40, 37, and 49 respectively which also indicates tilt towards west. Besides, relatively steeper western valley sides of these rivers also suggest westward tilt (Fig. 6). These findings corroborate with that of Biswas and Grasemann [2] where a westward tilt of the Jadukata basin has been determined based on the transverse topographic symmetric factor but contradicts the finding of Imsong et al. [13] which reported eastward tilt of the river basin.

Valley floor-to-height ratio (V_f): This index is defined by Bull and McFadden [4] as: $V_f = \frac{2V_{wf}}{(E_{ld}-E_{sc})+(E_{rd}-E_{sc})}$ where V_f is valley floor width-to-height ratio, V_{wf} is the width of valley floor, E_{ld} and E_{rd} are the left and right valley divides facing downstream respectively, and E_{sc} is the elevation of valley floor. High V_f values indicate wide valley floor and, therefore, low tectonic uplift. Conversely, low values will indicate higher tectonic activity. Values greater than 1.0 signify broad 'U' shaped valleys, whereas values less than 1.0 suggest presence of 'V' shaped valleys resulting from active incision. The V_f has been calculated at segments X, Y, and Z along the Kynshi river (Fig.3) and the values obtained at these segments are 0.57, 0.44, and 0.68 respectively suggestive of active incision.

5. CONCLUSIONS

The study area comprises a major south-central part of the Jadukata river basin, the latter occupying the southern part of the West Khasi Hills district of Meghalaya.

The derived areal parameters have shown lower drainage density (D_d) and stream frequency (F_s) values for the sub-basins of the PGU implying higher overland flow relative to the sub-basins of the MFS which is also substantiated by higher constant of channel maintenance (C) and length of overland flow (L_g).

Evolution of elongated basins, such as those of the MFS, is generally attributed to structural factors. Being elongated, the run-off outflow through the river mouth takes extended time with low peak discharge after the incidence of precipitation. This is contrary to wider (less elongated) basins (in the PGU) where the time required is shorter but with high peak discharge, thus increasing the possibility of flash flood. The form factor (R_r) and ruggedness number (R_n) are higher for the sub-basins of MFS implying more dissection.

The geomorphic indicators of the study area, falling in the near central part of the Shillong Plateau, suggest neotectonic uplift as well as tilt towards west. Preferred orientations of lower order streams along lineaments in the gneissic unit also suggest active tectonism. The presence of canyon topography with very narrow and deep river valleys in the MFS and very low valley floor-to-height ratio (V_f) suggest incision due to tectonic uplift. High hypsometric integral (HI) and pseudo-hypsometric integral (PHI) of all the selected sub-basins also indicate neotectonic rejuvenation. The presence of knickpoints at locations of intersections of major lineaments and river profiles suggests active fault. Dauki Fault is considered to be the major structure controlling the uplift of the plateau. Furthermore, the predominantly east-west trending lineaments are probably thrusts in this compressional regime.

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