SCIENCE VISION
Volume 2024, Issue 1, pages 12–23
31 Mar 2024
https://doi.org/10.33493/scivis.24.01.02

RESEARCH ARTICLE

Morphometric analysis of the Middle Tuirial watershed, Mizoram, India and its significance for soil loss risk

Imanuel Lawmchullova*, Lalrinkimi, Ch. Udaya Bhaskara Rao

Department of Geography and Resource Management, Mizoram University, Aizawl, India, 796004

This study aims to highlight the quantitative analysis of Middle Tuirial watershed in Mizoram, India and its significance for soil loss risk. In addition to understanding landscape evolution and hydrological characteristics of the river basin, it is crucial to implement appropriate soil and water conservation practices, to reduce further soil erosion risk in the basin. Linear, areal and relief aspects of morphometric parameters were analyzed using a survey of India topographical maps, advanced land observing satellite (ALOS) phased array type L-band synthetic aperture radar (PALSAR) digital elevation model (DEM), and geographic information system (GIS). The study reveals a high drainage density of 5.22 km/km^2 and stream frequency of 10.58 km^2, which denotes the basin exhibits high surface run-off with low ground-water recharge. In addition, it has 0.6 form factor, 0.3 elongated ratio and 0.43 circularity ratio indicating a highly elongated shape of the basin. Furthermore, the hypsometric integral values of 0.48 with an s-curve show the basin has attained a mature stage of landscape evolution.

Received 16 Jan 2024
Accepted 31 Mar 2024

*For correspondence:
lawmchullova@gmail.com

Contact us:
mizoacadsci@gmail.com

Keywords : Morphometry, Middle Tuirial River basin, DEM, Geographic Information System

Introduction

The analysis of landforms, shape and surface configuration measuring quantitatively and mathematically is known as morphometry. The morphometry of the river basin reveals the characteristics of the river catchment of hydrological and geomorphic processes including the drainage system. Geology, soil texture, terrain, topographic features and climate are the natural factors that govern river flow, direction, and pattern of drainage system in the watershed. Horton[1,2] introduced the quantitative measurement of the drainage basin to analyze the drainage system. Later, adjustment and further analysis were performed by Strahler[3,4].

Pioneering works of Horton[1,2] are concentrated in stream number, stream length, drainage density and channel frequency. Strahler[3,4] adjusted the Horton works to perform further analysis like stream order, form factor ratio, bifurcation ratio, relief basin, circularity ratio and stream length ratio. Likewise, various other researchers developed new parameters like elongated ratio, relief ratio,[5] relative relief ratio,[6] hypsometric integration,[7] ruggedness number,[8] hypsometric curve,[9] and gradient ratio[10].

Earlier, the river basin and sub-watershed level of the drainage characteristics studies were performed by conventional method. The advancement of information technologies in geographic information system and spatial remote sensing data provide a powerful tool for computation and assessment of various hydrological characteristics at global level. The systematic geo-

ISSN 0975-6175 (print) /2229-6026 (online) | CODEN SVCIC9

spatial approach of morphometric studies of the river basin is successfully conducted by various researchers.[10,11] They found out that, morphometric analysis by remote sensing (RS) and geographic information system (GIS) technique provides the principle information of landforms and hydrogeological features of the watershed. The advantage of geo-spatial approach is low in capital investment, expenditure and time saved. In the present study the linear aspects, areal aspects, and relief aspects of the morphometric parameters of middle Tuirial river basin were computed by applying formulae derived from pioneering works with geospatial data and GIS techniques. No significant study was conducted in this area with an attempt to establish relationship of relief aspects with hydrological parameters. This study aims to highlight the quantitative analysis of middle Tuirial watershed along with the morphometric parameters and its significant contribution for the soil loss risk. In addition to understand landscape evolution and drainage characteristics of the basin, to recommend the appropriate techniques for soil and water conservation .

Materials and methods

Study Site

The Middle Tuirial river basin is geographically located in between 23° 48′ N - 24° 28′ N latitudes 92° 45′ E - 93° 58′ E longitudes (Fig. 1). It forms the boundary between the two districts of Aizawl and Kolasib. Tuirial hydro-power station is constructed along the river with having 60 MW installed capacity to meet the requirement of power demand in Mizoram. The middle Tuirial river basin spreads an area about 683.10 km^2 with having 54 perennial tributaries river on both sides. The basin receives about 2000 mm of annual rainfall, mostly influenced by the southwest monsoon. There are 40 settlements, mostly found along the water divide. This river provides the water demand for public and irrigational facilities. Tuirial River basin is divided into three watersheds such as upper Tuirial D2CBAR26, middle Tuirial D2CBAR27 and lower Tuirial D2CBAR28, of which middle Tuirial watershed D2CBAR27 is selected for this study. Built-up land agricultural land, bamboo forests, open forests, and dense forests are the prominent land use and land cover types in the basin, while loamy, clay, and silt are the common soils found in the basin. In addition, shale, siltstone and sandstone are the major litho-units of Bokabil and Bhuban formations under the Surma group believed to be formed in Miocene to upper Oligocene epoch.

Data used and methodological approaches

Remotely sensed ALOS PALSAR digital elevation model (DEM) at 12.5 metres spatial resolution is acquired from Alaska university website[12] for analysis of

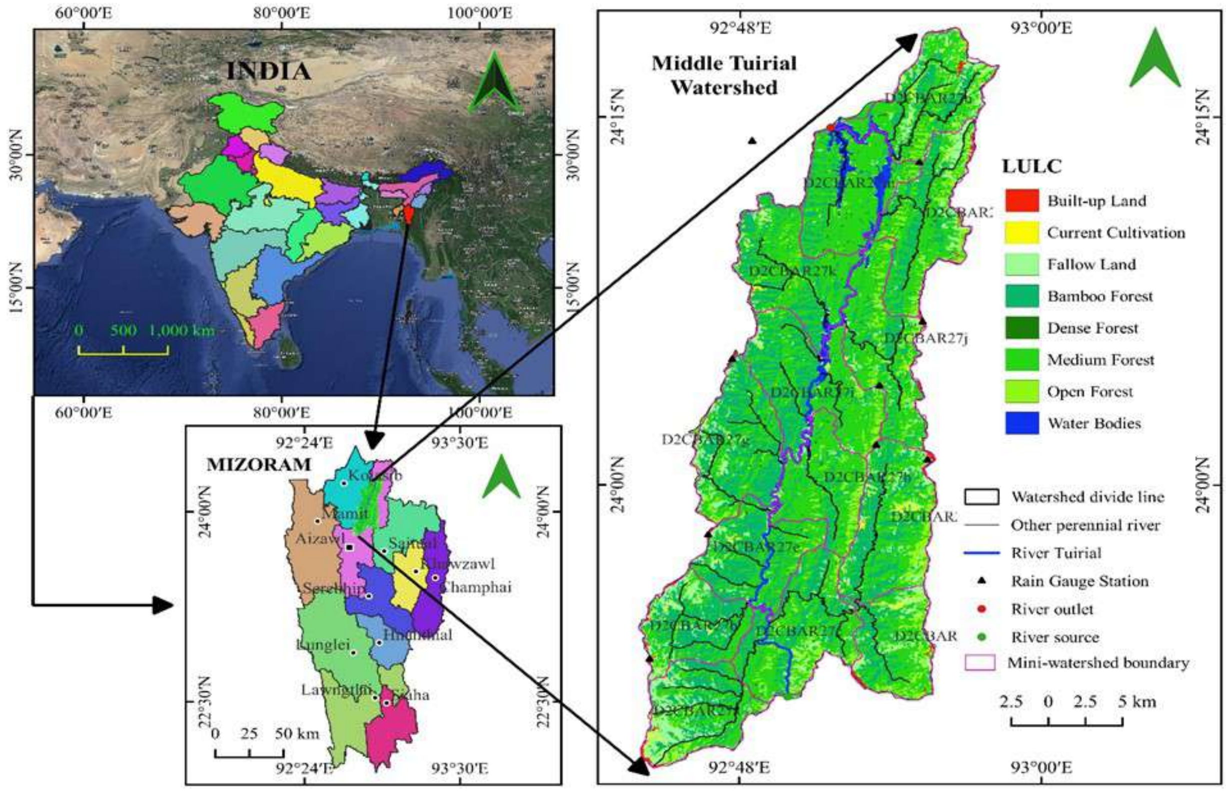

Figure 1. Study area map

Table 1: Details of morphometric parameters and equation

Category	Morphometric Parameter	Formula	References
Linear features	Stream order (U)	Hierarchical rank	Horton[2]
	Stream number (N_u)	$N_u = N_1+N_2+...+N_n$	Horton[2]
	Stream length (L_u)	$L_u = L_1+L_2+...+L_n$	Horton[2]
	Mean stream length (L_{sm})	$L_{sm} = L_u/N_u$	Horton[2]
	Stream length ratio (L_{ur})	$L_{ur} = L_u/L_u - 1$	Horton[2]
	Bifurcation ratio (R_b)	$R_b = N_u/N_u + 1$	Schumm[5]
	Bifurcation ratio (R_{bm})	R_{bm} = average	Horton[2]
	Basin length (km)	ArcGIS	
Relief features	Maximum basin height (m) (H)	ArcGIS	
	Minimum basin height (m) (h)	ArcGIS	
	Basin relief (m) (R)	$R = (H - h)$	Schumm[5]
	Relief ratio (R_r)	$Rr = R/L_b$	Schumm[5]
	Relative relief (R_{hp})	$R_{hp} = R/A$	Smith[27]
	Dissection index (D_i)	$Di = R_{hp}/R_a$	Pike and Wilson[7]
	Gradient ratio (G_r)	$Gr = (a - b)/L_s$	Sreedevi *et al.*[10]
	Ruggedness number (R_n)	$Rn = R \times D_d$	Schumm[5]
	Hypsometric integration (HI)	Elmean-Elmin/Elmax-Elmin	Pike and Wilson[7]
Areal features	Basin area (A) (km^2)	ArcGIS	
	Basin perimeter (P) (km)	ArcGIS	
	Drainage density (D_d)	$D_d = L_u/A$	Horton[2]
	Stream frequency (F_s)	$F_s = N_u/A$	Horton[2]
	Length of overland flow (L_o)	$L_o = D_d/2$	Horton[2]
	Constant channel Maintenance (C_m)	$Cm = 1/D_d$	Schumm[5]
	Form factor (F_f)	$F_f = A/L_b^2$	Horton[1]
	Circulatory ratio (R_c)	$R_c = 4\pi A/P^2$	Miller[20]

Where, N_u = number of stream segment, L_u = total stream length of order (u), L_{u-1} = the total stream length of its next lower order, N_{u+1} = number of segments of the next higher order, R_l = stream length ratio, R_b =bifurcation ratio, H = highest elevation, h = lowest elevation, B_h = basin relief, L_b = basin length, R = basin relief, A = basin area, R_{hp} = relative relief, R_a = absolute relief, a = the elevation at the source of the river, b = is the elevation at mouth of the river, L= is the length of main stream, D_d = Drainage density, P = perimeter of basin.

slope, elevation, areal and relief aspects of morphometric parameters. The Tuirial river shape file is acquired from Mizoram remote sensing application center (MIRSAC) for the analysis of linear and areal morphometric parameters. The river catchment is digitized from survey of India toposheets after rectification and projection to WGS 1984 UTM 46N coordinate system. The daily rainfall data at 9 rain gauge stations is acquired from National Aeronautics and Space Administration[13] (NASA) power to generate rainfall thematic layer. Since the river basin covers a large area that falls in two tiles of DEM were merged using ArcGIS 10.4 software. The study area shape file is used as a mask layer for clipping the DEM by clip vector tool and re-projected to WGS 1984 UTM 46N. Using hydrological tools, fill sink command was executed by Wang and Liu method, and other hydrological methods were performed by various pioneering works to accomplish the morphometric analysis (Table 1).

Results and discussion

Linear morphometric parameters of middle-Tuirial sub-watersheds

According to Horton stream ordering, the

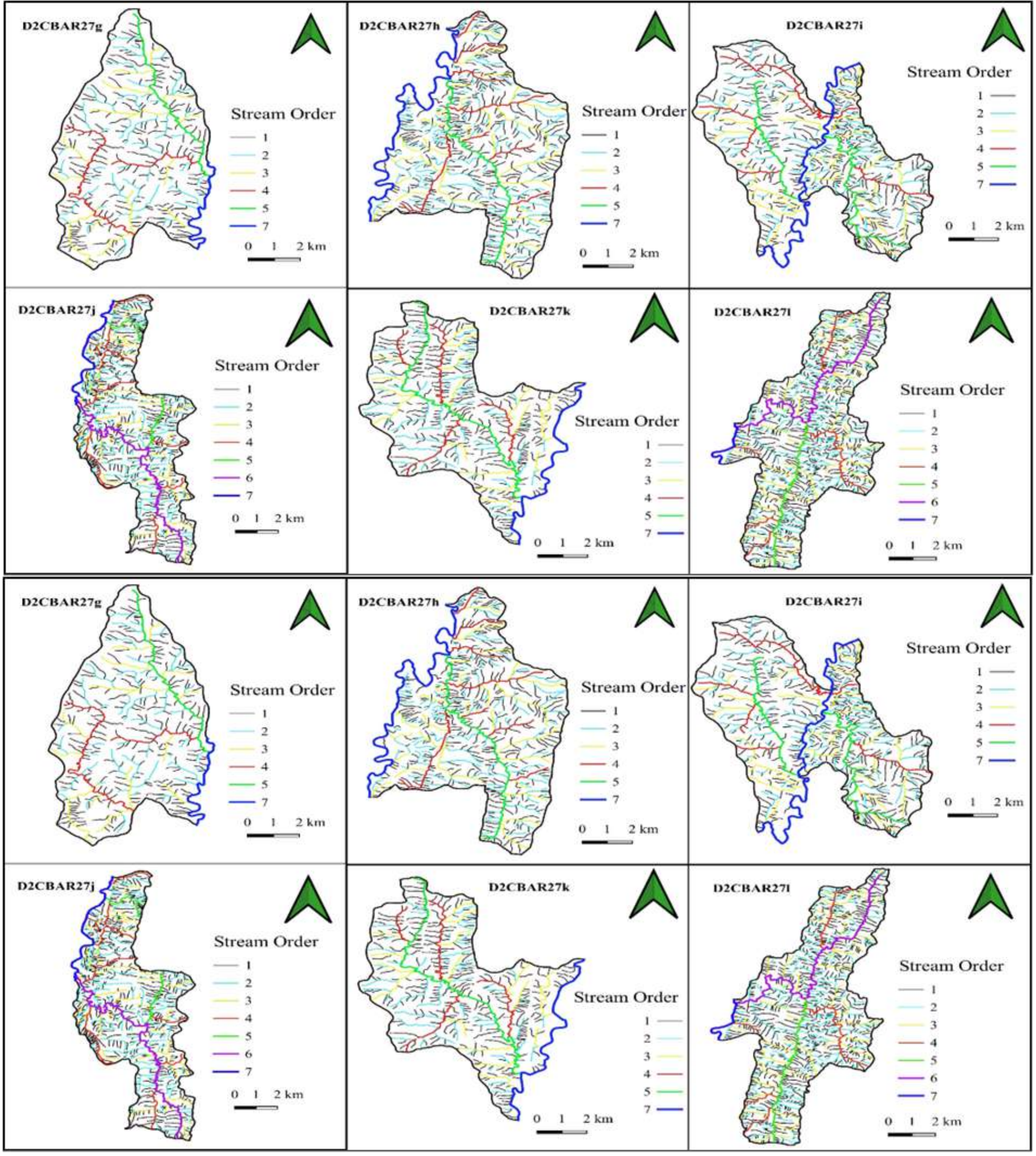

Figure 2. The sub-basin wise stream order

Table 2: Areal aspects of middle Tuirial sub-watershed

Sub-watersheds	Drainage area (km^2)	Perimeter (km)	Drainage density (km/km^2)	Stream frequency (n/km^2)	Drainage texture	Form factor	Elongated ratio	Circularity ratio	Compactness co-efficient
D2CBAR27a	44.42	30.08	5.35	10.31	15.23	0.58	0.38	0.62	1.27
D2CBAR27b	38.16	28.21	4.33	7.26	9.82	0.58	0.40	0.60	1.29
D2CBAR27c	56.42	41.71	5.63	12.78	17.29	1.17	0.43	0.41	1.57
D2CBAR27d	37.97	29.58	4.90	8.61	11.05	0.49	0.38	0.55	1.36
D2CBAR27e	44.95	35.36	4.72	8.97	11.40	0.32	0.33	0.45	1.49
D2CBAR27f	56.13	35.08	5.17	11.67	18.67	1.06	0.42	0.57	1.32
D2CBAR27g	51.53	36.73	3.73	6.00	8.41	0.84	0.40	0.48	1.44
D2CBAR27h	40.01	40.16	6.23	13.22	13.17	0.29	0.33	0.31	1.79
D2CBAR27i	59.92	53.28	4.92	9.20	10.34	0.52	0.34	0.27	1.94
D2CBAR27j	49.7	47.25	6.18	14.45	15.20	0.45	0.35	0.28	1.89
D2CBAR27k	51.87	42.56	4.49	7.21	8.79	0.72	0.39	0.36	1.67
D2CBAR27l	51.97	46.8	6.64	16.97	18.85	0.56	0.36	0.30	1.83
D2CBAR27m	51.1	36.08	4.74	7.83	11.09	0.59	0.37	0.49	1.43
D2CBAR27n	48.95	39.95	6.10	13.67	16.75	0.52	0.36	0.39	1.61

middle Tuirial watershed is up to 7th level of stream order. The sub-watersheds D2CBAR27a, D2CBAR27f and D2CBAR27d fall under 5th and 6th levels of stream order respectively. The sub-watersheds like, D2CBAR27b, D2CBAR27c, D2CBAR27e, D2CBAR27g, D2CBAR27h, D2CBAR27i, D2CBAR27j, D2CBAR27k, D2CBAR27l, D2CBAR27m, and D2CBAR27n have 7th level of stream order (Table 3 and Fig. 2), with the variation in stream order and size of the watershed influenced by structural and physiographic conditions.[14] The sub-watersheds exhibit varying drainage patterns like, trellis, dendritic, sub-dendritic and parallel, of which the dendritic pattern is predominant as the region is controlled by physiographic conditions and active tectonic activity.[11] The middle-Tuirial watershed was counted for 7273 streams, of which 882 streams fall in D2CBAR27l and 277 streams found in D2CBAR27b sub-watersheds to contribute the highest and lowest stream frequency, respectively. The total stream length of the watershed decreases with the increase in the stream order as per the law of Strahler. But, in Horton stream ordering one river is assigned as one order with no segment, because each river has an

Table 3: Linear aspects of middle Tuirial sub-watershed

Sub-watershed		D2CBAR27a	D2CBAR27b	D2CBAR27c	D2CBAR27d	D2CBAR27e	D2CBAR27f	D2CBAR27g	D2CBAR27h	D2CBAR27i	D2CBAR27j	D2CBAR27k	D2CBAR27l	D2CBAR27m	D2CBAR27n	Total
Stream order (km)	1st	131.29	83.79	157.05	79.97	104.42	131.62	90.22	107.51	133.93	137.24	111.91	171.28	108.84	138.68	1687.75
	2nd	55.09	36.44	75.04	45.87	38.79	67.20	43.56	59.00	62.26	75.32	43.53	81.87	61.28	70.69	815.9
	3rd	23.95	22.03	35.93	37.38	25.41	45.78	27.21	36.14	40.89	38.69	30.67	46.27	29.40	37.53	477.28
	4th	15.26	1.49	16.08	10.19	25.33	26.00	14.50	18.79	19.87	22.24	17.09	15.90	11.10	12.52	226.36
	5th	12.09	7.41	9.01	0.77	4.26	19.84	10.43	11.63	19.70	7.19	17.82	10.74	13.91	31.37	176.17
	6th	-	13.51	12.85	11.73	-	-	-	-	-	18.07	-	15.85	-	-	72.01
	7th	-	0.43	11.73	-	13.73	-	6.51	16.29	18.35	8.18	11.81	3.31	17.51	7.77	115.6
No.of stream		458	277	721	327	403	655	309	529	551	718	374	882	400	669	
Stream length (km)		237.68	165.09	317.70	185.91	211.94	290.43	192.42	249.35	295.01	306.93	232.82	345.22	242.05	298.56	
Stream length ratio		1.40	1.99	2.09	2.19	1.04	1.25	1.17	1.34	1.15	1.96	1.35	1.76	1.31	1.42	
Mean stream length		2.39	1.43	4.36	1.74	3.21	1.35	2.44	3.88	4.11	3.26	3.29	2.91	4.46	2.74	
Mean Bifurcation ratio		3.83	3.34	3.15	3.60	4.36	3.03	3.22	3.47	2.89	3.06	3.14	3.43	3.27	3.56	

origin and outlet, whereas in Strahler stream order it shortens the main stream length because more than one stream confluences form the bigger stream order, then it forms the main river. The middle Tuirial watershed stream length constitutes 1st stream order of 47.26 %, 2nd order 22.85 %, 3rd order 13.36, 4th order 6.34 % 5th order 4.93 %, 6th order 2.02 % and 7th order of 3.24 % of the total stream length. The 7th order stream length (115.63 km) is higher than that of the 6th (72.01 km) as the similar result highlighted by Iqbal and Sajjad[14] due to variations of the slope, topographic and lithological[15,16]. In addition, the steep slope and length of the slope with gentle slope gradient indicate short and longer stream lengths respectively.[17] The bifurcation ratio of the middle Tuirial River basin is 4.08, 2.77, 4.08, 3.60, 1.30, and 0.82 for the stream order of 1, 2, 3, 4, 5, and 6, respectively. The mean bifurcation ratio ranges from 2.89 to 4.36. The highest bifurcation ratio was found in D2CBAR27e with 4.36 while 2.89 is the lowest in D2CBAR27i. The bifurcation ratio between 3 and 5 indicates the drainage system of the basin is not controlled by geological structure, whereas less than 3 indicates that the basin is plain.[4] In this study, the middle Tuirial watershed, the mean bifurcation ratio ranges between 2.89 and 4.36 which implies the basin of the geological structure has no significant impact on the hydrological pattern, but it is highly affected by topographic structure (Table 3).

Areal features of middle Tuirial watershed

The analysis revealed that these sub-watersheds such as D2CBAR27a, D2CBAR27c, D2CBAR27f, D2CBAR27h, D2CBAR27j, D2CBAR27l, and D2CBAR27n are exhibiting high drainage

Table 4. Relief aspects of middle Tuirial sub-watershed

Sub-watershed	Maximum elevation (Metres)	Minimum elevation (Metres)	Basin relief (Metres)	Relief ratio	Relative relief	Gradient ratio (Gr)	Ruggness number	Hypsometric integration
D2CBAR27a	1474	144.75	1329.25	0.15	0.03	81.21	7.11	0.48
D2CBAR27b	1474	134.00	1340.00	0.16	0.04	51.81	5.80	0.48
D2CBAR27c	913	133.90	779.11	0.11	0.01	0.98	4.39	0.48
D2CBAR27d	1728	208.05	1519.95	0.17	0.04	65.46	7.44	0.49
D2CBAR27e	1230	120.61	1109.39	0.09	0.02	1.13	5.23	0.48
D2CBAR27f	1449	221.84	1227.16	0.17	0.02	21.48	6.35	0.49
D2CBAR27g	1096	113.59	982.41	0.13	0.02	1.09	3.67	0.48
D2CBAR27h	1123	105.77	1017.23	0.09	0.03	0.42	6.34	0.48
D2CBAR27i	1200	92.95	1107.05	0.10	0.02	0.76	5.45	0.48
D2CBAR27j	1175	80.45	1094.55	0.10	0.02	1.50	6.76	0.48
D2CBAR27k	738	81.90	656.10	0.08	0.01	1.39	2.94	0.49
D2CBAR27l	839	76.08	762.92	0.08	0.01	1.28	5.07	0.48
D2CBAR27m	656	59.89	596.11	0.06	0.01	1.26	2.82	0.47
D2CBAR27n	1039	59.31	979.69	0.10	0.02	1.12	5.98	0.47

density (>6km/km2). The sub-watersheds D2CBAR27b, D2CBAR27d, D2CBAR27e, D2CBAR27i, D2CBAR27k, and D2CBAR27m show moderate drainage density with 4-6km/km^2 (Table 2), whereas low drainage density with < 4 km/km^2 was found only in D2CBAR27g sub-watershed. The average drainage density of the basin is 5.22km/km^2. This implies that the basin is highly susceptible to erosion[2,4,18] with high run-off for triggering landslides,[11] low infiltration rate, high relief with low groundwater recharge. Whereas, low drainage density implies high groundwater recharge, coarse drainage texture and dense vegetation with low relief of the basin[19] but, the middle Tuirial river basin has high relief with dense vegetation cover (Fig. 5). The average elongated ratio of the middle Tuirial basin is 0.37. It is against Strahler[4] stated values of 0.6 to 1, it continues further, if the value close to 1 denotes homogenous low relief with a circular shape, inverse in the values close to zero is characterized by high relief and high infiltration.[20] In addition to the above, it is highly elongated with a low elongated ratio. This less elongated ratio of the middle Tuirial River basin implies high surface run-off with huge sediment transport towards low gradient. The average form factor of the middle Tuirial basin is 0.62, as Chopra *et al.*[21] stated if the value is less than 0.45 indicates the basin is more elongated, and a value greater than 0.78 exhibits more circular shape of a basin.[4] The sub-watershed D2CBAR27c, D2CBAR27f and D2CBAR27g are close to circular shape with more than 0.8 value, it indicates prone to high peak flow for short-term which led to flash floods in the lower course of river.[22] In addition to elongated ratio and form factor, the circularity ratio is also inferring the shape of the basin. The length of stream and frequency are influenced circularity of the basin. The value ranges from 0 to 1, if the values close to one more circular and vice-versa.20 The sub-watershed D2CBAR27a and D2CBAR27b are characterized by more than 0.6 circularity value.

Relief features of morphometric parameter of Middle Tuirial watershed

The middle Tuirial watershed is highly variation of relief features, it has an altitude between 59.31 metres to 1728 meters above sea level at the minimum and maximum elevation, respectively. The average basin relief of the middle Tuirial watershed is 1035.77 meters which indicates steep slopes with high erosion intensity. The basin relief ratio infers the ratio of basin relief to the length of the basin5. In the present study of the average basin relief ratio and relative relief ratio are 0.11

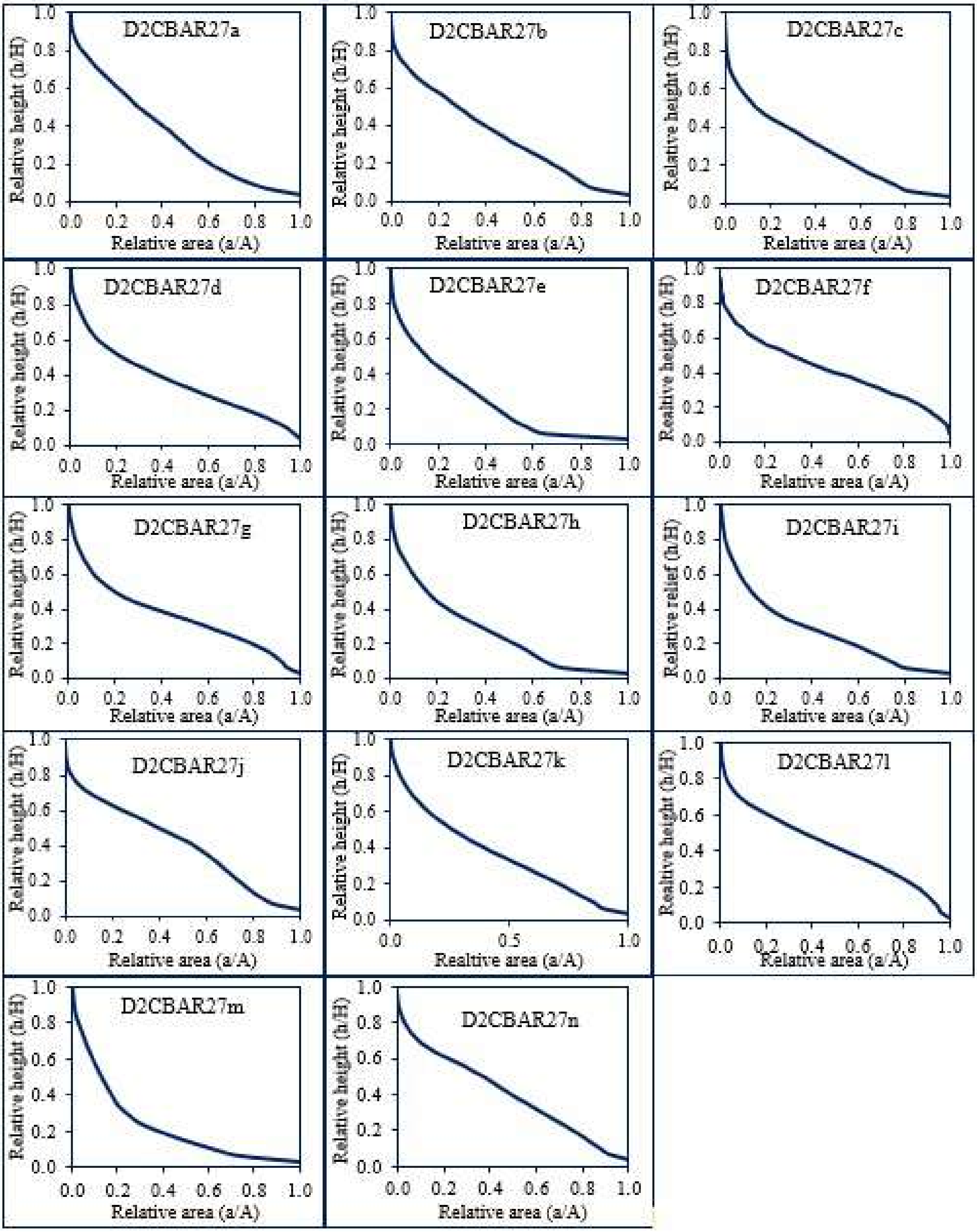

Figure 3. Hypsometric curves of middle Tuirial sub-watershed

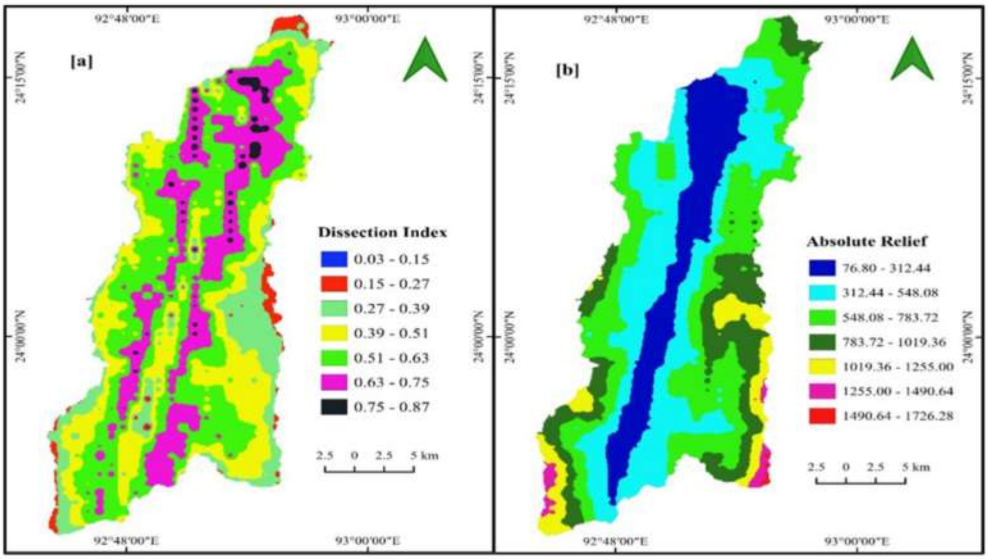

Figure 4. The relief layers (**a**) Dissection index and (**b**). Absolute relief

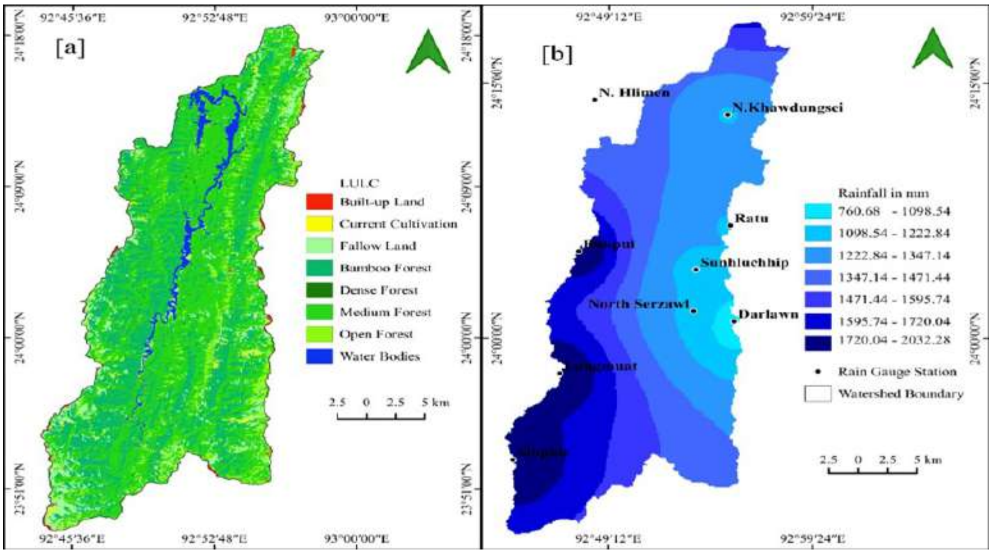

Figure 5. Basin thematic layers of (**a**). lulc, and (**b**). Rainfall

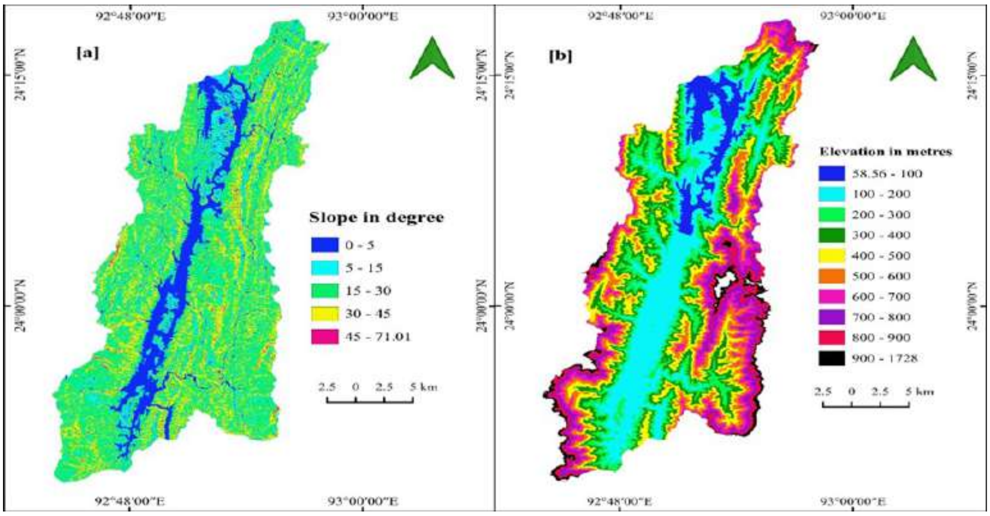

Figure 6. Basin thematic layers of (**a**). Slope and (**b**). Elevation

and 0.02 respectively. The gradient ratio of the middle watershed is 16.49, but at sub-watershed level, D2CBAR27a, D2CBAR27b, D2CBAR27d and D2CBAR27f has more gradient ratio which indicates more steep slopes and high erosion intensity. Whereas, sub-watersheds like D2CBAR27c, D2CBAR27h, and D2CBAR27i are characterized with low slope gradient and less erosion intensity. The river basin is highly dissected (Fig. 4a). The ruggedness number indicates the level of flatness and roughness of the basin topography.[22] Strahler[3] stated that the ruggedness value varies from 0 to 1. The value close to 1 indicates high in basin relief and smoother near to 0. The average ruggedness value of the middle Tuirial watershed is 5.38. An empirical study conducted in Tlawng river basin of India and Dhidhessa river basin in Ethiopia showed ruggedness value of 3.111,[23] it implies the basin is characterized by highly rugged terrain and more susceptible to soil erosion.[3,11,24]

Hypsometric integral and curve analysis

Hypsometric Integral (HI) is the computation of partial basin area to relative altitude.[25] Hypsometric curve indicates the stages of a drainage basin, like convex curve specify youth stage, s-curve indicate mature stage and concave show old stage of the basin.[3] The average hypsometric integral of middle Tuirial sub-watershed ranges from 0.47 to 0.48. As Strahler[3] stated HI values in the study arae range between 0.35 and 0.60 connotes maturity stage of landform and shrinkage of a huge volume of landmass over the past. Additionally, HI values below 0.35 and above 0.60 signify the basin has been experiencing old age and youth stage of landform evolution, respectively (Fig, 3).

Significance of morphometric analysis for soil loss risk assessment

Soil loss is a major concern of environmental degradation in the present scenario over Mizoram. The geological setting, topographic conditions of rugged nature, steep slopes, high dissection, heavy rainfall, high surface run-off, elongated shape, dense stream network and the land use pattern of shifting cultivation are incorporated for prompting to heavy erosion.[26] Linear, areal and relief aspects of the basin are the significant factors for the assessment of areas vulnerable to soil loss. Based on the analysis, it is observed that the basin with high density of 5.22 km/km^2 is experiencing more surface erosion by sheet flow and silt is deposited at the down slope resulting of the siltation problem. Similarly, the middle Tuirial river basin relief ranges from 59.89 – 1728 metres above sea level which signifies undulating terrain (Fig. 4b). Huge variation of relative relief exhibits the degree of slope is high with more soil risk.[27] In addition, higher the ruggedness number denotes that the area is prone to soil loss. Similarly, higher the value of form factor indicates the susceptibility of flood and high risk of peak flow. The steepness of slope in study area ranges from 0^0-71^0 it indicates the basin has high slope gradient. Higher the steepness of slope associated with heavy rainfall expected to be highly prone to soil risk (Fig. 5a; 5b; 6a and 6b). Land use and land cover pattern such as built-up area, agricultural land, bare-land and sparse vegetation cover are the significant factors of soil loss in the basin.[28]

Conclusion

The present study focused on the significant of morphometric characteristics that lead to soil and water degradation in the middle Tuirial basin. Despite the high drainage density, stream frequency, relative relief and ruggedness values, the basin has reached a mature stage of landform evolution. Steep slopes, excessive rainfall and shifting cultivation system triggering extreme soil loss with less groundwater recharge. The erosion risk can be minimized in association of local people, non-government organizations (NGO's) and government by check dams with implementation of strict forest conservation measures. Furthermore, the shifting cultivators must emphasize on sustainable agro-forestry and settled farming.

Acknowledgement

We gratefully acknowledge the Head of Department of Geography and Resource Management, Mizoram University for providing us the necessary facilities to carry out the present study. We also thankful to the European Space Agency for making accessible of ALOS PALSAR DEM freely and also Mizoram Remote Sensing Application Centre (MIRSAC) providing resourceful information on geo-spatial data. All the authors are thankful to the anonymous reviewers whose scholarly commented to improve the quality of this work.

References

1. Horton, R.E. (1932). Drainage-basin characteristics. *Transactions, American Geophysical Union*, **13(1)**, 350-361. https://doi.org/10.1029/TR013i001p00350
2. Horton, R.E. (1945). Erosional development of streams and their drainage basins;

hydrophysical approach to quantitative morphology. *Geological Society of America Bulletin*, **56(3)**, 275-370. https://doi.org/10.1177/030913339501900406

3. Strahler, A.N. (1952). Hypsometric (area-altitude) analysis of erosional topography. *Geological Society of America Bulletin*, **63(11)**, 1117-1142. https://doi.org/10.1130/0016-7606(1952)63[1117:HAAOET]2.0.CO;2
4. Strahler, A.N. (1964). Quantitative geomorphology of drainage basins and channel networks. In Chow, V.T. (ed.) Handbook of Applied Hydrology, McGraw-Hill, New York. pp 439-476.
5. Schumm, S.A. (1956). Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. *Geological Society of America Bulletin*, **67(5)**, 597-646. 10.1130/0016-7606(1956)67[597:EODSAS]2.0.CO;2
6. Melton, M.A. (1958). Correlation Structure of Morphometric Properties of Drainage Systems and Their Controlling Agents. *The Journal of Geology*, **66(4)**, 442–460. http://www.jstor.org/stable/30057347
7. Pike, R.J., Wilson, S.E. (1971). Elevation-relief ratio, hypsometric integral, and geomorphic area-altitude analysis. *Geological Society of America Bulletin*, **82(4)**, 1079-1084. https://doi.org/10.1130/0016-7606(1971)82[1079:ERHIAG]2.0.CO;2
8. Patton, P.C., Baker, V.R. (1976). Morphometry and floods in small drainage basins subject to diverse hydrogeomorphic controls. *Water resources Research*, **12(5)**, 941-952. https://doi.org/10.1029/WR012i005p00941
9. Kouli, M., Vallianatos, F., Soupios, P., Alexakis, D. (2007). GIS-based morphometric analysis of two major watersheds, western Crete, Greece. *Journal of Environmental Hydrology*, **15**, 1-17.
10. Sreedevi, P.D., Owais, S.H. H.K., Khan, H.H., Ahmed, S. (2009). Morphometric analysis of a watershed of South India using SRTM data and GIS. *Journal of the Geological society of India*, **73**, 543-552. http://dx.doi.org/10.1007/s12594-009-0038-4
11. Rao C.U.B., (2015). Estimation of Sediment Yield Rate in the Lower Tlawng watershed, Mizoram, *Geographic Journal of GAM*, **10**, 1-11
12. ALOS PALSAR DEM data, Retrieved from https://search.asf.alaska.edu,
13. Daily Rainfall data, Retrieved from https://power.larc.nasa.gov/,
14. Iqbal, M., Sajjad, H. (2014). Watershed prioritization using morphometric and land use/land cover parameters of Dudhganga Catchment Kashmir Valley India using spatial technology. *Journal of Geophysics and Remote Sensing*, **3(115)**, 2169-0049. http://dx.doi.org/10.4172/2169-0049.1000115
15. Singh, S., Singh, M.C. (1997). Morphometric analysis of Kanhar river basin. *National Geographical Journal of India*, 43(1), 31-43.
16. Vittala, S., Govindaiah, S., Gowda, H. (2004). Morphometric analysis of sub-watersheds in the Pavagada area of Tumkur district, South India using remote sensing and GIS techniques. *Journal of the Indian Society of Remote Sensing*, **32**, 351-362. http://dx.doi.org/10.1007/BF03030860
17. Withanage, N.S., Dayawansa, N.D.K., De Silva, R.P. (2014). Morphometric analysis of the Gal Oya River Basin using spatial data derived from GIS. *Tropical Agricultural Research*, **26(1)**, 175-188. http://dx.doi.org/10.4038/tar.v26i1.8082
18. Farhan, Y., Anaba, O. (2016). Watershed prioritization based on morphometric analysis and soil loss modeling in Wadi Kerak (Southern Jordan) using GIS techniques. International *Journal of Plant & Soil Science*, **10(6)**, 1-18. http://dx.doi.org/10.9734/IJPSS/2016/25321
19. Kaur, M., Singh, S., Verma, V.K., Pateriya, B. (2014). Quantitative geomorphological analysis & land use/land cover change detection of two sub-watersheds in NE region of Punjab, India. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, **40**, 371-375. http://dx.doi.org/10.5194/isprsarchives-XL-8-371-2014
20. Miller, V.C. (1953). A quantitative geomorphic study of drainage basin characteristics in the Clinch Mountain area, Virginia and Tennessee (Vol. 3). New York: Columbia University.
21. Chopra, R., Dhiman, R.D., Sharma, P.K. (2005). Morphometric analysis of sub-watersheds in Gurdaspur district, Punjab using remote sensing and GIS techniques. *Journal of the Indian Society of Remote Sensing*, **33**, 531-539. https://doi.org/10.1007/BF02990738
22. Selvan, M.T., Ahmad, S., Rashid, S.M. (2011). Analysis of the geomorphometric parameters in high altitude glacierised terrain using SRTM DEM data in Central Himalaya, India. *ARPN Journal of Science and Technology*, **1(1)**, 22-27

23. Kabite, G., Gessesse, B. (2018). Hydro-geomorphological characterization of Dhidhessa River basin, Ethiopia. *International Soil and Water Conservation Research*, **6(2)**, 175-183. https://doi.org/10.1016/j.iswcr.2018.02.003

24. Debelo, G., Tadele, K., Koriche, S.A. (2017). Morphometric analysis to identify erosion Prone areas on the upper blue Nile using Gis (Case Study of Didessa and Jema Sub-Basin, Ethiopia). *International Research Journal of Engineering and Technology*, **4(8)**, 1773-1784.

25. Asfaw, D., Workineh, G. (2019). Quantitative analysis of morphometry on Ribb and Gumara watersheds: Implications for soil and water conservation. *International Soil and Water Conservation Research*, **7(2)**, 150-157. https://doi.org/10.1016/j.iswcr.2019.02.003

26. Lawmchullova, I., Rao, C.U.B. (2024). Estimation of siltation in Tuirial dam: a spatio-temporal analysis using GIS technique and bathymetry survey. *Journal of Sedimentary Environment*, **9**, 81–97. https://doi.org/10.1007/s43217-023-00158-2

27. Smith, G.H. (1935). The relative relief of Ohio. *Geographical Review*, **25(2)**, 272-284.

28. Lawmchullova, I., Rao, C.U.B. (2023). Soil loss modelling in Himalayan region; A case of Tuirial Basin, Mizoram. *Advance Online publication*. https://doi.org/10.21203/rs.3.rs-3235471/v1