GIS-based morphometric analysis of sub-watersheds at Tut river basin, Mizoram

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The Tut river basin covers an area of 846 km^2 comprises of seven sub-watersheds namely Tuichar Lui, Dap Lui, Tlubing Lui, Chal Lui, Raiseh Lui, Telva Lui, Zawngek Lui. The drainage network of the sub watersheds was delineated and mapped using Survey of India toposheets and satellite imagery (IRS P6, LISS-III, FCC, Geocoded) on 1:50,000 scale. The morphometric analysis, digitization and statistical computation were carried out with the help of ArcGIS 9.3 software. The drainage network showed that dendritic and sub-dendritic with parallel drainage pattern spreads over the entire river basin. The highest stream order is the 6th order and the maximum stream number is 2029 first order 441 second order, 105 third orders and so on. Drainage density ranges from 0.37 to 4.66, stream frequency range between 0.65 and 8.10 and drainage texture varies from 5.63 to 19.56 showed that the area is characterized by permeable soils, soft sedimentary rocks such as sandstones and siltstones/shales with narrow valleys, dense floral coverage and high relief. The mean bifurcation ratio ranges between 3.03 to 6.58 indicate strong structural control over the area. The elongation ratio of sub-watersheds in the range 0.34 to 0.90 depicts sub-watersheds are more or less elongated characterizes high relief and steep slopes. The relief ratio ranges from 0.013 to 0.184 reflects high relief in the study area. The present study is an attempt to understand the nature of drainage and topography of river basin in order to implement sustainable development and management plan and practices at sub-watersheds level. Remote sensing and GIS proved to be an efficient tool and techniques for this investigation.

Keywords: GIS, sub-watersheds, morphometry, Tut river, ruggedness number.

INTRODUCTION

Drainage basin studies are essential for better under-stating of hydrological and terrain conditions for sustainable development of natural resources at micro level. This can be achieved based on drainage basin approach. The quantitative assessment of drainage characteristics is of great help in establishing the relationship among the drainage parameters and also the associated terrain conditions in a drainage basin. Morphometry is a tool to quantify and analyze the configuration of the earth surface including the dimensions of landforms (Agarwal, 1998). The pioneering studies carried out earlier on drainage basins based on conventional methods have gained importance in understanding a wide variety terrain conditions in various lithological formations (Horton, 1932, 1945; Smith, 1950; Strahler, 1957, 1964; Miller, 1953; Schumm, 1956; Krishnamurthy and Srinivas, 1995; Krishnamurthy *et al.*, 1996; Singh and Singh, 1997; Chopra *et al.*, 2005; Ratnam *et al.*, 2005; Solanke *et al.*, 2005; Joji *et al.*, 2013; Kuldeep and Upasana, 2011; Nayar and Natarajan, 2013; Agarwal, 1998; Biswas *et al.*, 1999; Kumar *et al.*, 2000; Nag, 1998; Kumar *et al.*, 2011; Thakur *et al.*, 2014).

The recent advanced studies made by Adel *et al.* (2011), Yasmin (2013), Kumar (2013), Harinath and Raghu (2013), Vaidya (2013), Shankar *et al.* (2014), Vibhu and Natarajan (2013), Mirzavand and Ghasemieh (2013), Withanage (2014), Sarita (2015), Samuel and Devadass (2015), Zakaria *et al.* (2016), Swetha *et al.* (2016), Ghany (2015), Senthamizhan *et al.* (2016), Saif Said (2016), Amulya and Dhanashree (2018), Taofik *et al.* (2017), Kumar and Kumar (2017) and Sanaullah (2018) by using geographical information systems as a tool yielded valu-

able information of drainage characteristics in various terrains and their implications in understanding tectonics. Further, drainage morphometric studies have also helped in flood vulnerability mapping and their effective management using GIS (Taofik *et al.*, 2017).

The most advanced techniques of GIS were applied to analyze the linear, areal and relief parameters of the seven sub-watersheds namely Tuichar Lui, Dap Lui, Tlubing Lui, Chal Lui, Raiseh Lui, Telva Lui and Zawngek Lui in Tut river basin.

MATERIALS AND METHODS

Study area

The Tut watershed stretches in north-south direction in parts of Lunglei and Mamit districts in an area of about 846 km^2 in the northwestern part of Mizoram. It lies between 23°10'-24°02' latitudes and 92°30'-92°42' longitudes (Figure 1). The main river Tut in this watershed originates at an elevation of about 900 m above mean sea level near Changpui village in Lunglei district and joins the river Tlawng at Tlangthang village in Mamit district. The river runs for about 117 km length before joining with Tlawng river. The Tut is enclosed by Tlawng river on the north and east, Teirei river on the west and Mat river on the south. The topographic relief of the study area ranges between 1387 m in the eastern part and 30 m at the confluence of the river. The study area is characterized by humid tropical climate with high amount of average rainfall of about 3000 mm. Temperature varies from 10 to 23°C in winter and 21 to 33°C in summer seasons.

Morphometric analysis

The present study is based on the analysis of various morphometric parameters using conventional methods coupled with remote sensing and GIS techniques. Survey of India topographical sheets 83D/12, 84 A/5, A/6, A/7, A/9, A/10, A/11 and 84A/12 and satellite imagery of IRS P6, LISS-III, FCC, Geocoded on 1:50,000 scales were used for delineation of drainage network and map. Drainage morphometric analyses of all the parameters were computed using standard methods and formulae. ArcGIS 9.3 software was employed for watershed digitization and computation of morphometric parameters like linear, aerial and relief aspects with integration of data on various morphological features of the river basin. Seven major 5th order sub-watersheds namely Tuichar Lui, Dap Lui, Tlubing Lui, Chal Lui, Raiseh Lui, Telva Lui, Zawngek Lui (BA1-BA7) including one 6th order sub-watershed, i.e. main river (BA8) within the Tut river basin were identified and digitized on the topographic map (Figures 2 & 3). The formulae adopted for computation of mor-
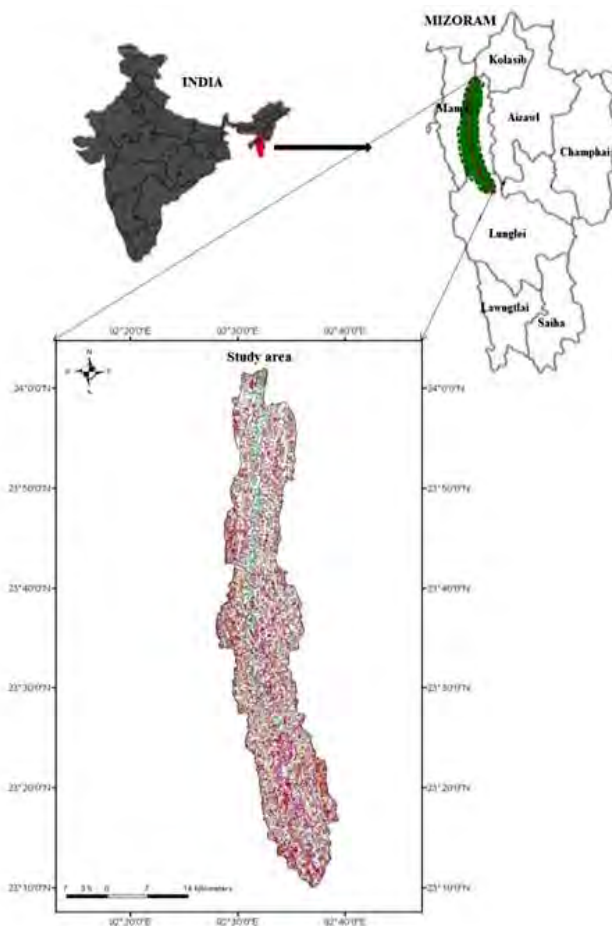

Figure 1: Location of Tut river basin.

phometric parameters are presented in Table 1.

RESULTS AND DISCUSSION

Morphometric analysis of linear parameters

The linear parameters such as stream order, stream length, mean stream length and bifurcation ratio were analyzed for the eight sub-watersheds (Tables 2 &3 and Figure 3).

The *stream ordering* (U) was carried out according to (Strahler, 1964) method. Numbers of streams for eight sub-watersheds were counted in each order with the help of GIS software. The highest order of stream in the Tut watershed is 6th order (Figure 3). It is evident from the study that the stream order increases as stream number decreases following (Horton, 1945) law of stream number. The maximum numbers of streams were found in the 1st order (Table 2). The presence of large number of streams shows that the topography is still experiencing erosion.

Stream length (Lu) is the length of streams of all orders in a river basin. The length of streams in each of the
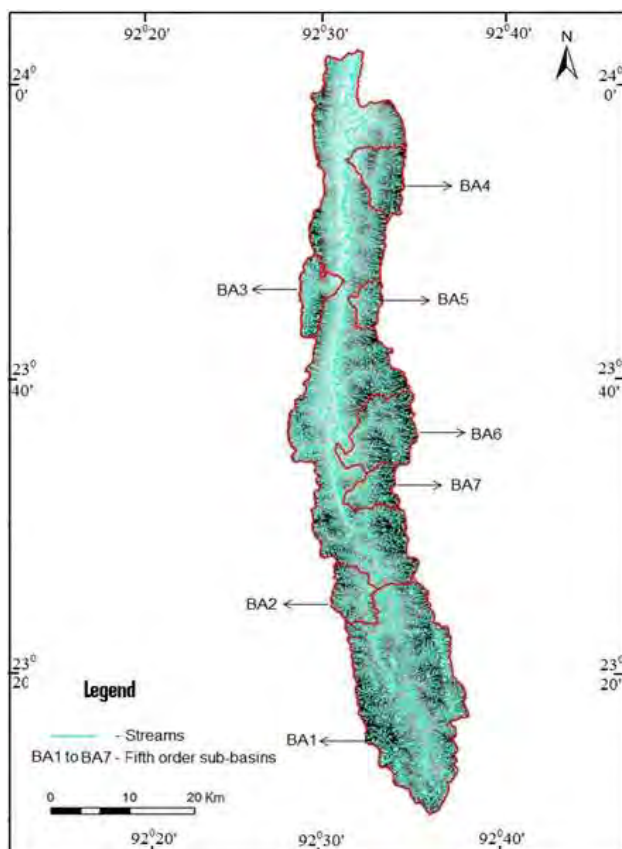
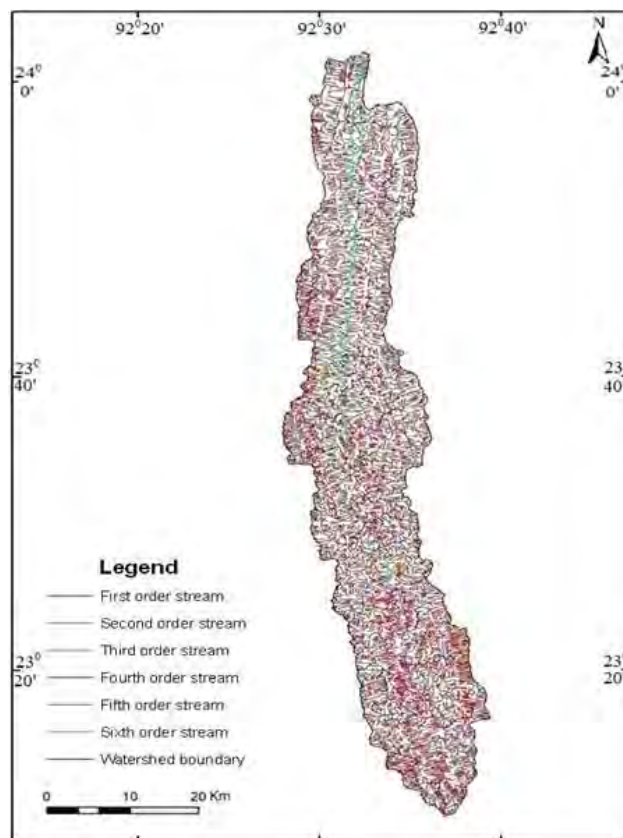**Figure 2:** Sub-watersheds of Tut river basin.

Figure 3: Drainage network of Tut river basin.

seven watersheds were calculated both manually and also with the help of GIS software. The total stream length of Tut river is 3414.16 km and the highest stream length was found in First order followed by second and so on following Horton law of stream length (Table 2). The values of *mean stream length* (Lsm) of all the sub-watersheds in the study area vary from 2.73 to 6.73. The sub-watersheds BA1, BA4, BA6 and BA7 have shown that Lsm of the given order is greater than that of the next lower order and less than that of its next higher order (Table 3). By contrast, there was deviation in Lsm values of sub-watersheds BA2, BA3, BA5 with the rest of the sub-watersheds. This deviation could be due to the variation in slope and topography of the sub-watersheds. This deviation could be due to the variation in slope and topography of the sub-watersheds.

According to (Schumm, 1956), *bifurcation ratio* (Rb) is obtained by dividing the number of streams in one order by the streams of the next higher order. The bifurcation ratio values range between 3-5, indicating that the geological structure does not have dominant control but the values greater than 5 indicate that the area is structurally controlled (Strahler, 1957, 1964). The bifurcation ratio values of the study area range between 2.00 to 12.00 with the mean bifurcation values in between 3.03 and 6.58 (Table 3). The high value of bifurcation ratio in the area implies strong structural control due to tectonic

activity in drainage development in the area.

Morphometric analysis of linear parameters

The areal parameters such as drainage density, stream frequency, drainage texture, form factor, circularity ratio, and elongation ratio were calculated (Tables 4&5).

Drainage density (Dd) is the ratio of the total stream length of all orders within a basin to the area of the basin. It shows the closeness of spacing of the streams and indirectly reflects the structure and lithological variations in the area (Horton, 1932). The values of drainage density in the study area range between 0.37 to 4.66 km/km2 (Table 4). The drainage density in majority of the sub-watersheds showed medium and high which is characterized by permeable soils, soft sedimentary rocks such as sandstones and siltstones/shales, dense vegetation cover and high relief whereas the sub-watershed BA7 has low drainage density that could be due to the presence of permeable sub-soil materials and dense vegetation with low relief.

Stream frequency (Fs) is the ratio of total number of stream segments of all orders within a basin to the area of the basin (Horton, 1932). It is expressed as the number of streams developed in a unit area. It is affected by the climatic and hydrological characteristics of the basin

Table 1: Formulae for computation of morphometric parameters.

Sl. No.	Morphometric parameters	Formulae	Reference
		Linear aspects	
1	Stream order (U)	Hierarchical Rank	Strahler, 1964
2	Stream number (Nu)	$Nu = N_1 + N_2 + \ldots N_n$	Horton, 1945
3	Stream length (Lu) km.	$Lu = L_1 + L_2 + \ldots L_n$	Horton, 1945
4	Mean stream length (Lsm)	$Lsm = \sum Lu / \sum Nu$	Strahler, 1964
5	Stream length ratio (Rl)	$Rl = Lu / Lu -1$	Horton, 1945
6	Bifurcation ratio (Rb)	$Rb = Nu / Nu + 1$	Schumm, 1956
		Areal aspects	
7	Drainage density (Dd)	$Dd = Lu / A$	Horton, 1932
8	Stream frequency (Fs)	$Fs = Nu / A$	Horton, 1932
9	Drainage texture (Rt)	$Rt = Dd * Fs$	Smith, 1950
10	Form factor (Ff)	$Ff = A / Lb^2$	Horton, 1932
11	Circularity ratio (Rc)	$Rc = 4 \ A / P^2$	Miller, 1953
12	Elongation ratio (Re)	$Re = 2 / L_b * (P/ \ )^{0.5}$	Schumm, 1956
		Relief aspects	
13	Basin relief (R)	$R = (H - h)$	Hadley and Schumm, 1961
14	Relief ratio (Rr)	$Rr = R / Lb$	Schumm, 1956
15	Ruggedness number (Rn)	$Rn = R \times Dd$	Schumm, 1956

Table 2: Order wise stream number and stream length of sub-watersheds.

Sub-water-shed	Stream numbers in different orders							Order wise stream lengths (km)						
	1st	2nd	3rd	4th	5th	6th	Total	1st	2nd	3rd	4th	5th	6th	Total
BA-1	1280	226	52	12	1	-	1571	700.36	146.97	75.17	47.01	37.26	-	1035.54
BA-2	134	29	6	2	1	-	172	72.73	14.66	13.75	3.31	2.88	-	107.34
BA-3	165	36	6	2	1	-	210	85.18	18.04	1.81	6.62	4.05	-	120.80
BA-4	134	33	8	2	1	-	178	82.57	16.88	8.78	9.05	7.17	-	124.44
BA-5	73	17	6	3	1	-	100	35.27	9.13	5.22	2.55	4.19	-	56.36
BA-6	307	65	17	5	1	-	395	144.49	31.50	17.82	22.63	13.00	-	218.14
BA-7	114	22	6	2	1		145	55.71	13.36	4.79	7.10	2.23	-	83.30
BA-8	2029	441	105	22	0	1	2598	1060.18	286.70	136.01	64.41	0	89.17	1728.24

Table 3: Mean stream length, stream length ratio and bifurcation ratio of sub-watersheds.

Sub-watershed	Mean stream length (Lsm)	Bifurcation ratio (Rb)				
		1st order	2nd order	3rd order	4th order	Mean Rbm
BA-1	6.54	5.66	4.34	4.33	12	6.58
BA-2	3.98	4.62	4.83	3.00	2	3.61
BA-3	4.62	4.58	6.00	3.00	2	3.89
BA-4	6.73	4.06	4.12	4.00	2	3.54
BA-5	2.73	4.29	2.83	2.00	3	3.03
BA-6	6.51	4.72	3.82	3.40	5	4.23
BA-7	5.42	5.18	3.66	3.00	2	3.46
BA-8	5.38	4.60	4.2	4.77	-	4.52

Table 4: Linear aspects of sub-watersheds.

Sub-watershed	Area (A) km²	Perimeter (P) km²	Length (Lb) km	Drainage density (Dd) (km/km²)	Stream frequency (Fs) (No/km²)	Drainage texture (Rt) (km-1)
BA-1	239.18	80.31	28.25	4.32	6.56	19.56
BA-2	27.38	23.62	6.50	3.92	6.28	7.28
BA-3	25.90	28.69	10.30	4.66	8.10	7.31
BA-4	35.87	28.10	9.00	3.46	4.96	6.33
BA-5	14.78	17.75	6.00	3.81	6.76	5.63
BA-6	56.40	37.25	12.00	3.86	7.00	10.60
BA-7	22.30	21.45	7.00	0.37	0.65	6.76
BA-8	845.32	245	96	4.07	6.13	6.13

along with the lithological conditions. The value of the stream frequency obtained for sub-watersheds in the study area vary from 0.65 to 8.10 km^2 (Table 4). The Fs value is high in the study area which is indicative of sparse vegetative cover and high relief with low permeability of rock formations.

Drainage texture (Rt) is the product of drainage density and stream frequency of a basin. Smith (1950) suggested that the fine drainage texture is developed mainly on soft rocks, sparse vegetative cover with humid climate. The values of drainage texture in the study area vary from 5.63-19.56 (Table 4). (Doornkamp and King, 1971) had classified the drainage texture as coarse, if the texture value is less than 4, 4–10 is intermediate, 10–15 is fine and it is ultrafine if the values greater than 15. According to this scale of drainage texture the values of drainage texture in the study area falls under ultrafine texture and there is a restricted development of coarse texture.

Form factor (Ff) is defined as the ratio of basin area to the square of basin length (Horton, 1932). According to (Schumm, 1956) scale of form factor value '0' indicates an elongated shape with flatter flow for long duration, 1 represents the circular shape with high peak flows for short duration The form factor value of the study area ranges between 0.091 and 0.648. It was observed that most of the sub-watersheds are elongated but a few sub-watersheds are more or less circular shapes (Table 5).

C*ircularity ratio (Rc)* is the ratio of basin area to the area of circle having same perimeter as the basin (Miller, 1953). The high Rc value indicates the sub-watersheds are more circular and are characterized by high to moderate relief and drainage system is structurally controlled while the lower Rc values of sub-watersheds indicate an elongated shape (Miller, 1953). The circularity ratio values of sub-watersheds in the study area vary from 0.13 to 0.61 indicate that the sub-watersheds are almost elongated having more or less uniform lithology with sandstones and silt-stones / shales.

Elongation ratio (Re) is the ratio of the diameter of a circle having the same area of the basin to the maximum length (Schumm, 1956). The elongation ratio values generally range from 0.60 to 1. The elongation ratio values

of the basins which range between 0.60 and 0.80 usually represent the regions of high relief and the values close to 1 are the areas show low relief with circular shapes. The elongation ratio values are further grouped into circular (> 0.9), oval (0.8-0.9) and less elongated (0.7) basins. The elongation ratio values of the sub-watersheds of the present study range from 0.34 to 0.90 indicating majority of the sub-watersheds are more or less elongated or oval shaped, characterized by high relief with steep slopes. The main Tut river (BA8) has the elongation ratio 0.34 shows highly elongated nature with high relief and steep slopes (Table 5).

Morphometric analysis of relief parameters

The relief morphometric parameters like basin relief (R) and ruggedness number (Rn) were computed (Table 5). Relief of the watersheds plays a vital role in drainage development, rate of surface run-off, infiltration into the sub-surface and channel flow.

According to (Hadley and Schumm, 1961) *basin relief (R)* is the difference between the maximum (H) and minimum (h) elevations in the basin. It is an important aspect to understand the denudational characteristics of the basin. The values of basin relief (R) of the study area vary between 0.85 km and 1.33 km reveal moderate to high gradient basin of low infiltration and high runoff conditions of the study area.

Relief ratio (Rr) is the difference between the highest and lowest elevations in a watershed to the ratio of the length of the longest axis in the basin (Schumm, 1956). Relief ratio (Rr) indicates the overall steepness of a watershed and also expresses the intensity of erosional processes operating on the basin slope. In general, the relief ratio increases with decreasing watershed area of a given fluvial basin. The computed relief ratio values of various sub–basins range from 0.013 to 0.184 (Table 5).

Ruggedness number (Rn) as the product of basin relief (R) and drainage density (Dd) indicates the structural complexity of the terrain (Schumm, 1956). The ruggedness number of the Tut sub-watersheds varies from 0.39 to 5.41 (Table 5). The high Rn values suggest structural complexity of the terrain with high relief and drainage density and the area is susceptible to erosion.

Table 5: Areal and relief aspects of sub-watersheds.

Sub-watershed	Form factor (Ff)	Circularity ratio (Rc)	Elongation ratio (Re)	Basin relief (R) (km)	Relief ratio (Rr)	Ruggedness number (Rn)
BA-1	0.299	0.46	0.61	1.20	0.042	5.18
BA-2	0.648	0.61	0.90	0.85	0.155	3.33
BA-3	0.244	0.39	0.56	0.94	0.091	4.38
BA-4	0.442	0.57	0.77	0.98	0.109	3.39
BA-5	0.410	0.58	0.72	1.10	0.184	4.19
BA-6	0.391	0.51	0.70	1.25	0.104	4.82
BA-7	0.455	0.60	0.76	1.06	0.152	0.39
BA-8	0.091	0.13	0.34	1.33	0.013	5.41

CONCLUSION

The morphometric analysis of sub-watersheds in the Tut river basin shows that the river channel follows the slope of the terrain and the terrain is made up of soft sedimentary rocks with impervious and non-porous nature that exhibit dendritic, sub-dendritic and parallel types of drainage patterns. The higher values of bifurcation ratios and drainage density indicate that the study area is influenced by structural disturbances. The values of form factor and circularity ratio of the sub-basins indicate that a majority of the sub-watersheds are more or less elongated in nature. The relief ratio and ruggedness values of the sub-watersheds reveal that the terrain has high relief and steep slopes and the area is subjected to erosion. However, it is revealed that the stream development in the Tut river basin is affected by slope, relief and climate. This study could be helpful in land and water resources planning, development and management in the Tut river basin.

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