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Research Article

Morphometric Analysis of Mun River Basin, Thailand: A Geographical Information System Approach

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Abstract The aim of present study is to investigate morphometric analysis of Mun river basin in Thailand. The drainage parameters performed such as linear, aerial and relief aspects of 23 sub watersheds in the concentrated area. The analysis shows that watershed conatins 6611 drainage segments and stream order from I to VII. From that 5275 segments are comes under I order stream, 1025 are II order, 235 are in III order, 57 are IV order, 16 are in V order, 2 and 1 segments are comes under VI and VII order, respectively. The total stream length of Mun river basin is 40353.8 km. The majority of basin contains the bifurcation ratio value is >5. This indicates that geologically hard rock terrain, less infiltration and high flash flood. This analysis helps to better understanding the management and planning activities in study area .
Keywords *Arc GIS; Morphometry; Linear aspect; Aerial aspect and Relief aspect*

1. Introduction

It is a tool for measuring Morphometric, mathematical analysis of the configuration of the earth's surface, form, and dimensions of its landforms (Clarke,1966). This examination provides a quantitative explanation of the basin geometry to grab initial slope or inequalities within the rock hardness, structural controls, recent geologic process and geomorphic history of the basin (Strahler, 1964). The current investigation deals with the fluvialmorphometry, which includes the consideration of linear, aerial and relief aspects of the Sub-watersheds. The study area has been divided into 23 sub-watersheds. GIS techniques are used for assessing various terrain and morphometric parameters of the watershed, as they provide a flexible environment and a powerful tool for the manipulation and analysis of abstraction data significantly for the feature identification and also the extraction of knowledge for higher understanding.

1.1. The Study Area

Mun river basin is located between 15°19′14″N latitude and 105°30′29″E longitude, 15°19′14″N latitude and 105°30′29″E longitude. The river begins in the Khao Yai National Park area of the Sankamphaeng Range, near Nakhon Ratchasima in the northeast (Isan) of Thailand. It flows east through the Khorat Plateau in southernIsan (Buriram, Surin and Sisaketprovinces) for 750 kilometres, until it joins the

Mekong at Khong Chiam in Ubon Ratchathani. The Mun River's main tributary is the Chi River, which joins it in Kanthararom district of Sisaket province. For the present study, as a preparatory work of Thailand Toposheet numbers ND 47-4, ND-8, ND 48-1, ND 48-2, ND 48-3, ND 48-5, ND 48-6, ND 48-7, NE 47-12, NE 47-16, NE 48-9, NE 48-10, NE 48-13 and NE 48-14 with the scale of 1:250,000 were used for preparing base map. Area of the basin is 116226 km² (Figure 1).

In 1994, The National Economic and Social Development Board (NESDB) commissioned a study on water availability in all of Thailand’s river basins. The studies were based on the Royal Irrigation Department’s (RID) classification of river basins in Thailand, which divides the country into 25 river basins. This classification, however, is based on both hydrological and administrative boundaries and as Alford (1994) pointed out, on the eight natural basins which are totally within Thailand. With the Chi river emptying in to the Mun river near Ubon Ratchathani, some 100 km upstream of the confluence with the Mekong river, the two river systems are split by RIDs classification, though the river system that lies within Thai territory would actually be the Mun basin with its largest tributary as the Chi river. As the largest tributary to the Mekong river and the very core of regional planning effort we will consider the Mun basin (in Alford’s sense), denoted here as the Chi-Mun river basin.

2. Materials and Methods

The general purpose of this analysis of watershed, from a Survey of India, toposheet on 1:2,50,000 scale have been used for preparation maps like base map and drainage network map of the watershed and demarcate the 23 sub-watershed in the concentrated area based on the elevation, slope and outlet points. The numbers were given in the Figure 2. The watersheds have been digitized through the ArcGIS Software 10.1 and calculated the stream orders, which was proposed by Strahler (1952). The various Quantitative morphometric analysis was carried out in 23 micro-watersheds separately for assessing their linear, areal and relief aspects.

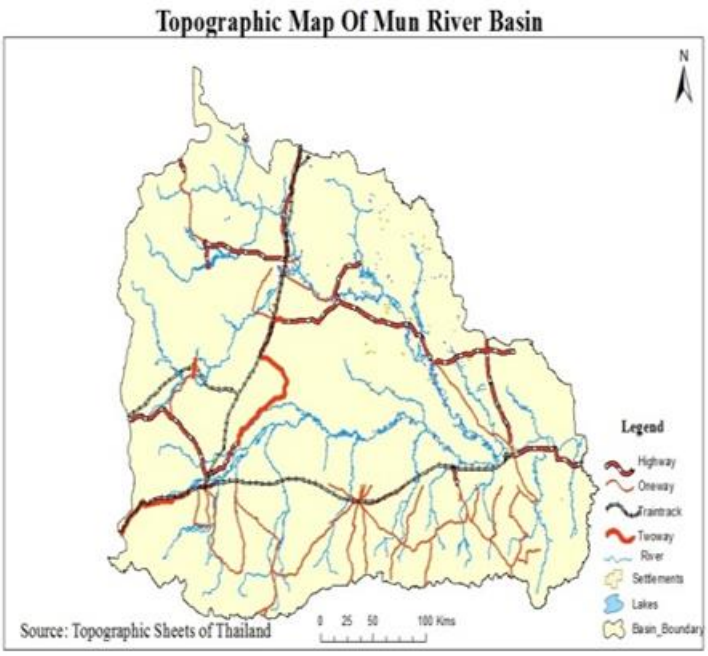

Figure 1: *Study area*

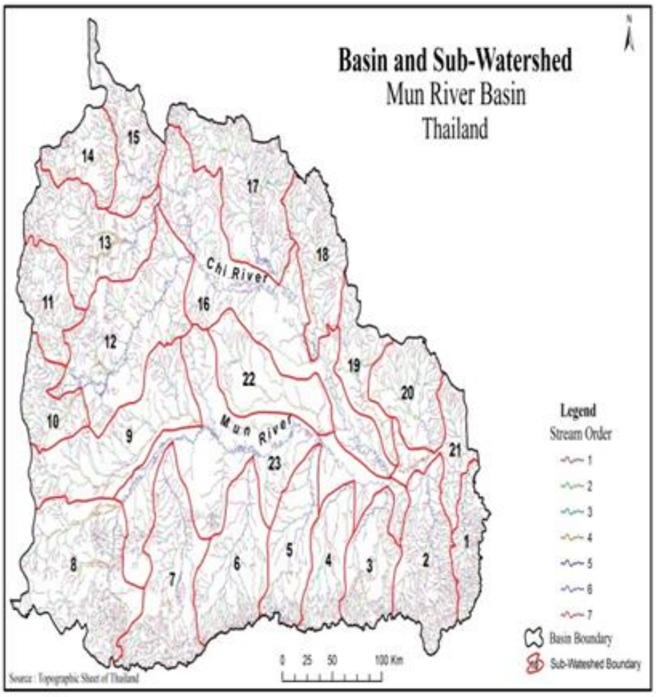

Figure 2: *Sub-watershed and steam orders*

Table 1: *Methodology adopted for computations of morphometric parameters*

Morphometric Parameters	Formula	Reference
	I. Linear Aspects	
Stream Order	Hierarchical rank of streams	Strahler (1952)
Bifurcation Ratio (Rb)	Rb=Nu/Nu+1 Nu=Total no. of stream segments of order "u' Nu+1= Number of segments of the next higher order	Schumm (1956)
Mean Bifurcation Ratio (Rbm)	Rbm= Average of Bifurcation ratios of all orders	Strahler (1957)
Stream Length (Lu)	Length of the stream (Km)	Horton (1945)
Mean Stream Length (Lsm)	Lsm=Lu/Nu Lu=Total stream length of order 'u' Lu-1=Total stream length of its next lower order	Horton (1945)
Stream Length Ratio (Rl)	Rl= Lu/Lu-1 Lu=Total stream length of the order 'u' Lu-1=Total stream length of its next lower order	Horton (1945)
	II. Areal Aspect	
Drainage Density (Dd)	Dd=Lu/A Lu=Total stream length of all orders (Km) A=Area of the Basin (Km^2)	Horton (1945)
Texture Ratio (Rt)	T=Nu/P Nu=Total no. of streams of all orders P=Perimeter(Km)	Smith (1950)
Stream Frequency (Fs)	Fs= Nu/A Nu= Total no. of streams of all orders A=Area of the Basin (Km^2)	Horton (1945)
Form Factor (Ff)	$Ff=A/Lb^2$ A=Area of the Basin (Km^2)	Horton (1932)

	Lb^2= Square of the basin length (m)	
Elongation Ratio (Re)	Re=2√(A/Pi)/Lb A= Area of the Basin (Km^2), Pi=3.14 Lb=Basin length (m)	Schumm (1956)
Circularity Ratio (Rc)	Rc=4*Pi *A/P^2 A= Area of the Basin (Km^2), Pi=3.14 P^2 =Square of the perimeter (Km)	Miller (1953)
Length of Overland Flow (Lg)	Lg=1/D*2 Lg=Length of overland flow Dd=Drainage density	Horton (1945)
	III. Relief Aspects	
Relative Relief (R) (or) Basin Relief (Bh)	R = H-h H=Maximum height (m) h=Minimum height (m)	Strahler (1952)
Relief Ratio (Rh)	Rh= R/Lb R= Relative relief (m) Lb= Basin length (m)	Schumm (1956)

The morphometric analysis of a drainage basin and its drainage network can be better achieved through the latest technologies like GIS, since conventional measurement of these parameters is laborious and cumbersome. The methodology adopted for the computation of morphometric parameters given in Table 1.

3. Results and Discussion

In the present study, the morphometric parameters such as linear, areal and relief aspects for the delineated sub-watersheds are calculated based on formulas suggested by various workers and the results are discussed below.

Linear Aspects

Linear aspects of the basin are related to the channel patterns of the drainage network wherein the topological characteristics of the stream segment in terms of open links of the network, which consists of all of the segment of stream of a particular river, is reduced to the level of graphs, where stream junctions act as points (nodes) and streams, which connect the points (junctions) become links or lines wherein the numbers in all segments are counted, their hierarchical orders are determined, the length of all stream segments are measured and their different interrelationship are studied. The nature of flow paths in in terms of sinuosity is equally important in the study of linear aspects of the drainage basins. Thus, the linear aspect includes the discussion and analysis of stream order (µ), stream number (nµ), bifurcation ratio (Rb), stream lengths (Lµ), length ratio (R_L), length of overland flow (L_g), sinuosity indices etc.

Stream Order

The designation of stream orders in the first step in drainage basin analysis based on a hierarchic ranking of streams. In the present study, ranking of streams has been carried out basin on the method proposed by Strahler (1964). According to him “each finger-tip channel is designated as segment of 1st order. At the junction of any two 1st order segments, a channel of 2nd order is produced and extends down to the point, where it joins another 2nd order segments whereupon a segment of 3rd results and so forth”. These streams may have additional stream segments of lower orders than their own order and thus these do not affect the classification (Figure 1). It may be mentioned that the hierarchical order increases only when two stream segments of equal meet and form a junction. The order does not increase if a lower order stream segment meets a stream segment of high order.

The entire basin consists 6611 segments of river in the range of stream order I to VII. Out of which 5275 segments are comes under I order stream, 1025 are II order, 235 are in III order, 57 are IV order, 16 are in V order, 2 and 1 segments are comes under VI and VII order respectively.

Taking into sub watershed individually seven and eight sub-watershed consist above 500 stream segments, 2,12,16,17 and 23 sub watersheds are consist above 400 stream segments, 6 and 13 sub-watersheds are consist above 300 stream segments, 1,3,4,5,9,15 and 18 sub watersheds are consist above 200 stream segments, 10,11,14,19,20, and sub-watersheds are consist of above 100 stream segments and 22 sub watershed is consist below 100 stream segments. The sub-watersheds with higher no of stream segments are characterized by bigger watershed area.

Table 2: *Stream order and stream length of mun river basin*

Sub-Watersheds	***Number of Streams (Nu)***								***Stream Length in Km (Lu)***							
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**Total**	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**Total**
1	186	42	9	2	1	-	-	239	718.5	229.2	109.5	20	105.9	-	-	1183.1
2	369	72	15	3	1	-	-	460	1442.2	385.3	180.6	126.1	160.8	-	-	2295.0
3	170	35	8	3	1	-	-	217	698.8	216.2	94	149.8	107.2	-	-	1266.3
4	164	29	6	2	1	-	-	202	443	179.1	185	69.1	84.4	-	-	960.6
5	218	26	8	3	1	-	-	256	489.8	168.4	113.6	102.4	171.1	-	-	1045.3
6	232	50	14	4	1	-	-	301	739.4	358.4	245.6	40.6	156.7	-	-	1540.7
7	401	75	20	4	1	-	-	501	1370.2	384.3	288.4	196.5	199.6	-	-	2439.0
8	427	102	25	5	3	-	-	562	1620.5	622	254.1	493.2	334.6	-	-	3324.4
9	169	36	8	2	-	-	-	215	927	326.3	263.5	267.1	-	-	-	1783.9
10	108	32	5	2	-	-	-	147	580.6	241.1	122.1	122.2	-	-	-	1066.0
11	151	35	6	1	-	-	-	193	752.7	265	137.7	120.4	-	-	-	1275.8
12	359	65	16	4	1	-	-	445	1393.3	534.5	288.5	137.5	428.3	-	-	2782.1
13	256	59	11	2	1	-	-	329	1303.5	443.3	160.5	370.7	105.8	-	-	2383.8
14	118	31	8	3	-	-	-	160	619.5	177.2	100.8	139.8	-	-	-	1037.3
15	202	47	8	5	2	-	-	264	828.3	226	151.9	117.9	179.9	-	-	1504.0
16	394	50	11	1	-	1	-	457	1619.3	450.8	219.7	33.7	-	775	-	3098.5
17	395	81	17	4	1	-	-	498	1555.6	587.5	307.2	40.7	276	-	-	2767.0
18	246	44	6	2	1	-	-	299	1062.7	374.6	124.7	160.5	49.5	-	-	1772.0
19	89	12	13	1	-	-	-	115	435.3	135.1	118.2	182.8	-	-	-	871.4
20	120	29	9	3	1	-	-	162	626.3	301.2	172.9	241.6	36.9	-	-	1378.9
21	110	23	2	-	-	-	1	136	533.9	196.2	79.1	-	-	-	118.1	927.3
22	43	12	2	1	-	-	-	58	355.4	184.1	26.5	165.4	-	-	-	731.4
23	354	40	8	3	1	1	-	407	1218.8	361	239.7	216.1	295.1	589.3	-	2920.0

Stream Length

The numbers of streams of various orders in watershed are counted and their lengths from mouth to drainage divided are measured with the help of GIS software's, (Table 2) the stream length (Lu) has been computed based on the law proposed by Horton (1945) for all the 23 sub watersheds (Table 1). Generally, the total length stream segments are maximum in first order streams and decreases as the stream order increases.

The total stream length of Mun river basin is about 40353.8 km of which first order stream length is about 21334.6 km. The second order stream length is 7346.8 km. The third order stream length is 3983.8 km. The fourth order stream length is 3514.1 km. The fifth order stream length is 2691.8 km. The sixth order stream length is 1364.3 km. and the seventh order stream length is 118.1 km.

The large sub-watershed such as, sub watershed 8, 16, 23, 12 and 17 are compressing the total stream lengths of 3324.4, 3098.5, 2920, 2782.1 and 2767 km are respectively. Obviously, the lesser total stream length is observed in the watershed of lesser area. Higher of I order stream segments are notably observed in sub watershed 8, 16, 17, 2, 12, 7,13, 23 and 18. Whereas in II order, the stream lengths are higher in sub watershed such as, Sub watershed 8, 17, 12, 16 and 13. Generally, the total length of stream segments is maximum in first order streams and decreases as the stream order increases.

Mean Stream Length

According to Strahler (1964), the mean stream length is a characteristics property related to the drainage network and is associated surface. The mean stream length (Lsm) has been calculated by dividing the total stream length of order 'u' and number of stream length of order 'u' (Table 1) it is noted from (Table 3) that Lsm varies from 4.08 to 12.61 and Lsm of any given order is greater than that of the higher order, this might be due variations in slope and topography.

Stream Length Ratio

Stream length ratio (RL) may be defined as the ratio of the mean stream length of the one order to the next lower order of stream segment (Table 1) Horton's law (1945) of stream length states that stream length segments of each of the successive orders of a basin tends to approximate a direct geometric series with streams length increasing towards higher of streams.

Table 3: *Mean stream length and stream length ratio of various sub-watersheds*

	Mean stream length in km (Lsm)								*Stream length ratio (Rl)*						
S.No.	I	II	III	IV	V	VI	VII	Lsm	II/I	III/II	IV/III	V/IV	VI/V	VII/VI	Average
1	718.5	229.2	109.5	20	105.9	0	0	4.95	0.31	0.47	0.18	5.29	0	0	1.04
2	1442.2	385.3	180.6	126.1	160.8	0	0	4.98	0.26	0.46	0.69	1.27	0	0	0.44
3	698.8	216.2	94	149.8	107.2	0	0	5.83	0.3	0.43	1.59	0.71	0	0	0.5
4	443	179.1	185	69.1	84.4	0	0	4.75	0.4	1.03	0.37	1.22	0	0	0.5
5	489.8	168.4	113.6	102.4	171.1	0	0	4.08	0.34	0.67	0.9	1.67	0	0	0.59
6	739.4	358.4	245.6	40.6	156.7	0	0	5.11	0.48	0.68	0.16	3.85	0	0	0.86
7	1370.2	384.3	288.4	196.5	199.6	0	0	4.86	0.28	0.75	0.68	1.01	0	0	0.45
8	1620.5	622	254.1	493.2	334.6	0	0	5.91	0.38	0.4	1.94	0.67	0	0	0.56

9	927	326.3	263.5	267.1	0	0	0	8.29	0.35	0.8	1.01	0	0	0	0.36
10	580.6	241.1	122.1	122.2	0	0	0	7.25	0.41	0.5	1	0	0	0	0.31
11	752.7	265	137.7	120.4	0	0	0	6.61	0.35	0.51	0.87	0	0	0	0.28
12	1393.3	534.5	288.5	137.5	428.3	0	0	6.25	0.38	0.53	0.47	3.11	0	0	0.74
13	1303.5	443.3	160.5	370.7	105.8	0	0	7.24	0.34	0.36	2.3	0.28	0	0	0.54
14	619.5	177.2	100.8	139.8	0	0	0	6.48	0.28	0.56	1.38	0	0	0	0.37
15	828.3	226	151.9	117.9	179.9	0	0	5.69	0.27	0.67	0.77	1.52	0	0	0.53
16	1619.3	450.8	219.7	33.7	0	775	0	6.78	0.27	0.48	0.15	0	22.99	0	3.98
17	1555.6	587.5	307.2	40.7	276	0	0	5.55	0.37	0.52	0.13	6.78	0	0	1.3
18	1062.7	374.6	124.7	160.5	49.5	0	0	5.92	0.35	0.33	1.28	0.3	0	0	0.37
19	435.3	135.1	118.2	182.8	0	0	0	7.57	0.31	0.87	1.54	0	0	0	0.45
20	626.3	301.2	172.9	241.6	36.9	0	0	8.51	0.48	0.57	1.39	0.15	0	0	0.43
21	533.9	196.2	79.1	0	0	0	118.1	6.81	0.36	0.4		0	0	1.49	0.45
22	355.4	184.1	26.5	165.4	0	0	0	12.61	0.51	0.14	6.24	0	0	0	1.14
23	1218.8	361	239.7	216.1	295.1	589.3	0	7.17	0.29	0.66	0.9	1.36	1.99	0	0.86

Bifurcation and Mean Bifurcation Ratio (Rb and Rbm)

The term bifurcation ratio (Rb) may be defined as the ratio of the number of stream segments of given order to the number of segments of the next higher order (Schumm, 1956). Strahler (1957) demonstrated that bifurcation ratio shows a small range of variation for different environmental except where the powerful geological control dominates.

Table 4: *Bifurcation ratio of various sub watersheds of Mun river basin*

	Number of streams (Nu)								Bifurcation Ratio (Rb)								
S.No.	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**Total**	**RB1**	**RB2**	**RB3**	**RB4**	**RB5**	**RB6**	**Rbm**	**S.No.**	**I**
1	186	42	9	2	1	-	-	239	4.42	4.66	4.5	2	0	0	2.60	1	186
2	369	72	15	3	1	-	-	460	5.12	4.8	5	3	0	0	2.99	2	369
3	170	35	8	3	1	-	-	217	4.85	4.37	2.66	3	0	0	2.48	3	170
4	164	29	6	2	1	-	-	202	5.65	4.83	3	2	0	0	2.58	4	164
5	218	26	8	3	1	-	-	256	8.38	3.25	2.66	3	0	0	2.88	5	218
6	232	50	14	4	1	-	-	301	4.64	3.57	3.5	4	0	0	2.62	6	232
7	401	75	20	4	1	-	-	501	5.34	3.75	5	4	0	0	3.02	7	401
8	427	102	25	5	3	-	-	562	4.18	4.8	5	1.66	0	0	2.61	8	427
9	169	36	8	2	-	-	-	215	4.69	4.5	4	0	0	0	2.20	9	169
10	108	32	5	2	-	-	-	147	3.37	6.4	2.5	0	0	0	2.05	10	108
11	151	35	6	1	-	-	-	193	4.31	5.83	6	0	0	0	2.69	11	151
12	359	65	16	4	1	-	-	445	5.52	4.06	4	4	0	0	2.93	12	359
13	256	59	11	2	1	-	-	329	4.33	5.36	5.5	2	0	0	2.87	13	256
14	118	31	8	3	-	-	-	160	3.8	3.87	2.66	0	0	0	2.40	14	118
15	202	47	8	5	2	-	-	264	4.29	5.87	1.6	2	0	0	2.29	15	202
16	394	50	11	1	-	1	-	457	7.88	4.54	11	0	1	0	4.07	16	394
17	395	81	17	4	1	-	-	498	4.87	4.76	4.25	4	0	0	2.98	17	395
18	246	44	6	2	1	-	-	299	5.59	7.33	3	2	0	0	2.99	18	246
19	89	12	13	1	-	-	-	115	7.41	0.92	1	0	0	0	1.56	19	89
20	120	29	9	3	1	-	-	162	4.13	3.22	3	3	0	0	2.23	20	120
21	110	23	2	-	-	-	1	136	4.78	11.5	0	0	0	2	3.05	21	110

22	43	12	2	1	-	-	-	58	3.58	6	2	0	0	0	1.93	22	43
23	354	40	8	3	1	1	-	407	8.85	5	2.66	3	1	0	3.42	23	354
Ave.									5.21	4.92	3.67	1.85	0.09	0.09	2.67	Ave.	

The mean bifurcation ratio (Rbm) may be defined as the average of bifurcation ratio of all orders (Strahler, 1957). The Mun river basin the higher mean bifurcation ratio has been observed for the sub watershed 11, 15 and 21.

Mean bifurcation shows stable trends in a region of uniform geological structure and lithologies but they show variable trends over varying geological structures, (Sing et al., 1984) have remarked that “geological structure and associated lithologies do not cause significant variations in bifurcation ratios and this observation holds parity with the conclusions of (Miller, 1953)”.

Horton (1945) classified the mean bifurcation ratio into two classes: 0 to 2 flat or rolling basin; 3 to 4 mountainous or hilly regions.

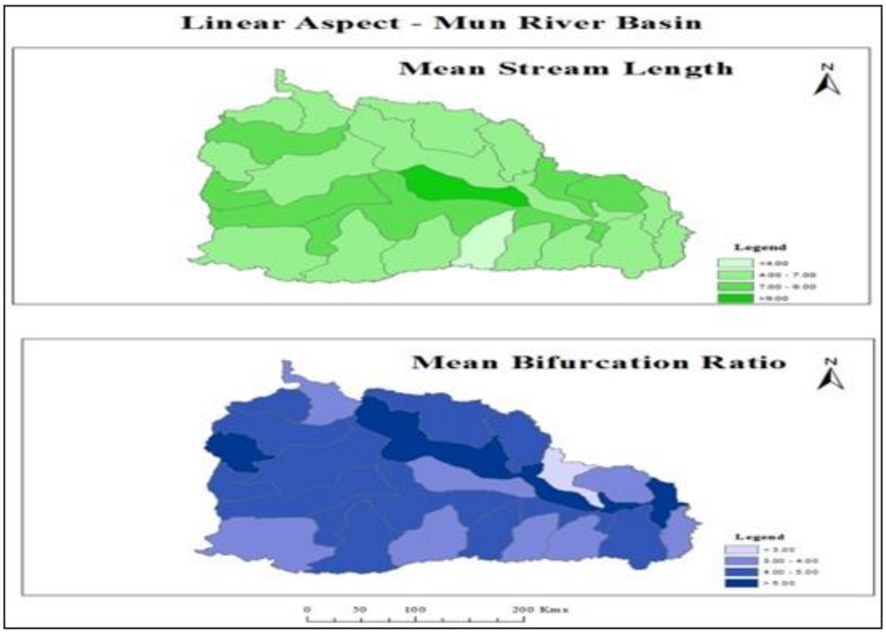

Figure 3: *Linear aspect – mun river basin*

“Mean bifurcation ratios register very small variation from region to region irrespective of structural control” (Savindra Sing et al., 1894). Fallowing strahler it may be postulated that mean bifurcation ratios show small variation from one region to another and such variations may be ascribed to chance variations.

The Mean bifurcation ratio (Rbm) of entire basin have identified as 2.67 whereas the Mean bifurcation ratio (Rbm) values of the 23 sub watersheds have varied between 1.56 to 4.07 notably the average basins bifurcation ratio of each stream order doesn’t possess any greater variations. Table 4 reveals sub watershed 3, 9, 10, 14, 15, 19, 20 and 22 are identified with the mean bifurcation ratio values of less than 2.5 and these sub watersheds are observed with the soil types of Palaviduthi or Aeolian or Vyologam, geological these sub watersheds are identified with either silliminate or recent alluvium.

Areal Aspect

The areal aspect of the drainage basin include the study of basin perimeter, geometry of closed links i.e. basin shape, law of basin area, law of allometric growth, stream frequency, drainage density, drainage texture, form factor, elongation ratio, and circularity ratio etc.

Basin Area

Basin area is very important Morphometric attribute as it is related to the spatial distribution of a number of significant attributes such as drainage density, stream frequency, drainage texture, slopes absolute and relative reliefs, dissection index etc. The drainage area is delineated on the basis of water divides and the areas of all stream segments of each order. All of the ground surface, which directly feeds the first order basins. The area of second order stream segments include the area of first order segments plus the areas of inter-basins, which are triangular patches of ground surfaces contributing directly to the second order segments. The same principle works for all the increasing successive order segments (Sing and Srivasava, 1974). Thus, the basin area becomes automatically cumulative from the first order to the successive higher orders. For the present study area of the sub watersheds is 116226 km² notably sub watershed 23, 16, 12, 8, 9 and 7 sub watersheds are the highest basin respectively (12316, 11148, 8322, 8172, 6871, and 6246 km²) (Table 5).

Table 5: *Basin area, Perimeter, Basin length of the Mun river basin*

No. of Sub.	Area (sqkms)	Perimiter (kms)	Length (kms)
1	2075	290.968	103.54
2	4838	354.407	122.05
3	3339	261.936	89.96
4	3016	268.839	103.17
5	3731	306.896	115.15
6	5088	319.568	122.8
7	6246	447.671	140.39
8	8172	468.675	125.92
9	6871	477.351	175.96
10	2598	270.126	95.86
11	2952	257.71	85.44
12	8322	495.377	159.22
13	5851	436.979	140.1
14	2657	238.967	85.45
15	3403	364.021	121.07
16	11148	873.762	309.54
17	6503	446.477	159.12
18	4029	349.418	116.18
19	2643	348.328	125.81
20	3565	258.527	78.35
21	2620	406.497	87.71
22	4242	330.375	135.72
23	12316	1141.32	365.48

Basin Shape

The geometry of basin shape is a paramount significance as it helps in the description and comparison of different forms of the drainage basins and it is also related to the functioning of the units of the basins and its genesis. On the average 3 sub-categories of basin shapes have been recognized viz. (i) circular, (ii) elongated, and (iii) indented.

Basin Length

Length in a straight line from the mouth of a stream to the farthest point on the drainage dived of its basin. The study area has total length of 3163.99 km and the 23 and 16 sub watersheds are the high basin length.

Form Factor (Rf)

According to Horton (1932), form factor (Rf) may be defined as the ratio of basin area to square of the basin length. With the reference to the Table 6 it is observed than form factor of the entire Mun river basin is 0.29. The sub watersheds are 2, 3, 6, 7, 8, 12, 14, 20 and 21 have observed the form factor value above 0.3 implies that the sub watersheds are relatively circular in shape, whereas the remaining watersheds have observed with less than 0.3 are comes under elongated in shape. Particularly sub watershed 23 have registered with the lowest value (0.09) and highly elongated. The elongated basin with low form factor indicates that the watershed will have flatter peak of flow for longer duration. Flood flows of such elongated basins are easier to manage of the circular basin.

Elongation Ratio (Re)

Schumm (1956) defined elongation ratio (Re) as the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin. In general the values of elongation ratio vary from 0.6 to 1.0 over a wide variety of climatic and geological types. Values close to 1.0 are typical of regions of very low relief, whereas values in the range 0.6 to 0.8 are usually associated with high relief and steep ground slope (Strahler, 1964).
These values can be grouped in to 3 categories namely:
i) Circular (>0.9)
ii) Oval (0.8 to 0.9)
iii) Less elongated (<0.7)

Elongation ratio of the sub watershed of the study area varies from (0.34 to 0.72) (Table 6). The lowest elongation ratio (0.32) in case of sub watershed 8 is indicates high relief (2236 m) and steep slope and less elongated in shape. Most of the study area covers the less elongated in shape. Especially the sub watershed IX and X are no relief or flat surface and sub watershed 21 and 22 are the circular in shape with low relief (191 and 253) and shape. A circular basin is more efficient in the discharge of runoff than an elongated basin (Sing, 1997).

Circularity Ratio (Rc)

The circularity ratio was proposed by Miller (1953) as comparison of the basin area with the area of the circular having the same perimeter. The circularity ratio is influenced by the length and frequency of streams, geological structure, landuse/landcover, climate relief and slope of the basin. In this study circularity value varies between 0.03 to 0.67 (Table 6). High circularity ratio values more than 0.4 have observed for the sub watershed 2, 3, 4, 5, 6, 8, 10, 11, 12, 14, 17, 18, 20 and 22 sub watersheds, and one can said it is more or less circular and notably characterised by the drainage density between 0.15 to 0.35 km/sq km.

The remaining watersheds are observed with the circularity value between 0.3 to 0.4 and it can be said the sub watersheds are elongated in shape, and the drainage density are in this area are observed with either lower density 3.5 to 10.5. Soil, geomorphology, land use and geological formation of this area implies no direct relationship with the variations in the circularity ratio. Notably there is a close relationship between number of stream and circularity ratio, the higher circularity ratio values are usually associated lower number of stream segments and vice versa.

Drainage Density (d)

Drainage density refers total stream lengths per unit area. Horton (1945) defines drainage density as ratio of total length of all stream segments in a given drainage basin to the total area of the basin.

The drainage density can classified into five categories (Savindra Sing, 1978).

i) Extremely low drainage density (0 – 0.25 km)
ii) Low drainage density (0.25 km – 0.35 km)
iii) Moderate drainage density (0.35 km – 0.4 km)
iv) High drainage density (0.4 km – 0.45 km)
v) Very high drainage density (above 0.45 km)

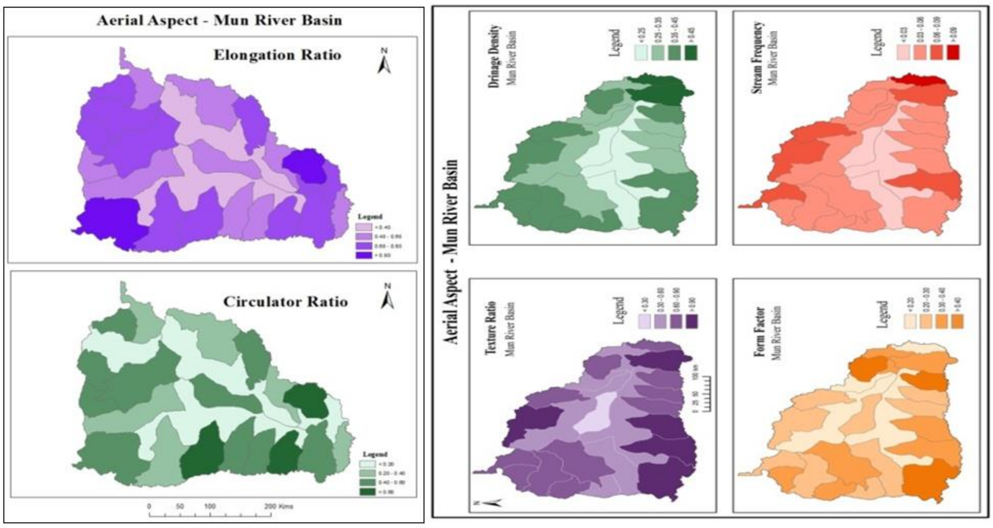

Figure 4: *Aerial aspect – mun river basin*

According to Nag (1998) low drainage density generally results in area of highly resistant (or) permeable sub soil material, and low relief. High drainage density is the result of weak (or) impermeable sub surface material and mountainous relief. Low drainage density leads to coarse drainage texture while high density leads to fine drainage texture.

The low drainage density of the study area are varies from (0.17 to 0.25) indicating low drainage density with low relief ratio of 67m, 162m and 0m respectively coarse drainage texture. Whereas the sub watershed 4, 5, 6, 12, 16, 19 and 21 sub watersheds indicating moderate drainage density (0.25 to 0.35) with high relief 529m, 729m, 2020m, 400m, 938m, 460m, 414m, and 365m respectively and it has the coarse to related coarse drainage texture.

Stream Frequency (Fs)

Stream frequency or drainage frequency is the measure of number of stream per unit area (Horton, 1932). The general categories of the stream frequency are:

- Poor (0.01 to 0.03)
- Moderate (0.03 to 0.06)
- High (0.06 to 0.09)
- Very high (above 0.09)

Sub-watershed 1 comes under the very high stream frequency, sub-watershed 3, 4, 5, 6, 8, 10, 11, 12, 13, 14, 16, 19, 20 and 21 are comes under the moderate stream frequency, sub-watershed 2, 7, 15, 17 and 18 are comes under the high stream frequency and the remaining 9, 22 and 23 sub watersheds are comes under the poor stream frequency.

Drainage Texture (Rt)

According to Horton (1945) drainage texture is the total number of stream segments of all orders per perimeter of that area. It is the one of the important concept of geomorphology which means that the relative spacing of drainage lines. Drainage lines are numerous over impermeable areas than permeable areas.

Smith (1950) has classified drainage density in to five deferent textures.

- The drainage density less than 2 indicates very coarse
- The drainage density between 2 to 4 is coarse
- The drainage density between 4 to 6 is moderate
- The drainage density between 6 to 8 is fine
- The drainage density is greater than 8 is very fine

In the present study the drainage density is less than 2, it indicates very coarse drainage texture.

Length of Overland Flow (Lg)

The length of overland flow, considered as a dominant hydrologic and morphometric factor is the mean horizontal length of flow path from the divided to the stream in a first order basin and is a measure of stream spacing and degree of dissection and approximately one half the reciprocal of the drainage density (Brice, 1964). It is the length of water before it gets concentrated into definite stream channels (Horton, 1945).

The Figure reveals that the length of overland flow is less in, Sub watershed 1, 2, 10, 11, 15, 17 and 18 sub watersheds, as drainage density is high in these sub watersheds, when comparing remaining sub watersheds. The computed value of length of overland flow for all sub watersheds varies from 0.87 to 2.94.

Table 6: *Areal aspects of various sub-watersheds of mun river basin*

S.No.	Area of Basin in sq.km (A)	Length of Basin in km (Lb)	Perimeter in km (P)	Drainage Density in km (Dd)	Texture Ratio (Rt)	Stream Frequency (Fs)	Form Factor Ratio (Ff)	Elongation Ratio (Re)	Circulatory Ratio (Rc)	Length of Overland flow (Lg)
1	2075	103.5	290.9	0.57	0.82	0.11	0.19	0.49	0.3	0.87
2	4838	122	354.4	0.47	1.29	0.09	0.32	0.64	0.48	1.06
3	3339	89.9	261.9	0.37	0.82	0.06	0.41	0.72	0.61	1.35
4	3016	103.1	268.8	0.31	0.75	0.06	0.28	0.6	0.52	1.61
5	3731	115.1	306.8	0.28	0.83	0.06	0.28	0.59	0.49	1.78
6	5088	122.8	319.5	0.3	0.94	0.05	0.33	0.65	0.62	1.66
7	6246	140.3	447.6	0.39	1.11	0.08	0.31	0.63	0.39	1.28
8	8172	125.9	468.6	0.4	1.19	0.06	0.51	0.81	0.46	1.25
9	6871	175.9	477.3	0.25	0.45	0.03	0.22	0.53	0.37	2
10	2598	95.8	270.1	0.41	0.54	0.05	0.28	0.6	0.44	1.21
11	2952	85.4	257.7	0.43	0.74	0.06	0.4	0.71	0.55	1.16
12	8322	159.2	495.3	0.33	0.89	0.05	0.32	0.64	0.42	1.51
13	5851	140.1	436.9	0.4	0.75	0.05	0.29	0.61	0.03	1.25
14	2657	85.4	238.9	0.39	0.66	0.06	0.36	0.68	0.58	1.28
15	3403	121	364	0.44	0.72	0.07	0.23	0.54	0.32	1.13
16	11148	309.5	873.7	0.27	0.52	0.04	0.11	0.38	0.18	1.85
17	6503	159.1	446.4	0.42	1.11	0.07	0.25	0.57	0.4	1.19
18	4029	116.1	349.4	0.43	0.85	0.07	0.29	0.61	0.41	1.16
19	2643	125.8	348.3	0.32	0.33	0.04	0.16	0.46	0.27	1.56
20	3565	78.3	258.5	0.38	0.62	0.04	0.58	0.86	0.67	1.31
21	2620	87.7	406.4	0.35	0.33	0.05	0.34	0.65	0.19	1.42
22	4242	135.7	330.3	0.17	0.17	0.01	0.23	0.54	0.48	2.94
23	12316	365.4	1141.3	0.23	0.35	0.03	0.09	0.34	0.11	2.17
Average	5053.26	137.52	409.26	0.36	0.72	0.05	0.29	0.6	0.4	1.47

Relief Aspects

The relief aspects of the drainage basins are related to the study of three dimensional features of the basin involving area, volume and altitude of vertical dimensions of land forms wherein different morphometric methods are used to analysis the terrain characteristics, which are the result of basin process. Thus, this aspect includes the analysis of the relationships between area and altitude (hypsometric analysis), altitude and slope angle (clinographic analysis), average ground slope, relative relief, relief ratio, dissection index, profiles of terrains and the rivers. The stream elevation can be estimated from the contour crossings on the topographic sheets. The total drop in elevation from the source to the mouth can be found for the elevation from the source to the mouth for the tributaries and the horizontal distances can be measured along the channel using a map measures.

Relative Relief

Relative relief also termed as “amplitude available relief” or “local relief” is defining as the difference in height between the highest and the lowest points (height) in a unit area. Relative relief is very important morphometric variable which is used for the overall assessment of morphological characteristics of terrain and degree of dissection (Glock, 1932).

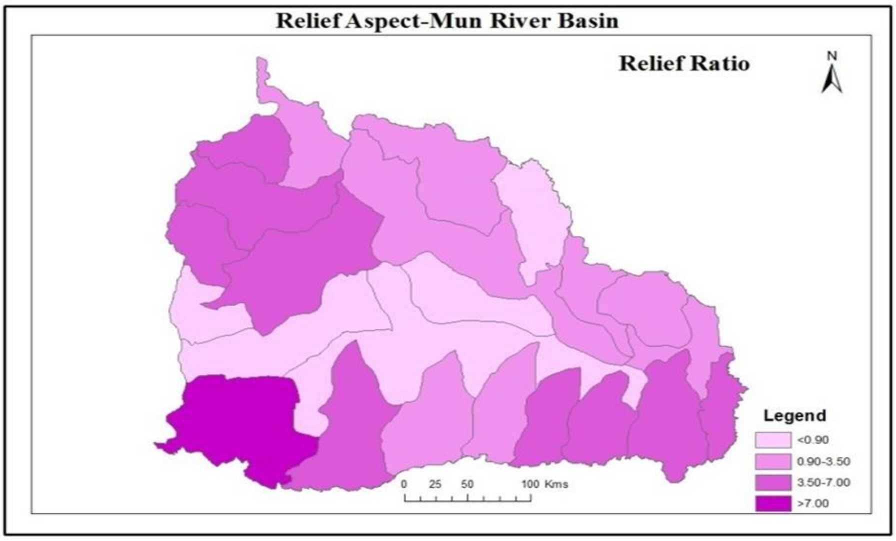

Figure 5: *Relief aspect – mun river basin*

Table 7: *Relief aspect of various sub-watersheds in mun river basin*

No. of Sub-Watersheds	Maximum Height (H)	Minimum Height (h)	Relative Relief (R)	Relief Ratio (Rr)
1	591	150	441	4.26
2	756	120	636	5.21
3	698	129	569	6.32
4	561	134	427	4.14
5	439	127	312	2.71
6	440	139	301	2.45
7	890	161	729	5.19
8	2236	216	2020	16.04
9	0	0	0	0
10	0	0	0	0
11	1340	940	400	4.68
12	1250	223	1027	6.45
13	1250	312	938	6.69
14	1310	850	460	5.38
15	650	236	414	3.42
16	565	123	442	1.42
17	557	192	365	2.29
18	492	388	104	0.89
19	370	128	242	1.92
20	280	135	145	1.85
21	259	128	131	1.49
22	191	124	67	0.49
23	293	131	162	0.44

The relative relief of sub watersheds of the study area varies from 0m to 2020m. Notably the extremely low relative relief (<160m) of the study area of sub watershed 9, 10, 18, 20, 21 and 22, moderately low relative relief of the study area is sub watershed 5, 6, 19 and 23, low relative relief 1, 3, 4, 11, 14, 15, 16 and 17. The remaining sub watershed 2, 7, 13 and 8, 12 are moderately high and high relative relief.

Relief Ratio

The relief ratio of maximum relief to horizontal distance among the longest dimension of the basin parallel to the principle drainage line is termed as relief ratio (Schumm, 1956). According to him there is direct relationship between the relief and channel gradient, there is also a correlation between hydrological characteristics and the relief ratio of a drainage basin.

The relief ratio normally increases with decreasing area and size of sub watersheds of a drainage basin (Gottschalk, 1964). Notably sub watershed 9, 10, 18, 22 and 23 are the larger sub watersheds observed with lower relief ratio of less than 0.90 respectively. Sub watershed 8 is the lower observed with higher relief ratio (above 7.00).

4. Conclusion

In over all, the mun river basin contains the 23 sub-watersheds, 6611 drainage segments and contains I to VII stream orders. In that 5275 segments are comes under I order stream, 1025 are II order, 235 are in III order, 57 are IV order, 16 are in V order, 2 and 1 segments are comes under VI and VII order, respectively. The total stream length of Mum river basin is 40353.8 km. The majority of basin contains the bifurcation ratio value is >5. This indicates that geologically mountanious terrain, less infiltration and high flash flood. This analysis helps to better understanding the management and planning activities in study area.

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