JOURNAL GEOLOGICAL SOCIETY OF INDIA
Vol.97, April 2021, pp.385-395

Geomorphic Analysis, Morphometric-based Prioritization and Tectonic Implications in Chite Lui River, Northeast India

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ABSTRACT

River morphometry is a useful approach in basin analysis which helps to interprets fluvially originated landforms. The aim of the present work is to evaluate the morphometric and morphotectonic parameters along with prioritization for soil erosion and water availability in Chite Lui watershed. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a useful approach to find out soil erosion and ground water potential zone with an aim to achieve successful management of a watershed. It helps to examine the susceptibility zone in watershed. The present paper documents the delineation of 14 sub-watersheds in Chite Lui River at 3rd order stream. Its prioritization has been performed using several morphometric parameters namely drainage density, elongation ratio and many other parameters using Analytical Hierarchical Process (AHP). Sub-watersheds are ranked from 1-14 based on soil erosion and groundwater potential zones.

The Chite Lui watershed is a fifth order drainage basin with a total area of 52.7 km^2. The tectonic parameters of the watershed as the asymmetry value is 34%, indicates the structural control over the area either by uplift or tilting. The hypsometric integral value is 0.5 and the valley width height ratio is 0.05 which also suggest tectonic activity in the area. Sinuosity related many parameters along with geomorphic indices like stream power index (SPI), stream gradient index (S_L) and topographic wetness index (TWI) were also calculated to suggest the watershed health. The present paper shows that the morphometric analysis is highly relevant and efficient in delineating susceptibility zones.

INTRODUCTION

A watershed is a part of land or an area in which draining water from different sources like rain, melting snow etc. usually converges to basin exit, where it joins another water body like any river or sea (Rahman et al. 2015). Morphometry is the mathematical analysis, calculation and evaluation of any hydrological unit (Obi Reddy et al. 2002; Chandniha and Kansal, 2014; Varma et al. 2020). Drainage morphometric parameters deals with factors related with structural controls in any watershed (Sharma and Sarma, 2013). The hydrological analysis along with the performing geomorphic activities in any watershed depend on the geo-morphometric individuality of basin (Thapliyal et al. 2017). The morphometric architecture of a drainage basin usually reflects the underlying geology, climate, relief and tectonics of a watershed. Horton (1932, 1945) was the first to discuss the utility of quantitative geomorphological analysis in the management of drainage basin. Further, the method of quantitative analysis and the inter-relationship between drainage morphometric parameters is well recognized by various workers (Melton, 1958; Strahler, 1964; Tandon, 1974; Jordan et al. 2005; Rudraiah et al. 2008; Barman et al. 2019; Yadav et al. 2020; Barman et al. 2021). Morphometry is also important to study the groundwater potential, groundwater management, pedology and assessment of environment. It is very significant for investigation, categorization, management and development of hydrological model in the basin (Sahu et al. 2017). The geological, geomorphological, hydrological and hydrogeological characteristics of any watershed have been demarcated under morphometric and morphotectonic parameters (Ahmed and Srinivasa, 2016; Lone, 2017; Mahala, 2020). Romshoo et al. (2012) also studied the topographic factors and explained its effect on basin hydrology. Digital elevation model (DEM) data has been used for synoptic view of basin as it is very effective source in identification and delineation of different landforms (Smith and Sandwell, 2003; Grohmann, 2004; Arabameri et al. 2020). Pre-processing of DEM is required to generate the morphometric parameters and geomorphic indices (Mesa, 2006; Magesh et al. 2011).

Hwang and Yoon (1981) first developed a multi-criteria decision-making (MCDM) model named TOPSIS (Triantaphyllou and Lin, 1996). It is a method which aggregates different efficiency criteria and evaluates the priority measures; depends on the distance of the efficiency criteria of the both values i.e., positive ideal value and the negative ideal value (Hwang and Yoon, 1981; Hwang et al. 1993; Malczewski 1999; Srdjevic et al. 2004; Rousta and Araghinejad, 2015). In the present paper, prioritization is done with the help of TOPSIS method and seven morphometric parameters. Morphometric parameters play a prominent role in prioritization to prepare a comprehensive basin management plan of sub-watershed (Avinash et al. 2011). An effective watershed management plan for soil, water and other natural resource conservation and development of watershed in a short span of time can be done using morphometric parameters (Arulbalaji and Padmalal, 2020). Several studies have explained the role of morphometric analysis, prioritization, morphotectonic analysis and groundwater potential zones (Sreedevi et al. 2005; Ratnam et al. 2005; Biswas et al. 1999; Khan et al. 2001; Javed et al. 2009). Sub-watersheds have been prioritized to analyze soil erosion and groundwater potential zones (Yadav et al. 2016; Choudhari et al. 2018). Various works related with morphometric study have been done earlier using different techniques like aerial photographs (Nautiyal, 1994),

0016-7622/2021-97-4-385/$ 1.00 © GEOL. SOC. INDIA | DOI: 10.1007/s12594-021-1696-0

remote sensing (Nag and Chakraborty, 2003; Biswas et al. 1999; Vittala et al. 2004; Chopra et al. 2005) and GIS (Vincy et al. 2012; Sreedevi et al. 2013). The comparative studies viz. role of nature of slope, structural fabric, lithology, climate and vegetation of a given area need to be invariably addressed for studies on hazard zoning or groundwater potential of a drainage basin.

Hack (1973) proposed the S_L index to determine and identify the influence of lithology and tectonics. It also attempts to establish the relationship between channel slope and channel length to determine the morphological equilibrium of the river (Magar and Magar, 2016). The evaluation of standard sinuosity index (SSI), topographic sinuosity index (TSI) and hydraulic sinuosity index (HSI) have been computed. For these sinuosity indices, channel index (CI) and valley index (VI) are also calculated with the help of ArcGIS software.

Topographic Wetness Index (TWI) is an important geomorphic index which indicates the runoff generation potential. This index is generally used to estimate the runoff. It is also useful in flood risk assessment and identification of flood prone areas. The value of TWI is directly proportional to its runoff generation. It means, low TWI indicates low potential of runoff generation and vice versa. Stream Power Index (SPI) generally measures the erosional potential of flowing water. It predicts the net erosion and net deposition of a particular basin (Wilson and Lorang, 2000; Danielson, 2013).

The objectives of present work is (i) to analyze the morphometric attributes using ASTER-DEM and GIS methods (ii) to determine the morphotectonic and geomorphic quantities (iii) to prioritize sub-watersheds by using TOPSIS model to demarcate water deficit and water surplus ground water zones.

STUDY AREA

Aizawl the capital of Mizoram covers an area of about 130 km^2. The district accounts for nearly one-third of the total population of the state (4, 00,309 out of 10,97,206 as per 2011 census). This area is highly prone to landslides and earthquakes and receives heavy rainfall (about 300 cm/annum). The Chite Lui (in Mizo "Lui" means river) watershed falls in the eastern most part of the Aizawl city, stretching over an area of about 52.50 km^2. Geographically, it extends between 23°38' to 23°46' N latitudes and 92°43' to 92°49' E longitudes (Fig. 1). The maximum elevation in the watershed in the upper reaches is 1159 m, which gradually decreases to 136 m towards its confluence with Tuirial river. The watershed area comprising various thick sedimentary sequences of sandstones, shales, siltstones with their admixtures in various proportions belongs to Bhuban Formation (Surma Group) of Lower to Middle Miocene age. The study area exhibits steep slopes with deep valleys. The Chite Lui is the tributary of Sonai or Tuirial river, which originates at the northwestern part of Aizawl city area at an elevation of 1159 m, which flows in different directions and finally joins Tuirial River at 136 m elevation. The upper reaches of Chite Lui show markedly straight-course, takes right angle turns and meandering nature is shown in the middle part of the basin.

Geology, Hydrogeology and Geomorphology

Chite Lui flows through Tertiary rocks of Surma Group. Physiographically, the terrain is mountainous with prominent relief. The study area consists of thick sedimentary sequence belonging to Bhuban Formation (Surma Group) of lower to middle Miocene age. The main rock types in the watershed are sandstones, shales, siltstones with their admixtures in various proportions. The geomorphology of watershed is highly influenced by the lithology and structure of the underlying geological formations.

Hydrogeologically, major physiographic units of the entire area of Aizwal district is occupied by denuded structural hills with low to moderate ridges and colluvium, formed along the steep sided slopes. Major water bearing formations of the study area are formed by semi consolidated Tertiary rocks. In general, the terrain is tectonically young and immature.

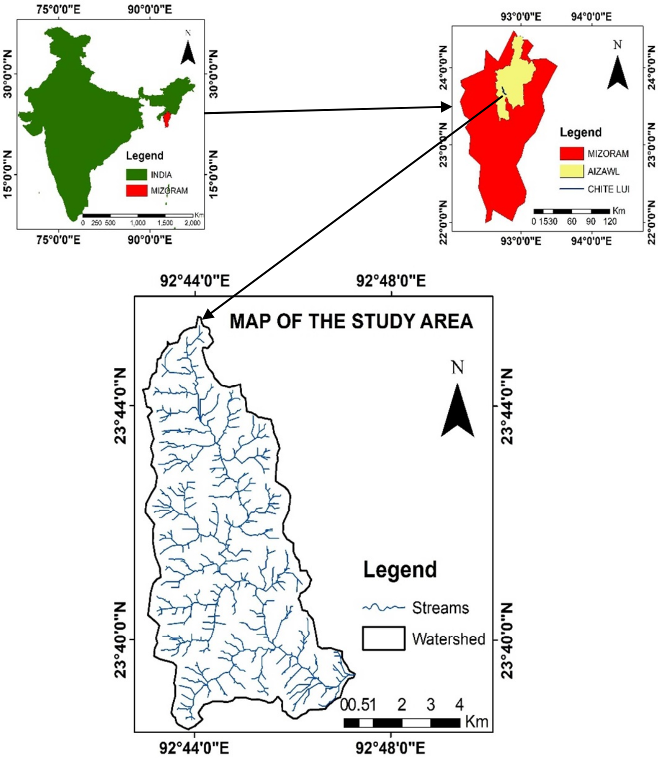


Fig.1. Study area location map of Chite Lui river, north eastern part of India

MATERIALS AND METHODS

Remote Sensing and GIS is a convenient method for analyzing hydrological characteristics and behavior of any watershed (Rai et al. 2017). The drainage characteristics along with tectonic observations suggest important clues about lithological formations of the watershed. (Singh et al. 2013). The entire stream network and altitude variations in the study area have been delineated from ASTER-DEM of 30 m resolution (source: https://asterweb.jpl.nasa.gov/gdem.asp). Different morphometric parameters have been successfully evaluated by remote sensing and GIS. Fill, flow direction, flow accumulation etc. have been delineated using Arc-hydro tool of Arc-GIS software. Then, further watershed delineated using pour point and streams extracted. The streams were ranked for order and their lengths measured. The estimation of morphotectonic parameters broadly covered under the study of hypsometric integral (HI), drainage basin asymmetry and valley width–height ratio. The adjacent Survey of India topographical sheets 84A/10 and 84A/14 on a 1:50,000 scale have been georeferenced for the cross verification of the drainage system extracted from ASTER DEM data.

The Chite Lui watershed is further divided into 3rd order sub-watersheds for the process of prioritization. Altogether fourteen sub-watersheds delineated through pour point are studied in detail with the help of TOPSIS MCDM model (Amiri et al. 2019). Prioritization is done using morphometric parameters to identify the soil erosion with water surplus and water deficit zones.

RESULTS

Morphometric Analysis

The slope map (Fig 2), hill shade map (Fig. 3) and drainage map (Fig. 4) were obtained from DEM data. The systematic description of drainage basin characteristics requires the measurements of (1) linear (2) areal and (3) relief aspects for the analysis, which are discussed below:

Linear Parameters

Stream Characteristics

Stream characteristics like number and length of different order streams, cumulative length of stream, mean stream length and intensity of dissection influence hydrological behavior of a basin. Stream length indicates the contributory area of the watershed of that order. The Chite Lui watershed is a 5th order basin (Table 1). According to Horton (1932), the basic parameters such as stream length and stream number show geometric relationship with stream order (Table 1). This relationship is shown graphically in the form of a straight line, when the log values of these variables (stream length and stream number) are plotted against stream order on an ordinary graph (Fig. 5 and Fig. 6) which showed negative correlation. The watershed further divided into 3rd order basins were analyzed for the morphometric study (Table 4). The contour map (Fig. 8), drainage density map (Fig. 9) and aspect map (Fig. 10) helps in better understanding the river morphometric characteristics and its orientation.

Stream Length (L_u)

It is the total calculated length for each order stream segment. The L_u measures the mean length of a stream for each order. The total length of all order streams of the Chite Lui watershed is 147.59 km (Table 1).

Stream Length Ratio (R_L)

Following Horton (1945) the average stream length segments of each of the successive orders of a basin follows a direct geometric series with L_u which increases towards a higher order of streams (Table 1).

Mean Stream Length Ratio (R_{LM})

In Chite Lui watershed, the R_{LM} is 3.57 km. The value of 'R_{LM}' of any given order is usually greater than that of the next lower order while less than that of its next higher order.

Bifurcation Ratio (R_b)

R_b is the proportion between the total numbers of drainages of one sort to that of the next upper order in a drainage basin and so on (Varma et al. 2020). The mean values of all these ratios leads to bifurcation ratio. The average bifurcation ratio of Chite Lui watershed is 4.17 (Table 1).

Table 1. Linear and Areal Morphometric parameters of Chite Lui watershed, Aizawl district, Mizoram

Sr. no.	Description of the Morphometric Parameters	Formula	Chite Lui Basin Values
A.	**LINEAR ASPECTS**		
1	Basin Perimeter (P) (km)	P	39.5
2	No. of streams in various orders		
	First order (N_1)	Hierarchical order	297
	Second order (N_2)		69
	Third order (N_3)		14
	Fourth order (N_4)		4
	Fifth order (N_5)		1
3	Total number of all streams (N)	N	385
4	Length of streams of various orders (km)		
	First order (L_1)	-	73.77
	Second order (L_2)		39.36
	Third order (L_3)		16.97
	Fourth order (L_4)		5.55
	Fifth order (L_5)		11.94
5	Total length of all order streams (L) (km)	-	147.59
6	Length of basin (L_b) (km)	-	12.23
7	Length of main stream(L_m) (km)	-	17.08
8	Mean Bifurcation ratio (R_b)	$R_b = N_u/N_{u+1}$	4.17
9	Mean Stream length ratio (R_L)	$R_L = L_u/L_{u-1}$	3.57
B.	**AREAL ASPECTS**		
1	Drainage area (A) (km^2)	A	52.7
2	Drainage density (D_d) (km/ km^2)	$D_d = L/A$	2.80
3	Constant of channel maintenance (C) km^2/km	$C = 1/D_d$	0.35
4	Stream frequency (S_f) in no. of streams/km^2	$S_f = N/A$	7.30
5	Form factor (F_f)	$F_f = A/L_b^2$	0.23
6	Circularity ratio (R_c)	$R_c = 4\pi A/P^2$	0.41
7	Elongation ratio ($R_{e)}$	$R_e = 2(A/\pi)^{0.5} / L_b$	0.66
8	Watershed shape factor (R_s)	$R_s = L_b^2/A$	2.83

Areal Parameters

Form factor (F_f)

It is defined as the ratio of basin area to square of the basin

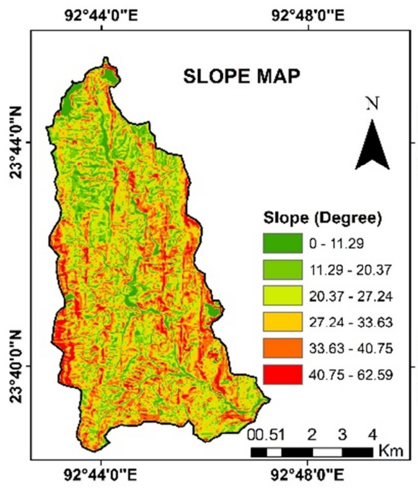


Fig. 2. Slope map of Chite Lui watershed

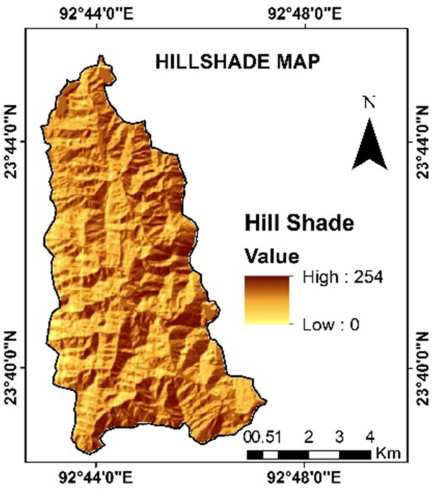


Fig. 3. Hill shade map of Chite Lui watershed

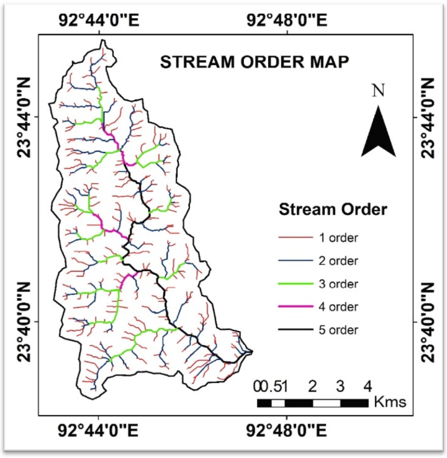


Fig. 4. Drainage map of the study area

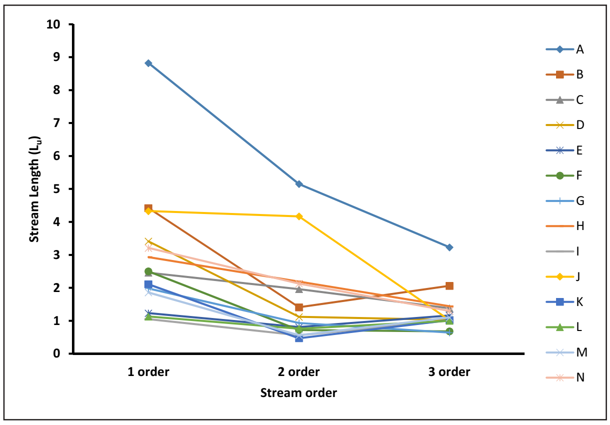


Fig. 5. Stream order Vs. Stream Length (-ve correlation) for fourteen sub-watersheds.

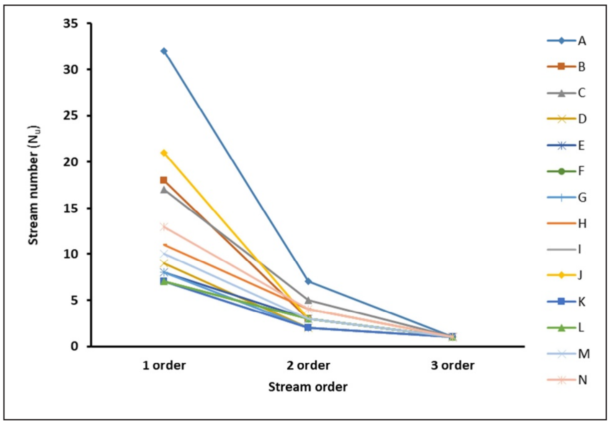


Fig.6. Stream order Vs. Stream number (-ve correlation) for fourteen sub-watersheds.

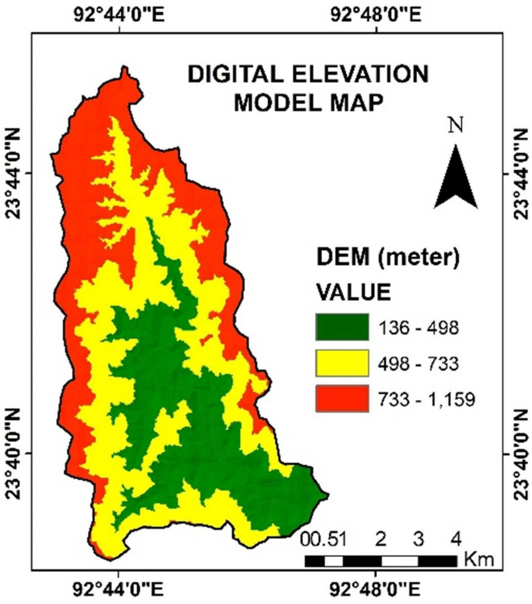


Fig. 7. DEM map of Chite Lui watershed

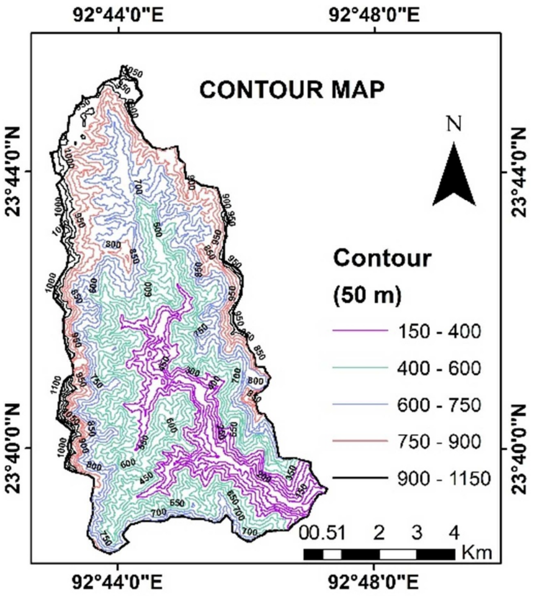


Fig. 8. Contour map of Chite Lui watershed

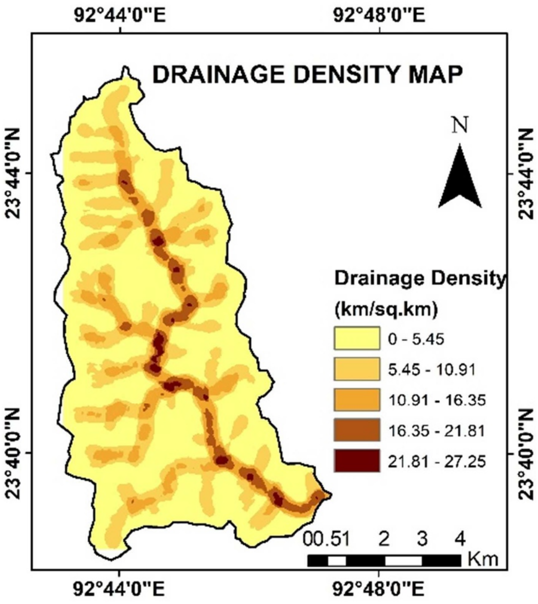


Fig. 9. Drainage density map of Chite Lui watershed

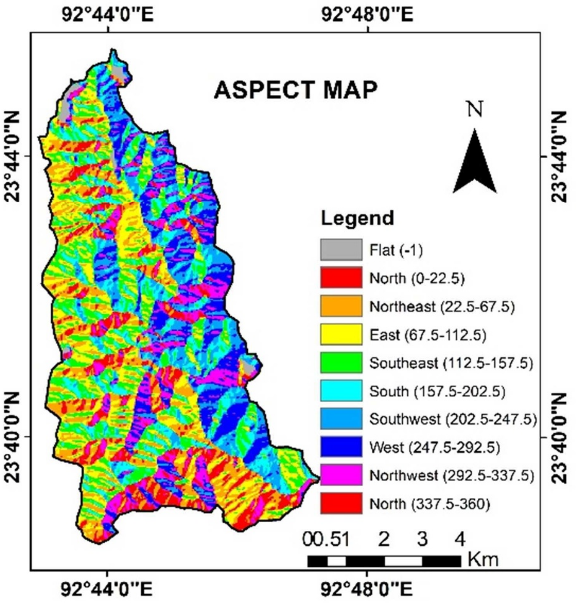


Fig. 10. Aspect map of Chite Lui watershed

Table 2. Relief and Tectonic parameters of Chite Lui watershed, Aizawl district, Mizoram.

RELIEF ASPECTS

Sr. no.	Relief Parameter	Formula	Unit	Chite Lui
1	Absolute Relief (H)	-	m	1159
2	Lowest point (L)	-	m	136
3	Mean Height (M)	-	m	647.5
4	Valley floor width (V_{fw})	-	m	40
5	Elevation on the left valley divide (E_{ld})	-	m	1029
6	Elevation on the right valley divide (E_{rd})	-	m	990
7	Elevation of the valley floor (E_{sc})	-	m	278
8	Total relief (H)	H	m	1023
9	Relief ratio (R_h)	$R_h = H/L_b$		0.083
10	Relative relief (R_p)	$R_p = H/P$		0.025
11	Ruggedness number (R_n)	$R_n = HD$		2.86

B. TECTONIC ASPECTS

Sr. no.	Tectonic Indices	Formula	Unit	Chite Lui
1	Hypsometric Integral (HI)	HI = (M- L) / (H-L)	m	0.5
2	Valley Width- Height Ratio (V_r)	$V_r = 2V_w/[(E_{ld} - E_{sc}) + (E_{rd} - E_{sc})]$	-	0.05
3	Drainage Basin Asymmetry (A_F)	$A_F = 100*(A_r/A_t)$	%	34.19

Table 3. Computation of sinuosity parameters for the analysis of Chite Lui basin

S. No.	Parameter	Formula	Result
1	Channel Index (CI)	CI = CL/AL	1.39
2	Valley Index (VI)	VI = VL/AL	1.32
3	Standard Sinuosity Index (SSI)	SSI = CL/VL	1.05
4	Topographic Sinuosity Index (TSI)	TSI = (VI-1)/(CI-1)	0.82
5	Hydraulic Sinuosity Index (HSI)	HSI =(CI-VI)/(CI-1)	0.17

CL = Length of the Channel, AL = Shortest distance between source and mouth, VL = Length of the valley between the base of the valley walls, AL = Shortest distance between source and mouth.

length (Horton 1932). Thus, it can be expressed as $F_f = A/L_b^2$ where, F_f = Form factor; A = watershed area; and L_b = length of the watershed. The form factor of Chite Lui watershed is 0.23 while the F_f of 3rd order sub-watershed ranges from 0.22 to 0.72 (Table 4).

Circularity Ratio (R_c)

R_c is the ratio between area of watershed to the area of circle having the same perimeter of the basin. Its value is affected by length, frequency and gradient of streams of different orders (Strahler 1957). The R_c value for the Chite Lui watershed is 0.41 and the various 3rd order sub-watersheds ranges from 0.50 to 0.79 (Table 4).

Elongation Ratio (R_e)

R_e represents the watershed shape of any river. Schumm (1956) defined R_e as the ratio of the diameter of a circle having the same area as the watershed and the maximum watershed length (L_b). It may be obtained by using the formula $R_e = 2(A/\pi)^{0.5} / L_b$ where 'R_e' is the elongation ratio, '2' is a constant, A is area, and 'L_b' is the maximum watershed length. The Chite Lui watershed R_e value is 0.66. The third order basins R_e ranges from 0.64 to 0.95 (Table 4).

Stream Frequency (S_f)

Horton (1945) discussed that S_f is the total segment of streams, present in unit area. It is an index of the different stages of landscape evolution. The Chite Lui watershed S_f is 7.30 (Table 1) and the 3rd order basins S_f range from 6.15 to 11 (Table 4).

Drainage Density (D_d)

A systematic evaluation of drainage density (D_d) was first introduced by Horton (1932). It is the ratio between total stream length (L) of all orders, present in any watershed to the area (A) of watershed. It indicates the closeness of spacing of the streams and texture of the basin. D_d indicates the linear scale of the landform elements in a drainage basin (Horton 1945). The Chite Lui basin D_d is 2.80/km^2. The 3rd order basins D_d ranges from 2.5 to 3.5 (Table 4).

Constant of Channel Maintenance (C)

It was first introduced by Schumm (1956) as the inverse of drainage density. The constant of channel maintenance value for Chite Lui watershed is 0.35 (Table 1) and the values for sub-watersheds of 3rd order ranges from 0.28 to 0.40 (Table 4).

Relief Parameters

Ruggedness number (R_n)

R_n is the product of drainage density and relief of the basin. R_n of Chite Lui watershed is 2.86 (Table 2). It indicates that both relief and drainage density are relatively high.

Relief Ratio (R_h)

The difference between highest height (H) and lowest height in

Table 4. Morphometric parameters of 3rd order drainage basins in Chite Lui watershed

Basin No / Parameters	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Number of streams	40	22	23	12	12	11	11	16	10	25	10	11	11	18
Length of streams (km)	17.2	7.8	5.8	5.5	3.2	3.9	3.5	6.5	2.6	9.5	3.6	2.8	3.5	6.6
Basin Area in (km^2)	6.5	2.8	2.2	1.9	1.2	1.1	1.2	2.1	1	3.6	1.2	1	1.4	2.5
Length of the basin (km)	3.99	2.64	2.11	2.38	1.58	1.53	1.43	2.24	1.74	2.57	1.68	1.51	1.45	1.86
Perimeter of the Basin (km)	12.3	7.9	6.3	6.7	4.9	4.6	4.8	6.4	4.9	9.5	5.4	4.8	4.7	6.8
MeanWidth of the basin (km)	1.62	1.06	1.04	0.79	0.75	0.71	0.83	0.93	0.57	1.4	0.71	0.66	0.96	1.34
Drainage Density (km/km^2)	2.6	2.7	2.636	2.8	2.6	3.5	2.9	3	2.6	2.6	3	2.8	2.5	2.6
Stream frequency	6.15	7.8	10.4	6.3	10	10	9.1	7.6	10	6.9	8.3	11	7.8	7.2
Circularity Ratio	0.539	0.563	0.697	0.532	0.627	0.656	0.654	0.644	0.522	0.501	0.516	0.545	0.799	0.680
Elongation Ratio	0.71	0.71	0.78	0.64	0.77	0.76	0.85	0.72	0.64	0.82	0.72	0.74	0.91	0.95
Constant of channel maintenance	0.38	0.37	0.38	0.35	0.38	0.28	0.34	0.33	0.38	0.38	0.33	0.35	0.4	0.38
Form factor	0.4	0.4	0.49	0.33	0.48	0.47	0.58	0.41	0.33	0.54	0.42	0.49	0.66	0.72
Watershed shape factor	2.44	2.48	2.02	2.97	2.07	2.12	1.7	2.38	3.02	1.83	2.35	2.03	1.5	1.38

any basin is known as relief. According to Schumm (1956), the R_h is the ratio of total basin relief to longest dimension (L_b) of the basin which tends parallel to the principle drainage. The R_h computes the overall steepness of any watershed to analyze the effectiveness of degradational processes that operates on basin slopes. The R_h of the Chite Lui watershed is 0.083 (Table 2).

Morphotectoic Parameters and Geomorphic Indices

Hypsometric Integral (HI)

Hypsometry of drainage basin has been used to evaluate the influence of varying forcing factors on basin topography. Low hypsometric integral values indicate that there is a small portion of the total basin area in the high elevation category (Singh and Singh, 2018; Kumar and Singh, 2021). With increase in basin area, the impact of fluvial processes increases, and the hypsometric curve becomes more concave and the hypsometric integral approaches zero. The hypsometric integral is estimated by Goudie (2004) as HI = (M-L)/(H-L) where, M=mean elevation, L= Minimum elevation and H= Maximum elevation. The hypsometric integral value of Chite Lui watershed is 0.5 (Table 2).

Drainage Basin Asymmetry

The asymmetry of a drainage basin is linked to the location of the trunk stream with respect to the right and left water divides. Structural control, in the form of tilting or dips, imposes asymmetry on the drainage network (Bloom, 2003). The drainage basin asymmetry is computed with the formula of Goudie (2004) $A_F = 100 (A_r/A_t)$ where, A_F = Asymmetry Factor, A_r = Basin area to the right side (facing down stream of the trunk stream), A_t = Whole area of the basin. For a symmetric basin the A_F value is 50. Divergence from this value indicates greater degree of tilt or dip. The asymmetry of Chite Lui watershed is 34.19% (Table 2).

Valley Width – Height Ratio

It is an important index commonly used to identify the tectonic imprints in the watershed area. The lowest value of the valley width-height ratio (<2) has been recorded and attributed to uplift of the watershed area. It is calculated by using the formula of Goudie (2004) as $V_r = 2V_w / [(E_{ld} - E_{sc}) + (E_{rd} - E_{sc})]$ where V_r = Valley width-height ratio, V_w = Valley width, E_{ld}, E_{rd} = elevation on the right and left valley divide respectively and E_{sc} = elevation of the valley floor. The Chite Lui watershed valley width-height ratio is 0.05 (Table 2).

Stream Gradient Index (S_L)

It is a quantitative geomorphic index, relating with the erosional and depositional process that includes the morphology and tectonically derived feature of valley to detect the local uplift and regional processes (Troiani and Della Seta, 2008; Alipoor et al. 2011). It correlates the stream power to the sediment transport along a stream profiler (Imsong et al. 2018). The S_L index of Chite Lui watershed is computed by the formula- $S_L = (\Delta H / \Delta L)\ L$, where $\Delta H/\Delta L$ is the evaluated slope of channel segment while L is the calculated length of channel measured from midpoint of channel reach to the divide. The profile of S_L index for Chite Lui watershed shows no systematic downstream change in size (Fig. 11).

Stream Power Index (SPI) and Topographic Wetness Index (TWI)

SPI measures the erosive power of flowing water. It is calculated based on slope and contributing area. The SPI of Chite Lui watershed ranges from 0 to 3.52 (Fig. 13). TWI quantifies the control of topography on hydrology of basin (Sörensen et al. 2006). High TWI value indicates high potential of water accumulation while low TWI indicated its low potential. For the Chite Lui basin, TWI value ranges from 2.8 to 21.2. (Fig. 12). Following Vijith & Dodge-Wan (2019), these values have been categorized into three classes (i) low wetness index (<5), considering 69.1% area of the basin. (ii) moderate wetness index (5-10), considering 24.7% area of the basin and (iii) high wetness index (>10), considering 6.21% area of the basin.

Sinuosity Analysis

The sinuosity analysis helps in the evaluation of effect of river course over terrain as well as terrain over river course (Panda and Bora, 1992). The Channel Index (CI) of the study area is 1.39 and the Valley Index (VI) of the study area is 1.32 (Table 3). There is not much difference between these values. It suggests that the valley is not fully developed. There are mainly three categories of sinuosity in any basin namely – standard sinuosity index (SSI), topographic sinuosity index (TSI) and hydraulic sinuosity index (HSI). SSI indicates the form of river course whether it is straight (SSI = 1.00), sinuous (SSI = 1.00-1.50) or meander (SSI > 1.50). The value of SSI for the Chite Lui watershed is 1.05. It means river can categorized as sinuous. TSI is valuable tool for drainage morphometry as it determines the stage of basin development and controlling factor of sinuosity (Mueller, 2005). The TSI of the Chite Lui watershed is 0.82 (82%). It indicates the greater irregularity of initial surface. The HSI of the present study

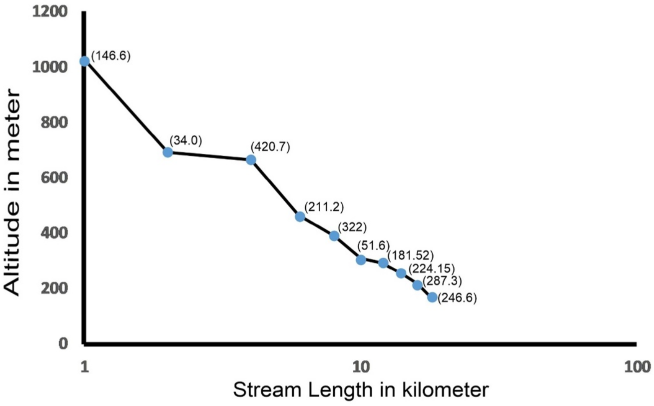


Fig.11. Profile of Chite Lui River with S_L values.

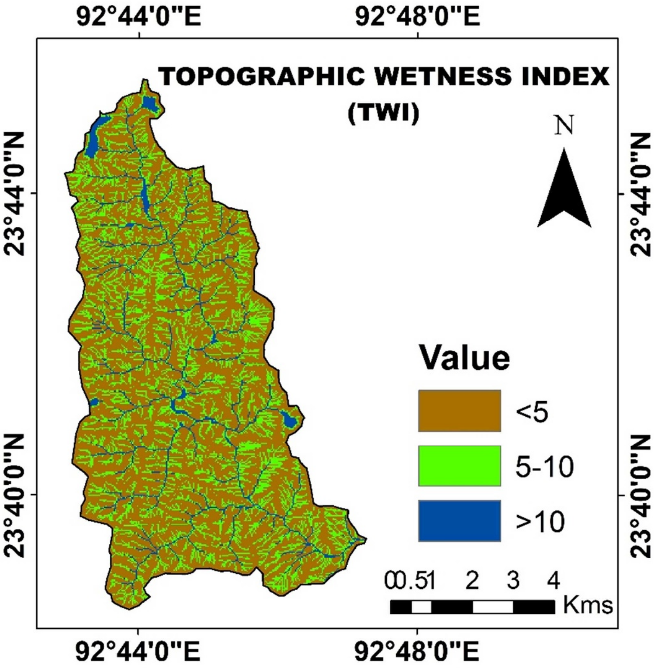


Fig.12. Map showing Topographic Wetness Index of Chite Lui watershed

Table 5. Assigned weights for Ground water potential analysis for different morphometric parameters of 3rd order drainage basins in Chite Lui watershed.

Morphometric Parameters	Drainage Density (km/km^2)	Stream frequency	Circularity Ratio	Elongation Ratio	Constant of channel maintenance	Form factor	Watershed shape factor
A	0.066	0.029	0.048	0.043	0.064	0.065	0.11
B	0.066	0.029	0.048	0.043	0.064	0.065	0.01
C	0.066	0.029	0.048	0.043	0.064	0.065	0.01
D	0.066	0.029	0.048	0.043	0.064	0.065	0.01
E	0.066	0.029	0.048	0.043	0.064	0.065	0.01
F	0.066	0.029	0.048	0.043	0.064	0.065	0.01
G	0.066	0.029	0.048	0.043	0.064	0.065	0.01
H	0.066	0.029	0.048	0.043	0.064	0.065	0.01
I	0.066	0.029	0.048	0.043	0.064	0.065	0.01
J	0.066	0.029	0.048	0.043	0.064	0.065	0.01
K	0.066	0.029	0.048	0.043	0.064	0.065	0.01
L	0.066	0.029	0.048	0.043	0.064	0.065	0.01
M	0.066	0.029	0.048	0.043	0.064	0.065	0.01
N	0.066	0.029	0.048	0.043	0.064	0.065	0.01

is 0.17 (17%). It suggests that the valley is constricted (Kumar, 2009).

Sub-watersheds Prioritization (groundwater potential and soil erosion)

The analysis of drainage characteristic parameters plays a vital role and it is very reliable and significant in demarcation of ground water prospect and soil erosion potential zones. The prioritization analysis of Chite Lui watershed is done by using TOPSIS model to evaluate morphometric parameters and their characteristics. The morphometric parameters help us to identify and determine the soil erosion susceptibility and water surplus and water deficit groundwater zones of the sub-watersheds with respect to the calculated values of linear and areal features of the basin and their prioritization. Prioritization has been done based on ranking from SW-A to SW-N (total number of sub-watersheds is 14) as per number of sub-watersheds (Fig. 14 and Fig. 15). Total seven morphometric parameters were selected for the prioritization (R_c, F_f, D_d, S_f and R_s, R_e), analytical hierarchical process (AHP) method was used to calculate the weight and TOPSIS model was applied for the ranking of sub-watersheds. The ranks were assigned from 1 to 14 to sub-watersheds based on highest relative closeness value (cl_i^+) to lowest value with the help of linear and areal morphometric parameters (Table 5, Table 6 and Table 7).

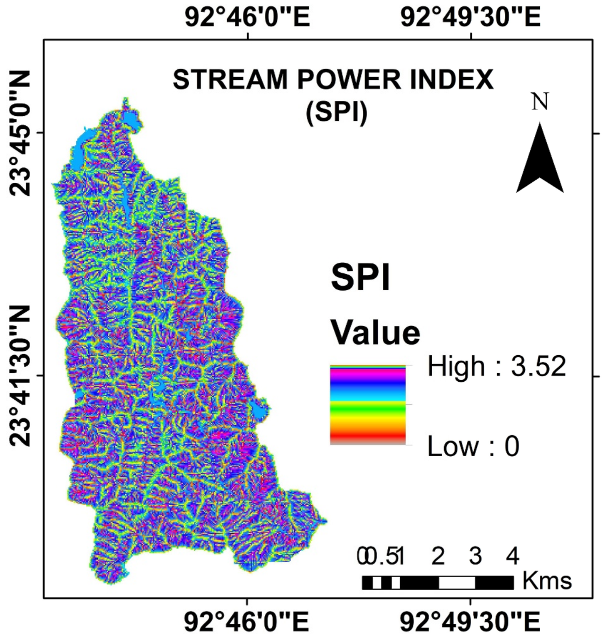


Fig.13. Map showing Stream Power Index of Chite Lui watershed

For the groundwater potential, it is found that SW-A has the least distance from positive ideal (0.014) and it also has the highest score for negative ideal (0.522) (Table 6). As a result, the relative closeness value (cl_i^+) of SW-A is highest and this sub-watershed is ranked first among all (Amiri et al. 2019). It is also observed in the (Table 6) that SW-I has the highest distance from positive ideal (0.125) with the lowest value of relative closeness (0.643) among all sub-watersheds. Hence, SW-I is ranked as last (14th). For the analysis of soil erosion susceptibility, it is found that SW-A has the least distance from positive ideal (0.009) and highest distance from negative ideal (0.616). It also has the highest value for relative closeness (0.985). Hence SW-A is ranked first among all sub watersheds. SW-I has ranked 14 due to lowest value of relative closeness (Table 8). This will help the local policy makers in conserving the soil and water.

DISCUSSION

The Chite Lui watershed was selected to study its drainage characteristics based on morphometry. Various allied studies like TOPSIS based sub-watersheds prioritization, tectonic implications and sinuosity analysis of the watershed have been done for the study. A good number of morphometric parameters have been evaluated to analyze drainage characteristics of watershed. In the study area, exponential increase in average stream length is found with reference to increase in stream order while the values of R_L seems to be changing

Table 6. TOPSIS based Prioritization Results for Groundwater potential analysis of the sub watersheds.

Sub-Watershed	Table D_i^+ Values	Table D_i^- Values	Relative closeness value (cl_i^+)	Rank
A	0.014914484	0.522845263	0.972	1
B	0.081873227	0.364180931	0.816	3
C	0.094111441	0.296498901	0.759	6
D	0.103986906	0.299057731	0.742	7
E	0.118516232	0.244075883	0.673	10
F	0.12108136	0.237394826	0.662	12
G	0.117619443	0.245987255	0.677	9
H	0.097808592	0.317435441	0.764	5
I	0.125199791	0.225351147	0.643	14
J	0.062685609	0.407521645	0.867	2
K	0.119051012	0.237711338	0.666	11
L	0.123606675	0.219483641	0.640	13
M	0.112537655	0.27053044	0.706	8
N	0.086366722	0.355433266	0.805	4

Table 7. Assigned weights for Soil Erosion Susceptibility analysis for different morphometric parameters of 3rd order drainage basins in Chite Lui watershed.

Morphometric Parameters	Drainage Density (km/km^2)	Stream frequency	Circularity Ratio	Elongation Ratio	Constant of channel maintenance	Form factor	Watershed shape factor
A	0.04	0.05	0.03	0.03	0.01	0.01	0.01
B	0.04	0.05	0.03	0.03	0.01	0.01	0.01
C	0.04	0.05	0.03	0.03	0.01	0.01	0.01
D	0.04	0.05	0.03	0.03	0.01	0.01	0.01
E	0.04	0.05	0.03	0.03	0.01	0.01	0.01
F	0.04	0.05	0.03	0.03	0.01	0.01	0.01
G	0.04	0.05	0.03	0.03	0.01	0.01	0.01
H	0.04	0.05	0.03	0.03	0.01	0.01	0.01
I	0.04	0.05	0.03	0.03	0.01	0.01	0.01
J	0.04	0.05	0.03	0.03	0.01	0.01	0.01
K	0.04	0.05	0.03	0.03	0.01	0.01	0.01
L	0.04	0.05	0.03	0.03	0.01	0.01	0.01
M	0.04	0.05	0.03	0.03	0.01	0.01	0.01
N	0.04	0.05	0.03	0.03	0.01	0.01	0.01

haphazardly at the watershed and sub-watersheds levels. This variation might be caused by changes in topography of watershed (Kumar et al. 2000; Sreedevi et al. 2005). Changes in R_L from one order to any other indicate early mature stage of watershed development (Singh and Singh, 1997).

The average bifurcation ratio of Chite Lui watershed is high (4.17), suggesting structural disturbance. The lower R_b values is because of presence of relatively high number of Ist and IInd order streams in the sub-watersheds. Sreedevi et al. (2005) reported that the values of R_b for structurally controlled Pageru sixth order in Cuddapah basin is 3.61. Usually, values of bifurcation ratio around 3 suggests that the watershed area is less influenced by geological structures while depend on the scale of the selected drainage basins.

There are three important areal parameters which describes watershed shape which are F_f, R_c and R_e. The form factor of Chite Lui watershed is 0.23 while the F_f of 3rd order sub-watersheds ranges from 0.33 to 0.72. In general, the value of F_f ranges from 0 to 1 (highly elongated to perfect circular shape). It means lesser the value of F_f the

Table 8. TOPSIS based Prioritization Results for Soil Erosion Susceptibility analysis of the sub watersheds.

Sub-Watershed	Table D_i^+ Values	Table D_i^- Values	Relative closeness value (cl_i^+)	Rank
A	0.009487764	0.616274015	0.985	1
B	0.116355364	0.386763697	0.769	3
C	0.131131002	0.350601396	0.728	4
D	0.156059509	0.262769974	0.627	7
E	0.174137167	0.178219432	0.506	10
F	0.174756849	0.179820235	0.507	9
G	0.175296367	0.172947504	0.497	11
H	0.142008882	0.312285584	0.687	6
I	0.182336709	0.119563389	0.396	14
J	0.095013758	0.439086449	0.822	2
K	0.176327569	0.161800219	0.479	12
L	0.180056166	0.141736604	0.440	13
M	0.173119832	0.187206162	0.520	8
N	0.133996978	0.339796217	0.717	5

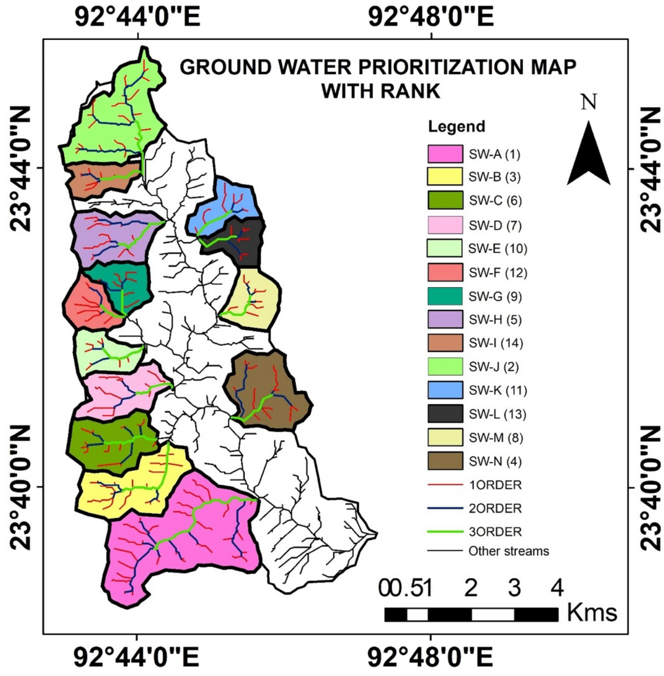


Fig.14. Groundwater prioritization map with rank of Chite Lui watershed.

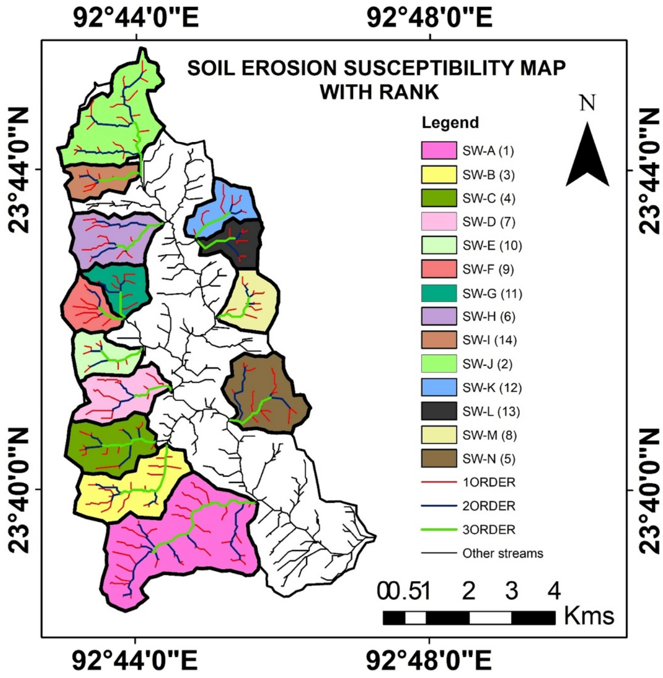
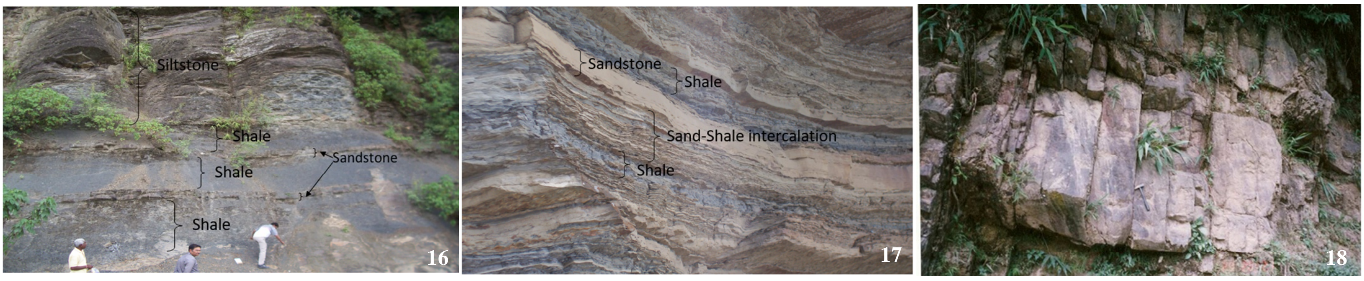


Fig.15. Soil erosion prioritization map with rank of Chite Lui watershed

Attitude of various lithological out crops in the basin area



Figs.16-18. (**16**) Horizontal Beds of sandstones, siltstones and shales. (**17**) Intercalation of sandstones, siltstones and shale. (**18**) Highly jointed sandstone beds of almost vertical inclination

Field photos of upper reaches of study area

Fig.19. V- Shaped valley topography indicating vertical incision and active tectonism. (**20a and b**). Deposition of huge quantities of sediments (pebbles and cobbles) along the river bed causing braided stream.

Fig.21. Massive sandstones overlain by thin layer of top soil indicating poor storage capacity of water

more the elongated shape of the watershed and vice-versa. Most of the sub basins in Chite Lui watershed show relatively lower F_f value.

The index of R_c is dimensionless as it indicates the outline form of drainage basins (Strahler 1964). The R_c value usually ranges from 0.6 to 0.7 indicate the homogeneous geological material (Horton 1945). The circularity ratio of the Chite Lui basin is 0.41 and the various 3rd order basins ranges from 0.50 to 0.79. It indicates that watershed has high to moderate relief. The R_c and R_e ratios are affected by length, geological structures, climate etc. of the basin (Vittala et al. 2004). The Chite Lui watershed R_e value is 0.66. The third order basins R_e ranges from 0.64 to 0.95, indicating steep slopes. R_e values usually ranges from 0.6 to 1.0 in different climatic and geologic types (Strahler 1957). The lower value of R_e for Chite Lui watershed (0.66) denotes elongated shape of the basin.

The stream frequency indicates stage of evolution of landscape as the higher S_f denotes larger surface run off with steep slope (Vittala et al. 2004). The 3rd order basins S_f ranges from 6.1 to 11 while the Chite Lui basin S_f is 7.3, which describes that six streams are developed in an area of one km^2 in the watershed. 'C' of the Chite Lui watershed is 0.35 which indicate that on the average, 0.35 km^2 of surface is required to maintain each km. of channel length. The values of 3rd order wise sub-watersheds range from 0.28 to 0.40 indicates that less than half km^2 area is required to maintain one km. stream length. Ruggedness number of Chite Lui watershed is a high value (2.86), which is indicating high basin relief (1023 m) and Drainage density are relatively high of the watershed. Such higher values suggest the mountainous region of with higher rainfall (Schumm, 1956).

The basin asymmetry value of Chite Lui watershed is 34.19%, which indicates the asymmetric nature of the watershed due to structural control, uplifting or tilting imposes the asymmetry on the drainage network. The low value of valley width-height ratio of Chite Lui watershed (0.05) indicates the high uplift rate in the watershed. The classified value of TWI suggests that nearly 70% of the study area has low wetness potential while nearly 6% of the study area has a high wetness potential. The range of SPI for the Chite Lui watershed indicates that more than 99% of the area has nearly 0 (zero) SPI value. It means less than 1% of the study area has high SPI value in the region having high slope with higher flow accumulation.

CONCLUSION

The present study is carried out using remotely sensed data (ASTER-DEM 30m) with GIS. The drainage pattern of Chite Lui watershed in Aizawl district is mainly dendritic type. The linear aspects of the watershed like Bifurcation ratio indicates normal watershed category and homogeneous geology with structural disturbance. Stream length ratio is changing arbitrarily at the basin and sub-watersheds levels with change in slope and topography which also indicates the late youth to mature stage of watershed development. It also reveals the relationship between erosional stage of the basin and surface flow discharge. Aerial aspects such as drainage density which is 2.80 km/ km^2 is categorized as moderate drainage density which indicates that watershed has moderate permeable sub soil. The values of form factor and circulatory ratio indicate that Chite Lui watershed is elongated. Relief aspects such as relative relief, ruggedness number show high basin relief. Morphotectonic parameters like valley width-height ratio, drainage basin asymmetry and hypsometric integral show the status of watershed and sub-watersheds. The sub-watersheds have been prioritized from rank '1' to rank '14', based on outcome TOPSIS. The weights of seven parameters were calculated using AHP method. With these parameters, the sub-watersheds are prioritized for the ground water potential and soil erosion susceptibility zones. In case of Ground water potential zone, it is found that the Relative closeness value is high for SW-A, J, B and N suggesting water deficit zones and low for SW-I, L, F, K indicating water surplus zones. High and low soil erosion potential area are also identified using prioritization. The relative closeness value of SW-A, J, B, C is high indicating highly prone zones for erosion while SW-I, L, K, G etc., has low value of relative closeness indicating low soil erosion zone.

References

Ahmed, F., and Srinivasa, R.K. (2016) Morphotectonic studies of the Tuirini drainage basin: A remote sensing and geographic information system perspective. Internat. Jour. Geol., Earth Environ. Sci., v.6(1), pp.54-65.

Alipoor, R., Poorkermani, M., Zare, M. and El Hamdouni, R. (2011) Active tectonic assessment around Rudbar Lorestan dam site, High Zagros Belt (SW of Iran). Geomorphology, v.128(1-2), pp.1-14.

Amiri, M., Pourghasemi, H. R., Arabameri, A., Vazirzadeh, A., Yousefi, H. and Kafaei, S. (2019). Prioritization of flood inundation of Maharloo Watershed in iran using morphometric parameters analysis and TOPSIS MCDM model. *In:* Spatial modeling in GIS and R for earth and environmental sciences. Elsevier, pp.371-390.

Arabameri, A., Tiefenbacher, J. P., Blaschke, T., Pradhan, B. and Tien Bui, D. (2020) Morphometric analysis for soil erosion susceptibility mapping using novel gis-based ensemble model. Remote Sensing, v.12(5), pp.874.

Arulbalaji, P. and Padmalal, D. (2020) Sub-watershed Prioritization Based on Drainage Morphometric Analysis: A Case Study of Cauvery River Basin in South India. Jour. Geol. Soc. India, v.95(1), pp.25-35.

Avinash, K., Jayappa, K.S. and Deepika, B. (2011). Prioritization of sub-basins based on geomorphology and morphometric analysis using remote sensing and geographic informationsystem (GIS) techniques. Geocarto Internat., v.26(7), pp.569-592.

Barman, B.K., Gogoi, C. and Rao, K.S. (2019) Remote sensing and GIS application for morphometric analysis of upper Mat watershed, Serchhip District, Mizoram. Jour. Appld. Geochem., v.21(2), pp.185-195.

Barman, B.K., Bawri, G.R., Rao, K.S., Singh, S.K. and Patel, D. (2021) Drainage network analysis to understand the morphotectonic significance in upper Tuirial watershed, Aizawl, Mizoram. *In:* Agricultural Water Management, Academic Press, pp.349-373.

Biswas, S., Sudhakar, S., and Desai, V.R. (1999) Prioritisation of subwatersheds based on morphometric analysis of drainage basin: A remote sensing and GIS approach. Jour. Indian Soc. Remote Sensing, v.27(3), pp.155.

Bloom, A.L. (2003) Geomorphology. A Systematic Analysis of Late Cenozoic Landforms. Pearson Education inc. Indian print, New Delhi, 482p.

Chandniha, S.K. and Kansal, M.L. (2017) Prioritization of sub-watersheds based on morphometric analysis using geospatial technique in Piperiya watershed, India. Appld. Water Sci., v.7(1), pp.329-338.

Chopra, R., Dhiman, R.D. and Sharma, P.K. (2005) Morphometric analysis of sub-watersheds in Gurdaspur district, Punjab using remote sensing and GIS techniques. Jour. Indian Soc. Remote Sensing, v.33(4), 531.

Choudhari, P.P., Nigam, G.K., Singh, S.K. and Thakur, S. (2018) Morphometric based prioritization of watershed for groundwater potential of Mula river basin, Maharashtra, India. Geol., Ecol. Landscapes, v,2(4), pp.256-267.

Danielson, T. (2013) Utilizing a high resolution Digital Elevation Model (DEM) to develop a Stream Power Index (SPI) for the Gilmore creek watershed in Winona County, Minnesota. Papers in resource analysis, v.15(11).

Goudie, S.A. (2004) Encyclopedia of Geomorphology. 1st Edition, Routledge, London.748-749.

Grohmann, C.H. (2004) Morphometric analysis in geographic information systems: applications of free software GRASS and R. Computers & Geosciences, v.30(9-10), pp.1055-1067.

Hack, J.T. (1973). Stream-profile analysis and stream-gradient index. Jour. Res. US Geol. Surv., v.1(4), pp.421-429.

Horton, R.E. (1932). Drainage basin characteristics. Eos, Trans. Amer. Geophys. Union, v.13(1), pp.350-361.

Horton, R.E. (1945). Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology. Geol. Soc. Amer. Bulletin, v.56(3), pp.275-370.

Hwang, C.L. and Yoon, K. (1981) Methods for multiple attribute decision making. *In:* Multiple attribute decision making. Springer, Berlin, Heidelberg, pp. 58-191.

Hwang, C.L., Lai, Y.J. and Liu, T.Y. (1993) A new approach for multiple objective decision making. Computers & operations Res., v.20(8), pp.889-899.

Imsong, W., Choudhury, S., Phukan, S. and Duarah, B.P. (2018) Morphodynamics of the Kulsi River Basin in the northern front of Shillong Plateau: Exhibiting episodic inundation and channel migration. Jour. Earth System Sci., v.127(5), pp.1-5.

Javed, A., Khanday, M.Y. and Ahmed, R. (2009) Prioritization of sub-watersheds based on morphometric and land use analysis using remote sensing and GIS techniques. Jour. Indian Soc. Remote Sensing, v.37(2), pp.261.

Jordán, G., Meijninger, B.M.L., Van Hinsbergen, D.J.J., Meulenkamp, J.E. and Van Dijk, P.M. (2005) Extraction of morphotectonic features from DEMs: Development and applications for study areas in Hungary and NW Greece. Internat. Jour. Appld. Earth Observation and Geoinformation, v.7(3), pp.163-182.

Kumar, B. A. (2009) Studies on river sinuosity of Meenachil river with special reference to its palaeo channels using remote sensing. Accessed on 20 May 2020. https://shodhganga.inflibnet.ac.in/handle/10603/22573

Kumar, K., Lohani, A. K., Sanjay, K., Chattered, C. and Nema, R.K. (2000) GIS based morphometric analysis of Ajay river basin upto Srarath gauging site of South Bihar. Jour. Appld. Hydrol., v.14(4), pp.45-54.

Khan, M. A., Gupta, V. P. and Moharana, P. C. (2001) Watershed prioritization using remote sensing and geographical information system: a case study from Guhiya, India. *Jour. Arid* Environments, v.49(3), pp.465-475.

Kumar, N. and Singh, S.K. (2021) Soil erosion assessment using earth observation data in a trans-boundary river basin. Nat. Hazards, pp. 1-34. DOI:10.1007/s11069-021-04571-6

Lone, A. (2017) Morphometric and Morphotectonic Analysis of Ferozpur Drainage Basin Left Bank Tributary of River Jhelum of Kashmir Valley, NW Himalayas, India. Jour. Geogr. Nat. Disast., v.7(208), pp.2167-0587.

Magar, P. and Magar, N. (2016) Application of Hack's stream gradient index (SL index) to longitudinal profiles of the river flowing across Satpura-Purna plain, Western Vidarbha, Maharashtra. Jour. Indian Geomorphol., v.4, pp.65-72.

Magesh, N.S., Chandrasekar, N. and Soundranayagam, J.P. (2011) Morphometric evaluation of Papanasam and Manimuthar watersheds, parts of Western Ghats, Tirunelveli district, Tamil Nadu, India: a GIS approach. Environ. Earth Sci., v.64(2), pp.373-381.

Mahala, A. (2020) The significance of morphometric analysis to understand the hydrological and morphological characteristics in two different morpho-climatic settings. Applied Water Sci., v.10(1), pp.1-16.

Malczewski, J. (1999) GIS and multicriteria decision analysis. John Wiley & Sons.

Melton, M.A. (1958) Correlation structure of morphometric properties of drainage systems and their controlling agents. Jour. Geol., v.66(4), pp.442-460.

Mesa, L.M. (2006) Morphometric analysis of a subtropical Andean basin (Tucuman, Argentina). Environ. Geol., v.50(8), pp.1235-1242.

Mueller, J. (2005) An Introduction to the Hydraulic and Topographic Sinuosity Indexes. Annals of the Association of American Geographers, v.58, pp.371-385.

Nag, S.K. and Chakraborty, S. (2003) Influence of rock types and structures in the development of drainage network in hard rock area. Jour. Indian Soc. Remote Sensing, v.31(1), pp.25-35.

Nautiyal, M.D. (1994) Morphometric analysis of a drainage basin using aerial photographs: A case study of Khairkuli basin, district Dehradun, UP. Jour. Indian Soc. Remote Sensing, v.22(4), 251-261.

Obi Reddy, G.P., Maji, A.K. and Gajbhiye, K.S. (2002) GIS for morphometric analysis of drainage basins. GIS lndia, v.4(11), pp.9-14.

Obi Reddy, G.P.., Maji, A.K. and Gajbhiye, K.S. (2004) Drainage morphometry and its influence on landform characteristics in a basaltic terrain, Central India–A remote sensing and GIS approach. Internat. Jour. Appld. Earth Observation and Geoinformation, v.6(1), pp.1-16.

Panda, P.C. and Bora, H.N. (1992) A study of sinuosity index of Siang River and its major tributaries: Arunachal Pradesh. Environ. Managmt., v.1, pp.97-101.

Rahaman, S. A., Ajeez, S. A., Aruchamy, S. and Jegankumar, R. (2015) Prioritization of sub watershed based on morphometric characteristics using fuzzy analytical hierarchy process and geographical information system–A study of Kallar Watershed, Tamil Nadu. Aquatic Procedia, v.4, pp.1322-1330.

Rai, P.K., Mohan, K., Mishra, S., Ahmad, A. and Mishra, V.N. (2017) A GIS-based approach in drainage morphometric analysis of Kanhar River Basin, India. Applied Water Sci., v.7(1), pp.217-232.

Ratnam, K.N., Srivastava, Y.K., Rao, V.V., Amminedu, E. and Murthy, K.S.R. (2005) Check dam positioning by prioritization of micro-watersheds using SYI model and morphometric analysis—remote sensing and GIS perspective. Jour. Indian Soc. Remote Sensing, v.33(1), pp.25.

Romshoo, S. A., Bhat, S. A. and Rashid, I. (2012) Geoinformatics for assessing the morphometric control on hydrological response at watershed scale in the Upper Indus Basin. Jour. Earth System Sci., v.121(3), pp.659-686.

Rousta, B. A. and Araghinejad, S. (2015) Development of a multi criteria decision making tool for a water resources decision support system. Water Resour. Managmt., v.29(15), pp.5713-5727.

Rudraiah, M., Govindaiah, S. and Vittala, S.S. (2008) Morphometry using remote sensing and GIS techniques in the sub-basins of Kagna river basin, Gulburga district, Karnataka, India. Jour. Indian Soc. Remote Sensing, 36(4), 351-360.

Sahu, N., Obi Reddy, G., Kumar, N., Nagaraju, M. S. S., Srivastava, R., and Singh, S.K. (2017) Morphometric analysis in basaltic Terrain of Central India using GIS techniques: a case study. Appld. Water Sci., v.7(5), pp.2493-2499.

Schumm, S. A. (1956) Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. Geol. Soc. Amer. Bull., v.67(5), pp.597-646.

Sharma, S., and Sarma, J.N. (2013) Drainage analysis in a part of the Brahmaputra Valley in Sivasagar District, Assam, India, to detect the role of neotectonic activity. Jour. Indian Soc. Remote Sensing, v.41(4), pp.895-904.

Singh, V. and Singh, S.K. (2018) Hypsometric Analysis Using Microwave Satellite Data and GIS of Naina–Gorma River Basin (Rewa district, Madhya Pradesh, India). Water Conservation Science and Engineering, v.3(4), pp.221-234.

Singh, P., Thakur, J. K. and Singh, U. C. (2013) Morphometric analysis of Morar River Basin, Madhya Pradesh, India, using remote sensing and GIS techniques. Environ. Earth Sci., v.68(7), pp.1967-1977.

Singh, S. and Singh, M.C. (1997). Morphometric analysis of Kanhar river basin. National Geograph. Jour. India, v.43(1), pp.31-43.

Smith, B. and Sandwell, D. (2003). Accuracy and resolution of shuttle radar topography mission data. Geophys. Res. Lett., v.30(9), pp.1467-1470.

Sörensen, R., Zinko, U. and Seibert, J. (2006) On the calculation of the topographic wetness index: evaluation of different methods based on field observations. Hydrol. Earth Syst. Sci., v.10, pp.101-112.

Srdjevic, B., Medeiros, Y.D.P. and Faria, A.S. (2004) An objective multi-criteria evaluation of water management scenarios. Water Resourc. Managmt., v.18(1), pp.35-54.

Sreedevi, P.D., Sreekanth, P.D., Khan, H.H. and Ahmed, S. (2013) Drainage morphometry and its influence on hydrology in a semi arid region: using SRTM data and GIS. Environ. Earth Sci., v.70(2), pp.839-848.

Sreedevi, P. D., Subrahmanyam, K. and Ahmed, S. (2005) The significance of morphometric analysis for obtaining groundwater potential zones in a structurally controlled terrain. Environ. Geol., v.47(3), pp.412-420.

Strahler, A.N. (1957) Quantitative analysis of watershed geomorphology. Eos, Trans. Amer. Geophys. Union, v.38(6), pp.913-920.

Strahler, A.N. (1964) Part II. Quantitative geomorphology of drainage basins and channel networks. Handbook of Applied Hydrology. McGraw-Hill, New York, pp.4-39.

Tandon, S.K. (1974) Litho-control of some geomorphic properties: An illustration from the Kumaun Himalaya, India. Zeitschrift für Geomorphologie, v.18, pp.460-471.

Thapliyal, A., Panwar, A. and Kimothi, S. (2017). Prioritization based on Morphometric Analysis in Alaknanda Basin. Global Jour. Sci. Front. Res.: Environ. Earth Sci., v.17(3), pp.28-34.

Triantaphyllou, E., and Lin, C.T. (1996) Development and evaluation of five fuzzy multiattribute decision-making methods. Internat. Jour. Approx. Reasoning, v.14(4), pp.281-310.

Troiani, F. and Della Seta, M. (2008) The use of the Stream Length–Gradient index in morphotectonic analysis of small catchments: A case study from Central Italy. Geomorphology, v.102(1), pp.159-168.

Varma, H., Sarup, J. and Mittal, S.K. (2020) Conception of Drainage Morphometry by using Remote Sensing and GIS. Internat. Jour. Emerging Tech., v.11(1), pp.72-77.

Vijith, H. and Dodge-Wan, D. (2019) Modelling terrain erosion susceptibility of logged and regenerated forested region in northern Borneo through the Analytical Hierarchy Process (AHP) and GIS techniques. Geoenvironmental Disasters, v.6(1), pp.1-18.

Vittala, S.S., Govindaiah, S. and Gowda, H.H. (2004) Morphometric analysis of sub-watersheds in the Pavagada area of Tumkur district, South India using remote sensing and GIS techniques. Jour. Indian Soc. Remote Sensing, v.32(4), pp.351-362.

Vincy, M.V., Rajan, B. and Pradeepkumar, A.P. (2012) Geographic information system–based morphometric characterization of sub-watersheds of Meenachil river basin, Kottayam district, Kerala, India. Geocarto Internat., v.27(8), 661-684.

Wilson, J.P. and Lorang, M.S. (2000) Spatial models of soil erosion and GIS. *In:* Fotheringham A.S., Wegener, M. (Eds.), Spatial Models and GIS: New Potential and New Models. Taylor & Francis: Philadelphia, PA, pp.83-108.

Yadav, S.K., Dubey, A., Singh, S.K. and Yadav, D., 2020. Spatial regionalisation of morphometric characteristics of mini watershed of Northern Foreland of Peninsular India. Arabian Jour. Geosci., v.13, pp.1-16.

Yadav, S.K., Dubey, A., Szilard, S. and Singh, S.K. (2016) Prioritisation of sub-watersheds based on earth observation data of agricultural dominated northern river basin of India. Geocarto Internat., v.33(4), pp.339-356.

(Received: 13 June 2020; Revised form accepted: 25 September 2020)