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DRAINAGE BASIN MORPHOMETRIC ANALYSIS IN BAGO RIVER BASIN USING GEOSPATIAL TECHNIQUES

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Abstract

Drainage basin morphometric information is very important to manage the incidence of flooding in an area. The main aim of the research is to assess the basin morphometry of Bago River Basin and evaluate its hydrological implication as relating to flooding. In this research, the topographic maps and satellite imageries are used to analyse for the hydrological and geographical techniques for basin delineation, stream ordering and digital elevation modelling. All of the results showed that the drainage basin is characterized by stream segments, mean bifurcation ratio and stream frequency. The flood potential area of the Bago River Basin assessed by the morphometric analysis,

Keywords: *Basin; dendritic; drainage; flood; morphometry.*

Introduction

The drainage basin is a unique geographical unit characterized by distinct drainage network and ecosystem (Samson et al., 2016). A drainage basin morphometry study involves linear and relief parameters of the basin which help us to understand the natural environment of the basin and also they summarize spatial characteristics of the basin. Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Jahan, C.S., Rahaman, M.F., Arefin, R. et al., 2018). In recent time, these methods are used to analyse in several ecological hazards directly or indirectly associated with drainage morphometry include flooding, erosion, mass movement, soil pollution and deforestation etc. Bago River Basin morphometric is provided to understand the underlying factors controlling the hydrological behaviour as well as providing the mandatory data and consequent implication of hydro-related disasters.

Study Area

The Bago River basin covers an area of approximately 5358 sq.km and is located between North Latitudes 17º 10" and 18º 05" North Latitudes and between 96º 00" and 96º 50" East Longitudes (Figure 1). In the study area, the northwestern part is higher than the south and southeastern part, at an elevation ranging from 6m to about 800 m above sea level. Bago City is also located in the study basin area.The Bago River basin is significantly affected by the lithological characteristics and faulting and jointing. According to the geology time scale, this study area has mainly found Holocene-Recent Alluvium, Miocene-Upper Pegu Group and marine, brackish and terrestrial equivalents. Miocene-Pliocene - Irrawaddy Group and equivalents. And also, Meadow Alluvium soil, Yellow Brown Forest soils are mostly found in this area.

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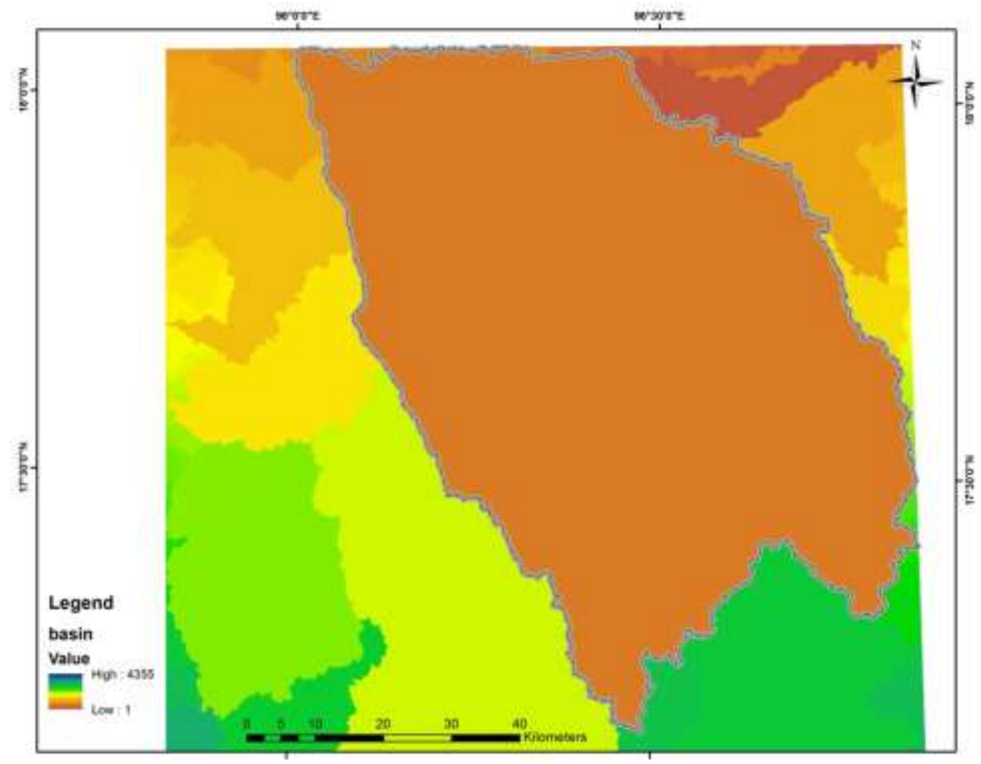


Source: created by ASTER DEM(30 m)

Figure 1 The Study area of Bago River Basin

Aim

- To assess the basin morphometry of Bago River Basin and evaluate its hydrological implication as relating to flooding.

Objectives

- To identify the drainage morphometric characteristics of the Bago River basin and
- To examine the implication of the morphometric characteristics on basin flood potential in the study area.

Methods and Data Used

Morphometric analysis for Bago River Basin was conducted using topographic maps with a scale 1:50,000 (10 m contour interval), ASTER DEM, and Arc GIS 10.4.1 software package. ASTER DEM is used at present to delineate watershed and sub-watershed boundaries, and drainage networks, to derive and calculate drainage morphometric parameters of the Bago River Basin. Different terrain features or maps for the study area such as aspect, slope, and elevation were generated using the Spatial Analyst tool. Topo sheets were used initially to demarcate the boundaries of the watersheds, then, the Arc Hydro tool was utilized to delineate the final watershed boundaries and stream networks of the Bago River Basin.

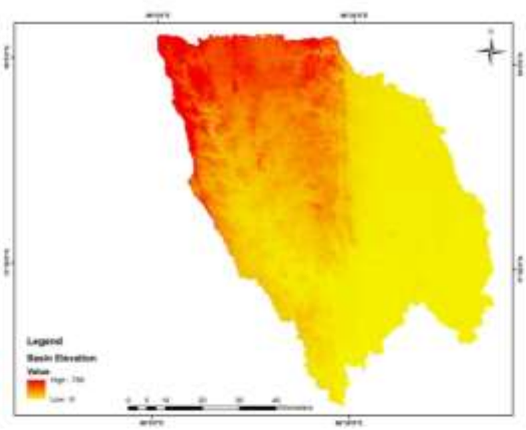
The stream order maps created from the flow direction map for each watershed using Stream Order tool. The stream ordering system was based on a Strahler's method. Basic morphometric parameters like area (A), basin length (L_b), perimeter (P), stream order (u), stream number (Nu), stream length (Lu), were measured directly from the DEM using GIS software. Other parameters are also included bifurcation ratio (Rb), drainage density (Dd), drainage frequency (Fs), length of overland flow (Lo), circularity ratio (Rc), elongation ratio (Re), basin relief (Bh), relief ratio (Rr), form factor (Rf), and shape factor (Bs) were calculated from mathematical equations illustrated in Table 1.

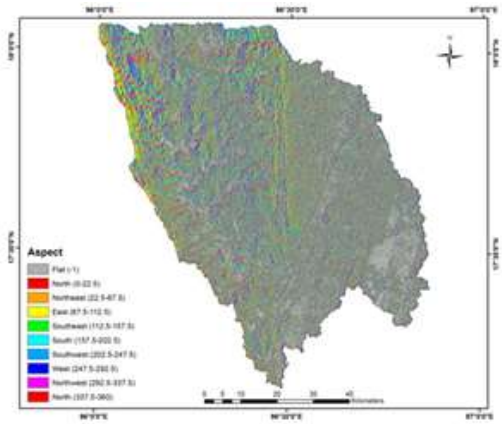
To assess floods potential for Bago River Basin, according to the Strahler (1958), the simple morphometric method which has been designated to estimate flood risk levels and the degree of hazardousness for the basin. Two different approaches were elaborated to determine the hazardous area. Among these approaches, the first is based on the relationship between bifurcation ratio (R_b) and drainage density (D_d) and the second is employed the relationship between bifurcation ratio (Rb) and stream frequency (Fs). Drainage density (D_d) refers to relief dissection, runoff potential, and infiltration capacity of surface materials, climate, and land cover of the watershed. Low values of D_d indicate the most favourable conditions of infiltration, thus decreasing runoff potential, while, high stream frequency (Fs) characterises impermeable sub-surface materials, poor vegetation cover, high relief, and low infiltration capacity, thus, increasing runoff potential. The resultant illustrations for D_d vs. R_b and Fs vs. R_b have to be plotted graphically, where each illustration contains two curves dividing the flood potential area. And also create Land cover and land use map using Landsat image.

Results and Discussion

Morphometric Analysis

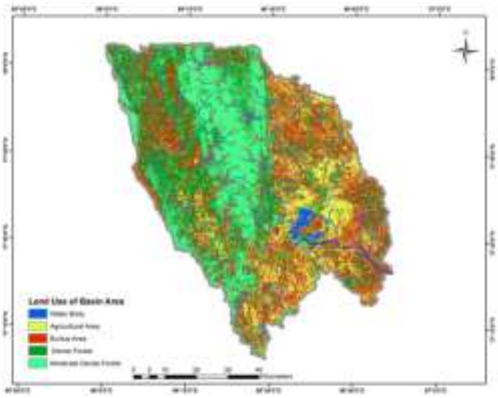
Quantitative analysis of the Bago River Basin was based on 19 morphometric variables which represent drainage network, geometry, texture, relief ,aspects and land use of the basin area (figure 2 to 6). The drainage pattern of the Bago River Basin is dendritic to sub-dendritic type on dip slopes. In the present study, stream ordering for the Bago River Basin has been ranked according to the Strahler's method of the hierarchical ranking system. The calculated morphometric parameters are illustrated in Table 1.

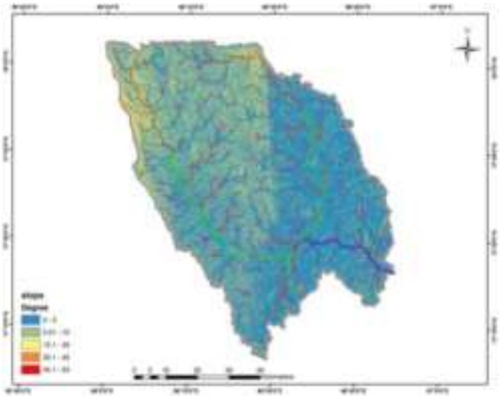




Source: created by Aster DEM (30 m)

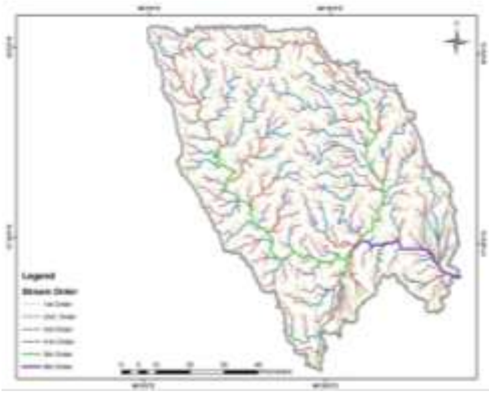
Figure 2. Elevation of Bago River Basin **Figure 3**. The Aspect of Bago River Basin





Source: created by Aster DEM (30 m)

Figure 4 The Land Cover / Landuse map **Figure 5** The Slope map



Source: created by Aster DEM (30 m)

Figure 6 The Stream order map of Bago River Basin

Table 1 **Morphometric parameters and their formula.**

Morphometric parameters	**Formula/definition**
I. Drainage network	
1) Stream order (u)	Hierarchical rank
2) No. of streams (N_u)	$N = N_1 + N_2 + \cdots + N_n$
3) Stream length (L_u) km	$L_u = L_1 + L_2 + \cdots + L_n$ (km)
4) Mean stream length (L_{sm}) km	$L_{sm} = L_u/N_u$ (km)
5) Stream length ratio (R_L)	$R_L = L_u/L_u-1$, where Lu = the total stream length of order"u", L_u-1 = the total stream length of its next lower order
6) Bifurcation ratio (R_b)	R_b = Nu/Nu+1, where Nu = total no. of stream segments of order"u", Nu+1 = no. of segments of the next higher order
7) Mean bifurcation ratio (R_{bm})	R_{bm} = average of bifurcation ratio of Strahler all orders
II. Basin geometry	
8) Basin length (L_b) km	Length of the basin (km)
9) Basin area (A) km^2	Plan area of the watershed (km2)
10) Basin perimeter (P) km	Perimeter of the watershed (km)
11) Form factor (ratio) (Rf)	$Rf=A/L_b^2$
12) Elongation ratio (Re)	$R_e = 1.128 \sqrt{A}/L_b$
13) Shape factor (B_s)	$B_s = L_b^2/A$
14) Lemniscate ratio (k)	K = L2/4A
15) Circularity ratio (Rc)	Rc = 4∗π∗A/P2
16) Drainage texture (Dt)	$Dt = N_u/P$, where Nu = Total no. Streams of all orders, P = perimeter (km)
III. Drainage texture analysis	
17) Stream frequency (Fs)	Fs = Nu/A
18) Drainage density (Dd)km/km^2	Dd = Lu/A
19) Drainage intensity (Di)	Di = Fs/Dd
20) Length of overland flow (L_o) km	L_o = 1/2 Dd
IV. Relief characteristics	
21) Basin relief (B^h) or total relief (H) m	Bh = h − h1, where, h = maximum height (m), h1 = minimum height (m)
22) Relief ratio (R_r)	Rr = H/Lb, Where H = total relief, Lb = basin length
23) Ruggedness number (R_n)	Rn = Dd∗(Bh/1000)
24) Dissection index (Dis)	Dis = Bh/Ra, where Ra = absolute relief
25) Hypsometric curve (HC)	HC is achieved by plotting the proportion of the total height (h/H) against the proportion of the total area (a/A) of the basin, where H is the total relief height, a is the total area of the basin above a given line of elevation h.
26) Hypsometric integral (Hi)	Hi = (H−H) (H−h) , where H = the weighted mean elevation H = maximum elevation h = minimum elevation

Source: Adapted from Strahler (1958)

Table 2 Morphometric Characteristics of Bago River Basin

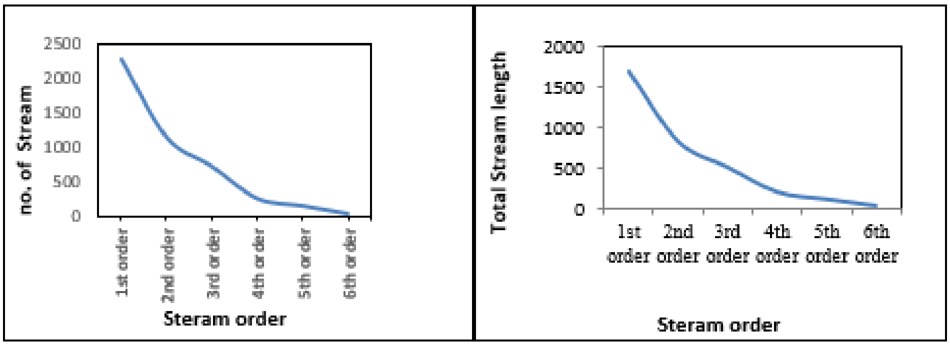
Sr.No	Streams	1st order	2nd order	3rd order	4th order	5th order	6th order
1	Total length(km)	2255.26	1137.33	721.76	262.09	155.51	42.82
2	Total no. of Stream	1691.00	825.00	508.00	202.00	113.00	33.00
3	Mean(Lsm)	1.33	1.38	1.42	1.30	1.38	1.30
4	Bifurcation Ratio (R_b)	2.05	1.62	2.51	1.79	3.42	
5	length Ratio(R_L)		0.50	0.63	0.36	0.59	0.28
6	Basin Length	116.02					
7	Basin Area	5357.65					
8	Basin Perimeter	502.13					
9	Drainage Density	0.85					
10	Basin Relief	753.00					
11	Relief Ratio	0.17					
12	Elongation Ratio	1.22					
13	Basin Shape	2.51					
14	Circular ratio	0.27					
15	Stream frequency (Fs)	0.63					
16	Form factor (Rf)	0.40					
17	Drainage texture (Dt)	6.72					
18	Drainage intensity (DI)	0.74					
19	Length of overland flow (Lo) Km	0.43					

Source: Adapted from Strahler (1958)

The calculated morphometric parameters are illustrated in Table 1 and this basin area is of sixth-order basin. The structure, lithology, morphology and slope steepness are mainly influencing on the drainage network development. By contrast, lithological uniformity and relative availability of rainfall and long dip slopes intensified erosional processes, thus stream length and area increased at a rate exceeding the rate of increase in stream number.

Drainage Network

The total number of streams (Nu) for the Bago River Basin is 3372, and among these stream order, the first order streams account for 50.15% of the total number of streams in basin. The details of stream characteristics are ascertained by Horton's first law (Horton, R. (1945), the "law of stream number", which states that the number of streams of various orders in a given drainage basin tends to closely approximate an inverse geometric ratio. This inverse geometric relationship is shown graphically in the form of a straight line when no. of the stream is plotted on an ordinary graph (Figure 7). It is also verified that the number of streams gradually decreases because the stream order increases. 1) Stream length (Lu) is a major effect of hydrological property and indicative of runoff characteristics, geomorphic development of stream segments, and tectonic instability. Generally, the higher the order, the longer the length of stream are in nature. The steam length has been calculated according to the law elaborated by (Horton, R. (1945).



Source: Horton's First law and second Law

Figure 7 Relationship between no. of Stream, Stream Length and Stream order

The total stream length is 4574.77 km of the basin. The first order streams constitute 50.15 % of the total stream length related to in the Bago River Basin. The stream length characteristics of the Bago River Basin verifies Horton's second law, the "law of stream length", which indicates that the average length of streams of each of the various orders in a drainage basin tends to closely approximate a direct geometric ratio. The geometric linear relationship is shown graphically when the log values of these parameters are plotted on a normal graph (Figure 7). However, slight deviations from a straight line are obvious at high and low orders due to uplifting of the Bago River Basin. 2) Mean stream length (Lsm) values of the stream order for the basin are nearly identical. Stream length ratio (RL) is that the ratio between the mean length of streams of a given order to the mean length of streams within the next lower order. RL is taken into account a significant factor about both drainage composition and geometric development of drainage basins. A significant variation occurs in RL values between the streams of different orders pertaining in Basin (0.5 – 0.28). This variation is attributed to morphological changes in slope and relief along the basin and also the youth-age stage of geomorphic development of the watersheds as verified later through hypsometric analysis (Table 2). 4) Bifurcation ratio (Rb) is elaborated by Horton as an index of relief and dissection. Its value is approximately 2 for flat or rolling drainage basins, and up to 3 or 4 for mountainous or highly dissected drainage basins. Characteristically, Rb values range between 1.62 and 4.42 for watersheds during which the geological structures distort the drainage pattern. In contrast, lower values of Rb are representative for structurally less disturbed catchments without any distortion in drainage pattern (Schumm, S.A. (1956). Abnormally high bifurcation ratio exposed the regions of steeply dipping rock strata. The result of the mean bifurcation ratio (Rbm) for the basin is 2.28, therefore, this basin is an almost flat area. The drainage development of the basin is remarkably influenced by structural disturbances such as faulting, uplifting of the Bago River Basin and rejuvenation of the drainage network.

Basin Geometry

A significant variation exists in the values of morphometric parameters which represent basins geometry like basin area, basin length and basin perimeter. The area of the Bago River Basin is 5357.65 km^2. Basin length of the study area is also 116.0191km (Table 2). Moreover, the perimeter of the basin is 502.13 km. Form factor (R_f) is expressed as the ratio between the area of the catchment (A) and the square of the catchment length (Horton, R. (1945)). The Rf parameter is examined to predict the intensity of a basin of a defined area. For a perfectly circular basin, the value of the form factor should always be less than 0.79 (Chopra, R., Dhiman, D. and Sharma, K. (2005)). The smaller the value of Rf (<0.45), the more the basin will be elongated. Catchments with high Rf have peak flows of shorter duration, whereas elongated watersheds with low form factors have lower peak flow of longer duration (Youssef, A., Pradhan, B. and Hassan, A. (2011)). The Rf value of the basin is 0.4 that is indicating elongated shape and suggesting a flat hydrograph peak for a longer duration. Flood flows of such elongated basins are easier to manage than watersheds developed towards rectangular to a circular shape. Thus, high peak flows of shorter duration are expected during flash floods. Therefore, the morphological characteristics of a basin have powerful impacts on watershed hydrology. Elongation ratio (Re) is defined as the ratio between the diameters of the circle of the area as represented by the drainage basin to the maximum basin length (Schumm, S.A. 1956). Strahler, A.N. (1964) stated that Re values vary generally between 0.6 to 1.0 over a wide range of climate and geological conditions. Values close to 1.0 are characteristic of regions with very low relief, whereas values in the range of 0.6 - 0.8 are normally diagnostic of watersheds with high relief and steep slopes. Where Re approaches 1.0, the shape of the drainage basin approaches a circle (Schumm, S.A., 1956). It has been concluded that a circular basin is more efficient in the runoff than is an elongated one (Singh, S. and Singh, M.C. 1997). Re value for Bago River Basin is greater than 1 (Table 2) that indicate are approaching the circular shape. Shape factor (Bs) is calculated by dividing the square of the length of a basin by the area of the basin (Horton, R., 1945) and is considered in inverse proportion to the form factor (Rf). The shape of the drainage basin along with the length and relief affect the rate of water and sediment yield. Bs values for the basin are 2.51, therefore, it may have a longer basin lag time.

Circularity ratio (Rc) refers to the ratio of catchment area (A) to the area of circle having the same circumference as the perimeter of the catchment (Miller, V.C., 1953). The Rc is controlled by the length and frequency of the streams, geological structures, landuse, land cover, climate, relief and slope steepness of the catchment. Drainage basins with a range of circularity ratios of 0.4 to 0.5 were described by Miller, indicating that they are strongly elongated, highly permeable, with homogeneous geological materials. The Rc for the basin is 0.27 indicating that is characterized by high relief, elongated and relatively permeable surface resulting in greater basin lag times, while catchments belonging to the dip slopes show delayed time to peak flow. It can be concluded that Rf, Re and Rc significantly influence the hydrological response of the Bago River Basin. Also, the combination with basin shape and the arrangement of stream segments has a direct influence on the size and shape of flood peak (Ward, R.C. and Robinson, M., 2000).

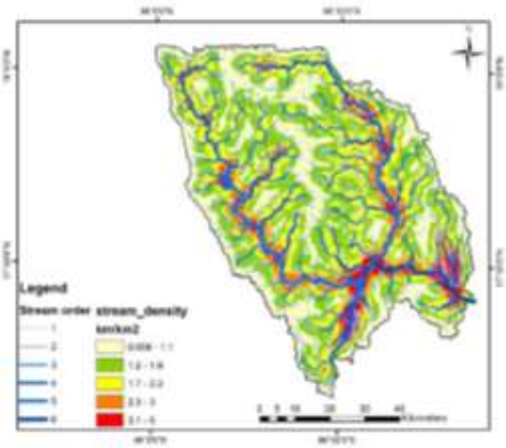
Drainage texture (D_t) denotes relative spacing of drainage lines in a fluvial dissected terrain. It is defined as the total number of stream segments of all orders per perimeter of the drainage basin (Horton, R., 1945). Drainage texture (D_t) is also one of the main concepts in drainage basin geomorphology. D_t is dominated by several intrinsic physical factors such as climate, rainfall, vegetation, soils, lithology, infiltration-capacity, relief and stage of basin development. Smith, K.G (1950) has identified five different texture categories: drainage density < 2 indicates very coarse texture, between 2 and 4 is described as coarse texture, between 4 and 6 is moderate, between 6 and 8 is fine, and >8 is very fine drainage texture. The D_t values for the Bago River Basin are 6.72 exhibits fine drainage texture.

Drainage Texture Parameters

Stream frequency (Fs) acts as the ratio of the total number of streams (Nu) in a basin to the basin area (A) and is defined as the number of streams per unit area (Horton, 1945). Fs values are mainly depended on the lithology of the catchment and reflect the texture of the drainage network. The Fs values are positively correlated with D_d value of a watershed, which means that the increase in stream population is connected to that of drainage density (Tucker, G.E. and Bras, R.L., 1998). High stream frequency means more percolation concerning to drainage density and thus more groundwater potential (Sreedevi, P.D., Sreekanth, P.D., Khan, H.H and Ahmad, S., 2013). The observed stream frequency (Fs) value is 0.63 in the Bago River Basin. The Fs values indicate steep slopes, with low permeability rocks, thus facilitating less infiltration and greater surface flow and high flooding potential area.

Drainage density (D_d) is examined the closeness of spacing of channels and regarded a quantitative expression of terrain dissection and runoff potential of the catchment. Drainage density is a measurement of the total lengths of streams in a catchment per unit area. High drainage density of an area illustrates high runoff, consequently low infiltration rate, whereas; low drainage density of an area also illustrates high runoff, and consequently low drainage density of an area refers to low runoff and high infiltration. Other significant parameters determining of the D_d are infiltration-capacity of the soils, and initial resistances of terrain to erosion well-drained basins have a drainage density of 0.85, in the study area.

Length of overland flow (L_O) associates with the length of water over the ground before it becomes concentrated into definite steam channels. It is considered the most important independent variable affecting hydrological and geomorphological development of drainage basins. According to Horton, (1945) the average length of overland flow is relatively half the average distance between stream channels, and thus, is approximately equal to half of the drainage density. Length of overland flow relates inversely to the average channel slope (Patel, D., Dholakia, M., Naresh, N. and Srivastava, P., 2012). The Lo value for the basin area is 0.43 indicating very steep slopes and shorter flow part.



Source: calculated from variables

Figure 8 Stream Density in Bago River Basin

Relief Characteristics

Basin relief (Bh) or "total relief" of a watershed is defined as the difference in elevation between the highest and lowest points on the basin (Schumm, S.A., 1956). Commonly, relief measures are indicative of the potential energy of a drainage system present by the elevation above a given datum (Strahler, A.N., 1964). Basin relief is a significant factor in understanding the denudational properties of the catchment, landforms and drainage networks evolution, overland flow, through flow, and erosional behaviour of the terrain. The total relief of the study area is 753m. Relief ratio (Rr) is analysed to measure the overall steepness of a drainage basin.

Conclusion

The 19 variables of the Bago River Basin is calculated for morphometric analysis. A significant variation exists in the geomorphometric parameters characterizing both categories. Drainage density (D_d), relief ratio (Rr), elongation ratio (Re), circularity ration (R_c) and ruggedness number (R_n) vary significantly. High values of mean bifurcation ratio (R_{bm}) designate the structural and lithological control on drainage network development across the study area. The variation in stream length ratio points out the variation in morphological characteristics of the watersheds especially slope and topography. A dendritic drainage pattern dominated in the study area. Bago City is located in the flat area and the stream density is also high. Due to the conditions, this area always experience under flooding every year. This study analysed the socioeconomic of the flood vulnerable areas are endangered, and recommends preparedness for potential flood hazards in the area. Therefore, most of the variables are important for the basin morphology and flooded area.

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