

Evaluating Discharge Capacity of Major Chara's of Sylhet City Using GIS

Gulam Md. Munna*, Jahir Bin Alam, Jobayer Ahmed, Abdullah Al Mamun

Department of Civil and Environmental Engineering, Shahjalal University of Science and Technology (SUST), Kumargaon, Sylhet-3114, Bangladesh

Email: *gmunna192-cee@sust.edu

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Abstract

Heavy rainfall is one of the most frequent and widespread severe weather hazards that affect Sylhet city. In Sylhet, nine natural channels locally called "chara" are mainly responsible for the drainage of heavy rainfall to the Surma River. The present condition of this natural drainage is not feasible due to the unplanned land development and manipulation by people. So water logging is a common scenario of Sylhet city. Many parts of Sylhet city are experiencing the severe inundation problem due to heavy rainfall. Time series analysis of rainfall data (1974-2015) is important for knowing and predicting of rainfall variation. Mann-Kendall analysis showed no trend for monthly and yearly rainfall data. The rainfall intensity of Sylhet is higher than other districts of Bangladesh. In this study, IDF (Intensity Duration Frequency) curve has been developed that is commonly used in engineering planning and design. By using IDF curve, ArcGIS software, DEM map, and normal discharge, maximum discharge for a different point of Mongoli chara and Bolramer chara has been calculated (for 25 years return period). Discharge through Mongoli chara and Bolramer chara has been represented in ArcMap using ordinary kriging. To keep the catchment of those chara free from inundation and water logging problem, this calculated discharge needed to be managed.

Keywords

ArcGIS, Canal, Chi-Square, Gamble Distribution, IDF Curve, Mann-Kendall, Rainfall

1. Introduction

Bangladesh is affected by various types of natural disasters almost every year because of the global warming as well as climate change impacts. Bangladesh is a low-lying country with more than 230 waterways, is one of the most disas-

ter-prone nations in the world [1]. Fifteen percent of its land floods annually on average [2]. As the lowest riparian in a huge trans-boundary river basin, Bangladesh faces increasing threat of massive flood exposure [3].

Floods are a natural and certain event. Natural flood management includes techniques and process that aim to work with natural hydrological and morphological processes, features and characteristics to deal with the sources and pathways of flood waters.

The outcome of urbanization is broadly known as hydraulic studies since there have been increasing problems in urban storm water drainage management. One of the most important facilities in preserving and improving the urban environment is an adequate and properly functioning storm water drainage system which includes storm water movement and storage capacity.

Numerous catchments in Bangladesh are currently under serious pressure from urban, industrial and infrastructure development where downstream receiving water bodies such as river, lakes, channels, pond and reservoirs have turned out to be touchy to build rates and volumes of overflow and contamination release.

Inadequate drainage causes needless death and disease and loss of home, property and live hoods. Poor storm water management also pollutes the environment and squanders limited freshwater resource. A sound investment in storm water can reduce those losses, but only after setting priorities and making different choices [4] [5].

Integrated storm water is still a moderately new idea in many countries including Bangladesh. Present experience indicates that end-of-pipe, rapid disposal, localized reactive and mono-functional drainage concepts have been generally practiced in Bangladesh. The local design makes and professionals are beginning to recognize the need for a new and broader approach to urban drainage, flood control and storm water management in the light of development in the country processing at a tremendous stress.

2. Study Area

Our study areas are Mongoli Chara and Bolramer Chara in Sylhet City (**Figure 1**) of Bangladesh. The local design makes and professionals are beginning to recognize the need for a new and broader approach to urban drainage, flood control and storm water management in the light of development in the country processing at a tremendous stress.

3. Materials and Methods

The study area contains many rainfall stations of Bangladesh Meteorological Department (BMD). The daily rainfall data was collected from BMD for the years 1973 up to 2015 (Total 41 years). For the continuity of the data, the entire record of gauging station was verified.

3.1. Trend Analysis

Mann-Kendall trend test is a nonparametric test used to identify a trend in a

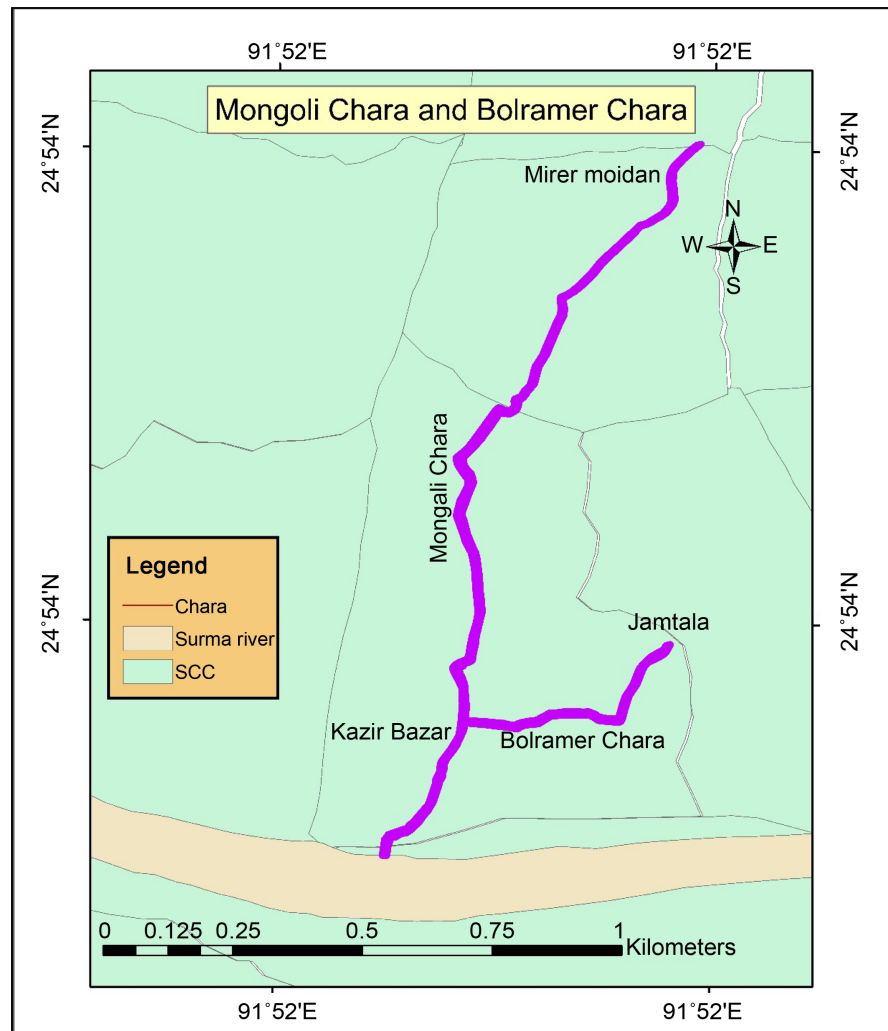


Figure 1. Mongoli Chara and Bolramer Chara in Sylhet, Bangladesh. Mongoli Chara: It flows from Mirer Moidan road to Old Medical, cross the Chouhatta-Rikabi bazaar road and flows southward to Soros pur, Jallar par, Kazir bazaar, Sheik Ghat and Taltota. Finally the chara falls into Surma River crossing the Kazir bazaar-Tookhana road. Bolramer Chara: Bolramer Chara is flowing from Jamtala (south of Jallar par road), Bondar bazaar and Taltota. One part of it meets with Mongoli Chara near the Mohan Market and another part falls on Surma River near Kazir bazaar.

series. The purpose of the Mann-Kendall (MK) test [6] is to statistically assess if there is a monotonic increase or decrease trend of the rainfall of 1974 to 2015 [7].

3.2. Development of Short Duration Rainfall Data

Short duration data are rare in development countries like Bangladesh. The data of 24-hour rainfall records are available in rain gauge stations.

Indian Meteorological Department (IMD) uses an empirical reduction formula [8].

$$P_t = P_{24} [t/24]^{1/3} \quad (1)$$

where, P_t is the required rainfall depth in mm at t hr. duration, P_{24} is the daily rainfall in mm and t is the duration of rainfall for which the rainfall depth is required in hr.

For estimation of various duration like 1-hr rainfall values from annual maximum daily rainfall data, Chowdhury *et al.* [8], used Indian Meteorological Department (IMD) empirical reduction formula to estimate the short duration rainfall from daily rainfall data in Sylhet city and found that this formula gives the best estimation of short duration rainfall [9]. In this study, this empirical formula was used to estimate the short duration rainfall in SCC.

3.3. Probability Distribution and Chi-Square Test

To identify a specific theoretical distribution for the available data it is important to find an acceptable method. The aim of the test is to find how good a fit is the observed and the predicted data. Chi-square is one of the most widely used tests to find the best fit theoretical distribution of any specific dataset which is represented by this formula [10].

$$X^2 = \sum_{i=1}^n \frac{(O_i - E_i)^2}{E_i} \quad (2)$$

where, O_i and E_i represent the observed and expected frequencies respectively. If the observed frequencies are close to the corresponding expected frequencies, the X^2 value will be small, indicating a good fit; otherwise it will be a poor fit. Chi-Square test was performed by sigma magic software.

3.4. Short Duration for Gumbel Distribution

Short duration rainfall data such as 5 min, 10 min, 15 min, 30 min, 45 min, 120 min have been developed using the depth-duration formula [10].

$$\frac{P_t^T}{P_{60}^T} = 0.54t^{0.25} - 0.50 \quad (5 \leq t \leq 120 \text{ min}) \quad (3)$$

$$\frac{P_t^T}{P_t^{10}} = 0.21 \ln T - 0.52 \quad (2 \leq T \leq 100 \text{ years}) \quad (4)$$

where, P_t^T is the depth of t -minute, T -year return period rainfall, P_t^{10} is the depth of a t -minute, 10-year return period rainfall and P_{60}^T is the depth of a 60-minute, T -year return period rainfall.

3.5. Development of Rainfall Intensity Duration Frequency (IDF) Curve

IDF curve is used for estimating the maximum rainfall intensity for the different duration and return period. A specified return period T and duration t is calculated for the rainfall depth. Its mean intensity I_m (mm/hour) has been obtained dividing it by the duration t (hour). Then the IDF curve is obtained by plotting, on a graph, the mean intensity I_m (mm/hour) against the duration D (min).

Mathematically, this curve can be represented in different forms as follows [9]:

$$i = \frac{a}{(b + D)^n} \quad (5)$$

$$i = x * (D)^{-y} \quad (6)$$

where, i is rainfall intensity in mm/hr, D is duration of rainfall in minutes, the parameters a , b , n , x , y define the shape and appropriate units for curve fitting to IDF data.

3.6. Catchment Area of Chara

The catchment area of Mongoli Chara and Bolramer Chara has been identified through field survey and contour map. The direction of runoff flow has been identified during field survey and consulting local people. And then the catchment area was divided into some regions.

3.7. Runoff Coefficient

The runoff coefficient C is the variable of the rational method. The runoff coefficient (C) is a dimensionless coefficient relating the amount of runoff to the amount of precipitation received. It is a larger value for areas with low infiltration and high runoff, and lower for permeable, well-vegetated areas [11]. Where watershed is not homogeneous, a weighted runoff coefficient should be determined. A weighted runoff coefficient is computed using the following equation [9]:

$$C_w = \frac{\sum_{j=1}^n C_j A_j}{\sum_{j=1}^n A_j} \quad (7)$$

where, A_j is the area for land cover j , C_j is the runoff coefficient for area j , N is the number of distinct land covers within the watershed, and C_w is the weighted runoff coefficient.

3.8. Time of Concentration

Time of concentration (T_c) is the time required for runoff to travel from the hydraulically most distant point in the watershed to the outlet. The hydraulically most distant point is the point with the longest travel time to the watershed outlet, and not necessarily the point with the longest flow distance to the outlet. Time of concentration is generally applied only to surface runoff and may be computed using many different methods. Time of concentration will vary depending upon slope and character of the watershed and the flow path characteristics [12] [13].

The U.S. Federal Aviation Agency (FAA) developed a simple estimation of T_c to be used with the Rational Method [14]. Time of concentration (T_c) is an important variable in many hydrologic methods, including the Rational and Natu-

ral Resources Conservation Service procedures. For the same size watershed, the shorter the T_c , the larger the peak discharge [14].

$$T_c = \frac{1.8 * (1.1 - C) * \sqrt{L}}{\sqrt[3]{S}} \quad (8)$$

where, C is the cover factor, L is the hydraulic length in ft, and S is the slope in Percent.

3.9. Discharge Due to Rainfall

The rational formula has developed the relation between rainfall and discharge. Discharge due to rainfall calculated by this formula [15].

$$Q_r = \frac{C * i * A}{360} \quad (9)$$

where, Q_r : Peak discharge (m^3/s) C : Runoff Coefficient.

i : Rainfall intensity during time of concentration (mm/hr).

A : Drainage Area (ha).

3.10 Discharge Due to Population

There are many formulas for population prediction. The geometric mean increase is used to find out the future increment in population. Assuming that, the future population is increasing at a constant rate. Geometric increase formula [16] is:

$$p_n = p_o \left(1 + \frac{r}{100} \right)^n \quad (10)$$

Here, p_n = population after n year, p_o = Present population, r = rate of growth and n = number of year.

Discharge Due to Population [14]:

$$Q_p = X * P \quad (11)$$

where, Q_p = Discharge due to population, X = Per capita discharge and P = Total population.

4. Result and Discussion

4.1. Monthly Rainfall Trend Analysis

There are several statistical tests available for testing stationeries of time series. In the present study, the Man-Kendell test (Table 1) for linear trend has been carried out for the monthly rainfall series from 1974 to 2015 of Sylhet.

Table 1. Trend analysis.

Kendall's tau	S'	P-value (one-tailed)	Alpha
-0.0619	-535	0.9766	0.05

There is no trend observed in monthly rainfall data series to find the best fit

that the observed frequencies are near to the corresponding expected frequencies.

4.2. Chi-Square Test

Chi-Square test has been performed by 1-hr rainfall data that shown in **Table 2**.

Table 2. Chi-square test.

Distribution	Chi-Square values	P	Fit
Beta	6.52	0.368	Ok
Cauchy	5.87	0.438	Ok
Erlang	6.58	0.362	Ok
Gumbel	3.43	0.753	Ok
Exponential	10.06	0.122	Ok
Gamma	5.46	0.486	Ok
Laplace	12.54	0.051	Ok
Log	4.94	0.551	Ok
Logistic	8.66	0.194	Ok
Log	6.15	0.406	Ok
Normal	11.94	0.063	Ok
Pareto	9.99	0.125	Ok
Power	11.7	0.069	Ok
Rayleigh	8.25	0.221	Ok
Weibull	732.09	<0.001	

Beta distribution, Cauchy distribution, Gamma distribution, Rayleigh distribution, Logistic distribution, Gumbel distribution fits the data. Chi-Sq. value is low for Gumbel distribution, so the Gumbel distribution best fits the selected data.

4.3 Gumbel Distribution

1-hour 2, 5, 10, 25, 50, 100-year rainfall depth for Sylhet is estimated using Gumbel distribution formula which has been show in **Table 3**.

Table 3. 1-hour rainfall depths at different rainfall periods.

T (year)	K	P_{avg} (mm)	S (mm)	P_T (mm)
2	0.16427			66.84
5	0.71945			82.10
10	1.30456	69.68	17.26	92.20
25	2.04385			104.96
50	2.59229			114.43
100	3.13668			123.82

Rainfall depth depends on return period. While return period is 2 year rainfall depth is low. But with the increase of return period rainfall depth increase simultaneously. In 2 year return period rainfall depth is 66.847 mm and in 100 year return period rainfall depth is 123.82 mm.

4.4. Development of Rainfall Intensity Duration

Within same return period rainfall depth depends on rainfall duration. Rainfall depth is increased with the increase of rainfall duration. In 2 year return period for 5 min and 120 min rainfall depth is 20.55474 mm and 86.05012 mm respectively. Average intensities of rainfall for different return periods have been calculated by dividing t minute rainfall depths by the corresponding duration of t (hour) (**Table 4**).

Table 4. Rainfall depths of Sylhet for t -minute.

Return period	Rainfall depth (mm)					
	5 min	10 min	15 min	30 min	60 min	120 min
2 year	20.55474	30.76783	37.61590	51.05708	66.84722	86.05012
5 year	25.24534	37.78905	46.19985	62.70831	82.10177	105.6868
10 year	28.35097	42.43780	51.88327	70.42257	92.20178	118.6882
25 year	32.27496	48.31151	59.06431	80.16960	104.9632	135.1155
50 year	35.18596	52.66891	64.39155	87.40039	114.4302	147.3021
100 year	38.07547	56.99413	69.67944	94.57779	123.8274	159.3987

4.5. Intensity-Duration-Frequency (IDF) Curve

Short duration rainfall data such as 5 min, 10 min, 15 min, 30 min, 45 min, 120 min for 2, 5, 10, 25, 50, 100-year have been developed using the depth-duration formula. Within same return period, rainfall intensity depends on rainfall duration. Rainfall Intensity decrease with the increase of rainfall duration. In 2 year return period for 5 min and 120 min rainfall Intensity are 246.6569 mm and 43.02506 mm respectively. For the same duration, rainfall intensity depends on rainfall duration. Rainfall intensity is increasing with the increase of return period. For 30 min duration 2 years and 100 years rainfall intensity is 102.1142 mm and 189.1556 mm. Intensity-Duration-Frequency (IDF) curve has been developed by plotting average intensities against the duration of rainfall. IDF curve for Sylhet has been shown in **Figure 2**.

For same year return period, rainfall intensity decrease with the increase of time duration. For same time duration rainfall intensity is higher for higher return period. It was observed in the study that the IDF empirical equation form

$$i = x * (D)^{-y} \text{ had the best fit rather than the equation form } = \frac{a}{(b + D)^n}.$$

4.6. Derivation of IDF Equation

To derive an equation for calculating rainfall intensity for the regions of interest

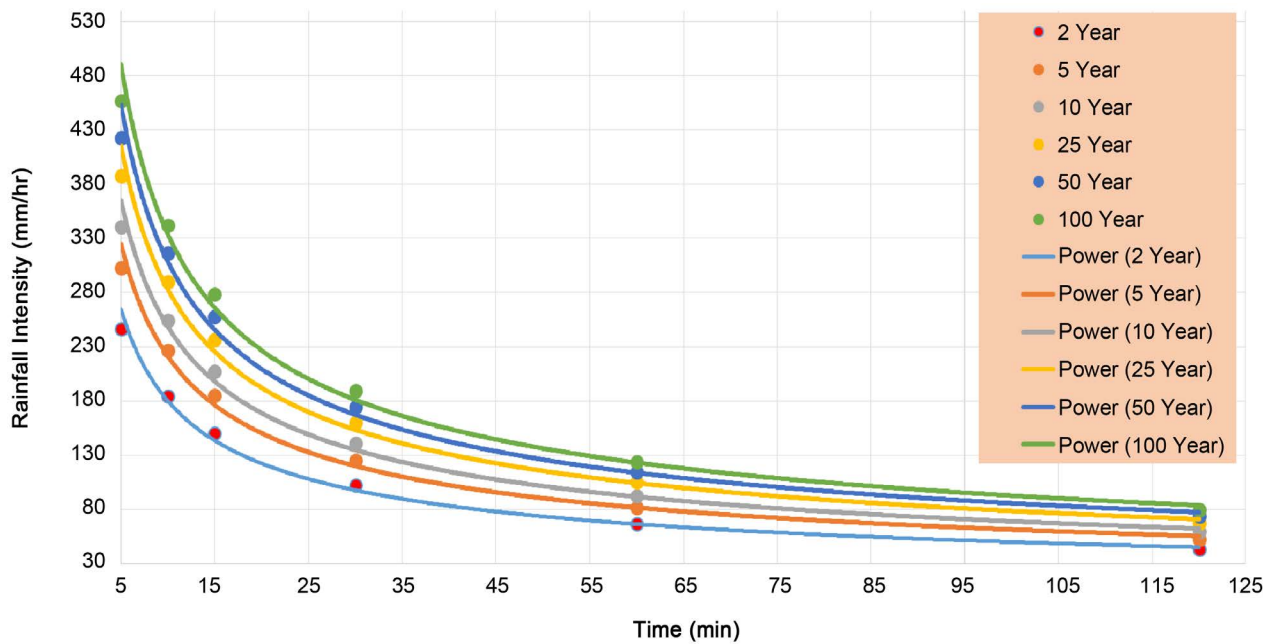


Figure 2. IDF curve for Sylhet city.

or the station, there are some required steps for establishing an equation suit the calculation of rainfall intensity for a certain recurrence interval and specific rainfall period which depends mainly on the results obtained from the intensity duration frequency (IDF) curves and the corresponding logarithmic conversion, where it is possible to convert the equation into a power equation (Table 5), and thus to calculate all the parameters related to the equation.

Table 5. Rainfall IDF curve equation and regression value for Sylhet city.

2 year	5 year	10 year	25 year	50 year	100 year
$i = 647.15D^{-0.556}$	$i = 794.84D^{-0.556}$	$i = 892.61D^{-0.556}$	$i = 1016.2D^{-0.556}$	$i = 1107.8D^{-0.556}$	$i = 1198.8D^{-0.556}$
$R^2 = 0.9944$	$R^2 = 0.9944$	$R^2 = 0.9944$	$R^2 = 0.9944$	$R^2 = 0.9944$	$R^2 = 0.9944$

100 year rainfall intensity is higher than 2 year rainfall intensity. Rainfall intensity equation format is $i = x * (D)^{-y}$. R^2 value is same for every rerun period.

4.7. Catchment Area Selection & Dividing into Sub-Areas

Catchment Area of was selected by using “Polygon” tools and then converted it to “Shape file” by using “Feature to Polygon” tools of ArcGIS. Separation into sub-area was done by the same process (Figure 3).

4.8. Development of Digital Elevation Model (DEM)

From Elevation map of Sylhet city DEM was created by using “geo-statistical analysis” tools of ArcGIS (Figure 4).

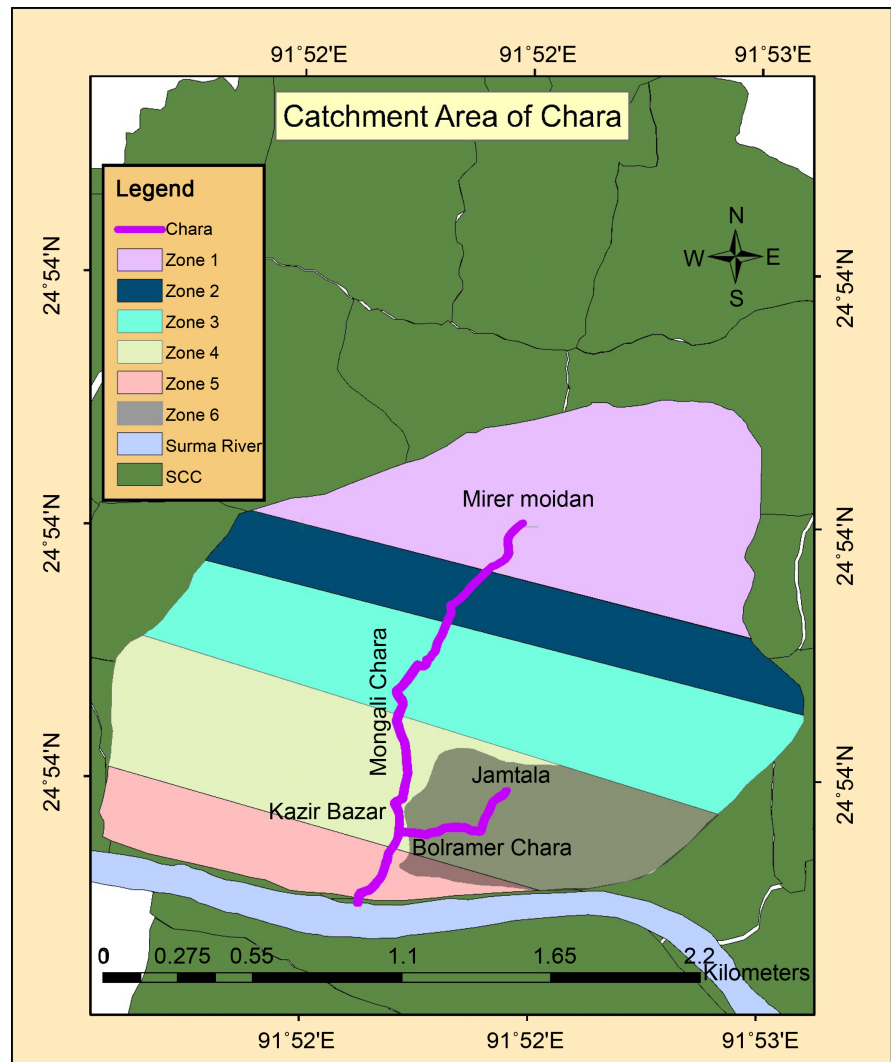


Figure 3. Catchment area of Chara.

4.9. Time of Concentration

Time of concentration (T_c) of six zone was estimated by Federal Aviation Agency (FAA) formula (**Table 6**). Length of flow and average slope was found from ArcMap. Length of flow and average slope is calculated from Shape file and DEM map. Time of concentration is highest at zone 3 and lowest at zone 6.

Table 6. Estimation of time of concentration using FAA formula.

Zone	Rational coefficient	Length of flow (km)	Average slope (%)	Length of flow (ft)	Time of concentration (min)
1	0.574	0.91	1.6	2985.5644	44.23841076
2	0.574	1.34	1.5	4396.3256	54.84850377
3	0.574	1.31	1.3	4297.9004	56.87786504
4	0.574	1.10	1.8	3608.9240	46.76720045
5	0.574	1.06	2.5	3477.6904	41.15188039
6	0.574	0.57	1.9	1870.0788	33.06459851

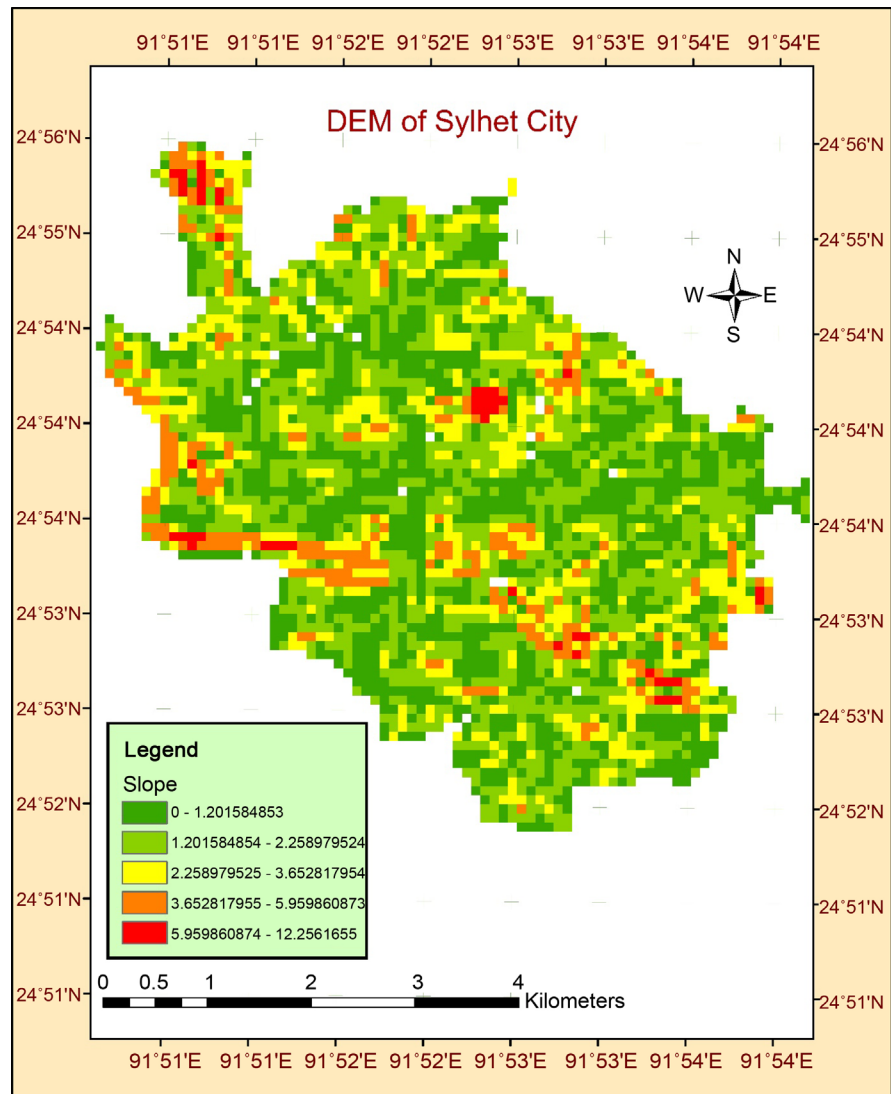


Figure 4. DEM of Sylhet city.

4.10. Discharge Due to Rainfall

Discharge was calculated by the rational formula. Rainfall intensity has been calculated from IDF curve for the duration equal to the time of concentration. 25 year return period has been selected for calculating rainfall calculated discharge has been given in below. Drainage area is calculated from Shape file. At zone 1 discharge is maximum as it has largest area, at zone 5 discharge is minimum as its catchment area is lowest. Peak discharge is the sum of discharge of this zone and peak discharge of previous zone. Peak discharge at zone 4 is the sum of discharge of zone 4, zone 6 and peak discharge of zone 3.

4.11. Discharge Due to Population

Averagely per capita use of water 100 - 120 liter/day (PHE) has been considered. Meantime, discharge due to population was measured. **Table 7** shows at zone 1 discharge is maximum, at zone 5 discharges is minimum. Peak discharge is the sum of

discharge of this zone and peak discharge of previous zone. Peak discharge at zone 4 is the sum of discharge of zone 4, zone 6 and peak discharge of zone 3 (**Table 8**).

Table 7. Discharge from different zone.

Zone	Discharge from zone (m ³ /s)	Peak discharge (m ³ /s)
1	0.029874421	0.029874421
2	0.015490394	0.045364815
3	0.028400116	0.073764931
4	0.018810764	0.106222569
5	0.010695718	0.116918287
6	0.013646875	0.013646875

Table 8. Calculated peak discharge.

Zone	Rational coefficient	Time of concentration (min)	Rainfall intensity (mm/hr)	Drainage area (Sq km)	Discharge (m ³ /s)	Peak discharge (m ³ /s)
1	0.574	44.23841076	123.570458	0.81	15.9591247	15.959124
2	0.574	54.84850377	109.648721	0.42	7.34280935	23.301934
3	0.574	56.87786504	107.456013	0.77	13.1926135	36.494547
4	0.574	46.76720045	119.809647	0.51	9.74252109	54.807927
5	0.574	41.15188039	128.640739	0.29	5.94820483	60.756132
6	0.574	33.06459851	145.282472	0.37	8.57085874	8.5708587

4.12. Total Discharge

Total discharge is the sum of discharge due to rainfall and discharge due to the population. **Table 9** shows the peak discharge for different zones, which is maximum (60.87 m³/s) at zone 5 and minimum (8.58 m³/s) at zone 6.

Table 9. Design discharge.

Zone	Peak discharge (m ³ /s)
1	15.98899918
2	23.34729892
3	36.56831257
4	54.91415004
5	60.87305059
6	8.584505613

4.13. Discharge in Chara

From the equation the corresponding discharge at different point of Chara in m³/s was obtained and plot them in the ArcMap software by using “kriging” tools of ArcGIS. After that, Geostatic analysis was carried out with Kriging which gave the following map (**Figure 5**).

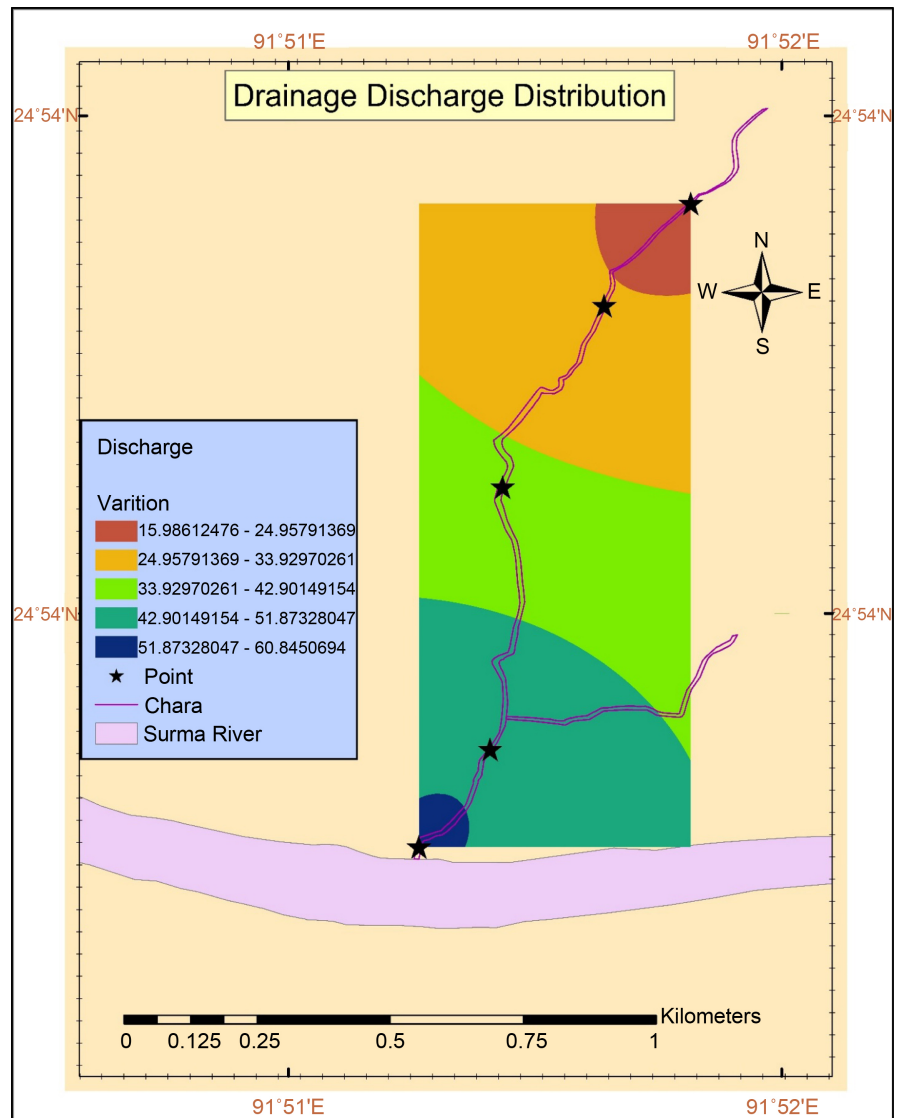


Figure 5. Discharge in Chara.

4.14. Existing and Required X-Sectional Area

The required cross-sectional area has been calculated which is shown in **Table 10**. Before meeting with Bolramer chara the existing x-section of Mongoli chara satisfy the required cross section. But after meeting with Bolramer chara the existing cross section is not sufficient.

Table 10. Existing & required x-sectional area.

Location	Existing X-sectional area (m ²)	Required X-sectional area (m ²)
Kazir Bazar (before meeting with Bolramer chara)	25.50	21.0
Kazir Bazar (after meeting with Bolramer chara)	34.96	37.5

5. Conclusions

Based on the result of the study, following conclusions were made:

- There is no trend in rainfall that could be detected at the 5% significance level in Sylhet.
- Average intensities of rainfall for 25 years return periods have been calculated. Average intensities for 5 min, 10 min, 15 min, 30 min, 60 min, 120 min are 387.2996, 289.8691, 236.2573, 160.3392, 104.9632, 67.55776 (mm/hr) respectively.
- Existing cross section area of chara at Kazir Bazar (before meeting with Bolramer Chara) & Kazir Bazar (after meeting with Bolramer Chara) has been found 25.5 m², 34.96 m² and required X-sectional area 21 m², 37.5 m² respectively. Peak discharges of Mongoli Chara and Bolramer Chara have been calculated to 60.87 m³/s and 8.58 m³/s respectively for 25 years return period.
- The required cross-sectional area has been calculated. Before meeting with Bolramer Chara, the existing x-section of Mongoli chara satisfies the required cross section. But after meeting with Bolramer Chara, the existing cross section is not sufficient.

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