URBAN DEVELOPMENT DIRECTORATE (UDD)

Ministry of Housing and Public Works

Government of the People's Republic of Bangladesh

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Preparation of Development Plan for Meherpur Zilla

Report on the Hydrological Assessment for Flood and Drainage Management in Meherpur Zilla

April 2025

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1. Background

Meherpur District located in the northwestern region of Bangladesh, is a historically significant and agriculturally productive district that shares an international boundary with West Bengal, India. As part of the Ganges River floodplain, the district exhibits gently undulating terrain with slightly elevated ridges and scattered low-lying depressions. It consists of fertile alluvial soils that are both agriculturally rich and hydrologically sensitive, making it fertile for agriculture production. The hydrological network of the project area comprises with river, natural canals (khals), man-made drainage structures, and seasonal wetlands that support agriculture and biodiversity.

However, over the past few decades, Meherpur has experienced increasing urbanization without corresponding proper development in its stormwater and surface drainage systems. This has led to frequent urban flooding, prolonged waterlogging, and associated socio-economic disruptions. Climate variability has further influenced the local hydrology of project area. Understanding the hydrological context of the area is therefore essential for urban and regional integrated land use planning.

This report aims to provide the necessary hydrological insights that can support resilient development and inform the formulation of a sustainable drainage and flood management strategy for the project area.

2. Objectives

The objectives of this study focus on understanding the hydrological characteristics of Meherpur District through systematic data analysis and evaluation. This involved collecting historical rainfall and surface water level data from respective authorities, followed by data processing, statistical analysis and hydrological interpretation which will be helpful for flood mitigation, urban drainage planning and long-term climate resilience regional, structural, urban and rural planning for the district.

- To Collect and compile historical rainfall data from the Bangladesh Meteorological Department (BMD) and surface water level data from the Bangladesh Water Development Board (BWDB)
- To preprocess and validate hydrological datasets for consistency and accuracy
- To perform statistical and frequency analysis for rainfall and flood return periods
- To develop Intensity-Duration-Frequency (IDF) curves to support drainage infrastructure design

3. Methodology

Drainage and flood management are important considerations for assessing the development prospects of Meherpur Zilla. The hydrological assessment in this study is based on both flood level and drainage analysis.

Flood analysis focuses on the estimation of the design flood level, which involves conducting frequency analysis using Probability Distribution Functions (PDFs) for selected return periods (i.e., 1.11, 2, 5, 10, 20,50 and 100 years). Historical data on annual peak water levels have been collected from the nearest BWDB gauge stations to assess flood magnitudes and recurrence. There are 5 BWDB gauge stations are available for Bhairab and Mathabhanga River surrounding the project area. These water level records are essential for evaluating and mapping the extent and frequency of inundation in project areas.

In parallel, rainfall data were collected from the Bangladesh Meteorological Department (BMD). Since there is no rainfall gauge station available in Maherpur district, the nearest gauge station i.e., Chuadanga station is considered in this study. This station measures 3 hourly and daily rainfall data. The 3-hourly rainfall data is available since 2004. So, 3-hourly rainfall records from 2004 – 2024 were collected, preprocessed, cleaned for missing data and analyzed for intensity and frequency using statistical methods. The rainfall analysis supports the development of Intensity-Duration-Frequency (IDF) curves. The IDF curves were developed using the Least Square Method to estimate rainfall intensities for various return periods and durations. This approach allows for estimating the design rainfall intensity corresponding to any given duration and return period, which is essential for hydrological design and flood risk assessment in the project area.

4. Characteristics of Rainfall in the Project Area

Rainy season is very prominent in the project area like other regions of the country. Maherpur district generally experiences a climate that is heavily influenced by the tropical monsoon system. Rainfall shows considerable variability from year to year, both in amount and distribution which can lead to periods of drought or excessive rain. The pre-monsoon season from March to May brings some rainfall often accompanied by thunderstorms locally known as "Kalbaishakhi" which can be intense but short-lived. The district receives the major amount of its rainfall during the monsoon season, which typically lasts from June to September. Post-monsoon rainfall, occurring between October and November, gradually declines as the monsoon withdraws. As per analysis of rainfall data of Chuadanga Meteorological Station, the mean annual rainfall in Project area is 1420 mm which is lower than the national average of 2300 mm. Since 2004, the maximum yearly rainfall ever recorded is 353 mm (daily maximum) in the year 2008.

Table-1: Annual Rainfall at Chuadanga Meteorological Station (2004-2024).

Year	Daily Maximum (mm)	Annual Total (mm)
2004	250.3	1896.7
2005	225.20	1706.2
2006	124	1445.5
2007	272.2	1744.5
2008	353.2	1861.7
2009	125.10	1239.2
2010	56	850.2
2011	106.2	1622.1
2012	81.8	1138.6
2013	98.3	1163.1
2014	108.2	1091
2015	105.6	1460.4

2016	168.1	1391.9
2017	102.2	1475.4
2018	93.8	1222.5
2019	86	1293.5
2020	204	1748
2021	98.80	1683.4
2022	136.2	1217.8
2023	168.60	1085.1
2024	130.4	1486.3
Max	**353.2**	**1896.7**
Average	**147.34**	**1420.147**

From the above table, the annual daily maximum and annual total rainfall recorded are 353.2 mm and 1896.7 mm and average daily and annual rainfall are 147.34mm and 1420.14. **Figure-1** represented the graphical distribution of mean monthly rainfall at Chuadanga Meteorological Station.

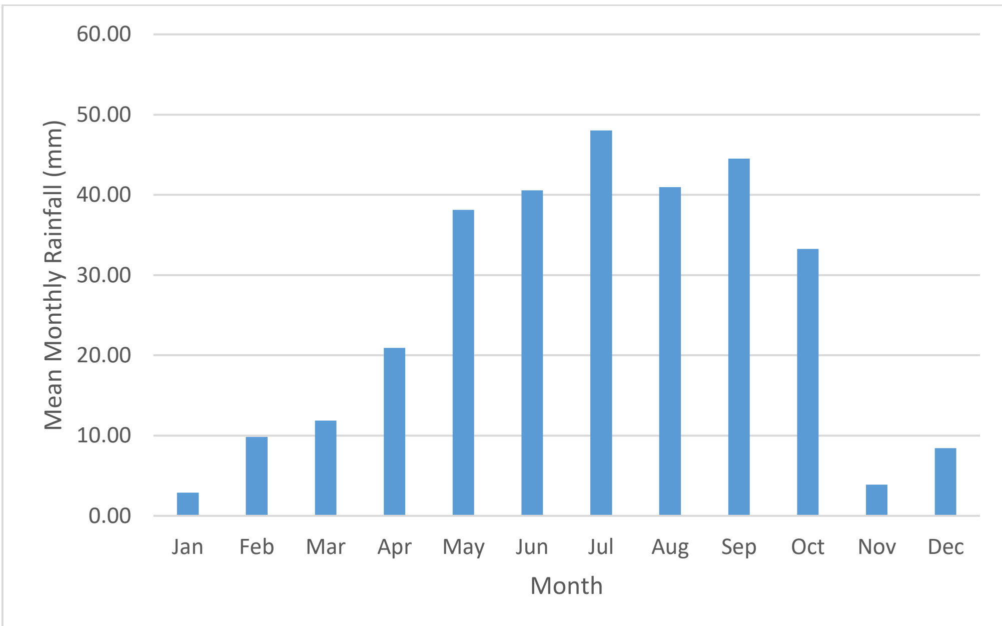

Figure-1: Distribution of mean monthly rainfall at Chuadanga

5. Rainfall Analysis

To determine the design rainfall for the project area, statistical techniques including frequency analysis are used. This process estimates the probability of a given rainfall event occurring based on a selected recurrence interval or return period. The recurrence interval is based on the probability that the given event will be equaled or exceeded in any given year.

The rainfall analysis results in developing Intensity-Duration-Frequency (IDF) curves that are essential for infrastructure design, flood risk management and urban drainage planning. The IDF curve graphically represents the relationship between rainfall intensity, rainfall duration, and the frequency (or return period) of rainfall events. One of the most important uses of IDF curves is in the design of drainage and stormwater management systems especially in urban areas. In urban areas, where impermeable surfaces prevent rainfall from naturally infiltrating the ground, effective drainage is critical to prevent flooding and waterlogging. The IDF curve helps to estimate the intensity of rainfall for specific storm durations, ensuring that drainage systems are appropriately sized to handle peak flows. The peak flows rate would be estimated by the Rational Method.

The Rational method is an empirical relationship of rainfall intensity, contributing drainage area, and a runoff coefficient that reflects land use and surface characteristics. The rainfall intensity used in the calculation of peak flow is obtained from the IDF curves for a rainfall duration equal to the time of concentration. The time of concentration (Tc) is the time required for runoff from the most distant point of the drainage area to reach the outlet. The Kirpich equation is applied to estimate this time of concentration based on the physical characteristics of the watershed. The rational method is expressed as

$$Q = CIA/360 \ldots\ldots\ldots\ldots\ldots\ldots \text{(i)}$$

Where, Q= Peak discharge (m3/s), C = a dimensionless runoff coefficient whose value depends on hydrologic characteristics of the drainage area, I = rainfall intensity in mm/hr for a duration equal to or greater than the time of concentration of the drainage basin, and A = area of the drainage basin in hectares.

The time of concentration can be estimated by Kirpich equation (1940) as

$$Tc = 0.01947\, L^{0.77}\, S^{-0.385} \ldots\ldots\ldots\ldots \text{(ii)}$$

Where, t_c= time of concentration (hr), L= maximum length of travel of water (m), S= Average catchment slope (m/m)

However, the peak runoff rate would be needed for the drainage design such as the size of the storm drain, retention pond and pumping station. The required size of the storm drains to convey the peak runoff would be designed by Manning's equation.

5.1 Development of IDF Curve

A statistical analysis of 3-hourly maximum annual rainfall data from Chuadanga station was conducted using the Least Squares Method to develop Intensity-Duration-Frequency (IDF) curves. The analysis was based on 21 years of observed data, where maximum 3-hour rainfall of each year value was ranked and corresponding return periods were calculated using the Weibull formula, T= (N+1)/m. The return periods were then transformed using a logarithmic function to fit a linear regression model, producing a relationship between rainfall depth and return period in the form y = A + Bx. This equation was used to estimate rainfall depths for various return periods ranging from 1.1 to 100 years. To determine the corresponding 1-hour rainfall intensities from 3 hours duration rainfall, an empirical formula was applied which is expressed as follow

$$I_c = \frac{F}{T}\,\frac{(T+1)}{(tc+1)} \ldots\ldots\ldots\ldots \text{(iii)}$$

Where, Ic = Rainfall intensity (mm/hr) corresponding to the selected duration tc, F= Estimated 3-hour rainfall depth (mm) for a given return period obtained through frequency analysis; T = observed rainfall duration (i.e., 3 hour)

The IDF curves of the project area for different return periods are shown in **Figure-2** and the design rainfall intensities for different return periods and durations are provided in **Table-2.**

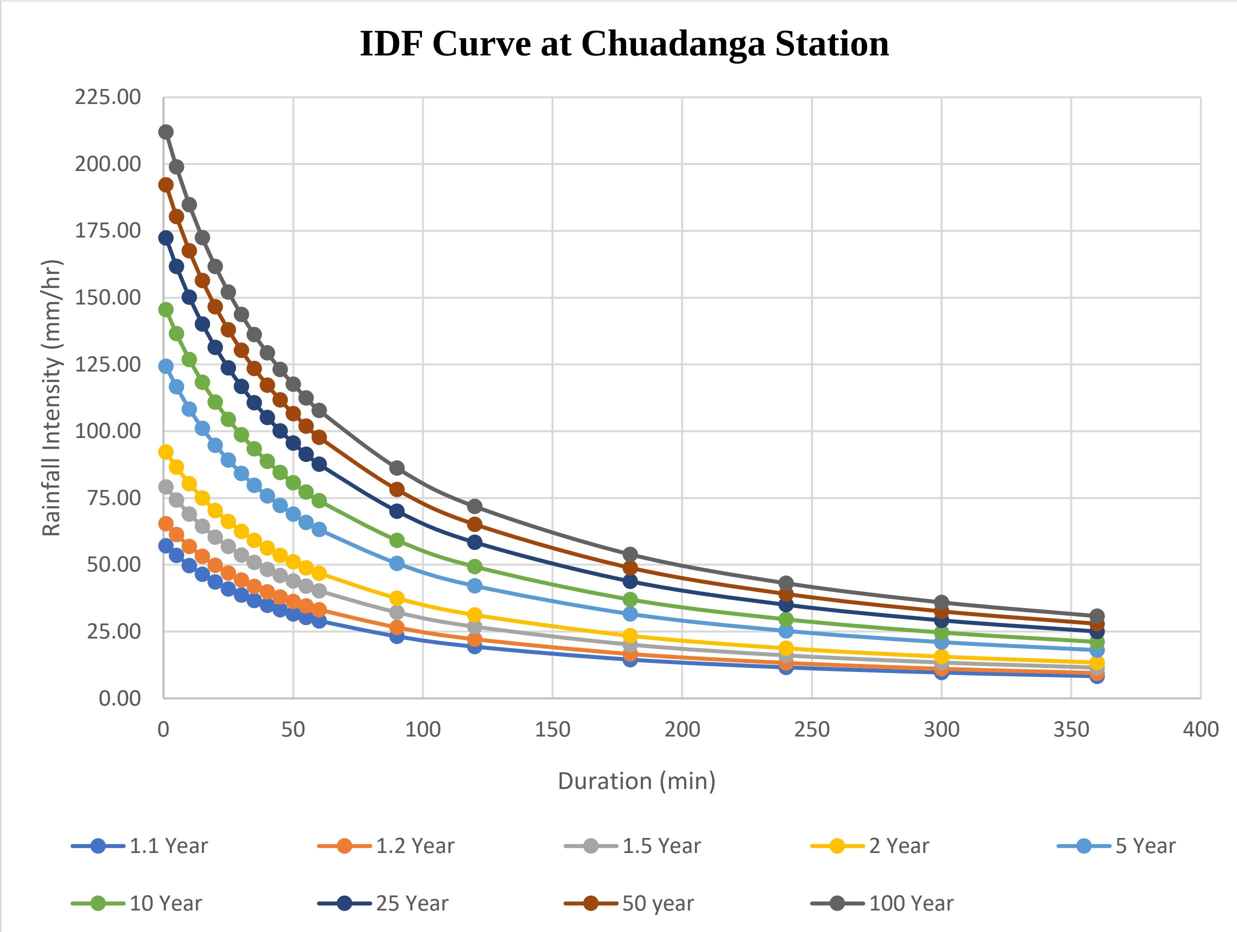

Figure-2: Intensity-Duration-Frequency (IDF) curve for different return periods at Chuadanga Station

Table-2: Design Rainfall Intensity (mm/hr) for different return periods and durations

Duration (min)	Design Rainfall Intensity (mm/hr)								
	1.1 Yr	1.2 Yr	1.5 Yr	2 Yr	5 Yr	10 Yr	25 Yr	50 Yr	100 Yr
1	57.10	65.34	79.18	92.22	124.29	145.52	172.35	192.26	212.01
5	53.58	61.32	74.31	86.54	116.64	136.57	161.75	180.43	198.97
10	49.76	56.94	69.00	80.36	108.31	126.81	150.19	167.54	184.76
15	46.44	53.15	64.40	75.00	101.09	118.36	140.18	156.37	172.44
20	43.54	49.82	60.38	70.32	94.77	110.96	131.42	146.60	161.66
25	40.98	46.89	56.83	66.18	89.20	104.43	123.69	137.97	152.15
30	38.70	44.29	53.67	62.50	84.24	98.63	116.82	130.31	143.70
35	36.66	41.96	50.84	59.21	79.81	93.44	110.67	123.45	136.14
40	34.83	39.86	48.30	56.25	75.82	88.77	105.14	117.28	129.33
45	33.17	37.96	46.00	53.57	72.21	84.54	100.13	111.69	123.17
50	31.66	36.24	43.91	51.14	68.92	80.70	95.58	106.62	117.57
55	30.29	34.66	42.00	48.92	65.93	77.19	91.42	101.98	112.46

60	29.02	33.22	40.25	46.88	63.18	73.97	87.61	97.73	107.77
90	23.22	26.57	32.20	37.50	50.54	59.18	70.09	78.18	86.22
120	19.35	22.14	26.83	31.25	42.12	49.32	58.41	65.15	71.85
180	14.51	16.61	20.13	23.44	31.59	36.99	43.81	48.87	53.89
240	11.61	13.29	16.10	18.75	25.27	29.59	35.05	39.09	43.11
300	9.67	11.07	13.42	15.63	21.06	24.66	29.20	32.58	35.92
360	8.29	9.49	11.50	13.39	18.05	21.14	25.03	27.92	30.79

6. Water Level

There are two water level gauge station data available within the project area named Kazipur (ID: SW205) on the Mathabhanga river and Kathuli (ID: SW32) on the Bhairab River. Nearby the project area, BWDB also operates and maintains three additional stations (SW206, SW207, SW208) on the Mathabhanga River. For this study, data from two of these stations (SW206 and SW208) were collected and analyzed effectively. **Table-3** and **Table-4** represents the historical annual maximum and minimum water level data of the Mathabhanga and Kathuli River at different gauge station.

Table-3: Annual maximum and minimum water levels in the Mathabhanga River at different stations

Year	SW 205		SW 206		SW208	
	Max (m MSL)	Min (m MSL)	Max (m MSL)	Min (m MSL)	Max (m MSL)	Min (m MSL)
2003	13.34	7.76	11.23	6.13	8.00	2.50
2004	12.04	7.57	11.10	6.18	9.27	2.92
2005	13.72	7.93	10.66	6.15	9.10	3.98
2006	11.98	7.98	10.16	5.96	8.30	3.21
2007	12.78	7.99	10.79	6.12	8.27	3.24
2008	12.26	7.97	10.53	6.16	8.89	2.26
2009	11.63	7.68	9.49	6.04	6.12	2.21
2010	11.28	7.37	9.57	5.89	7.28	3.56
2011	12.58	7.47	10.85	5.60	9.50	3.51
2012	11.76	7.33	9.98	5.89	7.44	2.41
2013	12.92	7.45	11.07	5.93	7.75	3.22
2014	12.00	7.53	10.15	6.57	8.12	4.07
2015	11.44	7.71	10.15	6.64	8.02	2.51
2016	11.87	7.25	9.89	5.89	7.81	2.38
2017	11.37	7.52	9.24	5.98	6.74	3.09
2018	10.93	7.39	9.05	5.94	5.99	3.20
2019	12.16	7.44	9.74	5.92	7.69	2.33
2020	11.50	7.47	9.58	5.90	7.06	2.04
2021	11.87	7.43	10.33	5.94	7.85	2.17
2022	11.41	7.42	9.26	5.88	5.61	2.54
2023	10.43	7.25	8.35	5.59	5.60	2.21
2024	-	-	9.25	5.49	6.74	2.24

Table-4: Annual maximum and minimum water levels in the Bhairab River at Kathuli station

Year	**SW32**	
	Max (m MSL)	Min (m MSL)
2003	11.42	10.16
2004	11.26	9.11
2005	0.80	0.50
2008	11.84	10.19
2009	11.24	9.56
2010	10.46	9.99
2011	12.09	10.02
2012	10.54	9.81
2013	10.85	10.06
2014	10.70	9.97
2015	10.74	10.10
2016	10.55	9.72
2017	12.04	9.79
2018	10.52	9.63
2019	10.42	9.64
2020	11.24	9.55
2021	10.72	9.29
2022	10.03	9.30
2023	10.41	9.03

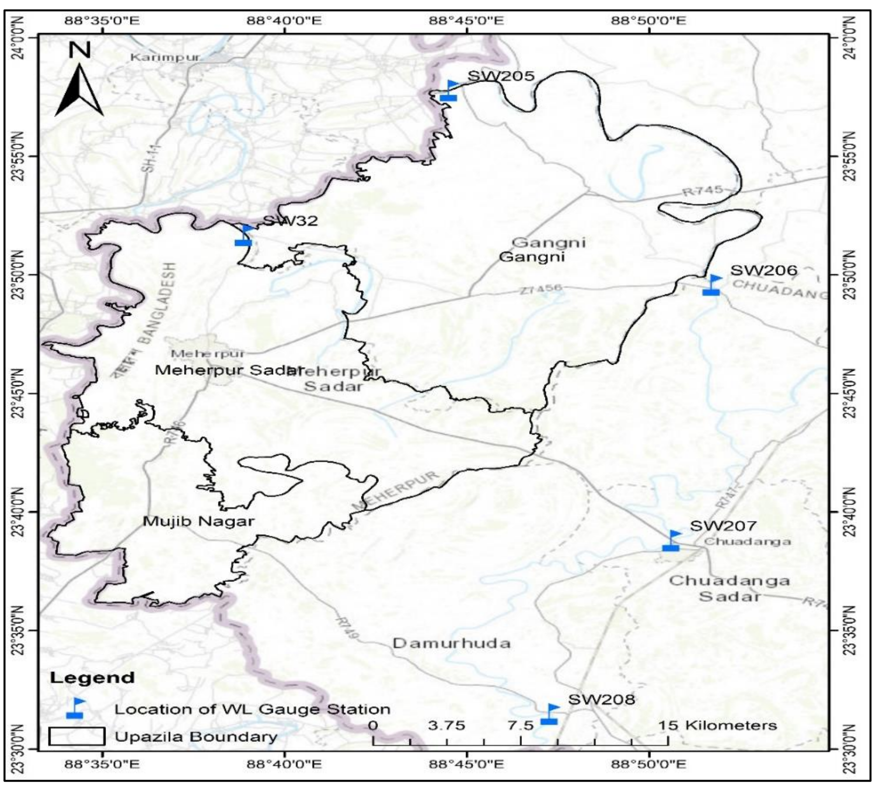

Figure-3: Water level Gauge station location map

7. Flood Frequency Analysis

Flood frequency analysis involves estimating the probability of flood events of varying magnitudes over different return periods using probability distribution functions (PDFs). Estimating of accurate flood frequency are critical for the design of hydraulic structures, floodplain mapping, and water resource planning. Flood frequency analysis was conducted for four stations namely SW32, SW205, SW206, and SW208 using the Hydrologic Engineering Center's Statistical Software Package (HEC-SSP). Different PDFs were applied and compared in this study including

- **Generalized Extreme Value (GEV)** with L-Moments (LM), Maximum Likelihood Estimation (MLE), and Probability-Matching (PM)
- **Log-Pearson Type III (LP III)** with LM, PM and MLE
- **Pearson Type III** with LM, PM and MLE
- **Log-Normal (Ln-Normal)** with LM, PM and MLE
- **Normal** distribution with LM, MLE, and PM
- **Exponential** distribution with LM, MLE, and PM

The performance of each distribution was assessed using two statistical goodness-of-fit tests: the Kolmogorov-Smirnov (KS) test and the Anderson-Darling (A-D) test. Based on these tests, distributions were ranked separately and then given a combined rank to determine the most appropriate fit. Lower values in both tests indicate better agreement with observed data and thus more reliable flood frequency estimates. The fitted PDFs and the corresponding values of KS and A-D test are presented in Table-5, Table-6, Table-7, Table-8 for SW 32, SW205, SW206, SW208 respectively.

Table-5: Fitted PDFs for SW32 and their combined rank based on KS and A-D test

Distribution	Goodness of Fit Test (KS Test)	Rank	Goodness of Fit Test (A-D Test)	Rank	Combined Rank
Generalized Extreme Value (LM)	**0.133**	**1**	**0.369**	**1**	**1**
Log-Pearson III (PM)	0.15	3	0.432	2	2
Generalized Extreme Value (MLE)	0.136	2	0.44	3	2
Ln-Normal (PM)	0.133	1	0.62	5	3
Generalized Extreme Value (PM)	0.153	4	0.44	3	4
Pearson III (PM)	0.153	4	0.443	4	5
Ln-Normal (MLE)	0.185	5	0.62	5	6
Normal (LM)	0.191	6	0.672	6	7
Normal (MLE)	0.191	6	0.677	7	8
Normal (PM)	0.191	6	0.677	7	8
Log-Pearson III (MLE)	0.492	7	4.656	8	9
Pearson III (MLE)	0.499	7	4.787	9	10

Exponential (LM)	0.6	8	7.449	10	11
Exponential (MLE)	0.6	8	7.449	10	11
Exponential (PM)	0.6	9	7.449	10	12

Table-6: Fitted PDFs for SW205 and their combined rank based on KS and A-D test

Distribution	**Goodness of Fit Test (KS Test)**	**Rank**	**Goodness of Fit Test (A-D Test)**	**Rank**	**Combined Rank**
Log-Pearson III (PM)	**0.099**	**1**	**0.214**	**1**	**1**
Generalized Extreme Value (PM)	0.099	1	0.216	2	2
Pearson III (PM)	0.099	1	0.219	4	3
Generalized Extreme Value (LM)	0.101	2	0.218	3	3
Generalized Extreme Value (MLE)	0.102	3	0.221	5	4
Pearson III (LM)	0.104	4	0.235	6	5
Ln-Normal (MLE)	0.116	5	0.255	7	6
Ln-Normal (PM)	0.116	5	0.255	7	6
Ln-Normal (LM)	0.117	6	0.256	8	7
Normal (PM)	0.129	7	0.311	9	8
Normal (MLE)	0.129	7	0.311	9	8
Normal (LM)	0.129	7	0.312	10	9
Log-Pearson III (MLE)	0.484	8	6.124	11	10
Pearson III (MLE)	0.488	9	6.199	12	11
Exponential (LM)	0.582	10	8.501	13	12
Exponential (PM)	0.582	10	8.501	13	12
Exponential (MLE)	0.582	10	8.501	13	12

Table-7: Fitted PDFs for SW206 and their combined rank based on KS and A-D test

Distribution	**Goodness of Fit Test (KS Test)**	**Rank**	**Goodness of Fit Test (A-D Test)**	**Rank**	**Combined Rank**
Generalized Extreme Value (LM)	**0.075**	**1**	**0.185**	**1**	**1**
Normal (LM)	0.076	2	0.197	3	2
Generalized Extreme Value (PM)	0.081	4	0.188	2	3
Ln-Normal (LM)	0.079	3	0.21	6	4
Normal (MLE)	0.082	5	0.208	5	5

Normal (PM)	0.082	5	0.208	5	5
Log-Pearson III (PM)	0.086	6	0.206	4	5
Ln-Normal (MLE)	0.081	4	0.217	8	6
Ln-Normal (PM)	0.081	4	0.217	8	6
Pearson III (PM)	0.089	7	0.213	7	7
Generalized Extreme Value (MLE)	0.106	8	0.227	9	8
Log-Pearson III (MLE)	0.335	9	4.372	10	9
Pearson III (MLE)	0.345	10	4.621	11	10
Exponential (PM)	0.565	11	8.675	12	11
Exponential (MLE)	0.565	11	8.675	12	12
Exponential (LM)	0.565	11	8.675	12	13

Table-8: Fitted PDFs for SW206 and their combined rank based on KS and A-D test

Distribution	Goodness of Fit Test (KS Test)	Rank	Goodness of Fit Test (A-D Test)	Rank	Combined Rank
Log-Pearson III (PM)	**0.106**	**1**	**0.218**	**2**	**1**
Normal (MLE)	0.106	1	0.218	2	1
Normal (PM)	0.106	1	0.218	2	1
Normal (LM)	0.107	2	0.216	1	1
Pearson III (PM)	0.107	2	0.216	1	1
Generalized Extreme Value (PM)	0.113	3	0.22	3	2
Generalized Extreme Value (MLE)	0.116	4	0.25	5	3
Generalized Extreme Value (LM)	0.119	5	0.221	4	3
Ln-Normal (MLE)	0.13	6	0.273	7	4
Ln-Normal (PM)	0.13	6	0.273	7	4
Ln-Normal (LM)	0.131	7	0.271	6	4
Log-Pearson III (MLE)	0.428	8	4.786	8	5
Pearson III (MLE)	0.442	9	5.228	9	6
Exponential (PM)	0.536	10	7.129	10	7
Exponential (MLE)	0.536	10	7.129	10	7
Exponential (LM)	0.536	10	7.129	10	7

From the above table-5,6,7 and 8**,** it is shown that the best fitted PDFs are Generalized Extreme Value (LM), Log-Pearson III (PM), Generalized Extreme Value (LM), Log-Pearson III (PM) for station SW 32, SW205, Sw206, SW208 respectively. Estimated flood levels for return periods of

1.01, 2, 5,10,20,50,100 years were derived from the best-fit distributions and are presented in **Table-9** below.

Table-9: Fitted PDFs and annual maximum flood levels (m MSL) for different return periods

Station	**Best Fit PDF**	Return Period (Year)						
		1.01	**2**	**5**	**10**	**25**	**50**	**100**
SW32	GEV (LM)	9.87	10.82	11.37	11.74	12.14	12.74	13.29
SW205	LP III (PM)	10.25	11.91	12.59	12.99	13.35	13.82	14.19
SW206	GEV (LM)	8.02	10.03	10.71	11.04	11.3	11.62	11.84
SW208	LP III (PM)	5.47	7.79	8.62	9.06	9.45	9.92	10.28

The probability plot of all stations, along with 5% and 95% confidence interval for the annual maximum flood level, are shown in Figure-5, Figure-6, Figure-7 & Figure-8**.** It is seen that the observed values of all stations fall well within the 5% and 95% confidence interval indicating satisfactory fitted distribution for the annual maximum flood level.

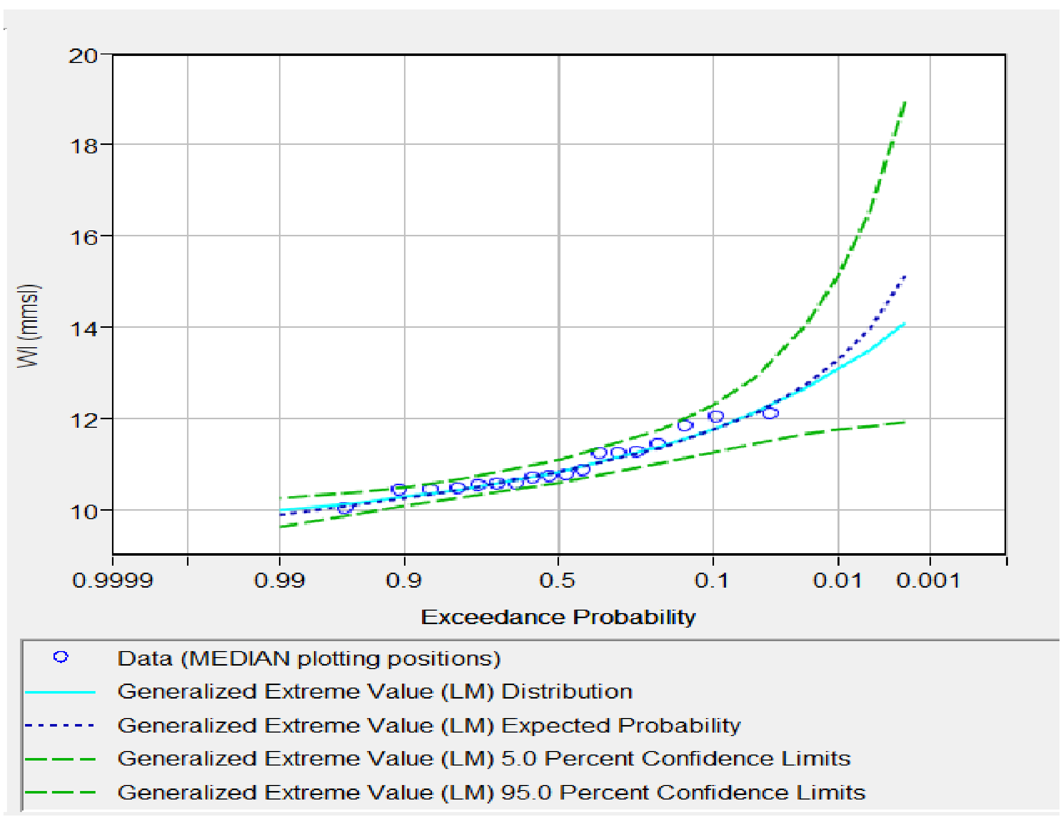

Figure-5: Probability plot along with 5% and 95%confidence interval of the GEV (LM) distribution fitted to the annual maximum water level data of SW32 station (Bhairab River)

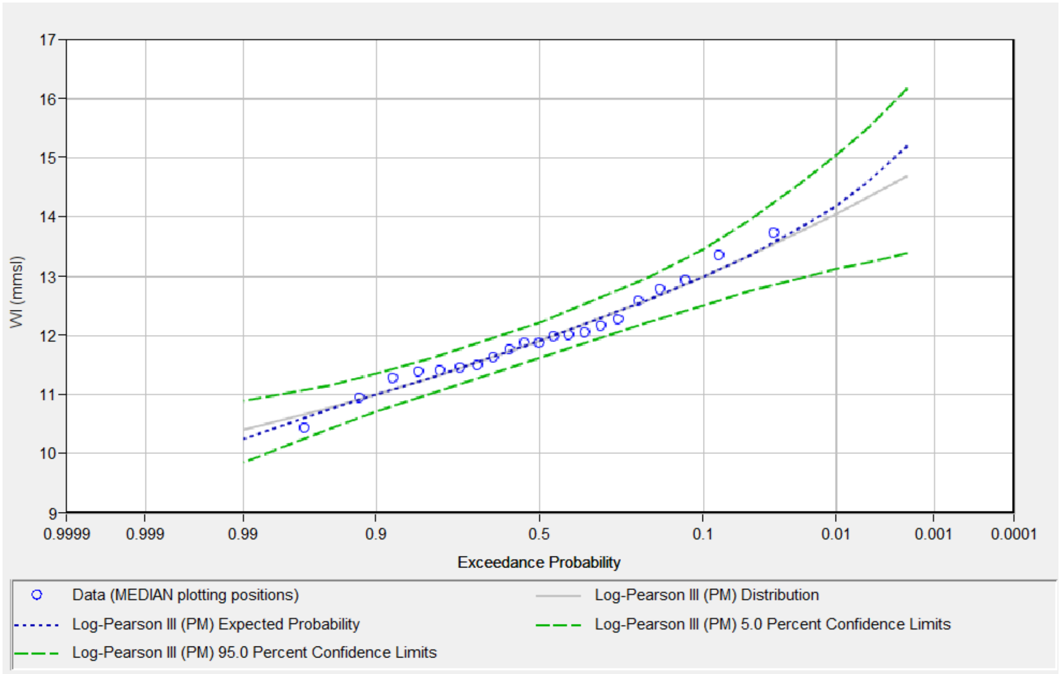

Figure-6: Probability plot along with 5% and 95%confidence interval of the LP III (PM) distribution fitted to the annual maximum water level data of SW205 station (Mathabhanga River)

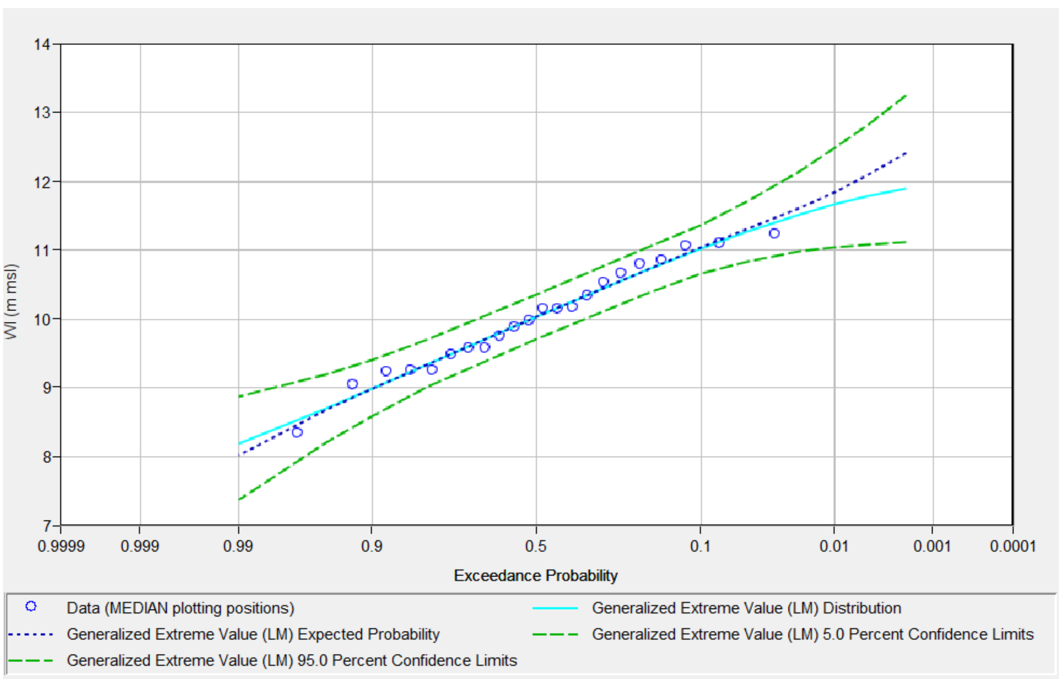

Figure-7: Probability plot along with 5% and 95%confidence interval of the GEV (LM) distribution fitted to the annual maximum water level data of SW206 station (Mathabhanga River)

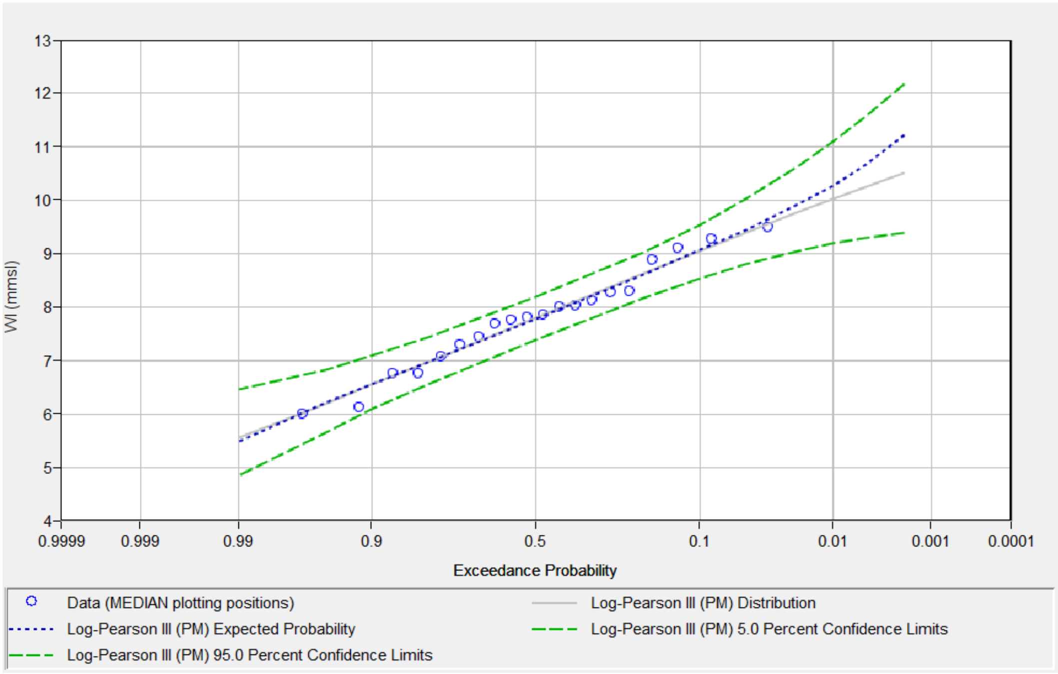

Figure-8: Probability plot along with 5% and 95%confidence interval of the LP III (PM) distribution fitted to the annual maximum water level data of SW208 station (Mathabhanga River)

8. Conclusion

The hydrological assessment in this study provides a critical understanding of rainfall patterns, flood risks, and drainage challenges in the project area which is essential for climate-resilient urban and regional planning. The mean annual rainfall in the project area is 1420 mm; however, extreme events like 353.2 mm daily rainfall in 2008 demonstrated that the region is highly vulnerable to intense, short-duration rainfall. Using 21 years of 3-hourly rainfall data from Chuadanga Station, IDF curves were developed through the Least Squares Method to calculate rainfall intensity for drainage system design. These curves provide essential inputs for peak runoff estimation using the Rational Method and inform hydraulic infrastructure sizing. Simultaneously, water level data from four BWDB gauge stations across the Bhairab and Mathabhanga rivers enabled a detailed assessment of flood risks. Frequency analysis using various probability distribution functions (PDFs) evaluated by goodness-of-fit tests (KS and A-D) helped in selecting the best-fit models for each station. These were used to estimate flood levels for return periods ranging from 1.01 to 100 years. The estimated flood levels will be further used to develop flood zonation maps, which is essential for identifying high-risk areas, informing planners to formulating climate-resilient land use policies and supporting decisions