ASSESSING URBAN WATERLOGGING AND DRAINAGE EFFICIENCY - A CASE STUDY OF SHAHJALAL UPASHAHAR, SYLHET

Kshonoda Mohon Debnath Pulak[1], Partho Protim Das[2], Israt Jahan[3], Md. Zahid Hassan*[4] and Hrithik Nath[5]

[1] *Department of Civil Engineering, Sylhet Engineering College, Sylhet-3100, Bangladesh, e-mail: pulakdebnath.secbd@gmail.com*

[2] *Department of Civil Engineering, Sylhet Engineering College, Sylhet-3100, Bangladesh, e-mail: partho.protim@sec.ac.bd*

[3] *Department of Civil Engineering, Sylhet Engineering College, Sylhet-3100, Bangladesh, e-mail: isratjahan4978@gmail.com*

[4] *Department of Civil Engineering, University of Creative Technology Chittagong, Chattogram-4212, Bangladesh, e-mail: zahid@uctc.edu.bd*

[5] *Department of Civil Engineering, University of Creative Technology Chittagong, Chattogram-4212, Bangladesh, e-mail: hrithiknath.ce@gmail.com*

*** Corresponding Author**

ABSTRACT

Inadequate planning, improper drainage system design, and the non-porous nature of concrete surfaces all contribute to the phenomenon of waterlogging in urban areas. Heavy rainfall can readily lead to urban waterlogging under these circumstances. In recent times, Shahjalal Upashahar, a significantly developed area within Sylhet city, has witnessed back-to-back waterlogging events. This study focuses on evaluating the current performance of Shahjalal Upashahar's drainage system and assessing its efficiency in managing stormwater flow. The entire study area has been divided into five sub-catchment areas and the catchment boundaries were determined by employing a digital elevation model (DEM) in conjunction with the ArcGIS tool. We calculate the discharge for each specific sub-catchment area at the point where its drain converges with the main drain alongside the road. The rainfall data of the past two decades (2002-2022) was collected from nearby meteorological stations. Intensity-Duration-Frequency (IDF) curves for several return periods were constructed through frequency analysis from the collected rainfall data and the surface discharge for each sub-catchment was determined using the Rational method for a peak rainfall event with a 25-year return period. The existing drain sizes provided by Sylhet City Corporation (SCC) for all five sub-catchments were observed to be inadequate solely for managing stormwater, even though these drains serve both stormwater and sewage purposes. The existing drains in the five sub-catchments area cover only around 50% of the mentioned flood event. The results of this research will provide valuable insights for the development of drainage systems to avoid the problems of overflow on the roads of the Shahjalal Upashahar area. Additionally, this study's findings may have broader implications for urban drainage planning and management in regions facing similar waterlogging challenges due to inadequate infrastructure and heavy rainfall events.

Keywords: *Waterlogging, urban drainage, stormwater management, Rational Method, IDF Curve.*

1. INTRODUCTION

In an era defined by rising urbanization and climate uncertainty, the threat of waterlogging looms large over cities around the world, providing a significant challenge to both infrastructure and population (Zhang et al., 2019). In the middle of this worldwide conundrum, Sylhet City emerges as an instance of the battle against flooded streets and neighbourhoods. Recent events highlight the importance of understanding the complexities of waterlogging in this region, which has left inhabitants dealing with the consequences of inundated roadways and degraded living spaces (Alam, 2022). The city was drowned by the weight of severe rainfall in the years 2020, 2021, and 2023, with the most recent episode occurring on October 7, 2023, marking the third flooding this year alone (The Daily Star, 2023). The consequences of such waterlogging went beyond the immediate inconveniences, affecting the city's infrastructure, public services, and citizens' overall well-being.

The multifaceted nature of Sylhet's waterlogging problem finds its roots in several sources. Excessive rainfall, an improper drainage system, obstructions to water flow, and the lack of adequate river excavation collectively contribute to the persistent challenges faced by the city (Pervin et al., 2020). Urbanization and unplanned development have resulted in the proliferation of impervious surfaces, such as roads and buildings, limiting the natural pathways for water drainage (Ahmed & Islam, 2014). Low-pressure atmospheric systems, which frequently accompany monsoon seasons, exacerbate the situation by increasing rainfall intensity and complicating adequate drainage. Despite the city corporation's coordinated efforts and large monetary investments in various water management measures, the situation remains persistent (Mia & Zakaria, 2023).

Understanding the underlying hydrological principles driving drainage dynamics is critical for addressing the complexities of waterlogging and developing effective mitigation methods (Subrina & Chowdhury, 2018). In this context, the Rational approach, a frequently used technique, and the Intensity-Duration-Frequency (IDF) curve can play pivotal roles. The IDF curve can provide useful insights about rainfall patterns (Noor et al., 2021), whereas the Rational Method is useful for estimating surface discharge (Chin, 2019). Properly comprehending and applying these approaches is imperative for determining drain size and developing drainage systems that can prevent waterlogging in urban settings (Campos et al., 2020).

The basic goals of this study are to assess the current performance of Shahjalal Upashahar's drainage system and assess its efficiency in managing stormwater flow. A major aim is to provide a comprehensive understanding of the system's capacity and limitations by dividing the study area into five sub-catchment areas and determining the discharge for each area. Beyond Shahjalal Upashahar's immediate concerns, the findings of this study would have larger implications for urban drainage planning and management in locations facing comparable issues due to inadequate infrastructure and an increased frequency of severe rainfall events. The goal is to provide significant insights that will lead the development of effective and resilient drainage solutions that will reduce the impact of waterlogging in urban contexts.

2. METHODOLOGY

2.1 Description of the Study Area

Shahjalal Upashahar, a recently developed area in Sylhet, is situated upstream of the Surma River basin in the northeastern part of Bangladesh, positioned between 24°53'28" latitude and 91°52'53" longitude, and 24°52'54" latitude and 91°53'44" longitude (Fig. 1). The entire catchment area is categorized into five sub-catchments based on drainage routes, road layout, and future expansion area. A strategic decision to divide the catchment area into five sub-catchments ensures that each sub-catchment has a single outlet connecting to the main drain. The length and slope from the highest to the lowest points of these catchments are determined through an analysis of Digital Elevation Model (DEM) data (Fig. 2). The study area contains different land uses such as buildings, streets, vegetation, commercial, and other public service areas. A land use map of the entire catchment area has been generated by compiling land use data from the National Housing Authority (NHA) (Fig. 3).

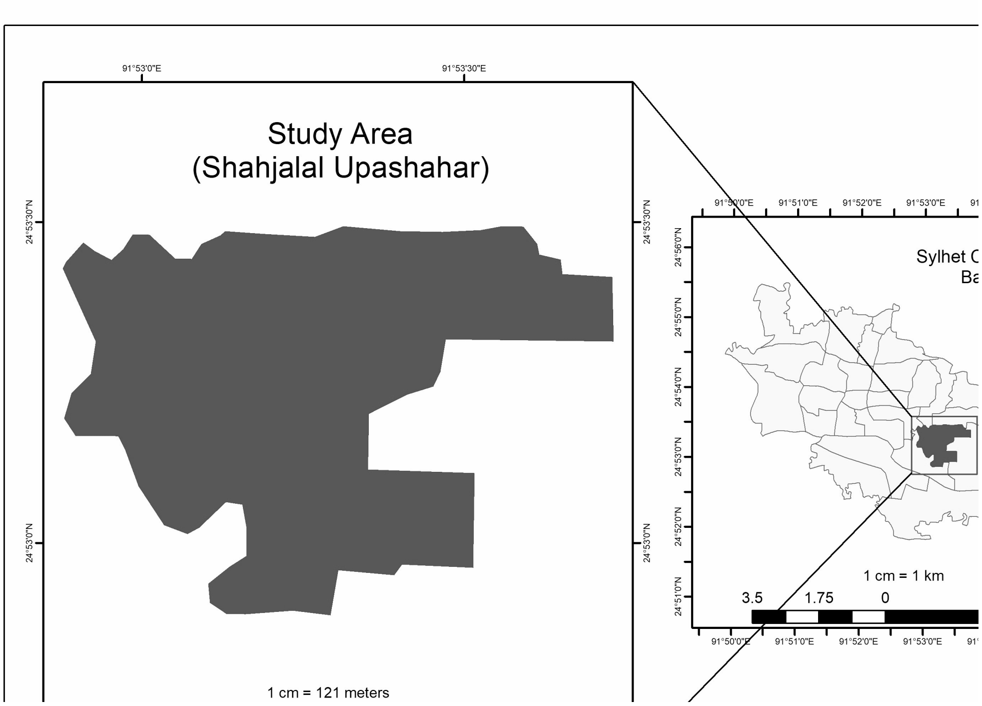

Figure 1: Study Area (Shahjalal Upashahar, Sylhet, Bangladesh)

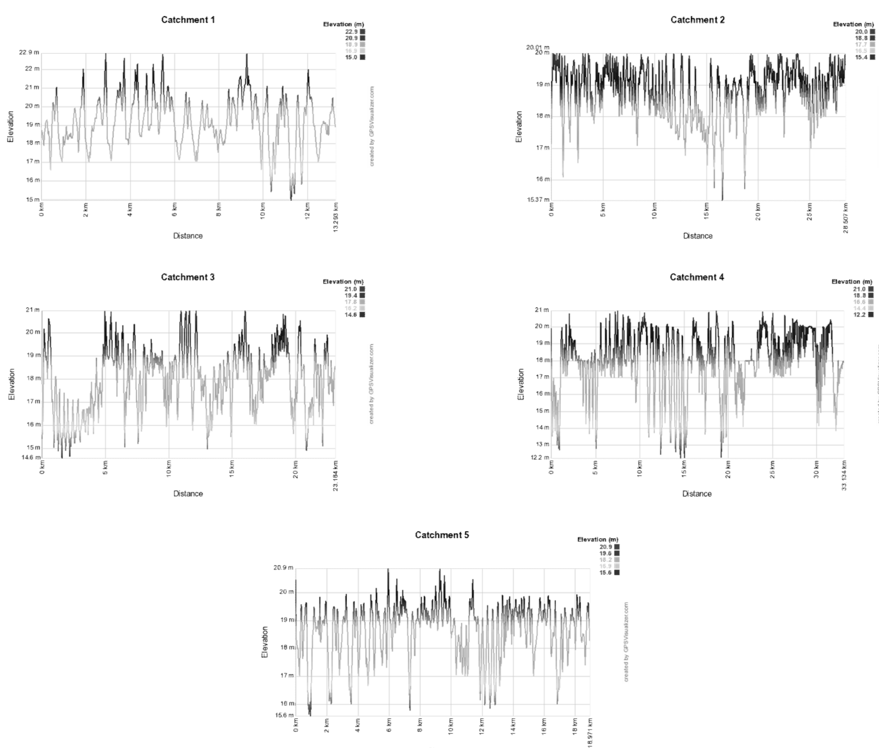

Figure 2: Elevation Map of Sub-Catchments 1,2,3,4,5

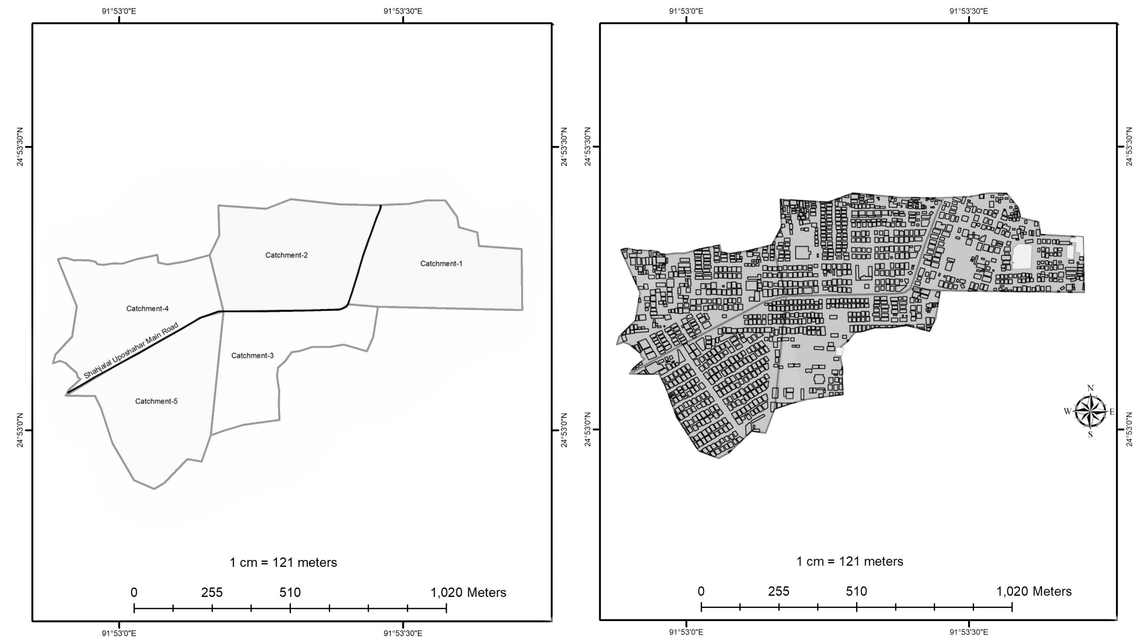

Figure 3: Land Use Map of Study Area

2.2 Shahjalal Upashahar Catchment Description

The runoff generated from each catchment area is directed into the expansive drain located alongside the main road, establishing a direct connection to the Surma River. Information derived from the recent masterplan of the Sylhet City Corporation indicates the presence of double-sided drains measuring 1.2m x 1.5m, designed to accommodate the conveyance of both sewage water and stormwater.

2.3 Collecting the Rainfall Data and Determining Rainfall Intensity

Climate change is another factor that affects the urban hydrological process. A slight change in design rainfall can cause severe floods and stress stormwater management systems (Hou et al., 2022). Therefore, in this study, the monthly and yearly precipitation data (2002-2022) were collected from the Bangladesh Meteorological Department (BMD). The required peak rainfall of the different years' data for existing drain performance analysis is presented in graph (Fig. 4). The rainfall intensity duration frequency (IDF) curves were then developed from rainfall measurements, the annual maximum rainfall intensity for some specific durations (5-min, 10- min, 15-min, 30-min, 1-hr,2-hr, 6-hr, 12-hr, and 24-hr) as well as some specific return periods.

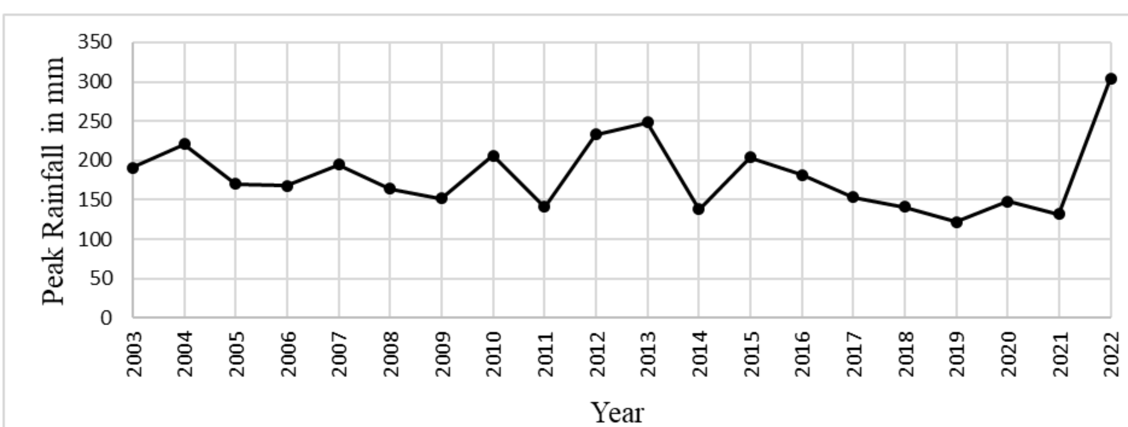

Figure 4: Peak Rainfall of Sylhet City from 2003 to 2022

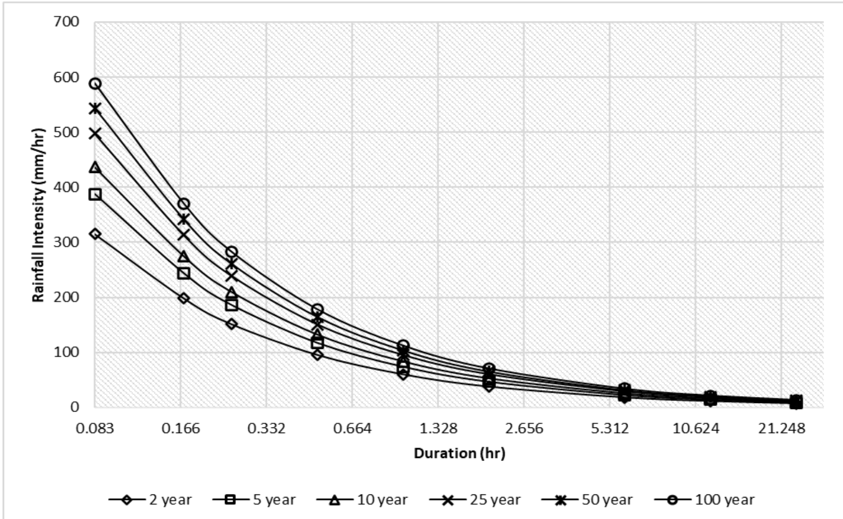

Figure 5: IDF Curve for Different Return Period and Duration

2.4 Methods

2.4.1 Gumbel Distribution Method

The study objective was to assess the efficiency of stormwater drainage systems of Shahjalal Upashahar, Sylhet. The estimated 1-hour maximum rainfall data of Sylhet station has been found to fit with Gumbel distribution method. According to (Gumbel E.J., 1941) distribution functions:

$$X_T = \bar{X} + k_T S \tag{1}$$

$$K_T = -\frac{\sqrt{6}}{\pi}[0.5772 + \ln [\ln \{\frac{T}{(T-1)}\}] \tag{2}$$

Where, X_T = The expected 1-hour T-year rainfall, $\bar{X}$ = The mean of the observations (e.g., arithmetic average of the observations), S = The standard deviation of the observations, k_T = The frequency factor associated with return period T, and T = Return period.

2.4.2 Rational Method

The rational method was used to conduct a hydraulic analysis to assess the drainage capacity at the outlet of every sub-catchment area. The rational method is a simple technique for estimating a design discharge from a small watershed with a catchment area less than 200 Acres (Thompson. D.B., 2006). As the area of each sub-catchment is less than 200 Acres, the rational method is undertaken in this study. The rational formula estimates the peak rate of runoff at a specific location in a watershed as a function of drainage area, runoff coefficient and mean rainfall intensity for duration equal to the time of concentration. The discharge is obtained using following relation,

$$Q = CIA/360 \tag{3}$$

Where, C = Run off coefficient, A = Area(hectare), I =Intensity of rainfall(mm/hr.),

Q = Discharge(m^3/s)

2.4.3 Time of Concentration

The basin time of concentration is defined as the time required for water to flow from the most remote part of the drainage area to the point of interest for discharge calculations. Time of concentration, tc has been easily determined according to (Kirpich, Z.P., 1940). The equation is,

$$T_c = 0.0078 \times L^{0.77} \times S^{-0.386} min \tag{4}$$

Where, L = maximum length of travel of water (m), S = slope of the catchment = ΔH/L in which ΔH = difference in elevation between the most remote point on the catchment and the out.

2.4.4 Runoff Coefficient

The ratio of runoff to rainfall is represented by this variable. It symbolizes the interplay of a variety of elements, such as the retention of water in surface depressions, infiltration, antecedent moisture, ground cover, ground slopes, and soil types. The theoretically defined range of runoff coefficients is 0 to 1. Values for runoff coefficients for various pervious and impermeable surfaces are taken from the land use data retrieved from National Housing Authority (NHA), Bangladesh.

3. RESULTS AND DISCUSSIONS

3.1 Estimation of Design Discharge

In Table 1, the composite runoff coefficient (C=0.68) for the entire watershed of the study area was initially determined. Subsequently, employing a systematic approach detailed in Table 2, the peak discharge for the five sub-catchments was determined by utilizing the rainfall intensity corresponding to the peak rainfall value recorded over a 20-years period (2003-2022). The stormwater drainage system was designed for a 25-years period by the Sylhet City Corporation (SCC), and thus a 25-years return period associated with a 15-minute rainfall duration event was chosen for selecting rainfall intensity (239.17mm). Additionally, a 15-minute rainfall event was selected as the time of concentration, given that the values were almost identical for each sub-catchment. The peak discharge for each sub-catchment area was calculated using the rational method, and the results are presented in Table 2.

Table 1: Calculation of Runoff Coefficient

Sub Catchment	Land Use	Catchment Area (m^2)	Runoff Co-efficient, C_i	C_iA_i
C_1	Residential	12976	0.75	9.732
C_2	Street	14347	0.95	13.630
C_3	Vegetation	10090	0.2	2.018
C_4	Residential	12327	0.6	7.396
C_5	Residential	13454	0.75	10.090
		$\sum A_i = 63192$		$\sum C_iA_i = 42.688$
			$C = \sum C_iA_i / \Sigma A_i = 0.68$	

Table 2: Calculation of Peak Discharge

Catchment Description	Runoff Coefficient	Rainfall Intensity (mm)	Catchment Area (m2)	Peak Discharge (m3/s)
C1	0.68	239.17	12976	5.86
C2		239.17	14347	6.48
C3		239.17	10090	4.56
C4		239.17	12327	5.57
C5		239.17	13454	6.08

3.2 Performance of Existing Drainage System

The velocity and time of concentration of each sub-catchment were concurrently identified in Table 3 by determining the length and slope of these areas. Utilizing the equation "Q=AV" based on the principle of continuity, the required drainage size exclusively for stormwater management in the five sub-catchments was derived and is summarized in Table 4. Subsequently, the percentage of the existing drainage capacity during the 25-year return period associated with a 15-minute rainfall duration event is illustrated in graph (Fig. 6) . The graph reveals that the existing drain sizes (1.2m X 1.5m) provided by the Sylhet City Corporation (SCC) for all five sub-catchments were observed to be insufficient for effective stormwater management, despite serving both stormwater and sewage purposes. The drainage infrastructure currently in place within the five sub-catchment areas provides coverage for only about half of the flood event mentioned. This indicates a significant shortfall in the existing drainage capacity, emphasizing the need for enhanced stormwater management measures to effectively address the potential consequences of such events in the studied region.

Table 3: Calculation of Time Concentration and Velocity

Catchment Description	Length (meter)	Slope	Time of Concentration (hour)	Velocity (m/s)
C1	536.63	0.0175	0.19	0.77
C2	561.66	0.0184	0.20	0.79
C3	459.36	0.0133	0.19	0.66
C4	593.21	0.0137	0.23	0.71
C5	512.57	0.0187	0.18	0.78

Table 4: Calculation of Each Sub-Catchment Drainage Performance

Catchment Description	Peak Discharge (m3/s)	Velocity (m/s)	Calculated Cross Sectional Area (m2)	Existing Drain Size	Existing Cross-Sectional Area	Drain Performance (%)
1	5.862	0.768	7.64	1.2 x 1.5 (Both Side of Road)	3.6	47.14
2	6.481	0.788	8.22		3.6	43.79
3	4.558	0.664	6.86		3.6	52.47
4	5.569	0.713	7.81		3.6	46.08
5	6.078	0.777	7.82		3.6	46.01

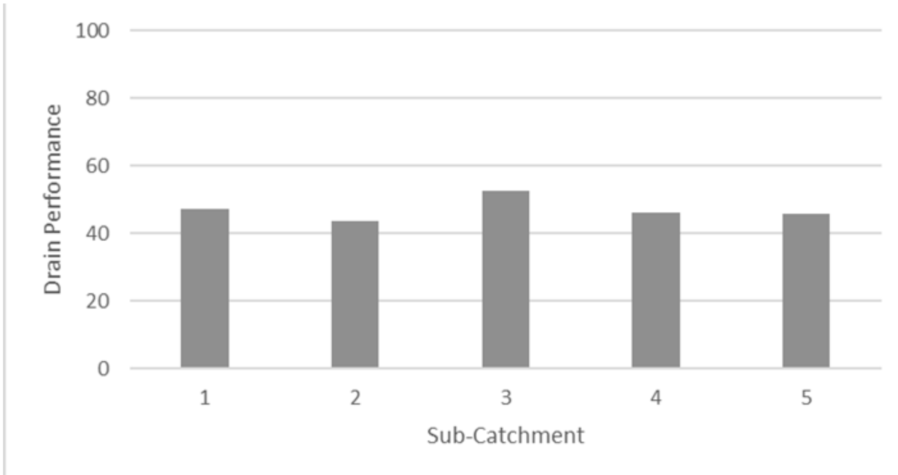

Figure 6: Existing Drain Performance Analysis of Each Sub-Catchment

While our study yields valuable insights into the performance of the drains in the sub-catchments, it is crucial to acknowledge certain limitations, such as the avoiding factors like infiltration, the original characteristics of channels, and blockages in drains caused by solid waste. Despite these limitations, our results contribute significantly to understanding the primary reasons for recent flood events in the study area. The findings of this research offer crucial significant for the development of drainage systems, aiming to mitigate overflow issues on the roads of the Shahjalal Upashahar area. Moreover, the study's results may have broader implications for urban drainage planning and management in regions experiencing similar waterlogging challenges due to inadequate infrastructure and intense rainfall events.

4. CONCLUSIONS

In conclusion, this study investigates the waterlogging challenges in Shahjalal Upashahar, Sylhet, emphasizing the inadequacies in the existing drainage system attributed to improper planning and design. Utilizing a comprehensive approach, including sub-catchment analysis and IDF curves, the research reveals the insufficiency of current drain sizes provided by the Sylhet City Corporation for effective stormwater management. Despite limitations, the study contributes valuable insights into the primary causes of recent flood events, advocating for urgent attention to resilient urban drainage planning. The findings not only propose solutions for Shahjalal Upashahar but also offer broader implications for regions facing waterlogging due to insufficient infrastructure and intense rainfall, stressing the need for well-designed drainage systems to withstand climate challenges and urban growth.

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