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DESIGNING AN URBAN DRAINAGE NETWORK FOR STORMWATER MANAGEMENT: A GIS-SWMM APPLICATION IN BOGURA, BANGLADESH

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ABSTRACT

Bangladesh's smaller cities are becoming more likely to flood because cities are growing quickly and it is raining more heavily. This study examines stormwater management in Ward 1 of Bogura Pourashava through the integration of GIS analysis and hydrodynamic modeling. The study area was mapped out using ArcGIS and EPA SWMM, which showed the watershed, land uses, and how rain and runoff interact. Gumbel frequency analysis (both log and natural-log methods) was used to get design storms for 5- and 10-year return periods. Five subcatchments were modeled with runoff coefficients that were adjusted to fit the area. Peak flows and conduit flows for design storms were obtained from the SWMM simulations, and these values were used to size the stormwater conduits to ensure safe water conveyance (0.8 m/s). The most important results are that the subcatchment runoff coefficients are between 0.72 and 0.83 and that the peak flows for the 10-year storm are up to about 56 m³/s. The planned drainage channels (with cross-sectional areas of up to ~69.9 m²) have more capacity than the calculated 10-year discharges. Comparisons with earlier studies indicate consistent results, as the obtained runoff and flow values align with those expected for urban Bangladesh, and the use of SWMM is supported by recent research. The log-base Gumbel method gave deeper storms than the ln-base method, and the calibration favored the log-based results. The limitations are that they depend on secondary rainfall data (20-year record) and 24-hour storm assumptions. The method gives a framework that can be used in urban areas with few data points and shows that well-designed Sustainable Drainage Systems (SuDS) can handle stormwater reliably in the present and near future. To make the model more accurate, future work should include longer rainfall records, storms that last for shorter amounts of time, and monitoring.

Keywords: *Sustainable Urban Drainage Systems (SuDS), Stormwater Management, GIS–SWMM Modeling, Gumbel distribution, Urban Flooding.*

1. INTRODUCTION

Rapid urbanization and changes in the weather have made managing stormwater a big problem in many developing countries. Secondary cities in Bangladesh, like Bogura, are especially at risk because of rapid population growth and unplanned urban growth, which have led to more impervious surfaces that make surface runoff much worse. These changes have overwhelmed existing drainage systems, leading to recurrent urban flooding and prolonged waterlogging (Maliha & Khan, 2017). Climate change is making things worse by making extreme rainfall events more common (Mahbub et al., 2024). Urban flooding not only disrupts transportation and livelihoods but also degrades environmental quality and public health by transporting pollutants into nearby water bodies (Rodríguez-Rojas et al., 2024).
Traditional drainage systems in Bangladesh are often inadequately designed, poorly maintained, and unable to cope with the increased runoff generated by urbanization. The absence of comprehensive hydrological and topographical data further impedes the establishment of efficient drainage systems. Environmental Protection Agency's Storm Water Management Model (SWMM) (Ahmad et al., 2024; Rossman, 2015). GIS facilitates spatial data processing, including watershed delineation, subcatchment identification, and drainage path extraction, while SWMM provides a robust platform for simulating rainfall–runoff dynamics and evaluating drainage network performance under varying rainfall scenarios (Si et al., 2024). This integration makes it possible to design Sustainable Drainage Systems (SuDS) that are both hydrologically efficient and good for the environment.

Globally, the adoption of SuDS has proven effective in mitigating flooding, improving water quality, and enhancing urban sustainability. Rodríguez-Rojas et al. (2024) showed that adding SuDS to urban planning in Spain made it easier to control stormwater and made cities more resilient. Ahmad et al. (2024) also created a GIS-SWMM-ABM framework for assessing flood risk in areas with little data. This showed how useful simulation-based methods can be for building urban drainage systems. Other researchers have pointed out that SuDS has many benefits, such as cleaning water, recharging groundwater, and cooling cities (García & Santamarta, 2022; Morgan & Fenner, 2019). SuDS can also reduce pollutant loads such as microplastics in urban runoff, contributing to healthier aquatic ecosystems (García-Haba et al., 2023). International guidelines, such as those by the Construction Industry Research and Information Association (CIRIA, 2019), emphasize the importance of community acceptance, maintenance, and long-term sustainability for successful SuDS implementation. Even with these improvements, there are still problems with governance, cost, and land-use conflicts that make it hard for many people to use these technologies (Qiao et al., 2018).

Climate change further complicates stormwater management by altering rainfall patterns and intensifying short-duration storms. The Intergovernmental Panel on Climate Change (IPCC) has said that extreme rainfall events are happening more often, which makes cities more likely to flood (Masson-Delmotte et al., 2021). Roy et al. (2008) stressed that depending only on traditional gray infrastructure is no longer enough. They called for hybrid solutions that mix gray and green infrastructure to make watersheds more resilient. Li and Zhang (2022) highlighted the Chinese "sponge city" initiative as a model that integrates SuDS and smart drainage technologies to improve flood resilience in rapidly urbanizing contexts.

Bangladesh, on the other hand, still has problems with clogged drains and flooding that happens over and over again. Several studies have analyzed the causes and consequences of inadequate drainage systems in the country. Maliha and Khan (2017) utilized GeoSWMM to develop a drainage network for Bogura city with constrained data, demonstrating the capabilities of GIS-integrated modeling. Mahbub et al. (2024) assessed drainage congestion in Chattogram and documented its socio-environmental impacts. Alom and Khan (2014) and Akbar (2023) noted analogous circumstances in Dhaka and Netrokona, attributing waterlogging to inadequate maintenance and uncoordinated development. In Khulna, Fayshal et al. (2023) identified drain water pollution as a critical issue and proposed sustainable management strategies. The International Growth Centre also found that better drainage systems in Barishal had positive effects on the economy and society, such as lower health risks and better community health (Budjan et al., 2024). These findings underscore the urgent need for sustainable, data-driven approaches to drainage design in urban Bangladesh.

Despite these studies, most research in Bangladesh has focused on conventional drainage infrastructure rather than sustainable or nature-based alternatives. Field-based evaluations of SuDS performance and long-term monitoring remain scarce, and climate change considerations are often overlooked in urban drainage master plans. Furthermore, the use of advanced technologies such as IoT-based monitoring and smart decision-support systems is still in its early stages. Therefore, a research gap exists in developing integrated, GIS- and SWMM-based SuDS models that can be effectively applied in data-scarce, flood-prone urban areas like Bogura.

To address this gap, the present study develops and evaluates a sustainable stormwater drainage network for Bogura Pourashava Ward No. 1 by integrating GIS spatial analysis with SWMM hydrological–hydraulic simulation. The study employs Gumbel frequency analysis to estimate design storms for 5- and 10-year return periods and compares log-base and natural-log-base results for calibration. The primary objectives are to (a) design a stormwater drainage system using GIS and SWMM, (b) evaluate conduit performance and cross-sectional adequacy, and (c) compare rainfall frequency analysis methods to ensure accurate storm design. This research contributes to advancing the application of sustainable drainage systems in Bangladesh and provides a replicable methodological framework for data-scarce urban environments. The findings are expected to support policymakers, urban planners, and engineers in improving drainage infrastructure and enhancing climate resilience in secondary cities across the country.

2. METHODOLOGY

The method combines spatial analysis (ArcGIS) with hydrological-hydraulic modeling (EPA SWMM). Figure 1 shows a flowchart of the process, which includes the study area, data collection, GIS processing, frequency analysis, and SWMM simulation.

2.1 Study Area

The study area, Bogura Pourashava Ward No. 1, is in Bogura Sadar Upazila in the north of Bangladesh. It is about 3 square kilometers. The land is mostly flat or gently rolling, and it is used for a mix of residential, commercial, and semi-urban purposes. There are some small canals and drains, and the roads are in pretty good shape. Rapid growth has made more areas that can't absorb water (like buildings and pavement) and less natural infiltration. To the west, a small stream outlet point marks the edge of the ward. This small area has a good drainage system that could be used as a model for other crowded areas in Bangladesh.

2.2 Data Collection

2.2.1 Spatial data

Data on administrative boundaries (Bogura Sadar, Ward 1), a digital elevation model (DEM), a stream network, and land use/land cover (LULC) were collected (Figure 2-3). The DEM was taken from USGS SRTM (30 m resolution) and changed to WGS84 UTM Zone 45N. Using the "Extract by Mask" tool in ArcGIS, the Bogura Sadar DEM was cut down to the ward boundary, which made the Ward 1 DEM (Figure 4–5). Products were generated from the DEM, including slope, flow direction, and flow accumulation. Topographic layers were used to digitize existing streams and drains, which were subsequently added to the DEM. Watershed delineation found five main subcatchments that drain toward the outlet (Figure 6). The LULC map was made by sorting high-resolution images into groups. Land uses were divided into four groups: built-up (impervious), vegetation/grass, bare/soil, and water bodies. These groups were then crossed with subcatchment polygons to find area percentages, as shown in Figure 7-8.

2.2.2 Rainfall data

Daily rainfall records for Bogura (with the station located in Ward 1) were obtained from Google Earth Engine (GEE) for the years 2004 to 2023, and the yearly maximum series of 24-hour rainfall events was extracted. Extreme value analysis was done carefully because there were only 20 years of data.

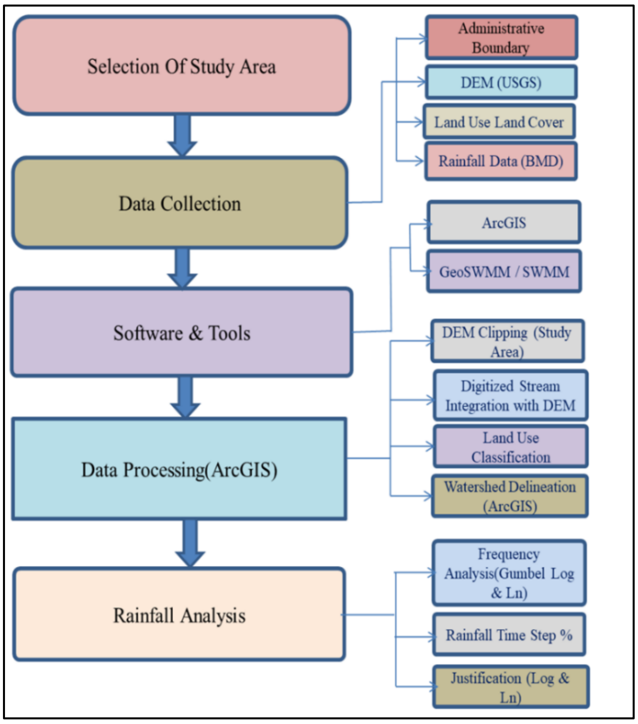

Figure 1. Flow chart of the overall methodology adopted in the study.

2.3 Data Processing

2.3.1 Frequency analysis

Estimating design rainfall is very important for designing sustainable urban drainage systems (SuDS). This research utilized the Gumbel Extreme Value Type-I (EV1) distribution, commonly employed for modeling extreme hydrological phenomena, including annual maximum rainfall (Chow et al., 1988; Rossman, 2015). Both common logarithm (log10) and natural logarithm (ln, base e) methods were applied to determine the design rainfall for return periods of 5, 10, 25, 50, and 100 years. This made it easier to compare and made sure that the methods were correct. The following formulas were used to find the reduced mean, reduced standard deviation, and frequency factor:

Log10 Method (Common Logarithm):

- Reduced mean: $Y_n = 0.5772 + \frac{0.5722}{\ln(N)}$
- Reduced standard deviation: $S_n = \frac{1.2825}{\ln(N)}$
- Reduced variate: $Y_t = 0.834 + 2.303 \cdot \log_{10}[\log_{10}(\frac{T}{T-1})]$
- Frequency factor: $K_t = \frac{Y_t - Y_n}{S_n}$
- Design rainfall: $X_t = \bar{x} + K_t \cdot \sigma_{n-1}$

Ln Method (Natural Logarithm):

- Reduced variate: $Y_t = -\ln[-\ln(1 - 1/T)]$
- Frequency factor: $K_t = Y_t$

- Design rainfall: $X_t = \bar{x} + K_t \cdot \sigma_{n-1}$

Where N is the number of years of rainfall data, T is the return period, x ¯ is the mean annual maximum rainfall, and σ_(n-1) is the standard deviation. Yt is the reduced variate, K_t is the frequency factor, $\bar{Y}_n$ is the reduced mean, S_n is the reduced standard deviation, and X_t is the estimated or design rainfall (mm) for the specified return period. (Chow et al., 1988; Rossman, 2015). The log and ln fits both gave design rainfall depths. For example, the log method gave depths of about 143–203 mm for 5y and 10y, and the ln method gave depths of about 136–161 mm. The temporal distribution of the design storms was determined by dividing the total 24-hour rainfall into 6-hour intervals. Percentage distributions were assigned based on how monsoons usually work, which is in line with how strong they are in the area.

2.3.2 SWMM modeling

The EPA SWMM (version 5.1) software was used to model stormwater flow. Five subcatchments (S1–S5) and their junctions were set up. A lookup table of runoff coefficients and the LULC composition were used to determine the impervious fraction and area of each subcatchment. The first runoff coefficients were taken from standard ranges, such as 0.85 for built-up areas, 0.55 for vegetation, and 0.3 for bare soil. They were then changed using pseudo-calibration. The meteorological input was a custom hyetograph for the design storms, with intensity blocks that matched the totals from the Gumbel method. Drainage conduits (C1–C5) connecting junctions in series to the outlet (Outlet1) were added. GIS measurements of stream segments were used to determine the lengths and slopes of the conduits. Manning's roughness (n = 0.013 for concrete) was assumed to be uniform throughout. Simulation runs were conducted for both the 5-year and 10-year events to measure surface runoff and conduit flows.

2.3.3 Calibration

A "pseudo-calibration" method was used because there wasn't any flow data to look at. The runoff coefficients for each subcatchment were adjusted repeatedly until the predicted total runoff volumes and peak flows were consistent with expected values for urban areas. The final runoff coefficients were between 0.72 and 0.83, which shows that S1 and S3 were very hard to get through. These values are in the range of what is normal for cities, according to hydrology books (Chow et al., 1988) and earlier studies (Roy et al., 2008).

2.3.4 Assumptions

The model presumes consistent rainfall intensity across each subcatchment, disregards groundwater infiltration, and employs 24-hour storm events, excluding shorter-duration occurrences of 3 to 6 hours. There wasn't much initial loss or depression storage. The study assumes that the current drainage system (streams) can handle runoff without any extra costs. To stop sedimentation and erosion, the design speed for conduits was set at 0.8 m/s. The cross-sectional areas were calculated from the peak flow, A=Q/V. The steps in the methodology make sure that the results can be repeated: all data sources (DEM, rainfall) are listed, software versions (ArcGIS 10.7, SWMM 5.1) are noted, and key equations (Gumbel, continuity) are standard (Chow et al., 1988). The input data and model schematics are written down so that other engineers can make the same drainage design.

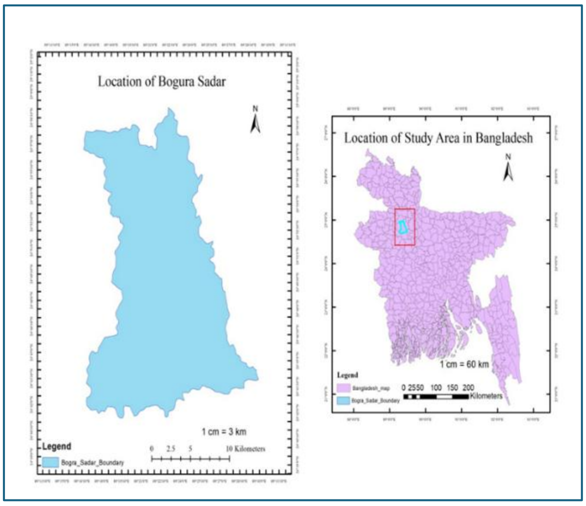

Figure 2. Map of Bogura Sadar

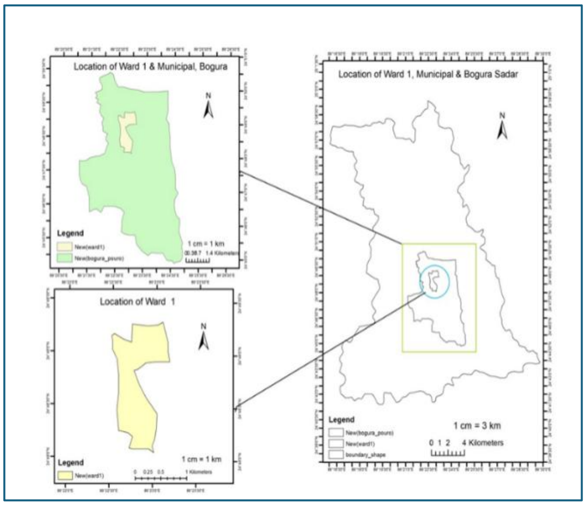

Figure 3. Study area map of Ward No. 1, Bogura Pourashava.

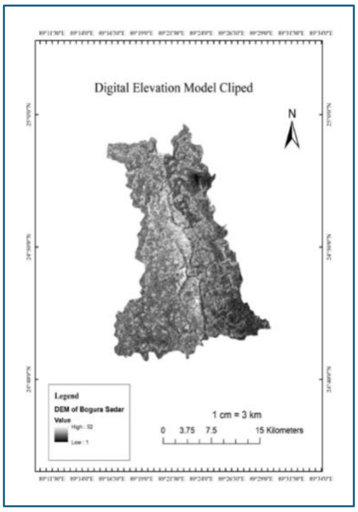

Figure 4: DEM of Bogura Sadar.

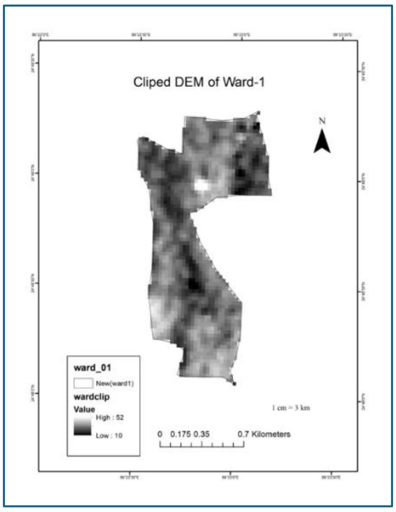

Figure 5: Clipped DEM of Ward No. 1.

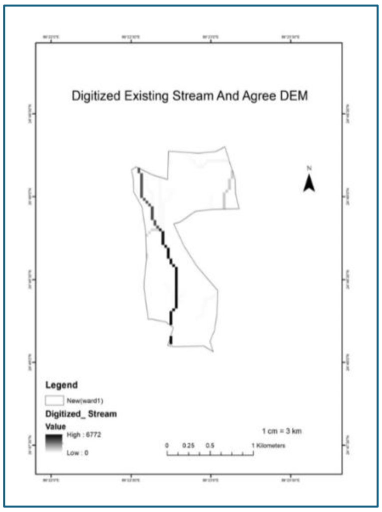

Figure 6: Digitized existing stream network.

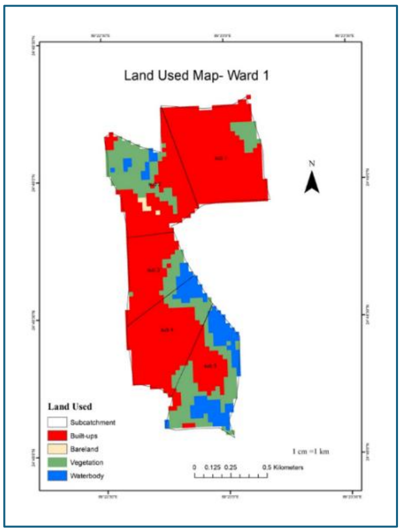

Figure 7: Land use / land cover map of Ward No. 1.

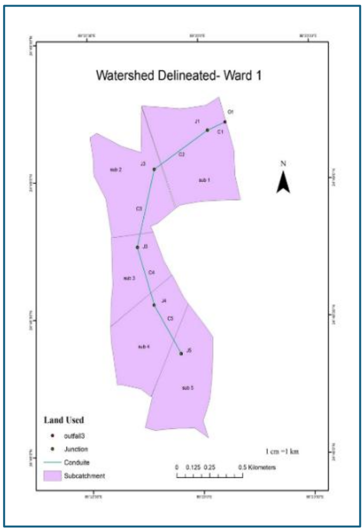

Figure 8: Delineated watershed and subcatchments in ArcGIS.

2.3.5 Justification for Using Log and Ln Methods

For SuDS design and stormwater management, it's very important to be able to accurately predict extreme rainfall. Using both log10 and ln transformations makes the variance more stable and the model fit better. The ln base makes exponential rainfall trends linear, which makes it easier to figure out return periods and intensity-duration-frequency (IDF) relationships. The log10 base guarantees methodological clarity and facilitates comparison with prior research (Chow et al., 1988; Rossman, 2015). Both methods improve the reliability of rainfall modeling, which helps with design elements like retention basins, infiltration trenches, and other SuDS features (Ahmad et al., 2024).

3. RESULTS

3.1 Simulation Model Description

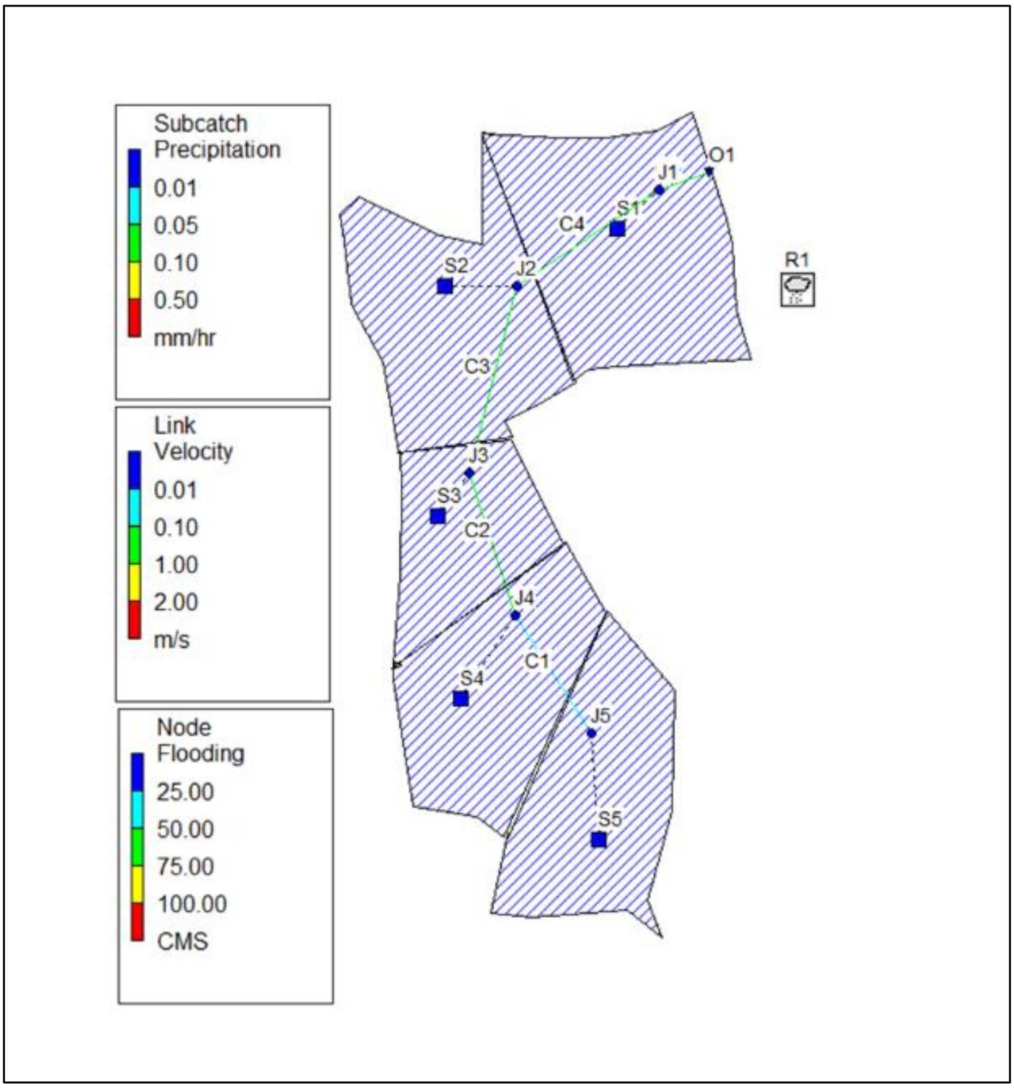

Figure 9: SWMM Model for Bogura Sadar Ward 1

SWMM was used to make the stormwater drainage model for Ward No. 1, which was based on clearly defined watersheds. There are 5 subcatchments, 5 junctions, 5 conduits, and 1 outfall in the system. The outfall is the last place where water leaves the system. There was a complete drainage network because each subcatchment was connected to its inlet and outlet points, and conduits were connected to junctions. Gumbel distribution analysis was applied to estimate rainfall amounts, and this information was used to simulate both normal and extreme storms. Figure 9 shows how the developed model is laid out, with the subcatchments, junctions, conduits, and outfall all in the right places. The SWMM setup made it possible to simulate how runoff is made, how it flows, and how the study area's drainage works in general.

3.2 Design of Stream Conduit Cross-Section

The hydraulic design of conduits was done to make sure that peak flows could pass through them safely without causing flooding or erosion. The continuity equation, A=Q/V, was used to find the needed cross-sectional area. Here, A is the cross-sectional area (in square meters), Q is the discharge (in cubic meters per second), and V is the design velocity (in meters per second). To keep the hydraulic stability, a safe flow speed of 0.8 m/s was chosen to stop sediment from settling and scouring. Table 1 shows a summary of the hydrological and hydraulic results.

Table 1. Summary of Hydrological and Hydraulic Results

Subcatchment Runoff					**Link Flow**					**Stream Cross-section Design**			
Subcatchment	**Total Precipitation (mm)**	**Total Runoff (mm)**	**Peak Runoff (CMS)**	**Runoff Coefficient**	**Link**	**Type**	**Max Flow (CMS)**	**Hour of Max Flow**	**Max Velocity (m/s)**	**Link**	**Discharge, Q (m³/s)**	**Velocity, V (m/s)**	**Area, A (m²)**
5-Year Return Period ln based													
S1	135.57	112.31	5.32	0.828	C1	Conduit	3.71	12:08	1.3	C1	3.71	0.8	4.64
S2	135.57	98.14	4	0.723	C2	Conduit	7.52	12:17	1.4	C2	7.52	0.8	9.4
S3	135.57	107.76	2.55	0.795	C3	Conduit	10.05	12:05	2.1	C3	10.05	0.8	12.56
S4	135.57	106.49	3.08	0.781	C4	Conduit	13.5	12:30	1.2	C4	13.5	0.8	16.88
S5	135.57	98.17	3.6	0.721	C5	Conduit	19.17	12:16	1.8	C5	19.17	0.8	23.96
10-Year Return Period, ln based													
S1	161.42	136.8	6.65	0.844	C1	Conduit	6.56	12:56	1.3	C1	6.56	0.8	8.2
S2	161.42	120.6	4.95	0.746	C2	Conduit	8.33	12:37	2.4	C2	8.33	0.8	10.41
S3	161.42	131.19	3.11	0.148	C3	Conduit	15.76	12:02	1.1	C3	15.76	0.8	19.7
S4	161.42	129.97	4.79	0.801	C4	Conduit	16.88	12:35	2.3	C4	16.88	0.8	21.1
S5	161.42	120.64	3.88	0.741	C5	Conduit	25.66	12:16	2.2	C5	25.66	0.8	32.08
5-Year Return Period, log based													
S1	142.81	118.98	5.65	0.833	C1	Conduit	16.7	12:05	1.08	C1	16.7	0.8	20.88
S2	142.81	104.3	4.25	0.73	C2	Conduit	10.8	12:11	2.4	C2	10.8	0.8	13.5
S3	142.81	114.29	2.71	0.8	C3	Conduit	30.67	12:05	2.2	C3	30.67	0.8	38.34
S4	142.81	112.97	4.09	0.791	C4	Conduit	14.65	12:20	1.7	C4	14.65	0.8	18.31
S5	142.81	104.24	3.83	0.731	C5	Conduit	20.35	12:18	1.8	C5	20.35	0.8	25.44
10-Year Return Period, log based													
S1	203.15	172.96	8.33	0.861	C1	Conduit	20.88	12:02	1.22	C1	20.88	0.8	26.1
S2	203.15	159.06	6.43	0.771	C2	Conduit	16.76	12:06	2.8	C2	16.76	0.8	20.95
S3	203.15	172.38	4.8	0.837	C3	Conduit	55.88	12:04	2.9	C3	55.88	0.8	69.85
S4	203.15	164.21	6.4	0.807	C4	Conduit	25.54	12:18	1.7	C4	25.54	0.8	31.93
S5	203.15	156.85	5.95	0.77	C5	Conduit	40.98	12:20	2.1	C5	40.98	0.8	51.23

3.3 Calibration

In urban hydrology, the runoff coefficient (C) shows how much of the rain that falls on the ground runs off. For Ward No. 1, Bogura Sadar, the first values were based on how the land was used and then changed using pseudo-calibration to better match the area. The following is a summary of the typical ranges for runoff coefficients found in the literature (Chow et al., 1988):

Table 2: Typical runoff coefficient ranges

Land Use / Land Cover	**Runoff Coefficient, C**
Built-up / Urban	0.75 – 0.95
Vegetation / Grass	0.30 – 0.60
Bare Land / Open Soil	0.20 – 0.40
Water body / Pond / River	0.0 – 1.0

The catchment runoff coefficient was calculated using a weighted approach:

$$\frac{(\%B \times 0.85) + (\%V \times 0.55) + (\%BL \times 0.3) + (\%W \times 0)}{100}$$

Where: B= Built-up (%), V= Vegetation (%), BL= Bare Land (%) and W= Water Bodies (%). Land use percentages for the 5 subcatchments were obtained from Figure 7, and the pseudo-calibrated runoff coefficients are presented in Table 3.

Table 3: Pseudo-calibrated runoff coefficient for subcatchments with Comparison of estimated and simulated runoff coefficients

	Simulation Model Runoff Coefficient					**Estimated Runoff Coefficient**
Subcatchment	**Built-up (%)**	**Vegetation (%)**	**Bare Land (%)**	**Water Body (%)**	**Runoff Coefficient**	
S1	94	6	0	0	**0.832**	**0.833**
S2	70	24	2	4	**0.733**	**0.730**
S3	86	12	0	2	**0.797**	**0.800**
S4	88	8	0	4	**0.792**	**0.791**
S5	78	12	0	10	**0.729**	**0.731**

3.4 Explanation of Design

The hydrological and hydraulic simulations for Ward No. 1, Bogura Sadar, provide significant insights into stormwater management in rapidly urbanizing regions. The five defined subcatchments had runoff coefficients ranging from 0.73 to 0.833, which is consistent with values expected for urbanized catchments with high impervious surface coverage (Ahmad et al., 2024; Chow et al., 1988). Subcatchments S1 and S3 had the highest coefficients, 0.833 and 0.80, respectively. This is because they had more built-up coverage and less potential for infiltration. The five conduits were tested for their hydraulic capacity, and it was found that they could handle more water than the highest flows that happen every 10 years. This shows that the proposed system can handle runoff from moderate to heavy rain without overflowing or flooding. The use of a safe flow velocity of 0.8 m/s made sure that the conduits stayed stable and reduced the chances of scouring and sediment buildup along the network.

When looking at the frequency of rainfall using logarithmic methods, the ln-based method always gave slightly lower rainfall intensities than the $\log_{10}$-based method. This would lead to more cautious estimates of runoff, which could mean that stormwater volumes are too low in design scenarios. When land use and pseudo-observed hydrology were used to calibrate the model, it showed that log-based estimates were more accurate than other methods. These values were then used for the final simulation results. The research also emphasizes the impact of impervious surface expansion on urban runoff. Ward No. 1 has become more urbanized quickly, which has led to more impervious surfaces and higher runoff volumes and peak discharges. This highlights the significance of incorporating Sustainable Urban Drainage Systems (SuDS), including infiltration trenches, retention basins, and green infrastructure, to decrease runoff coefficients and alleviate flooding risk (Ahmad et al., 2024; Alom & Khan, 2014).

The study's limitations encompass the availability of rainfall data, which was restricted to 20 years of 24-hour cumulative data obtained from Google Earth Engine. The lack of finer temporal resolution (e.g., 3- to 6-hour intensities) may affect how well frequency analysis and peak flow estimation work. Also, calibration depended on pseudo-calibration because there wasn't enough long-term data on runoff. Even with these limitations, the method gives good estimates for early planning, pointing out important subcatchments and conduit design needs. The results of this analysis give local governments and city planners a way to make decisions about how to improve drainage systems, prioritize actions, and use SuDS to make Bogura Sadar more resilient to heavy rain.

3.5 Discussion on Results

3.5.1 The Critical Role of Imperviousness in Runoff Generation

Solid waste dumping, including household garbage, plastics, and construction debris, frequently blocks drains and reduces their water-carrying capacity. Illegal discharge of household, commercial, and industrial wastewater into stormwater drains causes pollution, sediment buildup, foul odors, and health risks. Encroachment on drainage channels through unauthorized construction narrows or blocks water flow, while unplanned installation of utility lines inside drains damages structures and obstructs maintenance. Additionally, construction activities often lead to siltation of drains. These combined misuses result in chronic waterlogging, environmental degradation, and increased public health hazards in Bogura. The hydrologic simulation gives hard proof that the natural water cycle in Bogura Ward 1 has changed a lot because of rapid urbanization. The consistently high runoff coefficients (0.73 to 0.833) show that the catchment mostly acts as a transport surface and that natural infiltration is not very important. This finding is similar to what has been seen in quickly growing cities in South Asia (Ahmad et al., 2024; Maliha & Khan, 2017). The high impervious fraction directly causes shorter concentration times and higher flow volume and speed, which makes the area very likely to flood quickly (Xu et al., 2023). So, any long-term drainage solution needs to focus on both high-capacity conveyance and source control measures to handle both the peak flow and the total amount of runoff.

3.5.2 Efficacy and Resilience of the Proposed Drainage System Design

The large amount of cross-sectional area needed—especially 69.85 m2 for C3—shows how big the structural changes need to be to make room for the 10-year storm. This hydraulic deficit shows that the current system, which was made for smaller flows, is now working far above safe limits during storms. This causes surcharging and more structural erosion because the water moves so quickly (up to 2.9 m/s). The proposed design is an important step toward real flood resilience because it makes sure that the conveyance system can keep stable, sub-critical flow conditions even when it rains heavily. The confirmation that the system can handle the flow of a 10-year event gives local governments the exact technical details they need to plan for infrastructure investments that will last.

3.5.3 Methodological Implications of Gumbel Logarithmic Transformation

The significant variation in required conduit capacity—surpassing 70% for the primary links (C3, C1)—based solely on the selection of the logarithmic base of the Gumbel distribution, illustrates the critical complexity of statistical method selection in engineering practice. The Ln-Base method was statistically sound, but it produced results that would have led to a design that was not good enough and had a lot of risks. The final design is strong because it used the Log-Base design rainfall, which was strongly supported by the pseudo-calibration process. The study successfully overcame the absence of historical flow monitoring data by validating the Log-Base runoff against the established physical characteristics of land use, thereby achieving a significant level of internal consistency and credibility in a data-limited context. This method can be used as a model for other studies that have similar gaps in regional data.

3.5.4 Constraints Imposed by Data Scarcity and Temporal Resolution

One of the main problems with this analysis is that it relies on 20 years of historical rainfall data and only looks at storm intensities over 24 hours. The SWMM model used this data well by spreading it out over time, but the main problem of accurately capturing urban flash floods still exists. Urban catchments usually have very short concentration times, usually less than six hours. The 24-hour total rainfall, even when statistically distributed, may not accurately represent the peak intensity of short-duration, high-intensity cloudbursts, potentially leading to a slight underestimation of the peak discharge for short-lived, high-impact events (Yazdanfar & Sharma, 2015). This limitation, prevalent in developing contexts (Ahmad et al., 2024; Mahbub et al., 2024), underscores the necessity for institutional prioritization of higher temporal resolution (3–6 hour) precipitation data collection to enhance future hydrological evaluations.

3.6 Comparison with Past Studies

The results align with previous findings in similar contexts. Maliha and Khan (2017) also found that GIS-integrated SWMM design could mitigate Bogra’s flooding with limited data. Their research indicated urban runoff characteristics similar to those of this study. Akbar (2023) and Alom and Khan (2014) also say that Dhaka and other cities need strong drainage systems to deal with the heavy rains that happen often. The runoff coefficients (0.72–0.83) are in the expected range for cities (Chow et al., 1988) and are the same as what was found in case studies from Malaysia and Australia (Morgan & Fenner, 2019; Roy et al., 2008). The 10-year storm's capacity margin shows that the design is strong, which is in line with the goals of sponge cities (Li & Zhang, 2022) and resilient infrastructure. Rainfall frequency results indicate that the ln-based Gumbel method produced lower intensities, whereas the log-based fit, which yielded higher depths, generated runoff predictions more consistent with established expectations. This is similar to what Chow et al. (1988) found: log-transformations often give conservative estimates. After calibrating to land use, the log-based storms were used for the final design. This difference, on the other hand, shows how uncertain short-record analyses can be and suggests that field measurements would make them more accurate.

4. CONCLUSIONS

This study created a long-lasting stormwater drainage plan for Bogura Ward 1 by combining GIS and SWMM. The main results are: Five subcatchments were identified and modeled, yielding runoff coefficients ranging from 0.72 to 0.83, with the highest values observed in the most urbanized subareas. (2) Gumbel frequency analysis used log-transformed data to find 24-hour design storms of about 143 mm (5 years) and 203 mm (10 years). Results based on ln were lower. (3) SWMM simulations showed peak flows of up to 56 m^3/s (10-year storm), and all of the designed conduits (areas 13–70 m^2) can handle those flows safely. The proposed network can handle both normal and more extreme events, showing that it is structurally sound and resilient. (4) A comparison with other studies shows that the approach and results are consistent: they support GIS-based designs and SuDS for urban drainage, both in Bangladesh and elsewhere.

The suggested design gives other cities in Bangladesh that don't have a lot of data a model to follow. Using SuDS principles, like storing water along conduits, can help reduce flooding, improve water quality, and make cities greener. The study shows that local engineers can use modern tools like GIS and SWMM together, which can make planning better than older methods that don't take into account climate trends or spatial detail. The analysis utilized secondary rainfall data (GEE satellite estimates) with a mere 20 years of records, focusing on 24-hour storms. Storm intensities lasting less than 3 to 6 hours were not modeled, which may have resulted in peak flows appearing lower than actual values. Runoff coefficients were generalized for land use categories, and real-time flow calibration was not feasible. These data limitations create ambiguity. Future research should integrate extended local rain gauge records (when accessible) to enhance frequency analysis. Last but not least, scenario analyses (for example, with more imperviousness or climate change) will help make sure that Bogura's stormwater management system will work for a long time.

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DECLARATION OF USE OF AI

During the preparation of this work, the authors used ChatGPT, Gemini, Grammarly, and Mendeley Cite for summarization, grammar refinement, spelling correction, rearranging sentences to improve flow, clarity, and consistency of the writing, and citation management. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

REFERENCES

Ahmad, S., Jia, H., Ashraf, A., Yin, D., Chen, Z., Ahmed, R., & Israr, M. (2024). A Novel GIS-SWMM-ABM Approach for Flood Risk Assessment in Data-Scarce Urban Drainage Systems. *Water*, *16*(11), 1464. https://doi.org/10.3390/w16111464

Akbar, S. (2023). *Analysis of Urban waterlogging Risk in Bangladesh; Causes Effects and sustainable remedies: A Review*. *10*.

Alom, M., & Khan, Z. H. (2014). *Environmental and Social Impact Due to Urban Drainage Problems in Dhaka City, Bangladesh*. *3*(6).

Budjan, A., Cibin, C., Imran, K., Moellerherm, R., & Pan, J. (2024, March 31). *Fostering climate resilience: Socio-economic effects of improved urban drainage in Bangladesh*. International Growth Centre. https://www.theigc.org/collections/fostering-climate-resilience-socio-economic-effects-improved-urban-drainage-bangladesh

Chow, V. T., Maidment, D. R., & Mays, L. W. (1988). *Applied hydrology*. McGraw-Hill.

CIRIA. (2019). The SuDS Manual C753F. https://www.ciria.org/CIRIA/Books/Free_publications/C753F.aspx

Fayshal, Md. A., Jarin, T. T., Ullah, M. R., Rahman, S. M. A., Siddque, A. A., & Siddique, I. M. (2023). A Comprehensive Review of Drain Water Pollution Potential and Environmental Control Strategies in Khulna, Bangladesh. *Journal of Water Resources and Pollution Studies*, *8*(3), 41–54. https://doi.org/10.46610/JoWRPS.2023.v08i03.006

García, A. I. A., & Santamarta, J. C. (2022). Scientific Evidence behind the Ecosystem Services Provided by Sustainable Urban Drainage Systems. *Land*, *11*(7), 1040. https://doi.org/10.3390/land11071040

García-Haba, E., Hernández-Crespo, C., Martín, M., & Andrés-Doménech, I. (2023). The role of different sustainable urban drainage systems in removing microplastics from urban runoff: A review. *Journal of Cleaner Production*, *411*, 137197. https://doi.org/10.1016/j.jclepro.2023.137197

Li, F., & Zhang, J. (2022). A review of the progress in Chinese Sponge City programme: Challenges and opportunities for urban stormwater management. *Water Supply*, *22*(2), 1638–1651. https://doi.org/10.2166/ws.2021.327

Mahbub, H. A., Md Iqbal Sarwar, & Muhibbullah, M. (2024). *Drainage Congestion and Its Impacts on Urban Environment: A Case Study on Chattogram Metropolitan City, Bangladesh*. https://doi.org/10.13140/RG.2.2.11370.32964

Maliha, M., & Khan, M. S. M. (2017). *Design of Stormwater Drainage Network with Limited Data Using GeoSWMM: A Case Study for Bogra City*.

Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M. I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J. B. R., Maycock, T. K., Waterfield, T., Yelekçi, Ö., Yu, R., & Zhou, B. (Eds.). (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. https://doi.org/10.1017/9781009157896

Morgan, M., & Fenner, R. (2019). Spatial evaluation of the multiple benefits of sustainable drainage systems. *Proceedings of the Institution of Civil Engineers - Water Management*, *172*(1), 39–52. https://doi.org/10.1680/jwama.16.00048

Qiao, X.-J., Kristoffersson, A., & Randrup, T. B. (2018). Challenges to implementing urban sustainable stormwater management from a governance perspective: A literature review. *Journal of Cleaner Production*, *196*, 943–952. https://doi.org/10.1016/j.jclepro.2018.06.049

Rodríguez-Rojas, M. I., Garrido-Jiménez, F. J., Abarca-Álvarez, F. J., & Vallecillos-Siles, M. R. (2024). Advances in the Integration of Sustainable Drainage Systems into Urban Planning: A Case Study. *Sustainability*, *16*(7), 2658. https://doi.org/10.3390/su16072658

Rossman, L. A. (2015). *Storm Water Management Model User's Manual Version 5.1*.

Roy, A. H., Wenger, S. J., Fletcher, T. D., Walsh, C. J., Ladson, A. R., Shuster, W. D., Thurston, H. W., & Brown, R. R. (2008). Impediments and Solutions to Sustainable, Watershed-Scale Urban Stormwater Management: Lessons from Australia and the United States. *Environmental Management*, *42*(2), 344–359. https://doi.org/10.1007/s00267-008-9119-1

Si, Q., Brito, H. C., Alves, P. B. R., Pavao-Zuckerman, M. A., Rufino, I. A. A., & Hendricks, M. D. (2024). GIS-based spatial approaches to refining urban catchment delineation that integrate stormwater network infrastructure. *Discover Water*, *4*(1), 24. https://doi.org/10.1007/s43832-024-00083-z

Xu, Z., Ma, C., Gao, X., Ma, Y., & Zhou, J. (2023). A calibration method for SWMM to mitigate the impact of the structure defect without considering runoff on building walls. *Frontiers in Ecology and Evolution*, *11*. https://doi.org/10.3389/fevo.2023.1212501

Yazdanfar, Z., & Sharma, A. (2015). Urban drainage system planning and design - Challenges with climate change and urbanization: A review. *Water Science and Technology : A Journal of the International Association on Water Pollution Research*, *72*, 165–179. https://doi.org/10.2166/wst.2015.207