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Identification Of Drainage Systems Capacity Using EPA-SWMM 5.2 Version Modeling In Bastiong Karance, Ternate City

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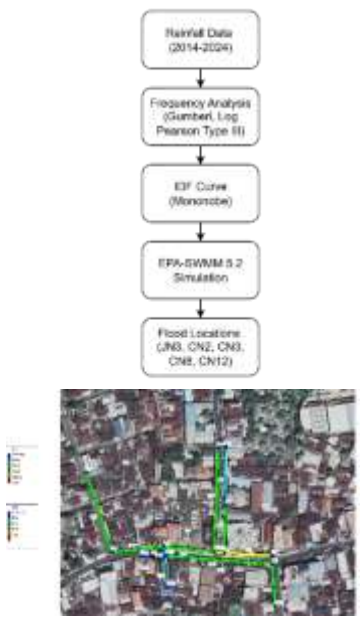
Graphical Abstract



Abstract
Flooding and waterlogging in Bastiong Karance, Ternate City, are recurring problems during heavy rainfall, primarily due to insufficient drainage capacity and high impervious land use. This study evaluates the performance of the existing drainage system through hydrological and hydraulic modeling using EPA-SWMM 5.2. Ten years of maximum daily rainfall data (2014–2024) were analyzed with Gumbel and Log Pearson Type III distributions to estimate design rainfall, while the Mononobe method was used to derive intensity-duration-frequency (IDF) curves. Field surveys provided drainage geometry, and topography data were obtained from Global Mapper. The study area was divided into seven Sub-Catchments, 13 junctions, 14 conduits, and two outfalls. Simulation results indicated that node JN3 experienced localized flooding for 0.09 hours with a peak discharge of 0.296 m^3/s and total volume of 0.055×10^6 liters. Conduits CN2, CN3, CN8, and CN12 experienced surcharge with exceedance durations of 0.01–0.26 hours. These findings highlight the limitations of the current drainage system in accommodating runoff during a 10-year return period storm. Recommended measures include widening critical conduits, constructing retention ponds, and implementing infiltration-based runoff reduction strategies to mitigate future flood risk.

Keywords: Urban drainage, EPA-SWMM, rainfall intensity, flooding, Ternate City

1. INTRODUCTION

Urban flooding is increasingly recognized as a major hydrological hazard in rapidly growing cities worldwide. It occurs when drainage infrastructure is unable to accommodate stormwater during extreme rainfall events [1], [2]. In many Asian cities, including Indonesia, urbanization has intensified impervious surfaces, leading to higher peak discharges and shorter times to concentration [3], [4]. This transformation significantly reduces natural infiltration capacity, and consequently amplifies runoff generation [5], [6].

Ternate City, located in the North Maluku Province of Indonesia, experiences heavy monsoonal rainfall and rapid urban development. Bastiong Karance, one of the subdistricts in South Ternate, frequently suffers inundation during intense rainfall events, with flood depths reaching 20 - 40 cm along major road corridors and residential areas. Similar urban flooding problems have been documented in Mumbai, India [7], Busan, Korea [8], and Cangzhou, China [9], where drainage networks were found to be undersized relative to current hydrological extremes.

Designing and evaluating drainage systems require robust hydrological analysis. Estimation of design rainfall commonly employs probability distributions such as Gumbel and Log Pearson Type III [1], [3]. These distributions have been successfully applied to derive rainfall return periods in data-rich contexts like Central

Vietnam [20] and to construct Intensity–Duration–Frequency (IDF) curves for large metropolitan areas [7]. In Indonesia, the Mononobe method remains the standard approach for transforming rainfall depth into design intensities [6].

Hydrological-hydraulic models provide an effective means of simulating runoff and drainage system performance under various design scenarios. The U.S. EPA's Storm Water Management Model (SWMM) has been widely used for over four decades [10]. Its flexibility allows the simulation of rainfall–runoff processes, channel hydraulics, and the performance of Low Impact Development (LID) practices [5], [11]. SWMM has been successfully applied in diverse contexts: assessing flood risk in Zhenjiang, China [12]; testing sponge city approaches in Beijing and China [13], [14]; evaluating green infrastructure in watershed-scale studies [15], [16]; and analyzing drainage performance in Gunung Pangilun, Padang City, Indonesia [17]. The Padang case demonstrated how SWMM can identify conduit surcharging and flooding hotspots under design storms [17], confirming its applicability in the Indonesian urban context.

Recent advances in flood modeling integrate SWMM with two-dimensional hydraulic solvers, such as MIKE21 [9] and Iber [18]. These coupled approaches enable more accurate representation of surface ponding and overland flow, which are critical in dense urban environments. However, in many medium-sized Indonesian cities, limited data availability constrains the use of complex coupled models [12]. Therefore, applying standalone SWMM with careful calibration remains a practical and reliable solution.

This study aims to evaluate the capacity of the Bastiong Karance drainage system through: (i) statistical analysis of rainfall frequency using Gumbel and Log Pearson III distributions, (ii) derivation of IDF curves with the Mononobe method, (iii) rainfall–runoff and hydraulic modeling with EPA-SWMM 5.2, and (iv) identification of flood-prone junctions and conduits under a 10-year design storm. The outcomes will provide actionable insights for local government planning and contribute to the broader literature on urban drainage performance in Southeast Asian cities.

(a) (b) (c)

Figure 1. Flood locations along Bastiong Karance Main Road (Primary Collector): (a) Residential area (2020), (b) Bastiong Karance Subdistrict Office (2022), (c) Nurul Fatah Mosque (2025).

2. METHOD

Study Area

Bastiong Karance is located in South Ternate District (0°47′N, 127°22′E) with an approximate area of 2.5 km^2. The topography is relatively flat with gentle slopes towards the sea, ranging from 0.1% to 8.4% as derived from DEM analysis. Land use is dominated by residential settlements (60%), commercial zones (30%), and minor green spaces (10%). Drainage infrastructure consists mainly of open rectangular channels with widths between 0.5–1.2 m and depths of 0.4-1.5 m, similar to conditions reported in other medium-sized Southeast Asian cities [19].

Data Collection

The following datasets were utilized:

1. Rainfall: Annual maximum daily rainfall for 2014–2024 from Sultan Babullah Meteorological Station (59.9–219.7 mm/day).
2. Topography: 12.5 m resolution DEM from Global Mapper, supplemented by Google Earth for validation of slopes.

3. Hydraulic geometry: Field survey of 14 conduits including lengths, depths (0.6–1.32 m), Manning's roughness, and slopes.

Rainfall Frequency Analysis

Annual maxima were fitted using Gumbel and Log Pearson Type III methods, both widely adopted in hydrological frequency analysis [1], [20]. The Chi-square test and probability plot correlation were used for goodness-of-fit evaluation [21]. Log Pearson III was found to provide the best fit, yielding a 10-year return rainfall of 120.15 mm. This is consistent with rainfall return estimates in tropical cities such as Mumbai [21] and Ho Chi Minh City [22].

Table 1. Rainfall intensity (10-year return period)

Year	Rainfall (mm/day)
2014	89.00
2015	59.90
2016	102.10
2017	70.60
2018	98.00
2019	142.80
2020	114.40
2021	96.90
2022	88.10
2023	96.00
2024	219.70

Table 2. Compatibility test result Chi-Square

Year	Assumptions	Results	Information
Gumbel	$Cs = 1.14$	1.99	Not Accept
	$Ck = 5.4$	8.25	Not Accept
Normal	$Cs = 0$	1.99	Not Accept
	$Ck = 3$	8.25	Not Accept
Log Pearson Type III	$Cs \neq 0$	0.32	Accept
Log Normal	$Cs = 3Cv + Cv^3$	0.00	Not Accept
	$Ck = 4$	3.00	Not Accept

Rainfall Intesity and IDF Curve

Rainfall intensities for durations of 1–6 hours were derived using the Mononobe method [6]. For the 10-year return period, intensities ranged from 64.16 mm/h (1 h) to 19.43 mm/h (6 h). The resulting IDF curves resemble those observed in Central Vietnam [22] and in Thessaloniki, Greece [18] .

Table 3. Rainfall intensity for differen durations (10-year return period)

Duration (hours)	Intensity (mm/hours)
1	64.16
2	38.76
3	28.13
4	23.20
5	20.33
6	19.43

EPA-SWMM Model Setup

The Bastiong Karance drainage network was modeled in EPA-SWMM 5.2 [10]. The system was represented by seven subcatchments, 13 junctions, 14 conduits, and two outfalls. Input parameters included imperviousness (40–80%), infiltration rates (Horton method), channel roughness, and conduit dimensions. The hyetograph used corresponded to the 10-year design storm distributed over six hours. Similar configurations have been reported in Busan [8], Surat [13], and Andong [23].

3. RESULTS AND DISCUSSION

Sub-Catchment Runoff

Simulations showed runoff coefficients between 0.399 (SC5) and 0.751 (SC6). Subcatchments SC3 and SC4 generated the highest peak flows (0.61 and 0.60 m^3/s). These values align with findings in Guangzhou [21] and Busan [8], where dense impervious areas amplified runoff response.

Figure 2. Sub-catchment runoff in the Bastiong Karance area

Table 4. Runoff coefficients and peak discharges of sub-catchments

Sub-Catchment	Runoff Coefficient	Peak Runoff (m^3/s)
SC1	0.55	0.41
SC2	0.62	0.48
SC3	0.70	0.61
SC4	0.68	0.60
SC5	0.399	0.32
SC6	0.751	0.57
SC7	0.60	0.45

Location of flood points

Only junction JN3 experienced flooding during the simulated storm. Flooding lasted 0.09 h with a peak discharge of 0.296 m^3/s and a flood volume of 0.055×10^6 L. Although the flood duration was short, its location on a main road suggests significant disruption potential, consistent with observations in Thessaloniki [18] and Cangzhou [9].

Table 5. Node flooding summary

Node	Duration (hour)	Peak Runoff (m^3/s)	Flood Volume ($\times10^6$ L)
JN3	0.09	0.296	0.055

Conduit Surcharge

Four conduits (CN2, CN3, CN8, CN12) experienced surcharge. CN2 had the longest surcharge duration of 0.26 h, indicating insufficient cross-sectional area. Similar structural inadequacies have been reported in Surat [13] and Ho Chi Minh City [22].

Figure 3. Overflowing channels identified by EPA SWMM 5.2 in Bastiong Karance area

Table 6. Conduit surcharge summary

Conduit	Hours Both Ends Full	Hours Upstream Full	Hours Downstream Full	Hours Above Normal Flow	Hours Capacity Limited
CN2	0.01	0.01	0.26	0.01	0.01
CN3	0.01	0.01	0.01	0.24	0.01
CN8	0.01	0.01	0.17	0.01	0.01
CN12	0.01	0.01	0.18	0.01	0.01

The results demonstrate that Bastiong Karance's drainage system cannot accommodate runoff from a 10-year storm. This deficiency is typical of rapidly urbanizing areas where infrastructure lags behind development [5]. Structural interventions such as conduit enlargement and detention basins are essential [19], [13]. Non-structural measures, including LID practices (green roofs, permeable pavements, bioretention) and sponge city principles [14], [16], should be integrated into future planning.

This study provides the first detailed evaluation of Bastiong Karance's drainage capacity using EPA-SWMM 5.2, offering direct implications for urban drainage planning in Ternate City. The findings also underscore the importance of data quality. As noted by Shrestha et al. [12], incomplete drainage data and coarse DEMs can lead to underestimation of flood risk. Incorporating dual drainage models such as Iber-SWMM [18] or coupling with MIKE21 [9] could improve prediction accuracy in future work. Furthermore, climate change is projected to increase rainfall extremes [24], suggesting that design standards must be revised to accommodate higher return periods.

The results highlight the inability of the current system to convey runoff from a 10-year storm. While flooding was localized, the risk of higher return period storms remains significant. Infrastructure improvements such as channel enlargement, retention ponds, and green infrastructure should be prioritized.

4. CONCLUSION

This study analyzed rainfall extremes and evaluated the Bastiong Karance drainage system using EPA-SWMM 5.2. The analysis confirmed that the existing system cannot manage runoff from a 10-year storm, as evidenced by flooding at JN3 and surcharges in CN2, CN3, CN8, and CN12. The methodology combining rainfall frequency analysis, IDF curve generation, and SWMM simulation was consistent with approaches applied globally. The findings highlight the urgent need for both structural (channel enlargement, detention basins) and non-structural (LID, sponge city approaches) interventions [14]. Future studies should extend analysis to higher return periods and incorporate climate change scenarios [24]. Integrating SWMM with 2D hydraulic models [9], [18] and applying green infrastructure planning [5], will enhance resilience and provide a robust foundation for sustainable urban drainage in Ternate City.

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