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ARTICLE

Study on Response Capacity of Drainage Systems in Coastal Urban of Vietnam Under the Impact of Extreme Weather Events

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ABSTRACT

Coastal cities in Vietnam face increasing urban flooding vulnerability due to climate change-induced extreme precipitation. This study evaluates the response capacity of urban drainage systems, using Vung Tau City as a case study. We employed a comprehensive approach, combining Intensity-Duration-Frequency (IDF) curve analysis with hydrodynamic modeling, to assess drainage performance under current and projected rainfall intensities. A significant rainfall event on June 19, 2020 (54.4 mm in 3 h, peaking at 42 mm/h), which exceeded the 5-year return period design (TCVN 7957:2008), caused widespread flooding (25-50 cm depths). Design rainfall hyetographs for 2, 5, and 10-year return periods (TCVN 7957:2008) were developed. Results show that under more extreme scenarios, flooded areas increase significantly, with depths up to 1.05 m in the 10-year scenario and prolonged durations due to stormwater routing through regulatory lakes. The analysis reveals the current infrastructure meets only 64% of the 5-year return period demands and merely 41% for a 10-year period. This research highlights the urgent need for enhanced flood management in Vung Tau and similar coastal cities, suggesting upgrades to drainage capacity, implementation of sustainable urban drainage systems, and improved early warning. These insights are valuable for developing climate-resilient infrastructure.

Keywords: Urban Flooding; Drainage System; Extreme Rainfall; IDF Curve; Climate Change

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1. Introduction

Climate change has emerged as one of the most pressing global challenges of our time, with far-reaching implications for countries worldwide, including Vietnam [1,2]. The convergence of rapid urbanization and climate change has significantly amplified the risk of urban flooding in coastal urban areas (CUAs) [3–5]. This phenomenon is particularly concerning given the critical role CUAs play in economic development and population concentration [6,7]. These activities have substantially contributed to the escalation of flood risks in CUAs [3,5,8]. The dramatic increase in impervious surfaces from rapid urbanization [9–11], coupled with the attenuation of river networks and inadequate drainage infrastructure, has heightened the vulnerability of urban areas to torrential rainfall events globally [12,13]. These anthropogenic activities have led to profound transformations in urban land use patterns, resulting in a distinct underlying surface characteristic that markedly diverges from the natural landscape [12–14]. Specifically, the proportion of impervious surfaces has risen substantially, while the density of river networks has diminished significantly [15,16]. The impact of urbanization on the hydrological cycle in CUAs is multifaceted [17,18]. As noted by [3], the urbanization process often replaces vegetation, which plays a crucial role in intercepting and storing rainfall, thereby altering surface runoff characteristics. This land cover change not only reduces natural water absorption capacity but also accelerates surface runoff rates, exacerbating flash flooding potential during intense rainfall events [7,17]. Climate change further compounds these challenges by increasing the frequency and intensity of extreme weather events, including droughts, heat waves, and heavy rainfall [5,9]. According to [7], climate change's negative impacts, particularly heavy rainfall events, exacerbate the frequency and severity of flooding in CUAs. Consequently, assessing future climate change impacts on urban flooding and adopting effective flood management measures have become increasingly critical [19,20].

Vung Tau City, a prime example of a Vietnamese coastal urban area, exemplifies the challenges many similar cities face [7,21]. With a 42 km coastline and situated in a tropical monsoon climate zone characterized by distinct rainy and dry seasons, the city experiences significant urban flooding, particularly during the rainy season (May to November), marked by an increasing number of heavy rainfall events in recent years [7,21]. The most common urban flooding events in Vung Tau involve extreme rainfall lasting 2 to 6 hours, resulting in widespread inundation [21]. Despite investments in drainage system upgrades, extreme rainfall continues to cause flooding on many main roads, with water depths typically ranging from 25–30 cm and reaching 40–50 cm in some areas [21]. While urban flooding from rainfall exceeding drainage system design capacity is not novel, the increasing frequency and intensity of these events have elevated this issue to a top priority for urban planners and policymakers [21]. The intensification of extreme rainfall due to climate change presents a complex challenge; both the intensity and frequency are subject to unpredictable changes influenced by ongoing urbanization [13,22,23]. In response to these challenges, the IDF method has become increasingly important for designing and evaluating urban drainage systems, particularly when modifying or replacing outdated infrastructure [24–26]. The concept of IDF curves, first proposed by Bernard in 1932 [24], has evolved significantly through numerous studies [27,28]. Derived from short-term rainfall frequency analysis, these curves provide crucial data for urban hydrological planning [7,29]. Recent research focuses on simulating IDF curves for various rainfall durations (5 minutes to 24 hours) and recurrence intervals (2, 5, 10, 25, 50, and 100 years) using daily rainfall data [28,29,30].

In light of these developments, this study aims to address a critical gap in the current understanding of urban drainage systems in Vietnamese coastal areas under extreme weather events, a context where increasing urbanization and climate vulnerability demand updated assessment methods. By focusing on Vung Tau City as a case study, this study evaluates the response capacity of the existing drainage infrastructure to various rainfall scenarios, including those exceeding historical norms. Through a comprehensive analysis of local rainfall patterns, drainage system capacities, and potential future climate scenarios, this study provides valuable insights for urban planners, policymakers, and engineers. The findings will contribute to developing more effective flood management strategies, not only for Vung Tau but also for other coastal urban areas facing similar challenges in Vietnam.

2. Materials and Methods

2.1. Study Area and Data

Ba Ria — Vung Tau Province, located in southern Vietnam, is a pivotal center for economic, financial, cultural, tourism, and transportation activities in the region [28]. At the heart of this province lies Vung Tau City, a strategically important urban area that exemplifies the challenges faced by many coastal cities in Vietnam. Vung Tau City is characterized by two distinct geographical features: the Vung Tau peninsula and the coastal islands. With a coastline stretching 42 kilometers and encompassing a total area of 141.1 square kilometers, the city is home to a population of 527,025 as of 2018 [28]. Administratively, Vung Tau is divided into 17 sub-units, comprising 16 wards and 1 commune, and is classified as a Grade I city, primarily developed for tourism and service functions (**Figure 1**). The climate is typical of tropical monsoon regions, featuring two well-defined seasons: a rainy season from May to November and a dry season for the remainder of the year. This climatic pattern plays a crucial role in shaping the city's hydrological challenges, particularly in recent years as extreme weather events have become more frequent [28].

Figure 1. The Study Area in the Study Area in Ba Ria-Vung Tau Province.

2.2. Methods

2.2.1. Intensity-Duration-Frequency (IDF) Curve

The IDF curve is a crucial tool in hydrological engineering, representing the relationship between rainfall intensity, duration, and frequency for a specific location over various return periods (**Figure 2**). This method is widely employed to determine rainfall intensities for different frequencies, essential for designing urban drainage systems, flood control structures, and urban planning. To identify the most appropriate empirical formula for the IDF curve in the research area, a comprehensive review of previous studies focused on Vietnam's climate, specific regions, or localities adjacent to the study site was conducted. This approach ensures the methodology is grounded in relevant, context-specific research. A notable study calculated design rainfall for Can Tho City (a Grade I urban area in southern Vietnam) using the CDF function and various empirical formulas previously applied in Vietnam and Asia, including those from Vietnamese Standard TCVN 7957:2008 [28]. Evaluating results using the Efficiency Index (EI) and Root Mean Square Error (RMSE), Minh et al. found the IDF curve constructed according to TCVN 7957:2008 demonstrated the best performance ($0.84 \leq$ EI ≤ 0.93; $2.5 \leq$ RMSE ≤ 3.2). Supporting the selection of this standard, another relevant study comparing various methods and TCVN 7957:2008 for constructing IDF curves in northern Vietnam also found relatively small mean square errors and correlation coefficients when applying the TCVN 7957:2008 formula [2,6,7,10,28].

Based on these findings and considering the regional relevance, this study utilizes the formula from TCVN 7957:2008 to construct the IDF curves for urban rainfall design in Vung Tau, Vietnam. This approach ensures the methodology is scientifically sound and aligned with established national standards proven effective in similar Vietnamese climatic contexts [25].

$$q = A(1+C.logP)/(t+b)^n \tag{1}$$

where q—rainfall intensity (L/S.ha); t—rainfall duration (minutes); P—calculated rainfall cycle (years); A, C, b, n—these parameters are determined according to local conditions (Vietnam Standard 7957: 2008; for areas not listed in **Table 1**, the nearest or neighboring areas were used) (**Table 1**).

Table 1. IDF Curve Calculation Parameters for the Study Area.

Parameter	A	C	b	n
Vung Tau	11650	0.58	32	0.95

2.2.2. Mathematical Modeling Method

In the field of urban drainage modeling, numerous studies have demonstrated that the integration of 1D+2D modules yields more effective results compared to 1D/1D approaches. This combined methodology allows for the simulation of both hydraulics within the sewer system and surface runoff on streets [7,21,24]. MIKE URBAN, a comprehensive model for calculating stormwater runoff processes, is primarily applied in urban drainage design. This model comprises three main modules:

(1) Runoff: Converts rainfall on the catchment surface into surface runoff.

(2) Transport: Routes flow through the system of channels and pipes.

(3) MOUSE: Integrates runoff, transport, and overland flow, simulating street flooding.

Our study utilizes a model inherited from the research project "Application of artificial intelligence combined with remote sensing in flood risk warning due to heavy rain and high tides for coastal urban areas" (**Figure 3**).

The study area encompasses five drainage subcatchments: Bai Truoc, Ben Dinh, Vo Thi Sau — A Chau Lake, Bau Sen Lake, and Bau Trung Lake — Rach Ba — Cua Lap catchment. The existing drainage system consists

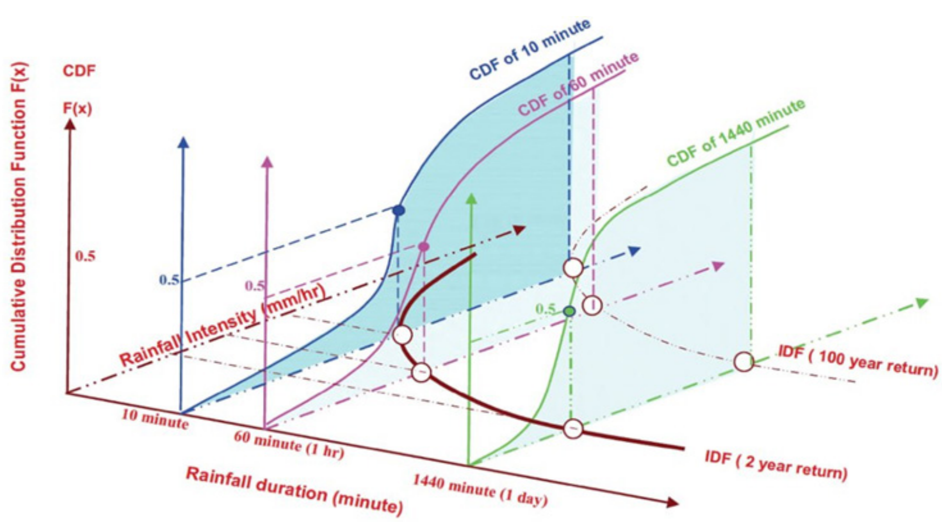

Figure 2. Relationship Between Cumulative Distribution Function and IDF Rainfall Curve [28].

of approximately 441.7 km of various pipe types ranging from 150 to 2000 mm in diameter, six retention ponds, and 107 outfalls. The main drainage axes of the city generally run from south to north and east to west, primarily utilizing a system of regulating lakes and artificial canals. This design adheres to the principle of preventing discharge into bathing areas (**Figure 4**).

This comprehensive approach to modeling allows for a detailed analysis of the urban drainage system's response to extreme weather events, taking into account both the underground pipe network and surface water accumulation. By employing this advanced modeling technique, our study aims to provide a more accurate assessment of flood risks and drainage system performance in Vung Tau City, thereby contributing to more effective flood management strategies for coastal urban areas in Vietnam.

In this study, daily water level data were collected from the Southern Regional Hydro—Meteorological Station at three stations Tan Chau, Chau Doc, and Vam Nao during the period of 1978–2023 (Vam Nao station from 1984 to 2023). As for the flow discharge, data at Tan Chau and Chau Doc stations were collected from 1978 to 2023.

Figure 3. Drainage System of the Study Area with Main Drainage Axis on Google Earth.

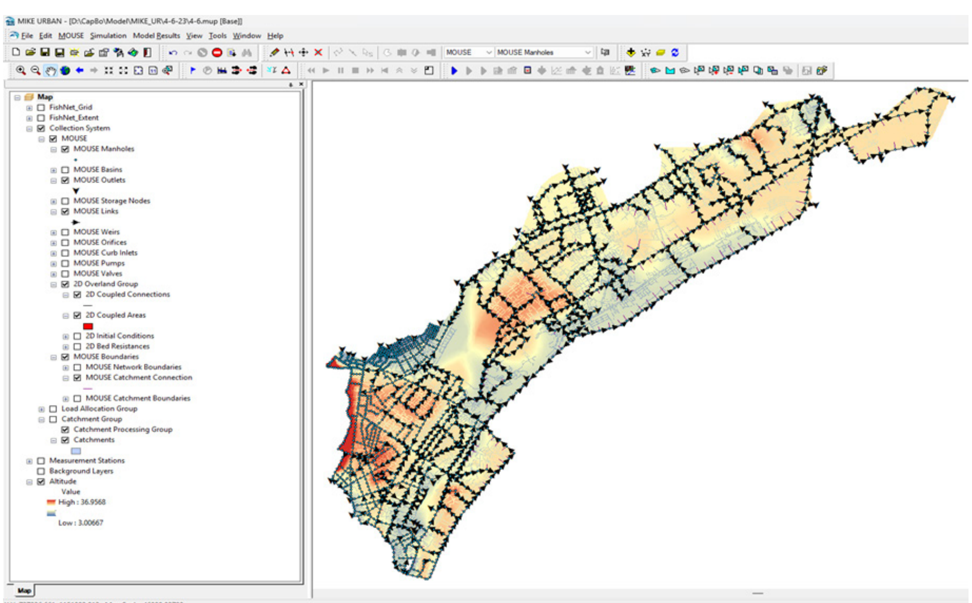

Figure 4. Drainage System of the Study Area with Set Up Drainage System, Road Terrain, Buildings on MIKE URBAN Model.

2.2.3. Design Rainfall Construction Database

Construction of IDF Curve of Rainfall in the Study Area

Based on the TCVN 7957: 2008 formula, we developed IDF curves for various durations (15’, 30’, 45’, 60’, 90’, 2h, 3h, 6h, 12h, 24h) and return periods (1, 2, 5, 10, 20, 50, and 100 years). These curves represent the current scenario and play a crucial role in calculating and constructing design rainfall hyetographs (**Figure 5**). This comprehensive set of IDF curves allows for a detailed analysis of rainfall patterns across different time scales and frequencies, providing a solid foundation for assessing the urban drainage system’s response to various precipitation events in Vung Tau City [25].

In Vung Tau, annual rainfall ranges from 1000 to 1900 mm, with rainfall during the rainy season accounting for about 90% of the total annual rainfall. Rainfall levels ≥ 40 mm and ≥ 50 mm occur mainly during the rainy season in Vung Tau city; levels ≥ 80 mm to ≥100 mm have the lowest frequency of occurrence (data collected from 1991 to 2024) (**Figure 6**).

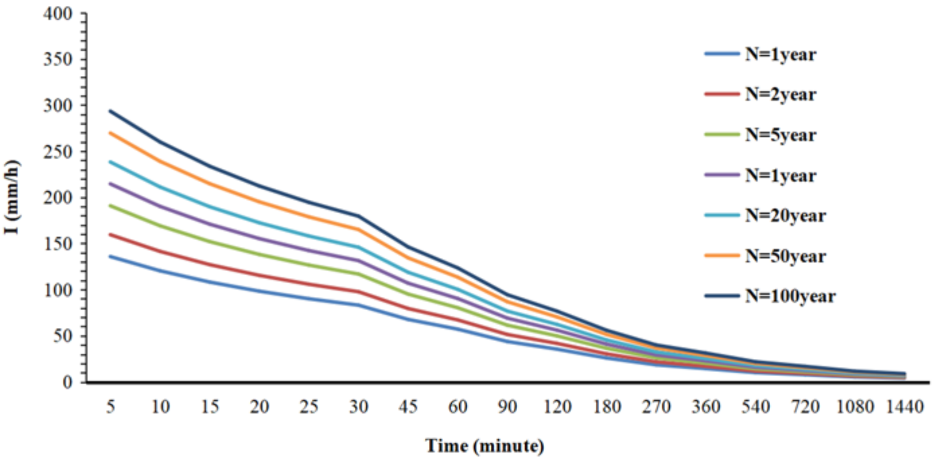

Figure 5. Rainfall IDF Curve of the Study Area.

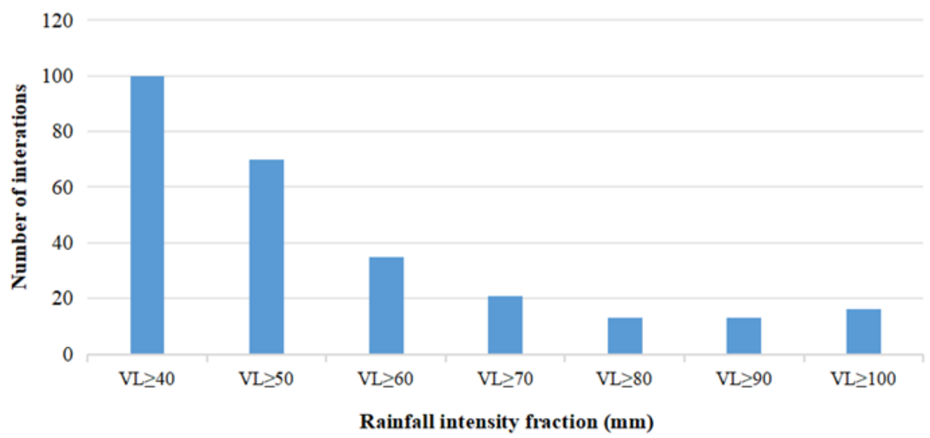

Figure 6. Distribution of Rainfall Levels (Considering the Rainy Season, May to November).

On average, in recent years, each year there are about 8–10 rainstorms with rainfall greater than 40 mm; these are also rainstorms with a high potential to cause flooding in the city. In the past 30 years, rainfall mainly fluctuated from 40–50 mm, the duration of these rainstorms was about 3 hours; accounting for 80% of the total 62 rainstorms recorded. Through reviewing the rainstorms in the area, the study selected the rainstorm on June 19, 2020, with a total rainfall of 54.4 mm, a peak rainfall of 47.8 mm lasting 3 hours (180 minutes) to build the design rainfall charts with frequencies of 2 years, 5 years, 10 years (**Table 2**).

3. Results and Discussion

3.1. Simulated Results of Urban Flooding with Current Rainfall Events

Based on the TCVN 7957:2008 formula, IDF curves were developed for various durations (15', 30', 45', 60', 90', 2h, 3h, 6h, 12h, 24h) and return periods (1, 2, 5, 10, 20, 50, and 100 years) (**Table 3**). The simulation results derived from these IDF curves provide crucial insights into rainfall patterns and their potential impacts on the urban drainage system. **Table 3** presents the analyzed rainfall intensities for various durations and return periods, allowing for a detailed analysis of precipitation trends.

In the analysis of the response capacity of urban drainage systems in Vung Tau City under extreme weather events, various flood scenarios were simulated to assess system performance. The results provide valuable insights into the city's flooding vulnerability and the effectiveness of its current drainage infrastructure. The current scenario (baseline), based on the June 19, 2020 rainfall event, represents the most severe flooding in recent history. This 180-minute event, with total precipitation exceeding 50 mm and a peak intensity near 50 mm/hr, resulted in 32 flooded areas across Vung Tau. Flood depths ranged from 0.10 m to 0.45 m (**Figure 7**), primarily affecting major traffic arteries, intersections, and roundabouts. The urban flooding was attributed to several factors: low-lying areas such as the Ton Duc Thang — Ben Dinh basin; insufficient storm drains on streets like Le Hong Phong and Truong Cong Dinh; rapid water accumulation due to hilly terrain near Vi Ba slope and Nui Lon; and inadequate drainage in older residential areas like Ngo Quyen and Luu Chi Hieu.

Table 2. Rainfall Diagram (mm) Designed for 2, 5, 10-Year Return Periods, Corresponding to 180-Minute Periods.

Rainfall Intervals (minute)	Rainfall Event 19 June 2020	Return Periods		
		2 year	5 year	10 year
60	0.5	0.8	1.0	1.1
120	47.8	80.1	95.8	107.7
180	6.1	10.2	12.2	13.7
Total	***54.4***	***91.12***	***109.03***	***122.57***

Table 3. Results of Rainfall Intensities for Return Intervals Across Vung Tau City, Ba Ria-Vung Tau Province.

Duration (minute)	Return periods (year)						
	1	2	5	10	20	50	100
15	108.2	127.1	152.0	170.9	189.8	214.8	233.7
30	83.1	97.7	116.9	131.4	145.9	165.1	179.6
45	67.7	79.5	95.1	106.9	118.8	134.4	146.2
60	57.2	67.1	80.3	90.3	100.3	113.5	123.4
90	43.7	51.3	61.4	69.1	76.7	86.8	94.4
120	35.5	41.7	49.9	56.0	62.2	70.4	76.6
180	25.9	30.4	36.3	40.9	45.4	51.3	55.9
270	18.5	21.7	26.0	29.2	32.4	36.7	39.9
360	14.4	16.9	20.3	22.8	25.3	28.6	31.2
540	10.1	11.8	14.2	15.9	17.7	20.0	21.8
720	7.8	9.1	10.9	12.3	13.6	15.4	16.8
1080	5.4	6.3	7.5	8.5	9.4	10.6	11.6
1440	4.1	4.8	5.8	6.5	7.2	8.1	8.9

For future rainfall scenarios, the IDF curve for the 2-year return period provides crucial insights into rainfall patterns that urban planners and engineers can expect to occur, on average, once every two years. This analysis focuses on durations ranging from 15 minutes to 24 hours, based on the data provided in **Table 2**.

3.2. Simulation Results of Urban Flooding Events with a 2-Year Return Periods

For future rainfall scenarios, the IDF curve for the 2-year return period provides insights into rainfall patterns expected, on average, once every two years. This analysis focuses on durations from 15 minutes to 24 hours (**Table 3**). In this scenario, a significant increase in flood severity occurred. The maximum flood depth reached 0.75m, 0.3m higher than the current scenario. Most flooded areas experienced depths between 0.15 m and 0.30 m (**Figure 8**). This demonstrates the existing drainage system's vulnerability to even moderately increased rainfall. For short-duration events under the 2-year return period (**Figure 5** and **Table 3**), rainfall intensities are high: a 15-minute event is expected to produce 127.1 mm/hr. This intensity decreases to 115.4 mm/hr for a 20-minute duration and 97.7 mm/hr for a 30-minute duration. This trend highlights the inverse relationship between rainfall intensity and duration for short time spans.

For medium-duration events, rainfall intensities continue to decrease. A 60-minute (1-hour) event shows an intensity of 67.1 mm/hr, reducing further to 41.7 mm/hr for a 120-minute (2-hour) event. This significant intensity decrease over relatively short duration increases underscores the importance of considering various time scales in urban drainage design. For longer durations, intensity decreases at a slower rate. A 6-hour (360-minute) event has an intensity of 16.9 mm/hr, while a 12-hour (720-minute) event has 9.1 mm/hr. The longest duration considered, 24 hours (1440 minutes), shows an intensity of 4.8 mm/hr (values from **Table 3**).

3.3. Simulation Results of Urban Flooding Events with a 5-Year Return Periods

The 5-year return period scenario revealed further deterioration. Maximum flood depth increased to 0.9 m, with most areas exceeding 0.3 m depth. Severely affected areas included major roads like 30/4 (near the airport), National Highways 51B and 51C, coastal areas, beaches, and embankments (**Figure 9**). This highlights the potential for widespread disruption under more intense rainfall. The simulated results for the 5-year return period IDF curve (**Table 3, Figure 5**) reveal critical non-linear relationships. For the shortest 15-minute duration, intensity peaks at 87.6 mm/hr (equivalent to 21.9 mm accumulated precipitation), reflecting susceptibility to convective cloudbursts. Intensity decays exponentially with duration, decreasing 41% to 51.8 mm/hr at 1-hour, then stabilizing quasi-linearly beyond 6 hours. Notably, the 24-hour maximum intensity (6.3 mm/hr) is only 7.2% of the 15-minute peak yet delivers 151.2 mm total precipitation—a volume exceeding the monthly average for 8 months annually.

3.4. Simulation Results of Urban Flooding Events with a 10-Year Return Periods

The most extreme scenario modeled was the 10-year return period event, showing a dramatic increase in flood depth and extent. Maximum flood depth reached 1.05 m, and 10 new flooding locations emerged. Notably, 80–90% of flooded areas experienced depths between 0.3 m and 1.0 m (**Figure 10**). Specific flood depth increases included: Ton Duc Thang - Ben Dinh areas (from 0.33 m to 0.76 m), Le Hong Phong and Truong Cong Dinh streets (from 0.18 m to 0.68 m), Vi Ba slope and Nui Lon (from 0.41 m to 1.0 m), and older residential areas (Ngo Quyen, Luu Chi Hieu; from 0.23 m to 0.49 m). The IDF curve for the 10-year return period (**Table 3, Figure 5**) provides critical insights into more extreme events expected, on average, once per decade. For short durations, intensities are particularly high. A 15-minute event yields 170.9 mm/hr, decreasing to 155.3 mm/hr for 20 minutes and 131.4 mm/hr for 30 minutes. This highlights the potential for intense, short storms to overwhelm drainage systems. For medium durations, intensities decrease significantly: a 60-minute (1-hour) event drops to 90.3 mm/hr, and a 120-minute (2-hour) event reduces to 56.0 mm/hr. For longer durations, intensity continues decreasing: a 6-hour (360-minute) event shows 22.8 mm/hr, and a 24-hour (1440-minute) event shows 6.5 mm/hr.

Figure 7. Simulation Results of Urban Flooding Based on the Representative Rainfall Event of June 19, 2020 with Color Bar Indicates Flood Depth (m).

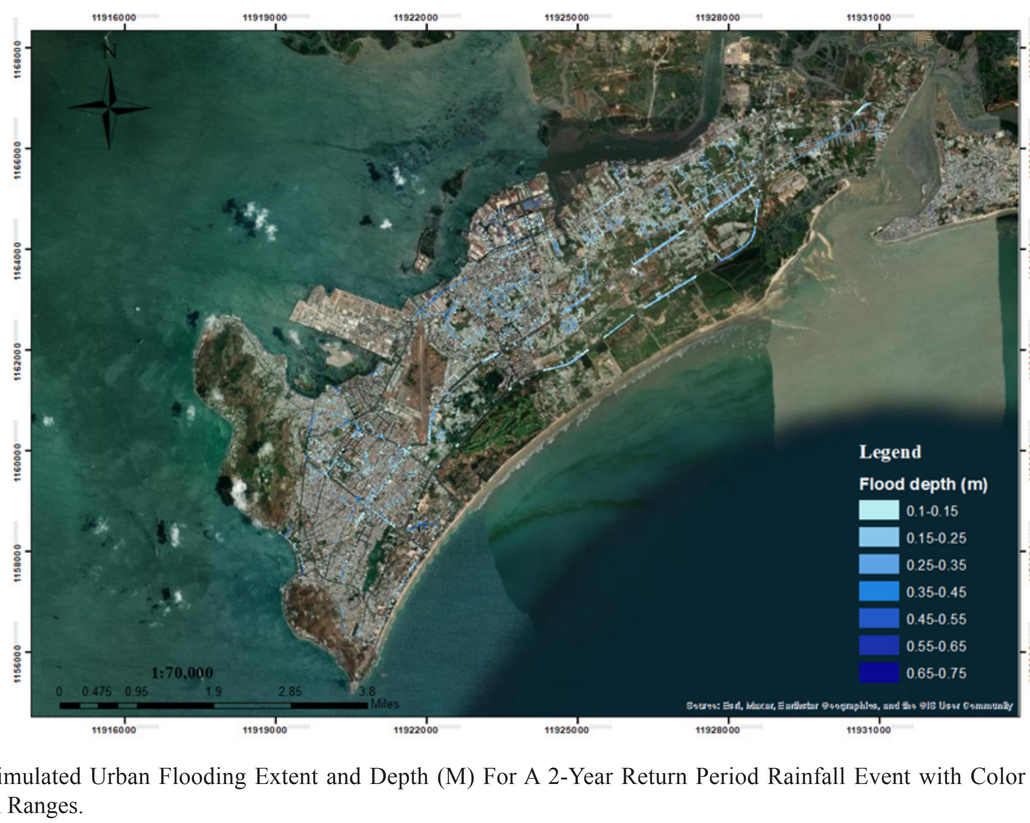

Figure 8. Simulated Urban Flooding Extent and Depth (M) For A 2-Year Return Period Rainfall Event with Color Bar Indicates Water Depth Ranges.

Figure 9. Simulated Urban Flooding Extent and Depth (m) for a 5-Year Return Period Rainfall Event with Color Bar Indicates Water Depth Ranges.

Figure 10. Simulated Urban Flooding Extent and Depth (m) for a 10-Year Return Period Rainfall Event. Color Bar Indicates Water Depth Ranges.

4. Discussion

This study of the response capacity of urban drainage systems in coastal Vietnam under extreme weather reveals critical challenges for cities like Vung Tau. The IDF curve analysis and simulation results highlight the complex interplay between rainfall intensity, duration, frequency, and their impact on urban flooding.

A critical finding is the relationship between flood depth and duration. Extreme rainfall not only increases flood depths but also leads to longer flooding periods after rainfall stops. This prolonged flooding, partly due to the city's drainage design routing stormwater through regulatory lakes, poses significant challenges to urban mobility, economic activities, and daily life. The study identifies particularly vulnerable areas: low-lying basins, locations with insufficient drainage infrastructure, and areas affected by rapid runoff from hilly terrain. These hotspots require prioritization in future flood mitigation efforts.

The IDF curve analysis reveals important patterns. Short-duration events (15–30 minutes) exhibit significantly high intensities; a 15-minute, 100-year return period event produces nearly double the intensity of a 1-year event (**Table 3**). This stark difference highlights the potential for extreme short storms to overwhelm drainage systems designed for less intense, more frequent events.

Interestingly, for longer durations (3–24 hours), intensity differences across return periods become less pronounced, suggesting the drainage system may be better equipped for longer, less intense rainfall. This inverse relationship between intensity and duration is crucial for urban planners designing systems to manage both short, intense bursts and prolonged precipitation. These findings underscore the need for robust, adaptable urban drainage systems capable of managing diverse precipitation scenarios.

Furthermore, the simulation results suggest a significant capacity shortfall. Comparing the system's performance under the design storms with its operational requirements indicates that the current infrastructure meets only approximately 64% of the demands for a 5-year return period and merely 41% for a 10-year return period, highlighting the severity of the deficit under more extreme events. The dramatic increase in flooding severity between the current scenario and the 10-year return period suggests the existing drainage system was likely designed for events with relatively short return periods, indicating a pressing need for infrastructure upgrades. While this study focused on return periods up to 10 years (with IDF curves developed up to 100 years), the trend suggests potentially greater challenges for lower-probability, higher-magnitude events anticipated under future climate scenarios. In the context of climate change, where extreme weather events are expected to increase in frequency and intensity, these results gain added significance. What is currently considered a 100-year event may occur more frequently, necessitating upgrades to existing infrastructure to ensure urban resilience.

Overall, this study provides valuable insights for urban planners and engineers in coastal Vietnam and similar regions. It highlights the importance of using comprehensive IDF analyses and flood simulations to inform drainage infrastructure design and upgrades. Doing so allows cities to better prepare for and mitigate extreme weather impacts, ensuring resilience against current and future rainfall patterns facing climate change.

5. Conclusions

Flood calculation results for Vung Tau city under the designed rainstorm scenarios reveal that increased rainfall intensity significantly overloads the drainage system's capacity compared to the representative (June 19, 2020) rainstorm. In the highest (10-year) scenario, the system appears unable to cope adequately. The rainstorm on June 19, 2020 (over 50 mm in 3 hours), considered a heavy event for the city, caused flooding up to 0.45 m depth, significantly affecting local conditions even if the spatial extent was not maximal compared to modeled scenarios.

Therefore, revising the city's drainage design frequency is necessary, considering economic development, urbanization, and the impacts of climate change driving more severe extreme rainfall. Changes should prioritize main roads with level II sewers to ensure adequate drainage to level I sewers. Concurrently, level III sewers require consideration for renovation and upgrading to handle future extreme rainfall events, which may deliver very high precipitation totals within short periods like 3 hours.

Author Contributions

Conceptualization: N.V.H. and N.T.H.; methodology: N.T.H. and P.T.L.; writing—original draft preparation: N.V.H., N.T.H., and D.T.A.; writing—review and editing: D.T.A. and N.V.H.; visualization: N.T.H. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

The data supporting the findings of this study have been generated but are not currently available in a public repository. The data can be made available by the corresponding author upon reasonable request.

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Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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