

DERIVING SHORT-DURATION DESIGN RAINFALL FROM DAILY RAINFALL FOR URBAN DRAINAGE ASSESSMENT IN A DATA-SCARCE AREA

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Abstract: Upgrading and improving urban drainage systems to prevent and mitigate urban flooding under the impacts of climate change and urbanization has become an urgent priority. The design of drainage systems should be based on appropriate design standards. Accordingly, this study develops design rainfall hyetographs based on intensity-duration-frequency (IDF) curves and the Alternating Block Method (ABM), combined with the Storm Water Management Model (EPA-SWMM), to assess the drainage capacity of an urban catchment. While typical urban areas generally have sufficient rainfall monitoring stations providing short-duration rainfall observations for drainage system design, newly developed urban areas often lack such data. Therefore, this study focuses on analyzing the correlation between daily and short-duration rainfall, using Tan Son Hoa (TSH) station as the reference station and Xi Mang Ha Tien (XMHT) station as the representative station for the data-scarce Thu Duc Canal catchment. The results show a strong correlation in maximum daily rainfall between the two stations, with $R^2=0.996$, while the relationships between daily and short-duration rainfall exhibit R^2 values ranging from 0.9047 to 0.9813, all of which are statistically significant at the 5% significance level. Based on the regression equations between $Z_{day}P$ and $Z_{duration}P$, IDF curves and design rainfall hyetographs were developed for return periods of $N=2-50$ years, using a peak position coefficient of $r=0.45$. The subsequent EPA-SWMM simulations provide a preliminary assessment indicating that the drainage capacity of the Thu Duc Canal catchment is limited, with several drainage pipes and manholes exceeding their design capacity thresholds in areas including Kha Van Can Street, Vo Van Ngan Street, and the Thu Duc Post Office area.

Keywords: Maximum daily rainfall, Short-duration rainfall, Rainfall correlation, Design rainfall, IDF.

1. Introduction

Under the combined impacts of rapid urbanization and climate change, urban flooding has become increasingly frequent and severe, causing significant economic and social losses. To effectively prevent and mitigate flood-related damages, it is necessary to identify the major drivers of urban flooding. These drivers can be classified into natural factors, such as extreme rainfall and tidal surges, and anthropogenic factors associated with socio-economic development and urban management practices. Among these factors, improving the stormwater drainage capacity

of urban systems represents a practical intervention measure to enhance resilience against high-intensity rainfall events.

Engineering solutions and urban drainage infrastructure are commonly designed based on design rainfall standards [1-4]. Various approaches have been developed to determine design rainfall characteristics, with most studies focusing on the Intensity-Duration-Frequency (IDF) relationship [5-14]. According to TCVN 7957:2023 [15], the design and assessment of urban stormwater drainage networks require two main steps: (1) Determination of rainfall intensity based on IDF curves and (2) Hydraulic analysis of the stormwater drainage system. Several studies have integrated IDF-based design rainfall with urban hydrological and hydraulic

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models to evaluate drainage performance [16-20]. Based on previous scientific studies, assessing the existing drainage capacity of urban areas and supporting the optimal design of drainage infrastructure require an integrated approach combining design rainfall derived from IDF curves with urban hydrological models. These two components represent the relationship between rainfall amount, rainfall duration, and temporal rainfall distribution over a catchment, which governs runoff generation and ultimately determines the required capacity and dimensions of drainage structures.

However, many study areas lack long-term, continuous, and reliable rainfall observations, particularly high-resolution rainfall data. For urban stormwater drainage design, rainfall data with short intervals of approximately 10-15 minutes are required to construct design storm events. Therefore, this study aims to establish rainfall correlations for areas lacking short-duration rainfall data. The proposed approach provides a useful reference for improving persistent urban flooding conditions and supporting the design of efficient drainage infrastructure while reducing unnecessary costs and time during construction and operation.

The Thu Duc Canal catchment was selected as a pilot study area based on its topographic characteristics, existing drainage conditions, and rainfall monitoring network. First, topography

plays an important role in runoff generation, flow concentration, drainage direction, and drainage capacity within urban catchments [21-22]. The Northern part of the Thu Duc Canal catchment has relatively high elevations, exceeding 25 m, gradually decreasing toward the canal head where elevations are approximately 2 m with steep slopes. The downstream area consists of low-lying zones with elevations of about 1.4 m. Second, the Thu Duc Canal is the only main drainage outlet of the catchment. The canal receives runoff from approximately 620 ha of upstream elevated areas, resulting in a significant concentration of stormwater flow toward Vo Van Ngan Street from Northern sub-catchments. This drainage pathway crosses Vo Van Ngan Street before reaching the receiving water body, the Thu Duc Canal (Figure 1). Furthermore, the existing stormwater drainage system has limited hydraulic capacity, with open channels and drainage conduits having relatively small cross-sectional dimensions, ranging from approximately 1.0 to 3.0 m in some sections. During rainfall events combined with tidal surges, several locations experience severe flooding, including the Pham Van Dong-To Ngoc Van intersection, Thu Duc Post Office area, and Duong Van Cam Street [23]. Therefore, the study area is considered a critical urban flooding hotspot requiring detailed assessment and improved drainage planning.

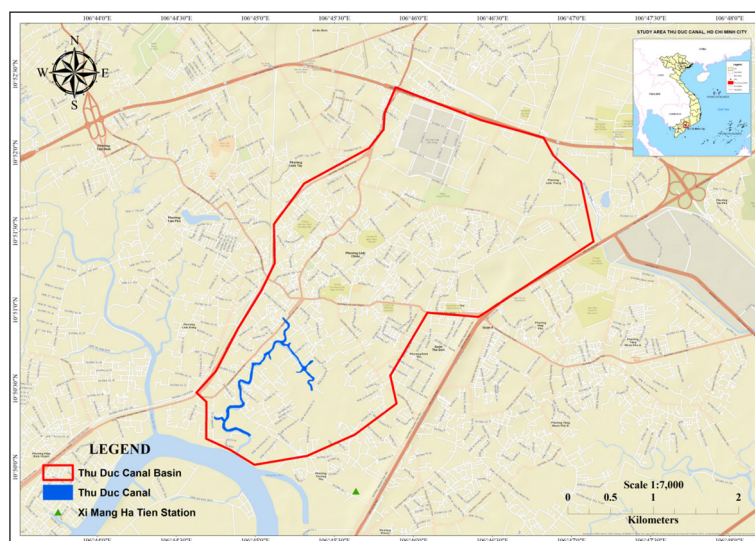


Figure 1. The study area - Thu Duc Canal Basin

Land-use demand and urban expansion have also contributed to a significant increase in surface runoff. Remote sensing image interpretation results indicate that the urbanized area accounts for up to 55.72% of the total catchment area of the Thu Duc Canal [23] (Figure 2a-d). The high proportion of impervious

surfaces has shortened the concentration time of runoff, while substantially reducing infiltration and depression storage losses. Consequently, both the total runoff volume and peak discharge within the study area have increased considerably, exacerbating the severity of urban flooding.

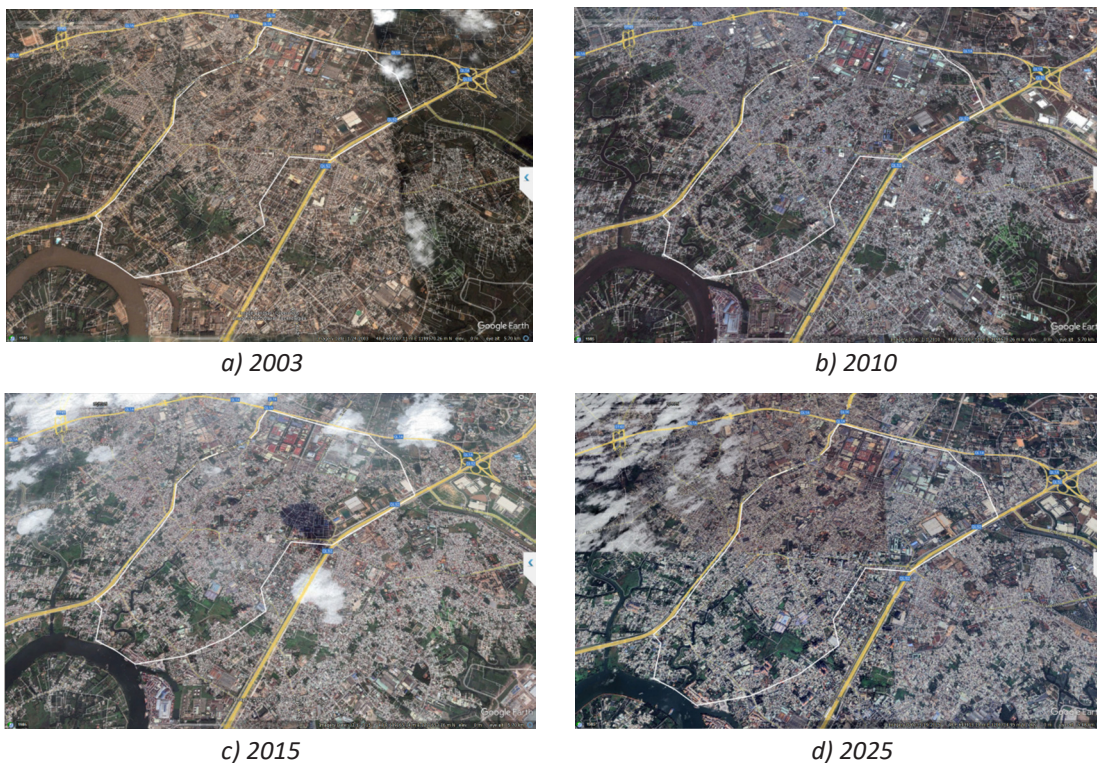


Figure 2. Urbanization process in the Thu Duc Canal Catchment

The rainfall monitoring network in Ho Chi Minh City has been expanded since 1977, with relatively high station density and favorable spatial distribution for rainfall analysis and estimation. However, most existing rainfall stations managed by the Southern Regional Hydro-Meteorological Center are currently semi-automatic stations or community-based rainfall observation stations. Among these stations, the Tan Son Hoa station is an automatic rainfall monitoring station with a relatively long observation record (1990-2025) and high-resolution rainfall data recorded at 15-minute intervals.

For the Thu Duc Canal catchment, the current rainfall monitoring network only includes the Xi Mang Ha Tien station; however, the available data are limited to the maximum

daily rainfall statistics. To overcome the lack of short-duration rainfall data for the design and construction of stormwater drainage systems in the study area, this study initially investigates the rainfall correlation between the Tan Son Hoa and Xi Mang Ha Tien stations. Subsequently, the Alternating Block Method (ABM) [1-3, 24-25] is applied to develop a site-specific design rainfall hyetograph for the Thu Duc Canal catchment.

2. Research methodology

To quantify rainfall distribution characteristics in urban areas, this study applies a rainfall correlation approach based on maximum daily rainfall data to derive short-duration rainfall characteristics required for urban drainage design.

The research methodology consists of the following steps (Figure 3):

(1) The correlation between the Tan Son Hoa and Xi Mang Ha Tien rainfall stations was evaluated using the maximum daily rainfall series from 1990 to 2025. The Pearson III frequency distribution was applied to analyze the frequency characteristics of extreme rainfall events at both stations.

(2) The relationship between maximum short-duration rainfall and maximum daily rainfall at different frequencies was established for the Tan Son Hoa station. The corresponding regression equation and correlation coefficient were determined to identify an appropriate rainfall conversion relationship.

(3) Once the results from Steps (1) and (2) satisfied the reliability criteria, the Intensity-Duration-Frequency (IDF) curves for the Xi Mang Ha Tien station were developed.

(4) Design storm hyetographs for the Xi Mang Ha Tien station were constructed using the Alternating Block Method (ABM). Design rainfall patterns corresponding to different frequencies and return periods were generated to support the design of urban drainage structures.

(5) The EPA Storm Water Management Model (EPA-SWMM) was applied using the derived design rainfall events at the Xi Mang Ha Tien station to simulate the hydraulic response of the Thu Duc Canal drainage system.

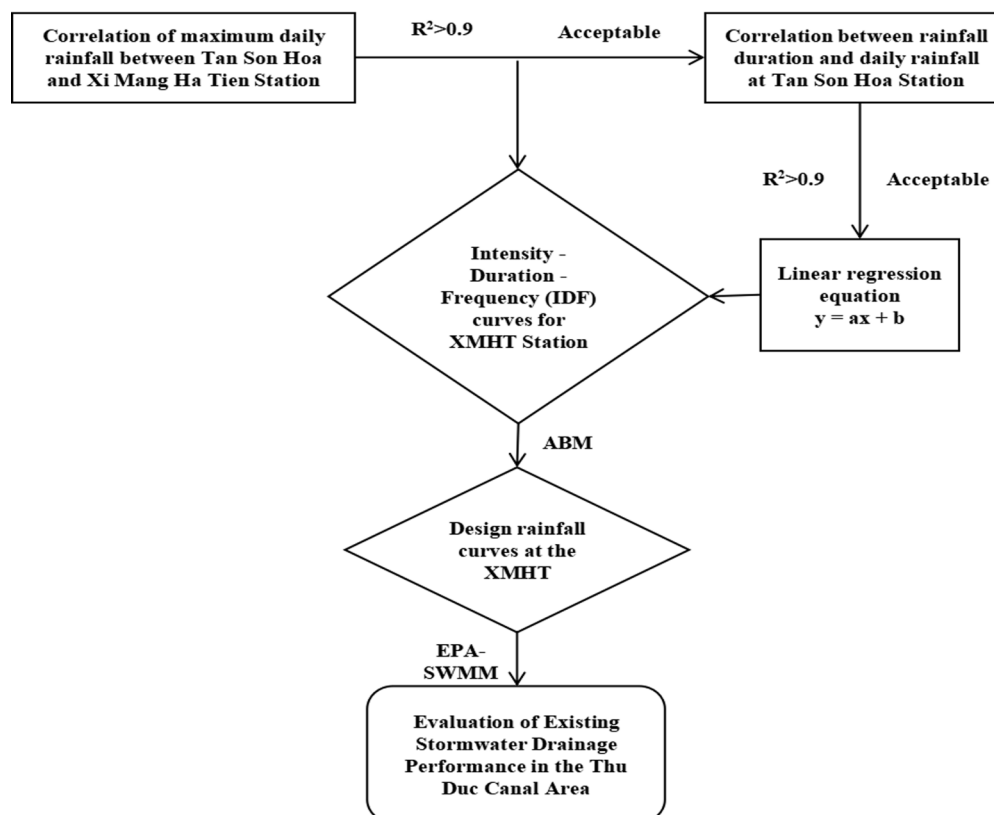


Figure 3. Flowchart of the calculation procedures

3. Results and Discussion

3.1. Development of the Design Rainfall Hyetograph for Xi Mang Ha Tien Station

The correlation results of the maximum daily rainfall corresponding to different return

periods between Xi Mang Ha Tien Station and Tan Son Hoa Station, based on the maximum daily rainfall data series from 1990 to 2025 using the Pearson III frequency distribution method [26], [27], show a very strong correlation ($R^2 = 0.996$) (Figure 4).

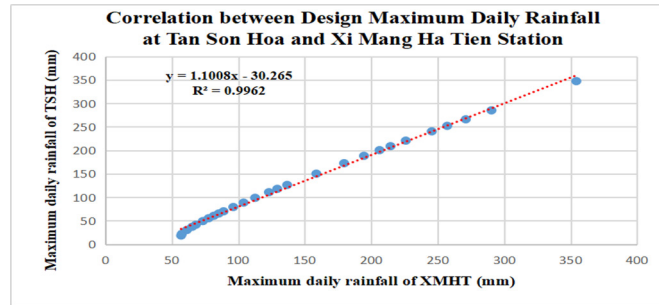


Figure 4. Relationship graph of maximum daily rainfall versus frequency at Tan Son Hoa Station and Xi Mang Ha Tien Station - Period 1990-2025

Subsequently, the study further evaluated the correlation between daily rainfall and rainfall durations at Tan Son Hoa Station. The correlation coefficients derived from the

daily rainfall-duration rainfall relationships demonstrated a high level of reliability, with the correlation coefficient (R^2) ranging from 0.90 to 0.98 (Figure 5 and Table 1).

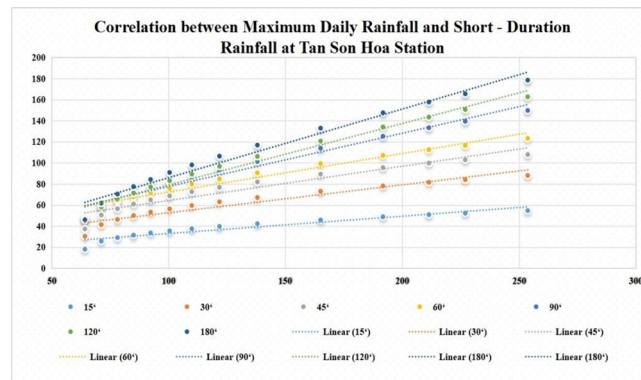


Figure 5. Correlation between maximum duration-based rainfall and maximum daily rainfall corresponding to different frequencies at Tan Son Hoa Station

Table 1. Correlation equations for Xi Mang Ha Tien Station

No.	Duration (min)	Correlation equation	R^2	P-value
1	15	$Z_{15'} = 0.1646*(Z_{day} P) + 16.499$	0.9047	1.76×10^{-7}
2	30	$Z_{30'} = 0.2646*(Z_{day} P) + 26.182$	0.9223	5.14×10^{-8}
3	45	$Z_{45'} = 0.3252*(Z_{day} P) + 31.71$	0.9259	3.87×10^{-8}
4	60	$Z_{60'} = 0.3656*(Z_{day} P) + 35.68$	0.9615	7.49×10^{-10}
5	90	$Z_{90'} = 0.5048*(Z_{day} P) + 27.069$	0.9786	2.19×10^{-11}
6	120	$Z_{120'} = 0.582*(Z_{day} P) + 20.853$	0.9813	9.63×10^{-11}
7	180	$Z_{180'} = 0.6514*(Z_{day} P) + 20.674$	0.9756	4.75×10^{-11}

The results in Table 1 show strong linear relationships between $Z_{day}P$ and $Z_{duration}P$, with R^2 values ranging from 0.9047 to 0.9813. All rainfall durations exhibit $R^2 > 0.90$, with corresponding p-values below 0.001. Therefore, all regression relationships are statistically significant at the 5% significance level.

Accordingly, based on the system of equations presented in Table 1, the IDF curves for rainfall durations of 15, 30, 45, 60, 90, 120, and 180 minutes at Xi Mang Ha Tien Station were developed (Figure 6), using the corresponding $Z_{day}P$ values representing the maximum daily rainfall at the station.

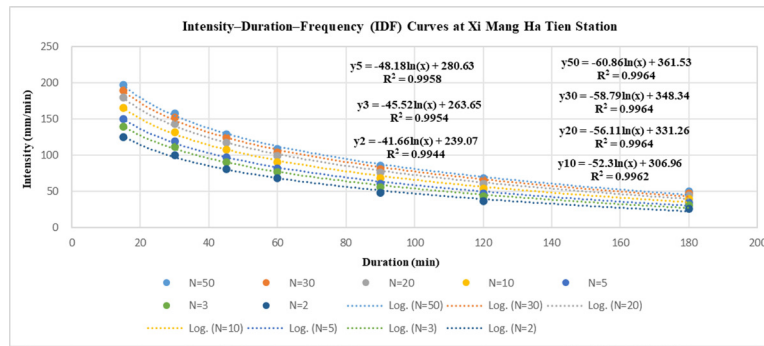


Figure 6. Intensity-Duration-Frequency (IDF) curves for Xi Mang Ha Tien Station

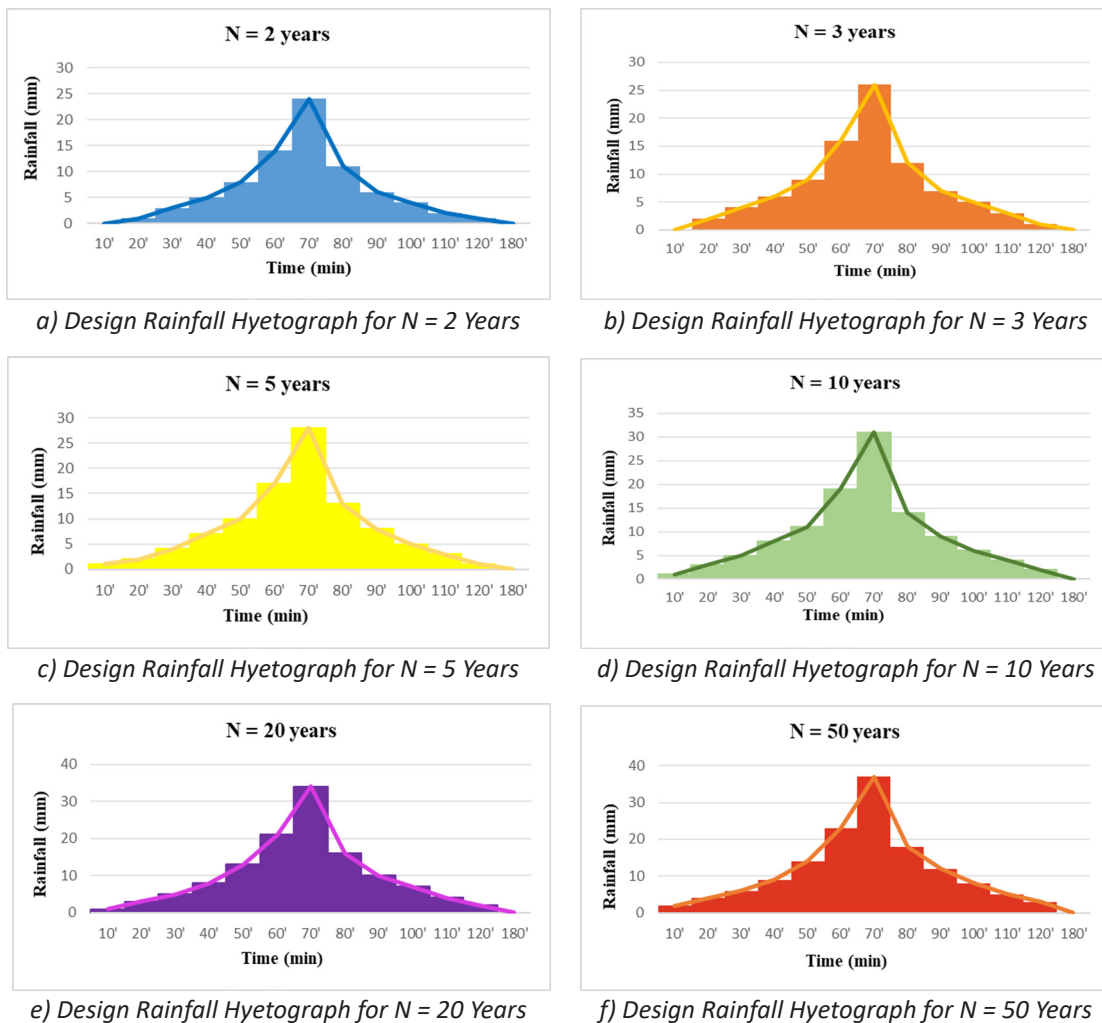


Figure 7. Design Rainfall Hyetograph for Xi Mang Ha Tien Station

Once the IDF curves for Xi Mang Ha Tien Station have been established, the study proceeds to develop the design rainfall hyetograph for assessing the drainage capacity of the Thu Duc Canal catchment using the

Alternating Block Method (ABM) (Chow et al., 1988 [25]). This method is used to transform the rainfall derived from the IDF relationships into a time-distributed design rainfall hyetograph. In essence, IDF curves provide rainfall intensity

corresponding to different rainfall durations and specified return periods, but do not directly describe the temporal distribution of rainfall within a storm event. Therefore, the temporal arrangement of rainfall blocks needs to be determined to construct the design rainfall hyetograph. The rainfall peak position coefficient (Keifer, 1957 [28]; McPherson, 1979 [29]), is used to determine the relative position of the rainfall peak within the total storm duration.

The rainfall peak position coefficient (r) is calculated as:

$$r = \frac{t_p}{T} \quad (1)$$

Where: t_p is the time from the beginning of the rainfall event to the occurrence of the rainfall peak; T is the total rainfall duration.

The study selected three representative rainfall events at Tan Son Hoa Station, occurring on September 26, 2016; June 2, 2018; and November 25, 2018, to analyze the temporal distribution characteristics of rainfall. These events exhibited similar characteristics, with a total rainfall duration of approximately 3 hours (180 minutes) and the rainfall peak occurring at approximately the 80th minute after the onset of rainfall. Based on the representative rainfall characteristics reported in [30], the rainfall peak position coefficient was determined as $r = 0.45$ by applying Equation (1). This value was subsequently used to construct the design rainfall hyetograph for Xi Mang Ha Tien Station (Figure 7a-f).

3.2. Evaluation of the Design Rainfall Model Results for Thu Duc Canal

The study area covers a part of Hiep Binh Ward, Tam Binh Ward, and Linh Xuan Ward (Thu Duc City), with a total area of 620 ha. The hydrological model consists of 64 subcatchments (divided according to the local drainage system - Table 2), 5 main outfalls. The current status of the study area indicates that there are no pumping stations and no detention reservoirs (Figure 8).

To evaluate the stormwater drainage capacity of the Thu Duc Canal catchment, the study applied the design rainfall hyetograph developed above in combination with observed rainfall data from the event on November 25, 2018. Based on simulations using the EPA-SWMM model, the locations of inundated areas were identified and compared with actual observed flooding conditions (Figure 9).

According to statistics from the Ho Chi Minh City Flood Control Operation Center, during the rainfall event on November 25, 2018, the downstream area of Thu Duc Canal experienced severe inundation. This area is subjected to concentrated runoff from the main drainage corridors in the Northern part of the catchment (including runoff from Kha Van Can Street, Linh Trung Street, Hoang Dieu 2 Street, and Dang Van Bi Street, which converges toward Vo Van Ngan Street). The inundated road sections corresponding to the manholes and drainage branches represented in the EPA-SWMM model of Thu Duc Canal are as follows (Figure 10a-c):

Table 2. Drainage system of Thu Duc Canal

No.	Drainage direction	From	to
1	Kha Van Can	Pham Van Dong	Thu Duc Canal
2	Linh Trung	Ha Noi Highway	Hoang Dieu 2
3	Hoang Dieu 2	Le Van Chi	Kha Van Can
4	Vo Van Ngan	Ha Noi Highway	Kha Van Can
5	S11	Kha Van Can	To Ngoc Van
6	Duong Van Cam	Le Van Tach	Kha Van Can
7	Dang Thi Ranh	To Ngoc Van	Duong Van Cam
8	Dang Van Bi	Nguyen Van Ba	Vo Van Ngan
9	S11	Ho Van Tu	Nha Tra Bridge

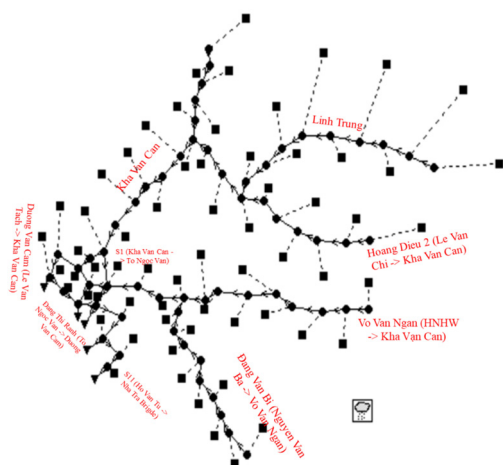


Figure 8. Schematic representation of the Thu Duc Canal study area in the EPA-SWMM model

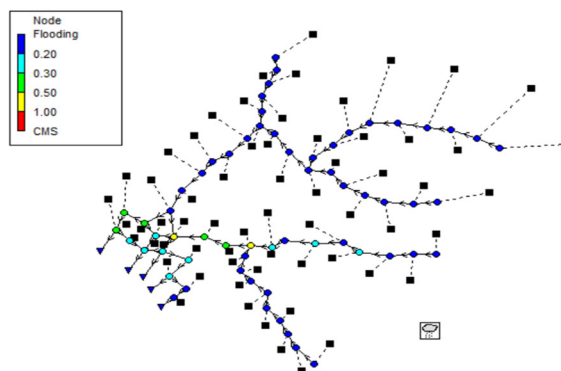
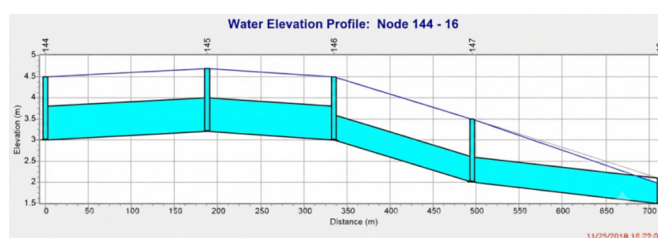
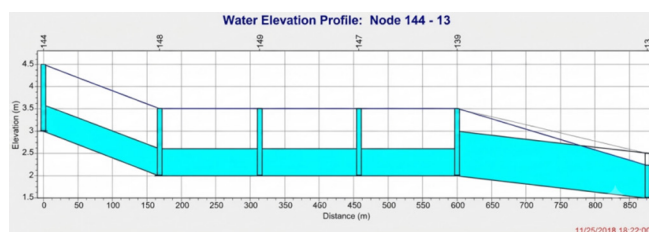


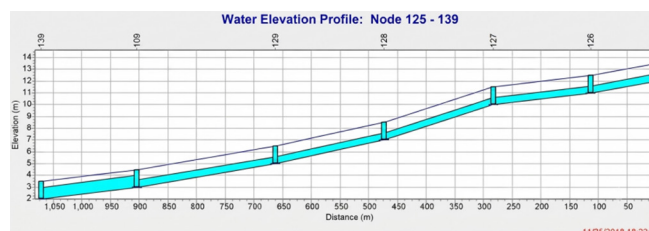
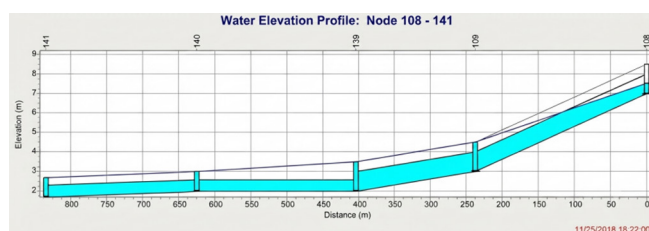
Figure 9. Locations of inundation points simulated by the EPA-SWMM model



a) To Ngoc Van - Dang Thi Ranh Street section extending to the outfall



b) Le Van Tach - Duong Van Cam Street section extending to the outfall



c) Road section from Kha Van Can Street and Vo Van Ngan Street converging toward Thu Duc Post Office Intersection

Figure 10. Water level variations in the drainage pipe network during the rainfall event

4. Conclusion

The study developed an empirical method based on the relationship between daily rainfall and short-duration rainfall at a reference station to support the establishment of intensity-duration-frequency (IDF) curves for data-scarce areas. By combining the design storm hyetograph developed using the Alternating Block Method (ABM) with the EPA-SWMM model, the study provided a preliminary assessment of the drainage capacity of urban infrastructure. The proposed method represents an initial step toward using rainfall correlation relationships to support urban drainage assessment under conditions of limited short-duration rainfall

data. However, a limitation of this study is the lack of sufficient observed short-duration rainfall data to independently validate the transferability of the empirical relationship from the reference station to the data-scarce area. To improve the reliability and practical applicability of the method for urban drainage planning and infrastructure improvement, future studies should strengthen the monitoring of short-duration rainfall and flow data at drainage outfalls. These data will provide a basis for independently validating the transferability of the proposed relationship and facilitate the application of the proposed method to other data-scarce urban areas.

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Declaration of Competing Interest: The authors declare that this article is their original research work, has not been published elsewhere, and does not duplicate previous studies. The authors also declare that there is no conflict of interest among the authors.

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