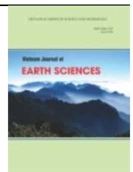
Vietnam Journal of Earth Sciences, 45(3), 438-455, https://doi.org/10.15625/2615-9783/18642

Vietnam Journal of Earth Sciences
https://vjs.ac.vn/index.php/jse



Evaluating the impacts of an improved sewer system on city flood inundations using MIKE Urban Model

Phuong Thuy Kim Doan[1*], Xuan Cuong Le[1], Van Thao Le[1], Julien Némery[2]

[1] *The University of Da Nang, University of Science and Technology, Lien Chieu district, Da Nang City, Vietnam*
[2] *Enseignant-chercheur HDR, Ense3/Grenoble-INP, France*

Received 12 June 2023; Received in revised form 12 July 2023; Accepted 10 August 2023

ABSTRACT

Urbanization is an objective law of socioeconomic development. However, the drainage system is incompatible with the development of urban areas and the increasing population. Some sewer lines are built or added, but they are not synchronized and poorly sloped with debris and inadequate cross-sectional areas, leading to local flooding. In this study, we applied and locally optimized the Mike Urban model to the sewer network in Da Nang City to evaluate the inundation capability as well as the current and future sewer system capacity. The model was calibrated and validated at three typical sites for the data on October 16 and November 7, 2011; evaluated for the heavy rain data on October 14, 2022; and tested scenarios for 2030. The results showed that during heavy rain on October 14, 2022, many urban areas of Da Nang City were crowded, and the number of flooded manholes along the river suddenly increased dramatically because of the high water level and low ground level, which was impossible for rainwater to flow into the river during the high tide. The study also revealed that the planning for the drainage system until 2030 has improved the water drainage situation in the city by adjusting and adding some drainage systems. While this region remains poorly studied, this study brings original information that will help stakeholders to adopt appropriate strategies for the management of their cities that experience critical inundation.

Keywords: Mike Urban model, sewer network, inundation, Vietnam.

1. Introduction

Urban flooding is one of the severe problems challenging the development of many countries. It directly affects the everyday life of residents, such as travel and trade. Furthermore, inundation also leads to significant public health challenges and environmental problems as pollutants and pathogens are spread in rainwater. In addition, this issue also affects the production capacity of the region, for example, industrial and agricultural factors (Eldho et al., 2018).

Vietnam's geographical location is in the tropical monsoon humid region, so rainfall is relatively abundant, and the average precipitation of the whole territory is approximately 2000 mm/year. Precipitation is mainly concentrated in the rainy season. The leading causes of rain are storms, tropical

*Corresponding author, Email: dtkphuong@dut.udn.vn

depressions, thunderstorms, etc., with high rainfall intensity in a short period and sizeable spatial variation of rainfall, even for small basins. As a result, urban flooding has occurred in many cities in Vietnam and has been on the increase recently. An upward trend is seen in both the intensity and frequency of urban flooding such as tropical cyclone events in the Red River Delta City (Neumann et al., 2015) or monsoon (Raghavan et al., 2017). Inundation in Ho Chi Minh City occurs more often as a result of the combination of extreme rainfall and high tides and urbanization (Storch and Downes, 2011; Vachaud et al., 2018).

Like other cities in the world, the cities in Vietnam are developing strongly. The population is increasing rapidly, especially after the country's unification. The expansion, especially spontaneous expansion, and drainage system are incompatible with urban development and population growth. The sewer lines were built and supplemented with patchwork and lack of synchronous connection, so many sewer lines have insufficient slopes. In addition, cross sections do not guarantee drainage capacity; thus, they are overloaded or damaged, causing local flooding.

On the other hand, lakes and low-lying areas have been levelled in urban areas, thus contributing to an increase in flooding. Moreover, the consequences of climate change, such as increased rainfall, irregular urban hydrological regime, etc., significantly affect the collection and drainage of water. Therefore, the problem of flooding in the rainy season is becoming an urgent environmental problem today in our country, causing obstacles to economic activities, people's daily life, and loss of urban beauty (Vo et al., 2019; Le T.C., 2019).

Flooding can also be caused by many reasons, such as poor awareness of people, inadequate management; especially, the operation of the drainage system, and the design and calculation that do not adequately describe the nature of the flow. Currently, in general, empirical formulas are predominantly used in the calculation methods for urban drainage in Vietnam. The flow-root formula is commonly employed to determine the maximum discharge for drainage purposes and assumes the flow to be stable, even when calculating the pipe size (Le, 2015). However, the nature of the flow is inherently unstable and irregular. Therefore, in the planning and designing of urban drainage systems, it is necessary to study and apply numerical modeling techniques to accurately describe the physical phenomena of the drainage system in space and time (Doan et al., 2015; Luan et al., 2018; Doan et al., 2018).

Located in the central critical economic region, Da Nang City is one of the localities with an intense development process of industrialization and modernization in Vietnam. In recent years, with the general trend of cities in this country, the urbanization rate of Da Nang City is no exception.

It has been rapidly developed, particularly many new urban residential areas have been formed along with projects on upgrading and expanding transport and drainage networks, parks, and services which make a new look of a civilized and modern city. Besides the above achievements, the city also faces many limitations and challenges, such as water pollution and especially the situation of overflowing water and flooding on roads and residential areas on heavy rainy days, which is affecting the health of the community and limiting economic and social activities of residents (CDM International Inc, 2013; Nguyen et al., 2016).

The existing canal system is not regularly dredged and has been encroached upon, obstructing water discharge channels. The cross-sectional area of the sewers is unreasonable and lacks synchronization, with undersized sewer sections compared to the drainage requirements and smaller downstream sewers compared to upstream ones. Additionally, the design of some manholes is flawed, as the height of downstream manholes is higher than that of the upstream ones, and they are located at a road level higher than the ground level of residential areas. Moreover, the connection between new and old drainage systems is not synchronized, accumulating water even on high-ground routes (CDM International Inc, 2013, Nguyen et al., 2016). Therefore, the rational planning, calculation, and design of technical infrastructure, especially the drainage system, is a matter of constant concern to Da Nang City. The main objectives of this study are to evaluate the impacts of an improved sewer system on flood inundations in Da Nang City using MIKE Urban Model. Specifically, we locally optimized the Mike Urban model to (i) evaluate the model with the heavy rain in 2022 and (ii) test scenarios in the future to evaluate a sewer system and inundation capability in Da Nang City. Some solutions for rehabilitation are proposed to ensure drainage and reduce flooding. In the Discussion section, results are put in a regional context, with a specific focus on the evaluation of the restoration process of drainage systems and flooding situations for similar cities/provinces. The paper ends with some perspectives which could be applied to other cities in Vietnam or other tropical developing countries.

2. Methods

2.1. Study Site

Da Nang City is the core of the Central Key Economic Region in Vietnam, at coordinates 15055'-16013'N and 107049'-108021'E. It is the third-largest international gateway in Vietnam. The city is on coastal plains with approximately 129,046 hectares (CDM International Inc., 2013). Da Nang City falls within the tropical monsoon climate zone, with an average annual temperature of 25.7°C. The population of the city is approximately 1,134,310 people according to the 2019 national census results.

In this study, the urban sewer network of Da Nang City covers six central districts: Hai Chau, Thanh Khe, Cam Le, Son Tra, Ngu Hanh Son, and Lien Chieu. It comprises primary and secondary drainage systems, canals, reservoirs, ponds, outlets, pumping stations, and more. The primary drainage sewer system consists of culverts with diameters greater than 1.5 m, while the secondary sewer system includes culverts ranging from 0.8 to 1.5 m. The sewer system in Da Nang is predominantly constructed in urban areas along rivers and coastal areas (Fig. 1). Figure 1 presents the drainage system map in Da Nang City, which describes the flooding at three main different sites based on their culvert status and degrees of flooding. Sites 3 (J-3900); 5 (J-2784); 8 (J-1141) are located at Ly Tu Trong, Huynh Ngoc Hue, and Phan Dang Luu streets, respectively.

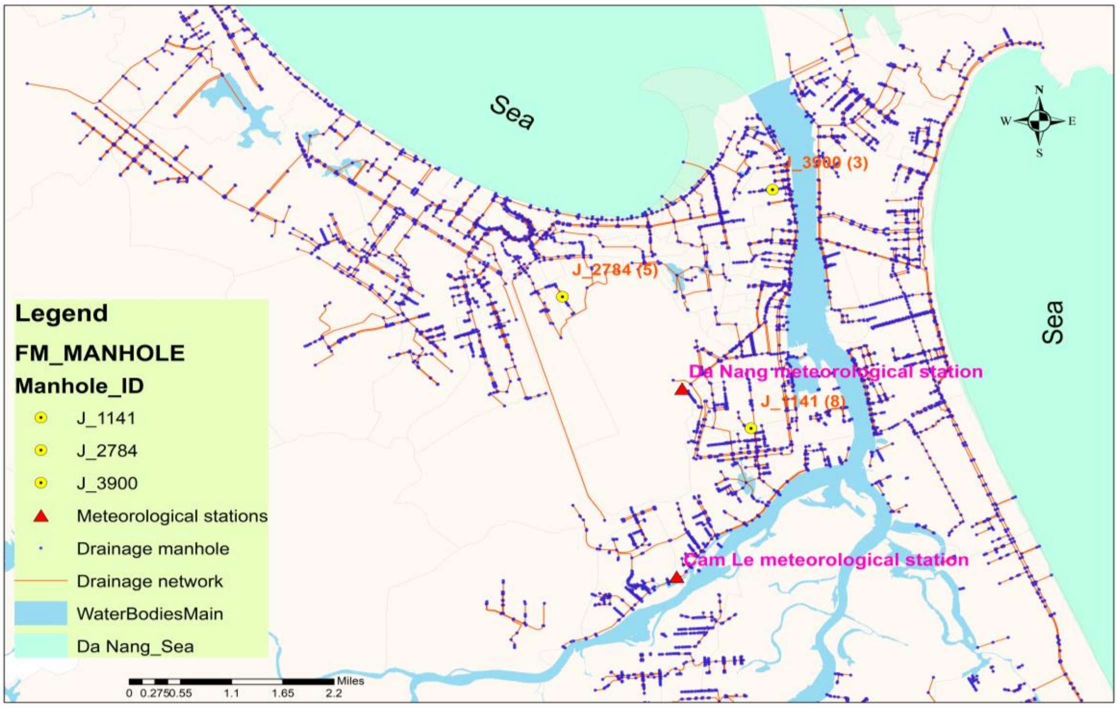


Figure 1. The map of the drainage system in Da Nang City includes three main sites: Sites 3 (J-3900), 5 (J-2784), and 8 (J-1141). The two main meteorological stations are Cam Le and Da Nang stations

2.2. Model description

The authors conducted a comparison of the top 5 software programs (Bentley Sewer-GEMS, DHI Mike Urban, MWH Soft InfoSWMM, InfoWorks, CHI PCSWMM) used for urban drainage based on the specific requirements of the Da Nang City project. This comparison was based on 11 critical features of the software, and each feature was assigned a weighting factor to indicate the importance of the features related to the specific requirements of the study.

After comparing the five software as mentioned above programs, the Mike Urban model set up by the Danish Hydraulic Institute was proposed for use in this study. This model not only meets all the requirements of the study but also provides all the tools for analyzing rainwater systems, sewer systems, water quality, transport of sludge, and water distribution systems in a single package (DHI, 2014 & Luan et al., 2018). In addition, the Mike Urban model is integrated into the ArcGIS environment, one of the world's leading GIS technologies established by the Institute for Environmental Systems Research. Mike Urban is a modeling tool that was widely used and accepted among the water engineering community (Elliott & Trowsdale 2007).

Based on the collected data, we applied a two-part sewer network model consisting of a hydrological module and a hydraulic module. The hydrologic module calculates wastewater flows and surface water overflows from the basins into the drainage system, and the hydraulic module calculates flow and water depth in the central sewer systems.

2.2.1. Hydrological model

The process of setting up the hydrological module is as follows:

- Divide the basins of the sewer system and attach each basin to a nodal point of the hydraulic model where water from the basin flows to. The basin is divided so that one basin has one manhole to avoid confusion when multiple manholes are in the same basin.

- Calculate the characteristics of the basin, such as type of soil, percentage of impermeability, width, slope, area, etc.

- Calculate the current and future wastewater flows produced from each basin.

- Distribution of existing and designed rainfall charts for each catchment.

Figure 2 depicts the catchment map of the entire drainage system of Da Nang City with attached legends.

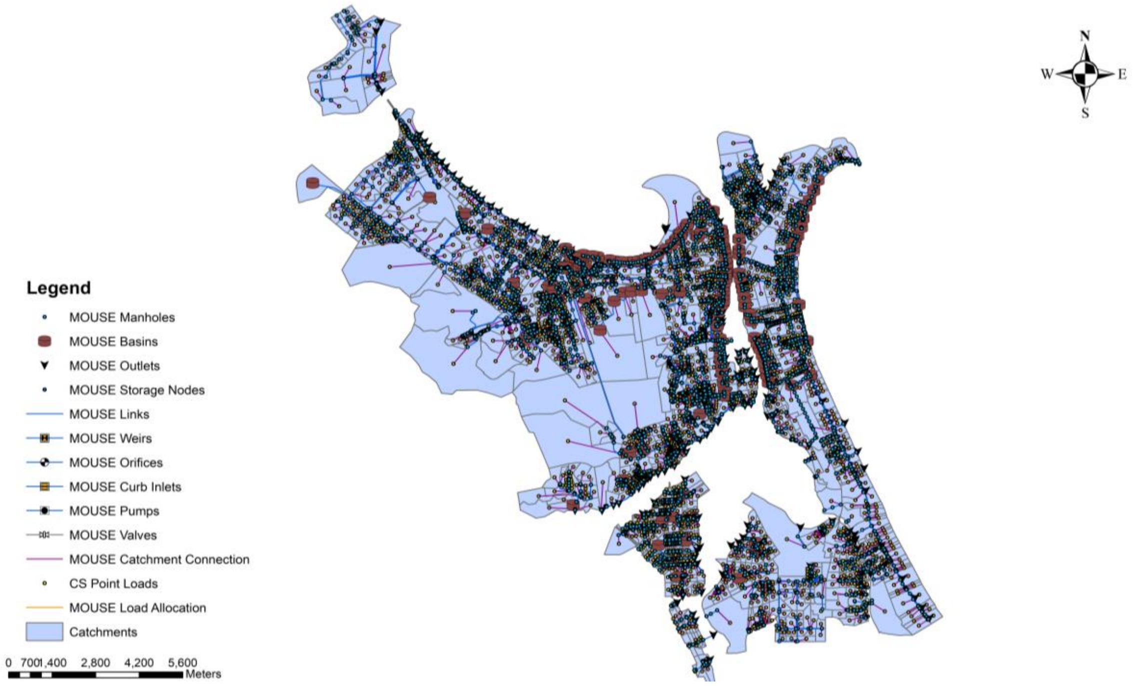


Figure 2. The catchment map of the entire drainage system in Da Nang City

2.2.2. Hydraulic model

Flow from the basins calculated by the hydro module is used as the inlet flow for the hydro module manholes. The hydraulic module transfers the flow from the manhole along the sewer network to calculate the sewer flow and water level of the manhole (nodes). The procedure for setting up the hydraulic model is presented as follows:

- Establish a network of nodes and seams in which the seams join the nodes.

- Prepare information on nodes such as coordinates, ground level, and bottom level, or size and operation of outlets and water retention bodies (e.g., lakes, lands; pump station tanks, tide levels, river levels, etc.);

- Distribution of wastewater flow and stormwater overflow to each nodal point of the hydraulic model;

- Prepare information about seams such as longitudinal section, length (shape, size, or cross-section), and roughness factor of sewers or open channels/rivers; operation schedule (or curve diagram); and characteristics of pumps, weirs, outlets, and openings.

The scope of establishing the urban drainage system model encompasses the primary and secondary existing sewer system for the entire urban area of Da Nang City, including all completed and ongoing project constructions related to it, as well as the planned future sewer systems for road networks and catchment areas. Establishing the hydrological-hydraulic model involves various stages, as depicted in Fig. 3.

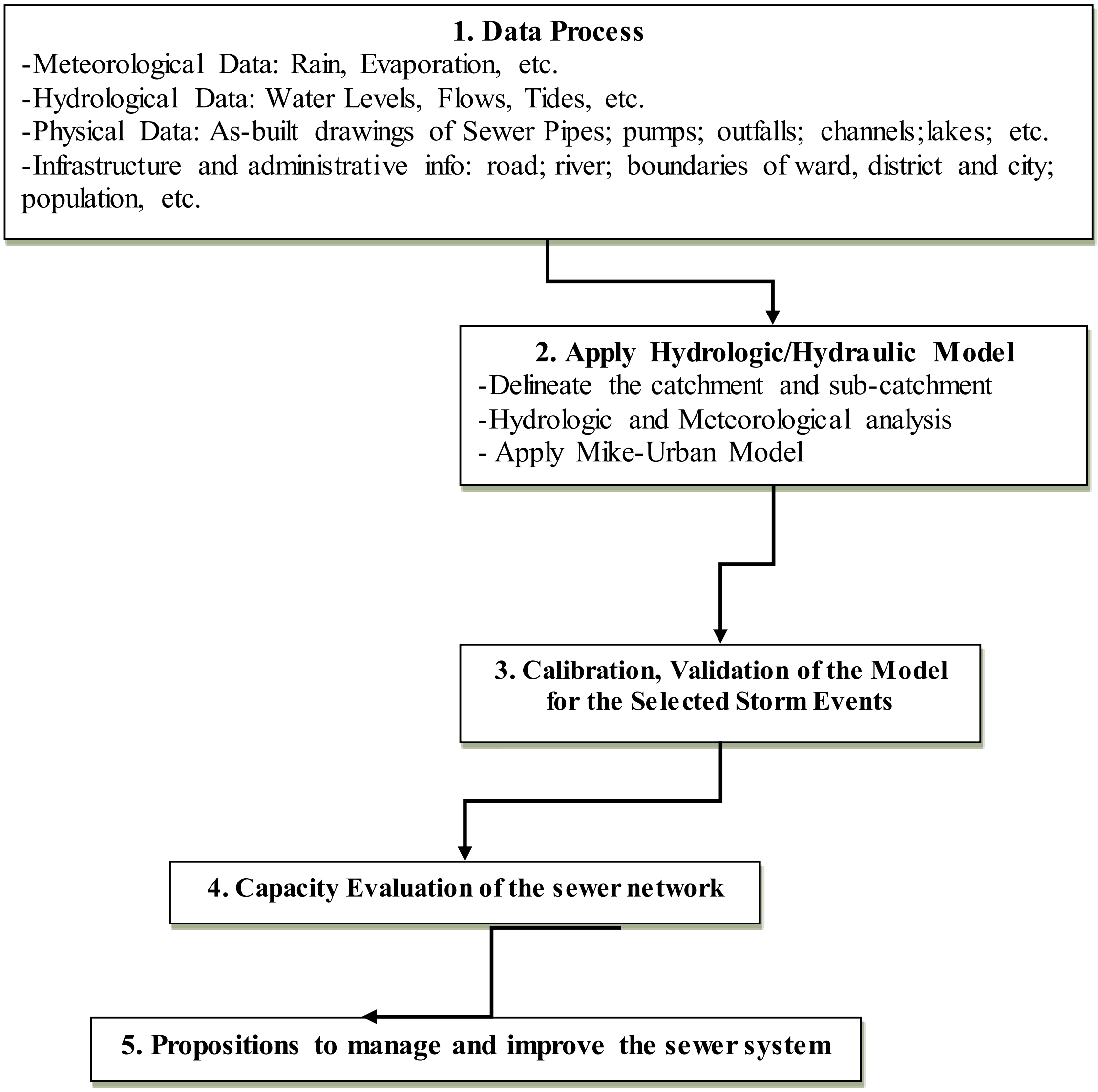


Figure 3. The establishment of the hydrological-hydraulic model

2.3. Field data

The data collection process commenced by evaluating the existing data in the Da Nang sewer system. Most of the sewer systems in Da Nang are combined sewers, while a few sewers are separate ones. The authors reached out to relevant authorities in Da Nang City and previous studies, such as the Urban Planning Institute, Department of Construction, Department of Transportation, JICA Research Group Report, Regional Meteorological and Hydrological Center for Central Vietnam, Department of Natural Resources and Environment, and CDM International Inc. to search for and gather available data, reports, as-built drawings, design drawings, and other essential information required to establish the model. The following data is required to establish the hydrological-hydraulic model of the drainage system in Da Nang City.

- The meteorological data, including the rainfall and evaporation records for Da Nang. The data is used as input data for the hydrological model. Rain data (at intervals of not more than 15 minutes at a time) must be recorded during the occurrence of the two heavy showers of rain. The monthly evaporation was collected at Cam Le and Da Nang meteorological stations (CDM International Inc., 2013).

- The hydrological data include all Da Nang region tidal records, the flows and water levels of the primary/trunk system, and the major rivers of Da Nang City. The water depth was measured at the manhole, while the flow velocity was measured inside the pipe at least 30 cm from the mouth of the pipe at the manhole. The sea and river levels in 15-30 minutes were also recorded during heavy rains (CDM International Inc., 2013).

- Physical data: We have conducted data on the existing central/primary drainage systems and planning, such as culverts, box culverts, pump stations, lakes, structures, etc., for both the drainage system and urban wastewater from Da Nang's Departments. The data includes diagrams, location, size, shape, slope, outlets and connectors of outlets, cross-section, longitudinal section, digitized drawings, and other information about existing outlets and expected outlets from the stormwater drainage system (CDM International Inc., 2013).

- Spatial, infrastructure, and administrative data: encompassing terrain information, road networks, rivers, coastal boundaries, administrative boundaries, and population data. These data were mainly taken from the information on the priority infrastructure investment project in Da Nang City (CDM International Inc., 2013).

Additionally, the authors collected data on water consumption levels from the 3,500 largest water consumers, primarily commercial units and administrative agencies. Furthermore, data on wastewater discharge rates from industrial establishments that utilize water was also collected.

2.3.1. Rainfall measurement station

The rainfall measurement stations of Cam Le and Da Nang are located within the city of Da Nang and are approximately 3.56 km apart. Therefore, they were used to collect rainfall data in this study. Significant differences in rainfall distribution were observed between the Da Nang and Cam Le stations on October 16, 2011, from 9:00 to 21:00, as well as on November 7, 2011, at 13:00, despite the relatively short distance between the two stations (Fig. 4). The rainfall event on November 16, 2011, had a significant difference in total rainfall, approximately 50 mm, compared to a slightly smaller difference for the rainfall event on November 7, 2011. Additionally, the total rainfall on November 7, 2011, was approximately double that on October 16, 2011.

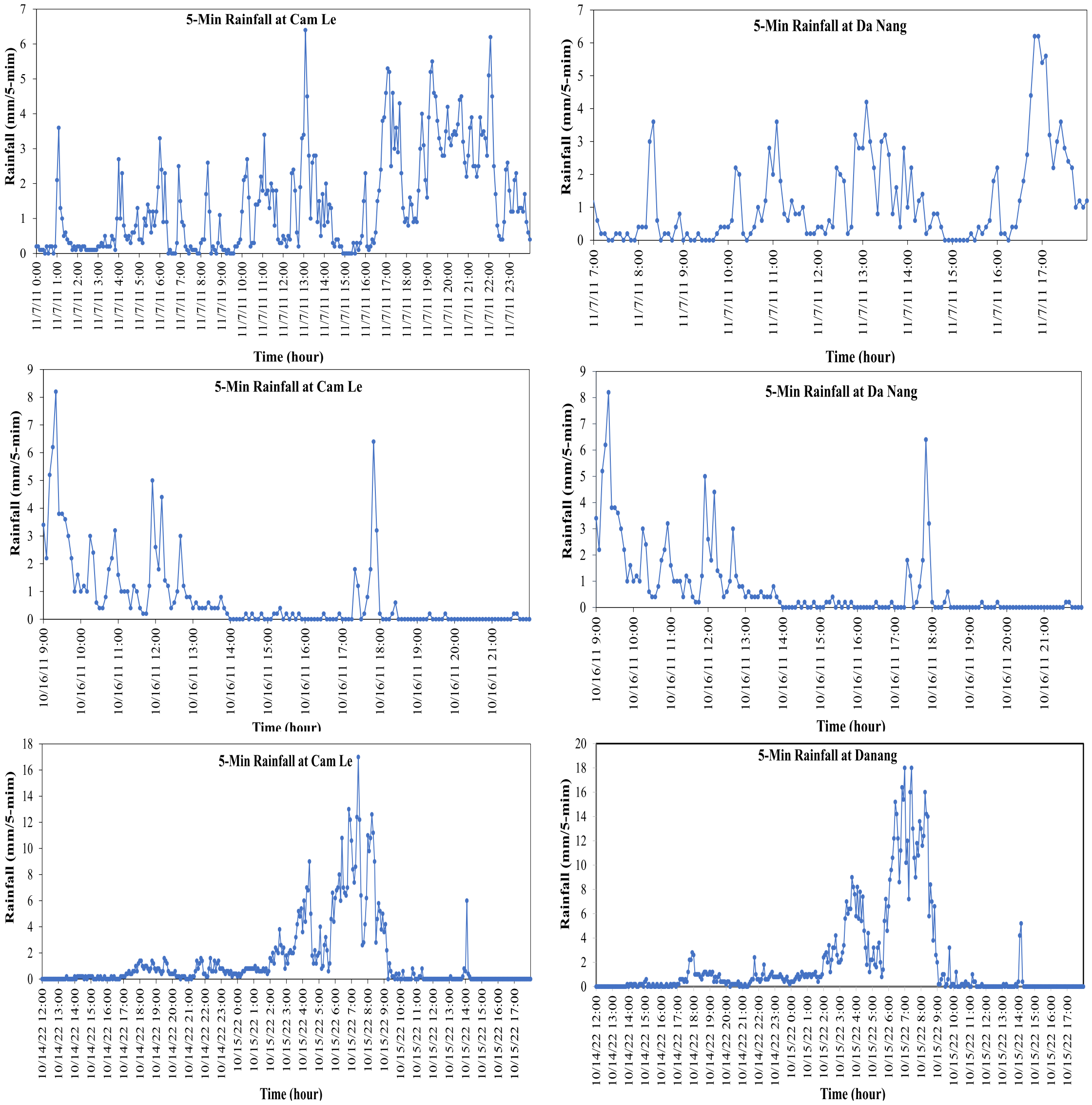


Figure 4. The rainfall data at Cam Le and Da Nang meteorological stations

2.3.2 Hydrological measurements

Hydrological measurement aims to measure the flow and water level at critical locations of the drainage system in the event of rain to correct the hydrological and hydraulic model parameters. The procedure and standards for conducting hydrological measurements at critical locations in the research area are as follows: (i) Determining the location for installing hydrological measurement devices; (ii) The recording interval for flow data should not exceed 0.25 hours. Hydrological measurements include water depth, flow velocity, and discharge. Water depth was measured at manholes using a ruler, while flow velocity was measured using a current meter inside the sewer at least 30 cm from the manhole; (iii) Monitoring two significant rainfall events during the rainy season from October to December;

(iv) Rainfall data (at intervals not exceeding 15 minutes) was recorded during the occurrence of the two significant rainfall events; (v) Water levels at the outlets of the drainage system (Son Tra and Cam Le stations) also recorded at 15-minute intervals throughout the significant rainfall events. A complete description and analysis on these field data were obtained from Da Nang Priority Infrastructure Investment Project (DN-PIIP) (CDM International Inc., 2013).

In this study, we collected flow rate and water depth data at three main manhole sites. Detailed information about these three sewer locations was showed in Table 1.

Table 1. The locations where flow rate and water depth were measured

Sites	Manhole names	Measuring sewer flows	X - Coor of manhole	Y - Coor of manhole	Captions
3	J-3900	J_3901-J_3900	523638.275	1778281.567	Ly Tu Trong Street- Across from the Da Nang Children's Cultural House
5	J-2784	J_2785-J_2784	519999.792	1776246.263	Tran Xuan Le Street, Next to the Thanh Khe Court
8	J-1141	J_1140-J_1141	523265.617	1773746.392	Across from Phan Dang Luu secondary school

2.4. Boundary conditions

Data on rainfall, flow, and water depth collected from hydrological measurements in three rainfalls on October 16, 2011; November 7, 2011; and October 14, 2022, were used to calibrate, validate and evaluate the hydrological and hydraulic models, respectively.

2.4.1 Hydrological model

The 5-minute rain data at Cam Le and Da Nang meteorological stations on October 16, 2011, November 7, 2011, and October 14, 2022, were entered into the hydrological module to calculate the overflow from the catchments into the hydro module manholes (Fig. 4).

2.4.2 Hydraulic model

Da Nang is located on a coastal plain with an altitude of 2 m to 6 m above sea level. Many locations with drainage pipes near the outlets are situated below sea level. Therefore, they are affected by tides. The tidal water level data on October 16, 2011; November 7, 2011, and October 14, 2022, at the outlets of the drainage system in Da Nang City (Son Tra and Cam Le stations) are used as boundary conditions for the calibration and validation of hydraulic module (Fig. 5). The data on water consumption from the largest 3,500 water consumers are mainly from commercial units and administrative agencies and the data on the volume of water discharged from industries using water are also used as boundary conditions.

2.5. Model calibration and validation

The model design includes all existing sluices and basins plus sluices and catchments for the project that have been designed and built. The model needs to be calibrated and validated with the field data, especially for the low land area where flooding may occur. The parameters of the hydrological model, such as basin length, basin slope, and permeability coefficients, are adjusted during the calibration process. The Manning roughness coefficient n of the hydraulic model is adjusted during calibration and validation.

2.6. Model evaluation

According to the report on the flooding situation, Da Nang experienced a particularly heavy rainfall phenomenon and unfavorable weather conditions on October

14-15th, 2022. What made these rainfall episodes even more disadvantageous was their coincidence with high tides (Da Nang City Department of Construction, 2022). This study also used the model to evaluate the historical rainfall event in 2022. From this, the current drainage situation of Da Nang City and the capacity of the existing sewer network can be assessed, and future proposals can be made.

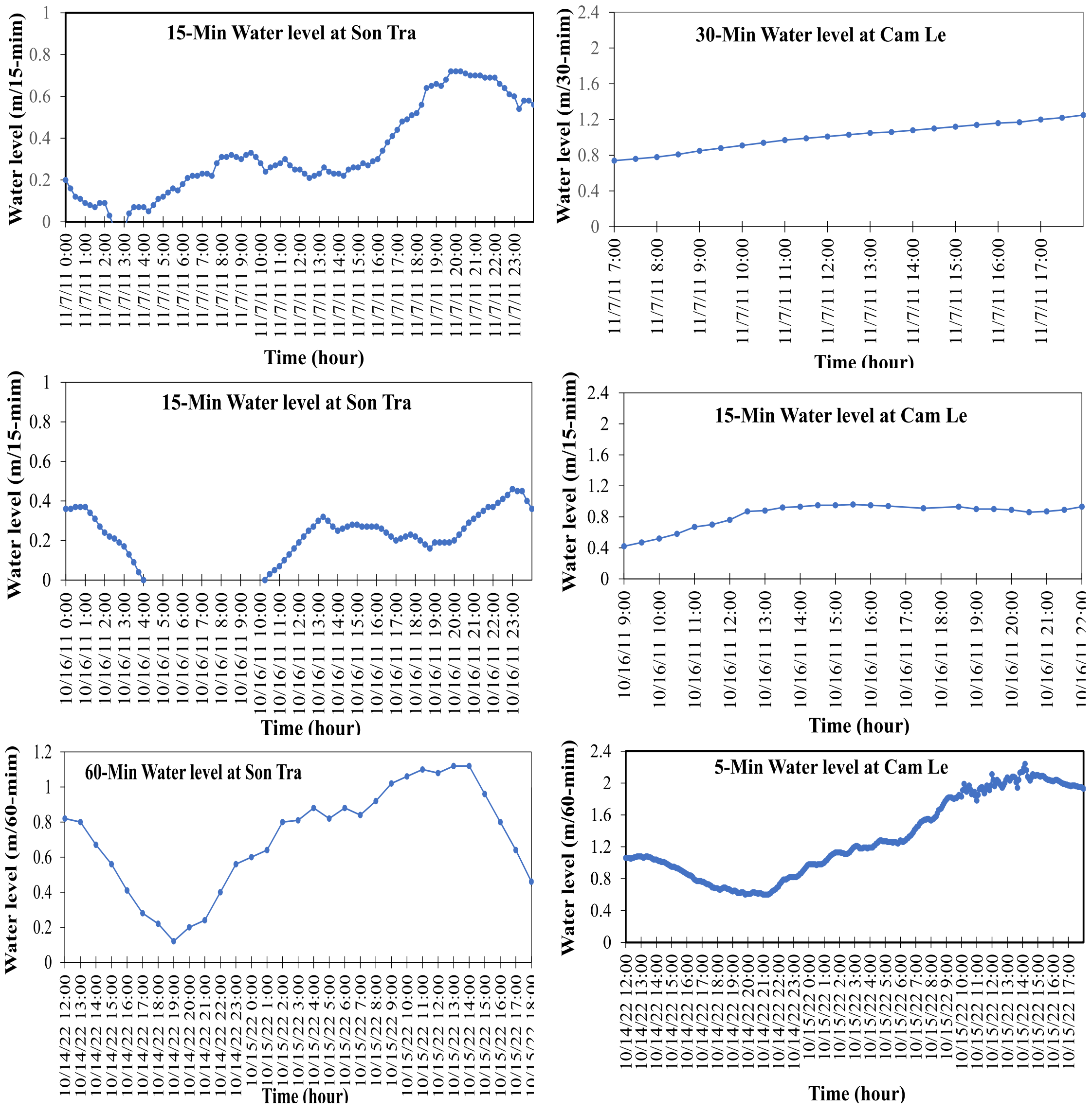


Figure 5. The water level data at Son Tra and Cam Le stations

2.7. Model scenarios

According to the plan, until 2030, the population of Da Nang City increase by then, and the city also invest in upgrading some drainage systems according to the plan to meet the water drainage capacity.

The drainage system planned until 2030, with a vision until 2045, was approved by the city but has not been implemented yet (The

People's Committee of Da Nang City., 2022). The culverts system will be modified, added, and built soon. The scenario for the year 2030 was compared with the run of the evaluated model for 2022, which will be referred to as the "Present" scenario.

Table 2 below shows the difference in the sewer systems in 2011, 2022, and 2030 regarding total lengths, diameters, numbers of pump stations, etc.

Table 2. The difference in the sewer systems in 2011, 2022, and 2030

Data	The year 2011	The year 2022	The year 2030
Number of sub-basins	4062	4444	4912
Total catchment area (ha)	2428.01	2428.01	5110.73
Number of manholes	5054	5514	6231
Number of drainage pipes	5391	5878	6598
Total length of drainage sewers (m)	441283	470325	549528
Pump	49	49	49
Overflow in the sewer	121	121	122

3. Model Results

3.1. Calibration and validation results

The data set on October 16, 2011, was used to calibrate the model, while that on November 7, 2011, formed the basis for model validation. Figure 6 illustrates the water discharge profiles observed and simulated during the calibration process at three distinct sites: Site 3 (J-3900), Site 5 (J-2784), and Site 8 (J-1141), with Percent Bias (PBIAS) values of -17%, 25%, and -14% respectively. Due to a favorable Percent Bias between the simulated and measured flows over time, the water discharges closely followed the measured profiles (Fig. 6). The model effectively reproduced the observed flows at the three sites, as indicated by the root mean square error R2 values of 0.89, 0.58, and 0.92, and the Nash-Sutcliffe Efficiency coefficients NSE of 0.62, 0.2, and 0.58, respectively.

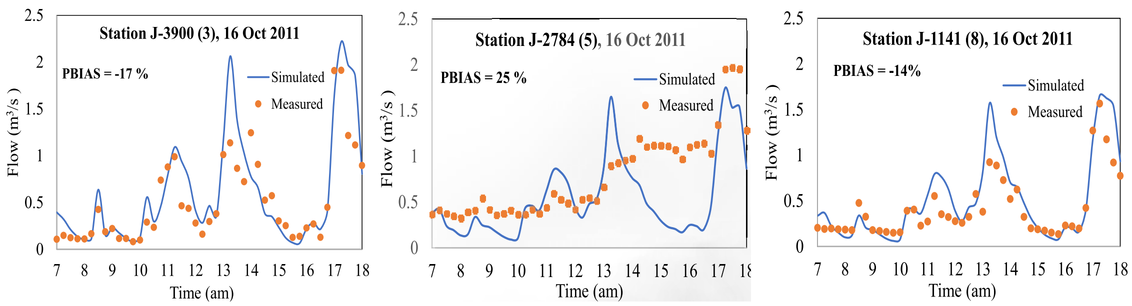


Figure 6. Flow comparison chart between simulation and measurement during calibration

Figure 7 depicts the variation of water discharges measured and simulated over time for the validation year at three different sites. The model results exhibit good agreement with the flow measurements in 2011, with Percent Bias values of -15%, 22%, and -15%, respectively (Fig. 7). The root means square errors between the measurements and simulations are relatively high at the three sites, with R2 values of 0.87, 0.57, and 0.91 respectively. Additionally, the Nash-Sutcliffe Efficiency coefficients (NSE) were calculated as 0.83, 0.31, and 0.71 for sites J-3900, J-2784, and J-1141, respectively. (Fig. 7).

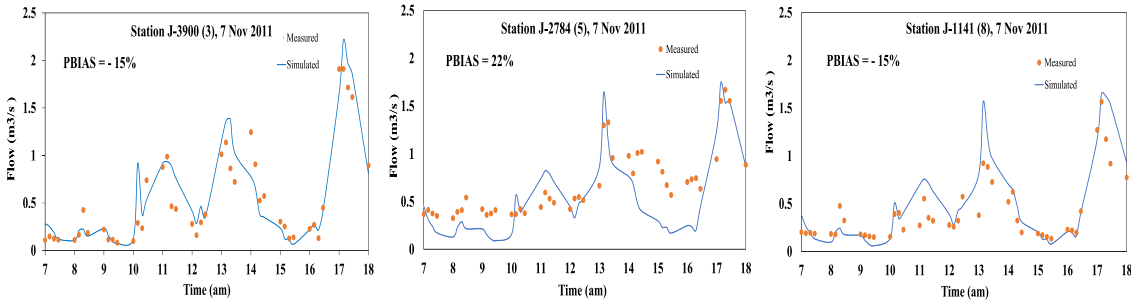


Figure 7. Flow comparison chart between simulation and measurement during validation

Figure 8 presents the calculated and simulated water depths in the sewer during the validation period. The water depth in the sewer was measured from the bottom of the sewer to the water level within it. Despite variations in hydrological and meteorological conditions, the model successfully reproduced the observed water depths at three different sites: Site 3, Site 5, and Site 8, with Percent Bias values of -11%, 2%, and -25%, respectively (Fig. 8). The overall trends of all measured variables were reasonably captured by the model simulations, with Percent Bias falling within the range of -25% to 25% (Moriasi et al., 2007). The model satisfactorily replicated the observed water depths at the three sites, demonstrating high correlation coefficients of 0.88, 0.80, and 0.94, respectively, and Nash-Sutcliffe Efficiency coefficients of 0.28, 0.4, and 0.71, respectively.

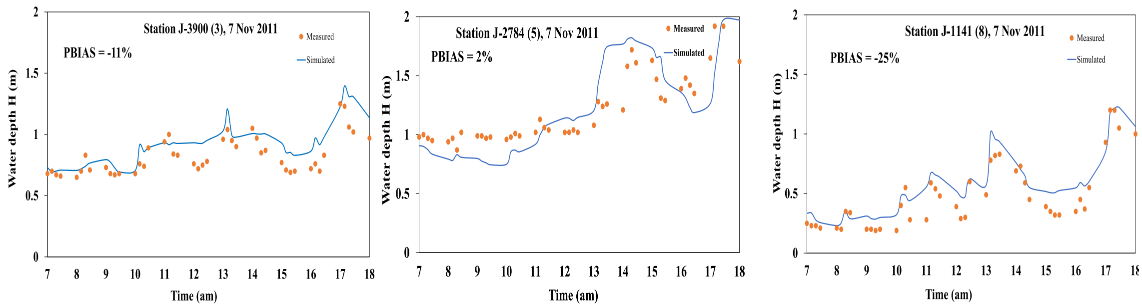


Figure 8. Measured and simulated water depth in the sewer at three stations during validation

3.2. Evaluation of the initial model for flooded areas caused by rain on November 7, 2011

Figure 9 shows the profiles of simulated flooding areas at the three stations: 3 (J-3900), 5 (J-2784), and 8 (J-1141) during the validation (7th of November 2011). Model simulations reasonably well represent the overall trends of the flood. The scale and number of flooded drains in 2011 were not significant, as shown in Fig. 9.

Table 3 presents the measured and simulated water depths in the calibration year 2011 at three locations corresponding to three road sections in different areas. CDM International Inc., (2013) obtained the measured water depths. With good Percent Bias values of 25%, 0%, -16% between the simulated and measured water depth at three different manhole sites, the water depths closely followed the measured profiles (Table 2).

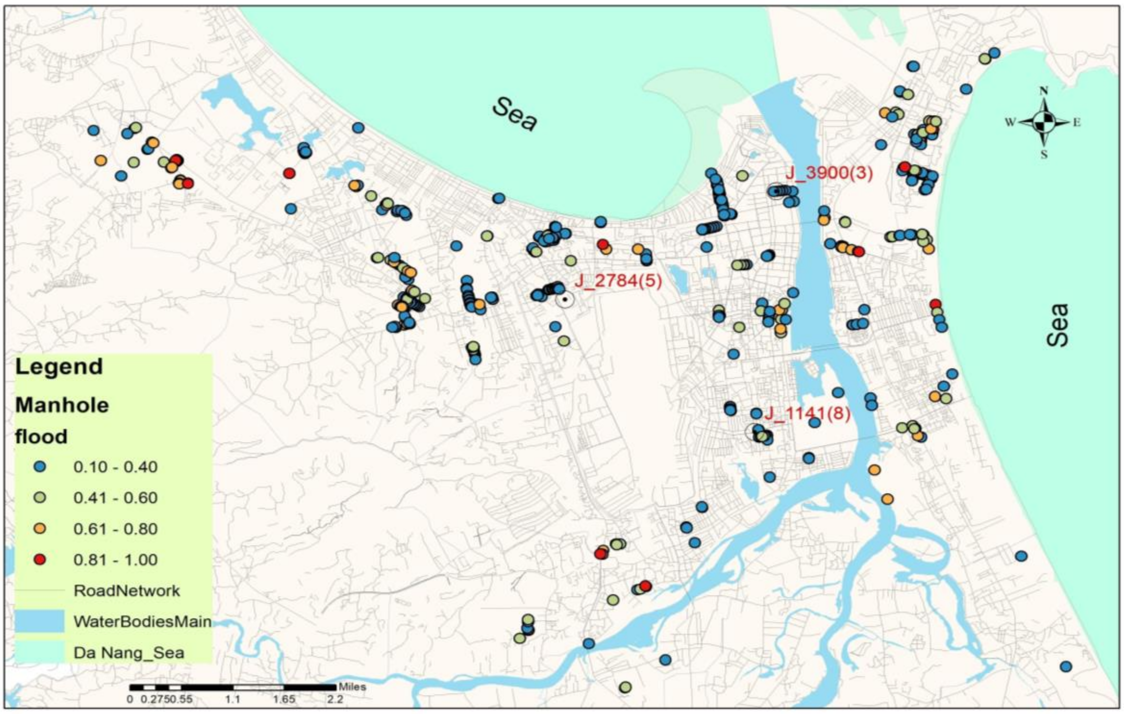


Figure 9. Simulated profiles of flood during validation 2011

Table 3. The measured and simulated flood depths during the calibration year of 2011

Street	Location	Measured flood depth (m)	Simulated flood depth (m)	PBIAS (%)
Ly Tu Trong	J-3900 (3)	0.2	0.15	25
Huynh Ngoc Hue	J-2784 (5)	0.2	0.2	0
Phan Dang Luu	J-1141 (8)	0.3	0.35	-16

4. Discussions

4.1. Evaluation of the drainage system and the level of flooding during the heavy rain in 2022

The hydraulic model was calibrated and validated for 2011 and then used to verify the historical rainfall event on 14-15 October 2022. From this, the current drainage situation of Da Nang City and the capacity of the existing sewer network can be assessed, and future proposals can be made. Figure 10 below illustrates the inundation depth at 6:30 pm on October 14, 2022, for the entire existing drainage system of Da Nang City, including 3 typical locations (3, 5, 8). The maximum inundation depth is 1.0 m in Lien Chieu, Cam Le, Hai Chau, and Son Tra districts and 0.8 m in the Thanh Khe and Ngu Hanh Son districts. The Hai Chau, Lien Chieu, Son Tra, and Cam Le districts have the highest number of flooded manholes. These districts also have the highest number of manholes in Da Nang City (Fig. 10). The measured flood depths were obtained according to the flood situation summary report in Da Nang City over the Years (Da Nang City Department of Construction, 2022).

The Percent Bias results between measured and modeled flood depths during the historical rain in 2022 at 3 different locations are 3%, -3%, and -4%, respectively, as shown in Table 4.

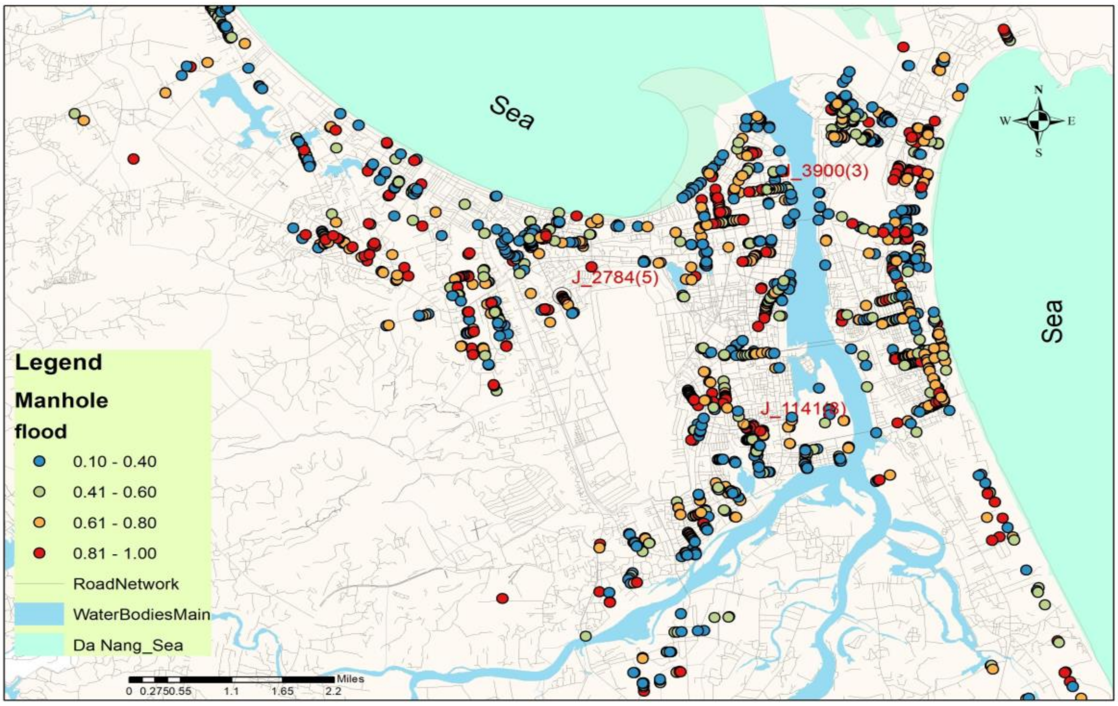


Figure 10. Simulated profiles of flood during big rainfall event in 2022

Table 4. The measured and modeled flood depths at 3 locations in 2022

Street	Location	Measured flood depth (m)	Simulated flood depth (m)	PBIAS (%)
Ly Tu Trong	J-3900 (3)	0.3	0.29	3
Huynh Ngoc Hue	J-2784 (5)	0.3	0.31	-3
Phan Dang Luu	J-1141 (8)	0.5	0.52	-4

On October 14, 2022, the rainfall data from rain gauges in Da Nang showed that the significant period of rainfall that caused this catastrophic flooding occurred from 3:00 pm to 9:00 pm (6 hours), with the highest amount of rainfall recorded at Son Tra station being 637 mm/6 hours. Four years ago, the rainfall measured at the Da Nang station from 0:00 am on December 9, 2018, to 0:00 am on December 10, 2018, was 767 mm/24 hours. Within four years, extreme and unusual rainfall events that had never happened before occurred, with the historical flood peak in 1999 only reaching 593mm. The drainage capacity of type I urban areas in Vietnam is currently at a level that can withstand rainfall of 70 mm/2 hours, meaning that within 6 hours, it can handle a total rainfall of 210 mm. Therefore, the large amount of rainfall over a short period has exceeded the capacity of urban infrastructure to withstand it (Da Nang City Department of Construction, 2022).

Moreover, the disadvantage during the October 14, 2022, rainfall was that it coincided with high tides. On the evening of October 14, the tide in Da Nang was high, and the rainwater could not drain through this route. The flood prevention pump system also failed to pump water in these conditions. As a result, the number of flooded manholes along the rivers in Da Nang increased suddenly because the water level was high, and the rainwater could not flow into the rivers during high tide. A typical example is the area of Bach Dang, Nhu Nguyet, Nguyen Tat Thanh, and 2/9 streets (Da Nang City Department of Construction, 2022).

4.2. Model scenarios: Evaluation of the drainage system and flooding level according to the drainage system planning until 2030

Figure 11 below illustrates the depth of flooding for the entire drainage system according to the drainage plan until 2030, including three typical drainage locations (3, 5, 8). The results indicate that, according to the drainage system plan until 2030, some new sewers and lakes will be added and modified, resulting in a good improvement in the drainage situation (Table 5).

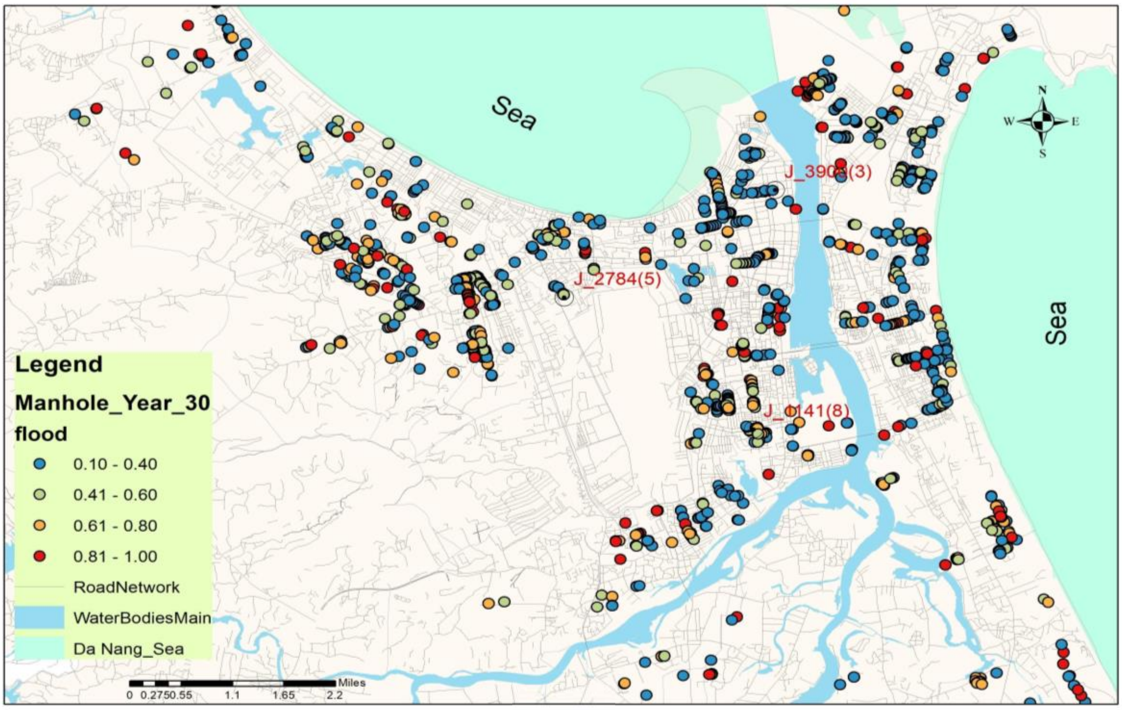


Figure 11. Simulated profiles of flood according to the drainage plan until 2030

Table 5. Simulation results of flooding depth at 3 locations in 2030

Street	Location	Flood depth simulation (m)
Ly Tu Trong	J-3900 (3)	0.28
Huynh Ngoc Hue	J-2784 (5)	0
Phan Dang Luu	J-1141 (8)	0.51

Figure 12 compares flooding depth at 3 different sites between 2022 (baseline) and 2030 (scenario year) from 6:15 pm to 6:30 pm on October 14. The solid lines indicate the depth of flooding for the existing culverts in 2022, while the dashed lines represent the depth of flooding for the planned culverts in 2030.

According to the 2030 drainage system planning, a new lake will be constructed at the head of the Phan Lang channel in the upstream area of Thanh Khe District. This lake will collect and regulate surface water from adjacent catchment areas before discharging it into the sea through the Phan Lang channel.

The city will also build a relatively large box culvert (2.4 m wide, 3 m high) in close proximity to facilitate drainage in the area. As a result, the area will experience easy, quick, and minimal flooding, as indicated by the cyan dashed line at site J-2784. However, in the Hai Chau area, the sewer system plan for 2030 remains similar to the current situation in 2022 at sewer locations J-1141 and J-3900. As a result, the level of flooding is expected to remain unchanged, with 0.5 m of flooding at sewer J-1141 (as indicated by the purple dashed line) and 0.3 m of flooding at sewer J-3900 (as indicated by the green dashed line). The results are illustrated in Fig. 12.

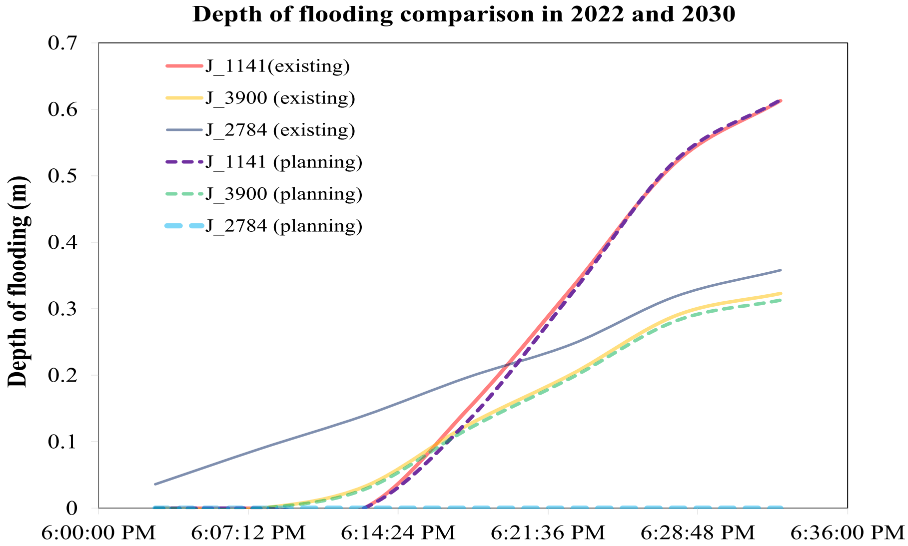


Figure 12. Depth of flooding comparison at three sites in 2022 and 2030

4.3. Solutions for rehabilitation of drainage system and flooding mitigation in Da Nang and other cities

With the rapid urbanization of cities and provinces in Vietnam, both currently and in the future, the existing sewer systems are almost unable to cope with the pressure of water drainage when rainfall directly accumulates in the manholes. In addition, the deteriorating sewer lines and gas chambers are not being renovated or maintained on time, and some areas still lack proper drainage systems. Furthermore, sedimentation and debris accumulation cause obstruction and increase roughness, resulting in slow and difficult water drainage (Le Thuy Chien, 2019).

The existing canal system is not regularly dredged and has been encroached upon, blocking the water discharge channels. The cross-sectional area of the sewers is unreasonable and lacks synchronization, with undersized sewer sections compared to the drainage requirements and smaller downstream sewers compared to upstream ones. Additionally, the design of some manholes is flawed, as the height of the downstream manholes is higher than that of the upstream ones. The road level where the manholes are located is also higher than the ground level of residential areas. Moreover, the connection between the new and old drainage systems is not synchronized, causing water to accumulate even on high-ground routes (Nguyen Q.B. et al., 2016).

The underground technical infrastructure has many shortcomings and overlaps, such as fiber optic systems, telephone lines, electrical installations, and water supply pipes crossing water intake gates, manholes, and sewers, reducing water drainage capacity. Encroachment and infringement on the drainage system occur, such as dumping soil, rocks, and waste into drainage canals, reservoirs causing flow blockages, and heavy trucks driving onto sidewalks, damaging components of the urban drainage system. Therefore, it is necessary to regularly maintain and dredge the canal routes and address congestion points in the drainage routes. Constructing new structures and improving the regulation capacity of reservoirs and pumping stations is essential.

5. Conclusions

This study applied the Mike Urban model to establish the current drainage system for Da Nang City. The model was calibrated and validated with two rainfall events in the year 2011. The model results showed the locations and levels of flooding, which were consistent with the survey results. The study evaluated the drainage system and flooding situation for Da Nang City during the historical rainfall event in 2022 and under the planned drainage system for 2030. The model results showed that the amount of rainfall in 2022 was very high in a short period, combined with a surge in the tide, which exceeded the capacity of urban infrastructure. Therefore, the number of flooded manholes in 2022 increased significantly, especially those along the rivers in Da Nang City. With the drainage system planning until 2030, some drainage systems have been added and adjusted, resulting in improved water drainage, especially at site J-2784. The culvert system did not undergo any changes in 2030 at sites J-1141 and J-3900, resulting in some flooding observed in manholes during heavy rain events. The study proposed solutions to enhance drainage and mitigate flooding on the road network in Da Nang City, in other cities of Vietnam such as Ha Tinh and Tam Ky, or in similar tropical developing countries where sewer systems are constructed along rivers and coastal areas. These solutions include constructing big sewers, accelerating the construction progress and putting into operation flood control pumping machines at some stations; developing a plan for regular dredging of sediment in drainage systems; carrying out the relocation of other underground infrastructure items from the drainage system to prevent blockages and obstruction of the flow; reinforcing water collection gates and creating water channels in low-lying areas, the capacity to collect water quickly, particularly during heavy rain events.

Acknowledgements

The University of Da Nang, University of Science and Technology, the code number of Project: T2022-02-29, supported this work.

References

CDM International Inc., 2013. Develop a Hydraulic Model for a sewer system in Da Nang City. Da Nang Priority Infrastructure Investment Project (DN-PIIP).

CDM International Inc., 2013. Preliminary assessment of flooding in Da Nang City.

Da Nang City Department of Construction, 2022. Flood Situation Summary Report in Da Nang City over the years.

DHI: Danish Hydraulic Institute, 2014. Mike Urban Manuals.

Doan P.T.K., Markovic S., Cadena S., Watson S.B., Guo J., McClure C., Mugalingam S., Morley A., Zhang W., Arhonditsis G., Dittrich M., 2018. Phosphorus retention and internal loading in the Bay of Quinte, Lake Ontario, using diagenetic modelling. Science of the Total Environment.

Doan P.T.K., Némery J., Schmid M., Gratiot N., 2015. Eutrophication of turbid tropical reservoirs: scenarios of evolution of the reservoir of Cointzio, Mexico. Ecological Informatics.

Eldho T.I., Zope P.E., Kulkarni A.T., 2018. Integrating Disaster Science and Management. Global Case Studies in Mitigation and Recovery 2018, 205-219.

Elliott A., Trowsdale S., 2007. A review of models for low-impact urban stormwater drainage. Environmental Modelling & Software, 22(3), 394-405.

Le Quang Chinh, 2015. Calculation for the Water Supply Network for Tam Ky City, Quang Nam according to the Planning Direction towards 2030, Master Thesis. The University of Da Nang.

Le Thuy Chien, 2019. Ha Noi National University, "Application of Mike Urban model to calculate drainage for Ha Tinh city under the impact of climate change". Master Thesis.

Luan Q., Zhang K., Liu J., Wang D., Ma J., 2018. The application of Mike Urban model in drainage and waterlogging in Lincheng County, China, Proc. IAHS, 379, 381-386.

Moriasi D.N., Arnold J. G., Van Liew M.W., Bingner R.L., Harmel R.D., Veith T.L., 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. American Society of Agricultural and Biological Engineers.

Neumann J.E., Emanuel K.A., Ravela S., Ludwig L.C., Verly C., 2015. Risks of coastal storm surge and the effect of sea level rise in the Red River Delta, Vietnam. Sustainability, 7, 6553-6572.

Nguyen Q.B., Nguyen T.H., Le Q.C., 2016. Evaluating the water supply network for Tam Ky city according to the planning orientation towards 2030 using The Mike Urban model. The University of Da Nang - Journal of Science and Technology, 7(104), 06-10.

Nguyen Q.B., Tran L.P., Nguyen T.H., 2016. Application of Mike Urban model to evaluate the rainwater drainage system of Cam Le district, Da Nang City. Proceedings of the advanced construction technology towards sustainable development - ATCESD.

Raghavan S.V., Vu M.T., Liong S.Y., 2017. Ensemble climate projections of mean and extreme rainfall over Vietnam. Global and Planetary Change, 148, 96-104.

Storch H., Downes N.K., 2011. A scenario-based approach to assess Ho Chi Minh City's urban development strategies against the impact of climate change. Cities, 28, 517-526.

The People's Committee of Da Nang City, 2022. Decision on approving the task of adjusting the high-level urban planning and surface water drainage in Da Nang City until 2030, with a vision until 2045.

Vachaud G., et al., 2018. Flood-related risks in Ho Chi Minh City and ways of mitigation. Journal of Hydrology, 573, 5861.

Vo D.P., Muhammed A.B., Vo N.D., 2019. Climate Change Impact on Urban Flooding in Quy Nhon City, Vietnam. Innovation for Sustainable Infrastructure Proceedings of the 5th International Conference on Geotechnics, Civil Engineering Works and Structures. No: Cigos 2019, 1025-1030.