JOURNAL OF
HYDRO-METEOROLOGY

Research Article

Assessment of the influence of urban flood in Thu Duc City in the period of planning

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Received: 8 October 2023; Accepted: 14 November 2023; Published: 25 December 2023

Abstract: Ho Chi Minh City is a low-elevation coastal city with and rapidly increasing population. Thu Duc, the city in Ho Chi Minh City, is the first city in Vietnam that belongs to the type of city administrative unit directly under the central city. This area is greatly affected by flooding, classified into three groups: heavy precipitation, tidal current, and combined tidal current and heavy precipitation. In this study, the flooding situation caused by the groups in the planning period (from 2010 to 2020) will be assessed and mapped by using GIS. The results show that, in the period from 2016 to 2021, flooding by heavy precipitation was more serious than that by tidal current. Compared to the drainage planning map in District 2, District 9, and Thu Duc District by 2020, some flooded locations due to no drainage system, lack of drainage systems, and unresponsive drainage systems have not yet been planned. In District 2 and District 9, some locations experienced flooding attributed to heavy precipitation, yet there is currently no drainage plan in place until 2020. In Thu Duc district, the majority of flooding incidents caused by precipitation can be attributed to the degradation of the existing drainage system, compounded by the absence of a sewer system. Furthermore, there were more points of re-flooding and more severe flooding compared to the same time in the previous period. This research is the scientific basis for flood control planning for the city as well as socioeconomic planning.

Keywords: Thu Duc City; Urban flood; Planning; Heavy precipitation; Tidal current.

1. Introduction

Urban flooding is the combined result of natural factors (precipitation and tidal current) and humans including drainage systems and river networks and other drainage structures [1]. Urban flooding causes serious damage to infrastructure, the economy, and people's lives. Cities with a high population density and high urbanization rate have many potential risks, including the problem of urban flooding [2–6].

In a recent report on natural disasters by the United Nations Office for Disaster Risk Reduction (UNISDR) and the Centre for Research on the Epidemiology of Disasters (CRED) in 2015, it was highlighted that 43% of such disasters occurring between 1995 and 2015 were attributed to floods. These flood-related events had a profound impact, affecting

over half (56%) of all individuals affected by any category of natural disaster, and tragically resulting in the loss of life for approximately a quarter (26%) of those affected [7]. In numerous Chinese cities, urban flooding has emerged as a significant peril [8]. This issue is exacerbated by the substantial lag in the development of underground stormwater infrastructure, including drainage facilities, which struggle to keep pace with the rapid urban population growth and economic expansion. Consequently, instances of severe urban flooding have become increasingly frequent [8]. In 2017, it was estimated that urban flooding resulted in a direct economic loss of approximately 214 billion RMB, equivalent to approximately US$ 31.7 billion [9].

Ho Chi Minh City is a large metropolis in Vietnam, which has been severely flooded in recent years [10]. It is ranked in the top 20 cities with the highest population size affected by coastal flooding [11, 12]. The topography of the city is relatively low (nearly 65% of the area has a natural elevation of < 1.5 m), influenced by tides from the East Sea, limiting the ability to drain water [13]. During the rainy season, flooding in low-lying areas and also in central districts occurs frequently between August and December. According to Circular No.338/BXD-KTQH dated March 10, 2003, of the Ministry of Construction, Vietnam on the urban water drainage program, urban flooding is a flood situation in which the flooding points in the inner city are determined according to the following parameters: the volume of water in the area must be greater than 1,000m^3, equivalent to an inundation range of 500m long, 20m wide, and 0 deep. 1m, flooding time is 30' after rain.

The causes of flooding in the city are summarized as: (1) runoff from heavy precipitation is generated that exceeds the drainage capacity of the sewer system [14, 15]; (2) the tidal increases in the river and canal system [16, 17]; (3) The influence of flood discharge from upstream reservoirs [18, 19]; (4) the infrastructure failure to respond to rapid urbanization [20]; (5) the concreting leads to increased runoff [21]; (6) the subsidence of ground level [22]; (7) the lakes, rivers, canals, natural low-lying areas have been leveled to serve socio-economic development [23]; (8) the planning and development of residential areas are not reasonable [15]; (9) the progress in implementing the plans is still slow [24]; (10) people lack awareness in protecting and maintaining the drainage system [25].

Thu Duc City, Ho Chi Minh City, Vietnam was established under Resolution 1111/NQ-UBTVQH14 of the UBTVQH14 (effective from January 1, 2021); is a city directly under Ho Chi Minh City (HCMC), which was merged by 3 districts: District 2, District 9 and Thu Duc District (natural area of nearly 212 km^2). The city is a low-lying coastal city has a dense population, with a total population of more than 1 million people [26]. Furthermore, it has a dense system of rivers and canals, strongly influenced by the hydrological regime of the Saigon River, when high tides and heavy precipitation often cause flooding in areas with topography below 2.0 m [13]. Although the drainage system is regularly maintained and upgraded, floods due to heavy precipitation, tidal current, and combined tidal current and precipitation occur on some of the city’s main streets which have seriously been affecting the people’s lives in the area [15, 27, 28]. Currently, Thu Duc City still has many flooded points, especially, some of these are major streets with high traffic volume, seriously affecting people's lives and the economy. Compared with the number of regular flooding points reported by the steering center of urban flood control in 2015 of 18 points, the number of statistical flooding points in 2022 has nearly doubled to 37 points in the whole city. Newly the points appear mainly in Thu Duc District and a few points in the west of District 9.

Specifically, for Thu Duc City, a very young city newly established in January 2021 through the merger of three districts: District 2, District 9, and Thu Duc District - the issue of flooding and the impact of climate change become even more severe without a coordinated development direction.

To adapt and prevent flooding, there are various computational methods such as mathematical modeling [29–31], Geographic Information System (GIS) [32, 33], ecological reservoirs, urban reservoirs, and machine learning, serving comprehensive planning. In practice, many strategic plans have been implemented, leveraging national resources to promote sustainable development trends in the region and control urban flooding. These include urban and rural system development planning, functional area development planning, technical infrastructure development planning, land use planning, 5-year land use plans, district and inter-district development planning, water resource exploitation and utilization planning, mitigation of water-related impacts, disaster prevention and response to climate change planning.

In this study, the flooding situation caused by tides, heavy precipitation, and a combination of these factors during the planning period (from 2010 to 2021) with 63 flooded points will be evaluated and mapped using GIS. Subsequently, a comparison will be made with the urban planning to assess 37 heavily street flooding locations. This assessment will aid in identifying the causes of flooding and proposing suitable solutions. The results will serve as the fundamental basis for designing future drainage systems and for the assessment and management of flood risks.

2. Materials and methods

2.1. Study area

Thu Duc city is located in the east of Ho Chi Minh City, in the southern key economic region, and is the focal point of the main traffic routes between Ho Chi Minh City and the Southeast provinces. It is contiguous as follows: The East is Bien Hoa City and Long Thanh District, Dong Nai Province with the border of Dong Nai River. To the west are District 12, Tan Binh District, Binh Thanh District, District 1, and District 4 with the boundary of the Saigon River. To the south are Nhon Trach district, Dong Nai province, and District 7 (through the Saigon River), and to the north is Binh Duong province (Figure 1).

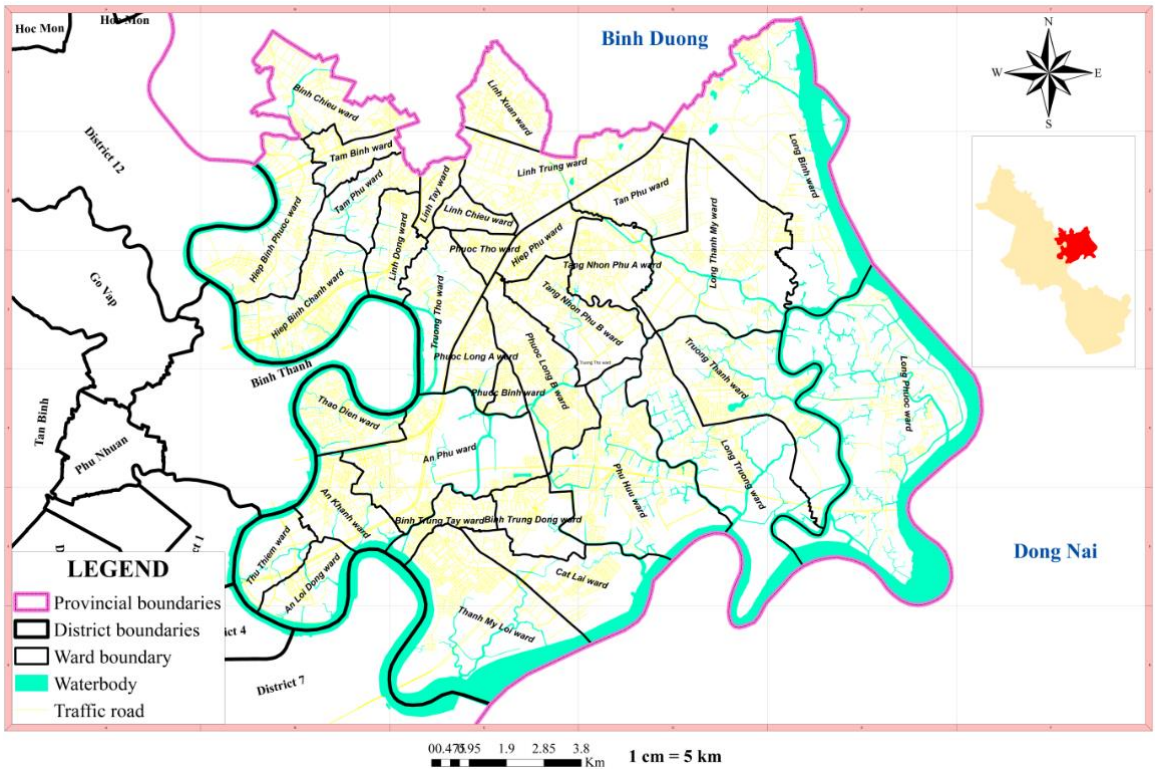

Figure 1. Study area.

Low-lying topography accounts for over 60% of the city's land with elevations below 2m (Figure 2). Besides, the geological foundation is weak and prone to subsidence, compression, and frequent bank failure. The drainage system, which doesn't meet the population growth rate in the area, is not continuous due to investment by many separate and asynchronous projects.

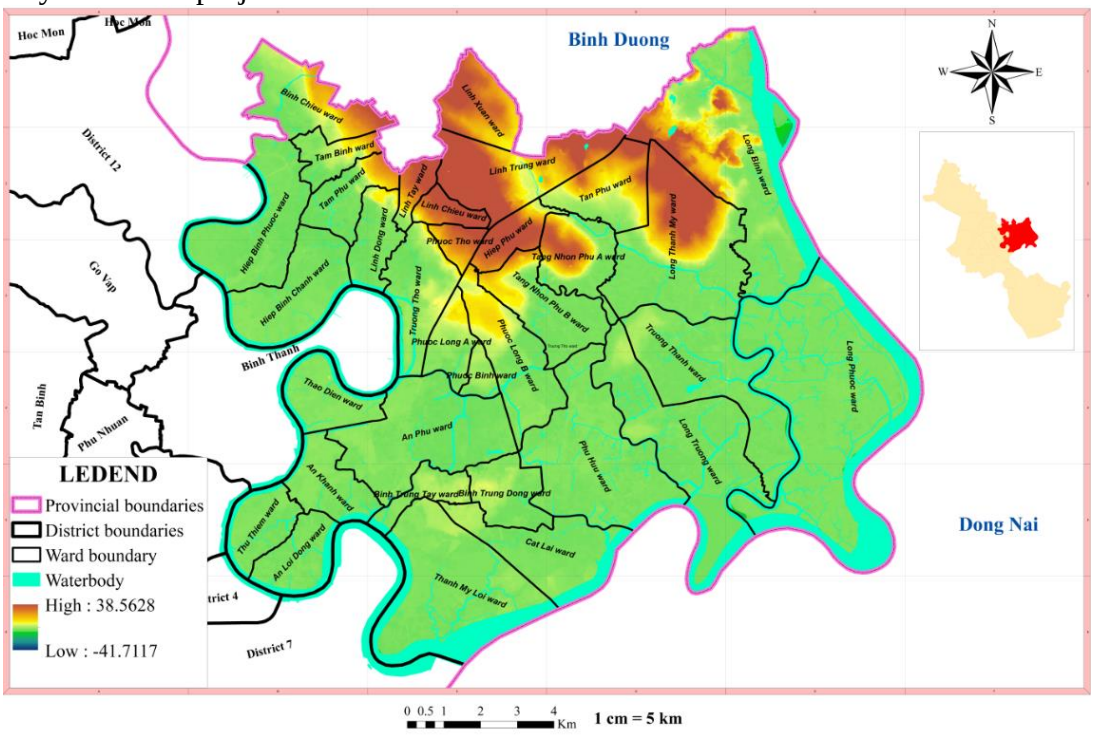

Figure 2. Digital elevation model.

2.2. Data collection

In the study, the number of times flooded and the average depth of flooding in the period of 2010-2021 of 63 flooded points in Thu Duc City, which was formerly Districts 2, 9, and Thu Duc District, is collected from Ho Chi Minh City Infrastructure Management Center and Urban Management Office of Thu Duc City. In which, the number of occurrences of flooding and the average depth of flooding are entirely sufficient for all 37 heavily flooded street locations.

The maps collected when merging the three districts are (1) The Administrative Map of Thu Duc City from the People's committee Thu Duc City, and (2) the Digital Elevation Map (DEM) from the Center for Applied GIS of Ho Chi Minh City (HCMGIS).

The other maps are collected individually for each old district at different times including: (1) Drainage planning map in District 2, District 9, and Thu Duc District by 2020; (2) Drainage map in District 2 in 2012, in District 9 in 2009, and Thu Duc District in 2011 (3) Environmental Assessment and Strategic Environmental Map in District 2 in 2012 from Ho Chi Minh City Department of Planning and Architecture.

2.3. Methodology

The study is structured according to the following framework (Figure 3).

There are three steps in this study:

Step 1: Data collection and mapping of flooding.

Step 2: Statistical analysis of flooding depth and area at 63 flooding points in the city, with detailed information on flooding depth and area for 37 heavily flooded streets during the periods 2010-2015 and 2016-2021.

Step 3: Analysis of the causes of flooding and comparison with urban planning.

Collecting and synthesizing documents

The method of collecting and synthesizing documents is carried out based on the inheritance, analysis, and synthesis of relevant sources of documents and information, selectively chosen from data such as reports, international and domestic documents, and from published studies/reports.

Geographic Information System

GIS - Geographic Information System, is an organized collection, including computer hardware, software, geographic data, and people, designed to capture, store, update, control, analyze, and display all forms of geo-location-related information. It allows the construction of spatial analysis, management, integration of information layers.

Applying GIS, remote sensing, and specialized software to systematize and map data and calculation results. In this study, the GIS method is used to visualize images, map flood points and process planning maps.

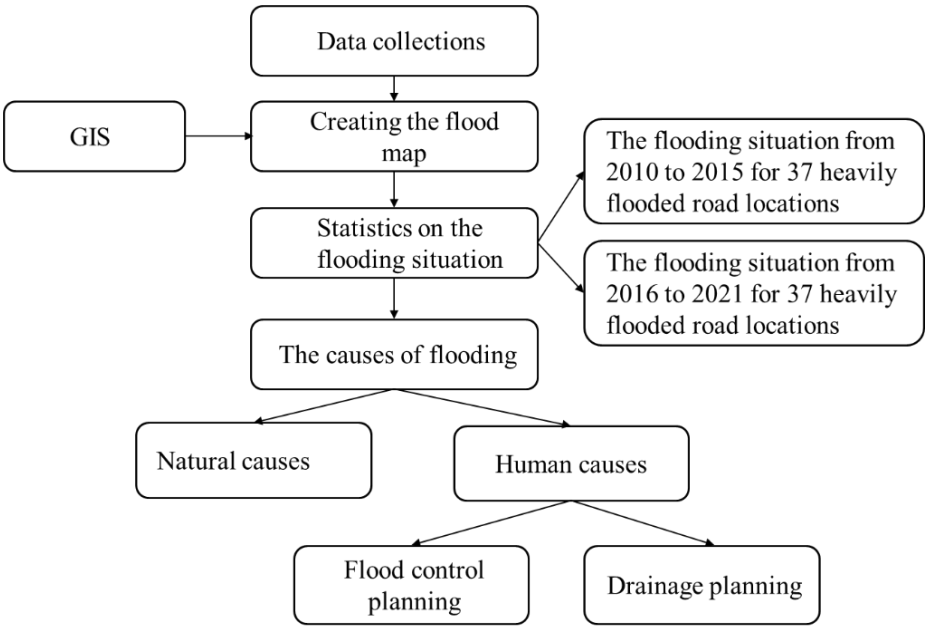

Figure 3. Implement framework.

3. Results

3.1. The flooding situation

Generally, the flood situation in Thu Duc City has been happening quite complicatedly. There is an increasing trend in both the number of flooded points and flooding times. Notably, heavy precipitation combined with tidal currents caused some streets in the central area of District 2 and Thu Duc where there is a low-lying and low foundation with low-lying foundations to be regularly flooded. The location of flood points is described in Figure 4 and the current flooding situation of all flooding points is described in Table 1.

a) Flooding due to heavy precipitation:

In the precipitation with a volume of 30 mm, mild flooding conditions begin to appear. When the precipitation volume reaches 40-50 mm or more, moderate to heavy flooding conditions occur.

In the precipitation of 60-70 mm in volume, about 50% of the existing flooded locations are moderately flooded. Meanwhile, all flooding locations in the city are flooded with moderate to severe precipitation with a volume of 80-100 mm or more. The areas heavily flooded by precipitation include National Highway 13 (No. 31, No. 32), Road No.

10 (No. 39) in Linh Dong Ward; Road 26 (No. 49) in Linh Dong Ward, Alley 789 (No. 42) in Tam Binh Ward; Cau Xay Street (No. 57) in Tan Phu Ward, etc.

The number of flooded points and the level of flooding will increase significantly when heavy precipitation coincides with tidal current. Flooding due to heavy precipitation not only impacts the living environment and people's lives but also directly affects transportation, causing severe traffic congestion.

According to a study by Huong (2022), in District 9, there are 350 streets, 74 traffic bridges, and 940 alleys. Waterlogging on the streets during heavy precipitation makes transportation challenging, leading to potential engine failures and accidents such as vehicle overturns and people being swept away. The streets are prone to congestion and flooding during precipitation, resulting in extended travel times, property damage, increased transportation costs, and elevated environmental pollution [34].

b) Flooding due to tidal currents:

The river and canal system of Thu Duc City is influenced by the semi-diurnal tidal regime from the East Sea through major rivers such as the Saigon River and Dong Nai River. The water level varies seasonally and at different locations due to the tidal changes downstream and the flood discharge regime of upstream structures. The annual water level on the Saigon - Dong Nai - Nha Be River fluctuates from +1.15 m to +1.70 m, with the difference between the highest and lowest water levels ranging from 3.5 m to 4.0 m.

According to survey results, tidal flooding in low-lying areas of the city begins to occur at tide levels from +1.0 m and can currently reach up to +1.7 m.

Regarding flooding by tidal currents, heavily flooded areas are concentrated in District 2 and Thu Duc District. Thu Duc District has heavily flooded areas including No. 43 street (No. 40) in Hiep Binh Chanh ward, street 12 (No. 41) in An Khanh ward, street 24 (No.48) in Linh Dong ward, etc. District 2 is a typical area flooded due to construction which doesn't pay attention to the background during construction work. It is a fact that many residential areas were built with foundations lower than the high tide level, so they are often flooded by tides. More specifically, the flood situation is more severe for the areas near the large canals and low-lying as Thao Dien ward and a part of Binh An ward (Figure 4).

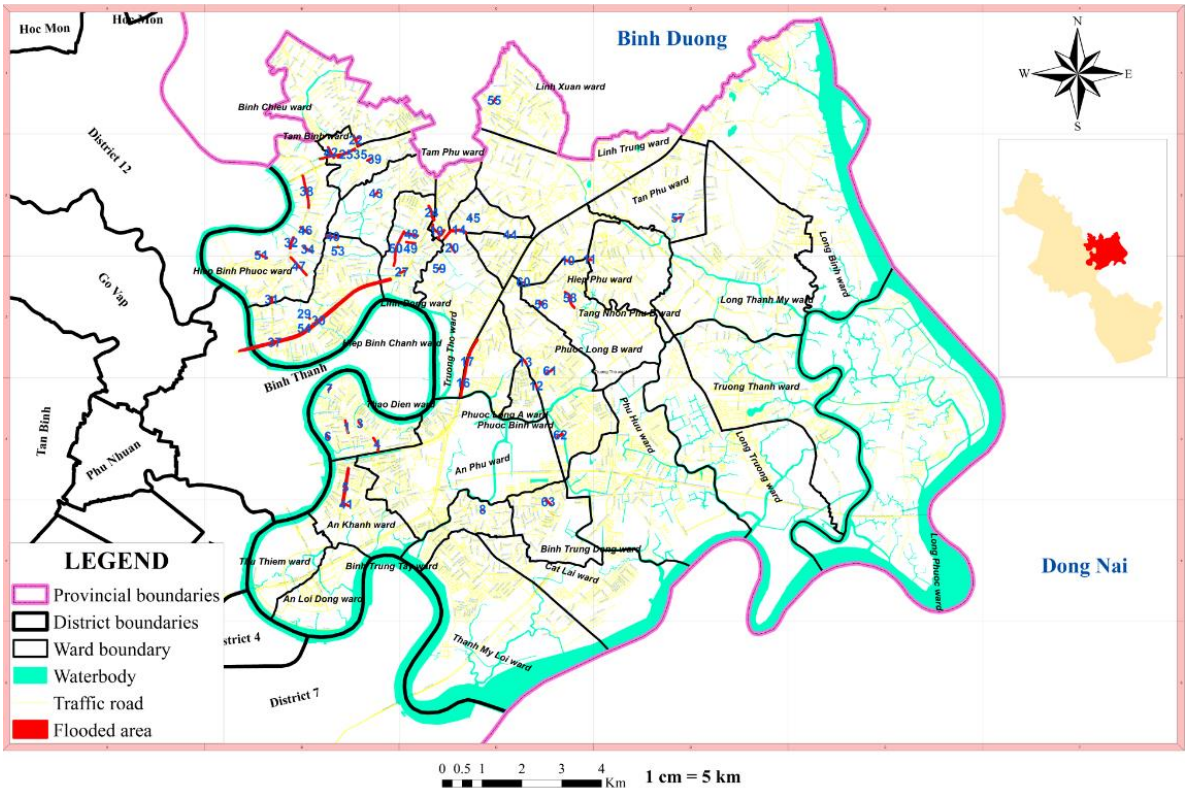

Figure 4. The location of flooded points in Thu Duc City, Ho Chi Minh City, Vietnam.

Flooding by tidal currents cause phenomena such as embankment breaches, overflow, and flooding in certain areas, such as Thu Duc District (Hiep Binh Phuoc, Hiep Binh Chanh, Ling Dong, Tam Phu, Tam Binh) and District 2 (Thao Dien, An Loi Dong, An Khanh), impacting the lives and activities of residents. This leads to environmental pollution, compromised living conditions, compromised sanitation and safety, challenges in food safety, disruptions to traffic, and difficulties in the mobility of residents.

Table 1. The current flooding situation of all flooding points.

No.	Street	Flooding range		Average flooded depth (m)	Average flooded area (m^2)	Average flooding time (minutes)	Causes of flooding		
		From	To				Tide	Precipitation	Tide & precipitation
1	Quoc Huong	Tong Huu Dinh	Alley 76	0.225	2080	80		x	
2	Quoc Huong	Tong Huu Dinh	Street 65	0.2	1550	260		x	
3	Thao Dien	Alley 95	Police of Thao Dien Ward	0.3	2700	-			x
4	Thao Dien	Hanoi highway	Xuan Thuy	0.15	2200	195			x
5	Tran Nao	Dieu Giac Temple	2nd Street	0.2	16800	38		x	
6	Nguyen Van Huong	In front of Hoang Anh Gia Lai Apartment		0.15	1500	200		x	
7	Nguyen Van Huong	Before House No. 170		0.2	1800	165		x	
8	Nguyen Duy Trinh	In front of the children's culture house in District 2		0.2	2000	40		x	
9	Luong Dinh Cua	Thu Thiem Bridge	Cat Lai ferry	0.13	3250	120			x
10	Le Van Viet	Phong Phu Communal House	Alley 201	0.15	1440	120		x	
11	La Xuan Oai	House number 34	Outlet	0.2	2000	90			x
12	Do Xuan Hop	People's Committee of Phuoc Binh Ward		0.35	1400	160		x	
13	Do Xuan Hop	Vocational colleges		0.23	1490	38		x	
14	Vo Van Ngan	Dang Van Bi	Thu Duc Market	0.2	4000	120		x	
15	Ha Noi Highway	Power pole T7C	Power pole T30C	0.2	8000	100		x	
16	Ha Noi Highway	Charging station	Rach Chiec bridge	0.2	1440	120		x	
17	Ha Noi Highway	Rach Chiec bridge	Tay Hoa	0.2	400	35		x	
18	Dang Thi Ranh	Duong Van Cam	To Ngoc Van	0.2	900	15		x	
19	Duong Van Cam	Le Van Tach	Dang Thi Ranh	0.4	1840	40		x	
20	Ho Van Tu	Kha Van Can	Police Department of Truong Tho Ward	0.175	1120	25		x	
21	Le Thi Hoa	Provincial Street 43	House number 21	0.5	3355	35		x	
22	Provincial Street 43	Binh Chieu	Highway 1	0.4	3600	25		x	
23	To Ngoc Van	Railway	Pham Van Dong	0.35	1300	60		x	
24	To Ngoc Van	Linh Dong	Linh Tay stream outlet	0.2	1200	25		x	
25	Highway 1	Thanh Binh gas station	Go Dua overpass	0.15	2000	20		x	
26	Kha Van Can	Duong Van Cam	Thu Duc Post Office	0.21	3453	10		x	
27	Kha Van Can	Gas station 7/27	Vo Uu Temple						
28	Kha Van Can	No. 1 outlet	House number 617						
29	Kha Van Can	Rach Mon area							

No.	Street	Flooding range		Average flooded depth (m)	Average flooded area (m^2)	Average flooding time (minutes)	Causes of flooding		
		From	To				Tide	Precipitation	Tide & precipitation
30	Pham Van Dong	House number 148	House number 7/29	0.3	3900	40		x	
31	National Highway 13	Ong Dau Bridge	Temple of Binh Trieu	0.146	916	71		x	
32	National Highway 13	Gia Dinh Shoe Company	Hiep Binh Street	0.2	1600	50		x	
33	Dang Van Bi								
34	Hiep Binh	1st Street	Hiep Binh Secondary School						
35	Go Dua	National Highway 1A (Binh Phuoc Overpass)	To Ngoc Van	0.2375	1767	58		x	
36	Le Van Tach	House number 3	Duong Van Cam						x
37	Binh Trieu Crosstrees	Binh Trieu Roundabout							x
38	Old Highway 13	Highway 1	Highway 13	0.2	4200	120		x	
39	Street no. 10	To Ngoc Van Street	Alley 30, street 10	30	360	60		x	
40	No. 43 street	Tam Binh	Rach Dia	0.3	1318.5	30			x
41	Street 12	Tran Nao	Residential Project of Caric Joint Stock Company	0.3	1000	90		x	
42	Alley 789	At the beginning of Song Hanh National Street 1	Thu Duc Farmers Market	0.2	1120	30		x	
43	Alley 37, Acacia Tree Street	After Chau Hung Pagoda	Ring Street 2 intersection (under construction)	0.3	880	30		x	
44	Alley 95, Vo Van Ngan Street	House number 95/26	House No. 95/36	0.5	80	30		x	
45	Alley 2, Street 17, Quarter 5	Street 17	At the end of the alley	0.3	13395900	60		x	
46	Alley 606 R13	National Street 13	Adjacent to Hong Long project	0.2	400	120			x
47	Sixth Street, Quarter 6	National Street 13	Kinh Do canal	0.2	600	150			x
48	Street 24	Street 22	Linh Dong Street	0.4	2400	120			x
49	Street 26	House No. 10	Linh Dong Street	0.4	-	120		x	
50	Street 30	Street 22	House number 47	0.5	-	120			x
51	Alley 34 - Street 36	Street 34	People's houses	0.3	240	30		x	
52	Tam Tam Xa Street	Duong Van Cam	At the end of the route	0.5	880	90			x
53	42nd Street	Tam Binh	People's houses	0.3	4050	24		x	
54	Alley 384 Pham Van Dong	Pham Van Dong	Street 26	0.5	960	30		x	
55	Alley 2 Street 13	Street No. 13	At the end of the route	0.4	750	60		x	
56	Street 8	Street No. 8	At the end of the route	0.5	700	60		x	

No.	Street	Flooding range		Average flooded depth (m)	Average flooded area (m^2)	Average flooding time (minutes)	Causes of flooding		
		From	To				Tide	Precipitation	Tide & precipitation
57	Cau Xay Street	Alley 41	Alley 15	0.3	1440	40		x	
58	Dinh Phong Phu Street	Street No.6	End of the Phong Phu Bridge	0.3	700	40		x	
59	Alley 99 Street 11	House No. 99/9A	At the end of the route	0.3	150	60		x	
60	Alley 26 Tu Xuong street	House No. 26B/2F	At the end of the route	0.4	150	45		x	
61	Duong Dinh Hoi Street	Street 359	Street 10	0.2	1600	40		x	
62	Lien Phuong Street	Tang Nhon Phu Street	Alley 2	0.3	600	45		x	
63	Street 63	Nguyen Duy Trinh Street	Project Zone Binh's population Trung Dong area 19.3ha	0.5	650	40-60		x	

3.1.1. The flooding in the period of five years from 2010-2015

Statistical results from 2010 to 2015 show that local flooding occurred on a series of streets such as Quoc Huong, Thao Dien, Nguyen Van Huong, Le Van Viet, ... (the total of 37 heavily flooded street locations), as a result, not only the traffic situation becomes congested, but also thousands of people face difficulties due to flooding. The number of times flooded from 2010 to 2015 and the average depth of flooding during the 2010-2015 period is described in Figure 5 and Figure 6, respectively.

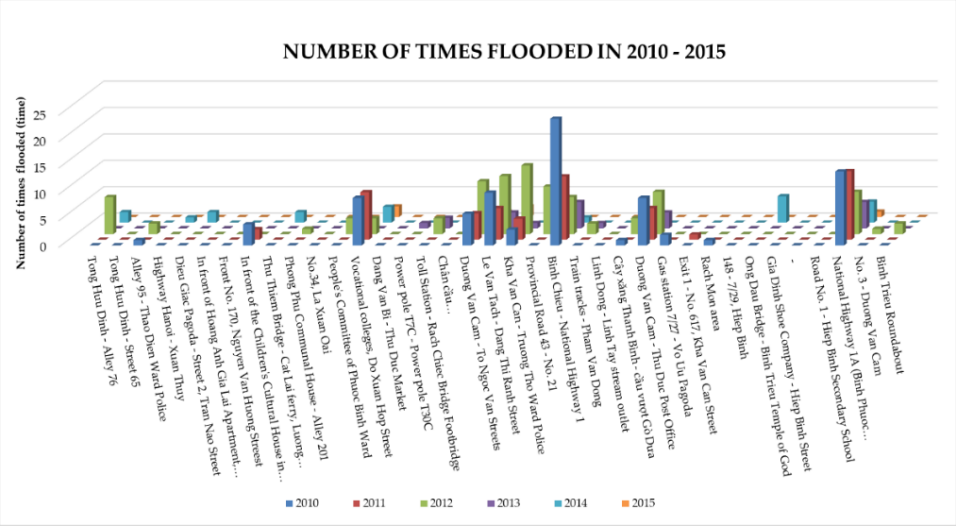

Figure 5. The number of times flooded from 2010-2015.

Particularly, Quoc Huong Street (the segment from Tong Huu Dinh Street to alley 76) was heavily flooded due to heavy precipitation from 2012 to 2014 and doubled in 2014 with average flooding of 80 minutes (Figure 5). Meanwhile, the sewer system was blocked leading to Dang Thi Ranh Street (from Duong Van Cam to To Ngoc Van Street) being flooded 10 times in 2012 (Figure 5). The segment of Duong Van Cam Street (from the intersection of Le Van Tach and Dang Thi Ranh) was regularly flooded due to heavy precipitation over the years, with the highest number of floods in 2012 (11 times) (Figure 5), at the average depth of 0.3 m flooding (Figure 6). Similarly, Ho Van Tu Street (the segment of the Kha Van Can Street to the police station of Truong Tho ward) was flooded 13 times (Figure 5) in 2012 with an average recorded depth of 0.22 m (Figure 6).

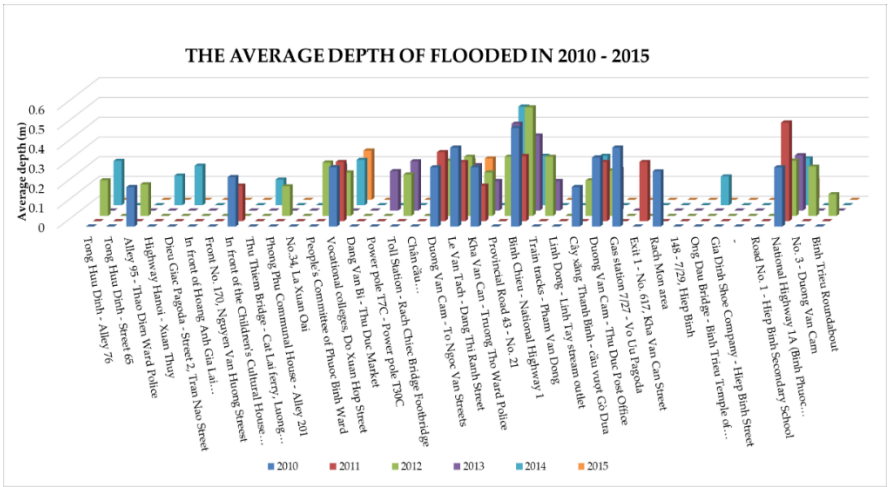

Figure 6. The average depth of flooding in the period 2010-2015.

It is noticeable that due to the deterioration of the drainage system, heavy rain has flooded some locations to an alarming level. TL43 street (the segment from Binh Chieu to National Highway 1) was an alarming flood route, with the highest frequency of flooding up to 24 times in 2010 (the average depth of 0.5 m) (Figure 5 and Figure 6). A decreasing trend of flooding depth was recorded in the street during the 2011-2015 period, but the highest frequency of flooding experienced was very high, compared to other streets. Additionally, in the segment of Go Dua street (from the Binh Phuoc overpass to the intersection of To Ngoc Van street), which is the most flooded place in the years 2010-2012, the number of flooding times was quite high, with approximate 8-14 times in 1 year (Figure 5). The statistical data shows that the average recorded depth of flooding in the street was up to 0.5 m (Figure 6).

According to the flooding due to the combination of heavy precipitation and high tide, the area in front of the Vocational College (Do Xuan Hop street) had the highest number of floods in 2010 and 2011 (9 times) (Figure 5). Heavy precipitation and high tide caused flooding in this area; in addition, the drainage system did not respond to the current situation, so flooding occurred frequently.

3.1.2. The flooding in the period of five years from 2016-2021

Compared with the flooding in the previous period, an improvement was noted in that the number of times flooding has decreased significantly, but the frequency of flooding has increased. The number of flooded times and the average depth of flooding in the streets in the period of five years from 2016 to 2021 are illustrated in Figure 7 and Figure 8.

The segment of Quoc Huong Street (Tong Huu Dinh Street - Street 65) has been flooded since 2016. The largest number of recorded floods in the whole period is 26 times (Figure 7), with the average depth of flooding of 0.23 m (Figure 8). The average flooded length was 135 m with an average flooded area of 1111 m^2. The frequency of the flooded location decreases gradually, at 5 times in 2021 (Figure 7) with a flood length of nearly 150 m and a recorded flooded area of 1400 m^2.

Although there is an operating sewer system, however, the segment of Thao Dien street (Alley 95 to Thao Dien ward police station) was still flooded sometimes up to 0.3 m in 2020 (Figure 8) with an average flood length of 270 m^2 and the average flooded area of 2700 m^2. High tide is the main cause of flooding in the area. Furthermore, it has directly affected people's lives and activities around the area. It is the cause of environmental pollution, food safety, and hygiene, obstructing traffic, and affecting the movement of people.

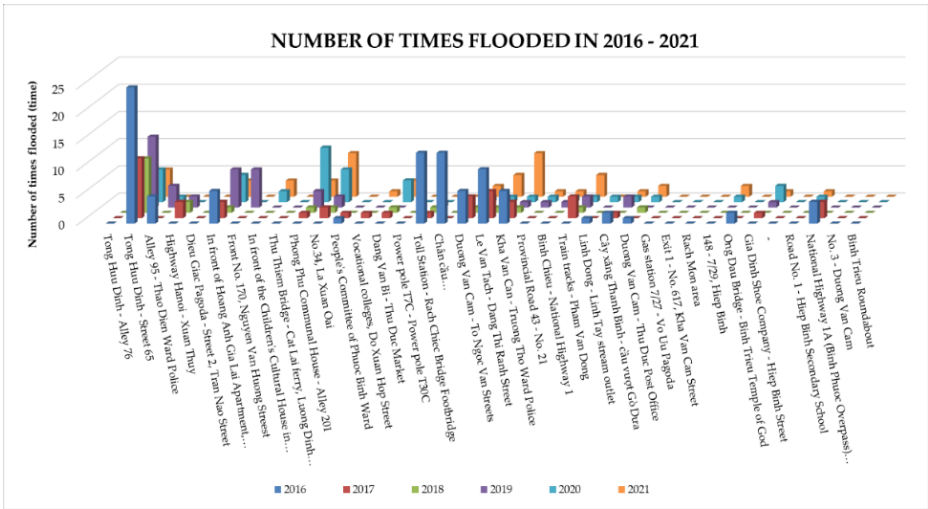

Figure 7. The number of times flooded from 2016-2021.

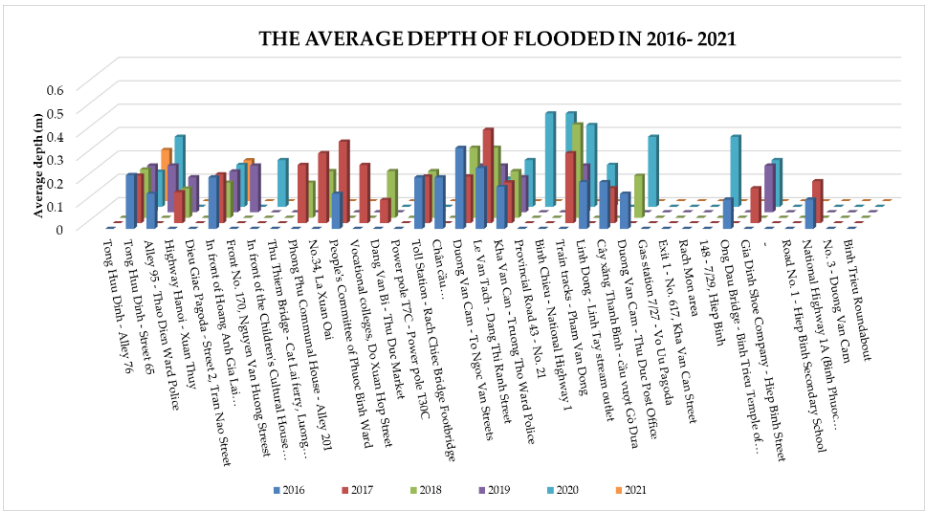

Figure 8. The average depth of flooding in the period 2016-2021.

3.2. The causes of flooding

3.2.1. Natural causes

Natural causes include topography, heavy precipitation, and tidal current. Studies on heavy precipitation and tidal current have been studied on many topics and projects. Therefore, in this study, the topography of the area is studied in more detail.

Thu Duc city has a rich and diverse topography, with an average height from 5m to 25m. There are 3 types of topography in this area including (Figure 2).

The elevation varies from 2.0 m to 30.0 m, concentrated in the north of the city, where it is adjacent to Binh Duong province. This place is not flooded by the tide but flooded by heavy precipitation, particularly Vo Van Ngan Street, To Ngoc Van Street...

The elevation varies from +1.5 m to +2.0m distributed in the south of the city such as An Khanh and Thao Dien wards... This place is flooded due to the combination of heavy precipitation and tides.

The elevation below 1.5m is distributed inwards along the Saigon and Dong Nai rivers. Typically, Hiep Binh Phuoc ward has an elevation of mainly 0-1 m and a part of 1-2 m while Hiep Binh Chanh ward has a terrain of 0-1m, accounting for about 50%. Furthermore, Thu Thiem ward has an elevation of 50% 0-1 m and 50% 1-2 m. Additionally, Long Phuoc and Thanh My Loi wards have mostly 0-1m of elevation.

3.2.2. Human causes

This study focuses on the causes related to management and planning in the region, including flood control and drainage planning

(1) Flood control planning

Flood control planning has been approved but not be completed until 2020. For planning 1547: approved by the Prime Minister in Decision 1547/2008 to propose irrigation solutions to solve the flooding situation in Ho Chi Minh City, specifically: Period to 2012: implementation of tidal control solutions, actively lowering the water level on the axis canals surrounding the right bank of the Saigon - Nha Be river. The period after 2012: implementing control measures in the confluence of Dong Nai - Saigon rivers. However, at present, there are no specific plans and guidelines for implementation. For planning 752: Master plan on the drainage of HCMC until 2020 funded by JICA, approved by the Prime Minister in 2001 in Decision No. 752/QĐ-TTg. However, this project only focuses on solutions to prevent flooding due to precipitation in the central area of Ho Chi Minh City.

(2) Drainage planning

Urbanization of the city has reduced the natural regulation of the watershed surface. When most of the land is concreted, and plasticized to build houses, factories, etc., there will be an increase in surface runoff to drainage locations. However, two prominent problems cause flooding: Due to lack of sewer or no sewer; overloaded drains, and due to urbanization and leveling of drainage sources. Many drainage projects have not been completed on schedule due to the following reasons: lack of capital, problems in compensation and clearance, relocation of underground works, problems in procedures, lack of construction contractors who can complete the project. According to the drainage planning map in District 2, District 9, and Thu Duc District by 2020, several flooded locations due to no drainage system, lack of drainage systems, and unresponsive drainage systems have not yet been planned, specifically:

In District 2: Locations 1, 2, 6, 7, and 41 (Figure 4 and Table 1) were flooded due to heavy precipitation but there is no drainage plan until 2020.

In District 9: Locations 56, 57, 59, and 62 (Figure 4 and Table 1) were also flooded due to heavy precipitation but there was no planned drainage system.

In Thu Duc District: Most of the flooding points due to precipitation are because the drainage system is degraded and there is no sewer system and up to now, there is no planned sewer system for these areas. Locations: 14, 19, 20, 27, 29, 30, 35-38, 40-44, 46-49, and 52-55 (Figure 4 and Table 1) are flooded locations due to drainage but there is no drainage system.

Thus, the slow implementation of the plans and the lack of implementation guidelines have affected the current flooding situation in the study area. Besides, the lack of synchronization in drainage planning makes this situation more serious. Flooding in District 2 and Thu Duc District are the prime examples.

The main causes identified are quite consistent with the primary causes of flooding in Ho Chi Minh City according to the research by [35].

Thu Duc City is aiming to become a green and smart city, and accordingly, the appropriate flood control strategies are as follows:

1. Implement rapid and coordinated flood prevention planning.

2. Hierarchical risk zoning: The hierarchical risk zoning is based on three criteria that constitute flood risk, including the level of the flooding event, vulnerability, and exposure. These criteria are then combined with input data, including flood assessment maps for extreme flooding events, such as the combination of heavy rainfall, tide, flood and climate change, and maps of population distribution and current infrastructure to identify areas with high, moderate, low, and no flood risk.

3. Tidal control corridors: Unlike traditional approaches using embankments or dikes, tidal control corridors help create integrated spaces for multiple infrastructure solutions to serve the goal of flood and salinity control. Tidal control corridors can narrow around areas with low foundations instead of covering an entire large area like traditional embankments. Additionally, to seal off tidal control corridors, it is necessary to construct tidal gates at canal entrances in the flood control corridors.

4. Reservoirs are the main solution for storing overflow caused by rain when the system cannot drain water out due to high river water levels.

4. Conclusions

Flooding in Thu Duc City has been happening for many years now and every year, there are some new flood spots in urbanizing areas. In general, tidal flooding only occurs in some areas, flooding due to heavy precipitation is a common form of flooding in Thu Duc City. Heavy precipitation combined with high tide caused some streets in the central area of District 2 and Thu Duc with low foundations to be frequently flooded. New flooding points appeared mainly in the Thu Duc District and a few points in the west of District 9.

Compared to the drainage planning map in District 2, District 9, and Thu Duc District by 2020, several flooded locations due to no drainage system, lack of drainage systems, and unresponsive drainage systems have not yet been planned. Especially in the Thu Duc District, almost all locations flooded caused of heavy precipitation but there was no drainage system.

The main reasons for such flooding are the slow implementation of the master plans, the lack of implementation guidance, and the lack of synchronization in the drainage planning which makes this situation more serious. However, this study has not yet classified flood risk zones, an essential premise for flood control strategies in the study area.

In addition, forecasting flooding corresponding to climate change scenarios for future planning has not been undertaken. These are limitations and represent the next research following this study.

Author Contributions: Conceptualization, N.T.P.T., T.T.K.; Methodology, N.T.P.T., T.T.K., N.K.P.; Formal analysis, N.T.P.T., T.T.K.; Investigation, N.T.P.T., T.T.K., N.K.P.; Resources, N.T.P.T., T.T.K.; Data curation, N.T.P.T.; Writing–original draft preparation, N.T.P.T., T.T.K.; Writing–review and editing, N.T.P.T., T.T.K.; Visualization, N.T.P.T., T.T.K.; Supervision, N.K.P.; Project administration, N.K.P.; Funding acquisition, N.K.P.

Conflicts of Interest: The authors declare no conflict of interest.

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