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APPLICATION IN ECOLOGICAL ENGINNERING FOR MITIGATING THE IMPACT OF FLOODING IN HO CHI MINH CITY

SUMMARY OF THE DOCTORAL THESIS IN ECOLOGY

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FOREWORD

1. The introduction

The urban flooding is considered as one of the important issues affecting the country's socio-economic development and receiving the attention from managers and the whole society as well. Flooding in Ho Chi Minh City has become worse due to the impact of climate change. In addition, the rapid urbanization, landslides and subsidence have been continued to affect not only the construction quality but also the increase in flooding in the city. The urban flooding has been attracted the attention and research by the scientists and authorities in order to reduce the flooding level in the City.

Therefore, the assessment program of current status and potential flood through modeling and calculation of inundation scenarios according to the climate change and sea level rise scenarios of the Ministry of Natural Resources and Environment to propose the application in ecological techniques to reduce the urban flooding for the sustainable development purpose is significantly needed to be addressed.

The thesis "**Application in ecological engineering for mitigating the impact of flooding in Ho Chi Minh City**" has been done in order to obtain the scientific assessments, orientations and more effective solutions by applying the ecological techniques in dealing with the local flooding in accordance with the conditions in Ho Chi Minh City.

2. Research aims of the thesis

The effective solutions in ecological engineering application for mitigating the impact of flooding in Ho Chi Minh City are going to be researched and suggested.

3. The main contents of the thesis

The current status and the risk of flooding in Ho Chi Minh City under impact of climate change were assessed by modeling methods (MIKE NAM, MIKE FLOOD, MIKE URBAN models). The scenarios RCP 4.5 and RCP 8.5 on climate change and sea level rise were used for modeling calculation and building the flood maps.

The application of ecological techniques to reduce the flooding from the extraction data of MIKE FLOOD model for Ho Chi Minh City scale, building a current status and risk map Flooding according to climate change scenarios (RCP 4.5 and RCP 8.5) in Binh An ward (now An Khanh ward, Thu Duc city, Ho Chi Minh City), combined with current status and land use planning up to 2030 to determine the flood risk for the study area for each land use unit was proposed. Furthermore, the more effective solutions in ecological techniques application to reduce flood risks in Ho Chi Minh city were addressed.

CHAPTER 1. OVERVIEW

1.1. Overview of the research topic

Flooding in urban areas is an increasingly concerning issue that receives a lot of attention. The flooding situation has severe impacts on production, daily activities, and the lives of residents. It damages construction works, destroys infrastructure, disrupts transportation, and causes environmental pollution. The fundamental causes of urban flooding include natural conditions, weather and hydrology, water drainage capacity of the drainage system, urban planning and management, and the organizational and administrative capacity of government authorities at all levels, as well as the awareness of the community.

For a long time, many cities around the world have primarily relied on infrastructure solutions to address the issue of urban flooding: (1) Constructing flood embankments to protect the city, establishing systems of sea and river barriers, installing tidal gates; (2)

Digging artificial canals for water drainage, building a system of box culverts for water discharge, temporary water storage reservoirs, regulating reservoir systems, and installing high-capacity pumping stations; (3) Raising the foundation level, ...

The issue of flooding and the solutions to address the flooding situation in Ho Chi Minh City have garnered significant attention from scientists, and numerous research findings have been published on this matter, focusing on the following key aspects: (1) Scientific research on water drainage systems. (2) Research on water drainage issues. (3) Research on the causes of flooding in Ho Chi Minh City. (4) Research on flood prevention solutions for the city based on proposed flood prevention planning.

Ecological solutions are being applied to enhance adaptive capacity and cope with flooding: interdisciplinary approaches in design and construction (Sustainable Urban Drainage Systems - SUDS), green infrastructure for flood mitigation.

1.2. Overview of the research area

In general, Ho Chi Minh City has a relatively flat and low-lying terrain, with some hills and ridges in the northwest and northeast. The ground elevation tends to decrease gradually from the northwest towards the south and southeast. The region features a significant distribution of undulating ridges in several districts: Cu Chi, Hoc Mon, the northern part of Thu Duc City, and the northern part of Binh Chanh District. Elevations ranging from 4-10m account for approximately 19% of the total area, while areas with elevations above 10m make up 11% of the total area.

Located in the watershed of the Dong Nai-Saigon river system, the hydrological regime of canals, streams, and rivers in Ho Chi Minh City is influenced not only by the city's topography, which is predominantly low-lying, with elevations below 2m, but also by the

semi-diurnal tidal regime of the East Sea. Additionally, the water systems are significantly impacted by the present and future exploitation of cascade reservoirs in the upper reaches, such as the Trị An, Dau Tieng, and Thac Mo reservoirs, …

The city is crisscrossed with a dense network of rivers and canals, totaling 7,955 km in length. The total water surface area accounts for 16% of the city's area, and the average flow density is 3.80 km2. Therefore, the low-lying areas with elevations below 2m and the water bodies covering 61% of the natural area are situated in the river mouth region, which is susceptible to significant flooding risks due to the presence of large regulating structures in the upper reaches.

Ho Chi Minh City has a relatively high average annual rainfall ranging from 1800mm to 2700mm. The majority of rainfall is concentrated in a span of seven months, from May to November, accounting for approximately 90% of the total rainfall.

In terms of hydrology, most of the rivers and canals in Ho Chi Minh City are influenced by the semi-diurnal tidal fluctuations of the East Sea. Every day, water levels rise and fall twice, causing tidal intrusion into the city's channels and canals. This has significant impacts on agricultural production and restricts water drainage in the inner city area.

The highest average tidal level is 1.10m. The months with the highest tidal levels are typically October and November, while the lowest tidal levels occur during June and July. During the dry season, the flow rate of small river tributaries and the salinity level of 4% can intrude into the Saigon River as far as Lai Thieu, and in some years, even reach Thủ Dầu Một. On the Dong Nai River, the intrusion can extend as far as Long Dai. However, during the rainy season, the flow

rate of major water sources increases, pushing the saltwater intrusion further away and diluting the salinity levels significantly.

The flooding situation in Ho Chi Minh City: According to statistical data and monitoring, at the beginning of 2008, there were 126 main road routes in the city that experienced flooding due to rainfall; by the year 2016, there were still 40 main road routes in the city that experienced flooding due to rainfall. Additionally, 95 main road routes were affected by tidal flooding. By 2016, there were still 9 main road routes in the city that experienced flooding due to tidal influences.

The drainage system of Ho Chi Minh City has been and is being developed according to four planning schemes, which include:

- The overall planning for the drainage system of Ho Chi Minh City until 2020 was approved by the Prime Minister in Decision No. 752/QD-TTg on June 19, 2001;

- The water resources and flood control planning for the Ho Chi Minh City area were approved by the Prime Minister in Decision No. 1547/QD-TTg on October 28, 2008;

- The general planning for the construction of Ho Chi Minh City until 2025 was approved by the Prime Minister in Decision No. 24/QD-TTg on January 6, 2010;

- The planning for the drainage system and wastewater treatment in residential areas and industrial zones within the Dong Nai River basin until 2030 was approved by the Prime Minister in Decision No. 1942/QD-TTg on October 29, 2014.

CHAPTER 2. RESEARCH CONTENT AND METHODS

2.1. The Approach

The logical framework for implementing the project:

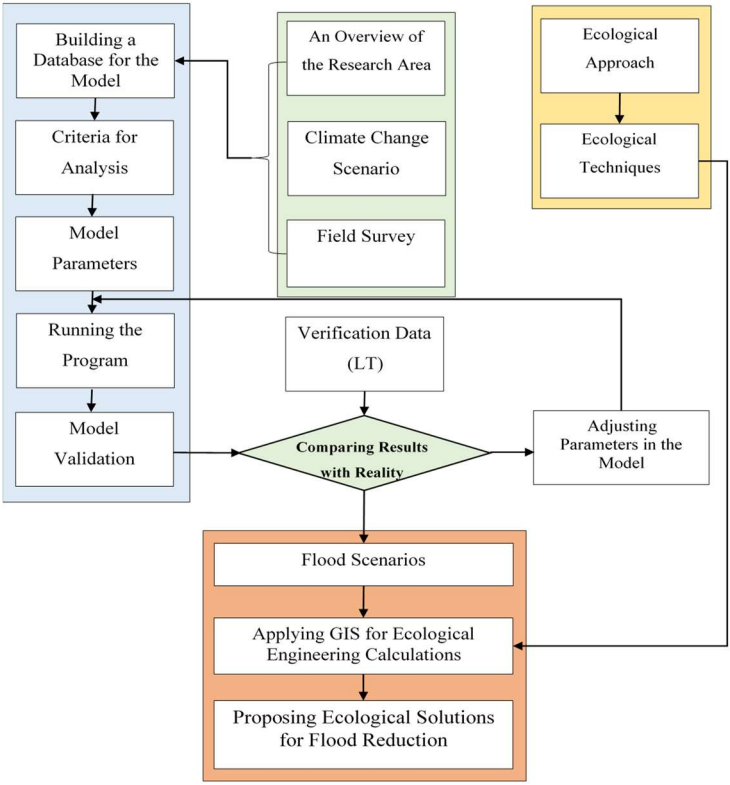


Figure 2.1. The logical framework

2.2. Research content and methods

The configuration of input parameters for MIKE FLOOD involves establishing parameters for three constituent models. The input parameter configuration for MIKE FLOOD comprises two distinct sections, each encompassing three calculation alternatives, and is further divided into five scenarios that pertain to the exceeding of design rainfall frequency and different tidal water levels:

- The configuration of computation parameters for assessing current flooding conditions encompasses multiple components. Firstly, input data is employed for water level calculations using MIKE 11 HD. Secondly, urban drainage calculations are conducted

using MIKE URBAN, considering the prevailing conditions of the year 2016. Lastly, the procedure involves the incorporation of terrain data and the establishment of the 2016 tidal defense structure, which are specifically tailored for MIKE 21.

- The configuration of computation parameters for various scenarios includes the following: starting with the specific climate change scenario for Ho Chi Minh City, the study will initially determine the current scenario and then propose additional scenarios. These supplementary scenarios encompass the 2030 sea-level rise scenarios (RCP 4.5 and RCP 8.5), the upper basin flood scenario that demonstrates amplification in response to changes in precipitation patterns under climate change conditions, and the urban rainfall scenario characterized by the utilization of a rainfall intensity-duration-frequency (IDF) curve.

For calculating water levels in the study area under different scenarios, we utilize the sea-level rise data for the year 2030 obtained from the specific climate change scenario of Ho Chi Minh City. Additionally, we incorporate future overflow data from Dau Tieng Lake and Tri An Lake, which varies according to the designated scenario (based on the overflow data provided by the Ho Chi Minh City Flood and Storm Control Center).

+ The future sea-level rise scenario (2030) involves Ho Chi Minh City's climate change scenario, which specifically focuses on the increase in coastal sea levels.

+ The scenario concerning the upstream reservoirs involves presumptive modifications in flow rates. Specifically, the regulated discharge of floodwater from Dau Tieng and Tri An reservoirs is considered a functional operation. During the rainy season, intensified and sustained rainfall in the upstream catchment area leads to substantial inflows into the reservoirs, reaching predetermined levels

based on inter-reservoir operation guidelines. Consequently, ensuring reservoir safety requires controlled spillage, and its discharge rate necessitates vigilant monitoring considering the impacts of climate change. Thus, alterations in precipitation patterns due to climate change can directly influence the spillway discharge rate of these reservoirs. Consequently, the computed flow rate includes both the turbine-generated discharge and the spillway discharge (subject to fluctuations corresponding to future rainfall variations) at the Tri An reservoir, in conjunction with the discharge rate at the Dau Tieng reservoir.

+ Urban Rainfall Scenario: The urban rainfall scenario is developed based on the Intensity-Duration-Frequency (IDF) curves combined with representative rainfall events to be applicable to different areas within Ho Chi Minh City. Each scenario will be accompanied by a rainfall design chart, constructed using representative rainfall events measured at stations within Ho Chi Minh City, and incorporating the IDF rainfall system developed for the Tân Sơn Hòa station during the base period. This system is employed to project future conditions for both average and high scenarios, covering the early century with a recurrence interval of 10 years.

Applying the GIS (Geographic Information System) method to build a flood map for Ho Chi Minh City amidst the backdrop of climate change:

- Gathering and compiling data
- Processing raw data
- Establishing the base map
- Handling the flooding outcomes derived from the Mike Flood model.

2.2. Utilizing Ecological Techniques to Mitigate Flooding in Ho Chi Minh City

Based on data extracted from the MIKE FLOOD model, flood calculations were conducted for the Thành phố Hồ Chí Minh area. The study involved constructing maps of the current conditions and flood risks under different climate change scenarios (RCP 4.5 and RCP 8.5) specifically for the Bình An ward, which now belongs to the An Khánh ward, Thủ Đức City, Hồ Chí Minh City. These assessments were combined with present land use and development plans up to the year 2030 to determine the flood risks for each land-use unit in the study area. Consequently, appropriate eco-technological solutions were proposed to mitigate flood risks effectively.

CHAPTER 3. RESEARCH FINDINGS

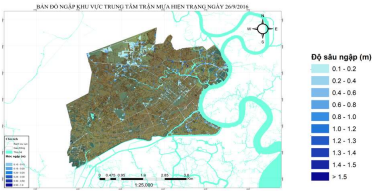
3.1. Assessment of the Current State and Flooding Risk in Ho Chi Minh City in the Context of Climate Change

3.1.1. Assessment of Current Flooding Situatio

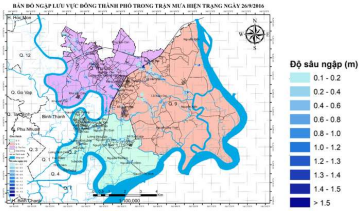
- Central City Drainage Basin: the drainage basin experienced flooding along Đinh Bo Linh Street, from Nguyen Xi Street to Street No. 3, with a maximum flooding depth of 0.35 meters. The onset of the flooding was observed at 4:00 PM on September 26, 2016, and it lasted for a duration of over 120 minutes. Similarly, Bạch Đằng Street, located in Tân Bình District, was flooded from house number B22 to house number B88, with a maximum flooding depth of 0.21 meters. The occurrence of flooding on this street was associated with the commencement of rainfall at 5:00 PM, and the flooding persisted for approximately 20 minutes.

- East City Drainage Basin: Vo Van Ngan Street, stretching from Đang Van Bi Street to Hanoi Highway, experienced flooding during heavy rainfall. The maximum depth of the floodwater reached 0.15 meters, and the flooding persisted for approximately 120 minutes. Likewise, Nguyen Van Huong Street, from the junction with Nguyen

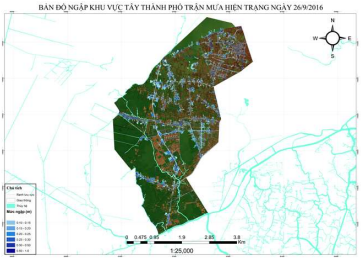
Cu Street to Alley 76, also encountered waterlogging during the rainfall from 4:00 PM to 4:30 PM, with the maximum depth recorded at 0.24 meters. The duration of this flooding event lasted nearly 90 minutes.



(a) Flood Map of the Central City

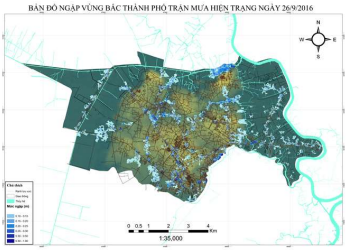


(b) Flood Map of the Eastern City Area in the Current Scenario

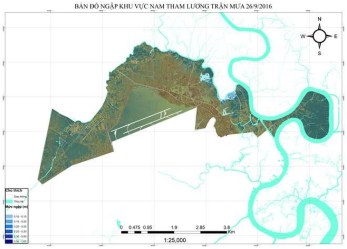


(c) Flood Map of the Western City Area in the Current Scenario

(d) Flood Map of the Southern City Area in the Current Scenario



(e) Flood Map of the Northern City Area in the Current Scenario



(f) Flood Map of the Southern Tham Luong in the Current Scenario

Figure 3.1. Current flood map of Ho Chi Minh City based on drainage basins

- Western City drainage basin: The sewer line on Provincial Road 10 operates relatively well because the water collection and drainage time are quite fast and reasonable. However, during heavy rain accompanied by clogged stormwater drains due to residents blocking them with plastic bags, the water collection time extends to approximately 120 minutes, causing flooding and affecting the mobility of the local residents.

- South City drainage basin: The drainage system on Huynh Tan Phat Street is not functioning well, as the water accumulation time is not fast, but the drainage time varies, sometimes quick and sometimes prolonged. The water level during floods is only about 0.35m, causing significant impacts, such as prolonged waterlogging, necessitating measures to improve the drainage system and sewerage in this area.

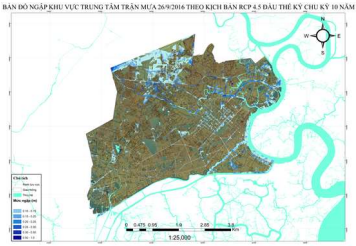
- Northern City drainage basin: The drainage system along Phan Van Hon Street is not functioning optimally due to the rapid accumulation of water during heavy rainfall and the slow drainage process. Moreover, the presence of plastic bags obstructing the stormwater grates worsens the situation, as residents tend to block them with these bags. As a result, water takes around 150 minutes to drain, leading to severe flooding that significantly hampers the mobility of the local residents.

- The South Tham Luong basin: the drainage system on Le Duc Tho Street operates quite efficiently, facilitating swift and proper water collection and discharge. However, during periods of intense rainfall, compounded by the obstruction of manholes due to the improper disposal of plastic bags by residents, water accumulation persists for approximately 110 minutes, leading to flooding and adversely impacting the mobility of the local population.

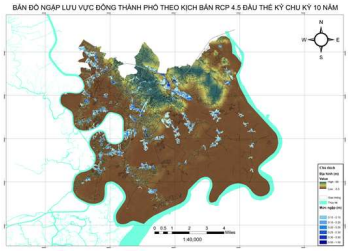
3.2.2. Flood risk assessment

3.2.2.1. Flood map according to the RCP 4.5 emission scenario

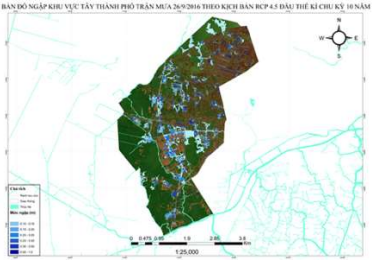
a) Central city Drainage Basin



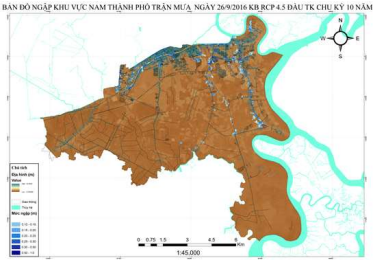
(a) Flood Map of the Central City in the RCP 4.5 emission scenario



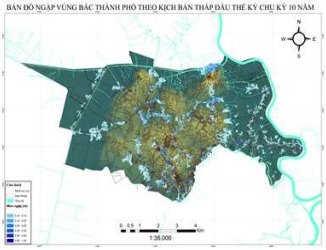
(b) Flood Map of the Eastern City Area in the RCP 4.5 emission scenario



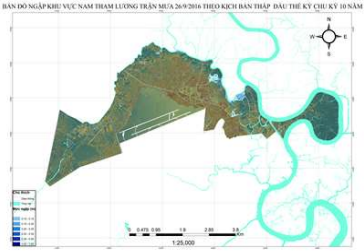
(c) Flood Map of the Western City Area in the RCP 4.5 emission scenario



(d) Flood Map of the Southern City Area in the RCP 4.5 emission scenario



(e) Flood Map of the Northern City Area in the RCP 4.5 emission scenario



(f) Flood Map of the Southern Tham Luong in the RCP 4.5 emission scenario

Figure 3.2. Flood Map of Ho Chi Minh City according to the RCP 4.5 emission scenario based on drainage basins

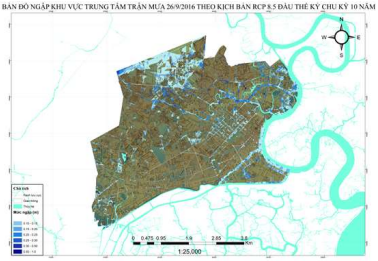
3.2.2.2. Flood map according to the RCP 8.5 emission scenario

- Central City Drainage Basin: In comparison to the current hydrological conditions, considering a precipitation event with a return period of 10 years and the prevailing sea level, the segment of Mai Thi Luu street extending from Dien Bien Phu to house number 99 exhibits a flood depth of 55cm, signifying a reduction of 7cm.

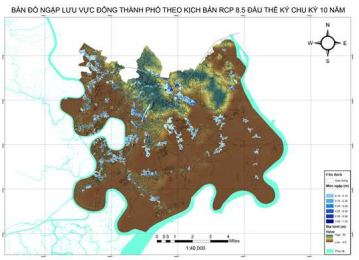
- Eastern City Drainage Basin: In contrast to the present state, Vo Van Ngan street encounters flooding from Dang Van Bi to Ha Noi Highway, with a flood depth of 35cm, representing an elevation increase of approximately 3cm.

- Western City Drainage Basin: Relative to the existing situation, Provincial Road 10 experiences flooding from SN1304 to SN1238, with a flood depth of 40cm, which denotes a rise of about 5cm.

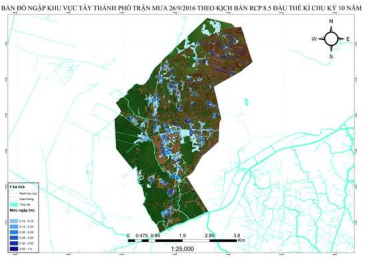
- South City Drainage Basin: The sewer line on Huynh Tan Phat street is functioning quite well because when encountering heavy rainfall, the water rises slowly and not in a straight vertical manner. Although the water doesn't gather quickly, the drainage time is prolonged. The water level is not causing significant impacts, but there are signs of prolonged waterlogging, which requires measures to improve the drainage system and sewerage here.



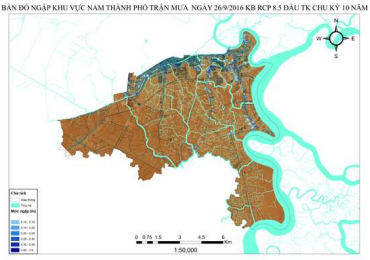
(a) Flood Map of the Central City in the RCP 8.5 emission scenario



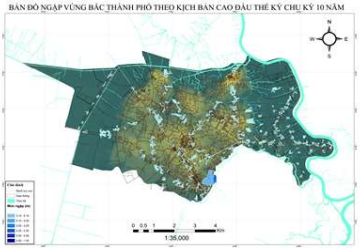
(b) Flood Map of the Eastern City Area in the RCP 8.5 emission scenario



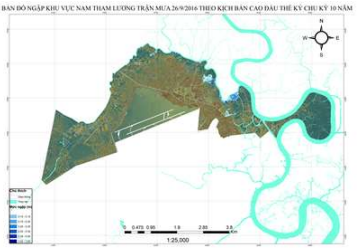
(c) Flood Map of the Western City Area in the RCP 8.5 emission scenario



(d) Flood Map of the Southern City Area in the RCP 8.5 emission scenario



(e) Flood Map of the Northern City Area in the RCP 8.5 emission scenario



(f) Flood Map of the Southern Tham Luong in the RCP 8.5 emission scenario

Figure 3.3. Flood Map of Ho Chi Minh City according to the RCP 8.5 emission scenario based on drainage basins

- North City Drainage Basin: Compared to the current situation, Phan Van Hon street, starting from house number 287 on National Highway 1A, experiences flooding with a water depth of 30 cm, approximately 5 cm higher than before.

3.2. Applying ecological techniques to mitigate flooding in Ho Chi Minh City, calculating for a specific scenario

Based on the computational results and flood mapping for Ho Chi Minh City that were presented in the previous chapters, along with the principles of ecological sustainability (utilizing architectural measures to ensure ecological balance dynamically within the permissible limits of changes in the interrelationships between humans, nature, and architectural structures), the Binh An Ward in

District 2, Ho Chi Minh City (currently located in An Khanh Ward, Thu Duc City, Ho Chi Minh City) has been chosen as the experimental area for investigating an ecological flood mitigation solution. The specific measures are as follows:

- This area has been leading the urbanization trend in Ho Chi Minh City in recent years, witnessing the establishment of numerous streets, commercial centers, and service facilities, which are remarkable achievements. Alongside these accomplishments, there are still several challenges and limitations that the authorities must address in the near future, notably the issue of waterlogging. Presently, this region is experiencing frequent inundation, with a high susceptibility to flooding. The current waterlogging situation is attributed to a combination of subjective and objective factors, including urbanization and climate change. This has resulted in a progressively intricate flooding scenario, characterized by an increase in the number of affected areas, the depth of water accumulation, and the duration of inundation.

- This region falls within the scope of a developing urban area currently undergoing construction. Urban planning and construction efforts are receiving paramount attention, while addressing flooding issues remains a significant concern. The implementation of ecological solutions and appropriate organizational measures, in accordance with environmental laws and priorities, is still feasible due to the available space in the area.

To execute flood mitigation strategies using eco-technical approaches, the research incorporated the Land Use Status map for the year 2017 and the Land Use Planning map for the year 2030 to recalibrate the dimensions of inundated areas, water depths, and flooded water volumes based on the various flood scenarios outlined in Chapter 2 (existing flood conditions, low emission scenario

RCP4.5-induced flooding, and high emission scenario RCP8.5-induced flooding) for each specific land use unit. Subsequently, these measures were implemented in close alignment with the natural ecosystem to alleviate flooding in the designated research area. These interventions not only curtail surface flow rates, thereby contributing to flood reduction, but also enhance groundwater recharge, contribute to landscape enhancement, and promote urban greening.

3.2.1. Assessment of the Flooding Status in Binh An Ward in Accordance with the Current Land Use Conditions

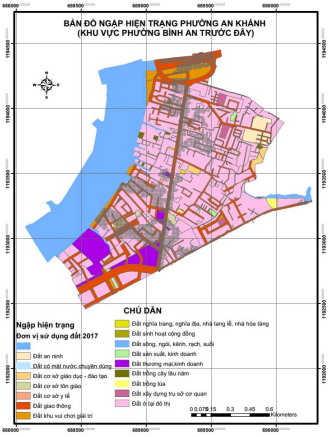


Figure 3.4. Current Flood Map of Binh An Ward

The computation results based on the 2017 Land Use Map reveal that the mean inundation area across the entire region is 12.79%, with a cumulative water volume of 66,832.67 m3. Among the various land types, Urban Land (13.94 ha) and Transportation Land (9.32 ha) are identified as having the highest proportions of flooded areas, characterized by water depths ranging from 0.22 to 0.25 meters. Subsequently, Commercial Land, Business Land, and Educational Institution Land are also impacted by flooding. The underlying cause can be attributed to the extensive surface concretization (e.g., sidewalks, yards, and internal roads) along with the sluggish drainage

system, which takes approximately 30 to 45 minutes for water to subside after flooding. Regarding River, Stream, and Canal Land, which encompasses an inundated area of 2.38 ha with a water depth of 0.46 meters, this can be attributed to the low topography in close proximity to the Saigon River and natural canals and streams

Proposed ecological measures: enhancing green spaces, limiting urban concretization, and implementing regular drainage system maintenance. Strengthening green areas, curbing urbanization, and utilizing highly permeable materials like pervious concrete and graded stones, are anticipated to substantially improve water drainage efficiency. Calculations demonstrate that the implementation of these measures would result in a remarkable reduction in flooding duration, from 45 minutes to approximately 9 minutes (equivalent to a decrease of 79.6%) for residential zones within urban areas and about 6 minutes (a decrease of 86.1%) for transportation zones. In accordance with the flooding classification standards, these areas can be deemed either non-flooded or experiencing only minor flooding.

3.3.2. An Evaluation of Flood Vulnerability in Binh An Ward Using the Low-Emission Scenario RCP 4.5

The computed outcomes based on the flood map utilizing the low average emission scenario and land use planning until 2030 reveal that the overall flooded area constitutes 11.3% of the entire region, with a total flooded water volume of 46,566 m3. Among the land types, Urban Land (7.99 ha) and Transportation Land (8.48 ha) exhibit the highest susceptibility to flooding, with a water depth ranging from 0.19 to 0.20 meters, followed by Cultural Land and Cultural Facilities Land. In case the current planning approach persists, involving concrete surface materials for sidewalks, yards, and internal roads, and the drainage system remains unexpanded, the estimated water recession time after flooding would fall within the range of 35-50

minutes. Concerning the River, Stream, Canal, and Ditch Land, encompassing a flooded area of 3.38 ha, this is attributed to its low-lying topography in close proximity to the Saigon River and natural channels.

Proposed Ecological Solution: Enhancing Green Spaces, Limiting Urbanization, Regular Drainage Maintenance, and Constructing Underground Reservoirs. The calculation results show that the flooding duration decreases from 50 minutes to approximately 8 minutes (a reduction of 83.4%) for residential areas and around 5 minutes (a reduction of 90.5%) for transportation areas. Compared to the flooding classification standards, this can be considered as either flood-free or experiencing only minor flooding.

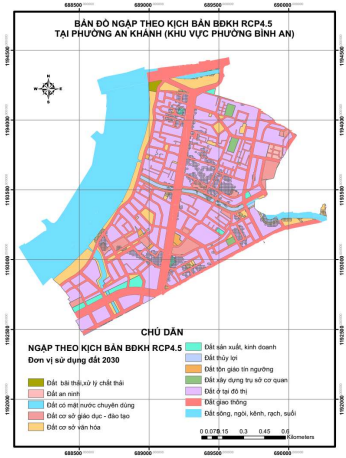


Figure 3.5. Flooding risk map of Binh An Ward under the RCP 4.5 scenario

3.3.3. An Evaluation of Flood Vulnerability in Binh An Ward Using the High-Emission Scenario RCP 8.5

The results of the calculations based on the flood map using the High Emission Scenario and Land Use Planning for 2030 demonstrate an average inundation area of 14.72% for the entire region, with a total

flooded water volume of 123,621.39 m3. Among the different land types, Urban Residential Land (12 ha) and Transportation Land (14.45 ha) exhibit the most extensive inundation, ranging from 47,892 to 54,714 m3 of flooded water, with flood depths ranging from 0.38 to 0.40 m. Following closely are Cultural Land and Educational Land.

If the planning adheres to the allocation of space for sidewalks, yards, and internal roads with a concrete surface, without expanding the drainage system, the estimated water drainage time after flooding would range from 40 to 60 minutes. Additionally, River and Canal Land, covering an area of 3.25 ha, is highly susceptible to flooding due to its low elevation in proximity to the Saigon River and canals.

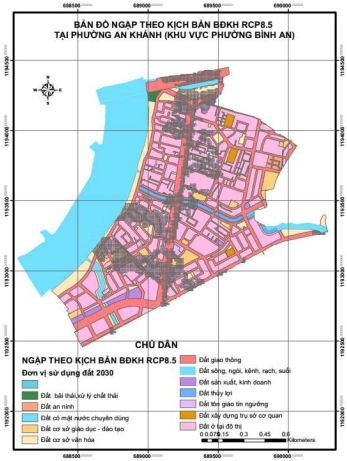


Figure 3.6. Flooding risk map of Binh An Ward under the RCP 8.5 scenario

Proposed ecological solution: enhancing green spaces, limiting urbanization, regular drainage maintenance, and building underground reservoirs. The calculated results indicate that the flooding duration decreases from 60 minutes to approximately 17 minutes (a reduction of 72.3%) for residential areas in urban zones and approximately 9 minutes (a reduction of 84.2%) for transportation

areas. Compared to the flooding classification standards, this can be considered as either non-flooding or experiencing only minor flooding.

3.3. Assessment of the feasibility of applying ecological techniques to reduce flooding in Binh An Ward

3.3.1. Assessment of the feasibility of implementing flood mitigation eco-techniques based on the current conditions

The computational results demonstrate a considerable increase in the SN value upon implementing the ecological technique of establishing urban green arrays, aimed at mitigating flooding in urban and transportation areas (0.74 - 0.84). Moreover, other land categories, such as educational, production, business, and riverine regions, also exhibit a high level of feasibility (0.63 - 0.84). Notably, the application of the JW ecological technique to transportation land use proves to be highly feasible (SN = 0.9). This preference is attributed to the advanced and effective nature of the JW ecological technique in combating sidewalk flooding, transportation routes, and residential zones, thereby enhancing the capacity for underground water storage. Noteworthy, the JW ecological technique has been successfully implemented in numerous countries, including Taiwan, Japan, Indonesia, Malaysia, and several European nations.

3.3.2. Assessment of the feasibility of implementing ecological flood mitigation techniques based on the RCP 4.5 scenario

The application of three eco-technical solutions for the RCP 4.5 scenario in Binh An Ward yields a feasible coefficient ranging from moderate to high. The green space solution and JW eco-technical approach for urban and transportation land utilization exhibit a favorable feasibility coefficient (SN=1), indicating their substantial potential to address the flooding issue in Binh An Ward. It is anticipated that these solutions can result in a reduction of over 85%

in both surface water area and volume. As for the remaining land types, their feasibility levels range from 0.1 to less than 1 (moderate) when implementing the three flood-reduction eco-technical measures in the research area. This endeavor is expected to effectively reduce flood risks and enhance adaptation to climate change as projected in the RCP 4.5 scenario.

3.3.3. Assessment of the feasibility of implementing ecological flood mitigation techniques based on the RCP 8.5 scenario

The evaluation results of the feasibility regarding the application of three ecological techniques to mitigate flooding in Binh An Ward, considering the RCP 8.5 scenario, demonstrate a comparable average feasibility to that of the RCP 4.5 scenario. However, it is worth noting that certain land-use types, namely urban residential and transportation land, exhibit a slight albeit insignificant reduction in their feasibility coefficients within the RCP 8.5 context. This observation indicates the rationale behind the implementation of the aforementioned ecological techniques in the study area to effectively alleviate surface inundation stemming from rapid shifts in precipitation patterns. In addition to their water management benefits in urban flood-prone zones, these ecological techniques contribute to the creation of recreational spaces for the local community and the enhancement of the natural environment. Moreover, they facilitate water infiltration and groundwater replenishment in urbanized areas, thereby mitigating damages to residential, construction, and public infrastructures, while optimizing flood control measures in response to the impacts of climate change.

CONCLUSIONS AND RECOMMENDATIONS

4.1. Conclusions

The research content of the thesis has provided a general overview of the current state and flooding risks in Ho Chi Minh City. It demonstrates the feasibility of implementing ecological solutions to mitigate flooding, thereby introducing a new approach to flood prevention. Specifically, the findings are as follows:

1. The research outcomes have successfully assessed the prevailing conditions and flood vulnerabilities in Ho Chi Minh City, predicated on the computational simulations of the MIKE FLOOD model, coupled with the development of flood hazard maps. The inundation predicament within the city has evolved into a complex scenario since 2005. Subsequently, in the recent years of 2018, 2019, and 2021, there has been a surge in the occurrence of highly severe flooding incidents, predominantly affecting the road networks situated in the pre-existing residential zones dating back to the initial phases of urbanization. These inundated areas exhibit prolonged inundation durations, lasting from 60 to 120 minutes, accompanied by water depths ranging from 0.2 meters to 0.4 meters.

2. The computational outcomes up to the year 2030, concerning the projected impacts of climate change in the foreseeable future on flood conditions, reveal a notable escalation in inundation events. These events encompass the temporal inundation duration, the water depth during flooding, and the overall flooded area at recurrently affected locations. Furthermore, there is a discernible upward trend in the frequency and severity of flooding incidents. The areas that merit particular attention in terms of flood vulnerability comprise the urban center of Thủ Đức, encompassing Districts 2, 9, and Thủ Đức itself, along with Nhà Bè District, Bình Chánh District, and District 12.

3. Based on the computed results and the establishment of flood maps for Ho Chi Minh City, alongside principles of ecological sustainability, a pilot study was conducted to implement specific

ecological measures (enhancing green spaces and employing permeable materials) aimed at reducing inundation across different land-use categories in the Binh An Ward area (currently a part of An Khanh Ward, Thu Duc City, Ho Chi Minh City). The calculated outcomes demonstrate that, both for the present conditions and projecting to the year 2030, the adoption of these two approaches results in a significant reduction in flooding duration compared to the current scenario.

4. The rationality and feasibility of applying ecological techniques to mitigate flooding in the research area within the context of climate change have been empirically substantiated. The feasibility analysis outcomes, considering three scenarios (Current Conditions, RCP 4.5, RCP 8.5), reveal a notably high SN value (feasibility coefficient) associated with the implementation of ecological measures, such as urban green infrastructure establishment and the expansion of permeable surfaces to ameliorate flooding across diverse land utilization patterns.

4.2. Recommendations

1. The effective management of urban flooding necessitates the incorporation of comprehensive research, encompassing harmonious amalgamation of non-structural and existing structural measures, aligned with the principles of sustainable adaptation inherent in natural laws. Such an approach should be based on the integration of social factors and the prudent consideration of urban development along modern lines.

2. Ho Chi Minh City necessitates a comprehensive review and adjustment of its flood control planning, ensuring its alignment with actual conditions and updated design parameters to address the challenges posed by climate change. Concurrently, a thorough assessment of the harmony and availability of natural conditions

should be conducted, with the ultimate goal of circumventing constraints and ameliorating existing repercussions. This endeavor is crucial to foster the development of a smart, sustainable metropolis capable of meeting future demands.

3. Ecological engineering represents a novel perspective on urban water management solutions, and its comprehensive implementation has been observed in numerous developed nations. Consequently, cities are increasingly recognizing the significance of adopting an eco-centric approach in formulating integrated strategies to effectively adapt to and mitigate urban flood occurrences during the process of urban development./.

THE THESIS'S NEW CONTRIBUTIONS

This study focuses on the calculation and construction of flood maps using various climate change scenarios with detailed granularity for the drainage system and model resolution for floodplains and research areas.

The main objective is to adopt an ecological approach to tackle centralized flood reduction in a specific target zone, with the primary aim being to enhance infiltration capacity and address the prevailing flood issues. These problems arise due to the current context of uneven infrastructural development in newly established urban areas and the potential impacts of climate change scenarios (RCP 4.5 and RCP 8.5).

The thesis contributes significantly to elucidating the feasibility and potential applicability of ecological techniques in mitigating flooding in the city of Ho Chi Minh. Based on the research findings, appropriate ecological strategies are proposed to minimize the flood occurrences in Ho Chi Minh City.

CATALOGUE OF PUBLISHED WORKS

1. Nguyen Ky Phung, Huynh Luu Trung Phung, Le Thi Phung, Tran Xuan Hoang, Le Ngoc Tuan, *Trends of Changes in Some Meteorological Factors in Ho Chi Minh City and Surrounding Areas*, Journal of Meteorology and Hydrology, Issue 676, April 2017.

2. Nguyen Ky Phung, Le Thi Phung, Huynh Luu Trung Phung, Tran Xuan Hoang, Le Ngoc Tuan, *Trends in changing some hydro-meteorological elements in Dong Nai province*, Journal of Climate Change Science, Issue 2, July 2017.

3. Huynh Luu Trung Phung, Nguyen Ky Phung, Le Thi Hien, *Assessing the impacts of some natural and anthropogenic factors on flooding in Ho Chi Minh City*, Journal of Meteorology and Hydrology, 704-08/2019.

4. Huynh Luu Trung Phung, Tran Tuan Hoang, Ho Cong Toan, Nguyen Phuong Dong, Huynh Thi My Linh, Nguyen Ky Phung, *Developing a flood reduction script for District 12 using mathematical models*, Journal of Meteorology and Hydrology, 705-09/2019.